UNDERSTANDING URBAN CYCLING BEHAVIOURS IN SPACE AND TIME

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ABSTRACT

The aim of this research thesis was to understand how the urban built environment interacts with utility cycling behaviours in space and time. Using mixed methods entrenched in the philosophy of pragmatism, the research contributed to an as yet under-developed research evidence-base within the British context by addressing the gap in knowledge relating to: the usability of *space-time* and *action space* theories within *visual analytics* context in facilitating the knowledge discovery process from spatio-temporal datasets; empirical evidence on perceived and actual movement behaviour of urban utility cyclists; methodological advancement in collecting, refining, analysing and visualising detailed utility cycling behaviours in a British urban environment.

Findings suggest that 57.4% of cyclists' bike trips were found on the cycle network and with 42.6% of cyclists still cycling outside the designated cycle network; it is therefore imperative that policy initiatives aimed towards strategic investment in cycling behavioural research and infrastructure. The findings also showed a higher concentration of cycling uptake around the south-eastern part of Newcastle upon Tyne suggesting this area may need more investment than other areas in Tyne and Wear. Systematic comparison of GPS data and travel diary data suggest 8.4% under reporting of the former. The null hypothesis that *urban transport network restrictions do not have any significant influence on movement of commuter cyclists* was rejected upon examination and it was found that observed routes tend to be significantly longer than their shortest path counterparts. Profiling activity spaces of utility cyclists utilising different geographies was found to be useful in the examination of cycling behaviours for the purpose of providing visual aid for planners and policy makers to identify areas for improvement and informed investment in support of sustainable transport. Several efforts were being made to enhance data availability to inform policy strategies, and facilitation of feasible solutions for improving the urban cycling infrastructure and encouraging more people to cycle as part of their daily commute, for which this research aimed to contribute by providing evidence on the use of the area's cycling infrastructure by utility cyclists and spatial variability of cycling in space and time.

Keywords: Cycling behaviours, cycle infrastructure, space-time geography, transport geography, travel behaviour, stated and revealed preferences, route choice, built environment, activity spaces, GPS, travel diary, GIS, visual analytics, statistics, planned behaviour

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GLOSSARY AND TERMINOLOGY

ABMS / ABM	:	Agent Based Modelling and Simulation / Agent Based Modelling (or Model)
CSA	:	Corridor Space Analysis
Cycle		Any vehicle which has at least two wheels and is propelled solely by the muscular energy of the person(s) on that vehicle, in particular by means of pedals (UNECE, 1993, p. 5)
Cycling behaviour	:	Cycling behaviour is defined here as the bicycle movement of cyclists together with a number of associated factors, such as perceptions of the built environment, along with the characteristics of the cyclists themselves
DfT	:	United Kingdom (UK) Department for Transport
DH	:	Department of Health
EDINA	:	EDINA is the national data centre designated by the Joint Information System Committee (JISC) in the UK
EU MOVE-COST	:	European Cooperation in Science and Technology project - COST Action IC0903
GIS	:	Geographical Information System
GISc	:	Geographical Information Science
GPS	:	Global Positioning System
JISC	:	JISC is a registered charity championing the use of digital technologies in education and research in the UK
LSOA	:	Lower layer Super Output Area
LSTF		Local Sustainable Transport Fund
LTP	:	Local Transport Plan
NICE	:	National Institute for Health and Clinical Excellence
NTS	:	National Travel Survey
ODbL	:	Open Data Commons Open Database License
ONS	:	Office for National Statistics
RP	:	Revealed or Actual Preference Survey
SP	:	Stated Preference Survey
Spatial analysis	:	Spatial analysis means a representation and use of “a collection of techniques and models that explicitly use the spatial referencing associated with each data value or object that is specified within the system under study” (Fernández-Avilés Calderón, 2009, p. 45)
STC	:	Space-Time Cube
STSM	:	Short-Term Scientific Mission
TADU	:	Tyne and Wear Traffic and Data Unit
TWHTS	:	Tyne and Wear Household Travel Survey
TWJTWG	:	Tyne and Wear Joint Transport Working Group
Utility cycling	:	*Utility cycling* is defined as any cycling not done primarily for fitness, recreation (such as cycle touring), or sport (such as cycle racing), but as a means of transport and covers activities such as traveling to work, to shops, to run errands, to see friends and family at various locations, and to locations of other social activities

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After going through such a personal transformation and a unique initiation to never ending continuous mental engagement with self and others, I agree with Argentine popular rock and roll pianist, lyricist, Spanish language singer and film director, *Rodolfo "Fito" Páez Ávalos,* who once said that "*The important thing is not to arrive; the important thing is the path*" stressing on the need to appreciate the path to whatever state one find oneself. In my mind, the paths are many as I have departed and arrived to and from several locations in thought, action and with the help of many whom I must acknowledge. They one way or the other helped in my quest for knowledge and experiences in completing this thesis. In short, my thinking process and actions have never been always linear and have enjoyed every step along the path despite the numerous challenges. Therefore, I feel so pleased to THANK all those who in one way or numerous ways have contributed in my PhD journey intellectually, psychologically, emotionally and technically. I would like to thank God, my family, academic supervisors (Dr. Seraphim Alvanides and Dr. Emine Mine Thompson), the entire team at Northumbria University, especially those in the Faculty of Engineering and Environment, as well as friends for their support towards the progress to this stage of my PhD programme.

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AUTHOR'S DECLARATION

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others. The work was done in collaboration with Northumbria University at Newcastle.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Faculty Ethics Committee in February 2011.

I declare that the Word Count of this Thesis is 84,990 words.

Name: Godwin Yeboah

Signature:

Date: May 2014

CHAPTER 1. INTRODUCTION

"When I see an adult on a bicycle, I do not despair for the future of the human race"

Herbert George Wells, English author, historian, and utopian (1866 - 1946)

(Cited in Simms and Potts, 2012, p. 16; Wells, 1896)

"Cycling for daily travel can provide a wide range of benefits that far outweigh the costs of cycling infrastructure, equipment, and programs"

(Pucher and Buehler, 2012, p. 347)

"Cycling makes life better for all"

(Goodwin, 2013, p. 2)

1.1 General background

1.1.1 International context

Internationally, few travellers in the developed world use the bicycle regularly as a means of transport, although adjustments to the built environment could serve as a facilitator to cycling uptake (Shephard, 2008). The choice of cycling as an active mode of transport is increasingly being considered as an integral part of urban transportation. Cycling in the UK has only received policy level attention in the last two decades with the introduction of *the national cycling strategy* in 1996 (Docherty and Shaw, 2008, p. 126). In the USA, cycling infrastructure has been identified as the backbone for building sustainable communities (RITA, 2009). Various programmes aimed at part of the search for sustainable ways of living are being implemented in Australia; for example, the voluntary travel behaviour change (VTBC) agenda (Taylor, 2007). Similarly, in Europe, several initiatives from the European Commission are geared towards the improvement of cycling: via the Road Safety Policy, Green Paper on urban mobility and the recent Cycling Lexicon (Commission, 2010; Committee, 2010; UNECE, 1993). These initiatives have become necessary due to low levels of cycling in the EU. According to an opinion survey conducted in 2010, more than half (about 53%) EU citizens used the automobile as their main mode of transport while only about one in fourteen (7%) used bicycle and 13% walked (EC, 2011). Building sustainable solutions to facilitate active lifestyles via active transport has the potential to reduce greenhouse gases and other non-sustainable problems associated with the use of motorised transportation. The rise in greenhouse gases, especially carbon dioxide, plays a major role in climate change and threatens the achievement of sustainable ways of living. The International Energy Agency's (IEA) latest report suggests that the projected rise in global temperature may exceed the limited target of 2 degrees Celsius and points to the urgency (i.e. before 2020) in the reduction of greenhouse gas emissions (IEA, 2013). Governments worldwide agreed to this ceiling during the United Nations Framework Convention on Climate Change Conference in Cancún, Mexico in 2010 (IEA, 2013, p. 14). The discussion around greenhouse gas emissions and its influence on climate change is shifting from *if* to *when* the climate situation will have an impact with global average temperatures likely to be hotter compared to historically known extremes within about 35 years from 2013 (Gewin, 2013). Any human effort that may reduce greenhouse gas emissions should be encouraged no matter how small the contribution. The literature suggests the need for more objective information on active commuting such as cycling, as well as consideration of such evidence coming from different built environments to allow comparisons and encouragement towards the uptake of active transport (GAPA, 2010b; NICE, 2012; Shephard, 2008).

1.1.2 British context

A major part of the contemporary lifestyle in Britain is how adults interact with the built environment including the use of public spaces and transportation systems (Foresight, 2007b, p. 66). The unsupportive nature of aspects of the built environment towards the improvement of public health has necessitated the creation of several future scenarios, towards 2050, to address the difficulties. Two of these scenarios suggest changes in the built environment such that infrastructure favours the movement behaviours of cyclists (Foresight, 2007b, p. 54). Moreover, two of the most serious global and national threats anticipated by the year 2050 are potentially high levels of obesity and climate change *(Foresight, 2007a, 2008, 2012; IEA, 2013)*. By definition, climate change comprises global warming and everything else that increasing greenhouse gas amounts will affect *(Conway, 2008)*. The *Foresight* (2007a) report suggests that over half the adults in Britain could be obese by 2050 unless some measures are adhered to. The report suggests that if current trends continue, 50% of women and 60% of men are likely to be obese, which will amount to an estimated value of £50 billion annual direct and indirect costs of obesity (Foresight, 2008). A recent review of obesity trends from 2008 to 2010 failed to identify any major changes, thus making it a pressing issue (Foresight, 2012). One aspect of the measures, with respect to active transport (such as cycling) and urban design, is to include increase in cycling and improvement in the design of communities. Also, the UK government has decided, via the Climate Change Act, to reduce greenhouse gas emissions by at least 80% by 2050. Out of this, 21% of domestic greenhouse gas emissions come from transport, of which 58% come from private cars.

Cycling plays an important role in ameliorating the impact of traffic congestion, climate change, low physical activity, health related issues such as obesity and non-communicable diseases, and sedentary lifestyles among others. There is growing interest in understanding cyclists and their environments (Tilahun et al., 2007), while cycling levels in the UK overall are increasing (Grous, 2011). Cycling in various British cities is on the increase, partly due to the increased costs of private and public transport as a result of the recession (Allen, 2012; Brignall and King, 2012), partly due to the hype of the 2012 London Olympics (Bauman et al., 2013; Stewart, 2012; Wood, 2012), occasional efforts towards healthy and sustainable transport (BMA, 2012; Docherty and Shaw, 2008), and sporadic political backing (Briggs, 2012; Charlesworth, 2012; Hill, 2012a, b; Shankleman, 2012). To a lesser extent, this increase in cycling is a result of active transport interventions (Cope et al., 2011) despite budget cuts in urban areas (Pank, 2013). The vast majority of these initiatives and interventions tend to be top-down, driven by environmental, health and political agendas, usually followed by improvements in the current cycling facilities for recreation and commuting, but hardly ever matched by significant investments in the infrastructure. The lack of significant investments in cycling infrastructure and limited consultation with commuter cyclists, employers and bicycle user groups (BUGs) is evidenced by the mushrooming of cycling campaign and activist groups in many British cities (Aldred, 2013; Alvanides and Yeboah, 2012b; NCC, 2012; Spokes, 2013). Examples of such groups are the Newcastle Cycling Campaign, the Gateshead Cycling Forum and the London Cycling Campaign (GCF, 2013; LCC, 2013; NCC, 2012). These groups question whether the recent wave of perceived cycling uptake presents a genuine mode shift in British commuting patterns or whether it is a temporary phenomenon hyped by the media and politicians with vested interests.

Despite the long history of British cycling, it is still seen as a contemporary issue and what may work best is still being discussed, as exhibited by the All Party Parliamentary Cycling Group cycling inquiry (APPCG, 2013a). There remains a danger that cycling will fail to reach a “norm” as a result of societal attitudes towards cyclists, coupled with a lack of real investment in cycling infrastructure and gaps in the current cycling facilities. Here, “norm” means a This means that following the Olympic summer and current recession, cycling uptake is in danger of imploding once the Olympic hype is over and we see past the recession, returning to old habits and a reliance on private and public transport even for the most “cycleable” of short trips. In addition, as cycling in British cities increases, so do conflicts between cyclists and other road users, as well as debates with city planners who are trying to balance cities’ transport infrastructures in the face of public spending cuts. In Tyne and Wear (North East England), incremental steps are taken by the local authorities to provide cycling infrastructure, albeit at a slow rate compared to the recent uptake of cycling in the commuting area. As a result, there appears to be increasing dissatisfaction from local campaign groups about the lack of a coherent cycling strategy, negative attitudes towards cyclists and even the refusal of the local public transport providers to allow bicycles on the metro system (Alvanides and Yeboah, 2012b; Brown, 2012).

Based on international examples, Pucher and Buehler (2012, p. 347) conclude that the benefit of cycling is greater than the cost of investment in cycling infrastructure together with associate programs and equipment. The consensus on the benefits of cycling is growing among researchers, but the means – *the how* – by which cycling uptake could be realised remains a challenging issue (Pucher et al., 2010, p. S107). Docherty and Shaw (2008, p. 125) argue that the major factors constraining everyday cycling are strongly related to the physical environment in which it takes place. Given an emphasis on “how”, the importance of infrastructure (i.e. the built environment) and planning for cycling should be considered alongside cyclists’ movement behaviours. This research aims to contribute to efforts in the Tyne and Wear area where the Local Transport Plan (LTP) strategy (2011-2021) points to the need to maximise the use of available datasets in decision making and promotion of everyday cycling (LTP3, 2011, p. 160). The next section addresses the boundaries of the current research.

1.2 Boundaries and limitations of the research

The boundary of this research should, first and foremost, be considered in relation to the chosen field of study – cycling research in the context of active transport. The term *active transport* is also synonymous with active commuting and sometimes with physical activity. These modes of transport demand some level of human activity in the process. Active transport is a form of travel where human muscle is (reasonably) active during the process (Cole et al., 2010), as a result of the vehicle (i.e.bicycle) used in the process (i.e. cycling). The inland transport committee of United Nation Economic Committee for Europe (UNECE) defines *cycle* as "*any vehicle which has at least two wheels and is propelled solely by the muscular energy of the persons on that vehicle, in particular by means of pedals*" (UNECE, 1993, p. 5). *Cycle* and *bicycle* are used interchangeably in this thesis.

Henceforth, the use of active transport in this thesis should be associated with cycling. Although the context of active transport also embodies walking, the focus here on cycling follows the argued case that cycling should be separated from walking (Pooley et al., 2011, p. 1604). In order to contribute to the investigation and understanding of cyclists' perceptions and actual movement behaviour, issues of utility cycling in the built environment are discussed within the research scope in relation to the collected (primary data) and available secondary data. *Utility cycling* is defined as any cycling not done primarily for fitness, recreation (such as cycle touring), or sport (such as cycle racing), but as a means of transport and covers activities such as traveling to work, to shops, to run errands, to see friends and family, and to locations of other social activities (Yeboah and Alvanides, 2013). This definition extends Skinner and Rose's (2007, p. 84) definition which suggest that utility cycling can be defined as "*day-to-day cycling for mundane trips to local shops, to work or to school*." In this thesis, the term *utility* is viewed as "practical, day to day" purposeful trips (LTSA, 2004, p. 10) and encompasses cycling for commuting purposes.

This empirical study employed a combination of spatial and statistical techniques together with visual analytics to investigate and understand cyclists' interaction with the urban built environment. By definition, the term *spatial data* means geographically referenced (or geo-referenced) data that can easily be located on a map (Fernández-Avilés Calderón, 2009, p. 45). Additionally, the term *spatial analysis* means a representation and use of "*a collection of techniques and models that explicitly use the spatial referencing associated with each data value or object that is specified within the system under study*" (Fernández-Avilés Calderón, 2009, p. 45).

To some extent, the sample used in the study limits the generalisation of findings and conclusions emanating from the new layer of knowledge. This knowledge is inferred from the collected detailed seven-day datasets but calls for a bigger study to justify how and where planned cycle infrastructure should be developed. This study particularly looked at four strands related to cycling behaviour: data capture and refinement, subjective behaviours, temporal behaviours and spatial behaviours. These thematic strands are further discussed in Chapter 3 and Chapter 9. For clarity, the term *cycling behaviour* is defined here as the movement characteristics of cyclists together with a number of associated factors, such as perceptions of the built environment, along with relevant characteristics of the cyclists themselves.

1.3 Research philosophy - Pragmatism

Research philosophy may be defined as a viewpoint which delineates what constitutes "valid" and "invalid" knowledge (Gregory et al., 2009). Such a viewpoint, however, must be based on two fundamental philosophical disciplines: *epistemology* and *ontology*. *Epistemology* is "any theory of what constitutes valid knowledge" or a "certain way of understanding what it means to know" or by using a combination of the Greek words "episteme [knowledge]" and "logos [theory] it simply means "the theory of knowledge" (Gregory et al., 2009). *Ontology* is the study of "what is" - the nature of existence (Crotty, 1998, p. 10); whatever that existence may be. Despite the claim for no consensus on a particular definition of research, geographical research holds both epistemological and ontological status (Amaratunga et al., 2002, p. 17; Crampton, 2001). All geographical research – no matter the philosophical view point – entails thinking of the connections between empirical evidence, concepts and constructs, hypotheses and conjectures, principles and laws, analytical and visualisation techniques and methods among others (Clifford et al., 2010, p. 7; Crotty, 1998, p. 18). Irrespective of the approach adopted (i.e. quantitative, qualitative, or mixed), geographical research demands some level of philosophical reflection to warrant the essence and meaning of the research process and outcome (Clifford et al., 2010, p.6).

Philosophical reflections regarding this research suggest that the most appropriate philosophical position is pragmatism. This choice is based on comparative study of four major philosophical paradigms by Tashakkori and Teddlie (1998, p. 23): positivism, postpositivism, pragmatism and constructivism. Unlike the others, the pragmatism worldview offers some characteristics which enabled the research to employ methods that could be both qualitative and quantitative; logic that could be both deductive and inductive; and epistemology comprising both objective and subjective viewpoints. In terms of axiology (value or worth), values play a major role in interpreting results; ontologically, external reality is acceptable and the best explanation is chosen to work out the desired outcome; and although causal relationships may be difficult to pin down, they do exist in such a worldview. Tashakkori and Teddlie (1998, p. 27) state:

"…pragmatists decide what they want to research, guided by their personal value systems; that is, they study what they think is important to study. They then study the topic in a way that is congruent with their value system, including variables and units of analysis that they feel are the most appropriate for finding an answer to their research question…..This explanation of the way in which researchers conduct their research seems to describe the way that researchers in the social and behavioural sciences actually conduct their studies, especially research that has important social consequences."

This philosophical viewpoint, therefore, serves as a guide towards the framing of research aim and objectives, mixed methods, analysis and interpretation throughout the study. Such a guided approach also follows the argument that the choice of a philosophical paradigm would have to precede the choice of methods (Tashakkori and Teddlie, 1998, p. 21).

1.4 Aim and Objectives

The aim of the study is to investigate and understand how the built environment interacts with the movement behaviour of cyclists in urban areas. Understanding the interaction is vital in urban planning to support cycling as a means of sustainable transport. The evidence base for understanding how the built environment influences cycling in Britain is very limited, particularly within the Tyneside conurbation; suggesting the need for more empirical research in order to fill the identified gap in knowledge.

Literature suggests that there is a need for research to incorporate the investigation and understanding of cyclists' perceptions and experiences (Forsyth and Krizek, 2011; NICE, 2012; Shephard, 2008). There is also the need to make available detailed data on built environment and travel behaviour such as cycling and the means to spatially match them to facilitate the analytical process towards understanding how the built environment and travel behaviour interact (Handy et al., 2002b). Understanding the interaction has been of "great concern among researchers and urban planners" (Buliung and Morency, 2009, p. 119). Moreover, cycling researchers are entreated to use some characteristics (e.g. socioeconomic status, age, gender, ethnicity, and infrastructure) to identify among others, how individual and local factors constrain or support cycling uptake by specifically including people's perceptions, connectivity for cycling trips, as well as local "visibility" of cycling as transport; key factors influencing cycling; how these factors interact and can facilitate cycling promotion and their effectiveness across different geographical areas; how individual and local factors constrain or support cycling uptake; and how individual interventions such as goal-setting interact with environmental factors such as distance or provision of facilities, to serve as enablers for people to continue cycling (NICE, 2012, pp. 45-46). Furthermore, the focus of this research will be on the utilisation of advanced technological and analytical tools in order to understand people's cycling behaviour and the constraints they experience within the built environment.

The objectives of this study are to deliver research that:

(A) Reviews the literature on cycling as active transport; space-time geography and behavioural geography; sustainable urban mobility studies, GPS, GISc and GIS technologies, stated versus revealed route choice preference studies; modelling, visual analytical techniques, and in general terms the linkage between transport and health.
(B) Contributes to the knowledge gap about empirical evidence of urban cycling behaviours within the British context through the collection and refinement of detailed adult cyclists' route choice preference data.
(C) Utilises a variety of novel techniques in space-time geography, statistics, spatial analysis, and visual analytics to provide understanding of urban cycling behaviours.
(D) Explores the relevance of the study towards sustainable urban transportation and policy by suggesting possible strategies towards improving urban cycling.

1.5 Research Questions and Hypotheses

Further to the aim and objectives discussed above, this research answers the following research questions:

1. What theories are capable of supporting efforts in understanding and explaining urban utility cycling behaviours? See Chapter 2.

2. What are the possible pragmatic survey methods that are useful in capturing both objective and subjective factors of urban utility cycling behaviours? See Chapter 2 and Chapter 5.

3. What is the empirical evidence on spatial variability of cycling prevalence and the use of cycling infrastructure across the study area? See Chapter 4, Chapter 5, Chapter 6 and Chapter 7.

4. What are the perceptions of adult utility cyclists and associated route choice characteristics in the British Urban Environment? See Chapter 5 and Chapter 7.

5. How can *space-time* and *action space* theories within *visual analytics* context facilitate the knowledge discovery process from spatio-temporal datasets derived from utility cycling behaviours? See Chapter 5, Chapter 6, and Chapter 8.

6. What are some of the possible policy strategies towards improving urban cycling around the study area? See Chapter 8 and Chapter 9.

The research draws upon the following hypotheses:

1. The built environment interacts with objective and subjective behaviours of adult utility cyclists in urban areas. See Chapter 4, Chapter 5, Chapter 6 and Chapter 7.

2. Transport network restrictions influence movement behaviours of urban utility cyclists. See Chapter 7.

1.6 Contribution to knowledge

This section starts with a quotation from T. S. Eliot, in his Four Quartets (a set of four poems), which states that "What we call the beginning is often the end. And to make an end is to make a beginning. The end is where we start from" (Cited in Leshem and Trafford, 2002, p. 31). To this end, this section gives a summary of the distinctive contribution to knowledge in this research. They are briefly summarised in the subsequent two sub-sections with extended discussion in Chapter 8 using the conceptual framework developed for this research. Finally, the conclusion chapter juxtaposes the discussion with the research aims and objectives, policy implications, research limitations and future research (Chapter 9).

1.6.1 Empirical contribution

The lack of detailed everyday mobility data still remains a setback in mobility studies *(Schonfelder and Axhausen, 2010, p. 45)*. The thesis contributes, substantively, to the body of knowledge by providing scientific data and thorough analysis on detailed stated and revealed preferences of 79 utility cyclists around the study area (Yeboah and Alvanides, 2013). Until now, and to the knowledge of the author, this is the first time that portable GPS devices were used to track *adult* utility cyclists in the British geographical context in a scientific manner. However, it should be mentioned that the use of GPS for tracking physical activity of children in the British context has already been reported by Gong and Mackett (2008). Still, the systematic use of GPS tracking in sensing and adding new layers of knowledge to our understanding of urban travel behaviours and lifestyles is relatively new (Bohte and Maat, 2009; Broach et al., 2012; Broach et al., 2009; Broach et al., 2011; Gong and Mackett, 2008). The systematic comparison of GPS data and travel diary data has also added to our understanding of the relative strengths; particularly for cycling trips.

1.6.2 Methodological contribution

The methodological contribution of this thesis is fivefold: (i) the demonstration of the utility of space time cube as a data processing tool; (ii) detailed exploration of various types of secondary data on cycling around the study area; (iii) the introduction of a buffering technique called corridor space analysis to compute trip shares of cyclists based on a given cycle network; (iv) combination of *space time* and *action space* concepts to visualise cycling flows within a proposed visual analytical framework; (v) the generation and statistical analysis of network constrained home-to-work cycle trips from the collected seven-day spatio-temporal data of 79 utility cyclists.

The research demonstrates for the *first time* how space-time cube is useful in facilitating the knowledge discovery process from spatio-temporal movement data within the context of GPS data processing (Yeboah and Alvanides, 2013). Space Time Cube (STC)-based data processing is the idea of exploiting and using the STC theoretical construct, as originally proposed by Hägerstrand (1970) and adopted by Kapler and Wright (2004), to refine raw GPS data by mainly visual inspection with additional data from maps and travel diaries (Yeboah and Alvanides, 2013). An additional contribution is a proposed and implemented visual analytical framework for the investigation of movement behaviour of cyclists based on suggestions from Andrienko and Andrienko (2013b) and related recent literature.

1.7 Thesis outline

This thesis consists of nine chapters in total. The *current chapter* introduces the *r*esearch giving the general background and the motivations for carrying out the project. The boundaries, limitations and philosophy of the research were discussed, while the aim and objectives section introduced the purpose of the study. The research questions and hypothesis within the context of the aim and objectives are discussed. The strands of contribution to knowledge were also highlighted here and will be revisited in the concluding chapter as a way of reflection on the purpose of the study, after taking the reader through the following chapters.

Chapter 2 discusses conceptualisations and policies from previous research on urban cycling studies and related policy documents, individual activity based analysis in space and time within the context of space-time and transport geography, GPS based cycling related studies, spatial analysis along with statistical techniques. The chapter continues by identifying the lack of existing empirical work on actual route choice information for everyday urban cycling due to the limited amount of available multi-day datasets and suggests the potential of employing available tracking technologies for collecting such datasets. The chapter concludes by pointing to three thematic areas where gaps in knowledge exist, while emphasising future research directions, particularly within the British context.

Chapter 3 introduces and describes the research methodology. The chapter begins with three sections, respectively, with introduction, research framework, and potential sources of secondary data on cycling. This is followed by the methods used in this thesis sectioned as follows: activity distribution across space; visual analytics framework for cycling behaviours; profiling activity spaces and times; mapping significant clusters of activities; network based corridor space analysis; generation of network constrained routes; and application of the theory of planned behaviour. The last two sections presented an overview of applied statistics and conclusion respectively.

Using the methods presented in Chapter 3, *Chapter 4* sets the scene by conducting an exploratory data analysis of various secondary datasets related to cycling at multiple scales using novel spatial analysis techniques. The findings informed the definition of the study area. The chapter closes with a discussion of the findings from the initial exploratory analysis.

Chapter 5 presents the primary data collection and cleaning processes together with exploratory of the primary data. This is followed by comparison of the primary data with available secondary data with subsequent section dedicated to systematic comparison of GPS data with travel diary data. A discussion section closes the chapter and points the reader to subsequent chapters.

Chapter 6 reports on the use of visual analytics, space-time concepts and Local Moran's I spatial statistics in understanding urban cycling behaviour. Using the proposed concepts of *stationary* and *motile* activity spaces, urban cycling behaviours were visualised in both space and time. These concepts were operationalised using already established and available area boundaries from the UK Electoral Ward and the Census Output Areas geographies. The chapter concludes with a discussion on major findings from visual analytics, paving the way for detailed network level route choice preference analysis of everyday urban cycling behaviours.

Chapter 7 develops a two-phase transport network level analysis of the captured and refined cycling behaviours using cycle network infrastructure along with some generated variables. The first phase, unlike the analysis of spatially configured activity spaces in *Chapter 6*, narrows the analytical frame and the line of inquiry to a corridor space level along with the observed route choice preferences. The second phase further refines the routes to the cycleway centre lines and performs statistical analysis. The refined observed routes of the sampled cyclists are compared with sets of network-based generated routes. Finally, a null hypothesis is tested, namely that *network restrictions do not influence movement behaviours of urban utility cyclists*.

Chapter 8 discusses the key findings and methodological issues. Six synthesised areas, based on the four thematic strands presented in the conceptual framework for the research in section 3.2, are discussed in this chapter comprising: cycling data capture, refinement and analytical issues; subjective behaviours of cyclists; temporal behaviours of cyclists; spatial behaviours of cyclists; spatio-temporal behaviours; and, systematic comparison of GPS data and travel diary data. The chapter closes with a section on the implications for policy, society, and cycling behaviour.

The thesis concludes with *Chapter 9*. The chapter is divided into three sections where the research aims and objectives are revisited, followed by research limitations and ends with future research ideas.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

Cycling can improve the impact of traffic congestion and climate change, increase physical activity, and reduce health risks such as obesity and non-communicable diseases and generally improve sedentary lifestyles (GAPA, 2010a, b; NICE, 2012). According to the Omnibus Survey conducted by UK Office for National Statistics (ONS), it was found out that about 87% of British people are of the view that traffic congestion is a serious problem for the country while 77% believe that congestion is an important issue that should be tackled by the Government (GreenerJourneys, 2011). Moreover, Sir Rod Erdington’s Transport Study conducted around the same period (i.e. 2006) suggested that by 2025, the cost of congestion, if left to go astray, could cost about £22 billion in terms of time value in England; and, around the same time, there could be about 31% and 30% increase in road traffic and congestion respectively (DfT, 2006). Car traffic congestion, poor air quality, physical inactivity and accidents are estimated to cost about £19 billion annually making efforts to understand and address these problems inescapable (CabinetOffice, 2009). There is growing interest in understanding cyclists’ perceptions and their actual preferences and movement interactions with the environment to which this work aims to contribute (Docherty and Shaw, 2008, p. 125; Forsyth and Krizek, 2011; NICE, 2012; Panter et al., 2013; Pucher and Buehler, 2012; Shephard, 2008; Tilahun et al., 2007; Yeboah and Alvanides, 2013). The problems that tend to prevent everyday cycling uptake are primarily associated with the environment in which it takes place (Docherty and Shaw, 2008, p. 125). The treatment of cycling as a subject is rather broad and can be examined from different complimentary and contrastive views. Harry (1890) argues that little space has little affinity when it comes to writing about cycling because of its in-exhaustive nature (Cited in Alderson, 1972, p. 5). Given the time and scope for the research, cycling is looked at here as a mode of active transport, whilst acknowledging the importance and contribution of other complimentary and contrastive views. Although cycling is performed in various forms and for different purposes around the world, the emphasis in this research is on bicycling as means of active transport in the western context.

Emerging research is looking at cycling in the UK by first trying to understand the kind of urban environment that will support cycling. A typical example is the UK Visions2030 project (visions2030.org.uk) which has undertaken an online survey and has designed several (artificial) sustainable urban scenes (Tight et al., 2011). The Lancaster study on understanding cycling and walking is another example (Pooley et al., 2011). However, there is scope for increasing cycling uptake in the UK as concluded by Adams (2010) and further suggestions from Mackett and Brown (2011, p. 69) that low levels of cycling in the UK, compared to other European countries, offer an opportunity for improvement; with quite detailed recommendations for future research around cycling and walking focusing on UK population (NICE, 2012, p.45).

The use of GPS trackers and travel diaries in tracking daily mobilities offer a very useful means to gather detailed information for understanding transportation issues – especially when dealing with non-motorised transport matters (Krizek et al., 2009a). Despite the challenges faced, these approaches are promising and further research would benefit this field, while the outcomes can be further used in non-motorised transport modelling. Challenging issues still remain around organisational and technical possibilities (Anderson et al., 2009). An example is the unwillingness by the UK Department for Transport (DfT) to complement travel diaries with personal GPS devices (discussed in section 0).A more complex analysis of travel behaviour is needed for better understanding cyclists' behaviours (Skinner and Rose, 2007); to support cycling policy interventions and transportation engineers and thereby increase cycling uptake. The relationship between the built environment features and cycling-related individual based (actual) behaviours is inadequately, deficiently and unsatisfactorily understood. As Guy and Marvin (2000, p. 17) conclude, in their discussion about models and pathways towards the diversity of sustainable urban futures, that some conceptual devices present opportunities in developing better understanding of strategic ways in achieving sustainable cities.

The objective of this chapter is to review critically the existing research on cycling, in particular the concept of cycling as a means of active transport. In addition, the chapter aims to reveal research opportunities in transport geography and mobility research with specific emphasis on cycling research. This review employed a comprehensive search of peer-reviewed and non-peer-reviewed (grey literature) research. Here, grey literature comprises of theses and dissertations, reports, conference proceedings, research in progress (working papers), leaflets, posters, media reports, patents, letters, diaries, newspapers (both online and offline). Potential bias that may exist in some grey literature, for example media reports, is taken care of by being cautious of its usage in the review. This choice was due to the evolving and contemporary nature of cycling research in the course of the research. The chapter discusses historical perspective of cycling briefly and proceeds with why cycling is important. Factors influencing cycling behaviours and a variety of theories and techniques that potentially support investigating and deepening our understanding of such behaviours are discussed. The literature on cycling and the environment are discussed which precedes cycling related policies and characteristics of urban cycling in the UK. The use of stated preference (SP) and revealed preference (RP) approaches to understanding cyclists' behaviours are discussed alongside modelling cyclists' perceived and actual/revealed behaviour. The chapter ends with some concluding remarks suggesting that further work is needed in understanding cyclists' interaction with the built environment before considering the explanatory and explorative behaviour modelling and simulation using agent based modelling (ABM).

2.2 A historical perspective of cycling

The history of cycling as a means of transport dates back centuries. Since the 18th century, bicycles have been on the minds and discussions of inventors, radio critics, professional engineers, historians, among others (Alderson, 1972; Forester, 1983; Woodforde, 1970); and cycling is still being discussed and researched in the 21st Century (Alvanides and Yeboah, 2012a, b; Hill, 2012b; Jones, 2012; Jones et al., 2012; NICE, 2012; Pucher and Buehler, 2012; Yeboah and Alvanides, 2013). The objective here is not to give a comprehensive account of the history of cycling but rather a brief overview. This will serve as a background as to why cycling is important and cannot be ignored in the quest for sustainable solutions to active lifestyles in urban environments in the UK.

Literature describes the earliest bicycles as a (wooden horse) machine with no pedals or steering mechanism; what was referred to as the célerifère (in 1791) which was later renamed as vélocifére in 1793 (Alderson, 1972, p. 12; Woodforde, 1970, p. 7). A French man - *Comte de Sivrac* (earlier referred to as *M de Sivrac*) - appears to be the first to have ideated, designed and demonstrated such a machine. According to Alderson (1972), some people believe that the Celeripede or a bicycle-like figure had been seen in a stained-glass window in the Church of Stoke Poges near Windsor and dated 1642. To take the reader even further back in history, somewhere around 3500 BC, there appears to be some evidence of usage of wheeled vehicles in the southern part of the plain of Shinar or Sumer (Alderson, 1972, p. 11). The wooden horse or what was also referred to as the "dandy horse" was later improved by an agriculturist who was the Master of Words and Forests to the Duke of Baden; he found it useful for his journeys during his work. The agriculturist, called Karl from Mannheim, introduced a steerable front wheel to the Velocipede via the fork through a socket. The 18th century and the very early 19th century were full of feet on the ground two-wheeled vehicles.

The two-wheeled vehicle emerged in 1839/1840 championed by a Scottish blacksmith called Courthill - Kirkpatrick Macmillan (Woodforde, 1970, p. 17, 20). He is known to have built the first pedal bicycle. It is also reported from the same source that a Russian serf man called Artomonov, from the Urals, had constructed forty years earlier, an advanced model. It is reported elsewhere that one Pierre Lallement from America constructed the first road worthy bicycle around 1865 (Pratt, 1891). In the UK, it was not only Macmillan who created a niche in history but his other two lowland Scots John Loudon McAdam and John Boyd Dunlop also had their fame. The last two decades of the nineteenth century witnessed major developments in cycling. The successful production of bicycles both for the rich and poor in society (like Rover based bicycles around mid-1880s and diamond-framed Humber bicycles, in 1890) paved the way for extreme lengthy journeys; for example, 15,000 miles journey completed across Europe, America and Asia with one Humber bicycle (Woodforde, 1970, p. 98). The cycling trade was also booming during that period having peaked in 1896; when agents ran helter-skelter for bicycles to meet demand.

For about thirty-four years, the 1902 Golden Sunbeam model by John Marston and Company appeared to reign, keeping calm the minds of inventors (Woodforde, 1970, p. 105). From the time of boneshakers (or bone-shaker referring to extreme uncomfortable ride due to the make of the bicycle at that time) till 1903, when the erection of road signs by county councils was enacted via the Motor Car Act, Cyclists or Bicycle Unions and Clubs have been seen to have contributed immensely to highlighting the danger spots and sections on roads across the UK towards helping the improvement of road safety. Chief among them were the National Cycling Union (NCU) and the Cyclists' Touring Club (CTC). By 1903, CTC had erected 2,331 Danger and 1,989 Caution signs. Good roads or paths are of essence both for the earliest and modern day cyclist. The automobile industry has also benefitted from such contributions paving the way for better roads; which, as it appears, are now almost claimed by motor cars.

The twenty-first century has not ignored cycling; issues about cycling still appear in BBC news (BBC, 2010; Kelly, 2011). It was only recently, in 2013, that huge investment (not necessarily enough) on cycling in Britain was being announced by politicians (Siddique, 2013; Walker, 2013a). The challenges being faced in the twenty-first century have prompted society to recall some of the useful lessons from the use of bicycles in the past to bear on the present as well as future issues. Issues about reduction in greenhouse gases, better air quality, rise in obesity, sedentary lifestyles, road congestion, and high demand of natural resources, to name a few, have prompted a new way of thinking towards healthy but sustainable lifestyles. Recent sustainable policies have been promoting cycling uptake and paving the way for an increase in urban cycling (DfT, 2013i).

2.3 Why Cycling?

Pucher and Buehler (2008, p. 496) suggest that there are many good reasons why cycling should be encouraged for everyday travel purposes. Cycling as active transport is viewed by many from different perspectives and purposes: as cheap transport, for personal health improvement and wellbeing, as part of the solution to obesity and climate change among others. Evidence suggests that cycling is well documented historically, and is an irresistible, safe, attractive, convenient, practical, and healthy means of transport (Pucher and Buehler, 2008). The benefits of everyday cycling can far outweigh the costs of cycling infrastructure, equipment, and programs (Pucher and Buehler, 2012, p. 347). Challenges in reducing obesity rates, climate change, and achieving sustainable ways of living in the twenty-first century have prompted society to recall some of the useful lessons in the past to bear on the present as well as future issues (Foresight, 2008; GAPA, 2010b; Martin, 2007); whilst comprehensive recommendations are being made for further research in the UK (NICE, 2012). Issues such as reduction in greenhouse gases, better air quality, rise in obesity, sedentary lifestyles, road congestions, and high demand of natural resources have prompted a new way of thinking towards achieving sustainable ways of living. Indeed, cycling is important and useful in the twenty-first century; it is healthy, convenient and practical (Pucher and Buehler, 2008). Motorised transport contributes to greenhouse gas emissions, which also impact climate change. But, cycling as a means of transport has the potential to ameliorate this negative situation on incremental emissions causing climate change. Hence, understanding cycling as means of transport is paramount. Given the increasing importance of cycling in developed countries, the importance of planning and investment for cycling infrastructure is paramount (Pucher et al., 2010, p. S107). Despite the importance of cycling, its acceptability and empirical evidence base still remains a challenge - for example in the UK, due to a lack of evidence on cycling behaviours in different community settings (Jones, 2012; NICE, 2012, pp. 45-47, 121-122); and also in Australia where there is the need to improve public acceptability of cycling (Daley and Rissel, 2011). Cycling also has the potential to cover most urban trips whilst keeping its environmentally friendly nature and activeness (Moudon et al., 2005).

It is important to emphasise here that this thesis is about cycling research within a western context and should be viewed as such in terms of scope and reach. The Netherlands, Germany. France, Belgium, Spain, and Denmark have demonstrated that, in a typical western context, cycling can blossom and find its place amongst motorised transport; unlike UK and America where cycling uptake is strikingly low (Committee, 2010, p. 4; Pucher and Buehler, 2008). UK has been trying various policies to catch-up with cycling uptake in order to reap its benefits; for example, cycling demonstration towns and the Local Sustainable Transport Fund. Adams' (2010) work which was based on the 2005 nationwide time use survey concludes that there is enough space for increasing active transport and acknowledges the lack of knowledge of active transport among adults in UK; (relatively) less affluent groups were found to be indulging in active transport.

2.4 Factors influencing Cycling Behaviour

Several factors such as activity, purpose and time, age, income, sex, weather, density of land use, transportation network and associated facilities, distance, topography/hilly terrain, cost/money, car availability, population demographics, politics and transport policies are noted to have some influence in cycling behaviours within urban/suburban areas (Aultman-Hall, 1996; Broach et al., 2012; Ehrgott et al., 2012; Fernández Heredia and Monzón de Cáceres, 2010; Harvey et al., 2008; Hood et al., 2011; Larsen, 2011; Mackett, 2011; Menghini et al., 2010; Pikora et al., 2003; Rietveld and Daniel, 2004; Sener et al., 2009; Snizek et al., 2013; Stinson and Bhat, 2004; Susilo et al., 2012; Zhao, 2013). These variables could be categorised into either quantitative (objective) or qualitative (subjective) factors. Since the focus of this thesis, which is an empirical research, was to understand urban cycling behaviour in space and also in time, these two categories are further discussed in the following paragraphs in this section.

The study by Rietveld and Daniel (2004) in the Netherlands focusing on determinants of cycling behaviour from inter-municipality perspective provides a general framework that captures factors that potentially influence bicycle use. They first acknowledge that the effort in determining factors influencing cycling behaviour is not an easy task given subjective factors that might also play a role. They further note that the perception of cycling as a mode of transport differs between countries; and by extension even between cities in the same country where there exist significant variations in perception. Their framework comprises of four main thematic areas. Their first theme covers individual features together with socio-cultural factors such as age, gender, income, activity, perception of bicycle as a mode of transport, ethnicity, and political lineage. The second and third are both generalised cost factors but divided into those for cycling and those for other modes of transport. Those for cycling covered travel time, physical needs (energy), monetary cost, risk of theft or injury, comfort and personal security. Those for other modes of transport, the third, were in two strands: public transport services provision and fuel tax, tolls and parking cost. The last theme, the fourth, consist of initiatives and policies at the local authority level such as capacity and quality of cycling infrastructure, spatial structure of the city as well as cost of private car use. Although the Rietveld and Daniel (2004) study did not mention Aultman-Hall's (1996) work in Canada and comprehensive variables considered in that study, they used most of the factors considered by Aultman-Hall (1996). One observed similarity between the two studies is that both of them considered multiple cities within same country, Canada and the Netherlands.

Based on the proposed framework by Rietveld and Daniel (2004) along with other reviewed literature, Fernández Heredia and Monzón de Cáceres (2010) re-categorised the thematic areas into three main partitions: *objective factors, subjective and evaluative factors, and individual features*. They suggested that the objective factors could be evaluated without necessarily having any direct interaction with the cyclist and that they should comprise of structural and environmental factors. They further divided these groups of objective factors into two, one for those that are personal in nature and another for those that have collective and are associated with the environment. Conditions associated with town planning that are friendly towards the use of the bicycle were considered structural factors. Their subjective and evaluative factors are somewhat based on perceptions of cyclists entirely; the intangible variables although measurable to some extent. The individual features are concerned with cyclists' socio-demographic variables. These three main partitions were used as a frame for discussion in subsequent paragraphs. The *subjective* measures influencing spatial existence of human activities are known to be equally important as the *objective* measures that influence human spatial behaviour (Golledge and Stimson, 1997, p. 2).

Journey, mode of transport, time, distance, purpose, weather conditions, cycle network, topography among others are all objective factors to be considered when investigating factors influencing cycling behaviours. These factors can also be of perceived value depending on how they are measured. Fernández Heredia and Monzón de Cáceres (2010) stress the importance of travel time when there is a decision to be made on the choice of transport mode and also suggest that the purpose of travel is an important influencing factor to be considered. Earlier, Rietveld and Daniel (2004) had also concluded that travel time is an important variable to consider and that directness of routes and few stops contribute to the uptake of cycling as a mode of transport. Commuting travel time and volume of heavy traffic have also been found to be essential attributes in bicycle route choosing (Sener et al., 2009, p. 532). Time-demanding but purposeful cycling should be separated from more time-flexible time-dependent cycling (Fernández Heredia and Monzón de Cáceres, 2010). The purpose of the journey and/or the type of cyclists has influence on bicycle use (Heinen et al., 2009; Stinson and Bhat, 2004). Based on an internet survey in the Netherlands, Heinen et al. (2009) unexpectedly found that the frequency of work days, location or hours and even possessing a driver's license did not influence bicycle use; but, car availability did. They examined how factors related to work – such as working time, kind of clothing worn, and colleagues opinions – affect three groups of cyclists: part-time, full-time, and non-cyclists.

Car availability and usage even for short (cycleable) trips in the UK are prevalent but policies aiming at reduction of car use are sensitive in nature and have political barriers (Mackett and Brown, 2011). In explaining how the road network in UK might develop, Jones (2011) refers to the love and dependence of cars as the transport paradox making further observation that urban areas in UK seem to be gradually moving away from private car use to a more sustainable and active travel lifestyles such as the use of cycling. This observation has some statistical truth as the latest figures show that there was about 2% increase of urban trips made less than 5 miles – or about 8km – by walking or cycling in England from 2010 to 2011 (DfT, 2012c). The difficulty in the implementation of car use reduction policies is also reported for the USA context (Stinson and Bhat, 2004); suggesting perhaps why both UK and USA have low levels of cycling uptake.

Objective factors could be topographical and meteorological in nature; the topography constituting the presence or absence of sloppy terrain while meteorology constituting wind and rain (Rietveld and Daniel, 2004). Rietveld and Daniel (2004) report that wind affects the pleasure, comfort, and effort of cycling and argue that wind is consistently stronger than impedance of rainfall on cycling due to its spatial variability at the coastal areas. The topography of an area offered has been found to influence cycling behaviour (Sener et al., 2009; Stinson and Bhat, 2004). When comparing flat topography to hilly topography, non-commuter cyclists preferred a hilly terrain although slightly (Sener et al., 2009). Even among commuter cyclists, more than half of the sample, about 63% preferred moderately hilly surface (Sener et al., 2009). The sample size was 1621 respondents with 814 as commuter cyclists and the remaining as non-commuter cyclists. These differences reiterate also the essence of the consideration of purpose of travel in cycling research. The exact definition of hilliness was not so clear in the study. The definition of hilliness may however defer from study to study due to use of different datasets. In the UK context, Parkin et al. (Parkin et al., 2008) examined two measures of hilliness, one being proportion of 1km squares, based on UK topographical data at district level, with a mean slope of 3% or more and the other being a mean slope of 4% or more and found the former having more significant correlation.

Transport infrastructure is another important set of variables to consider in the investigation of cycling behaviours. It is well acknowledged that physical infrastructure is an essential requirement for other forms of measures that might influence a physical activity such as cycling (Mackett and Brown, 2011, p. 46). Mackett and Brown (2011) in their literature research found that effective physical infrastructure such as transport network increases accessibility to work together with other essential services and thereby bring about health benefits and improved community severance. Individual features discussed in the literature comprise both the socio-demographic aspects of users of bicycles and the activities of such users (Rietveld and Daniel, 2004). Individual age or income levels have been noted to vary across several studies (Fernández Heredia and Monzón de Cáceres, 2010). The Sener et al. (2009) study in Texas in USA concludes that aside from the evaluation of route related attributes, understanding cyclists' demographics in the context of route choice decisions is essential.

The study of subjective measures is usually linked to studies that tend to concentrate on understanding the intangible aspect of the environment as perceived by individuals (Mackett and Brown, 2011, p. 42; Rietveld and Daniel, 2004). The image of the city inherent in the cognition of residents is found to contribute to how individuals interact within the city (Moiseeva, 2013; Rietveld and Daniel, 2004). Answers to research questions that demands the understanding of human perception of their environment often require direct in-person observation although noted to be time-consuming in nature (Brownson et al., 2009, p. s107).

Despite all the above discussed studies, the consensus on the factors influencing cycling behaviour is mixed. This observation offers future research opportunities which this research contributes to, particularly in the British context. Few studies have been found to combine the use of objective and subjective measures and even fewer attempted to link them and the debate on what may work best is still recent (APPCG, 2013a; Goodwin, 2013; Mackett and Brown, 2011, p. 42; NICE, 2012; Siddique, 2013; Walker, 2013a).

2.5 Characteristics of urban cycling in the UK

Barton et al. (2010, p. 146), in their handbook on shaping neighbourhoods for local and global health and sustainability, list some of the main characteristics of urban cycling in the UK. Their four main characteristics suggest that urban cycling in the UK:

- Has an average journey of 3km together with a normal use within a distance range of 1 – 5 km;
- Falls off in terms of bicycle use when distance goes beyond 5km having a normal maximum of about 8km;
- Has an average speed of about 25 kmph (i.e. 15mph or 7m per second) on flat terrain. This becomes less for the elderly, young or bikes having trailers; and,
- Tend to degrade with sloppy terrain suggesting that a normal maximum hill should be 5% (a ratio of 1:20) and about 10% (i.e. 1:10) for well-built cyclists for short distances when modern gears are being used.

The monitoring of cycling uptake in the UK has often been based on using cycle counters installed at points of interest across cycle networks as means to count and analyse movement activities of cyclists. These cycle counters have been useful in helping to predict as well as estimate existing number of cyclists within various regions across UK. However, though counter-based accounts have their place, it comes with some limitations:

- It is only when the cyclist passes over such detectors that counting is done;
- The actual revealed routes taken by a cyclist cannot be identified;
- Mode shift behaviour (routines and location change) of a cyclist cannot be deduced; among others.

For additional knowledge and understanding, the use of Global Positioning System (GPS) can be helpful in collecting such deficiencies. Disaggregate-like research towards understanding the connection between urban form and cycling related travel behaviour in society is only recent (Ogilvie et al., 2012; Ogilvie et al., 2011; Winters et al., 2010); likewise, efforts to use GPS tracking is the same (Dill, 2009; Ogilvie et al., 2010). Another approach for collecting information from cyclists has been the use of questionnaires as in the UK Census data and also in the Tyne and Wear Household Travel Survey data (TWJTWG, 2011).

The low levels of cycling uptake in UK compared with high levels of cycling in some EU countries can also be attributed to a lack of understanding of cycling (NICE, 2012). Efforts are being made in the study about cycling demonstration towns (Sloman et al., 2009); but more is needed. Because society is about people and not necessarily structures, it is important that micro-level planning – a bottom-up approach - based on understandings of behaviour of people is adopted to make transport infrastructure offer multiplicity of quality choices for the individual (Posselt, 2011).

2.5.1 Understanding Cycling using Stated Preference approach

The stated preference approach offers a mechanism for researchers to ask individuals (i.e. research subjects) refined sets of hypothetical questions or choices. The researcher controls the choices to be made to be selected by respondents (Tilahun et al., 2007, p. 289). In the case of cycling research, it is more or less about cyclists' route choice and destination preferences. Hopkinson and Wardman (1996) by using SP approach, within a route choice context, to review cycle facility provision in Bradford, in West Yorkshire, found that even in situations of relatively low cycle use, safety is highly valued than time arguing that new cycle schemes can be justified economically when considering the benefits to current cyclists. As reported, Bradford was among the UK cities with lowest (i.e. 0.7%) cycling uptake while Cambridge was nearly about 30% during the late twentieth century (Hopkinson and Wardman, 1996, p. 242). One of the reasons attributed to low cycling uptake in the case of Bradford was due to hilly topography. The 2011 Census, a stated preference survey, estimates about 18% for Cambridge as the highest proportionally, and the number of adults who cycle to work around 2% in England (DfT, 2013g). Moreover, evidence from the Active People Surveys from October 2010 to October 2011 (10/11) and from October 2011 to October 2012 (11/12) suggest that the proportion of residents who cycle, for any length or purpose for at least once a month in Cambridge significantly (95% CI) decreased from 58% (10/11) to 51% (11/12) (DfT, 2012e). Bradford decreased from 11% to 8% while Newcastle upon Tyne increased from 12% to 16% for residents who cycle for at least one month but these were not statistically significant changes at 95% CI (DfT, 2012e).

Despite some potential benefits in using SP approach in understanding cycling, it comes with drawbacks: difficulty in mapping textual or pictorial representations of real facilities; possible many missing salient features of a route either on paper or computer screen; strategic bias in a case where respondents think the outcome might influence policy; respondents may possibly compare their own usual routes with the given choices (Broach et al., 2009). Due to the limitation of SP in measuring actual or revealed behaviour of respondents, realistic efforts are made in its implementation. An example is an "adaptive" SP approach which attempts to include some aspects of RP approach (Tilahun et al., 2007); although in USA context.

2.5.2 Understanding Cycling using Revealed Preference approach

Unlike SP, the RP approach offers a mechanism for researchers to capture the real or actual behaviour of respondents. Theoretically, *RP* is same as *constrained* choice (Golledge and Stimson, 1997, p. 54). Golledge and Stimson (1997, p. 54) suggest "*Revealed preference states that by making choices we reveal the preferences that we have among sets of alternatives*". With some thought, this goes to show that all perceivable constraints are accounted for by the traveller and therefore makes preferred routes an interesting sets of routes to examine. In the case of cycling research, it is more about the actual / revealed / measured cyclists' route choice and destination preferences. The use of GPS in such studies offers a useful mechanism in measuring the cyclists' actual route choice preferences.

Very few published cycling studies in Britain implement the RP approach for cyclists' route choice preference survey. This research contributes to fill this emerging gap in the UK, whilst acknowledging identifying a few published studies: Portland (Broach et al., 2012), San Francisco (Hood et al., 2011); Zurich (Menghini et al., 2009); Auckland (Ehrgott et al., 2012); and even on-going work in Denmark (www.bikeability.dk). Almost all of these studies have some form of SP component as part of the research design, with the exception of Zurich where only GPS secondary data without additional stated preferences of the sample was used for the research.

Duncan and Mummery (2007) in comparing GIS measures with data from GPS conclude that the use of GPS in active transport research is encouraged; enabling further work to be undertaken especially in cycling (Yeboah and Alvanides, 2013). Prato (2009) reviews alternative solutions in determining preferences of various travellers with the aim of increasing route heterogeneity but in the context of general route choice modelling.

2.6 Theoretical link between Built Environment and Active Travel

Generally, some set of laws that is established based on sound empirical research and useful in the prediction and explanation of some phenomenon may be termed a theory (Handy, 2005, p. 7). The theory on built environment constitutes loosely a conglomeration of ideas about some specific characteristics of the built environment that influence travel behaviour in space although not considered as a behaviour theory explicitly (Handy, 2005). Handy's (2005) review of theoretical framework and challenges for discussion around linkages between the built environment and active travel behaviour, which included physical activity, suggests that there seem to be no one complete theoretical framework to aid in our understanding of such linkages. A few years later, Brownson et al. (2009) also performed a state of the art critical review on how the built environment could be assessed and measured to support active transport and suggested further research to incorporate technical qualities of measures, understanding of various population types, and the use of the measures for science and public health. Handy (2005) suggests a combination of theories from different disciplines in the study of linkages between the built environment and travel behaviour. Further, Handy (2005) suggests that the use of the Theory of Planned Behaviour and Social Cognition Theory together with utility-maximising framework may be quite useful in such studies. The utility-maximising framework is closely linked to application of multinomial logit model which is sometimes used for discrete choice modelling where utility is a linear function constituting a series of particular choice relative to all other choices where each coefficient of an attribute denotes the relative importance of the attribute (Handy, 2005; Menghini et al., 2010).

Docherty and Shaw (2008, p. 125) argue that the environment serves as a potential obstacle to everyday cycling. With further thought, with the obstacles removed or lessened, the environment can potentially serve as an enabler to everyday cycling. Perception of the environment, the urban structure, and self-identity by cyclists and society also may play a part in constraining or enabling cycling uptake in urban areas together with environmental conditions such as rain, snow, cold, wind, etc. Urban structure plays an important role in how and when people travel in urban environments, especially when one thinks of how cycling can be integrated into people's lifestyles (Pooley et al., 2011, p. 1607).

Handy et al. (2002a, p. 65) defines the built environment as comprising "*urban design, land use, and the transportation system, and encompasses patterns of human activity within the physical environment*" and proposes the dimensions of the built environment (Table 2-1).

Table 2-1: Dimension of the built environment

Dimension	Definition	Examples of measures
Density and intensity	Amount of activity in a given area	Persons per acre or jobs per square mile. Ratio of commercial floor space to land area
Land use mix	Proximity of different land uses	Distance from house to nearest store. Share of total land area for different uses. Dissimilarity index
Street connectivity	Directness and availability of alternative routes through the network	Intersections per square mile of area. Ratio of straight-line distance of network distance. Average block length
Street scale	Three-dimensional space along a street as bounded by buildings	Ratio of building heights to street width. Average distance from street to buildings
Aesthetic qualities	Attractiveness and appeal of a place	Percentage of ground in shade at noon Number of locations with graffiti per square mile
Regional structure	Distribution of activities and transportation facilities across the region	Rate of decline in density with distance from downtown Classification based on concentrations of activity and transportation network

Source: Handy et al. (2002a, p. 66)

Handy (2005) further suggests that the built environment could be defined as constituting three main general components namely *transportation system*, *design* and *land use patterns*. The transportation system was defined as the combined state of the physical infrastructure and the services making up the transportation system along with the spatial links that provide connections between activities. The importance of the quality of the spatial links was also mentioned to be of importance to the determination of distance, speed, safety, comfort and pleasure. Design constituted the built environment's aesthetic qualities and covers land use patterns as in design of buildings as well as the design of streetscapes as in transportation system. Broadly, Design is defined to cover the characteristics of public and private outdoor spaces together with interior design of buildings; these are visual details of the built environment such as textures and colour. Lastly, the spatial distribution of human activities is referred to as "land use patterns". The combined state of the built environment, natural landscape such as greenery and the use of public space by humans constitute the "physical environment". Handy (2005) also highlighted the importance of spatial scale in all of these definitions.

The process of addressing the relationship between the built environment and travel behaviour is argued to be initiated by the difficult task of developing appropriate measures (Handy et al., 2002a, p. 65). Taking the necessary efforts for measuring and processing relevant cycling data is not an easy task at all for a researcher (Krizek et al., 2009b, p. 734). The development of such measures appears to be more focussed on walking with the concept of "walkability" (Adams et al., 2009; Burgoine et al., 2011; Cerin et al., 2009; Leslie et al., 2005; Lwin and Murayama, 2011b; Van Dyck et al., 2009); with occasional discussion on cycling despite the equal importance of cycling (NICE, 2012). The limited research on non-motorised transport, although increasing, has at times been attributed to the lack, or difficulty, of acquiring and developing reliable datasets and the matching of the dataset to captured features of the physical environment using geographical methods (Handy et al., 2002a, p. 72). For example, it is argued that the relationship between land use and mobility is lacking in spatial policies in the City of Newcastle which is the sub-regional hub in the former county of Tyne and Wear (Hull, 2005, p. 325).

Terms like *active travel*, *physical activity*, and *active transport* could mean several things to several researchers depending on the context of usage. Handy (2005) defines active travel as the use of non-motorised means to travel from point A to point B; usually using either cycling or human legs despite rollerblading, wheelchair use, roller-skating among others also being other options. Additionally, any kind of movement of the body was referred to as physical activity. Handy's (2005) definition of physical activity suggests that there is movement of body but might not necessarily be a movement of the body for the purpose of travel; and, therefore suggests another term "other physical activity" to be given to activities not meant for the purpose of travel. These terms are used in this thesis interchangeably as that of the definition of active transport unless stated otherwise.

2.7 Route Choice modelling and Theory of Planned Behaviour

The use of route choice modelling, though difficult, has been identified to be useful in understanding (i.e. modelling and predicting) travellers' perceptions of route characteristics. Prato (2009) gives a state of the art review of route choice modelling and argues that difficulties in data collection might be the reason behind the small number of revealed preferences studies available. Such studies, including this current study, mostly used GPS data (Broach et al., 2012; Broach et al., 2009; Broach et al., 2011; Ehrgott et al., 2012; Hood et al., 2011; Menghini et al., 2009). None of the studies, apart from the current study, has incorporated possible use of STC in their methodology; not for route choice modelling but rather for data cleaning or visualisation. This might be due to no knowledge of STC theory or tools since they were not mentioned at all.

The theory of planned behaviour (TPB) offers another means of modelling or predicting human behaviour. Although explaining human behaviour appears difficult and complex, it can be tackled from different levels (Icek, 1991, p. 179). TPB was originally proposed by Icek Ajzen in the mid-1980s (Icek, 1991). Figure 2-1 shows a structural diagram of the TPB. The achievement of a behaviour (e.g. cycling) depends jointly on both the intention (i.e. motivation) and behavioural control (i.e. ability); hence the arrows towards the circled behaviour as shown in the figure. The arrows show the direction of influence (or information flow) towards the realisation of one's intentioned behaviour. Because "a person may believe that, in general, her outcomes are determined by her own behaviour (internal locus of control), yet at the same time she may also believe that her chances of [for example cycling] are very slim (low perceived behavioral control)" (Icek, 1991, p. 183), direct link from perceived behavioural control to behaviour is considered low or weaker than a link via intention to behaviour and therefore is indicated as a broken line.

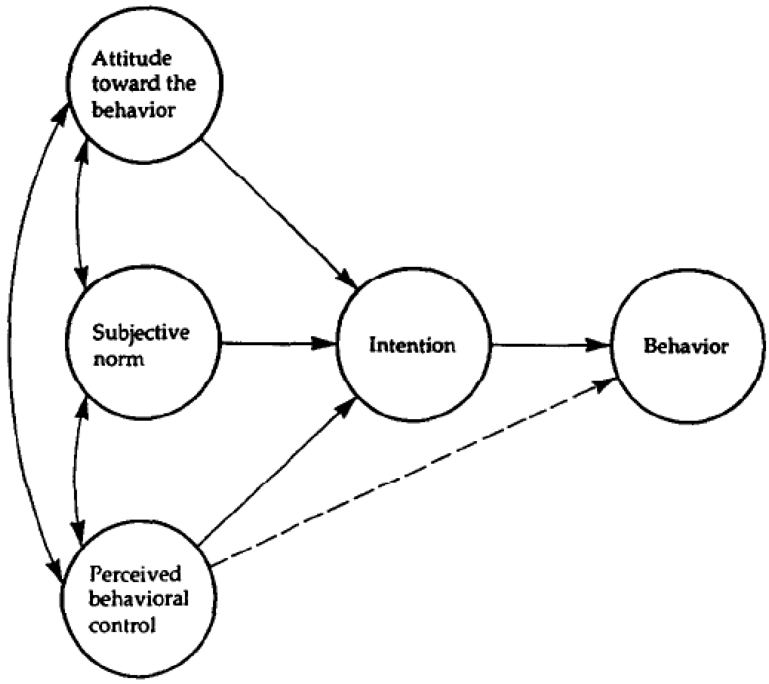

Figure 2-1: Structural diagram of the Theory of Planned Behaviour

Source: (Icek, 1991, p. 182)

A brief description of TPB is given here. Francis et al. (2004, p. 7) provide a brief explanation of what attitude, subjective norm and perceived behavioural control mean:

- *Attitude*: whether the subject is in favour of doing the behaviour;
- *Subjective norm*: how much social pressure the subject feels to do the behaviour; and
- *Perceived behavioural control*: whether the subject feels in charge of the behaviour in context. Icek (1991) points out that behavioural control is the *ability* to perform the behaviour and emphasises the difference in *actual behavioural control* and *perceived behavioural control*. He further suggests that the significance of actual behavioural control is self-evident in available resources and opportunities to a subject since they dictate the degree of executing the behaviour successfully. Perceived behavioural

control is of only psychological interest and they impact intention and behaviour as shown in Figure 2-1.

The central focus of TPB is the individual's *intention* to execute a given action (Icek, 1991, p. 181). According to Icek (1991, p. 181), *intentions* are motivation factors influencing behaviour. He suggests that intentions should serve as indicators of how much and how hard a subject is willing to try performing the behaviour in context. Further, he clarifies that such an intention can only find expression in behaviour in context if the subject can voluntarily decide to perform or not to perform the behaviour.

A typical, relevant, example where TPB has been used to predict active transport is evidenced in the work of Lemieux and Godin (2009). In this example, students' intention, habit and age predicted behaviour significantly without the use of any revealed preferences with GPS data. Furthermore, the need for further research was stressed to incorporate both objective and subjective measurements.

2.8 Space-Time Geography of Human Spatial Behaviour

2.8.1 Torsten Hägerstrand and the aquarium of human endeavours

In discussions relating to the built environment, space-time behaviour is often associated with spatial behaviour and the field of behavioural geography (Saarloos et al., 2009); as well as travel behaviours and transport behaviours, what Skinner and Rose (2007, p. 85) note as , the "*broader constellations of attitudes and practices*". All such behaviours are human based occurring within a particular space at a particular time and can be said to find their origin in human geography. The source of space-time (human centred) geography concept can be traced to august 1969 when an argued case, for researchers in regional science to interrogate the individual element of their aggregate models, was presented as a paper by Professor Torsten Hägerstrand (1970). The paper was presented at the European Congress of the Regional Science Association in Copenhagen, Denmark. The advanced and sophisticated intricacies of the *how* this (i.e. the argued case) could be implemented were left to posterity and future research. This discussion period were times when the gravity and entropy-maximising models reigned supreme; details of such models exist elsewhere, see, for example, Wilson (1974, 1981).

Hägerstrand's space-time concepts are situated in contextual theory (Lenntorp, 1999, p. 157); and clearly demonstrate what may be referred to as the talisman of human endeavours (Hägerstrand, 1970; Johnston et al., 2000, pp. 830-832). The concepts are used as a means of visualisation to understand human interaction in terms of space and time. The dimension of space is just like a Cartesian 3D space with the z-axis (height or altitude values) replaced by t-axis (time spent). In a way the undulation of the terrain is assumed to be irrelevant. Only horizontal values (x and y values) are assumed relevant with vertical values being the various times spent by an individual. The start of trip (origin) and end of trip (destination) of an individual travel behaviour (the path) defines the time spent (the time budget) and assumes the approximate centre of the potential path area (PPA) as shown in Figure 2-2. The prism holds all paths within a given time budget.

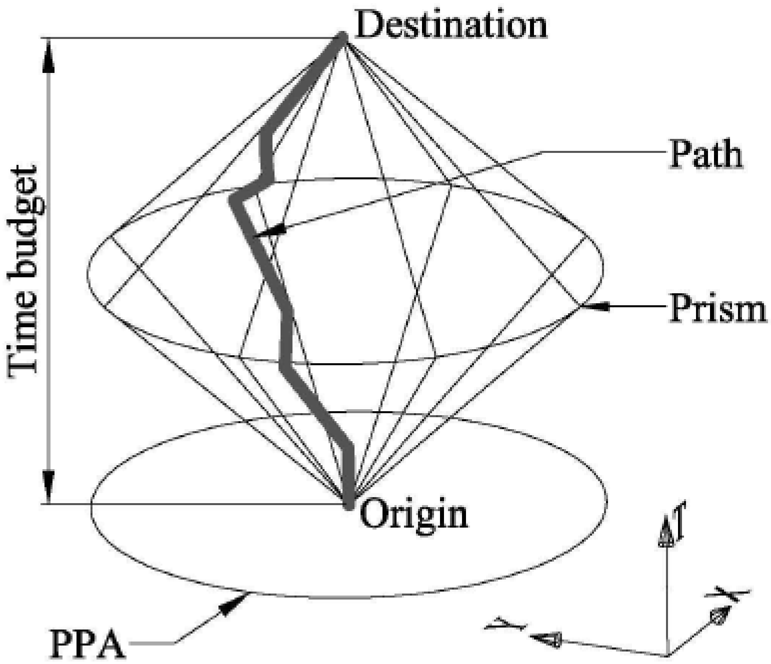

Figure 2-2: Time geographical concepts: space-time path, space-time prism, and potential path area with horizontal and vertical axes

Source: (Neutens, 2010, p. 14)

The classical space-time concept entails three general constraints: 1) *Capability constraints* which embody physiological and biological limitations and abilities; 2) *Coupling constraints* which are interactive factors that limit individual travel and activity participation and demarcates where, when and how long s/he is to connect other entities such as individuals, machines, toilet etc. for some purpose(s); and 3) *Authority constraints* which refers to accessibility definitions of a given territory where an individual or groups of individuals have control over. Such definitions are mostly found in laws, policies and policy interventions among others, although the “how” of the concepts implementation and frame of analysis had not fully been worked out at that time. As noted by one of Hägerstrand’s disciples at the time, using such concepts to describe world views was not clearly treated (Lenntorp, 1999, p. 157).

2.8.2 Beyond Torsten Hägerstrand

Although Hägerstrand's novelty of thought has been widely accepted, it has also received some critique. Such criticisms are mainly found to dwell more on a lack of constitution of the (behavioural traits) nature and intelligence of the individual. Also, the absence of experiential knowledge and featureless topography needed some attention (Buttimer, 1976, p. 287; Rose, 1993, p. 28). Although Hägerstrand's sense of conviction that the use of space-time framework to study human-based events characteristics is bound to yield results (Hägerstrand, 1970, pp. 20-21); such sense of judgement still lives on. It is interesting to note that Hägerstrand (1970), at the time of presenting space-time concepts, had simulation and invention of (technologically enabled) imaginary societies in understanding the impacts of social organisation and the ordinary days of an individual (Hägerstrand, 1970, p. 21). This is not surprising though since some work on dynamic models of segregation followed a similar type of technique at that time (Fagiolo et al., 2007). More recently researchers also still contemplate on such imaginative conjectures (Neutens, 2010, p. 241).

Beyond Hägerstrand's classical concepts, several researchers have been advancing such knowledge, some of which are: shortest path based calculations of space-time prisms (Kwan, 1998; Miller, 1991); zone-based neighbourhood multi-level modelling (Weber and Kwan, 2003); a three dimensional network based space-time prisms embodying non-uniform velocity assumption (Neutens et al., 2008); appraisal of error propagations in planar space-time prisms vis-à-vis their intersections using an analytical approach (Kobayashi et al., 2010). Furthermore, some of the key challenges in space-time approaches noted by Neutens (2010) are: 1) the application of space-time approaches with GPS-based datasets and analysis – what was referred to as location aware technologies ; 2) the use of non-uniform velocity that do not vary per arc to model movement; 3) The use of actual network in combination with micro-simulation techniques to understand social activities in space-time is missing but placed in the domain of future prospects; 4) Explicit accountability of traffic congestion effects in travel time estimation; and 8) Incorporation of cognitive and affective constraints of individuals among others.

A key aspect of spatially-enabled space-time visualisation is to represent some data in a certain fashion that may reveal some patterns and relationships. Generally, levels of such visualisation differ with purpose, tools and systems available and data used. Geographic information systems are often associated with data analysis, modelling and visualisation. Such associations are either simple or complex in conceptualisation and implementation. In this work, analysis and modelling have been separated (but only by approach) from visualisation mainly due to the fact that most GIS systems available, at the time of the research, appear not to have full implementation of space-time concepts as one full software package or tool. However, recent developments in the arena of visualisation of spatial-temporal interconnectedness appear to have matured for usage (Kapler and Wright, 2004).

2.8.3 The Space Time Cube and its usability

This section discusses what space-time cube (STC) is and what it is being used for in available literature. Hägerstrand (1970, p. 10) suggests that "The concept of a life path (or parts of it such as day path, week path etc.) can easily be shown graphically if we agree to collapse three-dimensional space into a two-dimensional plain or even a one-dimensional island, and use perpendicular direction to represent time; thus, giving fundamental definition of the space time cube. Hägerstrand (1970, p. 11) further argued that "Even if many constraints are formulated as general and abstract rules of behaviour we can give them a "physical" shape in terms of space, areal extension, and duration in time" and further used terms such as "time-space", "time-space tube", "time-space compartments", "time-space phenomena", "time-space walls", "time-space surroundings" giving perspectives to space time cube. Recent literature such as Kveladze and Kraak (2012) confirm that Hägerstrand (1970) proposed the concept of STC and Tang et al. (2010, p. 98) specifically points out that "Hägerstrand first proposed the space time cube" and simplified the definition as "the space time model is composed of two dimensional space data and one dimensional time data" and noted the difficulty in implementing the three dimensional cube. Figure 2-3 shows a simplified graphical definition of a space time cube; any location in the cube has three coordinates (e.g. X_3, Y_3, T_3) and that the time and spatial extents of the data in the boundary of the cube.

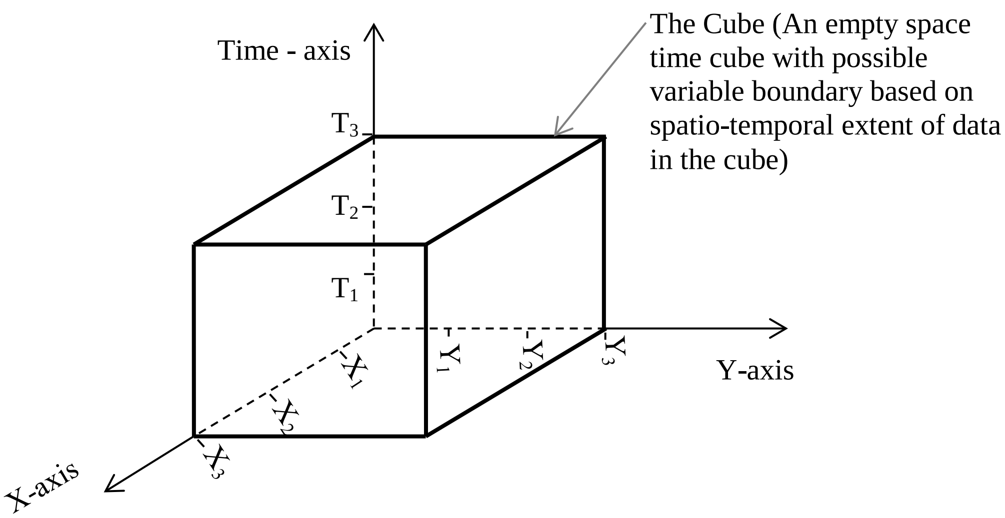

Figure 2-3: The Space Time Cube

Source: Adapted from Tang et al. (2010, p. 98).

In the case of the implementation of space-time cube, it appears that the latest GIS packages do not have full implementation other than some add-on packages. GeoTime[1] software package which works with ESRI ArcGIS software package has been identified to be state-of-the-art implementation. That notwithstanding, there are other implementations such as Activity Pattern Analyst (APA) by Chen et al. (2011); *CommonGIS* software by Andrienko and Andrienko (2013a);VISUAL-TimePAcTS by Ellegård and Vrotsou (2006); using browser based Google Maps as demonstrated by Gong and Mackett (2008); among others. The use of the space time cube may broadly be categorised into analysis and visualisation which are undertaken in turns until desired visualisation (could be static, animation or interactive in nature) is achieved. Earlier visualisations using the STC was based on a time consuming sketches due to limited possibility to create computer based graphics but recent implementations of dynamic STC environments have provided possibilities for researchers to view, analyse (i.e. manipulate and query) (Andrienko and Andrienko, 2013a; Chen et al., 2011; Ellegård and Vrotsou, 2006; Gong and Mackett, 2008; Kraak, 2003; Kristensson et al., 2009; Vrotsou and Coooper, 2006). The use of the dynamic environment usually ends up normally being an interactive interface where an investigator can perform variety of queries on same database to generate different 2/3 dimensional scenes, animations, static images. These ways of using the STC tend to input data already refined outside the STC before being imported into the cube for analysis and visualisation. This raises an interesting question: given that the STC can now be easily used to analyse and visualise GPS data, can it also be used for GPS data refinement rather than cleaning the data outside the STC before use the data inside the STC? This question will be revisited in section 2.14.1. Moreover, little knowledge exists for such a combination of sophisticated and advanced tools in cycling research.

2.8.4 Activity Space and Action Space concepts

An *activity space* can be defined as an area encompassing all visited locations by an individual within a definite time span (Thornton et al., 2011, p. 3). Visited locations therefore imply that the places have been contacted physically by the traveller in the course of the activity (Buliung et al., 2008, p. 703). The person performing the activity accumulates knowledge about locations, prior to, during or after the activity which need not necessarily be visited physically. The area containing the locations about which the person has some knowledge is termed *action space* (Thornton et al., 2011, p. 3). Activity spaces represent the actual daily travel patterns (Schonfelder and Axhausen, 2010, p. 122). Therefore, *activity space* could be said to be a subset of *action space*. Activity space may be defined as the collective movement of an individual

[1] GeoTime is software from Oculus Info, Inc. - http://www.oculusinfo.com
See information on GeoTime here - http://www.geotime.com/Company.aspx

situated within an action space (Golledge and Stimson, 1997, p. 279). Figure 2-4 shows the conceptual model of activity space.

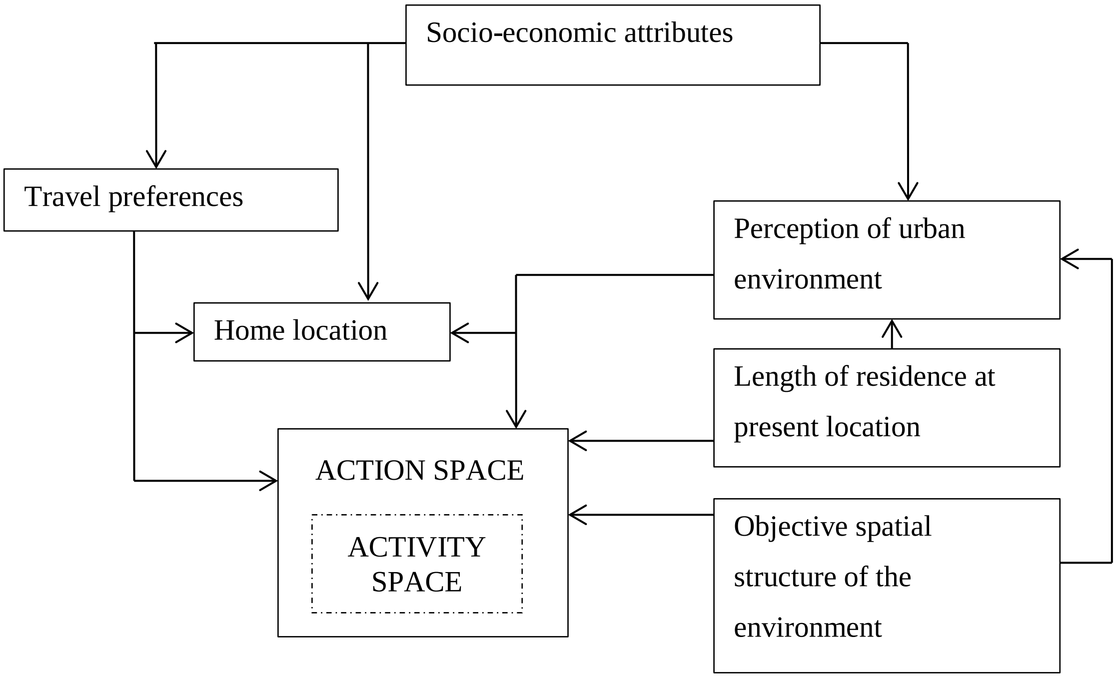

Figure 2-1: Conceptual model of activity space

Source: Adapted from Golledge and Stimson (1997, p. 279)

Additionally, a *potential action space (*PAS) may be defined as the area that contains all reachable activity locations and constrained by a set of spatio-temporal constraints comprising of location and type of activity, time interval, speed of travel as well as the travel time (Timmermans et al., 2002). A typical individual activity space constitutes three main things (Golledge and Stimson, 1997):

1. Movement near and within the home location

2. Movement to and from locations of regular activities, such as home to work trips, to shop among others

3. Movement in and around the locations where those activities are located

An activity space constitutes a set of activities desired by an individual or group of individuals and possesses both spatial and temporal properties (Golledge and Stimson, 1997, p. 280). Addition of the time dimension to these definitions connects them somewhat to space-time prism definition in space-time geographical concepts as discussed in section 2.8. As Neutens (2010, p. 14) notes, space-time prism contains all space-time paths within a time budget delimited by two vertices. The PPA could therefore be linked, or connected, to the PAS. This connection portrays the potential of space-time geography as it tends to focus on the interrelationships between space and time along with the constraints imposed by these interactions (Miller, 2004).

2.8.5 Visual Analytics and Activity-based Analysis approaches

Visual analytics (VA) is multidisciplinary in nature and entails the use of different kinds of techniques and is applicable in a wide variety of areas making its definition a difficult task (Keim et al., 2010). VA may be defined as the use of interactive visual interfaces as a science for the facilitation of analytical reasoning in problem solving (Thomas and Cook, 2006, p. 10). This definition makes the scope of VA very broad covering nine thematic areas and ranging from geospatial analytics to information analytics as earlier shown in Figure 2-5. This definition becomes more useful in situations where raw data itself has no value unless the data is mined and knowledge discovered in the process for visualisation (Keim et al., 2008). The process for knowledge discovery is not an easy task as there is a potential for an information overload. Information overload occurs when an analyst falls into a risky situation of working with data which may not be relevant to the line of inquiry, presented and/or processed in an inappropriate way (Keim et al., 2008). The gradual increment of spatio-temporal information on various urban phenomenon has necessitated the advancement of visual analytics tools, techniques and concepts with the aim of ameliorating the issues surrounding information overload (Andrienko et al., 2008; Andrienko and Andrienko, 2013b; Kapler and Wright, 2004; Kristensson et al., 2009); with concepts from space-time geography still prominent in the literature which will be discussed in subsequent sections in this chapter.

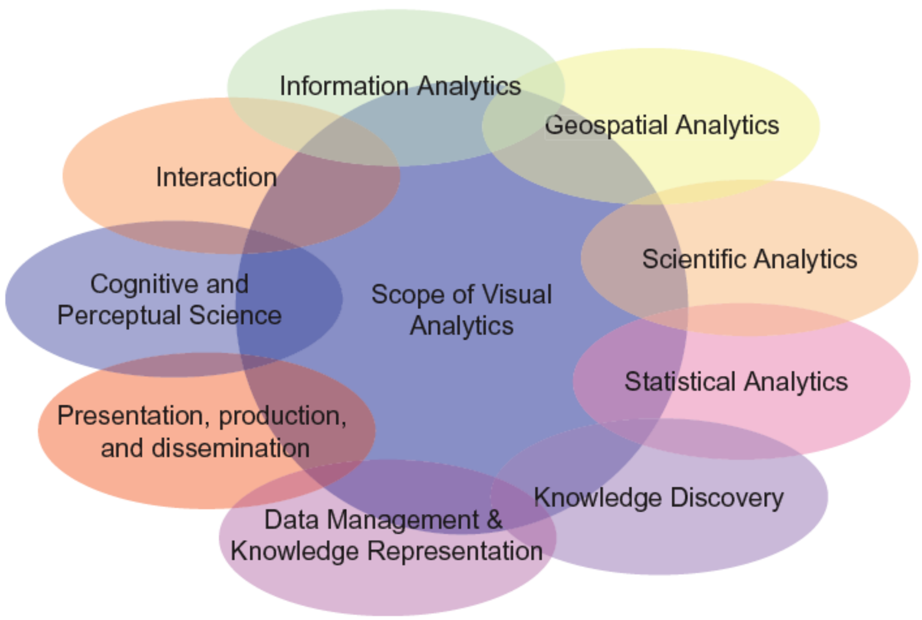

Figure 2-5: Scope of Visual Analytics

Source: (Keim et al., 2006, p. 2)

According to Rapoport (1982, p. 15), the analysis of any activity could be grouped into four main categories:

1. The activity proper;
2. The specific way of doing it;
3. Additional, adjacent, or associated activities that become part of the activity system; and
4. The meaning of the activity.

Another argued case is that the variability of categories 2, 3, and 4 leads to differences in acceptability and (subjective) judgements of the environment which all have a part to play in the representation of self. The further suggestion is that the meaning of an activity is rarely separate from its function making meaning a most important of function (Rapoport, 1982, p. 15). Juxtaposing this suggestion with (Aldred, 2013) phrase *cycling is functional* will not hold but makes some sense when her full sentence is stated which is: "*Cycling is just 'functional'; yet also something one enjoys, potentially threatening the 'functional' definition" (Aldred, 2013, p. 197).*

The conceptual foundation of the activity-based analysis (ABA) paradigm holds that "*the decision to change one's location, and therefore make a trip, is a consequence of a need which cannot be satisfied at the present place*" (Schonfelder and Axhausen, 2010, p. 29). Central to ABA paradigm is the assumption that the "*demand for travel is derived from the demand for activities*" (Handy, 2005). This means that activities performed at different places and times are commonly associated with social, cultural and physiological needs and therefore seen as a main focus for investigation in mobility research. Such a paradigm has led to the identification of complex behavioural patterns comprising of variability, periodicity, among other temporal phenomena as main focus of studies (Schonfelder and Axhausen, 2010, pp. 29-30).

2.9 Cycling and Environment

The space for cycling as well as the space beyond navigation may be referred to as the cycling environment. Environment as a term can mean several things, such as natural environment which covers the atmosphere, weather, climate among others; built environment which covers transport infrastructure and other built-up facilities. The formulation of policies around these environmental variables often needs some kind of framework with intelligence based on some kind of understanding. This section discusses some of these environmental concepts and how they relate to cycling as an active transport – utility cycling to be more precise.

2.9.1 Cycling and Natural Environment

Natural environment can be seen from many perspectives; some studies refer to natural environment as the green space and its neighbourhood on-Earth (Mitchell and Popham, 2008; Thornton et al., 2011) but can be as broad as near-Earth environment containing meteoroids, orbital debris per the definition from US National Aeronautics and Space Administration (Anderson and Smith, 1994, p. 1-1). Johnson et al. (1997, p. 586) study about meanings of environmental terms concludes that the natural environments are considered as those relatively undisturbed by human culture. The co-existence of cycling activities and the occurrence of natural environmental factors always need some sort of balance.

Until a human activity is defined and proven to be occurring, geographical space appears to be a natural environment. However small the indications of human activity may be within the natural environment, evidence shows that those activities affect the natural environment in several ways. An example of accounts of how harsh natural environment (i.e. mountainous areas and bad weather conditions) impedes cycling is the bicycle use study in Seoul and Busan areas in South Korea (Chung et al., 2009). It may also be possible to ameliorate such harsh conditions via strategic investment in cycling infrastructure such as cycling friendly bridges and tunnels as well as promoting low carbon methods of travel. Such possibilities dwells much on human behaviour and action in terms of constructive design and use of the built environmental structures and awareness of how the natural environment relates to and affects the built environment.

2.9.2 Cycling and Built Environment

The definition and scope of the built environment is pervasive but somehow provides a context frame for all human endeavours (McClure and Bartuska, 2007, P. 5). The association between the built environment and physical activity-for which cycling places an important role–is relatively a new area of inquiry (Forsyth and Krizek, 2011; Handy, 2005, p. 5; NICE, 2012). The built environment is embedded and entrenched in the natural environment. The built environment in several ways embodies both simple and complex spatial patterns. Such patterns can be said to have effects on people movements within the built environment (Knight and Ruddock, 2008, p. 19). The built environment can be argued to be a major factor in enhancing or degrading physical activities; especially pertaining to cycling.

Few studies have actually examined the relationship of the built environmental factors vis-à-vis active transport (Berrigan et al., 2010; Witten et al., 2011); especially objectively measured built environmental variables. Most of the available literature on these studies is mainly undertaken in USA and Australia (Jones et al., 2007, p. 12; Moudon et al., 2005). Even those existing studies addressing active transport and some built environment measures are skewed towards walking

(Berrigan et al., 2010, p. 16). Berrigan et al. (2010) conclude that combinatory analysis of the propensity and duration of active transport behavioural traits with explicitly geographic approach has profound potential towards studies of the built environment and active transport. It is not surprising therefore to identify recent studies in this direction (Witten et al., 2011); using a geographic approach to construct a neighbourhood accessibility index for walking - making it a Walkability index rather than Cyclability index. Little research exists on neighbourhood accessibility index for cycling in the literature, with exception to Moudon et al. (2005). This is mainly from the US perspective and examined how the built environment correlates to cycling - concluding that further transport-based (i.e. utility cycling) studies could help in understanding of the correlation, rather than non-utility cycling. Furthermore, Lee and Moudon (2006) provide a core construct for walkability by considering destination, distance, density and route – the 3Ds+R. It would be interesting to find out what impact such an index and 3Ds+R considerations within the built environment will have on cycling. Knowledge audit of how the built environment could be quantified and hypothesised somewhat as a baseline to build reliable tools for the creation of activity-friendly neighbourhoods is possible (Figure 2-6) (Moudon and Lee, 2003); but demands profound knowledge in geographical concepts.

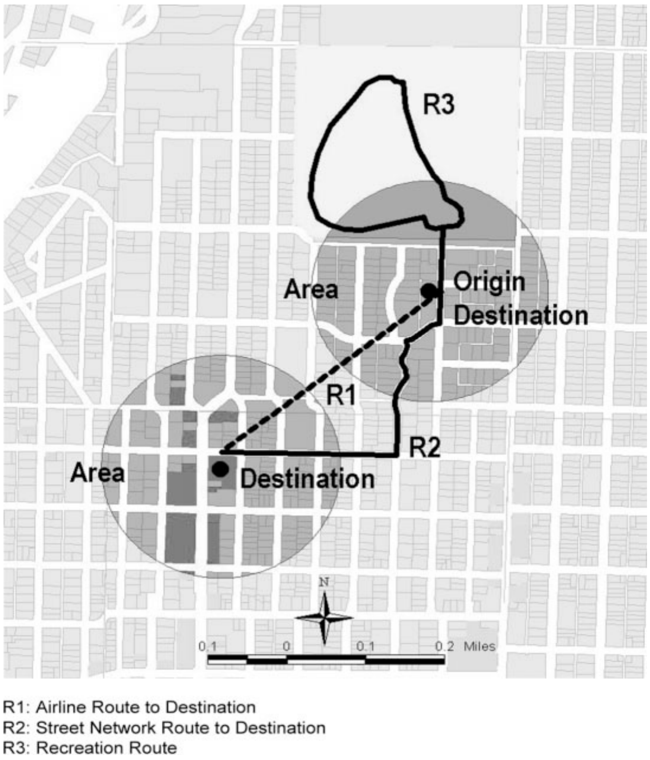

Figure 2-6: Behavioural model of Environment

Source: (Moudon and Lee, 2003, p. 23)

2.9.3 Cycling and Transport

The immediate rise of cycling, in 1888, in England and Wales, pushed an Act of Parliament to allow bicycle and bicyclist entitlement of a place on the road given the provision that the machine had a well fitted bell capable of continuous ring (Woodforde, 1970, p. 3). Before the Act of Parliament, road surveyors were under pressure from protest from cyclists for their negligence on keeping improper care of roads. Interestingly, just some few years before, in the early 1880s, there were still many people who saw bicycling as a craze (Woodforde, 1970, p. 2).

A recent debate in April 13, 2011, in the news was about possible introduction of new offence of causing death by reckless or dangerous cycling (Kelly, 2011). Kelly (2011) uses the term "lycra lout" to describe the cognitive picture from the minds of newspaper writers as well as motorists in elucidating the behaviour of cyclist on the road; "*jumping red lights, hurting pedestrians on pavements and denying the Highway Code applies to them.*" When it comes to the picture painted by supporters of bicyclist he writes "*To their supporters, Britain's bike-riders are clean, green, commuters-with-a-conscience, who relieve congestion on the nation's roads while keeping themselves fit.*" My opinion is that such exchanges depict some kind of blame game scenario and may not solve the situation; though the fact that attention has been drawn for a discussion or debate is a positive thing rather than perhaps demonstrations. In March 2011, a Conservative MP initiated a bill towards creating new offences of causing death or serious injury via dangerous or reckless cycling (Paliament, 2011b). There is the need for raising awareness among motorists, cyclists and pedestrians. The abolishment of Cycling England, on 1st of April 2011, and the introduction of Local Sustainable Transport Fund (LSTF) by the UK DfT may help in promoting cycling as an Active Transport by Local Authorities (LAs). The biddable fund, the LSTF, stretches over four years till 2015 (Paliament, 2011a).

2.9.4 Cycling and the Time Factor

Despite the importance of time to physical activity, time as a constraint is not well understood and making time for physical activity such as cycling is a matter of choice in everyday lifestyles (Handy, 2005, p. 166). For example, adult Americans spent about 3 hours watching television (Handy, 2005, p. 166), which part of this time could be used for physical activity. In the UK, the Adams's (2010) study using UK 2005 Time Use Survey of UK Adults suggests that less than one third (27.8%) of respondents (79.6% of 4941 individuals) reported any active transport and less than a fifth (18.6%) were sufficiently active through via active transport alone. The study concludes that active transport should be promoted as a method for increasing physical activity since more than one third of those (the 27.8%) who reported any active transport achieved the UK Department of health recommendations for physical activity (Adams, 2010) The UK government recommends about thirty minutes of physical activity for an individual within a week (at least five days a week) amidst the sedentary lifestyle in the 21st century (DH, 2004). The dynamics and complexity of modern lifestyles in developed countries like UK and shortage of time are known to serve as barriers to increasing cycling uptake (Mackett, 2011). Mackett (2011) links the shortage of time to employed mothers who tend to possess a perceived need to protect their children. By extension, this notion of time could be situated in timings for everyday life. The willingness to cycle depends also on financial and travel time constraints (Rietveld and Daniel, 2004). Travel time depends also on the spatial structure of the activity space and may comprise of essentials of cycling infrastructure, detours, waiting times at crossings (Rietveld and Daniel, 2004, p. 533).

2.9.5 Bikeability, Cyclability and Supportiveness

Usage of the term Bikeability in the UK is associated with professional training on the use of a bicycle rather than as an indicator of measure of cycling friendliness of a neighbourhood (Christie et al., 2011; DfT, 2011d). The term is considered as a brand for the latest training scheme for the 21st Century in UK (DfT, 2013c). Therefore, Bikeability in the UK generally means the knowledge of how to ride a bike and the ultimate aim is to provide the needed skills and confidence for everyday cycling on car-centric UK roads. There are three main Bikeability levels of training in the UK (DfT, 2013b). Level one training assists the trainee to control and master their cycle. Level two training offers a real cycling experience by allowing the trainee from level one to ride on a real road outdoors. Level three is the ultimate and trains the safe manoeuvring by level two riders in a variety of traffic conditions as occurring in everyday life situations. According to the latest Bikeability scheme delivery statistics, there is an increasing trend of training places among Local Highways Authorities (LHAs) and School Games Organiser Host Schools (SGOHS) formerly School Sport Partnerships (SSPs). Figure 2-7 shows the increasing trend of total Bikeability training places delivered per financial year during the period 2006/2007 to 2011/2012. The trend shows the number of training places delivered using Bikeability grants which could be used for level 2 training and with an amount of up to forty pounds per training place. The scheme tends to be more focused on young potential cyclists in schools. How the increasing trend could be linked to cycling uptake at adult age is not very clear as cycling uptake across UK is still low and does not appear to be increasing significantly, at least at the national level.

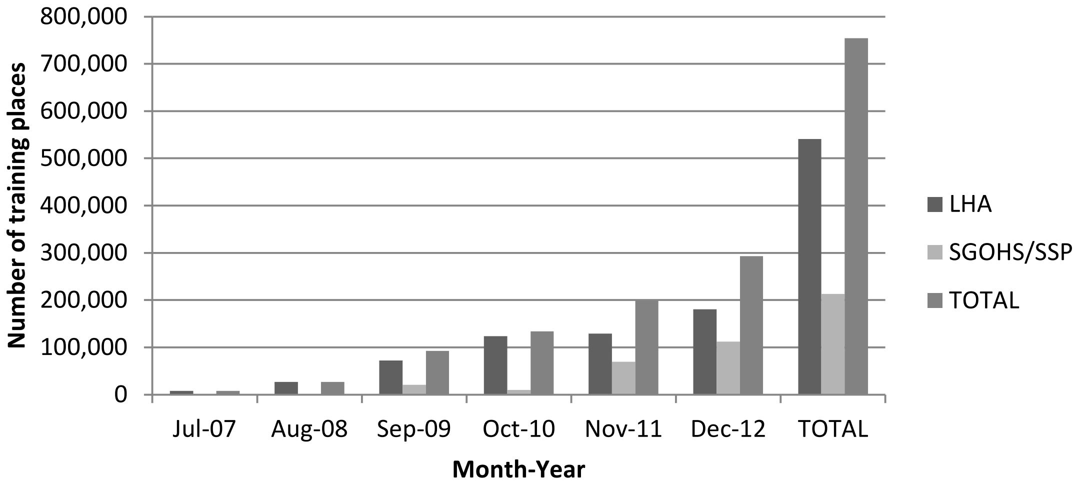

Figure 2-7: Total Bikeability Training Places Delivered per Financial Year

Note: This graph was generated using tabulated Bikeability delivery statistics from UK Department for Transport (DfT, 2013a).

The use of the term somewhat differs from one geographical area to another and among researchers. Compared with Walkability, Bikeability research appears to be at early stages (Wahlgren and Schantz, 2011). For clarity, Walkability may be defined as having different perspectives and twists but generally ends up as an indication of how a place appears to be walking friendly (Abley, 2005, pp. 2-3). Most recent work on computing some indices or scores for walkability are that of Lwin and Murayama (2011a) which is a walk score calculator for computing walkability based on modelling of urban green space while that of Witten et al. (2011) entails development of an index for measuring neighbourhood destination accessibility. What appears common amongst these works is the integrative approach and use of spatial data. The definition of Bikeability and how the term is used in a research design context is important (Wahlgren and Schantz, 2011). Wahlgren and Schantz (2011, p. 17) suggest that the term Bikeability should be associated with factors that relate to cycling and route environment, route distance, interaction between the cyclist and the cycle which affect the characteristics of a given trip. They suggest further broader consideration such that the term Bikeability should be related to aspects and factors interacting with the perception and behaviour of cyclists focusing on at least three purposes namely transport, recreation, and exercise which should include competition. These suggestions are more resonant with researchers outside the UK (Meyer, 2011; Wahlgren and Schantz, 2011). These suggestions are more or less in contrast with what the term Bikeability means in the UK. Wahlgren and Schantz (2011) findings were based on self-reports and therefore suggest more objective measures but in combination with some subjective measures. The acquisition and development of high quality measures is essential albeit challenging (Brownson et al., 2009). An example could be the use of personal GPS devices in measuring traces of cyclists as basis of inferring meanings to better understand Bikeability in the context of transport.

In addition to Bikeability, Cyclability as a term appears to be used also in the literature in the UK. Cyclability was mentioned about three times in the UK Foresight report on future choices for tackling obesity, while there was no mention of Bikeability (Foresight, 2007a, p. 106, 109, 124). The report seems to associate Cyclability with Walkability and the built environment without giving an explicit definition of Cyclability. The use of phrases such as "*increasing walkability/cyclability of the built environment*" or "*increasing the cyclability and walkability of the built environment, have the potential to have a direct impact on the prevalence of obesity*" suggest perhaps the meaning of Cyclability being more at par with what Bikeability as a term is used outside the UK as already discussed (Meyer, 2011; Wahlgren and Schantz, 2011). The observation is that there seem to be no consensus on the use or definition of the term Cyclability in the UK.

The term Supportiveness describes how supportive a neighbourhood environment is to a particular activity – for example, as a concept for physical activity or walking (Jones et al., 2007, p. 18); or cycling. Supportiveness is seen as a measurable environmental variable (Jones et al., 2007, p. ii). Very few studies have used the term in relation to physical activity (Jones et al., 2009; McCormack et al., 2006); but not cycling specifically. The term appears partially understood when used alone and therefore must be used with purpose when dealing with environmental issues.

Despite all these differences in usage of these terms and the notions behind them, two common features cut across their meaning or way of use as well as how they are being linked to the built environment and physical activity for which cycling plays an important role. The two common features are cycling as a utility function and affective measure (Aldred, 2013). Utility function refers to utilising cycling as a means of transport from point A to point B while affective measure is the joy of cycling from A to B. The combination and careful consideration of these common features are often central to cycling related policies and politics.

2.10 Cycling related policies and politics; a paradigm shift towards sustainability

Policy, as a term, has several dimensions and perspectives; mainly the course of action taken individually, by group or groups, institutions, or governments which affects our everyday life (Torjman, 2005). This section discusses strands of these actions in the literature, with more emphasis on cycling related issues. In the UK, there is now a major shift in government policy towards the improvement of cycling across England. Taking advantage of the success stories in the 2012 Olympics, the UK government has unveiled the largest investment of about £77 million to make cycling more visible and useful to encourage everyday cycling (DfT, 2013j; Stewart, 2012; Wood, 2012).

A recent funding policy for cycling is now the LSTF, as mentioned earlier (Section 2.3.3). The April 2011 policy appears to be the result of a three year 140 million pound budget plan for Cycling England to work hand-in-hand with Local Authorities (LAs), non-governmental organisations (NGO) among others with an interest in developing ways of understanding what works best scenarios and demonstrating several impact assessments of intermittent interventions (APPCG, 2013a; DfT, 2008a; Goodwin, 2013). What works best scenarios are still under discussion and being researched in various parts of UK; see, for example, Cycling Demonstration Towns or the Cycling City and Towns programme (Sloman et al., 2009) and the Get Britain Cycling inquiry by All Party Parliamentary Cycling Group (APPCG, 2013a; Goodwin, 2013). Unfortunately, Newcastle upon Tyne has not been selected for any of these earlier programmes except recently announced investment in cycling infrastructure across England by the Prime Minister, David Cameron, and the Transport Minister, Norman Baker (DfT, 2013i; Siddique, 2013; Walker, 2013a). In the US, amidst the huge automobile society, transport officials are urging citizens to take-up cycling as a means of transportation to work (BBC, 2010). With some thought, one could say that in the near future, cities or societies with friendly cycling culture will attract more people and arguably become very popular.

A call for the same level of institutionalisation and normalisation of cycling which should be on par with that of automobile transportation is paramount. As Jones (2012) concludes, one of the difficulties of such calls is political acceptance in UK unlike other developed western countries. The study further reveals that a focus on the provision of only nationwide cycling network of traffic-free urban cycle paths only may not be adequate in encouraging the shift from frequent car use to everyday utility cycling (Jones, 2012). Transport policies that reduce the convenience of car use and encourage cycling is required (Jones, 2012). Policy makers should aim at heavily invested cycling infrastructure as well as institutionalisation; perhaps, the only means of ensuring normalisation of cycling in society. Good institutions and policies may be able to change societal behaviour and vice versa. A well informed policy maker, who may not or may often kowtow to politicians, may carefully be able to place the needs of cycling infrastructure without any major hurdles. In this context, it is important to have a good understanding of the issues to be addressed. Policies are divided: mainly towards ideologies and scientific basis (Forester, 1983, p. 231).

2.10.1 Institutionalisation and normalisation of cycling

Cycling transportation appears to be re-emerging since the attention given to it by John Forester in the twentieth century (Forester, 1983). Recent discussions in the British media tend to gear towards the notion that the timing for the institutionalisation and normalisation have come of age and are needed for proper policies on cycling as an active transportation without avoiding the contemplation of other equally needed adjustments for societal integration (Triggle, 2012).

There appears to be the need for the same level of institutionalisation and normalisation of cycling (especially as active transportation) which should be on par with that of the automobile transportation in the UK (Jones, 2012). Institutionalisation means governing institutions having clear and concise pro-cycling policies and frameworks. Normalisation means a cycle-centric culture and bicycle infrastructure is wide spread and established. Harker (2011) attributes normalisation of cycling as the Holy Grail for bicycle advocates and argues that it has played a major role in the Danish success story. UK health and other institutional experts have argued that the norm should be that everyday cycling should be encouraged within communities especially for shorter routes (NICE, 2012; Triggle, 2012); and must be placed at the centre of strategic transportation (DH, 2010).

The level of cycling as active transport, or what Forester (1983) refers to as bicycling transportation, is relatively low in the UK compared with the Netherlands, Denmark and Germany and much understanding is needed to facilitate the cycling uptake. Politicians have realised the need for particular investment in cycling in Britain as evidenced in recent reported £77 million investment in cycling in England with the aim of gradual promotion of cycling in eight British cities to bring the nation closer to successful countries like the Netherlands, Denmark and Germany (Siddique, 2013; Walker, 2013a).

2.10.2 The hierarchy of provisions and users for cycle infrastructure

The practicality and convenience of cycling for many journeys is well acknowledged by the DfT cycle infrastructure design policy (DfT, 2008a). The policy further acknowledges the increasing importance of cycling among local authority planning towards tackling congestion, improvement of air quality, promotion of physical activity and improvement of place to place accessibility. As a way of providing design guidance among stakeholders on the improvements to cycling infrastructure, the policy suggests the *hierarchy of provisions* which entails some stepwise considerations as shown in Table 2-2. As pointed out in the policy, the hierarchy of provisions are not to be rigidly applied as some of the measures may not be viable. For example, the reduction of traffic volume or speed may not always be feasible. Also pointed out in the policy document is another way to look at designing improvements to cycle infrastructure from the perspective of the *hierarchy of users*. This idea is originally from the *Manual of Streets* policy where pedestrians are placed as first priority followed by cyclists, public transport, and lastly unaccompanied private car users.

Table 2-2: Hierarchy of provision

Consider first	Traffic volume reduction
↓	Traffic speed reduction
	Junction treatment, hazard site treatment, traffic management
	Reallocation of carriageway space
	Cycle tracks away from roads
Consider last	Conversion of footways/footpaths to shared use for pedestrians and cyclists

Source: (DfT, 2008a)

2.10.3 Health

Cycling is considered an important mode of transport for a healthy reason that it has the potential to decrease the rise in obesity in England (Mackett, 2011). Health benefits associated with higher uptakes of cycling can absorb the cost of initial investment (NHS, 2008, p. 13). These identified benefits have generated so much interest in the UK that there are now published comprehensive recommendations from the National Institute for Health and Clinical Excellence (NICE) which cover details of gaps in knowledge that researchers should aim to address (NICE, 2012). Most health-wise policies for cycling appear to emanate via the concept of cycling as a physical activity with the message that "Cycling is healthy" (Gatersleben and Appleton, 2007; Gilbert and McCarthy, 1994; Scottish-Government, 2009). This simple message seems to have taken centre stage in contemporary health policies. Pucher and Buehler (2008) argue that cycling is highly irresistible given its cache of health, economic and environmental benefits. Evidence from the Netherlands suggests that people mostly cycle to work for health reasons (Engbers and Hendriksen, 2010, p. 4).

Despite such overwhelming evidence, about 60% of world population is exposed to higher health risks due to a lack of physical activity. For example, the Toronto Charter for physical Activity being championed by Global Advocacy Council for Physical Activity (GAPA) which is the advocacy council of International Society for Physical Activity and Health (ISPAH) (GAPA, 2010a, b). Cycling as active transport cuts across all the recommended seven best investments in the prevention of non-communicable-diseases (NCD) by GAPA.

As GAPA notes, the *seven best investments* for physical activity (active transport among others) are namely:

1) *"Whole-of-school" programs* - which encourages schools to provide physical activity supporting active transport (walking/cycling);

2) *Transport policies and systems that priorities walking, cycling and public transport* – which encourages cycling for travel purposes among others;

3) *Urban design regulations and infrastructure that provide for equitable and safe access for recreational physical activity, and recreational and transport-related walking and cycling across the life course* – which supports complete network of bikeways among others in support of active travel;

4) *Physical activity and NCD prevention integrated into primary health care systems* – which propounds, if not predict, that most health professionals will need (top up) training physical activity (active transport) towards building competencies in NCD effectual hindrance. Moreover,

primary health care systems are urged to embrace physical activity (active transport) as an explicit constituent of periodic behavioural traits screening for NCD prevention, referral and patient education;

5) *Public education, including mass media to raise awareness and change social norms on physical activity* – which encourages mass media promotion of physical activity (active transport). Sensitisation and eradication of wrong perceptions from many people will create a fertile platform for institutionalisation and normalisation (i.e. "what is cool among peers") of cycling uptake;

6) *Community – wide programs involving multiple settings and sectors and that mobilise and integrate community engagement and resources*

7) Sports systems and programs that promote "sport for all" and encourage participation across the life span – which encourages the use of physical activity as sport for all via the concept of community sport where access to community sporting facilities should be available for all.

The latest recommendations from the UK Department of Health (DH) advise adults between ages 19 to 64 years to undertake either moderate intensity or vigorous intensity physical activities where cycling is considered as a moderate intensity physical activity (DH, 2011). At least 150 minutes of moderate intensity activity is recommended over a week or thirty minutes on five days a week minimum. Such efforts help in the following: the reduction of risks of getting diseases such as coronary heart disease, stroke, Type 2 diabetes; healthy weight; low risk to obesity, depression and anxiety; improvement in self-esteem; and general well-being (DH, 2011).

2.10.4 Climate Change

The term Climate Change comprises global warming and everything else that increasing greenhouse gas amounts will affect (Conway, 2008). The rise in greenhouse gases, especially carbon dioxide, plays a major role in climate change and threatens the achievement of sustainable ways of living. Global reports such as International Energy Agency (IEA) and World Energy Outlook (WEO) suggest that the projected rise in global temperature may exceed the limited target of 2 degrees Celsius which has been agreed by Global leaders at the United Nation (UN) climate change talks in Cancun-Mexico in 2010 (IEA, 2011; WEO, 2011). *Climate Change* and Obesity are two most serious potential threats anticipated by the year 2050.

The UK government has decided, via the Climate Change Act, to reduce greenhouse gas emissions by at least 80% by 2050. One of the clear and apparent bridges that connect climate change and cycling is the emission of greenhouse gases (GHG); especially CO_2. Health benefits aside, cycling has comparative advantage over motorised transportation in terms of its potentiality in not contributing to GHG.

2.10.5 Sustainable Transportation

One of the major goals for transportation and spatial planning is the provision of accessibility (Dijst and Vidakovic, 2000). The dominance of road transportation policies has rendered and given little or no room for cycling transportation policies in the UK. As Pucher and Buehler (2008, p. 496) emphasise *"In many respects, the UK and the USA have given the green light to the private car, almost regardless of its economic, social and environmental costs. In sharp contrast, cycling has prospered in the Netherlands, Germany and Denmark over the past three decades precisely because these countries have given the red light, or at least the yellow warning light, to private cars."*

Some efforts have been made to facilitate cycling uptake in the UK although more is needed. One example is the Cycling Demonstration Towns (CDT), from 2005 to 2009, which was followed up with the Cycling City and Towns programme, from 2008, as a second phase (Sloman et al., 2009). The report on the City and Towns programme has been deleted recently (8 April 2013) from the UK Government (GOV.UK) website (DfT, 2013e) making the outcome unclear. The CDT programme evaluated six British towns using a combination of automatic cycle counters installed across each town together with some qualitative surveys. The six towns were Brighton & Hove, Aylesbury, Darlington, Lancaster with Morecambe, Exeter, and Derby. The findings suggest an average mean increase in cycling uptake of 27% across all the six towns. The Cycling City and Towns programme seems to cover the following 12 towns Blackpool, Cambridge, Chester, Colchester, Greater Bristol, Leighton-linslade, Shrewsbury, Southend, Southport, Stoke-on-Trent, York, and Woking. The emphasis here is that none of these towns are close to Newcastle upon Tyne area suggesting more evidence from areas around Tyneside conurbation (Newcastle upon Tyne, Gateshead, North Tyneside and North Tyneside) in North East England.

In the UK, the latest funding policy for cycling is the LSTF which is a £560 million fund set aside until 2015 to support LAs in their effort to promote sustainable transportation (DfT, 2013h). The new policy appears to be the result of an earlier three year £140 million budget plan for Cycling England to work hand-in-hand with LAs, NGOs among others with an interest in developing ways of understanding what works best (APPCG, 2013a; DfT, 2008a; Goodwin, 2013). What work best is still under discussion by researchers and practitioners (APPCG, 2013a; Goodwin, 2013; Sloman et al., 2009) and budgets for safe cycle lanes (Pank, 2013). Recently, in July 2011, Tyne and Wear Integrated Transport Authority (TWITA) won £4.9 million in funding to initiate the creation of active forms of sustainable, low carbon travel across Tyne and Wear

(TWITA, 2011). This project is reported to target parents and children by providing practical alternatives to car use. It was also reported by TWITA that a bid for about £24 million had been submitted for further funds from the LSTF fund suggesting that the initial bid won was not enough for a larger scale enhancement of sustainable transport. Both bids aim to follow TWITA's vision for transport in the Local Transport Plan three (LTP3) spanning from 2011 to 2021. Elsewhere, in America, amidst the huge automobile society, transport officials are urging citizens to take-up cycling as a means of transportation to work (BBC, 2010). Urban initiatives towards integrated transport planning for all modes and forms are still being implemented at the European level (EU, 2013). A typical example is the European CIVITAS initiative (CIVITAS, 2013), involving about 200 cities in 31 countries and with the aim of promoting exchanges of ideas among practitioners, technical experts and politicians.

2.10.6 Interventions and strategies from non-governmental entities

The assessment of cycling-related interventions is not an easy task (Krizek et al., 2009a). Researchers, charity organisations, cycling clubs, staunch cycling activists, enthusiasts, campaigners as well as intermittent interventions and donations from some donor agencies appear to be on the increase in the UK. Jones' (2012) work is a typical example of cycling studies that aim to understand interventions efforts in UK but with focus on everyday cycling on the National Cycle Network developed by Sustrans – a charity organisation. The outcome of the study suggests that an integrated approach to promoting cycling is needed and should entail social marketing with built environment measures such as cycle facilities, speed restrictions, and landuse (Jones, 2012).

2.10.7 Situation around the study area

Despite the adoption of a cycling strategy policy in Newcastle upon Tyne, the decline in people's health, especially in relation to obesity, has necessitated the need for a new cycling strategy (Clark, 2011; Todd, 2011). Recent policy regulation on funds for cycling related activity improvement is the biddable (competitive) LSTF. Beyond the UK, cities like Amsterdam, Berlin among others are mostly mentioned. However, efforts are being made to champion the cycling uptake around Newcastle upon Tyne, some of which are:

1) Low level (intermittent) upgrades of cycling infrastructure by Newcastle City Council as well as recently proposed cycle network comprising of key and strategic routes;

2) Recent entry by the researcher and others to UK Ordnance Survey's Geovation Challenge 2011 – which had the highest number of comments thereby generating interest for massive infrastructure development within the city (Alvanides et al., 2011). The entry proposed an "*8-*

spoke city: a radial cycling route system for Newcastle" – an easily recognisable route system to be interrogated by researchers, campaigners, and policy makers. Recently, for simplicity, the cycling routes for Newcastle have been modified to a schematic diagram (Figure 2-8) and working groups (NewcastleCityCouncil, 2013b) have been set-up to study the routes and the author of this thesis was part of the *Newburn to Newcastle City Centre* working group with report from Dodds (2012). The report suggests that Elswick Road meets the set out criteria when the corridor between Scotswood road and the West road was inspected. The criteria for the strategic routes are that they should (NewcastleCityCouncil, 2013a):

a. Link to the city centre and key destinations

b. Enable uninterrupted, unobstructed movement at an average speed of 12 mph

c. Be easy to follow with adequate signs or on-carriage branding

d. Be well surfaced and well maintained

e. Enhance the environment, with a distinctive character which improves its surroundings

f. Identify and address cyclist casualty locations

g. Manage conflict with motor traffic and pedestrians

h. Raise awareness with motor traffic and pedestrians

i. Clarify the positioning of cyclists and other highway users

j. Be consistent in design approach

k. Be enforced by design as well as by statutes

Moreover, there exist improvement suggestions from the Newcastle Cycling Campaign group as shown in Figure 2-9;

3) Sustrans, a charity organisation promoting cycling, promotion of smarter travel choices within the city and beyond (Sustrans, 2011). The charity owns some of the safe routes (right of ways) and manages installed cycle counters that records most of the passes by cyclists along built cycle paths. Sustrans played a key role in the management of cycle counters in the cycle demonstration towns programme; and,

4) The research for the current thesis aims to use Newcastle-upon-Tyne area as a case study and provide evidence to the use of the area cycling network and infrastructure by cyclists.

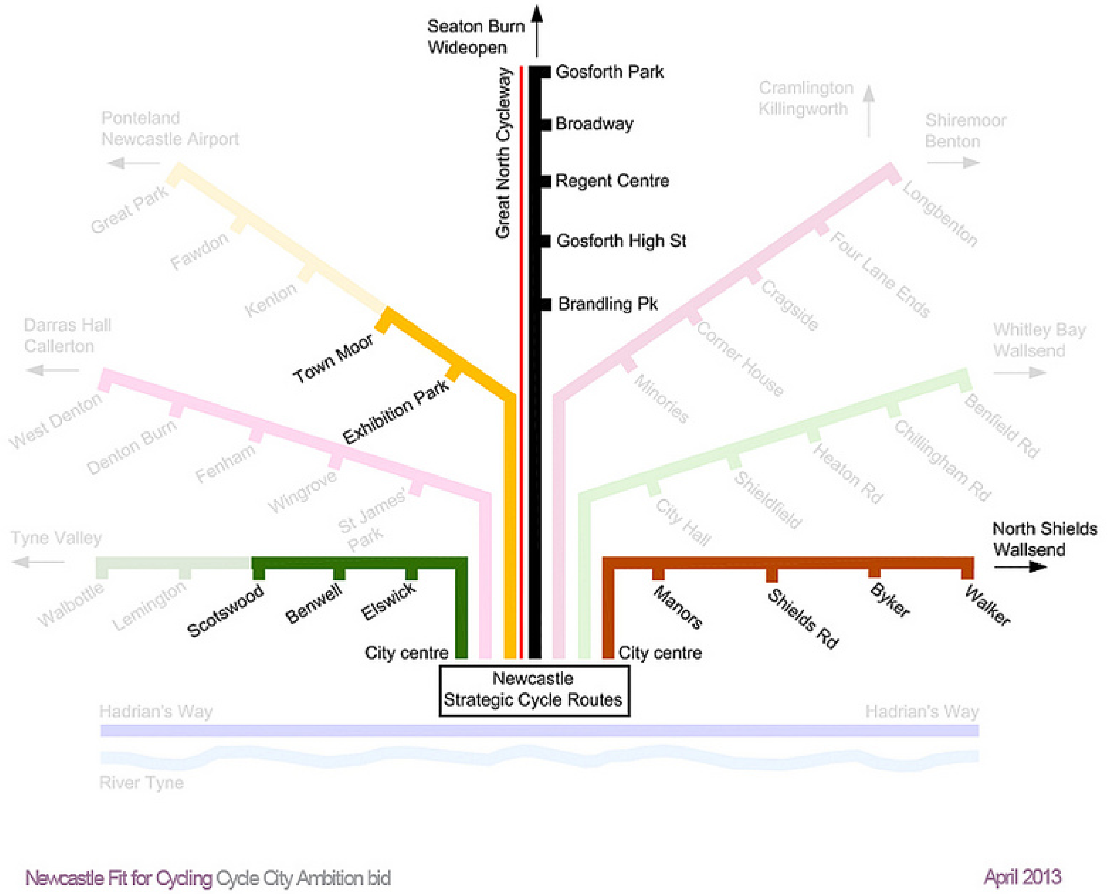

Figure 2-8: Seven Strategic Cycle Routes into the Heart of Newcastle

Source: Newcastle Cycling Campaign (NCC, 2011b)

Strategy (draft, approval January 2012): 10-year document

⇓

Action Plan: 5-year document (to be reviewed annually)

⇓

Work programme (forum: monitor, review, consult): 1-year document

⇓ ⇑

Working groups: monthly meetings

- Outstanding (minor works) list (Heather's list)
- Cycle strategic network
- Others may be: specific strategic route or area, soft measures: training, bike parking map development, professional driver liaison group, road users debate

Figure 2-9: Improvement suggestion from Newcastle Cycling Campaign Group

Source: (NCC, 2011a)

2.11 A Critique: Understanding Cycling using Agent-Based Modelling and Simulation

The investigation of real-world policy questions can be facilitated using ABMS techniques but not without some challenges. The ability of ABM to capture emergent phenomena providing a natural description of a system, and its flexibility are some of its strengths (Bonabeau, 2002), which could be of benefit in using it to understand cycling behaviour either at the city, corridor or route levels. The intention has always been to use the power of computer based technologies to simulate real world phenomena thereby revealing various forms of understanding from complex and non-linear phenomena. The uses of such simulations are numerous: 1) to enquire better understanding of some aspect of the real social world (Axelrod, 1997a, b); 2) to enable prediction or forecasting (Gilbert and Troitzsch, 1999, p. 4-5); 3) to fabricate new tools to substitute weakness in human capabilities (Gilbert and Troitzsch, 1999, p. 5); 4) for training; 5) for entertainment; 6) potential in facilitating discovery and formalisation; and,7) *flows* comprising crowd evacuation and traffic flow management (Bonabeau, 2002, p. 7281). Despite the great potential for the use of ABM in understanding various societal problems, very little is known about how ABM can be used for understanding cycling behaviour. There is an emerging evidence that the built environment affects individual travel behaviour, but the characteristics of the correlates and how they support cycling uptake are being recommended especially in the UK (APPCG, 2013a; Forsyth and Krizek, 2011; Goodwin, 2013; NICE, 2012; Skinner and Rose, 2007). The only recent work, identified which includes the use of ABM in cycling related research are: the Danish Bikeability project (Bikeability.dk); a personal short term scientific mission to explore how an ABM toolkit called NETLogo can be used to model cycle tracks (Yeboah, 2012a); and, to some extent, the recent ESRC seminar series “Modelling on the Move” (modellingonthemove.org) focusing on transport modelling.

Literature suggest some key challenges facing the use of ABM for GIS based simulation: the purpose of the model, the theory behind the model, the possibility of model replication, the model verification method, model calibration and validation methods, representation of model dynamics regarding agent interactions, the operational level of model, and the ways and means of explaining the model to others (Crooks et al., 2008, p. 418). Also, the misconception between the linkages between social macro-properties and micro-properties within the context of individualistic fallacies (Epstein, 2011; O'Sullivan and Haklay, 2000). Attempts to outline such challenges may be partly due to early criticisms that ABMs lack proper documentation (Lorek and Sonnenschein, 1999); prompting proposal for proper documentation (Grimm et al., 2006); although not mentioned by Crooks et al. (2008). All of these identified challenges aim to aid in the ability for another curious scientist or researcher to reproduce the model and possibly advance or challenge the proposed idea. So, justifiably, these challenges can easily be considered a reproducibility challenge. This is because reproducibility is considered as one of the main principles of the scientific method. All theoretical and technical challenges need to be explained in a better way than to leave most hard reasoned routines in a sort of black box. Technically, ABM implementations come with strenuous demand on sizable resources; namely, computational power, software and hardware, length of time, and technical expertise in mostly computer programming as well as the underlying theories and contextual knowledge. Most technical challenges are in the skill and act of modelling, visualisation and communication for harnessing policy strategies (Crooks et al., 2008; Yeboah, 2012a). Moreover, technically, the state of the input data for the ABM, especially cycling infrastructure data, can demand lots of time from the researcher or implementer. More so, the choice of ABM platform to use for the modelling can demand more time too. Despite the benefits in using ABM to understand cycling behaviour, the argued case is that more detailed data and understanding of cycling behaviours is needed to serve as input to meaningful and realistic models.

2.12 Philosophical perspectives on GIS based Approaches

Despite the increasing use of GIS in cycling research (Moudon et al., 2005; Yiannakoulias et al., 2012); there are debates on whether GIS is a tool or science and its development in geography (Goodchild, 2010; Schuurman, 2002; Yano, 2000). Recently, GIS appears to have been celebrated formally regarding twenty years of its introduction giving attention to the next decade (Goodchild, 2010), though its origin and definition appears debatable (Coppock and Rhind, 1991; Maguire, 1991). However, the extent of GIS usefulness and importance cannot be underestimated. This section acknowledges weaknesses in the use of GIS, but posits that the pros available for the usability of GIS based approaches in research supersede the cons. The use of GIS based approach is evidenced in several research works: from assessing the costs of sea-level rise and extreme flooding at the local level in Israel (Lichter and Felsenstein, 2012); identification of source of anthropogenic impacts on metallic elements in sediments from the mid Guangdong coasts in China (Gu et al., 2012); explorative space-time analysis of human activity in transportation research in Beijing, China (Chen et al., 2011); to identification of locations for new cycling infrastructure using grid cells in Montreal, Canada (Larsen, 2011). GIS based approaches help in explaining sophisticated phenomena using spatial analytics (Longley, 2000); but it is not without challenges (Crooks et al., 2008).

2.12.1.1 An Objectivist Approach

The objectivist view suggests that the meanings and truths embedded in objects are completely isolated from any form of consciousness (Crotty, 1998). Objectivity claims from (logical) positivist research is often criticised - by humanistic, radical, feminist, and other philosophical positions - due to what is argued to be its limitations: deficiency in accounting for human behaviour; vehemence on abstract geometries and theoretical modelling; as well as incapability to identify causal structures (Goetz et al., 2009, p. 325). Bridging this critical divide is paramount, after all critical and quantitative approaches, especially in transport-related research – for example mobility research such as commuting - need not be mutually exclusive (Goetz et al., 2009). Although GIS based approaches deals limitedly with ephemeral factors, such limitations are characterised by technological limitations (Leszczynski, 2009). One other line of thought, objectivity (i.e. quantification and mathematisation) does not pose much of a problem than how the results are interpreted (Kwan and Schwanen, 2009); bringing to the fore a sense of constructivism which is discussed in the next section. Just as technology and quantitative geography has limits, it is arguably so that language has limitations (Bergmann et al., 2009, p. 281); likewise, emotion or humanistic expression holds some form of limitation – what can only be expressed. Thus, it is safe to suggest that advancement in technology may extend the use of GIS - especially in addressing the inclusion of critical views which is often argued from qualitative research perspectives. Despite human geographers scepticism about objective approach to human behaviour – often thinking of subjective approach, it is interesting to note that humanistic research entails same steps outline in quantitative research design formulation (Clifford et al., 2010, p. 7); suggesting there are similarities.

2.12.1.2 A Constructivist Approach

GIS is affected by both sociotechnical parameters – for example, model building (Schuurman, 2002). Constructivism is an epistemology which is often concretised in many theoretical perspectives: where epistemology implies the body of knowledge present in chosen theoretical views and research process (Crotty, 1998, p. 3). Both constructivists and objectivists agree that there is a real world; but differs as to where the “meaning” of objects in this real world lies (Duffy and Jonassen, 1992, p. 3). Unlike the objectivist, a constructivist concurs that we as observers or researchers impose “meaning” on objects of our world (Duffy and Jonassen, 1992, p. 3). The active involvement of the observer or researcher in the construction and shaping of “meaning” of objects is the underlining principle (Alemu et al., 2011, p. 40). The extent of the meaning is limited to, to some extent, how the observer perceives or constructs the object. However, there is another limitation, which is the medium for expressing the meaning of the (shaped) object.

2.12.1.3 A Bottom-up Approach

The quest to understand how individual decisions facilitate or prevent problems about urban sprawl and congestion, among others have led to another increasingly acceptable (bottom-up) approach to enquiries into urban research (Crooks et al., 2008). The bottom-up approach has been echoed by many but its roots can be found in complexity theory. Complexity of the urban form vis-à-vis people's everyday lifestyles – say movement patterns can be taken into account when adopting a bottom-up approach (Kwan and Schwanen, 2009). In such an approach, "*one is allowed to simulate the individual actions of diverse agents [individuals], measuring the resulting system behaviour and outcomes over time*" (Crooks et al., 2008); with or without social structures or urban forms – the built environment.

2.12.1.4 Metric, Reality, Subjectivity and Objectivity

A metric can mean several things to several people depending on the epistemological take on the term. Metrics matter in several spheres (Abbott et al., 2010). The same applies to reality, subjectivity, and objectivity which will be treated later in this section. In this discussion, and research, a metric is an analytical measurement intended to quantify the state of a system–such as the use of "route efficacy" to describe the directness of a route in a neighbourhood. Reality is what we think is real - which might be different or same. As an example, the use of GIS measures in the computation of indices – such as walkability may not resemble a reality one may wish to see (Burgoine et al., 2011); but such indices themselves may be someone's reality.

Theories about experiences or the environments can be tested in several ways, one through the notion of subjectivity, the other being objectivity. These notions give a clear indication of what can be justified objectively and perceivably (subjectivity). For example, good maps have the potential of telling the truth – the objective truth (Perkins, 2009); but, also, its visualisation form can ignite quite interesting perceived imagination of the world which might not necessarily be the way that mapped world is in reality (Crampton, 2001, p. 395). Such notions are mostly debated in exalted realms of epistemology and ontology in geographical research.

2.12.1.5 A Pragmatic approach

A pragmatic viewpoint allows researchers to construct frameworks that offers a mechanism to add new but useful information to primitive GIS elements such as "*points, polylines, and polygons, relate their attributes, facilitate data collection and sharing, and build analytical and representation functionality*" (Glennon, 2010). The combination of approaches and notions explained in this section therefore constitutes the scope of pragmatic viewpoints in this research.

2.13 Literature study on GPS technology for data collection

Generally, the last two decades have seen emerging interest in the use of GPS based personal travel surveys as an alternative to traditional travel survey methodologies. Traditional travel survey methodologies mean, mainly, paper and or computer based telephone interviews and travel diaries; which has its origin in the late 1970s (Ampt et al., 1983). In the mid-1990s, concerns among transportation planners and policy makers (within the offices of the Federal Highway Administration) on changes in personal travel gave birth to a research idea (including proof of concept field test in Lexington area) of using GPS for the collection of personal travel data (Wagner, 1997, p. i). During the same period, as reported by Taylor and Ampt (2003), Australian transport departments also sensed the need to use mode-shift of transport as a trade-off to balance demand and supply of ever increasing nature of transport infrastructure; these, however, needed some form of measurement and evaluation.

Since then (i.e. mid-1990s), various entities (i.e. researchers, institutions, firms among others) have discussed and built on the idea (Anderson et al., 2009; FHWA, 2000; Guensler and Wolf, 1999; Kochan et al., 2006; Stopher et al., 2008a; Stopher et al., 2010a; Stopher et al., 2007; Stopher, 1998). Recently, in 2010, the UK Department of Transport conducted a national travel survey GPS feasibility study which indicates the emergence of GPS based travel surveys (Anderson et al., 2009). Economic and policy wide benefits of using GPS based travel survey have been discussed and recognised making it more acceptable to both research and practice (Gibson and McKenzie, 2007). This author is of the opinion, given rapid development of GPS technologies; it appears traditional travel survey methodologies may disappear in the near future or less attention given to it. This perceptive opinion has not been made in isolation as other researchers have a similar opinion; emphasising the burdensome and lengthy nature of traditional travel survey methods (Ampt, 2003; Stopher, 1998).

Whilst agreeing with some researchers (Kochan et al., 2006; Stopher et al., 2002; Stopher et al., 2009), generally, most of the GPS based personal travel surveys comprise two categories of GPS devices, namely: 1) GPS enabled Personal Data Assistant (GPSePDA); 2) Passive GPS (PGPS) devices. For the purposes of the current research, the interest is skewed towards the PGPS devices. Stopher et al. (2009) argue that other than the respondent carrying the device and making sure it is charged, a standard, personal PGPS requires almost no action which means fewer effort/time on the respondent.

Approaches to GPS based personal travel surveys need faithful, honest and loyal GPS data logger carrier(s) (i.e. the respondent or participant) to take the logger from one place to another on one or several travel days, weeks and at times months. Beside this attribution and characterisation given to the respondent, the GPS device must always have un-obstructive communication with a constellation of satellites emitting the signals to the GPS device. Failure to establish communication over time will merit no position fixing; meaning no data logging for the trips being made by the respondent. So far, during the time of writing, existing GPS based technologies are unable to capture travel modes and trip purposes (Chen et al., 2010). However, other equally important data can be captured in better ways using GPS based technologies such as: speed, time, location (i.e. longitude, latitude, and altitude), date, and many more depending on the type of the GPS device.

Two main approaches of conducting GPS based personal travel surveys have been discussed in the literature, namely: interactive approach and passive approach (Chen et al., 2010; Stopher et al., 2008a; Stopher et al., 2008b). The interactive approach requires the respondent to answer questions before and/or during and/or after a trip (Chen et al., 2010). As discussed elsewhere (paragraphs above), since GPS survey is not (at least at the moment) able to capture other needed essential information, some researchers often collect additional data from respondents to achieve survey completeness. Such additional surveys have been described and coined as Prompted Recall surveys (Bachu et al., 2001; Stopher et al., 2010b). Prompted recall surveys appear to be completely ignored in the case of the passive approach. Though the passive method is still useful and important in its ability to detect changes and purposes of transport mode-shifts is still problematic (Chung and Shalaby, 2005; Schönfelder and Samaga, 2003). Instead of Prompted recall survey, passive approach often uses GIS algorithms with secondary data as backdrop for further processing (i.e. post-processing) (Du and Aultman-Hall, 2007) and analysis. The reliability of the secondary data, to some extent, is essential.

Unlike the interactive GPS data loggers, the passive GPS device types have the capability of recording trips of respondents without initiating an action in return (Chen et al., 2010). The technologies employed in these devices are being improved rapidly; gradually making them light weight and more user-friendly. The first “wearable” GPS devices were developed by the Dutch which weighted about 2kg; though it was meant to be mounted on a bicycle it was not so user friendly due to its weight (Stopher et al., 2008a). Subsequently, the United States continued with the development of (in-vehicle) passive GPS devices which needed no response from respondents during a travel survey.

In 2010, a final report on a National Travel Survey of GPS feasibility study was released by the United Kingdom Department for Transport (the primary source of personal travel data) which investigated three passive GPS devices (Anderson et al., 2009). The purpose was in the following: 1) to investigate how best to collect, clean and analyse GPS data; 2) to link GPS data with the data collected from a travel diary in order to explore any differences; and to examine the practical issues of equipping individuals with personal GPS devices and make recommendations for future implementation. Given the availability of devices at that time (in 2006), in the market, GeoStats shortlisted three GPS devices, namely: 1) Atmel BTT08; 1) the Global DG-100; and 3) iBlue 747. Though none of the devices fully met all the desired criteria, Atmel device was eventually selected for the data collection phase. Furthermore, it is important to note that several pilot surveys are on-going to both unearth a passively enabled personal GPS device as well as the possible permanent use of such devices instead of the use of written form of travel diary (DfT, 2011c, p. 8).

Various researchers, especially in Australia, have also been found to be using this type of device (Speisser and Stopher, 2011; Stopher et al., 2008a; Stopher and Speisser, 2011). The characteristics of the Atmel GPS devices are in the following: Dimension of 77mmx46mmx23mm; weight of 68g; wearable on a lanyard around the neck or attached to a bag or belt with a clip; vibration sensor; generates audible messages related to GPS signal reception; Bluetooth connectivity; can record date, time, latitude, longitude, latitude, speed, bearing, Horizontal Dilution of Precision (HDOP) and number of satellites; 512,000 GPS point storage capacity; and a GPS data logging device (Anderson et al., 2009). GPS technology has advanced to the extent that it can even be used together with inertial monitoring units for testing speed of wild cheetahs in the "wild" revealing the animals quick reflexes and acceleration which provides new ways of collecting real time hunting data (Kaplan, 2013; Wilson et al., 2013).

The advancement of GPS based technologies has given rise to different uses of GPS enabled tracking devices (Section 2.13). In answering the question – *what is the value of GPS as "sensor technology" measuring activities of people?* - Van der Spek et al. (2009) concludes that GPS serves as an indispensable means to collect spatial temporal data on different scales and in different settings adding new layers of knowledge to urban studies. Amidst this indispensability dwell future prospects, some of which are, namely: expected GPS data in the near future; automation of data collection and processing; the evaluative capacities of tracking technologies; the increased relevance of multiple, visual environments to communicate results from tracking studies (Van der Spek et al., 2009, p. 3052); and, eventually, database systems for the management of spatial temporal data such as SECONDO (Güting et al., 2006; Guting, 2007) or , more simply, using Microsoft Access databases or Excel workbooks. SECONDO is an extensible database management system for moving objects (http://dna.fernuni-hagen.de/Secondo.html). The use of GPS as a research technique could give further insight in to the use of urban spaces as well as the study of behaviour in time and space (Van der Spek et al., 2009, p. 3036).

In between data collection and databases lies some kind of data processing (i.e. cleaning and validation) and analysis. Van der Spek et al. (2009) used ArcGIS to further process trajectories from GPS data by merging various categories of trajectories (i.e. routes as tracks from GPS device logs). GeoStats is the firm that conducted the review of the devices. SPSS was also used to process and analyse trip/trajectory attributes collected in addition to the GPS data. Some analyses applied to the GPS data were filtering, layering and point/line density calculations (Van der Spek et al., 2009, p. 3039). Repast-S (http://repast.sourceforge.net/index.html) among numerous software packages in implementing ABMS technique rest upon the fact that it is known to be one of the best, if not the best package available for social science research (Allan, 2010, p.16); but comes with its associate technical difficulties just like NETLogo (Yeboah, 2012a). Interested reader is referred to NETlogo website (http://ccl.northwestern.edu/netlogo/). Furthermore, there are other equally competent software packages which also need attention, such as MATSim (Multi-Agent Transport Simulation Toolkit - www.matsim.org).

2.14 Identified gaps in knowledge

Following on from the literature review about understanding urban cycling behaviours in space and time, this chapter has identified three major areas where it was found that further research was needed. This finding confirmed the research aim and objectives in Chapter 1.

2.14.1 Revisiting the space time cube

Space time cube offers a unique space in understanding sensed spatio-temporal information about moving objects. Two key areas in which the STC has been useful until now have been within the time-geographic framework where it was originally conceptualised and the visual analytics framework where it is being applied for visualisation of spatio-temporal information as part of an explorative process. Researchers using the time-geographic framework have been mostly concerned with the use of STC for the analysis and visualisation of end products – as in already refined movement data. These observations situate the use of STC in two strands: analysis and visualisation. An attempt by international researchers to seek the usefulness and limitations of STC tried to answer the question: “What can the Space-Time-Cube do for you?” in an EU supported workshop on “analysis and visualisation of movement data” (Kraak et al., 2012). One of the proposals was to consider STC as a data processing tool as a way of extending its usability (Yeboah, 2012b). The proposition here is that the usability of STC is incomplete and therefore encourages research that seeks to extend the usability of STC to account for a third strand which should cover empirical data refinement as part of a knowledge discovery process.

2.14.2 Sensing urban cycling behaviours in new areas

Sensing human behaviours in urban environments provide us with new layers of knowledge which aid in our understanding of urban transportation, designs and serve as input to related policies to facilitate the efficient use of the built environment by removing barriers to cycling uptake (Mackett, 2011; Van der Spek et al., 2009). Recent inquiries from transport experts suggest that cycling will play a critical role in the future of transportation in Britain and in Europe (APPCG, 2013b; EC, 2011; Goodwin, 2013). Therefore, it is appropriate that both revealed and stated preferences of cyclists are well understood using correct and reliable datasets.

The availability and easy access to such datasets enable useful analysis and visualisations which could be vital inputs to effective and working policies towards the improvement of health, transportation, and addressing climate change. Goodman suggests there is value in complementing population level analysis with individual-level analysis of cycling to work by examining individual socio-economic along with demographic characteristics of commute modal share to determine, for example, who is changing their travel behaviour (Goodman, 2013). Most often in research the case has always been that primary data collection is undertaken when available secondary data is not sufficient – especially for cycling research (Broach et al., 2011; Hood et al., 2011). Until the time of the research, no literature had been found to suggest that empirical evidence of cyclists' route and destination choices were available around the chosen study area. Such lack of evidence is considered a gap which was addressed by this research, as shown in subsequent chapters of the thesis.

2.14.3 Methods for understanding cycling behaviours

Analysis and visualisation of revealed cycling behaviours is growing globally. Novel methods for understanding cycling behaviours have become necessary due to the increasing interest in cycling as a means of transport. Earlier analysis of cycling behaviours have been based on stated preference survey data and the need for quantification of such behaviours have become necessary (Gong and Mackett, 2008; Mackett and Brown, 2011; NICE, 2012; Ogilvie et al., 2010; Panter et al., 2013; Shephard, 2008). Therefore, it seems appropriate that methods for analysing and inferring useful meanings from cycling behaviour datasets are still needed. The complexity of analysis increases when one considers the spatio-temporal dimension of the dataset. Spatio-temporal data information is normally present in GPS based datasets. The larger the dataset, the more challenging it becomes to analyse and draw meaningful conclusions (Stopher et al., 2008a). The outcome of recent consultations about the use of GPS devices in the National Travel Survey organised by the UK Department for Transport is a typical example of the need for new methodologies for data processing and analysis. One major aspect of the conclusion of the consultation was the fact that a lack of data processing methodologies will hamper the use of GPS device usage in the National Travel Survey (Anderson et al., 2009; DfT, 2011c, 2012d). This is a clear call for further research. Moreover, at the national and regional levels, there are attempts by researchers to implement methodologies for fusing datasets to further understand trends in cycling behaviours (Goodman, 2013).

2.15 Conclusion

This literature review has identified three areas that need further research as part of this study. The literature suggests the importance of cycling and the fact that very few studies have investigated revealed route choice preferences of cyclists within a British urban environment. Factors influencing cycling behaviours were discussed pointing to theoretical frameworks within which such factors could be studied. Theories from space-time geography, behavioural geography, and visual analytics encompassing other exploratory data analytical frameworks were identified as potential fields serving as ways and means for understanding cycling behaviours.

The chapter has discussed the importance of cycling for urban transportation – especially making a case for research opportunities towards understanding movement behaviours of adult urban utility cyclists. The need for objective and subjective understanding of revealed patterns of movements from place to place is highlighted; cycling particularly. The chapter suggests that the importance of cycling appears to be on the rise in the quest for finding solutions to sustainable ways of living and healthy lifestyles – particularly in the British context. The importance of location and design of preferred routes for cycling cannot be neglected (Winters et al., 2011). However, given limited budgets, investments should be considered alongside a better understanding of cycling–especially preferred and revealed route choices–are undertaken within the areas of need. Literature suggests that there is a need for future research to incorporate the investigation and discovery of cyclist's perception and experiences (Forsyth and Krizek, 2011; NHS, 2008; NICE, 2012; Ogilvie et al., 2011); to support urban designers as well as cycling policy interventions and transportation engineers and thereby increase cycling uptake.

The critique of agent-based modelling and simulation technique was deemed necessary to clarify the need for more understanding before any useful model using such a technique could be implemented in cycling research context. The findings from this study therefore could give clues to how cyclists as agents could be modelled. Despite the increase in modelling, simulation and visualisation of several human movement activities which has depended on our understanding of such activities, the same case for cycling appears less apparent in the literature. A case has been made that although the ABMS technique appears useful and promising in the quest for understanding cycling research, more work needs to be undertaken using advanced spatial and statistical methods to first examine and elucidate our understanding of the behaviour of cyclists in relation to the built environmental features influencing their behaviour.

Possible ways of gathering, processing and exploring micro data about cyclists require further research since the need for micro data for cyclists and other moving objects is increasing. Useful information from such micro data will help in deepening our understanding of cyclists' stated and revealed preferences which will further the agenda of reversing the "top-down" policing trend to a "bottom-up" based policy strategies; placing the individual cyclist at the heart of transport and health policy strategies (DH, 2010). Policy makers should aim at strategic investment of cycling infrastructure and institutionalisation; perhaps, the only realistic means of ensuring normalisation of cycling in society. There are indications of efforts being made towards incremental shift from a non-sustainable way of framing transport policy to a more sustainable transport policy both at the national level and local level in the UK. Some examples are the LSTF national policy and the LTP as in the case of Tyne and Wear.

The three broader areas suggested by the literature study for further research are: a reconceptualisation of the usability of space-time cube as known in space-time geography; the need to sense urban cycling behaviours in new geographical areas to aid in our understanding of cycling behaviours in space and time; and, the improvement of methodologies for analysing space-time data in our understanding of cycling behaviours. Further to the review of methodological issues discussed in this chapter, the next chapter explains the methodology used in this research in detail.

CHAPTER 3. METHODS

3.1 Introduction

Conclusions drawn from Chapter 2 demonstrate the need to increase the uptake of commuting by bicycle in communities, especially in the UK. The recent paradigm shift in policy both at the national and at the local level in adopting and promoting low carbon methods of travel is encouraging. However, translating policy to practice introduces methodological challenges for understanding issues on the ground. It appears that existing policies and strategies still lack "spatial reasoning" in understanding cycling as a form of active transport. This deficiency is partly due to a lack of necessary primary and secondary data (Schonfelder and Axhausen, 2010, p. 45) and to a greater extent due to insufficient methods for collecting refined mobility datasets and further analysing such rich data. This chapter discusses the methods used for data exploration and analysis throughout the thesis. It starts by justifying the selection of the study area for this research and addresses the methods used in order to address the research aim and objectives outlined in Chapter 1. Table 3-1 illustrates the configuration for the usage of data, methods and their associations with the respective chapters in this thesis

Table 3-1: Overview of Data and Methods used in this thesis

DATA
Primary (collected by the researcher for this thesis) 1. Individual level GPS datasets (79 Cyclists) 2. Self-reported attitudinal survey data (79 Cyclists) 3. Baseline socio-demographic survey data (79 Cyclists) ***Secondary (obtained for the purpose of this research)*** 4. Tyne and Wear Household Travel Survey (2003 – 2011) data 5. Average annual weekday cycling traffic flows (2004 – 2012) from Tyne and Wear Accident Data Unit 6. Updated 2009 Cycle network data from Newcastle City Council 7. 2009 parkings and crossings data from Newcastle City Council 8. Newcastle Cycling Campaign Petition Survey data (2010) ***Secondary (widely available for research)*** 9. National Travel Survey (2002 to 2012) 10. 2001 Census – Lower layer Super Output Area (LSOA) data 11. 2001 Census (District level statistics/geography) data

12. 2001 Census – Output Area (OA) data
13. 2012 Office for National Statistics (ONS) ward data
14. 2011 Census – Lower layer Super Output Area (LSOA) data
15. 2011 Census (District level statistics/geography) data
16. Edina Ordnance Survey Mastermap ITN data
17. 2013 OpenStreetMap (Last update date: Fri Mar 29 19:31:02 2013 UTC)

METHODS	**Chapters where methods were used**
GPS Tracking survey and data refinement	5, 6, 7
Self-reported attitudinal survey (using theory of planned behaviour)	5
Kernel density estimation	4
Flow mapping	4
Index of dissimilarity	4
Corridor space analysis	7
Exploratory regression analysis	4
Descriptive statistics, spatial analysis and comparative analysis	4, 5, 6, 7
Statistical hypothesis testing	
Wilcoxon Signed Ranked t-test	5, 7
Paired sample t-test	7
Visual analytics	4, 5, 6, 7
Activity based analysis	6
Spatial Statistics	4, 5, 6, 7
Route choice analysis	7
Baseline socio-demographic survey	5
Space-time base data processing	5
Space-time visualisation	5, 6, 7

Table 3-1(continuted)

3.2 Conceptual framework for the research

This section draws on thematic properties of this thesis and suggests a conceptual framework for the research as illustrated in Figure 3-1. With a pragmatic philosophical view, the research focused on understanding cycling behaviour using four thematic strands: spatial behaviour, temporal behaviour, subjective behaviour underlined by data capture and refinement. These four strands are linked to the main theme which is *cycling behaviour with dash-dot lines as shown in* *the figure*. A strand passing through a chapter means that it was partly addressed in that chapter. For example, all strands passing through Chapter 3 means that methods associated with the investigation of these themes are addressed in this chapter. The location of Chapter 7 in the figure highlights its focus on spatial behaviour. Chapter 9 provides a summary of key findings and conclusions while pointing to future prospects; therefore it encompasses material from both the methodological and the substantive chapters.

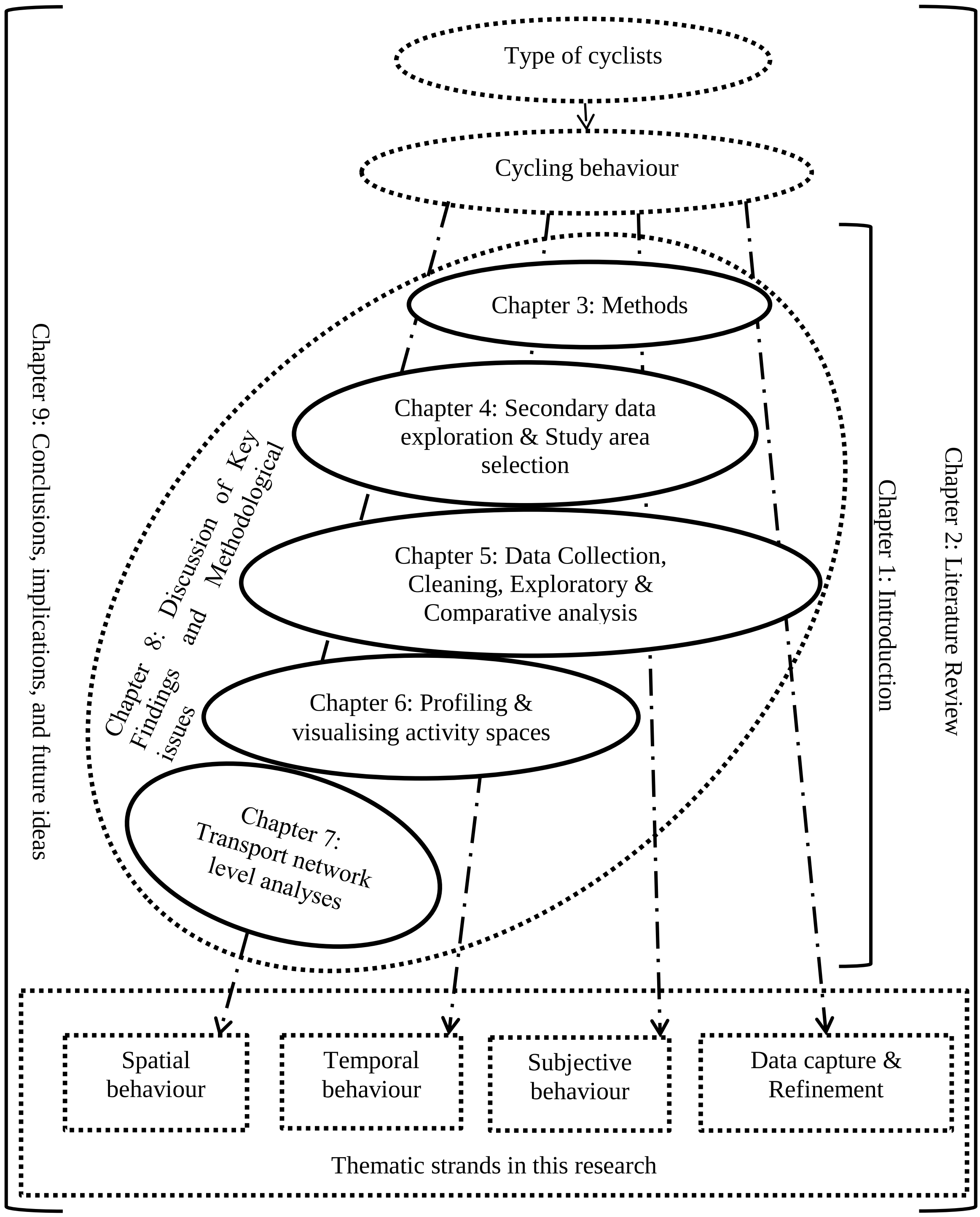

Figure 3-1: Conceptual framework for the research

3.3 Secondary data on cycling

Secondary data is mostly used as a way of triangulation and back-end to data analysis. This section considers relevant sources of secondary data and evaluates their usefulness in this research. Attention to such sources of data and the usefulness of the available data situates understanding of research questions in their proper perspective – triangulation (Clifford et al., 2010, p. 8). This section explains how the extensive secondary data used in this research was acquired. The data is grouped into two broad categories: *widely available* data and *not-widely available* data.

3.3.1 Widely available data

3.3.1.1 Census data

Census as a term may be defined as a comprehensive process of socio-economic and demographic data collection, compilation, and publication where the sole aim is to account for all human beings resident in a given geographic space and time (Johnston et al., 2000, p. 70). As comprehensive as the process might be, the outcome still stands to be perceived as an estimate since capturing every single person appears to be almost impossible. The past two centuries[2] have witnessed different aspects of census history in the UK. In UK, census is undertaken every ten years with the latest being 2011; at the time of writing. Technological and contemporary views preceding the census do play part in how the exercise is conducted; and to some extent the nature of data released to the public.

Census information can be derived from the Office of ONS using their website[3] in combination with Edina Maps and Data online[4] services which required special registration. EDINA is the national data centre designated by the Joint Information System Committee (JISC) in the UK and is based at the University of Edinburgh. JISC is a registered charity championing the use of digital technologies in education and research in the UK. Copyright issues were addressed by using Northumbria University's subscription license available for research, as well as strict adherence to copyright directives. In order to reduce errors when comparing and reporting small area statistics of collected data at the national level, combination of Output Areas (OA), Lower layer Super Output Areas (LSOA), and Electoral Ward areas were used depending on the area size and level of analysis at various parts of this thesis. These areas were used for statistical

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[2] Since 1801, see webpage of the Office for National Statistics (ONS) - ONS, 2008. 200 years of the census. Office for National Statistics (ONS), London.
[3] Source of Census 2001 Neighbourhood Statistics from ONS source: http://www.neighbourhood.statistics.gov.uk/dissemination/
[4] Edina online service source: http://edina.ac.uk/maps/index.html

purposes based on the 2001 and 2011 Censuses in terms of average population size (ONS, 2013b); to allow comparative analysis. OAs have an average population size of 125 households with about 300 residents to adhere to the confidentiality threshold of 40 households with about 100 residents.

Unfortunately, the official release schedule of detailed travel to work statistics from the 2011 Census was not released at the time of data analaysis and therefore was not available for this thesis. However, the 2011 Census ad-hoc table (CT0050) released on 17th June 2013 (ONS, 2011b), is used for the analysis in this thesis. This table included the geography code and names of output areas. Furthermore, the table contains estimates of alternative *method of travel to work* at Output Area levels in England and Wales on census day (27th March 2011). The content of the table is officially reported to be comparable to the 2001 Census (ONS, 2011a).

Until now, the current available data suggests that understanding non-motorised means of travel to work should be approached separately for each mode (i.e. for walking and cycling). For example, descriptive statistics that combines cycling and walking as a single estimate may be misleading due to small numbers. This can be seen in the two tables from ONS; Table 3-2 shows that there were no changes in travel to work by bike between 2001 and 2011 and a slight drop (-0.3%) in travel to work on foot at the same period. However, Table portrays a different result suggesting that either travel to work by bike or on foot fell by 0.3%. Thus, merging results to inform policy may be problematic, especially for non-motorised mode of travel where levels of uptake are very low. This observation confirms other suggestions that cycling should be studied separately from walking to improve our understanding of each mode of travel (Pooley et al., 2011, p. 1604). Recent reports now tend to explicitly show the estimates for both cycling and walking. For example, recent opinion survey about the future of transport within EU clearly stated estimates for cycling (7%) and walking (13%) (EC, 2011).

Table 3-2: Other transport commuters for England and Wales, 2001-2011

	Percentages		
	2001	2011	Percentage Point Change
All Other	14.8	14.3	-0.6
Walk	10.0	9.7	-0.3
Bicycle	2.8	2.8	0.0
Motorcycle Scooter	1.1	0.8	-0.3
Taxi Minicab	0.5	0.5	0.0
Other	0.5	0.5	0.0

Source: 2001 and 2011 Census - Office for National Statistics

Table 3-3: Change in travel to work modes for England and Wales, 2001 - 2011

	Percentage Point Change
Car/Van/Taxi/Motorcycle	-2.7
Walk/Cycle	-0.3
Other	0.0
Public Transport	1.4
Work from Home	1.5

Source: Census 2011, Office for National Statistics

Table 3-4 gives summarised information on travel to work characteristics of Newcastle upon Tyne, North East and England geographical regions. This information suggest that out of 101, 498 persons in employment in Newcastle upon Tyne, only 1, 781 (1.75%) persons travel by bicycle and almost 50% drive a car or van. It is not surprising though as they confirm reported concentration and spreading of peak hour condensation as well as a lack of comprehensive network of routes for cycling (Council, 2006, p. 8).

Table 3-4: Travel to work (KS15) statistics of Newcastle upon Tyne

		Newcastle upon Tyne	North East	England
All people aged 16-74 in employment (Persons)[1]	Count	101,498	1,032,968	22,441,498
People who work mainly at or from home (Persons)[1]	Count	7,066	79,308	2,055,224
People who work mainly at or from home (Persons)[1]	%	6.96	7.68	9.16
People aged 16-74 who usually travel to work by: Underground, Metro, Light Rail or Tram (Persons)[1]	Count	5,591	22,266	709,386
People aged 16-74 who usually travel to work by: Underground, Metro, Light Rail or Tram (Persons)[1]	%	5.51	2.16	3.16
People aged 16-74 who usually travel to work by: Train (Persons)[1]	Count	950	9,119	950,023
People aged 16-74 who usually travel to work by: Train (Persons)[1]	%	0.94	0.88	4.23
People aged 16-74 who usually travel to work by: Bus, Mini Bus or Coach (Persons)[1]	Count	19,156	113,224	1,685,361
People aged 16-74 who usually travel to work by: Bus, Mini Bus or Coach (Persons)[1]	%	18.87	10.96	7.51
People aged 16-74 who usually travel to work by: Motorcycle, Scooter or Moped (Persons)[1]	Count	487	6,967	249,456
People aged 16-74 who usually travel to work by: Motorcycle, Scooter or Moped (Persons)[1]	%	0.48	0.67	1.11
People aged 16-74 who usually travel to work by: Driving a Car or Van (Persons)[1]	Count	46,561	570,214	12,324,166
People aged 16-74 who usually travel to work by: Driving a Car or Van (Persons)[1]	%	45.87	55.20	54.92
People aged 16-74 who usually travel to work by: Passenger in a Car or Van (Persons)[1]	Count	7,233	94,389	1,370,685
People aged 16-74 who usually travel to work by: Passenger in a Car or Van (Persons)[1]	%	7.13	9.14	6.11
People aged 16-74 who travel to work by: Taxi or Minicab (Persons)[1]	Count	889	7,113	116,503
People aged 16-74 who travel to work by: Taxi or Minicab (Persons)[1]	%	0.88	0.69	0.52
People aged 16-74 who usually travel to work by: Bicycle (Persons)[1]	Count	1,781	16,786	634,588
People aged 16-74 who usually travel to work by: Bicycle (Persons)[1]	%	1.75	1.63	2.83
People aged 16-74 who usually travel to work by: On foot (Persons)[1]	Count	11,235	105,271	2,241,901
People aged 16-74 who usually travel to work by: On foot (Persons)[1]	%	11.07	10.19	9.99
People aged 16-74 who usually travel to work by: Other (Persons)[1]	Count	549	8,311	104,205
People aged 16-74 who usually travel to work by: Other (Persons)[1]	%	0.54	0.80	0.46
Average distance (km) travelled to fixed place of work (Persons)[1]	km	13.84	15.71	13.31
Public transport users in households: With car or van (Persons)[1]	Count	13,824	86,626	2,307,988
Public transport users in households: With car or van (Persons)[1]	%	53.80	59.90	69.00
Public transport users in households: Without car or van (Persons)[1]	Count	11,719	57,482	1,018,494
Public transport users in households: Without car or van (Persons)[1]	%	45.60	39.75	30.45

Last Updated: 02 June 2006
Source: Office for National Statistics

[1] National Statistics

3.3.1.2 National Travel Survey data

The National Travel Survey (NTS) has been in existence since 1988 and is known to be the most authentic source of data on personal travel patterns covering British households (DfT, 2011c, p. 3). NTS is under the supervision of the UK Department of Transport. The UK NTS data holds details of personal travel in the UK, mainly collected by the UK DfT (DfT, 2013m; Taylor et al., 2013). The NTS information comprises how, when, why, and where people travel and factors which constrain personal travel. These factors cover availability and use of travel modes and access to key services such as parking, and filling stations, to name a few. NTS contains a representative sample of 15,048 Postcode Address File (PAF), a list of all (delivery points) addresses in the UK except about 2.2% of these addresses covering Isles of Scilly and Scottish islands (Taylor et al., 2013). According to Taylor et al. (2013), this sample size had been maintained since 2002. Before 2002, the norm was a combination of three years' data for analysis with the aim of enhancing the degree of precision for annual estimates provision. Average groupings of about 2,900 deliver points constituted a primary sampling unit (PSU). A stratified two-stage random probability sample of these addresses in UK was performed based on car ownership, regional variable and population density. The regional grouping or strata was based on the European wide *Nomenclature of Units for Territorial Statistics* (NUTS) areas which is a geographical classification developed by the European Office for Statistics. NUTS is classified into three levels: NUTS1, as level one, for major socio-economic regions; NUTS2, as level two, for basic regions for the application of regional policies; and, NUTS3, as level three, for small regions for specific diagnoses (Eurostat, 2012). NUTS2 was used as the regional variable in the NTS which roughly and spatially relates to a single or groups of counties in England (Taylor et al., 2013). The regional variables within North East England covered Tyne and Wear, County Durham, Northumberland and Cleveland.

The fieldwork was conducted by the National Centre for Social Research and consisted of face-to-face interviews and a self-completed written travel diary for a week. Each annual collection constitutes approximately 20,000 individuals covering 8,000 households. The latest updated information, in July 2013, was used in this thesis to triangulate, compare and contrast evidence of personal travel from other sources. Although GPS tracking of personal travel is currently not supported (DfT, 2012d), the stated preference data could assist in data analysis, visualisation and interpretation with the aim of understanding cycling behaviours within the regional and national context.

Recently, NTS undertook a pilot feasibility study to find out the potential in using GPS in their future surveys (Anderson et al., 2009). UK is not the first to undergo such pilot exercises; United States, the Netherlands, France and Israel are reported to have done some pilot studies (DfT, 2011c, p. 8). This research will not attempt to re-invent the wheel as it were but will adapt some of the strategies in the identified pilot fieldworks to inform its own primary data collection approach. This will enable further research and synchronisation of findings. What is of essence here is that it appears some non-GPS based data exist as a result of the use of the personal travel diaries and could help in better understanding personal travel patterns. It is currently uncertain about availability of possible GPS based data on cycling in the study area. One of the major merits for GPS based data over travel diaries for personal travel based analysis is the need for accurate or better estimation of travel time and distance.

The unwillingness by the UK DfT to complement travel diaries with personal GPS devices for the national travel survey could even worsen the situation in the future (DfT, 2012d); since such datasets are needed to test methodologies which eventually will enable better and refined datasets for policy based analysis. Some of the reasons for the unwillingness comprise issues surrounding data quality along with the challenge of inferring and isolating accurate travel mode and purpose (DfT, 2012d). The accuracy of distance and travel time logged by portable GPS devices was however acknowledged in the report (DfT, 2012d). DfT admits and respondents to their public consultation acknowledge the benefits of using GPS for data collection and that there is a lack of GPS based data processing methods (DfT, 2012d). The summarised public consultation findings suggest that "*Data quality and the accurate inference of mode and purpose are vital factors in determining whether GPS devices are a viable method of data collection*" (DfT, 2012d). Daily mobilities are too important to ignore for all sorts of reasons (e.g. sustainable transport, employment exclusion, active living). In the 21st century, with all the technological advancement and technical knowledge, the DfT should be in a position to muster the resources to collect this type of data as they would significantly improve the explanatory power of current and future research in understanding daily mobilities for individuals and societies. Upon reflection, it appears the decision by DfT to stop using GPS trackers to track travellers from 2013 onwards will greatly demotivate efforts to advance GPS data processing methods (Guell et al., 2012, p. 4) but, research will have to go on where possible to find ways of understanding everyday cycling given the health and economic benefits (NHS, 2008; NICE, 2012).

3.3.1.3 UK Ordnance Survey data

The UK Ordnance Survey also holds both topographic and an integrated transport network data which covers the entire United Kingdom. Unfortunately, cycling data appears to be limited but efforts on the part of Ordnance Survey, towards updating urban paths are still in progress. The Ordnance Survey Mastermap Integrated Transport Network (ITN) data was acquired from the Edina Digimap web service by special registration as a postgraduate student. The transport network layer covering the Tyne and Wear region was extracted from the Edina online data warehouse to cover the geographical extent of all route choices of participants. The format of the data was delivered as a compressed folder which contained various file formats (i.e. .gml.gz, .txt, and .pdf). These files later converted to ArcGIS readable files using UK ESRI Productivity Suite 2.1 software.

3.3.1.4 Web Map Services

Four main web map services were utilised to aid in the editing of the collected GPS tracks: Google Maps, Ordnance Survey Open data stream, Openstreetmap and Bing Maps. The Google Maps interface is an integral part of the QTravel software which comes, as a package, with the Qstarz BT-Q1000XT GPS devices (Qstarz, 2011). QTravel software is the only custom developed software which works with the Qstarz GPS device for the purposes of downloading the GPS logged data and initial visualisation and editing in two dimensional spaces. QTravel with the Google Maps allows the downloaded data from the GPS devices to be viewed for the first time, with Google Maps as the basemap, although an internet connection is necessary for the basemap to be seen. The other three web map services were used with the ArcGIS and GeoTime software.

3.3.2 Not-Widely available data

3.3.2.1 Counters data from Tyne and Wear Accident Data Unit and Sustrans

In Tyne and Wear, however, there is also TADU, which manages two main datasets: traffic flow (counter) data; and, road traffic accident data in both Tyne and Wear and Northumberland. The online interface of the database is hosted at Gateshead Council (gateshead.gov.uk) as part of their transport strategy service. The geographic locations of counters as well as recorded number of passes by bicyclists exist within the study area. This information is helpful but limited to only where such counters are installed within the network of cycleable routes. Tyne and Wear Traffic and Accident Data Unit (www.northeast-tadu.gov.uk/) plays a key role to support the delivery of transport solutions and economic development across Tyne and Wear. It is jointly funded by the 5 Tyne and Wear districts. Average annual weekday traffic (AAWT) cycling flow datasets from automatic cycle counters across Tyne and Wear from 2004 to 2012 were obtained from TADU. The data was used as part of the exploratory data analysis in Chapter 4. Within and beyond Tyne and Wear, Sustrans also manages some counter data which are usually sourced from local authorities (Section 2.10.7 for further information about Sustrans).

3.3.2.2 Tyne and Wear Household Travel Survey data

Since its first introduction in 2003, with 25 year-old existing data at that time, the Tyne and Wear Household Travel Survey (TWHTS) has helped in complementing transport monitoring efforts in Tyne and Wear (TWJTWG, 2011; TWLTP, 2006). The survey is based on a random sampling methodology where a random sample is generated from Gazetteer database for each district in Tyne and Wear using the number of households reported by the 2001 Census data (TWLTP, 2006). TWHTS is the most detailed and comprehensive database available that also has some information (e.g. stated origin and destination trips) about cyclists in Tyne and Wear. The available data, however, do not contain revealed preference data of cyclists' route choices. Stated and revealed preference approaches to data collection are discussed in section 2.5. The TWHTS data was sourced from the Tyne and Wear LTP Team based at Newcastle City Council. The survey was introduced in 2003 with latest report in 2006 (TWLTP, 2006). The datasets from 2003 to 2011 were obtained as an MS Access database containing three data layers:

1. *TripsProfile* having 87,345 records;
2. *Person Profile* having 26,242 records; and,
3. *HouseholdProfile* having 12,844 records.

Newcastle upon Tyne has the second largest sample size for the survey after Sunderland (Table 3-5). This table shows sample sizes generated for each district in Tyne and Wear stratified from the number of households reported by the 2001 Census using a random sample from the Gazetteer database.

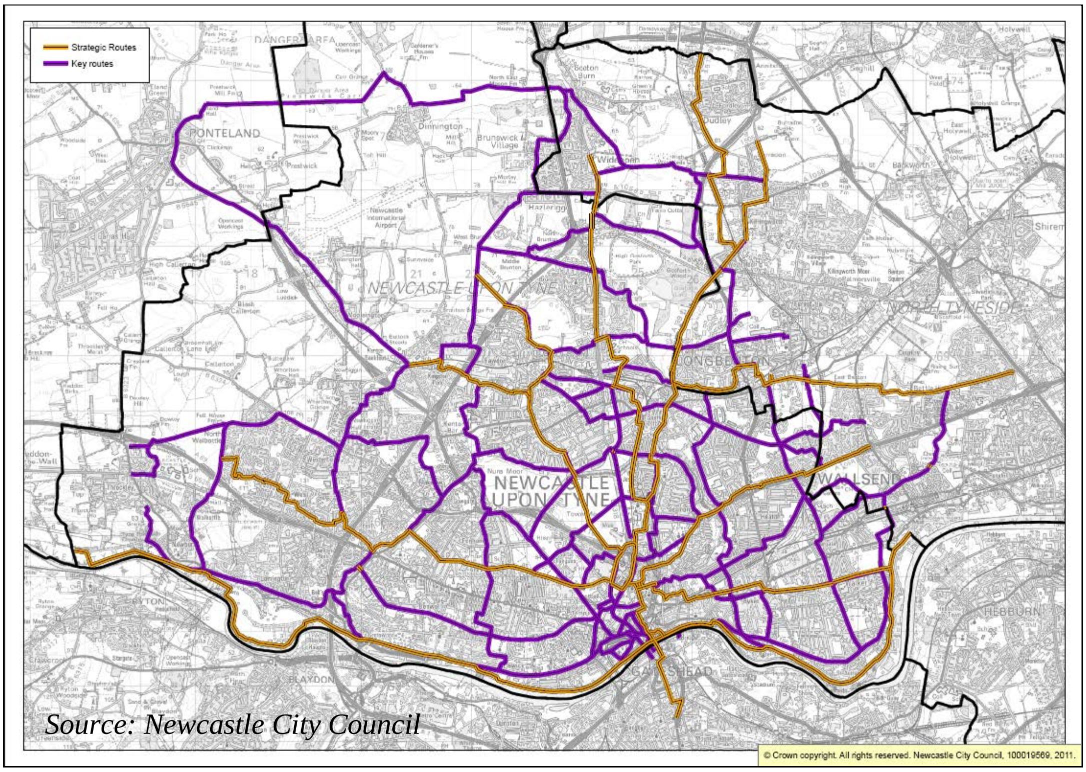
Table 3-5: Tyne and Wear Household Sample Sizes per district

District	Gateshead	Newcastle	North Tyneside	South Tyneside	Sunderland
Sample Size	400	528	403	314	553

Data source: (TWJTWG, 2011)

3.3.2.3 Cycling route network, parking, crossing, 20mph data, travel plan

The Newcastle City Council has recently proposed some strategic and key routes for cycling (Figure 3-2). The main framework is informed by the findings from the Newcastle Cycling Campaign (petition) survey which is about a proposed concept of 8-Spoke radial cycling route system shown in Figure 3-3.



Contains National Statistics data © Crown copyright and database right 2012

Figure 3-2: Newcastle City Council proposed Strategic and Key routes

Figure 3-3: Proposed 8-Spoke City Concept

Source: Ordnance Survey GeoVation Challenge 2011 (Alvanides et al., 2011)

Cycling infrastructure data, covering the Tyne and Wear conurbation, including the designated cycling route network, cycle parking locations, and cycle crossing datasets were sourced from the Newcastle City Council where the cycling officer and the analytical officer of the LTP team provided this information. In addition, hard copy (printed) lists of selected 20mph roads were also sourced from the same authority in order to determine whether cyclists from our sample tend to use these proposed roads or not. The introduction of speed limit on roads had become necessary due to emergence of speeding drivers around the area (Warburton, 2011). In Newcastle upon Tyne alone, there were 3,813 streets and roads with about 90% carrying a 20mph speed limit (Warburton, 2011). Upon further analysis, it was decided to leave analysis based on 20 mph for future research as complete data conversion was too time consuming for the research time frame. About 73% of conversion from textual to spatial is discussed here to aid future work. The length of the total list of road names was 2,772. Of those road names, 73% were detected in the OS ITN road network without editing road names; except removal of unnecessary characters such as space. The remaining 27% contained repeated road names due to part or multi-parts of the road being selected rather than the entire road. In total, 9% roads were not detectable in the ITN data. Figure 3-4 shows the summary of conversion of 20mph list of roads to spatial data.

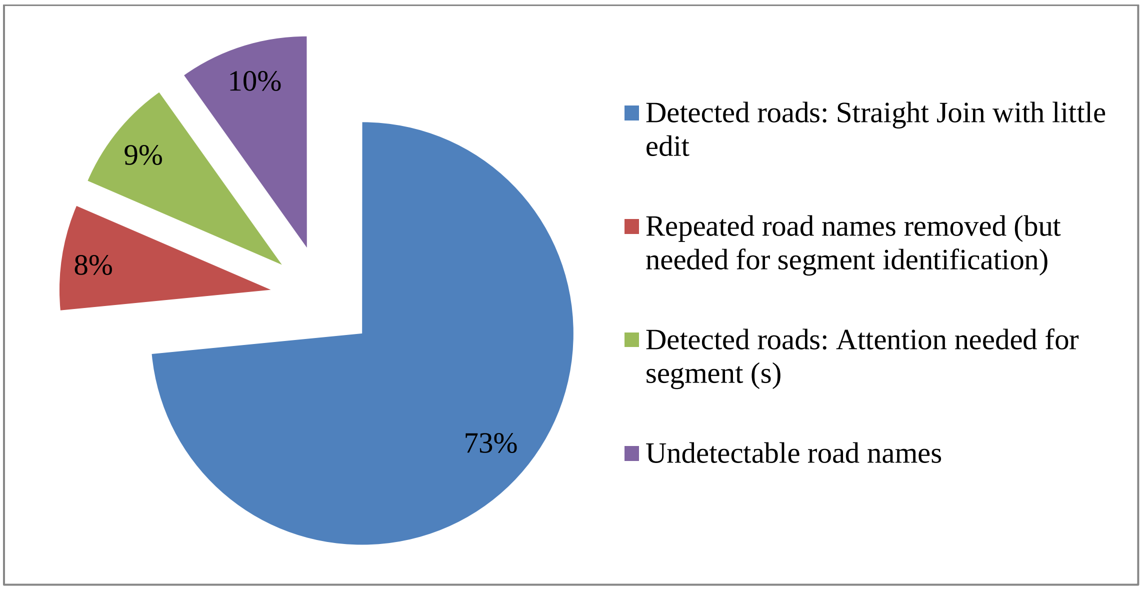


Figure 3-4: Summary of conversion of 20mph list of roads to spatial data

Original data source: Newcastle City Council

Personal travel planning (PTP) may be defined as a comprehensive approach with the sole aim of encouraging people to decide on well-known sustainable travel choices (DfT, 2008b, p. 5). The generic nature of the planning technique makes it adaptable to any travel related agenda towards the notion of sustainability or otherwise. Historically, PTP was first introduced in the UK in late twentieth century (DfT, 2008b, p. 6).

3.3.2.4 Newcastle Cycling Campaign survey data

A one month survey about safe cycling in the city centre of Newcastle upon Tyne has been conducted by Newcastle Cycling Campaign (NCC) (Layendecker, 2010). The main aim was to determine the degree to which people want improvement of cycling facilities in the city centre and further use the outcome as a yardstick to petition the city council. The survey has 803 responses with 673 providing postcode information. The survey suggests 80% of respondents (or 641 respondents) commute by bike. However, the survey has limitation. For example, given the absence of the use of GPS based travel survey approach, the survey data lacks the potential of revealing commuters' actual route choice preferences.

The survey generated 803 responses with 673 of them providing postcode information. The aim of the one month petition survey was to determine the level of support for cycling among the cycling community around Newcastle upon Tyne. The actual online stated preference survey was conducted in 2010 starting from Sunday 11th April to Monday 10th May. Although 673 postcodes were available, 653 were well defined to be able to link to the list of UK postcodes provided by Doogal. This meant that the 20 remaining provided postcodes could be wrong entries. Doogal is a web service dedicated to exploring UK postcodes and maps (i.e. doogal.co.uk/UKPostcodes.php). This means that about 81.3% (i.e. 653 from 803) of the respondents' data were useful for further spatial analysis since postcode coordinates were available. The data was explored together with the Tyne and Wear Household Travel survey as a way of providing spatial context to cycling prevalence in the area while providing empirical evidence on "spatial reasoning" as part of our understanding of urban cycling around the study area.

3.3.2.5 GPS Survey data

The only GPS survey information identified in UK was from the NTS GPS Feasibility Pilot Study (Anderson et al., 2009). This pilot survey covered three geographical areas in the UK, all very far from North East of England: Swindon, Stoke on Trent, and Lincoln. These areas were selected mainly due to convenience as existing NTS trained interviewers were needed to conduct the survey. But more importantly, the survey did not specifically focus on understanding urban cycling but rather on the experimentation of the feasibility of incorporating GPS tracking in the National Travel Survey. In this respect, this thesis is an additional contribution to these efforts in the context of the potential of using GPS devices for sensing travel behaviour using state-of-the-art portable GPS trackers and updated NTS Travel Diary form.

3.3.3 Enhancing the cycling network from disparate data sources

Various spatial datasets were sourced and used as a backdrop to the cycle network obtained from Newcastle City Council. The UK Ordnance Survey ITN data was first converted to network dataset by using UK ESRI Productivity Suite 2.1 software. The ITN data was used together with the Digimap openstream web map service from EDINA in ArcGIS 10.0 as both file and web data servers. EDINA is the national data centre designated by the Joint Information System Committee (JISC) in the UK.

3.4 Activity distribution across space

Five specialised variants of exploratory data analysis techniques used with the aim of assessing the distribution of activities across geographical space are discussed in this section and later used in Chapter 4. Outputs from such computations help in the triangulation and validation of results from exploratory analysis.

3.4.1 Flow mapping approach

Let us assume origin (O) and destination (D) point-sets ((O_1, D_1), (O_2, D_2),…,(O_i,D_i)) having directions ($Direction_1$, $Direction_2$, …, $Direction_i$), then a flow map function (fm) may be represented as:

$$fm = Plot_{i=1}^{n} (O_i, D_i) + Direction_i$$ Equation 3-1

Practically, the flow mapping (fm) is generated by exploiting the "*XY to line*" function in ESRI ArcGIS 10 Software to plot origin (O) to destination (D) point-sets. The direction of travel was added manually using cartographic line symbol and properties in ArcGIS. The data is categorised into utilitarian (U) and non-utilitarian (NU) trips:

- home to work to home (U);
- Home-education/shopping/PersonalBusiness-home (U); and,
- Home-social/Recreation/Escort-home cycle trips (NU).

3.4.2 Kernel density estimation for cycling trend analysis

Kernel Density Estimation (KDE) falls into the category of non-parametric methods which is very useful for point pattern analysis as well as hot spot exploration (Thierry et al., 2013, p. 2). Generally, density estimates are known to be valuable in exploring, explaining and presenting data meaningfully (Silverman, 1986). Nelson and Boots (2008) conclude that KDE suitable for identifying areas with most frequent activity of a phenomenon and improves visualisation. Nelson and Boots (2008) study was about detecting spatial hot spots in landscape ecology. The purpose of KDE for point events across geographic space is to generate a smooth density surface of the activity over space by calculating activity intensity as density estimation (Xie and Yan, 2008). Very little is known about the use of KDE in examining spatial variability of cycling flows in general although it had been used for traffic hazard intensity of urban cyclists, detection of pedestrian crash zones, highway and wild-life accident analysis (Xie and Yan, 2008). *K*ernel density estimation implementation in ESRI ArcGIS 10.0 was used to estimate the spatial variation of denseness / concentration of departures and arrivals of utility cyclists. Origin-Destination matrix of cycle trips were derived from the Tyne and Wear Household Travel Survey data from 2003 to 2011. The origin and destination layers are used as inputs to ArcGIS. Unlike other interpolation techniques such as kriging (also known as Gaussian process regression), trend surfaces, Dirichlet tessellations (also known as Voronoi tessellation), KDE appeals to modern applications as it is more appropriate for analysing the variability of an event which is characterised as individual point locations (Ned, 2010; Schonfelder and Axhausen, 2010, p. 138).

Mathematically, if we assume X_i as one of n points within a neighbourhood of *h width (or smoothing parameter or bandwidth or window)*, and that x is the mean of neighbourhood values where K is a kernel function, a kernel estimator is defined by Silverman (1986) as:

$$\text{Kernel estimator (KE)} = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right) \qquad \text{Equation 3-2}$$

From Equation 3-2, varying the smoothing parameter *h* has varying effect on the derived estimate. Silverman (1986) defines the KE as the summation of "bumps" put over an observation such that the K determines the bumps while the h determines the width. The kernel function could be any of the known existing variants: Normal/Gaussian, Quartic/Spherical, Exponential/Negative, Triangular/Conic, Uniform/Arc, and Epanechnikov/paraboloid/quadratic (de Smith et al., 2013). The Quadratic kernel is usually considered the optimal smoothing function (de Smith et al., 2013), and was used in all analysis in this thesis. As shown in Figure 3-5, the estimation process involves the superimposition of symmetrical surfaces over each individual point with the use of a mathematical function to evaluate the distance from the point to reference location and eventually taking the summation of all values estimated by the function for that reference location. This makes it possible for one to compute density values for all locations across space in a continuous way. Thierry et al. (2013, p. 2) summarise KDE approach as follows "*…a symmetrical kernel function is first superimposed over each event. The set of overlapping functions is then summed to create a continuous density surface*". This means that points surrounded by many other points will have higher density due to the overlapping effect of a kernel function.

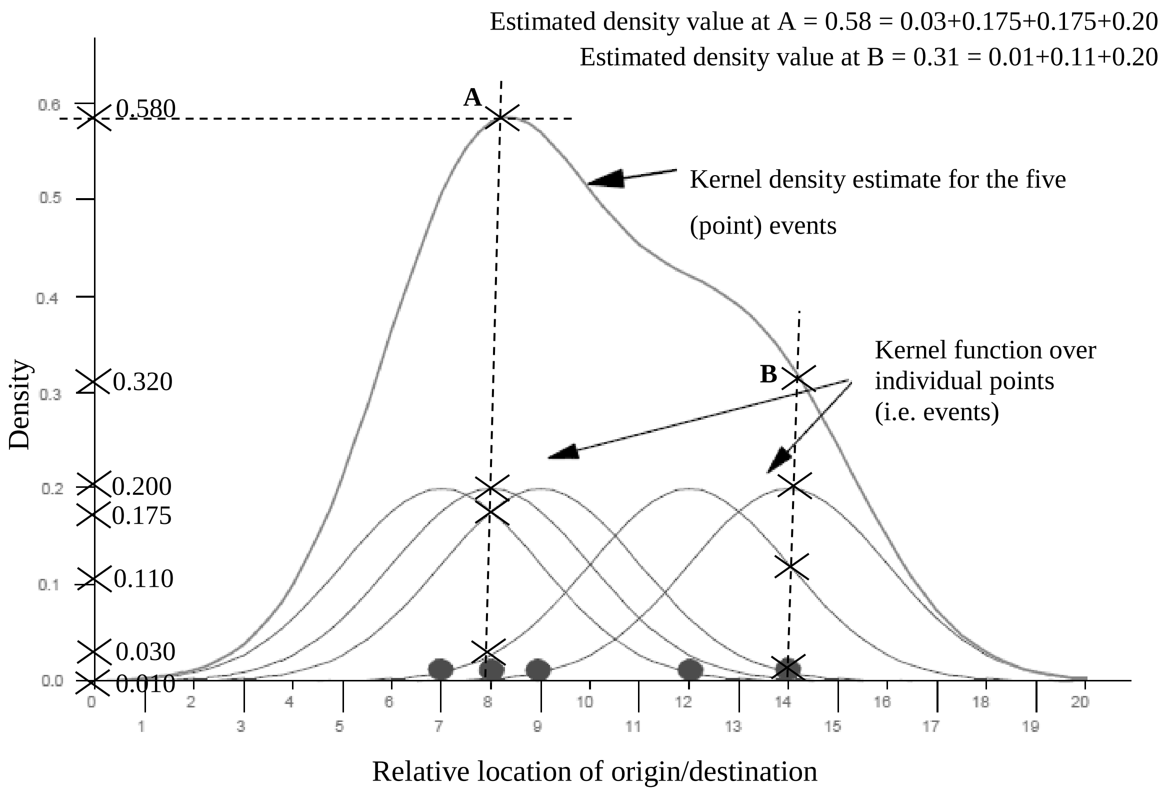


Figure 3-5: Fundamentals of kernel density estimation

Source: Adapted from Ned (2010, p. 5)

Once the various cell values are computed by the KDE approach, the output from the ArcGIS is a single band raster layer. To get a meaningful thematic representation of the raster layer, standard deviation values are computed from the cell values of the raster layer and in turn used to classify the values with respect to estimated mean. This way, the derived classes show the amount each cell value varies from the computed mean value. The number of classes was narrowed to four because the differences appeared visually meaningful and also with the understanding that people tend to distinguish up to seven colours (Mitchell, 1999, p. 60). The capacity of the human mind to process information using immediate memory has been also studied in human psychology research (Miller, 1994; UNSW, 2012). While Miller (1994), an American psychologist, suggest that the human mind can process information with about 7 (±2) chunks of information in short term memory, Gordon Parker, an Australian professor of psychiatry, from the University of New South Wales, challenges this number suggesting that the "magic" number is rather 4 (UNSW, 2012). In the current research, classification of variables for visualisation purposes is informed by these studies.

3.4.3 Location Quotient and Lorenz Curve

According to (Burt et al., 2009), by assuming an activity *i* in region *j* is equal to the percentage of total activity in region *j* devoted to activity *i* divided by the percentage of the base region's total activity devoted to activity *i*, the location quotient, LQ, may be represented as

$$LQ(i,j) = \frac{A(i,j)/\sum_{i=1}^{n} A(i,j)}{B(i,j)/\sum_{i=1}^{n} B(i,j)} \quad \text{Equation 3-3}$$

Where A(i,j) represents the level of activity *i* in region *j*, B(i,j) represents the level of activity *i* in the base region, and n denotes the number of activities. The LQ is interpreted as follows:

- LQ value greater than one means a relative concentration of activity *i* in the region of interest compared to the base region;
- LQ value equal to one means the region's share of activity *i* mirrors the base region's share of that activity;
- LQ value less than one means the region's share of activity *i* is lower than that generally observed, or lower than that found in the base region.

In situations where activity *i* regions are numerous in the summary process, another closely related measure/index is used to explain the relative concentration of the activity in relation to a base by using a single computed number often called the Coefficient of Localisation (CL) ranging from 0 to 1 (Burt et al., 2009, p. 126). A CL of value zero means that the distribution of the given activity is evenly spread across the regions in relation to the distribution of total activity. Another alternative to CL is the use of Lorenz Curve which is more commonly used as a basis for determining inequality of an activity (Burt et al., 2009, p. 127).

The Lorenz Curve is a form of graphical display comparing the spatial distribution of some activity to a base distribution and is constructed using the following rules:

1. Calculate the location quotients for the various regions that comprise the study area. Reorder the regions in decreasing order of their location quotients

2. Cumulate the percentage distributions of both the activity of interest and the base activity in the order determined in step 1

3. Graph the cumulative percentages for the activity of interest and the base activity, and join the points to produce the curve.

The LC is more preferred by researchers who are inclined towards using graphical summaries to statistical measures (Burt et al., 2009, p. 127). According to Creedy (1998, p. 13), LC provides a convenient descriptive tool for summarizing data. The Lorenz curve is a straight line following the 45 degrees diagonal (the ideal situation) but deviates from the diagonal line depending on the degree of concentration of the activity (Burt et al., 2009, p. 127). The graphical representation of LC will be shown in the next section (i.e. 3.4.4).

3.4.4 Dissimilarity Index

The Index of Dissimilarity, also known as the *Gini Coefficient* or *Dissimilarity Index*, is another specialised variant of descriptive statistics often used to measure the degree of similarity, or dissimilarity, of the percentage distributions of any two activities (Burt et al., 2009, pp. 124-129). This is not the first time Dissimilarity index has been used in human geography as it has a long history in this field which often is used as a measure of residential segregation (Kuha and Firth, 2011, p. 376). The dissimilarity index formula is used to access the evenness of activity of interest at neighbourhood level to the national or regional level averages using available cycling related data. Following Rees (2009), dissimilarity index is defined as follows:

$$D_{ef} = \mathbf{0.5} \sum_{i}^{n} \left| \mathbf{100} \left(\frac{\mathbf{Pie}}{\mathbf{P*e}} \right) - \mathbf{100} \left(\frac{\mathbf{Pif}}{\mathbf{P*f}} \right) \right| \qquad \text{Equation 3-4}$$

Where D_{ef} equals the Dissimilarity Index of relative distribution of population of *cyclists*' vis-à-vis *other commuters* across a given area; for example, areas such as North East of England. P_{ie} is the number/counts of cyclists per defined area within North East England. P_{*e} is the total counts of all listed areas within North East of England. Similarly, P_{ie} is the number/counts of *other* *commuters* per defined area and P_{*f} the total thereof. A zero value, from Equation 3-4, for D_{ef} indicates no dissimilarity while 100 indicates complete dissimilarity.

Another way, a graph based approach, of computing the index of dissimilarity is to calculate the maximum vertical deviation between the Lorenz curve and the diagonal using the Lorenz Curve Graph. The graph based approach is used in determining the Dissimilarity Index or Gini Coefficient. Also already discussed in section 3.4.3, Lorenz Curve is produced by calculating location quotients (LQ) for each area of interest; reordering the areas in decreasing order of their LQ values; determining the cumulative percentage distribution of activities; and, making a graph of activity of interest against the base activity.

From the discussion so far and with various graphical representations of LC for industrial data (Burt et al., 2009, p. 128), and for income (Creedy, 1998, p. 14), a graphical representation of Dissimilarity Index for cycling data can be represented graphically as shown in Figure 3-6. Both graphical and formula approaches in the determination of Dissimilarity Index arrive at similar results.

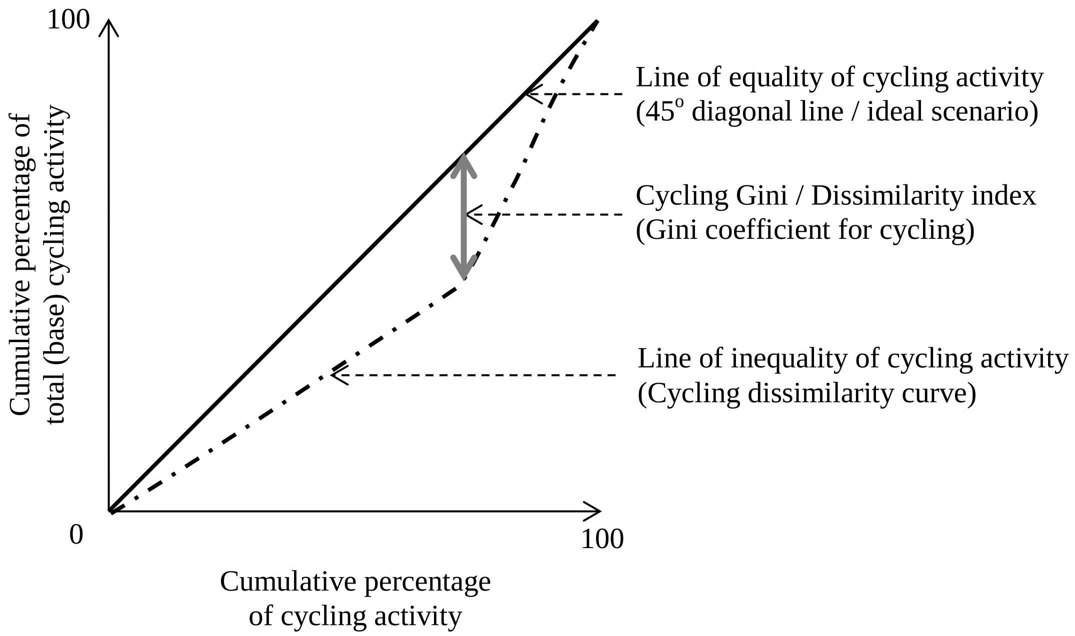


Figure 3-6: The principles of LC and Dissimilarity Index for cycling activity

Source: Adapted from Creedy (1998, p. 14) and Burt et al. (2009, p. 128)

3.4.5 Standard Directional Distribution

The generation of elliptical polygons based on events/activities in the form of point locations are useful ways of representing trends of the events. A standardised way to represent these ellipses of events is to compute the standard deviational ellipse (SDE) as it gives a clear representation of the orientation and trend of the event spatially (Mitchell, 2005). SDE is also termed as standard directional distribution (SDD) as the ellipses tend to mimic the directional distribution of the events. They are also called prediction-interval ellipses or confidence ellipses as it shows trend with certain probability (e.g. 68%, 95%, 99%) (Schonfelder and Axhausen, 2010). Unless stated, all generated ellipses in this thesis were 68%. This means that 68% of most dense centroids of activities were used for the computation so that the ellipses do not become unnecessarily large due to the “spatially random” nature of the input data. Schonfelder and Axhausen (2010, p. 133) note that very few studies in human geography have applied SDE in exploring travel diary data. Their work is probably the first to use SDE explaining multi-day data. In their analysis, they moved the mean centre of the events to home location based on the focus of the research inquiry which was around the home location. Also, they used only one respondent from (a Mobidrive) study data collected over a week conducted in two German cities of Halle and Karlsruhe around autumn of 1999 (Schonfelder and Axhausen, 2010, p. 67, 133, 135). The Mobidrive data was based on paper-pencil self-completion travel diaries (Schonfelder and Axhausen, 2010, p. 59). The exact locations of interest reported were geocoded similar to work by Aultman-Hall (1996) in three cities in Canada: Guelph, Toronto and Ottawa. Therefore, the use of this method in explaining utility cycling behaviours measured using GPS trackers from 79 respondents should be considered partly as contribution to knowledge. Very few studies have used the SDE methodologically (Mitchell, 2005). After computing the mean of the x and y coordinates (i.e. X and Y), the method calculates the standard deviation of both the x and y coordinates (i.e. SDEx and SDEy) and use them as inputs to define the axes of the ellipse as show in Equation 3-5 and Equation 3-6. In cases where the events are sub-grouped to with the intention of showing sub-group trends is termed as weighted SDE. In such a case,

The SDE is represented mathematically as:

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mathbb{X})}{\mathrm{n}}} \quad \text{Equation 3-5}$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \mathbb{Y})}{\mathrm{n}}} \quad \text{Equation 3-6}$$

Where the coordinates for feature i are shown as x_i and y_i. $\mathbb{X}$ and $\mathbb{Y}$ represent the coordinates for the mean centre for the features while n is the total number of features. The angular rotation (θ) of the long axis measured from noon is:

$$\tan\theta = \frac{\mathrm{A} + \mathrm{C}}{\mathrm{B}} \quad \text{Equation 3-7}$$

$$A = \sum_{i=1}^{n} \dot{x}_i^2 - \sum_{i=1}^{n} \dot{y}_i^2$$ Equation 3-8

$$B = \sqrt{(\sum_{i=1}^{n} \dot{x}_i^2 - \sum_{i=1}^{n} \dot{y}_i^2)^2 - 4(\sum_{i=1}^{n} \dot{x}_i \dot{y}_i)^2}$$ Equation 3-9

$$C = 2\sum_{i=1}^{n} \dot{x}_i \dot{y}_i$$ Equation 3-10

The deviations of the x and y coordinates from the Mean Centre are ẋ and ẏ respectively. X-axis and y-axis standard deviations are σ_x and σ_y respectively shown below:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}(\dot{x}_i \cos\theta - \dot{y}_i \sin\theta)^2}{n}}$$ Equation 3-11

and;

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n}(\dot{x}_i \sin\theta - \dot{y}_i \cos\theta)^2}{n}}$$ Equation 3-12

3.5 Visual analytics framework for cycling behaviours

Analysis of movement is quite challenging and demands several approaches and techniques to enable proper extraction of meaningful information. A recent review of visual analytics focussing on the application of analytical perspectives on movement data classified recent works into four categories (Andrienko and Andrienko, 2013b):

a. *Looking at trajectories*: The focus is on trajectories of moving objects considered as whole entities. Methods should support exploration of the spatial and temporal properties of individual trajectories and comparison of several or multiple trajectories.

b. *Looking inside trajectories*: The focus is on variation of movement characteristics along trajectories. Trajectories are considered at the level of segments and points. Methods should support detecting and locating segments with particular movement characteristics and sequences of segments representing particular local patterns of individual movement.

c. *Bird's-eye view on movement*: The focus is on the overall distribution of multiple movements in space and time. Individual movements are not of interest while generalisation and aggregation are used to uncover overall spatio-temporal patterns.

d. *Investigating movement in context*: The focus is on relations and interactions between moving objects and the environment in which the moves occur (i.e. their context). This includes various kinds of spatial, temporal, and spatio-temporal objects and phenomena. Movement data is analysed together with other data describing the context. Computational techniques are used to detect occurrences of specific kinds of relations or interactions and visual methods support overall and detailed exploration of these occurrences.

In this section, a visual analytical framework is proposed for the analysis of spatio-temporal data of cyclists' movement based on the classification from Andrienko and Andrienko (2013b) and recent literature as shown in Figure 3-7. The discussion here will follow the linkages between the proposed framework and the classification.

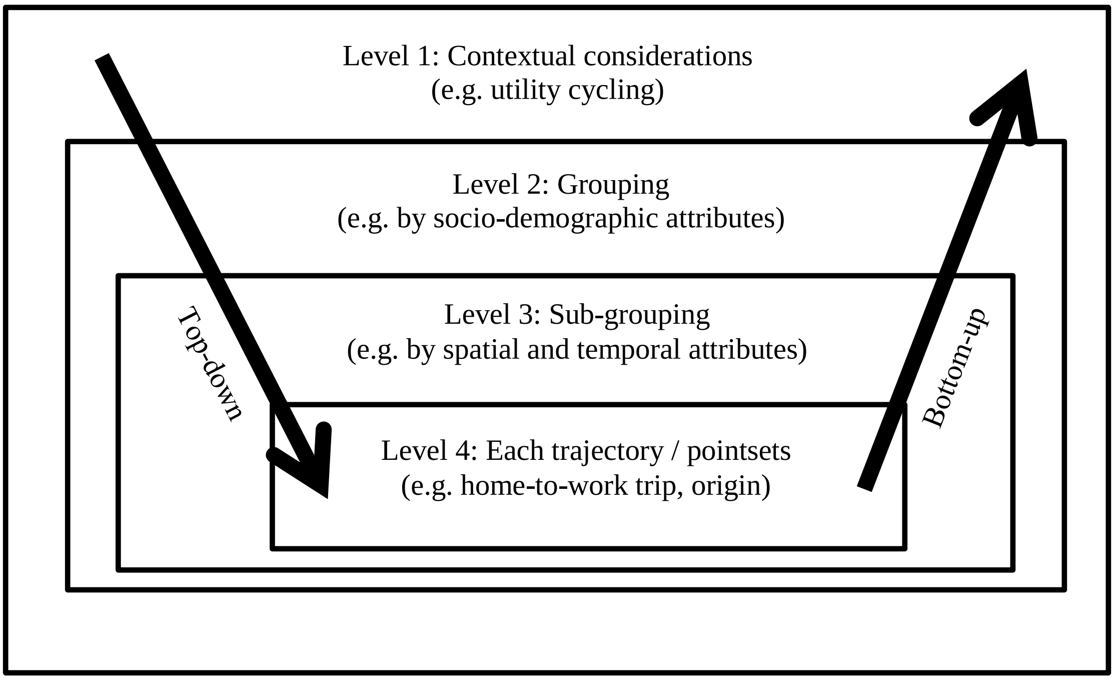


Figure 3-7: Framework for visual analytics of cycling behaviours

The contextual considerations (Level 1) demand careful determination of the context in which the available data was collected. This is important because the analysed and presented information should be considered in this particular context to avoid ambiguities. Here, the contextual considerations are defined as a combination of all modes taken by utility cyclists. In this respect, the level agrees with the fourth category of the classification which is about "*investigating movement in context*". A further assumption is that this level (occasionally) takes on the third category if all analysis and visualisations are being performed at that level. This addition becomes more useful when one intends to visualise the results in a two-dimensional Euclidean space. Perhaps it is important to add that any three-dimensional space in the context of the space-time theory constitutes the Euclidean space with time as the third dimension. It is however possible to ignore the "*Bird's-eye view on movement*" classification and visualise results at Level 1 using an entire space time cube or other two-dimensional views with time as one dimension along with any other attribute, for example, distance.

The Level 2 – grouping - in the framework suggests that the analyst should determine and use variables that have potential to derive meanings from the entire dataset, consideration should be given to non-spatial attributes only. An example is the use of socio-demographic variables if available for the data. Such variables could be gender, employment status, and economic status to name a few. Given that the attributes being considered for grouping are external to the actual spatio-temporal data, this level takes also the characteristics of both the third and fourth classification as in Level 1.

The Level 3 - sub-grouping - is a form of grouping like Level 2 but conducted mainly on the basis of spatial attributes of the spatio-temporal data. This level conforms to the first category of the classification which is about "*looking at trajectories*". Where the analysis ends at this level, the third classification could also be considered. To avoid repetition, the arguments for inclusion or exclusion of the third classification for this level are same as Level 1. Any analytical results at this level fall under clearly defined groups using socio-demographic attributes in Level 2 such as males or females. Otherwise, the results fall under level 1. This is possible if the data was collected without any additional information from the participant or if a decision was made in the analytical process to skip level 2.

The final level - Level 4 - is considered the basic level, because it concerns the basic (geometric) unit of movement data collected with a portable GPS device. This level conforms to the first category of the classification which is about "*looking inside trajectories*". The end of trajectories, if extracted reliably, could represent the origin and destination of a cycle trip. These origin-destination locations could then be grouped using higher Levels 3 and 4, which is bottom-up analysis. Level 4 can also draw on the fourth category of the classification if the consideration of any part of the individual trajectories are contextualised and linked to the environment in any way. On the other hand, approaching the analysis from Level 1 to Level 4 is considered top-down. Once an approach is taken it is possible to jump levels and the choice is mainly based on the discretion of the analyst. The analysis performed in this chapter combines both top-down and bottom-up approaches in profiling activity spaces of the cyclists sampled. A detailed discussion of the data used for the analysis presented in this chapter follows next.

3.6 Profiling activity spaces and times

Based on the concepts of visual analytics and activity based analysis (Section 2.8); interactive software interfaces were used in this thesis to facilitate reasoned analysis and visualisation of actual urban cycling flows in space and time. The approach to examine point object population (i.e. events as point locations) is taken from Golledge and Stimson (1997, p. 269):

1. To *geographically* develop explanations regarding the ways in which individuals and groups in the same space-time frame or region; and

2. To (socio) *demographically* develop explanations based on numbers and descriptive characteristics such as gender

Similarly, line object population (i.e. events as polylines) followed the same approach. In order to realistically operationalise the development of the explanatory process in this thesis, two main definitions of activity spaces were conceptualised and clearly defined and situated within the proposed confines of a visual analytical framework. The definitions and operationalisation of both the activity spaces and visual analytical frameworks have been presented in Chapter 6 and section 3.5 respectively. Golledge and Stimson (1997) suggest that activity spaces are known to be an important way of examining and drawing useful information about the environment while attaching meaning to it. The visual analytical framework discussed was based on Andrienko and Andrienko (2013b) recent literature as discussed in section 3.5.

3.7 Mapping Significant Clusters of Activities

Clustering technique based on Anselin's *Local Moran's I statistics was* utilised to enable meaningful but significant visualisation of stationary activity spaces (Anselin, 1995; ESRI, 2013). A brief description of how the technique could be applied follows. Terms such as *stationary* or *stationary activity* are used to represent stops in movement or non-vigorous activity around stops in space-time geography. Horner et al. (2012) used the term to explore unlocatable activity locations derived from travel surveys and examines individual time budget allocated to travel and stationary activity. Miller (2007) used the term to illustrate an analytical definition of the space-time prism. It is also used by urban designers to discover and quantify where people walk and what they do in central parts of cities (Palazzo and Steiner, 2011, p. 86). In the current research, the term stationary activity is used to discover and quantify where people stop or move at a low speed in their cycling trips.

Among many spatial concepts, *Local Moran's I statistics* was used based on the line of inquiry, knowledge and technical expertise of analyst as well as use of available licensed software. The term motile or motile activity is taken from biological science research where the ability to move and energy is spent in the movement process (Baez, 2013; Davis et al., 2011). This is taken as a description of cycling as an active transport when combined with (Cole et al., 2010) notion of active transport as a form of travel involving active human muscle during the journey (Cole et al., 2010). Although, it was possible to manually extract all stops, for only cycling journeys, from the dataset using the detailed travel diary, we utilised time constraints with the use of clustering method for the significantly low speed detections within the dataset. Here, significantly low speed clusters constituted Stationary Activity Space (SAS) and significantly high speed clusters constituted Motile Activity Space (MAS). SAS and MAS were further explained in section 6.3.

The Local Moran's I algorithm is given as shown using equations Equation 3-13 to Equation 3-17 (Deshpande et al., 2011; ESRI, 2013). The algorithm is among few popular algorithms serving as indices for spatial autocorrelation and available in off-the shelf commercial GIS software such as ESRI ArcGIS (Deshpande et al., 2011, p. 344). These techniques were used in Chapter 6. Z-score is a value of an observation which has been expressed in the units of the standard deviation. The Z-score is computed by deducting from the observation the mean of all observations and eventually dividing the result by the standard deviation for all the observation (Field, 2009, p. 796).

The Local Moran's I statistic of spatial association is given as:

$$I_i = \frac{x_i - \bar{\chi}}{S_i^2} \sum_{j=1, j\neq \mathrm{i}}^{n} w_{i,j}\,(x_i - \bar{\chi}) \qquad \text{Equation 3-13}$$

Where x_i is an attribute for feature i, $\bar{\chi}$ is the mean of the corresponding attribute, $w_{i,j}$ is the spatial weight between feature i and j, and

$$S_i^2 = \frac{\sum_{j=1, j\neq \mathrm{i}}^{n} w_{i,j}}{\mathrm{n}-1} - \bar{\chi}^2 \qquad \text{Equation 3-14}$$

with *n* equating to the total number of features.

The z-score for i[th] observation,

$$z_{Ii} = \frac{I_i - \mathrm{E}[I_i]}{\sqrt{\mathrm{V}[I_i]}} \qquad \text{Equation 3-15}$$

Where:

$$\mathrm{E}[I_i] = -\frac{\sum_{j=1, j\neq \mathrm{i}}^{n}}{\mathrm{n}-1} \qquad \text{Equation 3-16}$$

$$V[I_i] = E[I_i^2] - E[I_i]^2$$ Equation 3-17

3.8 Network based corridor space analysis (CSA)

This section discusses the concept of corridor space for exploring movement patterns as well as some merits and potential drawbacks of such an approach for data analysis.

3.8.1 CSA for exploring movement patterns

Data collection, alone, is not enough for analysis. Matching GPS-tracked data to other spatial datasets is also necessary, albeit difficult a task. It is in this difficulty that the concept of corridor space is introduced to address what and how spatial analysis could be done when collected data and available datasets do not fit properly due to data inaccuracy issues. Corridor space is defined as a buffer zone around cycle lanes/paths use for detecting cycle trips/cycle trip sections/other available cycle infrastructure. The analysis associated with the use of corridor space in determining an area of interest and further inquiry therein is what is termed the corridor space analysis here. A cycle trip is defined here as any journey by an adult cyclist bounded by stops and identifiable in both a travel diary by purpose(s) and GPS data by geometry. The concept is used to find cycle trips off, on or near the "official" cycle network in the study area.

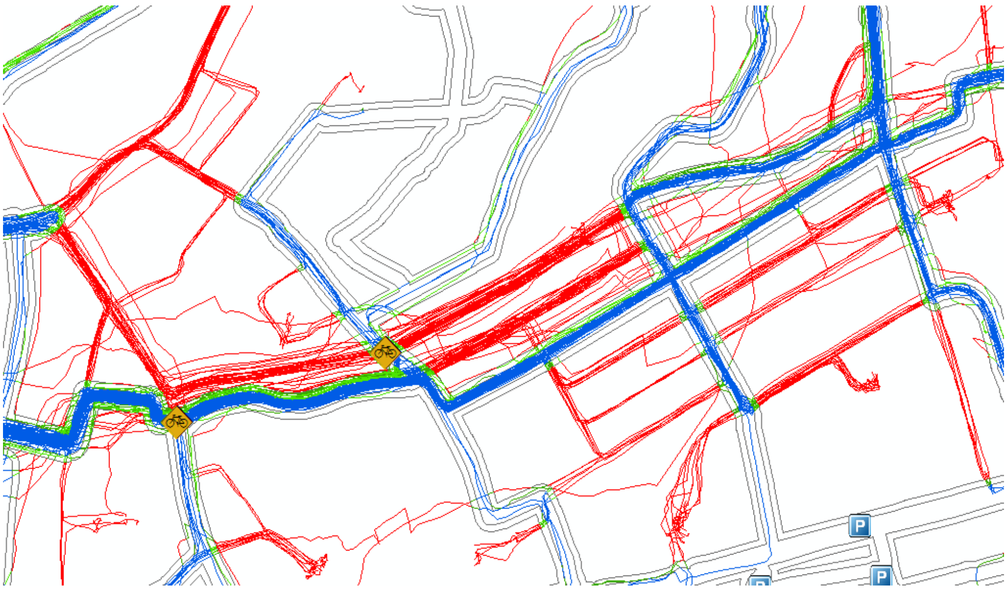


Figure 3-8: Corridor space definitions using a map

The colours in Figure 3-8 were defined as follows. Blue represent cycle trips on the network, green for trips close to the network and red for cycle trips off the network. Figure 3-9 shows a conceptual sketch underpinning Figure 3-8 above, with the colours matching these activities.

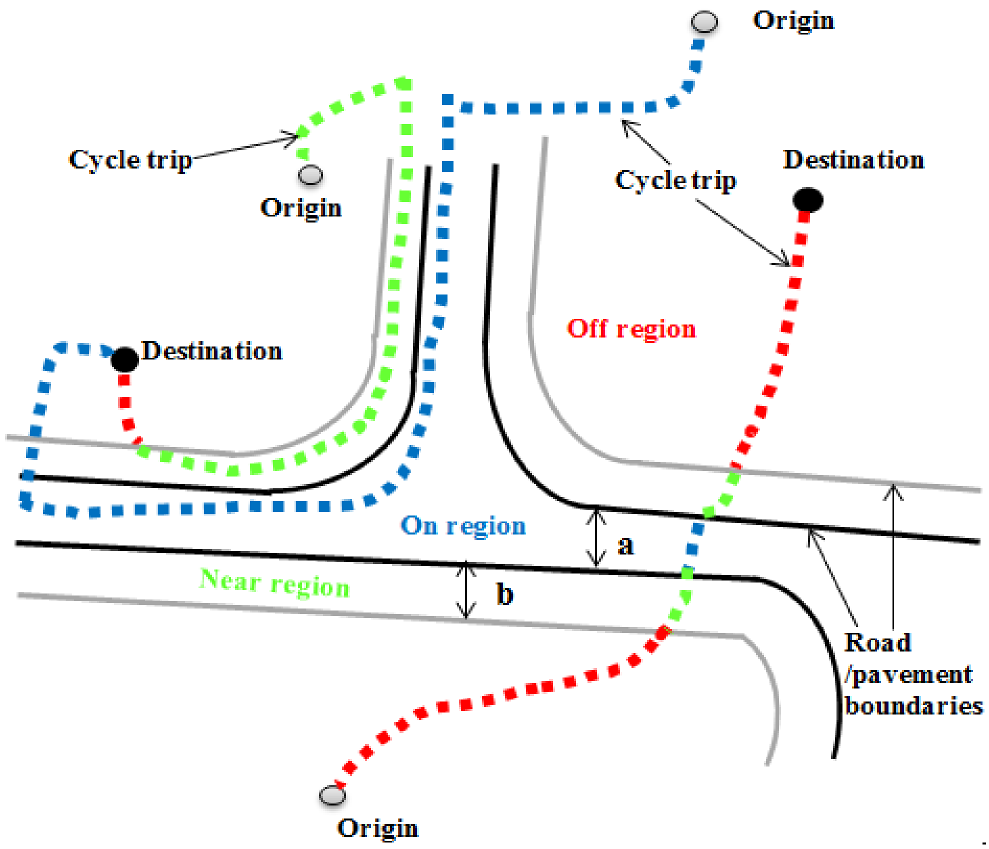


Figure 3-9: Conceptual mapping of corridor space analytical frame

Source: (Yeboah et al., In press)

For a given buffer distance "a," half of that would equal "b" as shown in Figure 3-9. Mathematically, we assume B = (B_1, B_2, …, B_n) where B_1 is a trip or trip segment within the blue region (i.e. the on-region). Similarly, G = (G_1, G_2, …, G_n) where G_1 is a trip or trip segment within the green region (i.e. the near-region) whereas R = (R_1, R_2, …, R_n) where R_1 is a trip or trip segment within the off-region. The total distances for each region (i.e. BT, RT, and GT) could be represented as:

$BT = \sum_{k=0}^{n} B_k$ Equation 3-18 $RT = \sum_{k=0}^{n} R_k$ Equation 3-19 $GT = \sum_{k=0}^{n} G_k$ Equation 3-20

Such that the total distance for all cycle trips should approximate BT+RT+GT and that BT≠GT.

The "near" fuzzy region, the green region, and its estimate serve as a trade-off and a measure of whether the "on" as well as the "off" estimates make comparative sense. The notion of "trade-off" here is similar to argued case for using a calibration process as a trade-off between bias and standard error in the mechanics of Geographical Weighted Regression method (Fotheringham et al., 2002, p. 52). Thus, a "near" estimate equal to or close to the "on" estimate may give clues to the reliability of the latter. The decision on best estimates with associated multiple buffers is left to the analyst but with some reasonable justification. The assumption is that a “near” estimate equalling or less than one third of an “on” estimate is meaningful trade-off.

3.8.2 Advantages and disadvantages of CSA

Corridor based analysis has been used in several transport related studies: the location of high crash concentrations within the context of bridging the gap in highway safety analyses (Smith et al., 2001); prehistoric cultural activity (Hazell and Brodie, 2012); as well as modelling and identification of species migration corridors (Hargrove and Westervelt, 2012). Understanding route choice preferences of people’s travel behaviour is important in the context of transportation research. Both the built environment in which the travel behaviour occurs and the behaviour itself needs to be measured to allow for comparisons and further analysis. In doing so, the measured data for both realms will need to match, otherwise comparative analysis becomes difficult. Where captured data for both realms are matched, the difficulty in analysis is reduced. On the contrary, if captured travel data does not match the available transport network data, then the introduction of new analytical approaches becomes imperative and is more useful in applications where uncertainties are difficult to eliminate. For example, estimating travel behaviour in terms of trips on, near and off a given transport network (Yeboah and Alvanides, 2013).

A drawback to the application of corridor space analysis depends on the needed accuracy of outcome and more importantly the context of usage. For example, in highly precise applications where millimetre to centimetre levels of output is needed, the need for such approaches to data analysis may not be as demanding as tolerable metre level estimates will not be acceptable. Corridor analysis, however, is very useful in furthering understanding in data analysis (Yeboah, 2013; Yeboah and Alvanides, 2013).

The next best approach to route choice related data analysis demands prior alignment (i.e. map-matching) to the road network (Chapter 7). Such an approach, however, comes with further demands: a high resolution right-of-way network which has a high probability of containing most, if not all, the potential route choices. Given the time consuming nature of data integration, in a case where such a high resolution network is not available or disparate or somewhat questionable in terms of well-connected end to end points in the network, careful consideration of the research scope and feasibility is necessary to avoid excessive delay of progress. This depends largely on time constraints and data availability; the decision is in the hands of the researcher. It is in this spirit that the concept of corridor space was developed and the method used in this research.

3.9 Generation of network constrained routes

According to Papinski and Scott (2011), the process for generating observed routes from GPS points should start from, first, identification of origin and destination of the route (Box A of Figure 3-10). The second step suggests that the GPS points for the route should be overlaid on the network (Box B of Figure 3-10). The shortest path algorithm, via the "Solve" function in ArcGIS, is employed to compute the shortest route connecting the origin and destination (box C of Figure 3-10). Finally, intermediate stops are created manually to force the shortest route to follow the observed route (Box D of Figure 3-10). The intermediate stops should be strategically placed to influence the computation of the observed routes. This strategic placement was done repeatedly until the shortest route followed the observed routes.

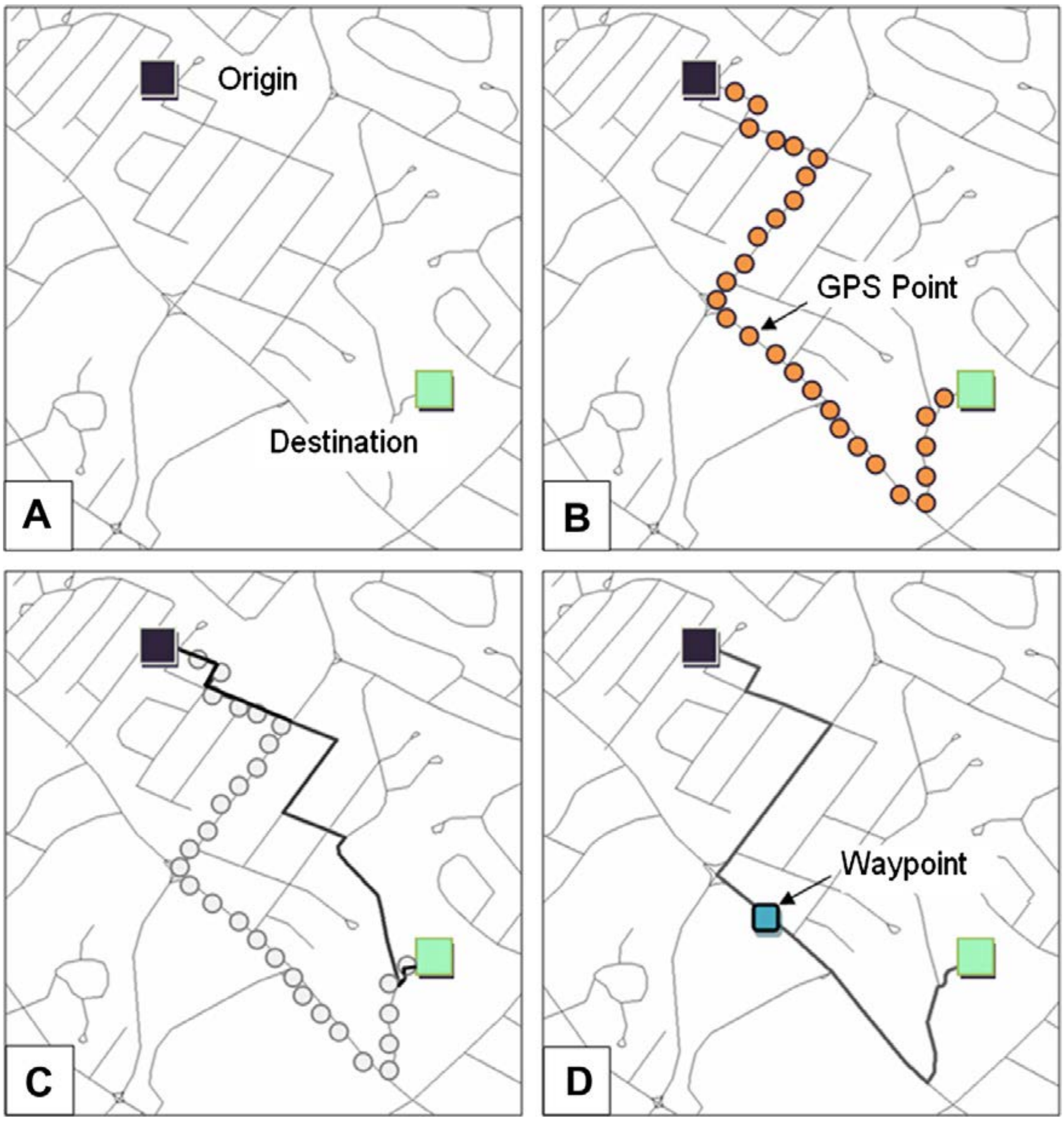


Figure 3-10: Steps for generation of an observed route from GPS data points.

Source: (Papinski and Scott, 2011, p. 438)

3.10 Application of the theory of planned behaviour

The theory of planned behaviour (TPB) was used as a theoretical base to capture useful psychometric variables supporting the movement behaviour of cyclists sampled. To avoid reinventing the wheel, this work built on the travel diary developed by Lemieux and Godin (2009). In their study, they developed a self-reported questionnaire based on TPB to capture psychometric variables of students to understand how they travel to work or school within the context of active transport. They found out that cognition of travellers is important in explaining active commuting and that age, habit and intention predicted behaviour of those sample populations significantly. One of the limitations of the study was that only stated preference was used without any revealed (objective) preferences like tracking participants' movement over the data collection period. In this study, the participants were also tracked using GPS devices making it possible to explain both their cognition and actual movement behaviours. The revised form was used with the aim of capturing and explaining psychometric variables covering participants' attitudes, subjective norm, and perceived behavioural control leading to intended travel behaviour during their normal week. Section 2.7 further discussed the TPB. Limitations of TPB are summarised as follows (Boston-University, 2013), TPB:

- assumes that, regardless of the intention, the subject has the opportunities and resources to be successful in performing the behaviour in context;
- does not account for other potential variables such as threat, mood, fear, or past experience that may factor into behavioural intention and motivation;
- does not take into account environmental and/or economic factors that may influence a subject's intention to perform a behaviour, although it does consider normative influences;
- does not give consideration that behaviour can change over time, and assumes that behaviour is the result of a linear decision-making process;
- does not address actual control over behaviour, although the addition of perceived behavioural control was a significant addition to the theory; and
- does not include the time frame between "intent" and "behavioural action".

3.11 Overview of applied statistical analytical approaches

This section first gives an overview of statistical analytical techniques used in the thesis and points out the various techniques used in each chapter. Descriptive and spatial statistical analyses were used as part of the data analysis by considering the various variables of interest. With the exception of exploratory regression (ER) analysis, all other statistical techniques were employed using IBM SPSS statistical package. In doing so, two main applications are used in aiding the analysis namely IBM SPSS Statistical package version 20 and ESRI ArcGIS Desktop version 10. The IBM SPSS statistical package was used to generate most of the tables and graphs presented in this thesis with occasional use of Microsoft Excel and sometimes using graphing techniques available in ESRI ArcGIS 10.0.

3.11.1 Descriptive and inferential statistical analysis

Descriptive statistical analysis may be defined as the utility of some particular methods to describe and summarise characteristics of a given sample while inferential statistical analysis may be defined as the utility of some methods to infer something meaningful about the sample population (Rogerson, 2006, p. 13). Some of the most used descriptive statistics are central tendency measures such as arithmetic mean and median as well as measures of dispersion such as standard deviation and coefficient of variation (Flowerdew and Martin, 2005). Rogerson (2006, p. 4, 13) further suggested that methods used for descriptive statistical analysis should be considered as exploratory techniques while methods used for inferential statistical analysis should be considered to be confirmatory in nature and gave an example to support it. In his example, he cited that visualisation and descriptive methods that led to discovery of clusters per a given set of points were exploratory methods and statistical methods that confirm that the configuration of the points could not have occurred by chance would be confirmatory methods. In this thesis, both approaches were used in a separate form or combined. We considered significance of variables or hypothesis testing as confirmatory and subsequent visualisation as descriptive. It must, however, be noted that the difference between confirmatory methods and exploratory methods are quite fuzzy particularly in GIS domain and both methods demand robust statistical measures such as the use of median (Flowerdew and Martin, 2005, p. 157; Fotheringham and Charlton, 1994, p. 316).

3.11.2 Exploratory data analysis

Exploratory data analysis (EDA) is concerned with the detection and description of trends, patterns and linkages in data (Andrienko and Andrienko, 2005). EDA is a kind of data analysis comprising of wide variants of techniques and situated in an inductive framework; meaning that hypothetical suggestions about the dataset are made along with the related underlying process (Flowerdew and Martin, 2005, p. 157). When EDA is more spatially inclined it is referred to as an exploratory spatial data analysis (ESDA). By extension, when ESDA is visually intensive then it would not be too far from the Visual Analytics paradigm (Section 2.8.4). The kind of ESDA approach employed in this thesis follows that of Murray et al. (2001); although not for crime studies but for cycling studies. Murray et al. (2001, p. 316) by acknowledging the wider variety of techniques for ESDA adopted a three-fold approach within the context of ESDA for examining crime which we found useful as a guide to examine cycling behaviours. The three-fold approaches were utility of commercial GIS: 1) as only a visualisation tool; 2) with spatial modelling techniques; and, 3) with statistical techniques. Another variant of ESDA that is utilised in this thesis is Anselin's Local Moran I statistics which is also called local indicator of spatial association (LISA) (Anselin, 1995; Burt et al., 2009, p. 560). An alternative to LISA is G_i-statistic (Burt et al., 2009, pp. 553-566). Burt et al. (2009) suggest the distinction between G_i-statistic and Local Moran I statistic is that the former do not offer an explicit comparison of the value of a variable between one or more locations. The Local Moran I statistic is used because it offered such a comparison. Chapter 6 discusses further the Local Moran I statistic.

3.11.3 Exploratory regression analysis

With a long list of explanatory/predictor variables, finding a good regression model can be tricky (Rosenshein et al., 2011a, b). The use of a particular exploratory regression analysis technique constrained within ArcGIS environment is just one of several acceptable methods. Braun and Oswald (2011) suggest that "Although there is no definitive or unambiguous method for establishing predictor [or explanatory] variable importance, there are several accepted methods." They go further to add one more method using a developed program in Microsoft Excel (http://dl.dropbox.com/u/2480715/ERA.xlsm?dl=1) arguing that such exploratory approach in data analysis has the advantage of yielding both theoretical and practical benefits.

The regression approach used does not add any new method to the palette of existing methods but rather select the convenient technique for the exploratory data analysis. To this end, the approach developed in ArcGIS is chosen for convenience (Rosenshein et al., 2011a, b).

Exploratory regression (ER) is a newly proposed powerful data mining tool for finding statistical models based on Ordinary Least Squares (OLS) linear regression (Rosenshein et al., 2011a). ER looks for Ordinary Least Squares (OLS) models that explain a given dependent variable per given user specified criteria (ESRI, 2012; Rosenshein et al., 2011a). ER does this by evaluating all the possible combinations of explanatory variables against the specified criteria. The default criterion follows:

Search Criterion	Cutoff
Min Adjusted R-Squared	> 0.50
Max Coefficient p-value	< 0.05
Max VIF Value	< 7.50

Min Jarque-Bera p-value > 0.10

Min Moran's I p-value > 0.10

The adjusted R-Squared ranges from 0.0 to 1.0 and the default (0.50) suggest that 50% of the variation in the dependent variable is explained in the model. The coefficient p-value ranges from 1.0 to 0.0 and the default (0.05) suggest that model passing this threshold contains only explanatory variables having coefficients that are statistically significant at 95% confidence level. The variance inflation factor (VIF) value suggests the extent of tolerance of redundancy (multicollinearity) amidst the explanatory variables in the model. VIF is independent of sample size (Braun and Oswald, 2011, p. 332). The suggestion is that a value more than 7.5 makes a model unstable so a smaller value such as 5.0 is more preferable. The Jarque-Bera p-value suggests whether the residuals of the model are normally distributed and it is suggested that this value can be relaxed to a lower confidence interval if no model is passing. The Moran’s I p-value is a Global Moran’s I p-value and if it is small (statistically significant), it means that the model is not telling the whole story and it is likely that some key explanatory variables are missing.

Figure 3-11: Framework for Exploratory Regression analysis

Source: (ESRI, 2012)

3.11.4 Hypothesis testing

Both paired sample t-test, a parametric technique, and Wilcoxon Signed Ranked t-test, a non-parametric statistical technique were used to test the null hypothesis that urban transport network restrictions (i.e. one way, turn restrictions, and access) do not have any significant influence on movement of commuter cyclists. Unlike parametric techniques which assume that the input data must be normally distributed, non-parametric techniques do not depend on normal distribution and considered a distribution free testing technique (Patel, 2012, p. 325). The Wilcoxon Signed Ranked t-test compares two dependent samples by using the ranks of the pairs of scores that are formed by the matched pairs in the samples (Argyrous, 2005, p. 353).

Chapter 4 used a combination of both descriptive and inferential statistics to examine both secondary and primary data on cycling. The chapter also employed the first two of the three-fold ESDA approach. Chapter 6 combines ESDA approaches explained above within the context of visual analytical and space-time geography frameworks. Also, Chapter 6 utilised the first two of the three-fold ESDA approach leaving the last fold for Chapter 7. Chapter 7 employed the entire three-fold by using ESRI GIS application to visualise home-to-work observed routes on a cycling friendly transport network while computing shortest path on the network and to also generate inputs for hypothesis testing using SPSS statistical package.

3.12 Conclusion

The advancement of GPS based technologies has given rise to different uses of GPS trackers and the use of GPS devices in sensing movement behaviours of users of built environment is relatively new (Gong and Mackett, 2008). In answering the question–*what is the value of GPS as "sensor technology" measuring activities of people?*-Van der Spek et al. (2009) concludes that GPS serves as an indispensable means to collect spatial temporal data on different scales and in different settings adding new layers of knowledge to urban studies. Amidst this indispensability dwells future prospects, some of which are, namely: expected GPS data in a near future; automation of data collection and processing; the evaluative capacities of tracking technologies; the increased relevance of multiple, visual environments to communicate results from tracking studies (Van der Spek et al., 2009, p. 3052); and, eventually, database systems for the management of spatial temporal data such as SECONDO (Güting et al., 2006; Guting, 2007) or, more simply, using Microsoft Access databases or Excel workbooks. SECONDO is an extensible database management system for moving objects: http://dna.fernuni-hagen.de/Secondo.html/. The use of GPS as a research technique could give further insight on the use of urban spaces as well as study of behaviour in time and space (Van der Spek et al., 2009, p. 3036). The recent decision by the UK DfT not to use GPS trackers for the National Travel Survey from 2013 onwards (Guell et al., 2012, p. 4) is revisited here by both reflecting on the experiences in the current study and the decision by DfT on GPS usage. It appears that the decision by DfT is partly based on the insufficiency, or under development, in the data processing methods in support of surveys.

This chapter discussed the methodological approaches used in this study. One of the novel developments was the use of STC in processing raw GPS data in order to isolate cycle tracks from the messy dataset. The successful refinement of the messy data using the STC approach allowed further analysis to be performed in subsequent chapters. The next chapter, Chapter 4, used flow mapping, kernel density estimation and dissimilarity indexing to explore activity distribution across Euclidean two-dimensional space. The chapter explored Tyne and Wear Household Travel survey, annual cycling traffic flow from TADU and 2001 and 2011 census data. Descriptive statistics were used together with the primary data collected in this study to set the scene for the subsequent chapters (i.e. Chapter 6 and Chapter 7). Captured psychometric variables about participants' cognition and perception of their environment were analysed and explained. Another novel approach introduced here was the conceptualisation of *Stationary Activity Spaces* and *Motile Activity Spaces* within the theoretical construct offered by Hägerstrand's theory in space-time geography and the *action space concept* to identify popular activity spaces. These concepts were further operationalised in Chapter 6. Chapter 7 utilised both corridor space analysis and (non-parametric and parametric) statistical hypothesis testing techniques to perform route choice analysis at different scales respectively. Prior to the hypothesis testing, the method by Papinski and Scott (2011) was used to generate network constrained routes as an input to the testing.

CHAPTER 4. EXPLORATORY ANALYSIS

4.1 Introduction

One substantive contribution of this thesis is the combination of disparate techniques for exploring urban cycling related data as evidenced in this chapter. Exploratory data analysis is mainly concerned with the detections and descriptions of patterns, relations, and trends in data which is motivated by some purposeful investigation (Andrienko and Andrienko, 2005). Through exploratory analysis of rich data, new questions and hypotheses may arise for more detailed examination (Andrienko and Andrienko, 2005). This chapter is sectioned in three main parts. The first part examines available but unexplored cycling related secondary data, presenting a detailed perspective of cycling behaviours in North East England with occasional extension of discussion within the national context. The second part discusses in detail all the primary data collected as part of this thesis and explains how it can make a substantial contribution to our understanding of urban cycling behaviours – particularly in the UK context. The concluding part brings together the findings of the current chapter and points to the need for in-depth analysis carried out in subsequent chapters.

The secondary data used to set the scene for this chapter comes from five different sources: the TWHTS from 2003 to 2011; 2012 NTS; 2010 Newcastle Cycling Campaign survey; AAWT flows from cycle counters across Tyne and Wear from 2004 to 2012; and the 2011 and 2001 UK census data. Detailed descriptions of these datasets can be found in section 3.3; therefore only a brief discussion follows here to avoid unnecessary repetition. The TWHTS and NTS were sourced from Newcastle City Council (special request) and DfT respectively. The 2010 Newcastle Cycling Campaign data and the AAWT were sourced from the Newcastle Cycling Campaign group and the TADU respectively; all through special requests. The 2001 census data was sourced from the former EDINA UKBORDERS data service, which is now UK Data Service Census support (EDINA, 2013). The 2011 census data was sourced partly from the UK Data Service and Office for ONS data archive. In this analysis, the Lower layer Super Output Areas (LSOAs from 2001), rather than the census Output Areas (OA), are used because the numbers of commuter cyclists captured were very small in North East England. Therefore, the OA data would suffer from small number effects and other census data inaccuracies resulting from adjustments to preserve confidentiality. Although it is becoming dated, the 2001 UK census data allows for comparisons with the national average and illustrates the distribution and concentration of cycling for commuting purposes. Instead of simply mapping absolute numbers of cyclists, various maps, graphs, and tables have been generated in order to explain and visualise the census data by assessing the spatial variability and dissimilarities of cycling prevalence across all and parts of North East England.

Subsequently, the second part explores the primary data collected for this thesis. This covers both the stated and revealed preferences from 79 urban utility cyclists, along with their perceptual and attitudinal views. Stated and revealed preferences survey studies were already discussed in sections 2.5, while the procedures used for primary data collection were discussed in section 3.5.

Various spatial analytical approaches are used here to identify dissimilarities and spatial variability of cycling prevalence around the study area for different geographies. In other words, different configurations of geographical areas are used depending on data availability and type of information that needs to be analysed, visualised, and interpreted as part of the research process.

The approaches, already in detail in Chapter 3, comprise:

- Flow mapping to visually present cycling flows across Tyne and Wear;
- Kernel density distribution to assess the concentration/denseness of cycling activity across Tyne and Wear;
- Location quotient calculation to assess inequalities at local authority district level;
- Lorenz curve graph together with Dissimilarity Index to assess cycling differences in the North East of England;
- Standard directional distribution to describe the spatial extent of cycling across the study area using the primary data; and,
- Exploratory regression analysis to examine the perceptions and attitudes of the participants in this study.

4.2 Exploring secondary datasets for cycling patterns

The exploration of the available secondary data on cycling was divided into three main phases. The first phase explored data available only within the Tyne and Wear area. In this respect, the TWHTS data, which is a cross-sectional survey, was used to identify more detailed travel patterns. Despite its usefulness, it lacks actual route preferences of respondents since it was a stated preference survey. In the case of using the origin-destination information from the TWHTS data, Cycling Prevalence (CP) was defined as the degree of occurrence of cycling trips around origin or destination locations (i.e. postcodes locations). In all other cases in the thesis, CP is referred to as degree of cycling uptake. In addition, the 2012 National Travel Survey along with data collected by the Newcastle Cycling Campaign was used for this phase. The second phase explored cycling traffic flows from automatic cycle-counters which were obtained from the

TADU. The third phase explored the available census data for the whole of North East of England to examine the dissimilarities of travel to work by bike across the region.

4.2.1 Rhythms of cycling patterns in Tyne and Wear

This section explores, in a novel way, the cycling patterns from the Tyne and Wear Household Travel Survey from 2003 to 2011 for the first time. Rivas Perez and Hodgson (2011) have used the 2003 - 2009 version of the dataset with a combination of 2007 indices of multiple deprivation and ordnance survey maps to show variation in employment geographies of households. However, the emphasis was not on cycling patterns. Therefore, the case here is that the analysis shown here is being done for the first time and should be considered as a contribution to knowledge. In order to understand the dynamics of preferred cycle trip making across Tyne and wear, a cycle trips' matrix is generated based on the Tyne and Wear Household Travel Survey from 2003 to 2011 is shown in Table 4-1.

Table 4-1: Matrix of cycle trips by purpose

Purpose description from Tyne and Wear Survey	**Cycle Trips' Matrix**												
	Own Code		**PurposeTo**										Total
			ED	**ES**	**NW**	**OB**	**OW**	**PH**	**PB**	**SH**	**SR**	**TH**	
Education	**PurposeFrom**	**ED**	0	0	0	0	0	33	0	1	1	0	35
Escort		**ES**	0	0	2	0	0	8	0	1	1	0	12
Normal place of **w**ork		**NW**	0	0	0	**1**	**3**	**90**	0	0	4	0	98
On employers **b**usiness		**OB**	0	0	**1**	0	0	**4**	0	0	0	0	5
Other place of **w**ork		**OW**	0	0	0	**2**	**1**	**17**	0	0	0	0	20
Permanent **h**ome		**PH**	33	7	**99**	**2**	**16**	0	16	23	111	1	308
Personal **B**usiness (eg going to bank, doctor, dentist)		**PB**	0	0	0	0	0	13	1	1	1	0	16
Shopping		**SH**	0	1	0	0	0	25	0	0	1	0	27
Social/**R**ecreation		**SR**	2	0	**3**	0	0	106	0	0	11	0	122
Temporary **h**ome/**h**otel		**TH**	0	0	**1**	0	0	1	0	0	0	0	2
Total			35	8	106	5	20	297	17	26	130	1	

Categories for flow mapping	Total Count	%
Home-work-home	240	**37**
Home-education/shopping/PersonalBusiness-home	149	23

Home-social/Recreation/Ecort-home	256	40
Total	645	100

Source: Tyne and Wear Household Travel Survey from 2003-2011

The generation was based on two columns in the database of the survey shown in the table as "PurposeFrom" and "PurposeTo". To get the numbers for each pair, structured query language (SQL) is used to query the database. For example, to the number for the pairs "Permanent Home (PH)" and "Normal place of work (NW)", the SQL query looks like this:

*SELECT * FROM TABLE WHERE PurposeFro = 'Permanent Home' AND "PurposeTo" = 'Normal place of work'*

The "SELECT *" means to select all records from a table extracted into ArcGIS. The query selects all the records having their *PurposeFro* and *PurposeTo* columns equivalent to *Permanent Home* and *Normal place of work* respectively. This query resulted in 99 cycle trips as shown in Table 4-1. Although relatively low values, the method used for the survey ensures representativeness of the population and therefore the data can still be used to infer meanings of cycle trip making albeit a stated preference survey. The table shows utilitarian trips as well as non-utilitarian cycle trips. Utilitarian trips are sub-divided into commuting and non-commuting in order to understand cyclists' preferences. The commuting trips are grouped under "*Home-work-home*" and non-commuting under "*Home-education/shopping/PersonalBusiness-home*". The "*Home-social/Recreation/Ecort-home*" is considered to be non-utilitarian cycle trips.

The map labelled C in Figure 4-1 is generated based on the divisions as deduced from Table 4-1. The arrows on the map show the direction of cycling flow and their colour reflect those of the numbers in Table 4-1. The concept of flow mapping used here was discussed in section 3.4.1. Utilitarian cycle trips constitute 60% of all cycle trips from 2003 to 2011 with the other 40% for non-utilitarian trips. According to the matrix, almost half of cycle trips (308) were undertaken from *permanent home* to various destinations and vice versa (297). Cycling to work (117) from permanent home is slightly higher than social/recreational cycling (111). This trend is about five times more than that of cycling for shopping. Map C shows "plottable" cycle trips as Euclidean distances joining origin and destination. Only the departures and arrivals were captured making the survey deficient in actual route preferences. The use of 645 "plottable" cycle trips was based on the fact that the original database obtained had 700 cycle trips as captured by the Tyne and Wear Household survey from 2003 to 2011. Cycle trips constitute about 1% of all trips in the Tyne and Wear Household Travel Survey from 2003 to 2011. Furthermore, the gap, or lack of actual route preferences in the study area, is filled by the primary cycling data collected as part of this research.

The cycling flow pattern, in the map of Figure 4-1, portrays prevalence of cycling around the central part of Newcastle upon Tyne. The map also shows cycling prevalence around the Southern and Northern areas of North Tyneside and South Tyneside respectively. Relatively low cycling prevalence is found in Gateshead. Also, the northern part of Sunderland seems to have relatively high prevalence but denser compared to Newcastle upon Tyne visually. The morning peak departure cycle trips occurred between 7.45am to 8.45am as shown in graph A in Figure 4-1. The afternoon peak departure cycle trips occurred between 4pm to 6pm. Similarly, for the arrival cycle trips, morning peak occurred between 7.55am to 9am while that of afternoon peak occurred between 4pm to 6.20pm as shown in graph B in Figure 4-1. Comparatively, there is a slight shift in the morning timings for departures and arrivals. This may be due to duration of cycle trips as the computed average time expenditure per cycle trip is about 15 minutes (i.e. total time expenditure (9,487 minutes) by total trips (645)). This trend, however, is not the same for the afternoon timings for both departures and arrivals.

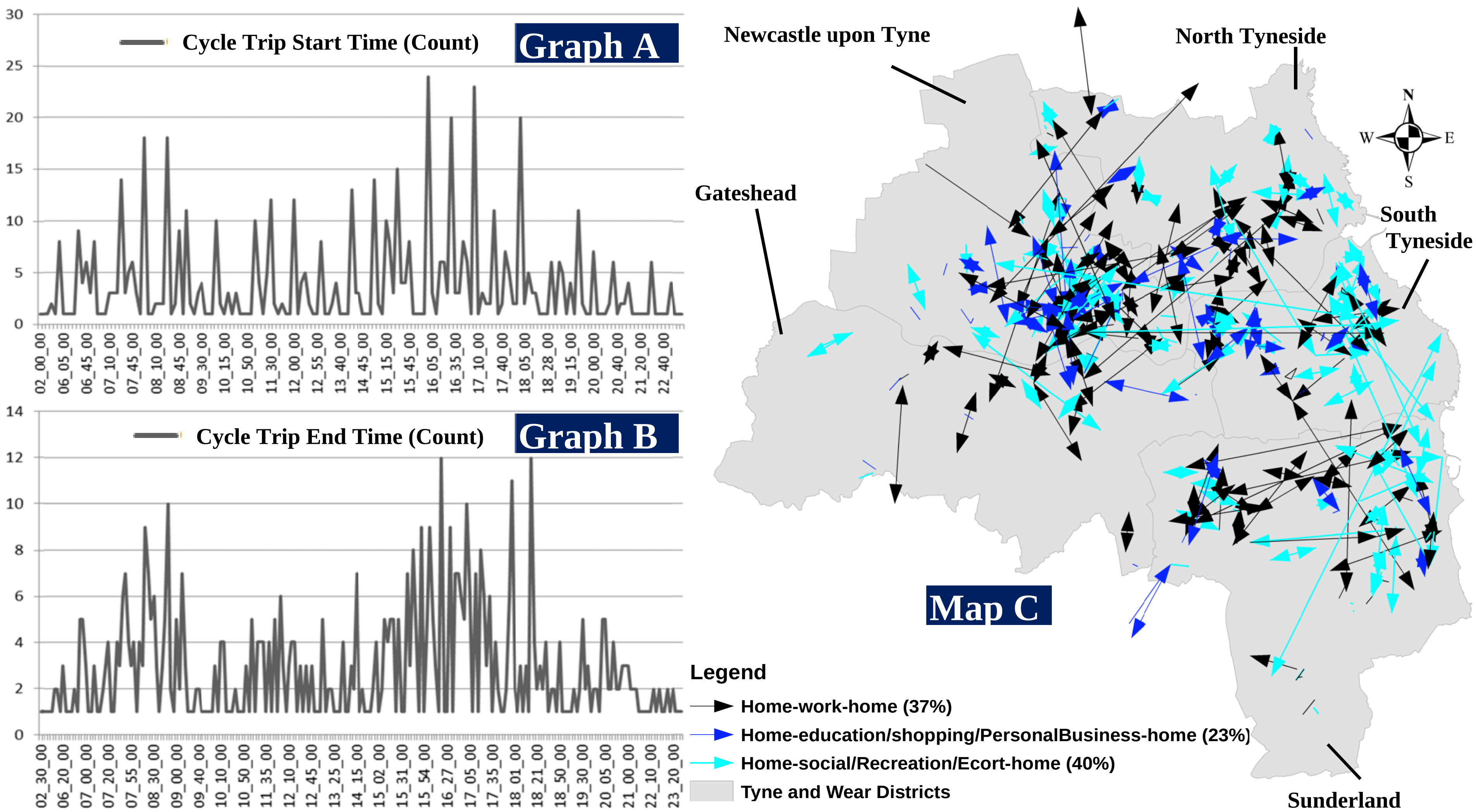


Figure 4-1: Cycling patterns in time and space from the-Tyne and Wear Household Travel Survey 2003 to 2011

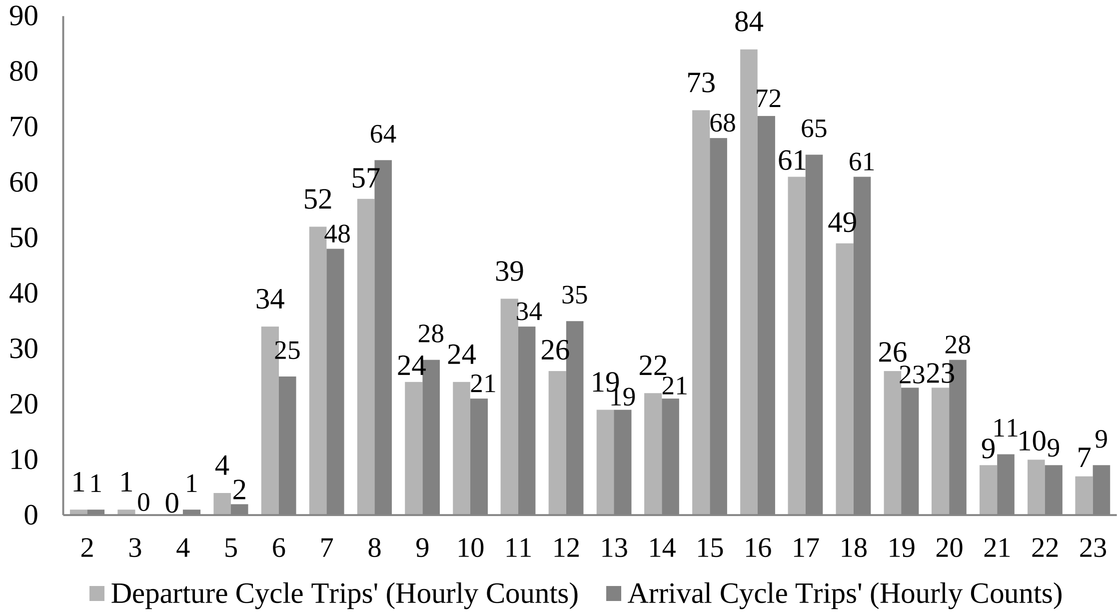


Figure 4-2: Hourly counts of cycle trips in Tyne and Wear (2003-2011)

Data source: Tyne and Wear Household Travel Survey from 2003-2011

A combined hourly count from 2003 to 2011 is shown in Figure 4-2. Hourly interpretation suggests that both departure and arrival cycle trips start increasing from 6am and peak at 8am; thus, 57 departure trips and 64 arrival trips. These fall from 9am to 2pm with little increases around 11am to 12noon and then start increasing again from 3pm to 6pm with peaks around 4pm for both departures and arrivals. Generally, both the departures and arrival timings tend to start from around 2am to 11pm daily. As shown in Figure 4-3, Newcastle upon Tyne has more reported cycle trips (25%) followed by Sunderland with 23%. South Tyneside and North Tyneside percentages were around 19% and 16% respectively. Gateshead had the lowest at 9%.

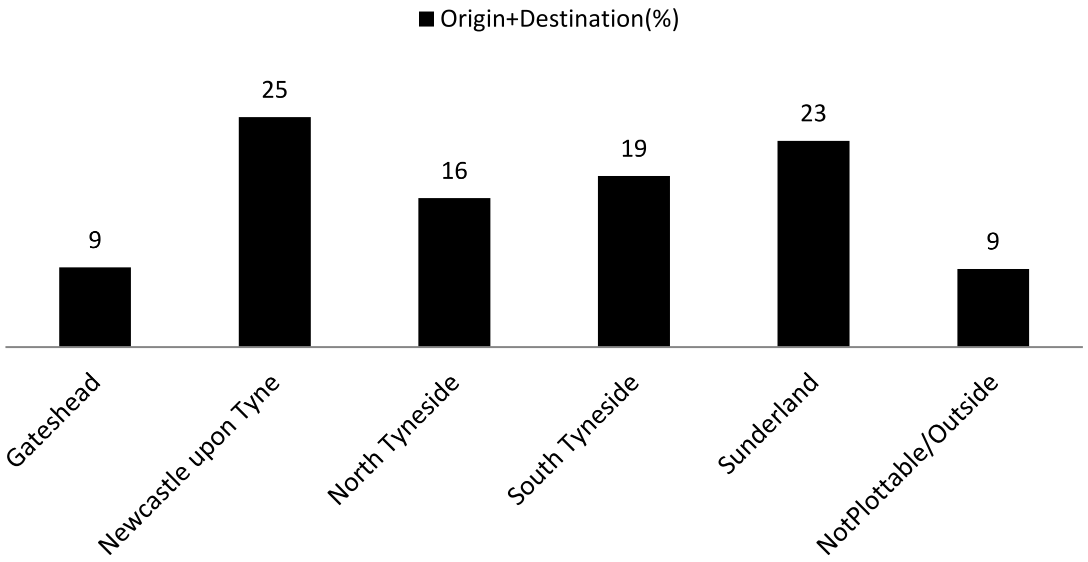


Figure 4-3: Percentage of reported cycle trips by district in Tyne and Wear (2003-2011)

Data source: Tyne and Wear Household Travel Survey from 2003-2011

CP was determined by computing the frequency of departures and arrivals since only origin and destination information were captured in the Tyne and Wear Household Travel Survey. Each of the CP counts was assigned to their respective postcodes. The count field was then used as a population field and as an input to an already implemented kernel density function in ESRI ArcGIS. The theory behind kernel density estimation is discussed in section 3.4.2 in (methods) Chapter 3. The outcomes of the kernel density analysis suggest that the denseness / concentration of cycling prevalence are more visible around Newcastle city centre and some part of Tyneside conurbation. This is pointed out in Map A and B in red circle in Figure 4-4. The maps suggest that origins and destinations of cycle journeys are not very different in Tyne and Wear. The maps also confirm the output of the flow mapping presented in Figure 4-1. They also reflect the statistics presented in Figure 4-3 which suggest that, for example, Gateshead had the lowest reported departures and arrivals combined. After several iterations in generating various density maps to compare with the flow mapping output, two kernel density parameters were finally used; 1000 m^2 as the bandwidth together with a cell size of 100 m^2. The cell values are classified by varying standard deviations from the mean values. The larger the standard deviations are from the mean values, the higher the number of departures or arrivals.

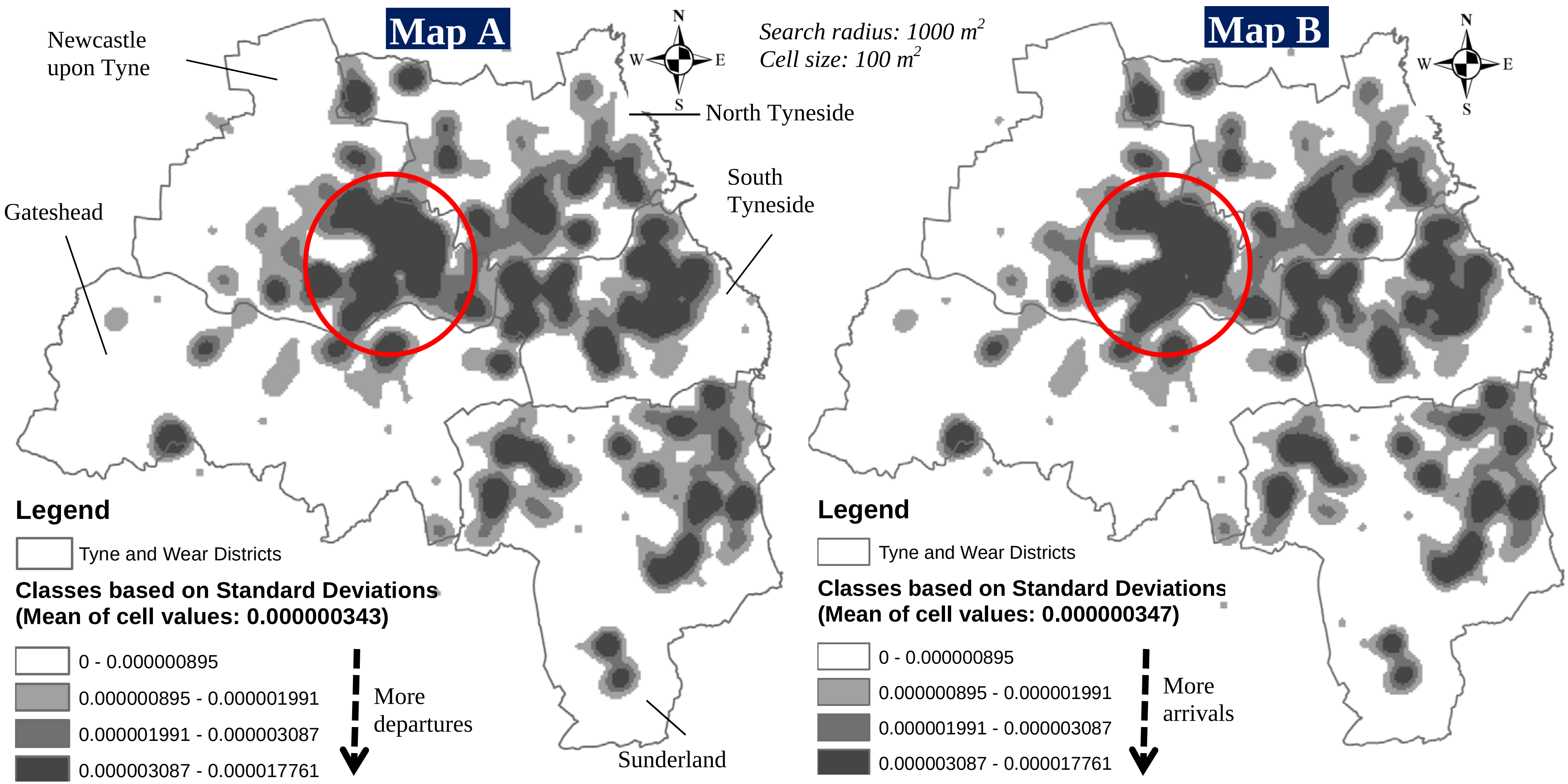


Figure 4-4: Kernel density distribution of cycling prevalence: Departures (Map A) and Arrivals (Map B)

Data source: Tyne and Wear Household Travel Survey from 2003-2011

Further analysis was carried out to find trends between the nine years (2003 to 2011) of collected data. Given the increasing interest in cycling in the region, it is proper that the data is explored to deepen our understanding of cycling with the hope of informing policy strategies. Different graphs were generated based on some age-groupings and superimposed to show how various age groupings made various kinds of trips in their method of travel categories (Figure 4-5). To give clarity to the differences in the patterns shown in the graphs, logarithmic scaling was used by applying a log function on the computed percentage values derived from the number of trips counted per age groupings. Cycling uptake was relatively low among all age groups when compared to other modes of transport as shown in Figure 4-5.

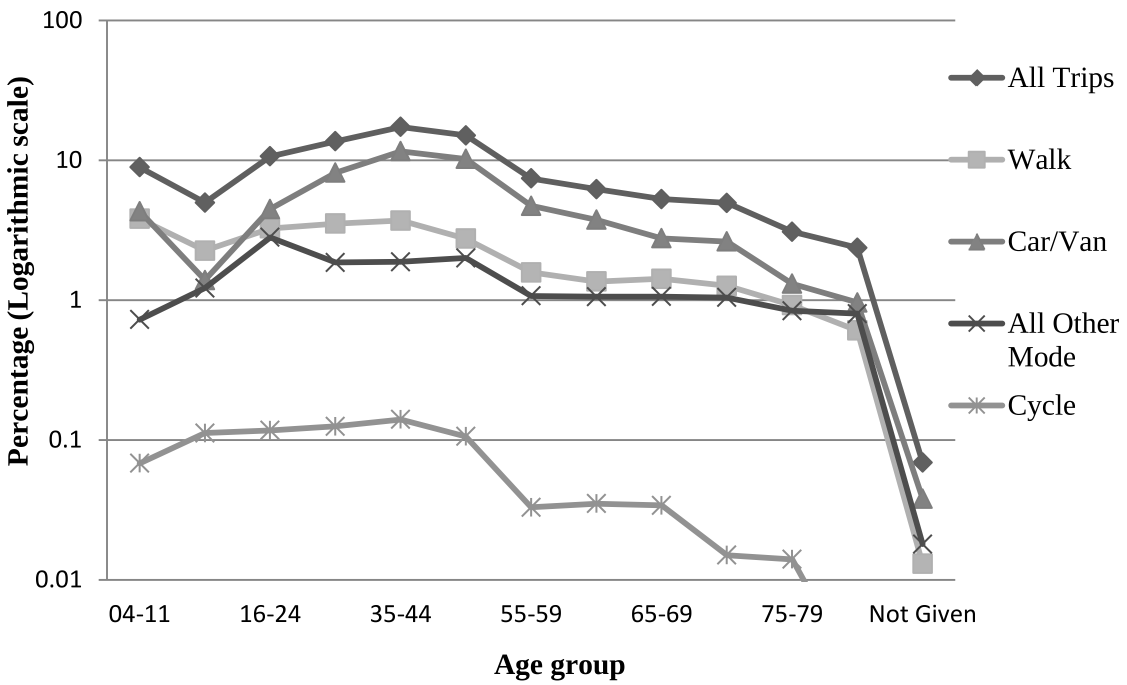


Figure 4-5: Age-band based travel patterns in Tyne and Wear (2003 – 2011)

Data source: Tyne and Wear Household Travel Survey from 2003-2011

The uptake tends to increase gradually from adolescents till about 25 to 34 years and then it decreases again after a decade. The uptake increases again from (35-44) years to (45-49) years, but slightly less than the uptake volume during (25-34) years. There is continuous decrease from the (45-49) year age group onwards. As expected, cycling uptake decreases with age due to the energy requirement to perform a motile activity. Motile activity is discussed in Chapter 6. Most of the travellers fall between 35 to 44 years old with combined trips over 10% as shown in Figure 4-5. However, their cycle trip share is far below 0.1% of all trips. This age group tends to use car/van and also walk more than cycle (Figure 4-5). A higher percentage of the cycle trips for the period is taken within a distance of one kilometre and decreased over time till around 30 kilometres shown in Figure 4-6.

Most of the travellers' trips were based on car/van method of travel followed by walking. The high prevalence of walking among all age groups is not so surprising as walking tends to compliment the other modes giving the physiological state of the traveller. Figure 4-6 suggests that high prevalence of walking is usually high but only for shorter trips less than one kilometre. Most of the walking trips for the period were taken within a distance of one kilometre and decreased over time until around 30 kilometres as shown in Figure 4-6, but increased from 30-50 kilometre range. A closer examination of the walking trips part of the data suggested that the increment might be due to the trip-purpose as they were found under "social/recreational" activities. Walking and cycling follow similar trends (decreasing) as distance increases from 5km to 20km (Figure 4-6).

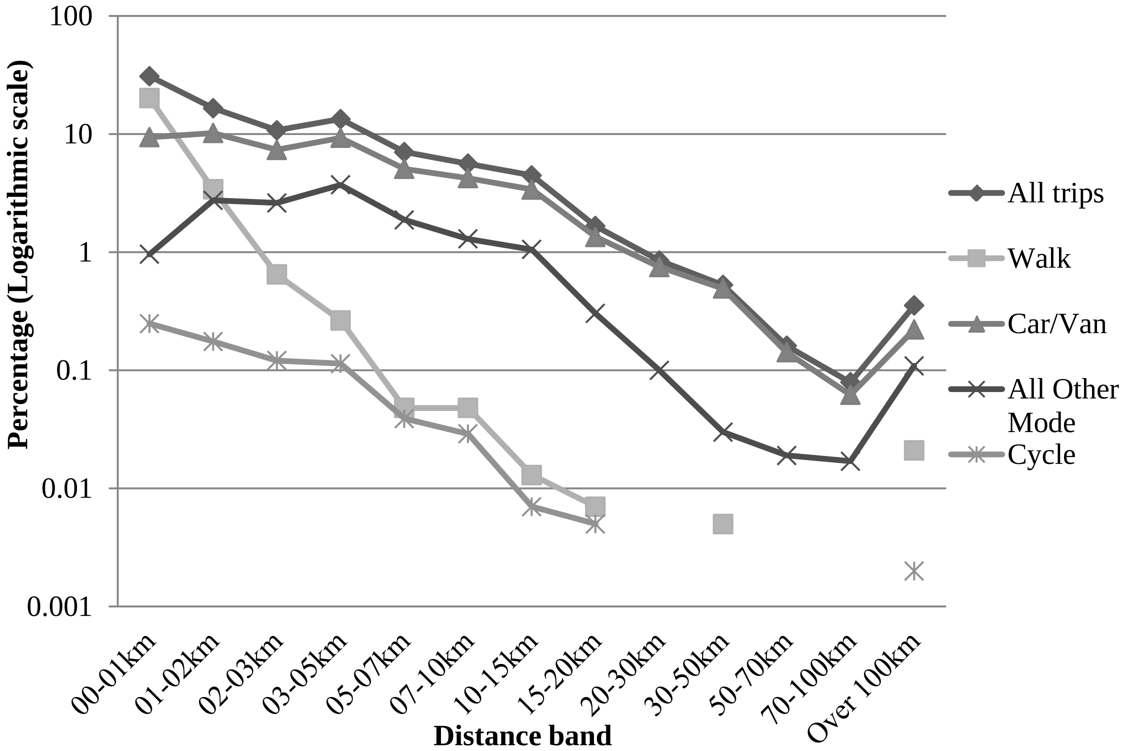


Figure 4-6: Distance-band based travel patterns in Tyne and Wear (2003-2011)

Data source: Tyne and Wear Household Travel Survey from 2003-2011

Figure 4-7 was generated from the latest National Travel Survey data. Here, the purpose of the national statistics was to situate the findings from the Tyne and Wear Household Travel survey in the national context. While there was an increase in cycling from journeys less than 1.6km up to less than 3.2km nationally with a downward trend subsequently, the downward trend tends to start right from journeys less than 1km within Tyne and Wear alone with stability around distances from 3-5km.

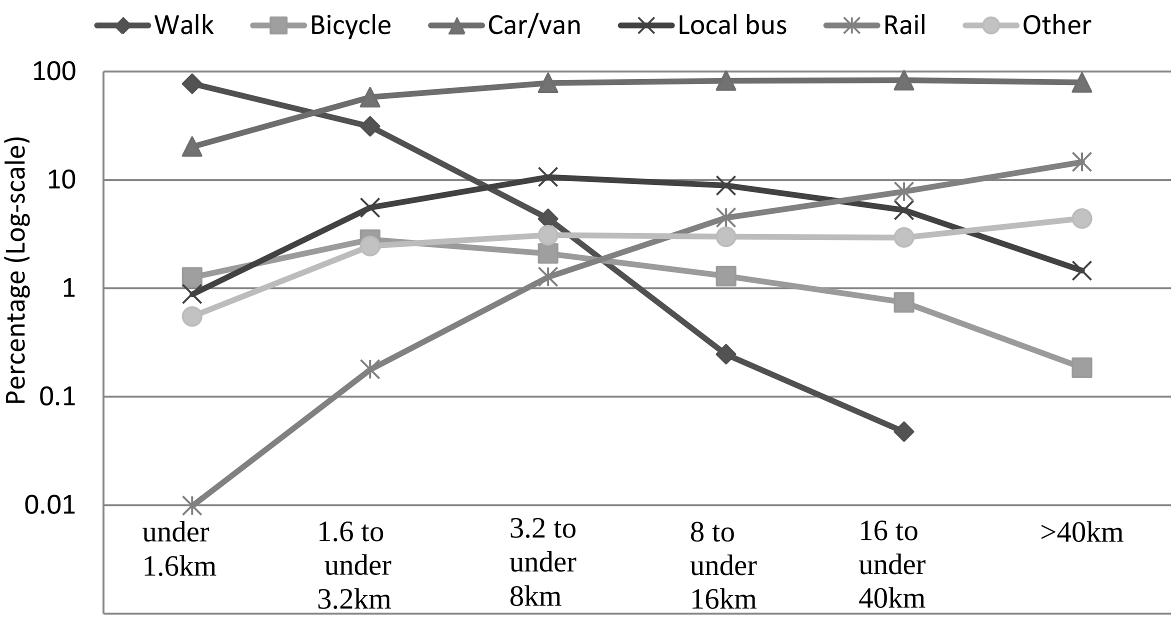


Figure 4-7: Trips by length and main mode in UK, 2012

Data source: 2012 National Travel Survey. Note: Used 2012 NTS 0308-chart data to generate this graph. Last updated July 30 2013. Unweighted total trips (sample size) for 2012 Survey: 335,288

The general trend for non-motorised transportation in the 2012 National Travel Survey follows the Tyne and Wear Household Survey trend from 2003 to 2011 (Figure 4-6 and Figure 4-7). The last paragraph for this section discusses the investigated patterns of the reported trips over the nine year period by employment status and main method of travel. This way, an understanding of what method of travel was used by category of employment could be obtained. This adds to our understanding of cycling as a preferred mode of transport and can serve as an input to integrated transport policies in Tyne and Wear. Figure 4-8 shows the pattern of employment status against main method of travel from 2003 to 2011 in the Tyne and Wear. By definition, main method of travel is the primary mode of transport stated by the participants from the Tyne and Wear Survey. As shown in Figure 4-8, the main method of travel ranges from walk, train, cycle to name a few. The other category comprised of ferry, aeroplane, heavy/light goods vehicle, any uncategorised method of travel by the survey. Cycling uptake of those in employment or were self-employed was similar to those in education but the number of trips increase rapidly when car/van method of travel is considered. While car/van use by those in education was less than 1%, car/van use by those in paid employment/self-employed were about 32%.

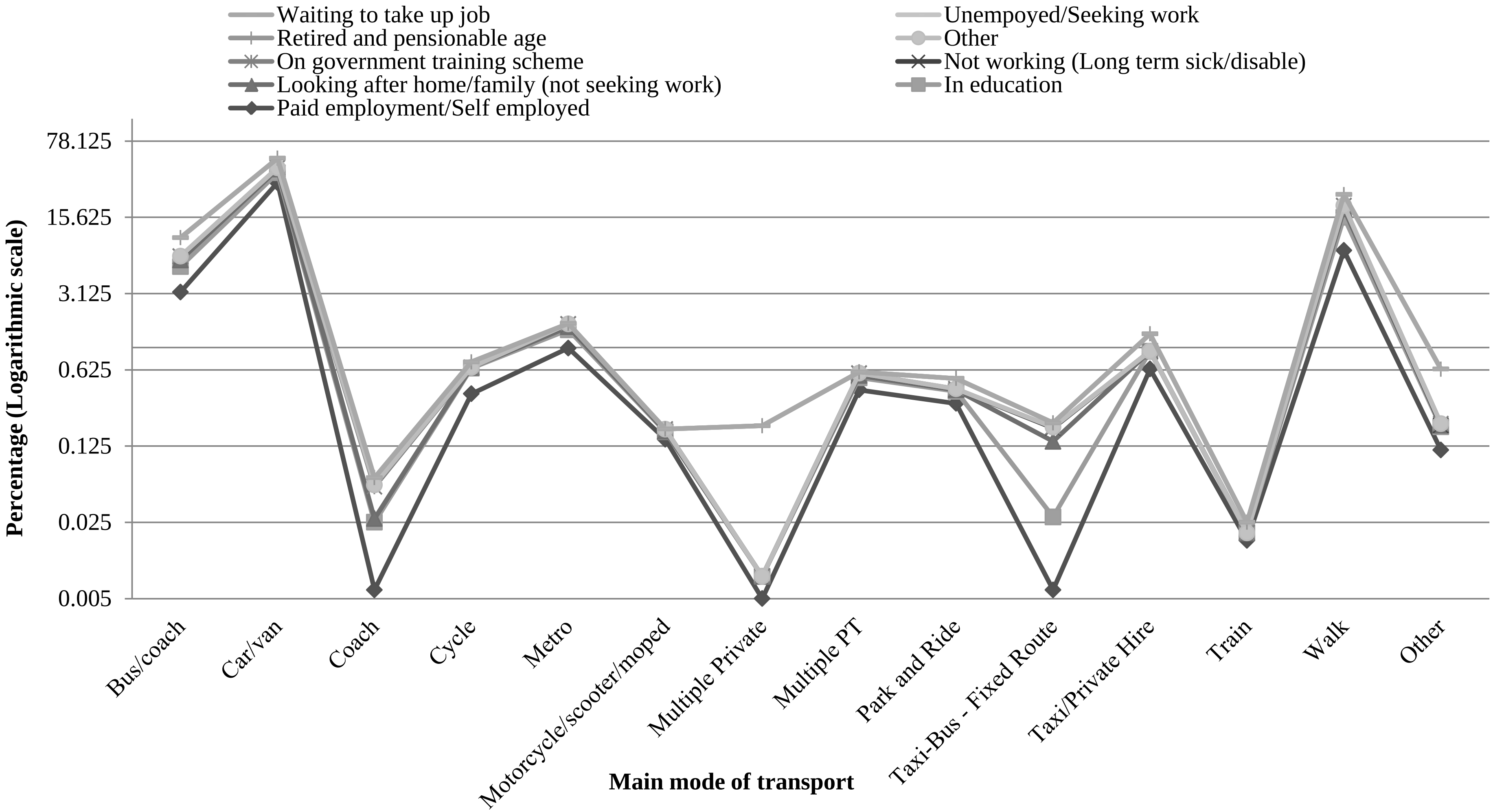


Figure 4-8: Pattern of employment status versus main travel mode in Tyne and Wear (2003-2011)

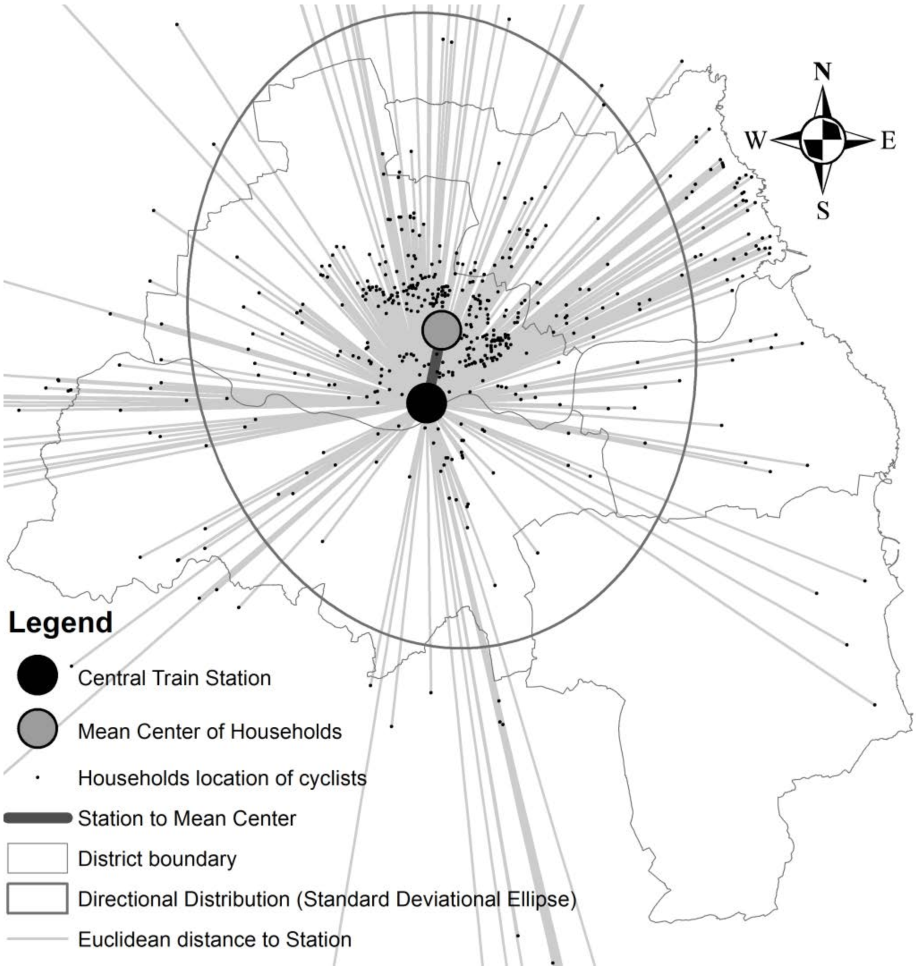
Source: Tyne and Wear Household Travel Survey from 2003-2011

Those looking after family or home tend to use bus/coach/taxi more than the other main methods of travel. Those retired and at pensionable age tend to use all the main methods of travel suggesting perhaps they have more time to travel to various places and for several purposes. Overall, the level of cycling in the Tyne and Wear region compared with the National Travel Survey statistics suggest that the cycling uptake in the region is less than half of the national level which was at 2% in 2011 (DfT, 2012a).

Those who appeared to have used least of all the main modes of travel were under the category of *unemployed seeking work*. It is however unclear in the data as to whether this same group started being mobile when their status changed, as was the case of those "waiting to take up job" shown in Figure 4-8, and even very mobile when they actually assume the full status of being employed using all methods of travel. Apart from those *unemployed seeking work*, all the remaining groups of travellers used cycle as the main method of travel at some point in time during the nine year period with those in education slightly ahead of those in employment. Those looking after home/family and not seeking work have similar cycling uptake levels as those retired and of pensionable age. Those on government training schemes have the lowest cycling uptake over the period 2003 to 2011 in Tyne and Wear.

A survey undertaken by Newcastle Cycling Campaign in 2010 has never been analysed spatially. To further contribute to our understanding of cycling around the study area, we examine spatial characteristics of the survey data. The mean distance from the Central Rail Station in Newcastle upon Tyne to any of the reported households is computed and used as part of the analysis. Additionally, the location of mean centre of the reported households (postcode) locations and how far it is from the Central Station is computed. Standard directional distribution of the spatial location of the households is also determined. The Central Rail Station was assumed to be the transit hub for all modes of transport in the area. The DfT considers the improvement of facilities at railway stations for cyclists as one of the top priorities and mentioned as one of the projects in response to the one of eighteen recommendations of recent APPCG "Get Britain Cycling Inquiry" report (DfT, 2013k). This makes central rail stations one of the strategic locations for investigation as they serve as a facilitator in support of integrated transport.

Although the Tyne and Wear Metro service do not allow bicycle on-board trains, the main train service providers such as NorthernRail do and therefore make it possible for cyclists to combine rail service with cycling where possible to commute to and from work within the Tyne and Wear area and beyond. Cycling to train stations could be one of the useful ways of maximising the use of public transportation (Conti et al., 2012, p. 74). We also looked at the minimum and maximum Euclidean distances from a household to another to give clues to the extent to which one could cycle from one area to another. Figure 4-9 shows a spider map representing the spatial patterns and geography of reported household locations from the survey. Spider maps are a particularly useful way of comparing the patterns between several locations with the possibility to inquire how far a location is from another (Mitchell, 1999, p. 131). Spider map generation follows the flow mapping technique described in Chapter 3 with the assumption that an arbitrary point represents all locations of origins along with various destination locations and no arrows for directional representation.



Contains National Statistics data © Crown copyright and database right 2012

Figure 4-9: Spatial statistics and geography of cyclists' households

Source: Newcastle Cycling Campaign 2010 Petition Survey

The distances computed here are all Euclidean (straight-line or "as the crow flies") distances within the UK national grid system. The distance from the mean centre of households to the Central Rail Station is 2.7km. The computed mean distance from the Central Rail Station to cyclists' households was 7km with a standard deviation of 8km. This finding suggests the possibility of a majority of cyclists being able to comfortably cycle to the Central Rail Station from their dwelling. This may not be the case though when actual routes are considered. Unfortunately, the survey data did not capture the actual route preferences of the sampled cyclists. From a total of 654 household locations from the survey, the average minimum distance to cycle to another household is found to be around 578 meters while the maximum distance was about 7km. The standard directional distribution of household locations suggests that cyclists reside in all the five districts in Tyne and Wear but more reside in Newcastle upon Tyne as shown in Figure 4-9 where the ellipse almost covers the entire district boundary of Newcastle upon Tyne.

4.2.2 Cycling traffic flows from cycle counters across Tyne and Wear

This section examines the AAWT within Tyne and Wear using data obtained from Tyne and Wear Accident Data Unit (TADU). Figure 4-10 shows five-day AAWT flows from cycle counters monitored by TADU across Tyne and Wear from 2004 to 2012. It is evident from the figure that the Newcastle upon Tyne district registered more cycle traffic flows from 2004 onwards except in 2010 (51 counts) and 2012 (217 counts) where Gateshead registered more cycle traffic flows. These findings shown by Figure 4-10 confirm the outputs of the kernel density estimation and flow mapping that Newcastle upon Tyne had more volume of cycling flows compared to the other districts in Tyne and Wear. There seems to be a considerable difference in cycling flows between Newcastle upon Tyne and all other districts in Tyne and Wear from 2004 till 2009. It is also evident that all districts increased their cycling traffic flow volume with the exception of South Tyneside which started to decrease cycling uptake from 2007 onwards.

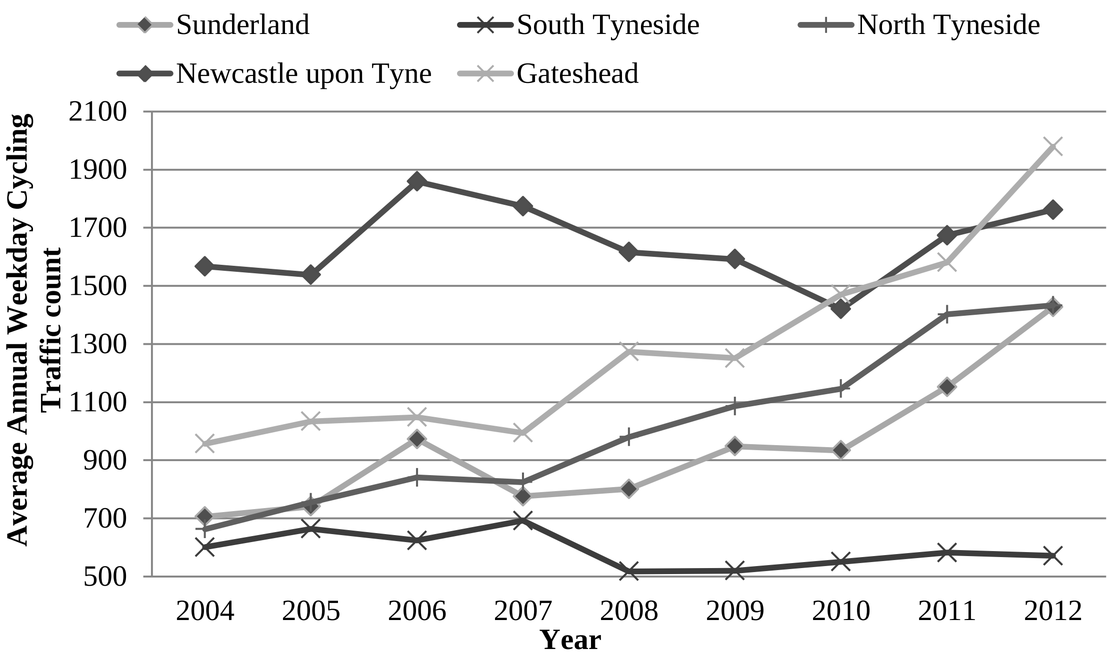


Figure 4-10: Average Annual Weekday Cycling Traffic in Tyne and Wear (2004-2012)

Source: 2004 to 2012 TADU AAWT flows from cycle counters in Tyne and Wear

We now examine the AAWT flows in a spatial sense to understand the spatial distribution across the region while visualising the density of cycling traffic volume in 2012. 2012 data was used here because it is the latest and has the highest volume. The cycling traffic in 2012 tends to be more frequent and intense at the southern part of Newcastle upon Tyne than the remaining districts in Tyne and Wear as shown in Figure 4-11. This finding agrees with the findings from the results from the analysis of the Tyne and Wear Household Travel Survey data. The standard direction distribution of the automatic cycle counters, as red dots, fell around the centre of the region. This distribution of counters could hardly be used to monitor route and destination choice preferences of individual cyclists as that would demand installing them along almost every cycle path with the means to uniquely identify each individual in order to follow their trajectory. At the moment, there is no technology that can do this other than using personal and portable GPS devices to be carried by the one being tracked.

Let us classify lane types from the cycling infrastructure data obtained from Newcastle City Council into two groups to enable us to find the closeness of the installed cycle counters to either group visually. Group one contains the lane types that we expect the locations of the counters to be close or on any part of the segments. These lane types comprise cycle lanes, national cycling network (NCN) off-road lanes, NCN on-road lanes, sign posted lanes, and traffic-free lanes. Group two contains the lane types that we expect the locations of the counters to be either visibly away from the lanes and if found close or on the lane they should be few in number. These lane types comprise of advisory lanes, bus lanes, metro bus only lanes (MTBonly), and walk lanes. As shown in Figure 4-11 the majority of automatic counters were on lanes of group one with a few exceptions.

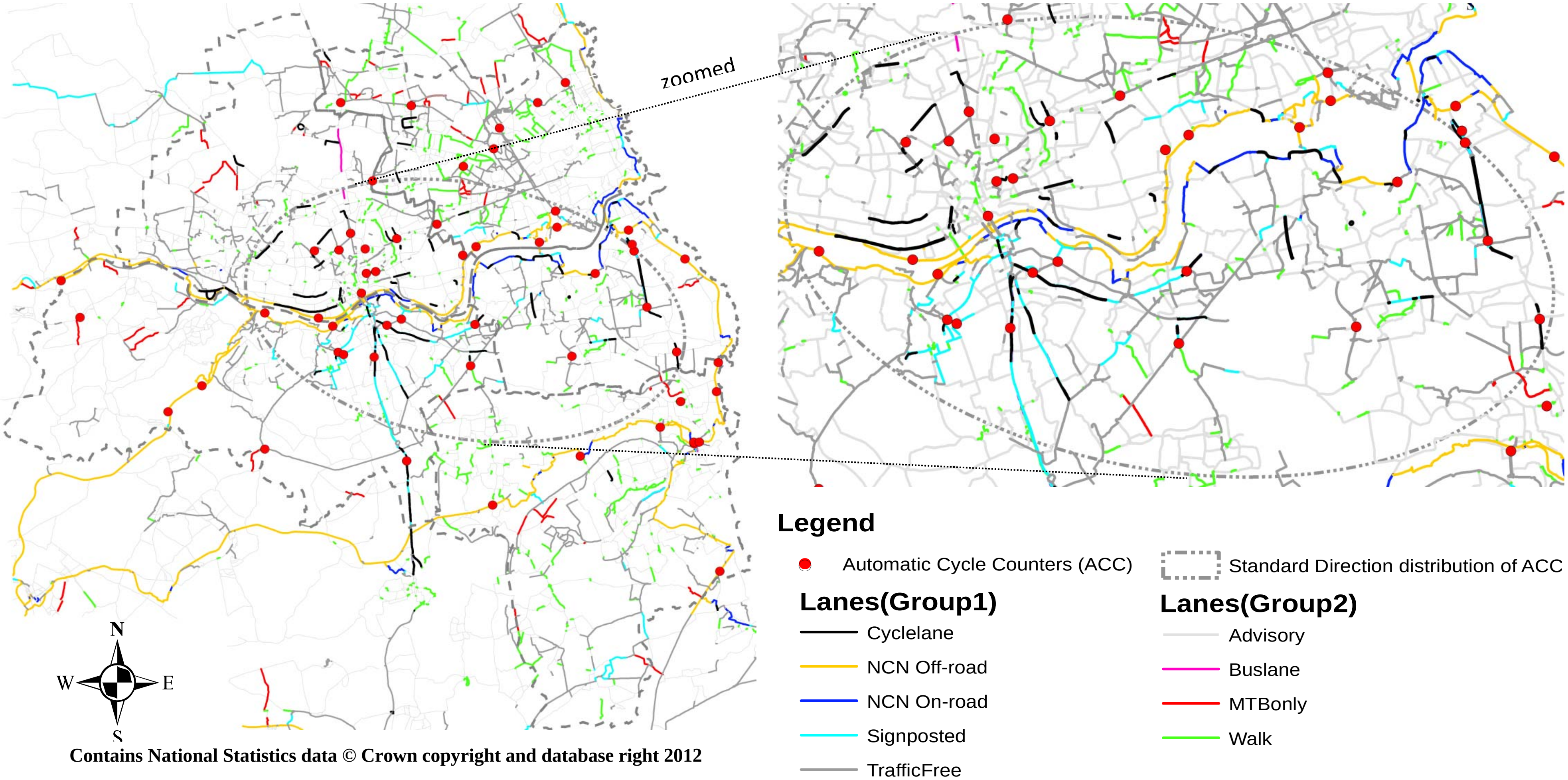


Figure 4-11: Lane types with automatic counter locations in Tyne and Wear

Source: 2012 TADU AAWT flows from cycle counters in Tyne and Wear

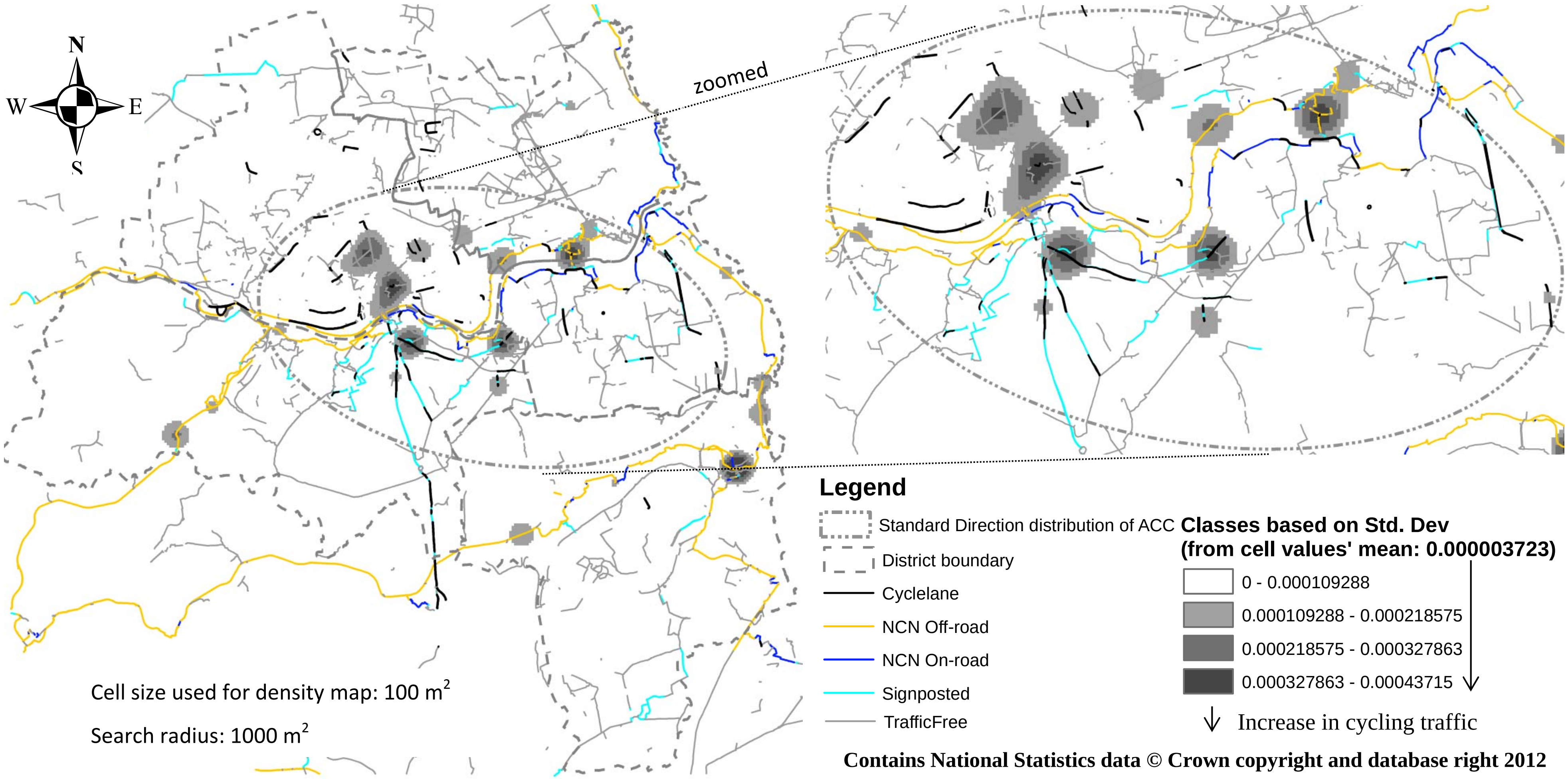


Figure 4-12: Kernel density map for AAWT flows from cycle counters in Tyne and Wear-2012

Source: 2012 TADU AAWT flows from cycle counters in Tyne and Wear

Figure 4-12 shows kernel estimates as shades of grey colours around a red dot (Figure 4-11) and suggest an occurrence of high levels of cycling flow at that location. These shades are volume of cycling flows within a radius of thousand square metres at the counter location. Counter locations exhibiting high volumes of cycling flows tend to be on traffic-free lanes and the NCN off-road lanes as shown in Figure 4-12. These findings could also mean that those who cycle on these lane types constituted a higher percentage of captured flow volume for 2012. Furthermore, there seem to be no counters along the NCN on-road lanes. Figure 4-11 shows that the counter locations tend not to be on the group two lane types. Both figures also show that counters in most parts of South Tyneside and North Tyneside did not register higher volumes of cycling flows.

4.2.3 Dissimilarities of Travel to Work by Bike

Briefly, the Index of Dissimilarity, or Gini Coefficient, is defined graphically as the maximum vertical deviation between the Lorenz Curve (LC) and the 45 degrees diagonal, which represents the ideal situation where cycling equality is similar for all areas. The LC is produced by calculating location quotients (LQ) for each local authority district; reordering the areas in decreasing order of their LQ values; determining the cumulative percentage distribution of activities; and, making a graph of activity of interest against the base activity to determine the dissimilarities across the North East of England. This section compares results using both 2011 and 2001 Census data on Travel to Work information. Coefficients of Localisation (CL) values were also computed to validate the calculated dissimilarity indices.

First, information on Travel to Work for North East England was extracted from the 2011 Census data as shown in Table 4-2. The use of the *Rest of North East England* by definition means all areas in the North East of England excluding the local authority districts of Tyne and Wear. Using North East England values as base for activities, both the LQ and CL values were computed (Table 4-3 and Table 4-4). The cumulative percentages added to the LQ values are later used to generate the Lorenz Curve (Figure 4-13).

Table 4-2: 2011 Method of Travel to Work statistics at District level in North East England

Mode	Tyne and Wear Districts					Rest of North East England	North East England
	Gateshead	Newcastle upon Tyne	North Tyneside	South Tyneside	Sunderland		
By Bike	1,311	3,210	2,327	1,387	1,575	10,017	19,827
By Other	146,768	209,654	145,562	107,594	203,977	1,090,824	1,904,379
Total	148,079	212,864	147,889	108,981	205,552	1,100,841	1,924,206

Source of original data: (ONS, 2013c)

Generally in North East England, the total number of people who cycled to work, around March 2011, is higher in Newcastle upon Tyne than the other districts in the same region with Gateshead being at the bottom (Table 4-2). The quantification of dissimilarities of cycle commuting across the region demands further computation with different techniques. Using LQ, CL and LC statistical and analytical techniques, cycle commuting across North East England is analysed using the tabulated values in Table 4-2 to enable us to compare district and sub-district share of cycling activity with their relative share at a more aggregate spatial level. The LSOA geographical units from the 2001 and 2011 censuses are used at the sub-district level of analysis. The share at a more aggregate level means the total numbers supplied by the 2001 and 2011 Censuses. Ultimately, dissimilarity indices across the North East England region is calculated as an inequality measure based on 2001 and 2011 censuses separately. This will allow for easy comparison over the decade.

Table 4-3: Location Quotients (LQ) tabulated values with cumulative percentages for North East England using 2011 Census data

Region	Location Quotients (LQ)		Percentage of Travel to Work by Bike (%)	Percentage of Total Travel to Work by multi-mode (%)	Cumulative Percentage (%) *Note: Difference between column values = vertical deviations in LC graph*	
	By Bike	By Other			Travel to work by Bike	Total
North Tyneside	1.527	0.995	12	8	12	8
Newcastle upon Tyne	1.464	0.995	16	11	28	19
South Tyneside	1.235	0.998	7	6	35	24
Rest of North East England (Without Tyne & Wear)	0.883	1.001	51	57	85	82
Gateshead	0.859	1.001	7	8	92	89
Sunderland	0.744	1.003	8	11	100	100
Total			100	100		

How LQ values are interpreted is explained in detail in Chapter 3 and in section 3.4.3. Briefly, if LQ value is less than one, the interpretation is that the region's share of cycle commuting is lower than that found in North East England which is the selected base. If LQ value is equal to one, the interpretation is that the region's share of cycle commuting mirrors the base region's share. If LQ is greater than one, then the interpretation is that there is a relative concentration of region's share compared to the base region's share. The LQ values indicate that the relative concentration of travel to work by bike in North Tyneside, Newcastle upon Tyne, and South Tyneside is higher than the rest of North East England. Thus, LQ values of these aforementioned districts are greater than one.

Table 4-4: Coefficient of Localisation (CL) tabulated values for North East England using 2011 Census data

North East Region	Share of Travel to Work by Bike	Share of total Travel to work	Difference	
			-	+
Gateshead	0.0661	0.0770	0.0108	
Newcastle upon Tyne	0.1619	0.1106		0.0513
North Tyneside	0.1174	0.0769		0.0405
South Tyneside	0.0700	0.0566		0.0133
Sunderland	0.0794	0.1068	0.0274	
Rest of NorthEast	0.5052	0.5721	0.0669	
Total			0.1051	0.1051
Coefficient of Localisation			**0.11**	

How CL values are interpreted is explained in detail in section 3.4.3. Briefly, if CL is equal to zero, the interpretation is that cycle commuting is evenly spread across North East England. Otherwise, the interpretation is that cycle commuting is relatively evenly spread over the regions under investigation. The CL value of 0.11 which is not equal to zero but approaching one albeit far from one suggests that cycle commuting is relatively evenly spread over the regions in North East England.

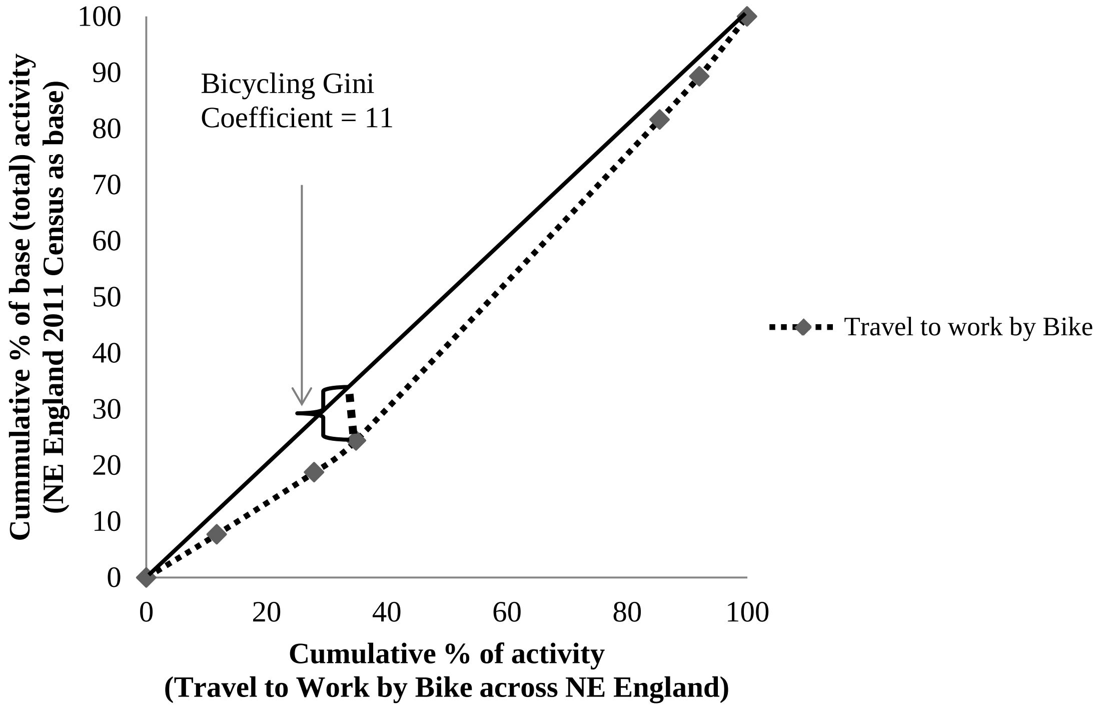


Figure 4-13: Lorenz Curve for Travel to Work by Bike using 2011 Census data

How the Dissimilarity index value is deduced from LC graph is explained in detail in section 3.4.4. By definition, the dissimilarity index is the maximum vertical measurement from the LC and the 45^o diagonal line representing the (ideal) line of equality (Section 3.4.4). From Figure 4-13, the Dissimilarity Index computed is 11. Multiplying the CL value by 100 gives same value for computed Dissimilarity Index of 11 (i.e. 0.11 * 100). This comparison validates and confirms that both calculations are correct and shows that the spread of travel to work by bike is not the same across the North East of England. The above metrics LQ, CL and LC were also calculated using the 2001 Census data and are shown in Table 4-6, Table 4-7, and Figure 4-14.

Table 4-5: 2001 Method of Travel to Work Information at District level in North East England

	Tyne and Wear Districts						
Mode	**Gateshead**	**Newcastle upon Tyne**	**North Tyneside**	**South Tyneside**	**Sunderland**	**Rest of North East England**	**North East England**
By Bike	816	1,781	1,692	1,143	1,525	9,829	16,786
By Other	77,970	99,717	82,006	57,756	112,594	586,139	1,016,182
Total	78,786	101,498	83,698	58,899	114,119	595,968	1,032,968

Table 4-6: Coefficient of Localisation (CL) tabulated values for North East England using 2001 Census data

Region	**Share of Travel to Work by Bike**	**Share of total Travel to Work**	**Difference**	
			-	**+**
Gateshead	0.0486	0.0762	0.0276	
Newcastle upon Tyne	0.1061	0.0982		0.0078
North Tyneside	0.1008	0.0810		0.0197
South Tyneside	0.0681	0.0570		0.0110
Sunderland	0.0909	0.1105	0.0196	
Rest of North East England	0.5855	0.5770		0.0086
Total			0.0472	0.0472
Coefficient of Localisation			**0.05**	

Table 4-7: Location Quotients (LQ) tabulated values with cumulative percentages for North East England using 2001 Census data

Region	Location Quotients (LQ)		Percentage of Travel to Work by Bike (%)	Percentage of Total Travel to Work by multi-mode (%)	Cumulative Percentage (%)	
	By Bike	By Other			Travel to work by Bike	Total
North Tyneside	1.244	0.996	10	8	10	8
South Tyneside	1.194	0.997	7	6	17	14
Newcastle upon Tyne	1.080	0.999	11	10	27	24
Rest of NorthEast	1.015	1.000	59	58	**86**	**81**
Sunderland	0.822	1.003	9	11	95	92
Gateshead	0.637	1.006	5	8	100	100
Total			**100**	**100**		

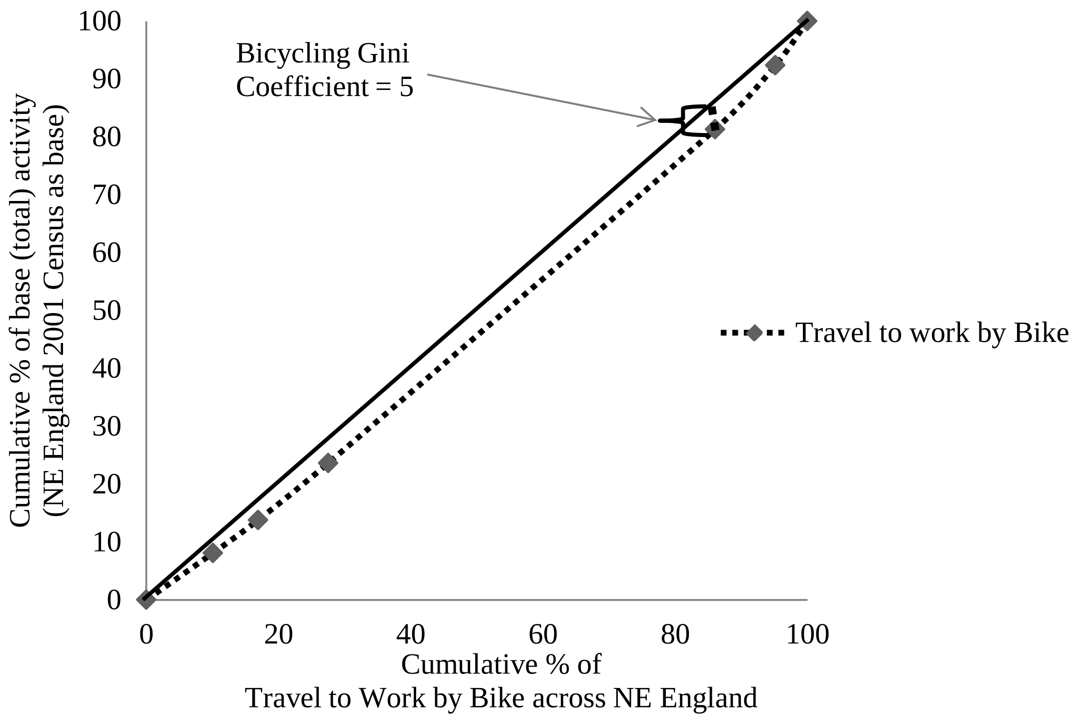


Figure 4-14: Lorenz Curve for Travel to Work by Bike using 2001 Census data

Comparatively, the Dissimilarity Index of 5 deduced from the district level travel to work information from 2001 Census data suggests that district level inequalities / dissimilarities of bicycle transportation increased over the ten year period (2001 to 2011).

We now examine the spread of cycle commuting at the sub-district level by using the LSOA statistics. The picture is completely different when dissimilarity assessment was undertaken at the Lower layer Super Output Areas (LSOAs). This assessment was done using both the 2001 and 2011Census data. Using the extracted cycle commuting numbers out of the 1,656 LSOAs covering North East of England, taking from 2001 Census, the computed Dissimilarity Index was 26% indicating a measure inequality and the relative distribution of cycle commuting across the North East of England (Figure 4-15). Similarly, using the extracted cycle commuting numbers out of the 1,657 LSOAs covering North East of England, taking from 2011 Census, the computed Dissimilarity Index was 25% indicating a measure inequality and the relative distribution of cycle commuting across the North East of England (Figure 4-16).

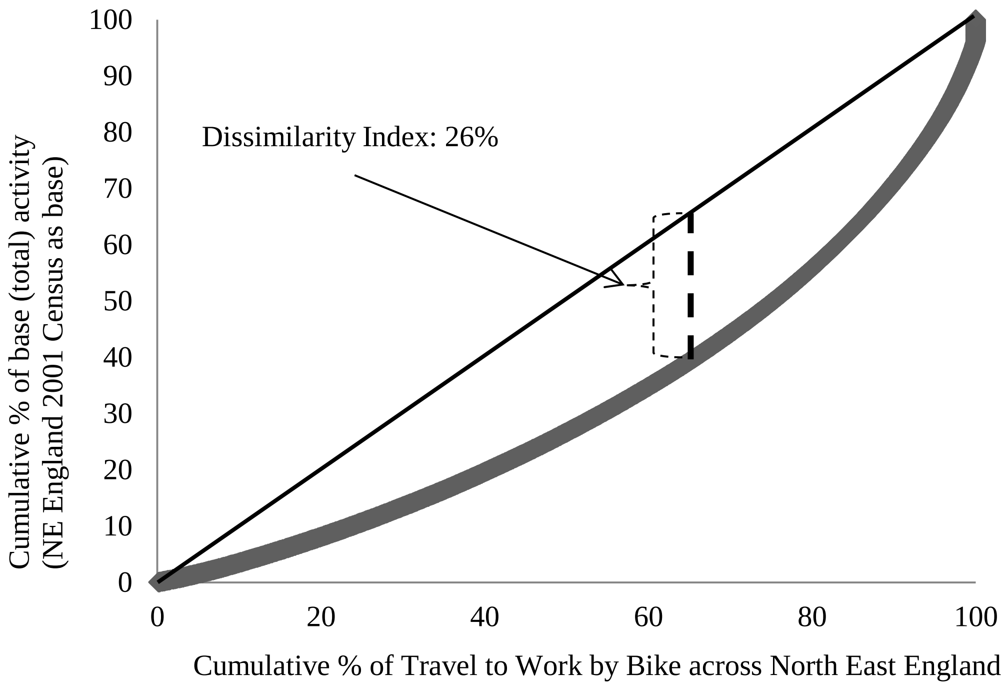


Figure 4-15: 2001 Lorenz Curve and Dissimilarity Index at LSOA level

The difference in the number of LSOAs (i.e. 1,656 and 1,657) is due to modifications of output areas made in the 2011 Census (ONS, 2011c). This was to account for population change, local boundary changes, re-alignment of output area boundaries to England/Scotland border to name a few. These findings will be discussed further in the concluding section of this chapter (Section 4.4).

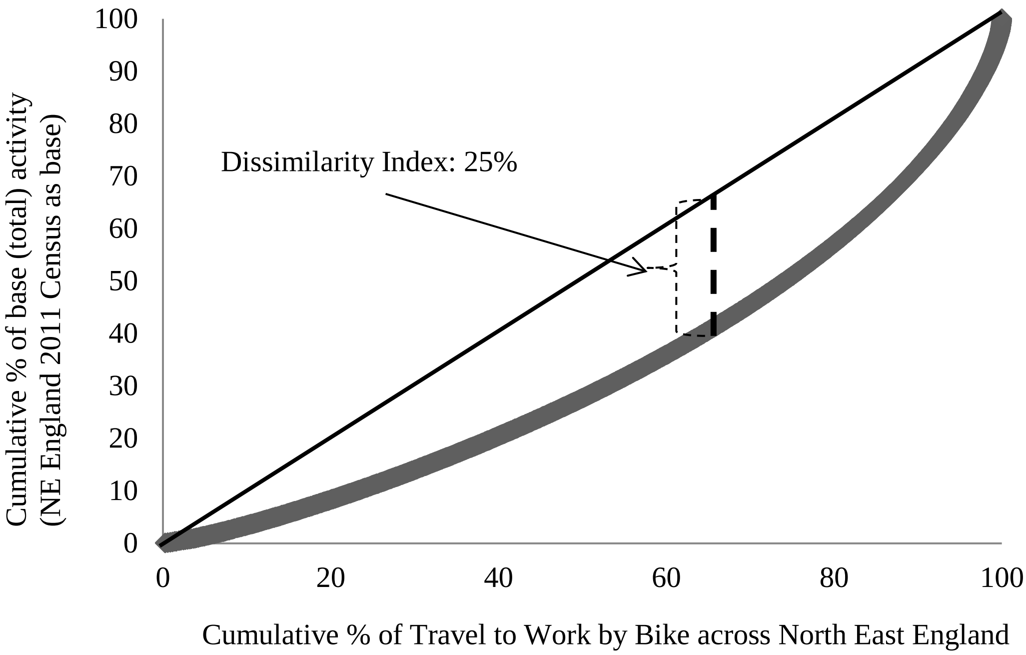


Figure 4-16: 2011 Lorenz Curve and Dissimilarity Index at LSOA level

Figure 4-17 shows the 2001 Census travel to work by bike variability by LQ at LSOA level. There was no LSOA that mirrored the share of travel to work by bike at the base (i.e. North East England). For this to occur, the LQ should be equal to one. Map A in this figure indicates variability of travel to work by bike using the LQ values which are categorised into two; thus, LQ>1 and LQ<1. LQ>1 indicates areas with relative concentration of travel to work by bike activity compared to the base. LQ<1 means that travel to work by bike activity is lower than the base. Details of interpreting LQ values were discussed in Chapter 3. Map B in the figure covers the Tyne and Wear region in detail, showing that there is about 14% more of LSOA areas that are lower than that of the base and means that these areas have lower travel to work by bike activities compared to other areas in Tyne and Wear.

Figure 4-18 shows the 2011 Census travel to work by bike variability by LQ at LSOA level. Comparatively, the variability in Tyne and Wear from 2001 to 2011 (*Map B* in both figures) shows that the concentration of travel to work by bike has shifted to the northern part of Tyne and Wear and partly in Newcastle upon Tyne and North Tyneside districts. Within North East England, there are few changes. The changes between 2001 and 2011 are shown on *Map A* in Figure 4-18 which needs to be compared with *Map A* in Figure 4-17. For areas with relative concentration, there seems to be reductions in travel to work activity. Areas *c* and *e* which are shown in Map A in Figure 4-18 have almost disappeared over the decade (2001 to 2011) while area *d* is clearly increasing in travel to work by bike activity.

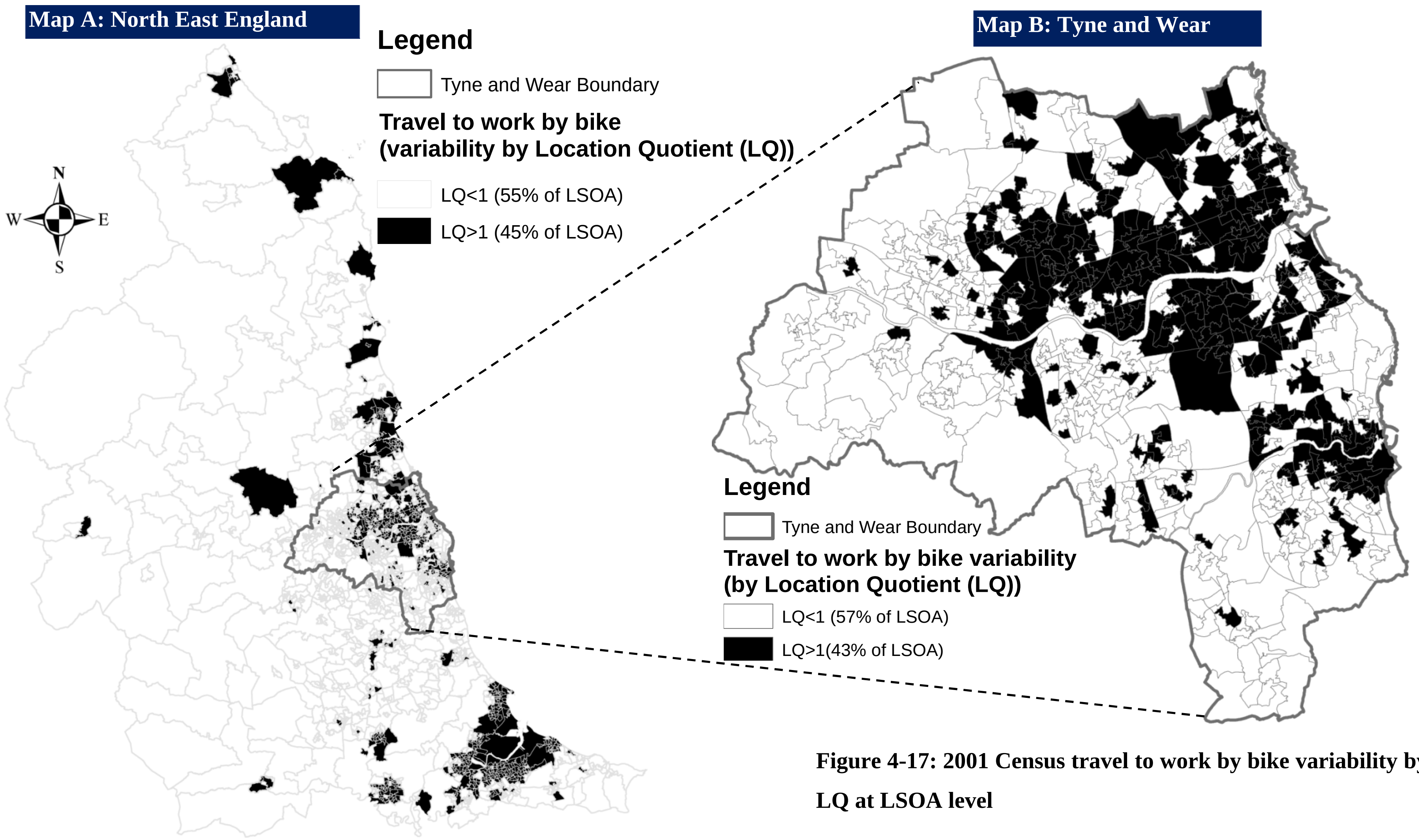


Figure 4-17: 2001 Census travel to work by bike variability by LQ at LSOA level

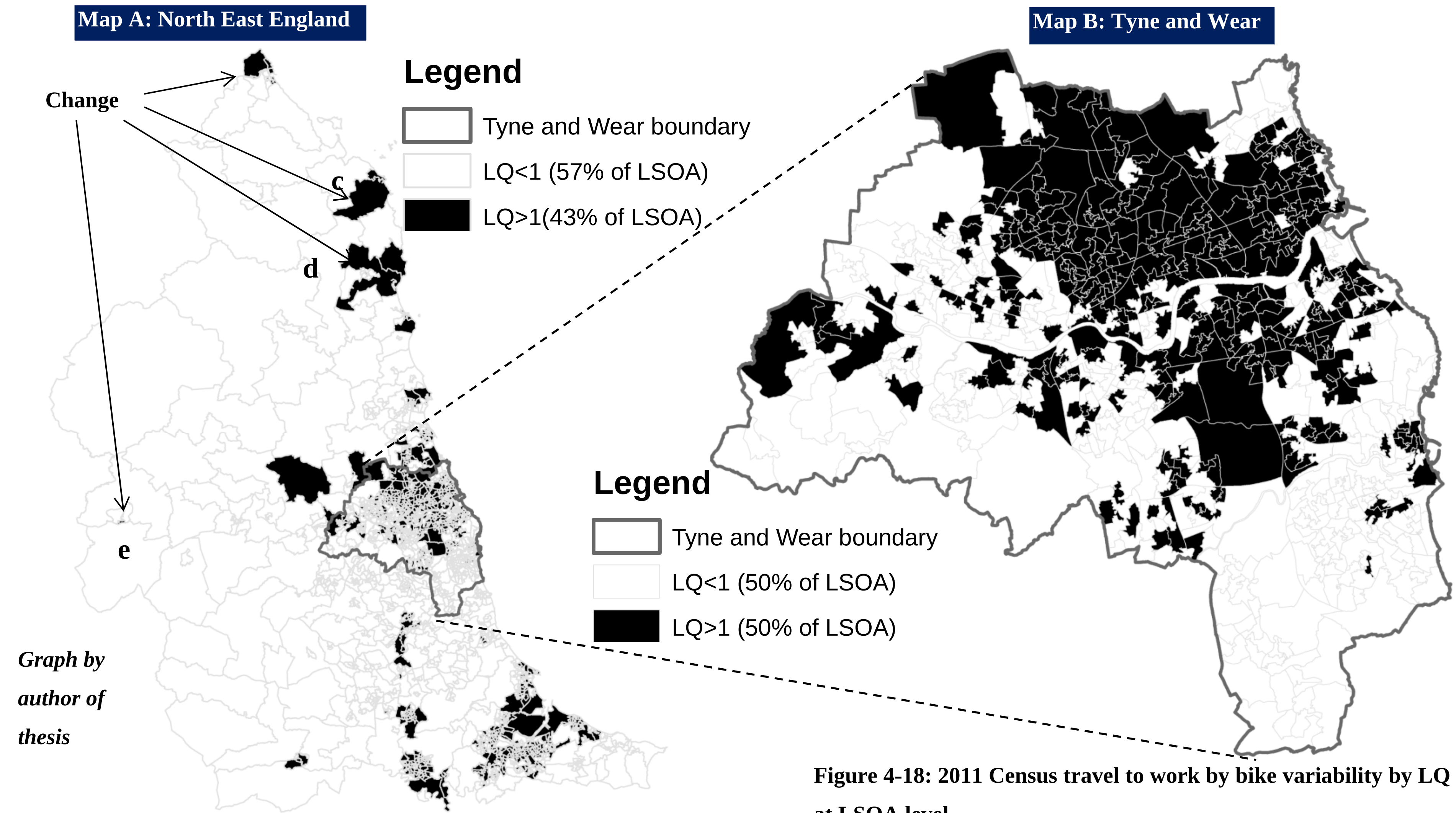


Figure 4-18: 2011 Census travel to work by bike variability by LQ at LSOA level

4.3 Study area

The selection of the study area was informed by the findings from the exploratory analysis in sections 4.2. The choice of study area was based on assumptions focusing on: the fact that cycling appears to be prevalent around the central part of the Tyneside conurbation; practicality; and convenience. The Tyneside conurbation comprises four local authorities: Newcastle upon Tyne, Gateshead, North Tyneside and South Tyneside. Newcastle upon Tyne, North Tyneside and South Tyneside were found to have relative prevalence of cycling activity with the area around the central station of Newcastle upon Tyne being more visible. This area constitutes the central part of the conurbation although no exact boundary definitions exist. That notwithstanding, Newcastle upon Tyne has long been acknowledged as the central place for the conurbation (Freeman and Snodgrass, 1966, pp. 180-205). Map C in Fig. 4-1, Map A and Map B in Fig. 4-4, Fig. 4-9, Fig. 4-12, and Fig. 4-17 provide the empirical evidence to suggest that the central part of the conurbation would be ideal to focus in terms of strategy for data collection. Since the intent is to use GPS technology as part of the data collection and it was not explicitly evident as to which routes potential participants could cycle on, a selection criteria could provide the means to capture cycling activity which reflects the pattern identified. The selection criteria are discussed in Chapter 5.

Furthermore, the central part of the Tyneside conurbation also had a high potential of traffic congestion as reported in the Local Transport Plan 3 (LTP3, 2011). Traffic congestion increases the operation costs of employers in situations where travel demand increases (Aditjandra et al., 2013, p. 55). According to the area's next decade strategy for LTP3, the promotion of sustainable and safe communities has been considered as one of the challenges to address. Given that the least prosperous areas in Tyne and Wear are reported to be the most deprived in England, there are motivations to improve active travel modes such as cycling while promoting healthy living lifestyles (LTP3, 2011, p. ii). Rogers (2011) report, based on the 2010 Index of Multiple Deprivation data and summary measures constructed by Social Disadvantage Research Centre at Oxford University, ranks (average LSOA scores) districts in Tyne and Wear as Newcastle upon Tyne (40), Gateshead (43), Sunderland (44), South Tyneside (52) and North Tyneside (113) in increasing order respectively. Moreover, understanding cycling behaviours can help transportation engineers to devise strategies to control traffic flow in and around the area. Given the design of the research, the criteria for the sample for data collection was around the central part of the Tyneside conurbation whereas the observed route choices of cyclists were more flexible but generally constrained to the North East region of England. Taking this approach allowed the spatial characteristics of the primary sample to reflect the spatial dynamics identified prior to the primary data collection. The potential of the area to register traces of movement of cyclists is shown in the exploratory analysis presented in Chapter 4. Figure 4-19 shows the study area depicting only home and work/school geographic locations of respondents with Google map as the background; a fuzzy red boundary is also shown on the right map. The map on the left shows the major transport networks with the major hub around Newcastle Central Rail Station.

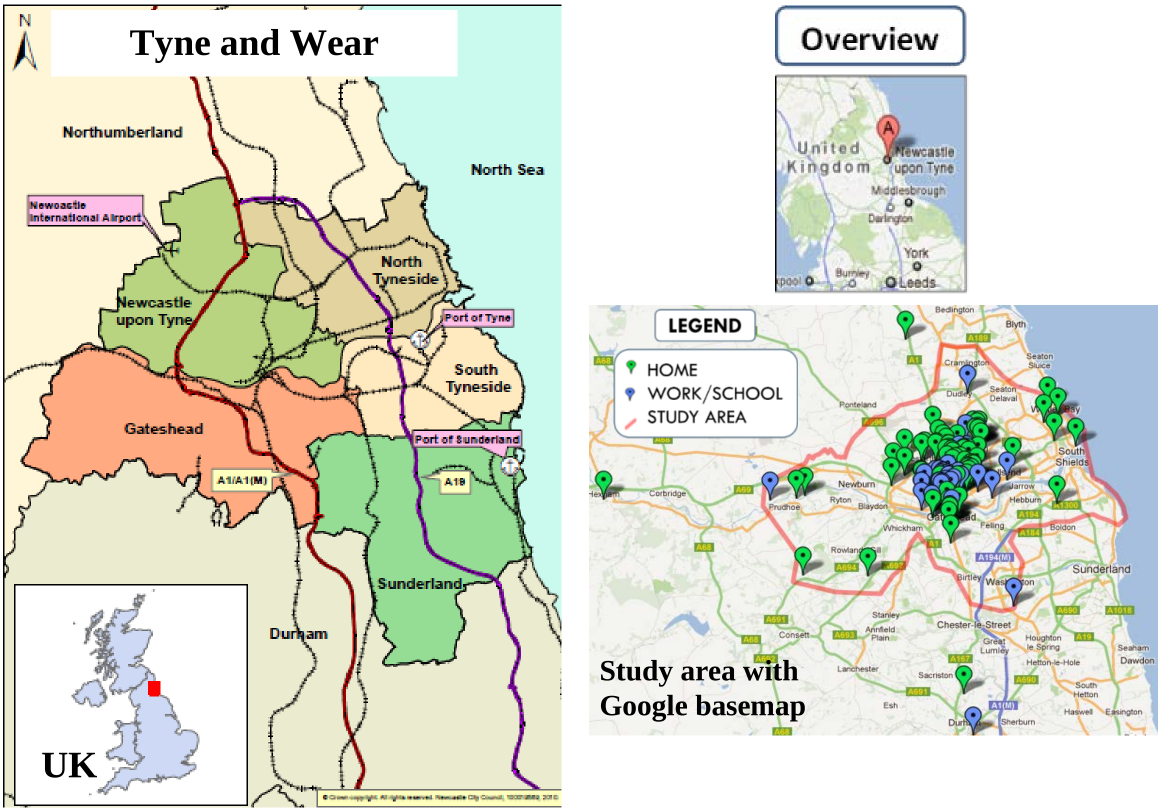


Figure 4-19: Map of study area with major transport network

Source: Tyne and Wear map taken from LTP3 (LTP3, 2011)

4.4 Discussion

This chapter has examined extensively several secondary datasets related to cycling around the study area to further deepen our understanding of cycling in the first half of the chapter. The second half covered exploratory analysis of the primary data collected specifically for this research. The chapter has analysed and discussed stated and actual/revealed preferences of regular cyclists since it was impossible to objectively measure their "subjective" cycling behaviour. The findings suggest that objectively measured distance and time expenditures are significantly different from corresponding subjective measurements. This confirms the reported case that subjective and objective measurements of the environment are not the same (Lemieux and Godin, 2009, p. 7); therefore a combination of the two strands is recommended when researching perceptions of the environment. The outcomes of the kernel density together with the flow mapping analyses of the Tyne and Wear and the AAWT flow suggest that the denseness/concentration of cycling uptake is more visible around the Newcastle city centre and parts of South and North Tyneside.

A Dissimilarity Index of 11 (from the 2011 Census data) indicates that the spatial distribution of travel to work by bike across North East England is not evenly distributed. As a result, the Lorenz curve revealed relatively higher concentrations of travel to work by bike in North Tyneside, Newcastle upon Tyne, and South Tyneside according to the location quotient values derived from the Travel to Work data (2011 Census). Compared to the computed 2001 Dissimilarity Index of 5 it is evident that dissimilarity is increasing across the region. The collected route choice preference information (from primary GPS tracks) suggests that many cyclists cycle across the whole study area, regularly crossing local authority boundaries; therefore, the different Councils need to work closer when planning cycling infrastructure and interventions.

CHAPTER 5. DATA COLLECTION, DATA CLEANSING, EXPLORATORY AND COMPARATIVE ANALYSIS

The possibilities of using GPS technologies in tandem with GIS and affiliated technologies are quite promising in the area of route choice analysis given the fact that actual (periodic) choice data is almost not existent (Schönfelder, 2006, p. 51); especially in the UK (Section 3.3). There are major challenges in empirical research which take into consideration the use of observational and GIS measures. As Brownson et al. (2009, p. S119) note, observational measures demand investments in staff, travel, training, data management and analytical know-how. Therefore, the limit of investment imposes financial and temporal constraints on research design. As far as this author is aware, the one week primary data collection which gave empirical evidence on details of daily route choice characteristics of *adult utility cyclists* is the *first* in the UK. However, the first time use of GPS for tracking children's physical activity behaviour could be attributed to the remarkable empirical study by Gong and Mackett (2008) in the British town of Cheshunt, Hertfordshire. In their study to understand movement patterns of children, considered as users of the built environment, they monitored almost 160 children from two local primary schools between September 2005 and June 2006 using portable GPS devices and energy monitors. They emphasised that "*The application of the GPS monitors to study individual movements in built environment is relatively new. Latest developments in GPS technology enables the traditional data gathering process to move out of the laboratory environment into the 'wild' urban space.*" (Gong and Mackett, 2008, p. 3).

The methodological approaches used in capturing and processing movement data of cyclists within and around the central part of the Tyneside conurbation are reported in this chapter. The architecture for the data collection is discussed and some descriptive statistics are presented about the participants along with evidence on how they perceive their environment. More importantly, the data processing techniques applied are discussed, alongside the space-time visual approach to GPS data processing. It is argued here that the current use of space-time cube for visualisation should be extended to handle actual processing of spatio-temporal (raw) data such as data from emerging portable small-sized GPS enabled devices. Additionally, times spent on some of the procedures were monitored and results presented.

This research adopted methods which demanded processing of raw GPS data with additional information and devised fieldwork architecture as well as a novel processing approach to ensure reliable data for further analysis and visualisation. Furthermore, detailed discussions on the methodological issues and experiences gathered in the course of the data collection and processing were given.

Processing of raw GPS data – especially data from daily mobilities – is often approached from two distinctive perspectives. On the one hand, processing without additional information with extensive post-processing procedures, such as the use of deterministic rules based on travel speed (Bohte and Maat, 2009). On the other hand, processing with additional information such as travel diaries (Cervero, 1996; Van der Spek et al., 2009). These methodological approaches ensure data reliability and correctness for further visualisation and analysis. Although progress is being made (Anderson et al., 2009; DfT, 2011b), there are still challenges for both GPS based data collection and processing for tracking daily mobilities (Chen et al., 2010, 838), suggesting the need for further research especially by sensing non-motorised transport flows (Van der Spek et al., 2009, 3052). This chapter discusses aspects of the fieldwork architecture shown in Figure 5-1, as well as a novel processing approach, to ensure reliable data for further analysis and visualisation (Yeboah and Alvanides, 2013). The red arrows show stepwise flow during the testing phase of the field work where the instruments were tested with seven participants before the main survey whereas the blue arrows and boxes show the stages and stepwise flow of main survey (Figure 5-1). The data from the pilot study was not included in the final dataset for analysis, because the National Travel Survey form was used in its normal structure but in A3 which later demanded introduction of new structure of travel diary to allow participants to tick most of the items.

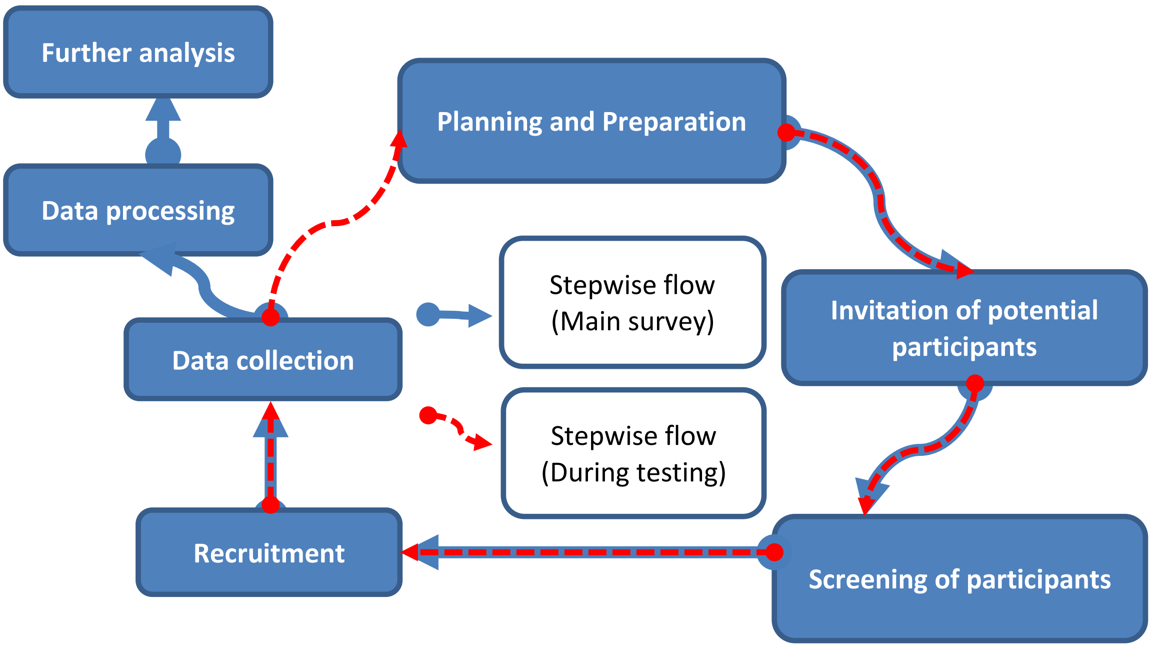


Figure 5-1: Architecture for GPS based data collection, processing, and analysis

5.1 Selection of GPS and survey instruments

The use of GPS in tracking movement behaviours of users of built environment is relatively new (Gong and Mackett, 2008; Stopher et al., 2008a; Van der Spek et al., 2009; Yeboah, 2013; Yeboah and Alvanides, 2013; Yeboah et al., 2012). One of the first decisions when designing GPS based research is the device selection (Kerr et al., 2011). Given the ever increasing advancements in GPS technologies, this study examines other available GPS devices in the market. Kerr et al. (2011, p. 534) note that researchers face a "confusing array of choice" when it comes to selection of GPS devices for research. In their experience, they cited three relevant factors when one aims to select or test a GPS device, which were battery life, fix time, and chipset sensitivity or accuracy. Additionally, they noted that these factors as well as other features of a GPS device varies from study to study suggesting that researchers should be prepared to test their own devices as manufacturers' specification do not always reflect true performance in the field. A study by Gong and Mackett (2008) considered weight, memory capacity, size, battery life and affordability (i.e. cost) in selecting a portable GPS device for their research on tracking movement behaviours of primary school children. Some of the devices identified in the literature were:

1. Mobile Action i-gotU GPS Tracker GT-1800A (900 / 1800 MHz)[5];
2. Mobile Action i-gotU GPS Travel Logger (GT-600)[6];
3. Mini Global GPS Tracker with GPRS connection[7];
4. QStarz BT-Q1000XT[8];
5. Keychain GPS Data Logger[9];
6. Canmore GT-750F(L)[10]; and the heaviest,
7. Garmin eTrex Legend HCx Handheld GPS System[11].

In the above list, number 1 and 3 have the ability to employ Web based Tracking Service. Especially for GT-1800A, though relatively expensive, it may be interesting to collect additional data such as cell positioning and compare with GPS logged data to enhance post-processing of data collected. Such an approach may demand that the mobile service provider with most dense cell tower positions in the sample area be used. BT-Q1000XT appears to have an advantage over GT-600; in that, it has almost twice the memory capacity and slightly longer battery life as shown

[5]http://www.expansys.com/mobile-action-i-gotu-gps-tracker-gt-1800a-900-1800-mhz-207738/
[6]http://www.expansys.com/mobile-action-i-gotu-gps-travel-logger-gt-600-193988/
[7]http://www.amazon.co.uk/Mini-Global-Tracker-GPRS-connection/dp/B003XDQUQE/ref=sr_1_2?s=electronics&ie=UTF8&qid=1300043940&sr=1-2
[8]http://www.qstarz.com/Products/GPS%20Products/BT-Q1000XT-F.htm
[9] http://www.sackstark.com/store/product_info.php?products_id=92
[10] http://www.canadagps.com/CanmoreGT-750FL.html
[11] http://direct.tesco.com/q/R.209-2672.aspx

in Table 5-1 using an open sky testing under continuous logging shown in Figure 5-2. All the devices possess one disadvantage with the exception of the Garmin etrex HCx; none has a display screen although they have small *light emitting diode* (LED) indicators as a means of communicating with the user.

Another interesting component of these GPS devices is the chipset placed in the device casing. How “intelligent” a device is depends on the “chipset” it has. Intelligence means the ability of recording properly and interacting easily with the user. Among the devices mentioned earlier, three main GPS chipsets are found, namely: MediaTek[12]; SkyTra Venus[13]; and SiRF[14]. Most of the competition among these manufacturers, in the market, revolves around: the number of channels; power consumption; Time Taken for a First-Fix, and other interesting features such as Bluetooth among others.

After careful consideration of the above issues, four personal GPS devices were purchased by Northumbria University and made available to the researcher for testing, namely: 1) GT-600; 2) Atmel BTT08; 3) Canmore Bluetooth GPS receiver; and 4) Qstarz BT-Q1000XT. The main focus of the testing was the ease of use in terms of data collection in the passive mode and possible logistics to support data processing. Battery life, and memory capacity were also tested in addition to considering the cost (i.e. market price against budget) of each device. QStarz BT-Q1000XT device appeared easier to use and with safe lock-on/off button. Unlike the QStarz BT-Q1000XT, the GT-600 does not have a safe lock-on/off button but can only be configured via the accompanying software. Devices with non-lock-on/off button may increase uncertainty of complete data capture because they can be accidentally switched on/off in a bag or pocket where participants carry them. The issue about software stability mentioned in Table 5-1 relates to connecting the GPS device to a Windows 7 PC platform using a USB port and the ease to import the measured data from the device to the computer via the provided software interface (i.e. the software that comes with the GPS device). The term *stable* therefore meant that the GPS device works well with the accompanying software such that the user experience for using the import functions, importing data and initial visualisation of the data remained the same irrespective of whether the memory of the GPS device is empty, half full or full. There might be bias, however, as this test was only done by the researcher and is therefore generalizable only to the researcher’s experience of the devices.

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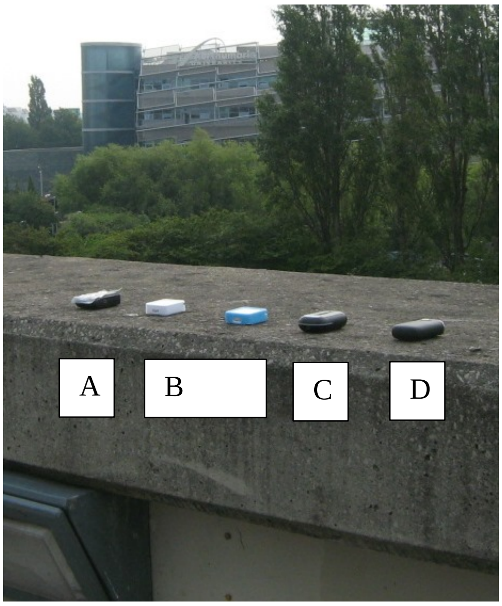
[12] http://www.mediatek.com
[13] http://www.skytraq.com.tw/index.htm
[14] http://www.csr.com/products/technology/gps

Table 5-1: Test summary of GPS devices

GPS device model	Software Stability	Memory capacity (GPS points)	Battery life estimate (continuous logging)	Market Price per item	Motion sensor
GT-600	Unstable with more points loaded	262,000	20hrs	£ 64.00	Yes
Atmel BTT08	Stable but unfriendly	512,000	22hrs	US$278	Yes
Canmore GT-750(L)	Unstable at times during PC-GPS connection	256,000	16hrs	CA$ 54.95	No
QStarz BT-Q1000XT ***(SELECTED FOR THIS STUDY)***	Stable and friendly	400,000	21hrs	£76.80	Yes



A) QStarz BT-Q1000XT

B) GT-600

C) Atmel BTT08

D) Canmore GT-750(L)

Figure 5-2: GPS devices continous logging test

Three survey instruments were developed, in addition to the use of GPS trackers and materials for the field campaign, for the purposes of this research.

First, a self-reported travel diary was designed, which was partly adapted from questionnaires used by the DfT (DfT, 2011b); and used to collect detailed information on the mode and duration of each daily trip by participants (Appendix A).

Second, a self-reported form for the collection of further information of participants (Form A) such as demographic and socioeconomic characteristics, experience with use of GPS tracker for the data collection, confirmation of collected data.

Third, a self-reported travel behaviour form for the collection of cognitive and attitudinal data (Form B) on participants' travel environment, attitude, behaviour, norm, intention, and habit. Form B was adapted from Lemieux and Godin (2009) which was based on the theory of planned behaviour. In order to be able to standardise the responses to the variables on habits and perception, three to five-point Likert psychometric scaling were used. Figure 5-3 shows an illustration of how the psychometric variables were coded in SPSS for analysis using Likert scaling concept. Where a variable can be put into an order form, the scale of measurement of the variable is considered to be *ordinal* (Burt et al., 2009, p. 26). The code "Q1101" for one of the Likert type questions in capturing perceptions mean "Q" for question, "11" for the 11th question, and "01" for the first of the questions on perception. As can be seen from the figure, the fourth Likert type perception question becomes "Q1104".

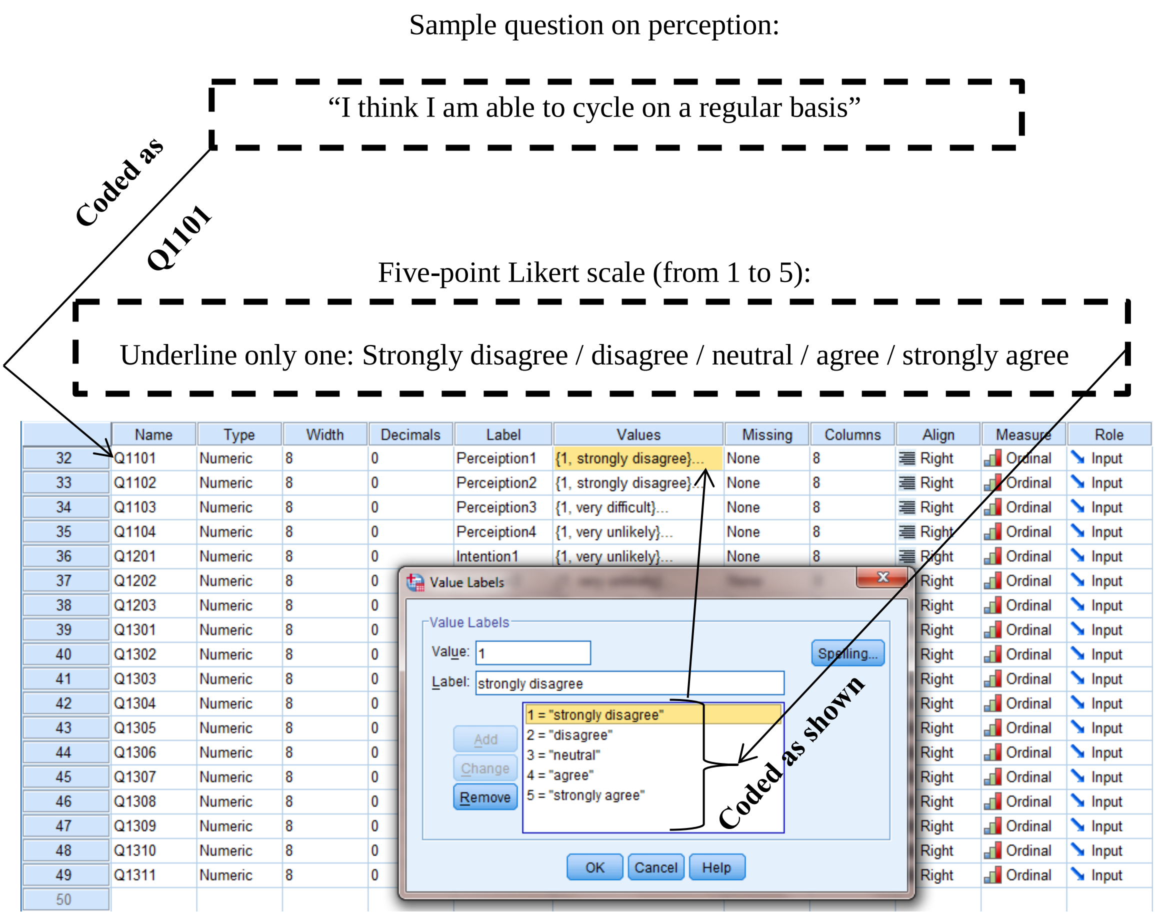


Figure 5-3: Coding of variables from questionnaire in SPSS

5.2 Piloting and recruitment of participants

Despite the introduction of minor changes, and piloting with 7 participants, which were not included in the analysis, the psychometric qualities of the baseline questionnaire were assumed to be stable given the test-retest reliability study conducted by Lemieux and Godin (2009). The changes covered the introduction of two questions in order to capture usage of sidewalks / pavements / footpaths and the availability of bicycle signage. There is interest in traffic calming using 20mph zones as a way of ensuring cycling safety around the study area. Further discussion on 20mph can be found in section 3.3.2.3.

Moreover, even though 84 participants completed the baseline questionnaire, 79 participants were included in the analysis to allow for consistency of interpretation and comparison with the available measured trips. The 79 participants participated fully for both the attitudinal and GPS surveys. The reason for the other five not participating in the GPS survey was mainly due to non-availability due to other responsibilities. An incentive of package of £50 was part of the call for participation (Appendix D: Examples of email messages). The data collection process follows a seven-day design. Participants, before filling the questionnaire, were instructed to consider a normal week of their lifestyle whilst completing the questionnaire. After the questionnaire completion, an agreement was made where the considered normal week is used for filling travel diaries and carrying a portable GPS device. Rather than using a revised question at baseline to capture the number of times participants had used active transport to get to/from work or school (Lemieux and Godin, 2009); the information gathered from travel diary and GPS traces were used.

Additional materials, mainly for the field campaign, were prepared: flyers, brochures and posters (Appendix B); three web pages using Survey Monkey web service (Appendix C); drafted email messages (Appendix D); campaigned on author's twitter page; a leaflet containing frequently asked questions (Appendix E); as well as important issues on the use of the GPS tracker with frequently asked questions (Appendix E). The leaflet was added to the travel diaries and given to participants during the data collection phase. Consent form and research statement was also prepared and added to the instruments in accordance with Northumbria University policy on Ethics (Appendix F).

Both an online and an offline campaign strategy were used to approach potential participants. The selection and face-to-face invitation of cyclists who expressed an interest in the research was undertaken in three stages (i.e. first 10, 45 and remaining) due to limited resources such as number of GPS devices; personnel and time (Table 5-2). The campaign period for the field data collection was during September 2011. For the online campaign, an email was sent to three hundred and fifty (350) email contacts, including two email-lists of bicycle user groups of both Northumbria and Newcastle Universities. Approval for these email-lists was sought before used. A dedicated email address was created and introduced to the potential participants in the first call message and used thereafter. The idea of using a separate email address was to allow ease of management of email responses from participants. In addition, the social media tool Twitter was introduced in order to solicit participation. The offline campaign techniques included the distribution of flyers; brochures, and A4-size notice board-posters, in order to ensure balance between age and socioeconomic groups due to limited access to technology (internet and email).

Table 5-2: Pilot and recruitment phases

Activity phase	Begin Date	End date	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9
Pilot	01/10/11	07/10/11	■								
Phase I (Group 1)	07/10/11	26/10/11		■	■	■					
Phase II (Group 2)	21/10/11	16/11/11				■	■	■	■		
Phase II (Group 3)	24/10/11	30/11/11				■	■	■	■	■	■

Note: Randomly grouping participants and inviting them for face-to-face meetings and administering survey instruments were necessary due to limited number of GPS devices. W=Week

A total of 118 responses were received from the field campaign with 111 screened as utility cyclists making the response rate about 34% (i.e. 118/350 times 100). The idea behind the screening and sample size was to ensure the expected wide-range of activity and movement patterns (Van der Spek et al., 2009, 3052); relevant to the investigation. The sampling criteria for the study are articulated as follows:

- any adult *utility cyclist* who is more than 19 years and willing to freely volunteer as a participant;
- should be a *utility cyclist* and commute with bicycle at least once a day in a week;
- must have home, work or school location within the centre of Newcastle upon Tyne geographic area; and,
- must be willing to carry a personal GPS tracker continuously for one week along with filling a travel diary.

A week is defined as seven days from Monday to Sunday. Utility cycling means any cycling not done primarily for fitness, recreation such as cycle touring, or sport such as cycle racing, but as a means of transport. Full definition is given in Chapter 1 (Section 1.2).

The 111 participants were invited for a face-to-face individual meeting where they were introduced on how to use the GPS trackers; how to fill the questionnaire; to receive and take home a GPS tracker with case, USB cable, and forms to be filled whilst carrying the GPS tracker; signed a consent form and completed the questionnaire. Each participant was expected to start the survey the day after the meeting day or to be agreed date reflecting their normal week; and have in mind the collection date which was a week from agreed date. Eventually, 79 participants successfully filled the forms and carried the GPS device making the response rate about 23% (i.e. 79/350 times 100).

5.3 GPS tracking of utility cyclists and weather situation

In the search for data to support this research, it became evident that actual individual route choice data was not available for the research area. The lack of such data is an indication of the difficulty of collecting such individual level active travel data. A review of the relevant literature suggests possible track-able samples within particular data collection waves given research scope and available resources such as personnel, money, and time among others. Two examples of published studies are showing track-able sample sizes: UK NTS GPS Feasibility Study which was done in two waves where GPS traces from 66 adults in October-November wave and 68 adults in January-March wave were collected (Anderson et al., 2009). In addition, the Delft University studies in the town of Almere, where 15 families initially agreed to participate in, where 40 participants carried GPS devices for one week in the end (Van der Spek et al., 2009, p. 3042-3043). Van der Spek et al. (2009, p. 3042-3043) also note that "*the use of GPS-technology and deployment of GPS-devices still offers significant challenges for future research*". Participants in the current study carried the GPS tracker for one week (7 days) while filling the forms described earlier. Form B was filled during a face-to-face meeting day and Form A was attached to the travel diary and given to participants to be filled during the travel week or last day of returning given materials. The data collection wave was from October to November 2011.

Literature suggests some variation of duration for GPS based data collection but most studies are about one week (Anderson et al., 2009; Van der Spek et al., 2009). Reasons for choice of duration as well as time or distance logging interval can depend on several factors: for example, memory capacity, battery life, as well as the research design and scope. The log interval used in the design of this research is "5" seconds. This interval was selected to curtail the anticipated magnitude of data size and data processing, analysis and visualisation challenges. Although the use of GPS for data collection is nearly unlimited, a big data size could nearly make it extremely time consuming and impossible to conduct any useful data analyses covering editing, visualising, and making queries on locations and attributes (Stopher et al., 2008a). Here, it is also argued that, for example, a GPS log interval of a second could log more precisely but with more effort/time on participants and researchers as the battery life will be shorten for multi-day survey leading to frequent battery re-charge whereas big data will demand more time for data downloading, data processing, analysis and visualisation. In this study, a careful consideration was also given to the battery life duration and the effort/time on participants to re-charge the device. GPS log intervals tend to vary in active transport research from 2-6 seconds for a one-week tracking duration and no specific reasons seem to be given for choice of log interval, but might be possibly due to in-study pre-testing or prior knowledge from literature or reliance on guidance from manufacturers specification (Bohte and Maat, 2009; Dill, 2009; Van der Spek et al., 2009).

In the course of the travel week for the data collection for each of the participants there were two email follow-ups. In the second face-to-face meeting where participants returned survey instruments, they were shown the raw GPS data with a Basemap and asked if the data reflected normal travel week and observation in the GPS data not tallying with the travel diary were noted and corrected. What follows are selected comments from the participants suggesting success of the data collection design and implementation.

ID-1010XT11600002: "No problems whatsoever. All smashing."

ID-1480XT11500947: "No problem……….. into day 2 …… cycled in today despite the weather ☺"

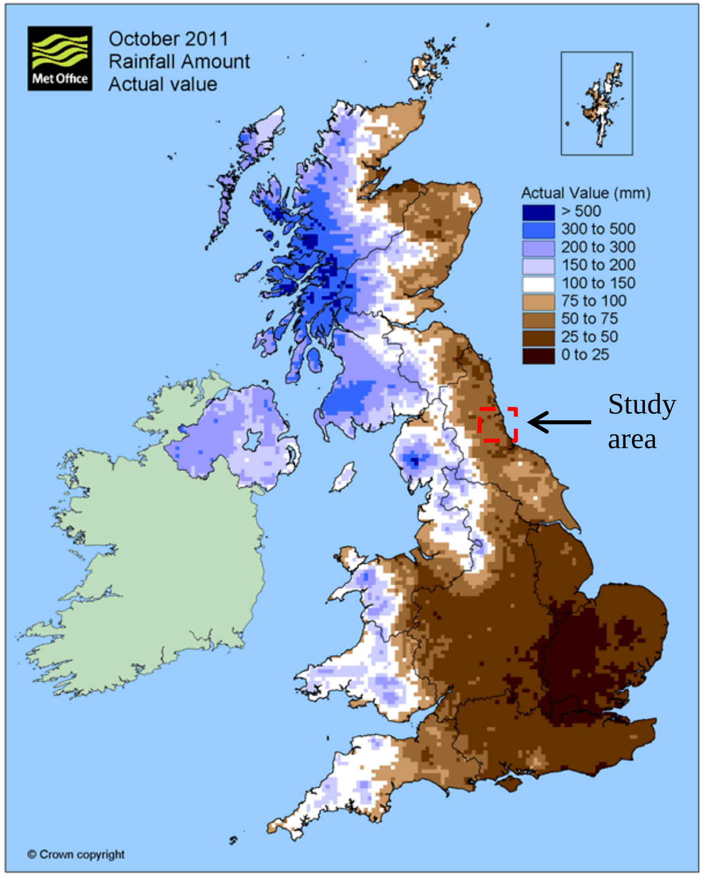
The total number of only cycle trips within the month of October and November 2011, as per the finalised sample of 79 cyclists, was 941. The 79 cyclists were made up of 27 females and 52 males. Further descriptive statistics were provided in the exploratory analysis Chapter 4.

The actual values of weather data (e.g. rainfall, temperature etc.) was not collected explicitly as part of the data collection. However, an option was provided for the participants to tick one or more of nine options in answering the question "How would you describe the journey?": 1=Took shortest route known; 2=Uncertain of cycling routes; 3=Unsafe (heavy traffic); 4=Safe and enjoyed it; 5=Used a map as an aid; 6=Bad weather; 7=Attractive green vegetation; 8=GPS charged before trip; and 9=Other (specify). Out of the total trips reported (i.e. 2432 trips), Table 5-3 shows reported bad weather statistics of participants' journeys along with weather estimates from UK Met Office (MetOffice, 2013a, b, c, d, e, f, g, h, i, j, k, l); 3% described their journey as bad weather. The estimates in the table were inferred values around the study area based on the maps from Met Office as shown, for example, in Figure 5-4 and Figure 5-5. The figures also show relative distribution of rainfall and mean temperature across the UK during the data collection period. Actual weather estimates shown in Table 5-3 suggest that there was no snow, thunder and lightning. However, there was relative reduction (i.e. 2 to 4 degrees Celsius) in mean temperature and sunshine (i.e. about 20 to 25 hours of sunshine) in November 2011 when compared to that of October 2011 making percentage of trips described as bad weather 0.8% more in November than October.

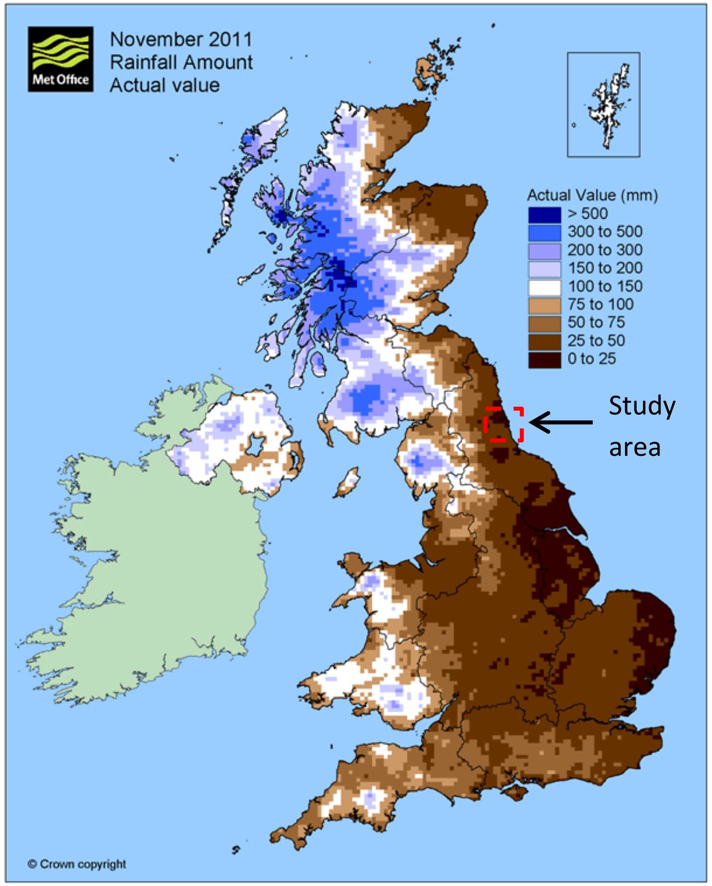
Table 5-3: Reported weather statistics of participants' trips

<table>
<tr><th rowspan="3">Mode</th><th colspan="2" rowspan="2">Trips with bad weather description (%)</th><th colspan="12">UK Met Office actual weather estimates</th></tr>
<tr><th colspan="2">Rainfall (mm)</th><th colspan="2">Mean Temp. (°C)</th><th colspan="2">Sunshine (hours)</th><th colspan="2">Days of snow lying</th><th colspan="2">Days of thunder</th><th colspan="2">Lightning strikes</th></tr>
<tr><th>O</th><th>N</th><th>O</th><th>N</th><th>O</th><th>N</th><th>O</th><th>N</th><th>O</th><th>N</th><th>O</th><th>N</th><th>O</th><th>N</th></tr>
<tr><td>Bike</td><td>0.7</td><td>1.6</td><td rowspan="7">0 to 75</td><td rowspan="7">0 to 75</td><td rowspan="7">10 to 14</td><td rowspan="7">8 to 10</td><td rowspan="7">80 to 100</td><td rowspan="7">60 to 75</td><td rowspan="7">0</td><td rowspan="7">0</td><td rowspan="7">0</td><td rowspan="7">0</td><td rowspan="7">0</td><td rowspan="7">0</td></tr>
<tr><td>Walk</td><td>0.4</td><td>0.1</td></tr>
<tr><td>Taxi</td><td>0</td><td>0</td></tr>
<tr><td>Train</td><td>0</td><td>0</td></tr>
<tr><td>Bus</td><td>0</td><td>0</td></tr>
<tr><td>Car</td><td>0</td><td>0.2</td></tr>
<tr><td>Total</td><td>1.1</td><td>1.9</td></tr>
</table>

Note: O = October and N=November

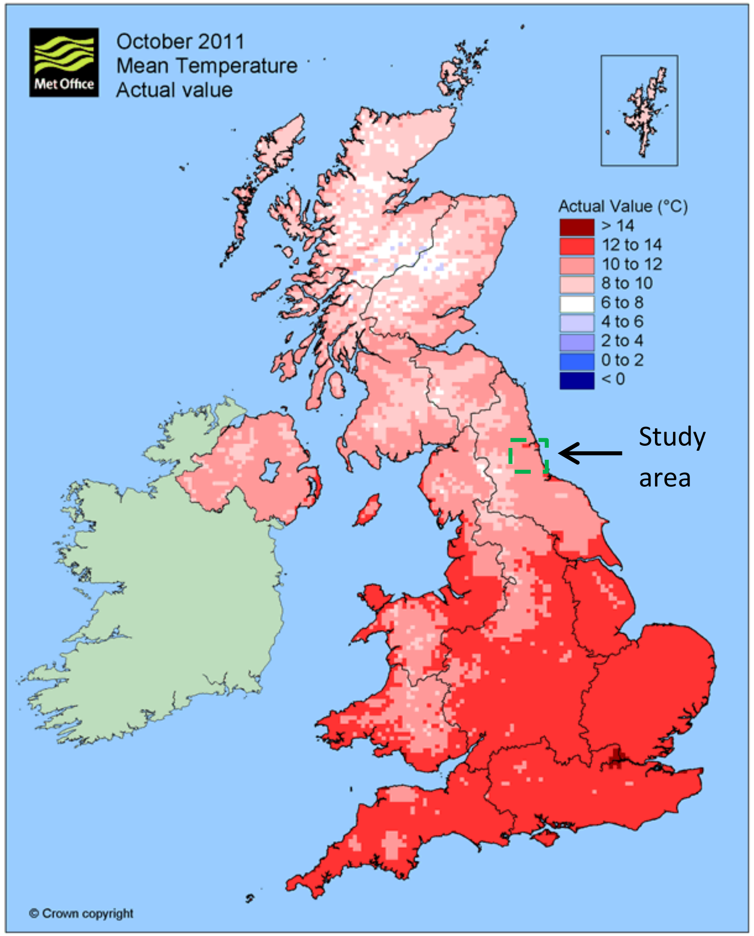


Source: (MetOffice, 2013k)

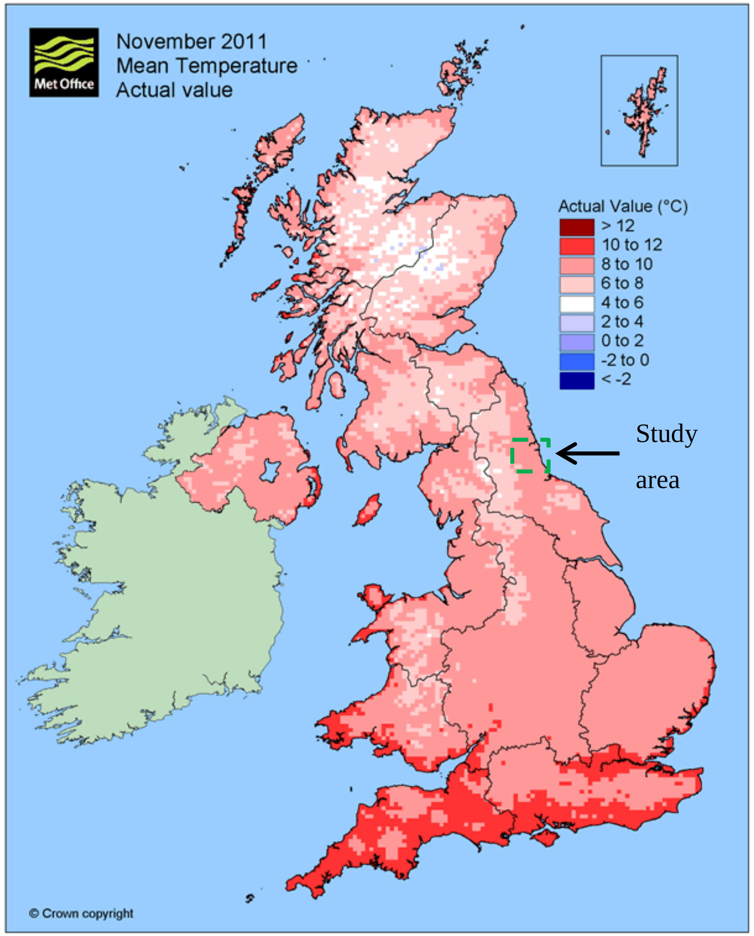


Source: (MetOffice, 2013e)

Figure 5-4: Rainfall Actual Amount in data collection period (October-November 2011)



Source: (MetOffice, 2013j)



Source: (MetOffice, 2013d)

Figure 5-5: Mean Actual Temperature during the data collection period (October-November 2011)

5.4 STC based Visual Inspection as a data cleaning method

Space time as a central theory in time geography still receives attention from researchers since its introduction by Torsten Hägerstrand (Hägerstrand, 1970; Pouliot, 2007). More recently, various attempts have been made to explore the applicability of the space-time cube (Neutens et al., 2012) and to utilise tools and methods emerging from Hägerstrand’s theoretical constructs (Bopp et al., 2012, p. 25). So far, the emphasis has been on the use of space-time cube for visualisation and analysis but not as a data processing tool. The detailed information from the travel diaries were used in order to clean up the collected GPS tracks and identify the cycling tracks for further analysis using, a novel approach – STC based GPS data processing – extending the usability of STC.

This section illustrates an approach used for GPS data processing where space-time cube is used as an environment to process (i.e. edit) raw data from the portable GPS trackers used here. The downloaded data was first checked considering the time zone, column headers and coordinate system. Given the data collection wave, the time zone considered fell on Sunday 30th October 2012 where all logged points time on 02:00:00 (HH:MM:SS) UTC time was corrected backwards to 01:00:00 (HH:MM:SS) UTC time the same day to reflect local time. What followed after was import into ESRI ArcMap software, part of ArcGIS, which works well with GeoTime software. GeoTime is commercial standalone software developed by a US company called Oculus which has a full implementation of STC theory. The software offers a highly interactive 3D view space for the display and tracking of events objects and activities (Kapler and Wright, 2004). The data was then exported in STC in GeoTime using GeoTime data link in ArcMap environment. In the process of export/transfer, the attributes of the data were mapped to enable GeoTime to load all attributes of the raw data to enable further selection and visual inspection in STC space in GeoTime. Additional secondary information, such as OpenStreetMap basemap, was loaded in ArcMap and this reflects automatically in the GeoTime STC space. At this point, the travel diaries were consulted to identify cycle trip in a particular date and time. The identified information was visually inspected in the STC by categorising the loaded week data by date and selecting that date and subsequently navigating to find a particular journey in that day as recorded in the diary.

Once the journey was identified, visual inspection continued using the loaded secondary data loaded vis-à-vis the diary information such as start/stop location name to support decision making in visually detecting outliers and redundant points. Figure 5-6 shows the STC based data processing workflow. The outcome was a refined point-set (i.e. processed data) describing a particular trip as shown in Figure 5-7. Average STC based processing time recorded, as per cycle trip, is 00:07:09 (HH:MM:SS). This estimate covers the period from when the single trip was identified till when that trip was satisfactorily refined as a cycle trip tallying with the details in the travel diary. Additionally, this estimate resonates with a data refinement analyst who was considered to have expert knowledge in the functionality of all toolsets available within the STC in GeoTime and have a high degree of familiarity with the area under investigation. The later consideration may be replaced by someone who has expertise in interpretation of maps such as an experienced cartographer.

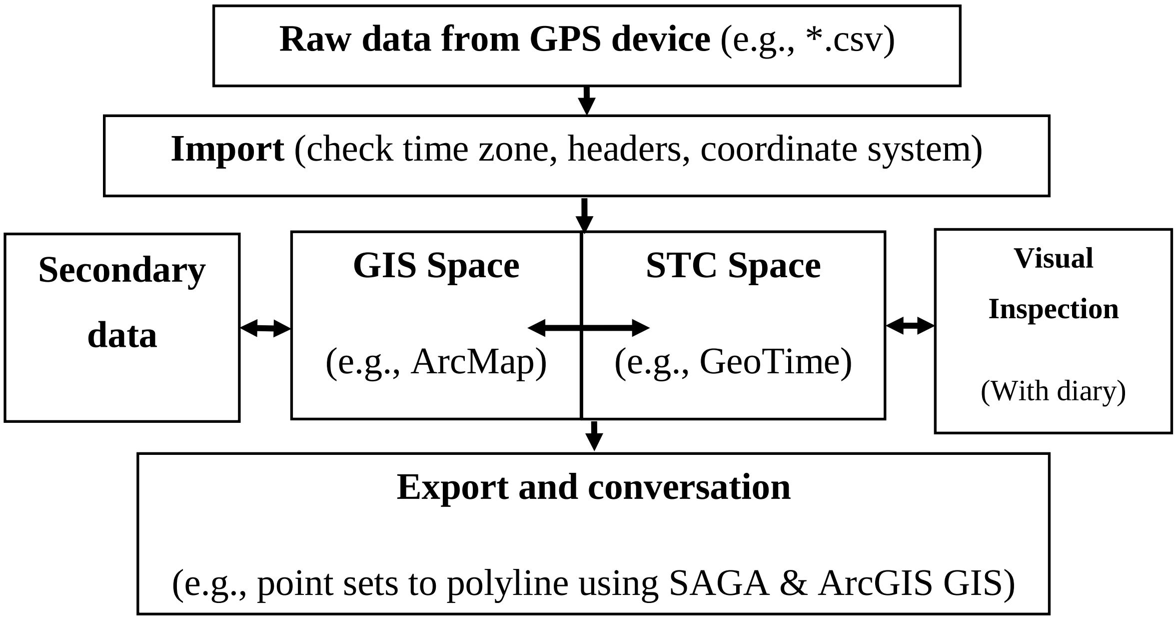


Figure 5-6: STC based GPS data processing workflow

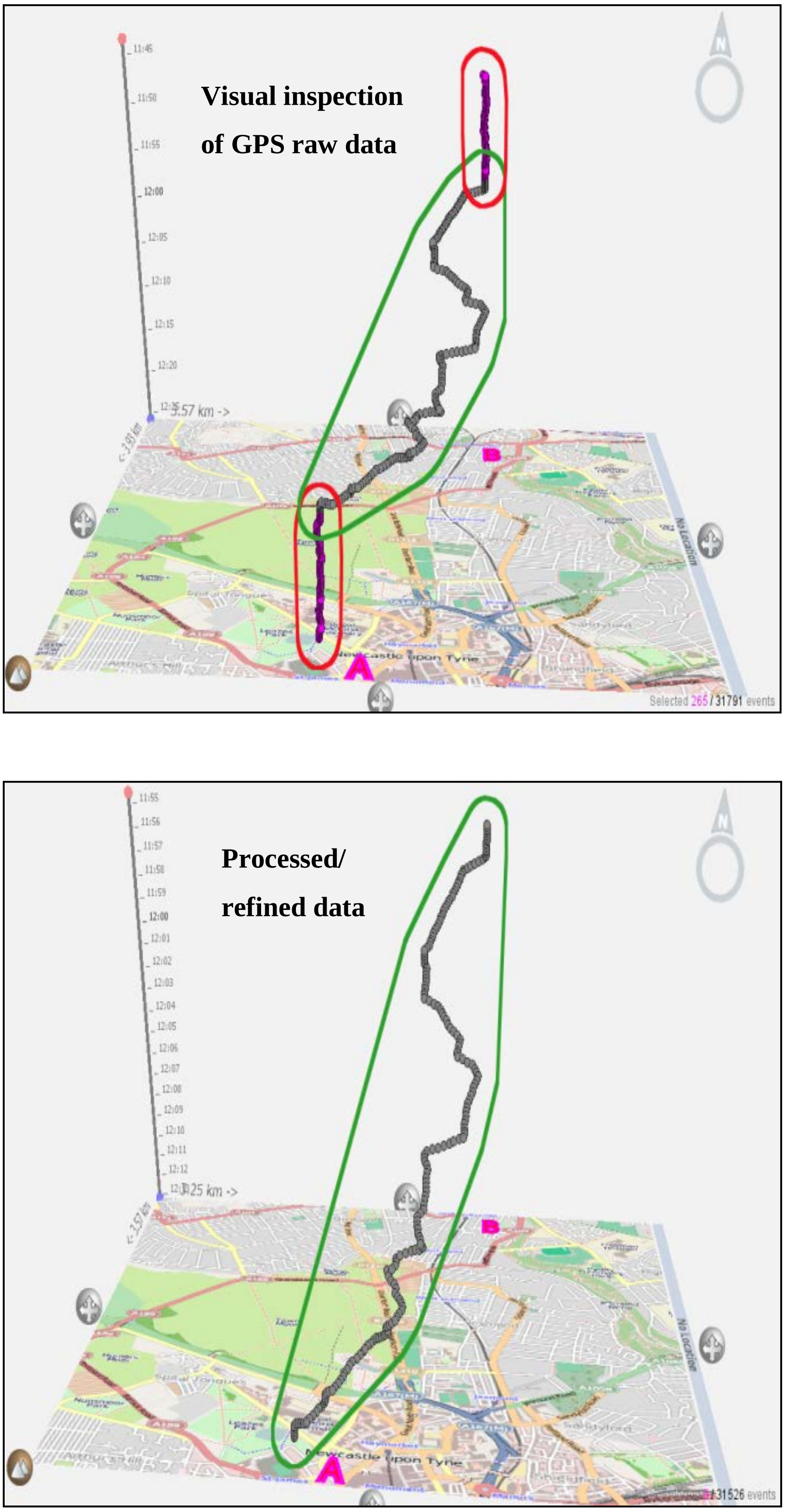


Figure 5-7: An example of visual inspection showing GPS raw data (up) and processed data (down) in space time cube in GeoTime Software

One could approach the STC based refinement process using four main steps: load raw data, identify date and time, identify related trip, and edit using secondary data with frequent checks with travel diary. Figure 5-8 shows these step-wise processes using real data. In the illustration in the figure, the first step which is labelled as letter A indicates the loaded one week GPS data of one of the participants. The next step, labelled as letter B, identifies the date and time of interest from the travel diary. Step C uses the information obtained from step B to identify the particular trajectory. The final step - labelled as letter D - is about examining the selected trajectory in detail together with secondary data as basemaps and back-forth checks with the travel diary to ensure that the self-reported information tallies with the self-tracked trajectory.

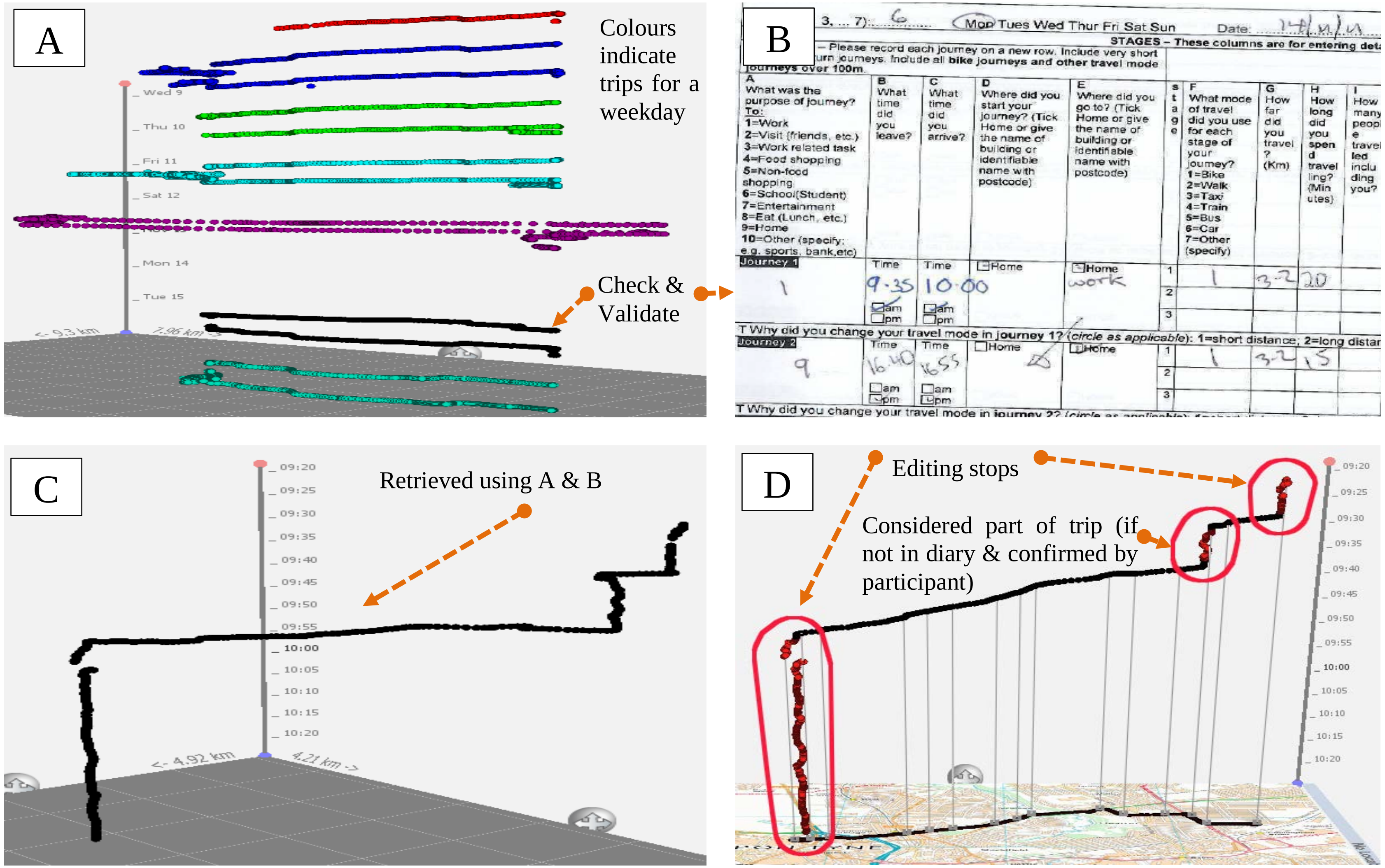


Figure 5-8: STC based data processing in four steps

It is feasible to use GPS trackers given attention to available resources, sample sizes and expected scale and detail of information needed. In this research, 79 cyclists were tracked within two months using 54 GPS trackers. A single researcher had the responsibility to prepare survey materials, conduct field campaign, arrange meetings with participants, conduct face-to-face recruitment, supervise the data collection process, and subsequently process the data using visual approach with additional information. Over three hundred and sixty eight emails were exchanged covering meeting arrangements and other responses to participants. The use of email exchanges demanded continuous internet connection, typing speed and attention to simple courtesies. The use of a stationary venue to meet participants proved useful rather than meeting participants at their preferred meeting place. The use of social networks for soliciting participation was also useful as a field campaign medium.

Experiences gained from GPS tracking suggest that participants preferred face-to-face meeting outside working hours but emphasis was on flexibility to enable participants to decide when to meet rather than any imposition from the researcher. Although most participants were conversant with GPS technologies, it is advisable to prepare a concise list of frequently asked questions (FAQs) as well conducted introductory section where participants know what to do during the tracking week. Few participants were, prior to the tracking week, concerned about their logged data.

As discussed in section 3.3.1.2 and reflecting upon the experience gained from this research, it appears the decision by DfT to stop using GPS trackers to track travellers 2013 onwards will greatly demotivate efforts to advance such GPS data processing methods. Here, it is argued that it would have been better to keep collecting data so that emerging processing methods can be used for proper testing on large datasets such as the National Travel Survey data. Unlike using raw data attributes, such as speed (Anderson et al., 2009, p. 35), with algorithms to edit or clean the data, it is argued here that a visual approach should be considered. Visual approaches are especially important when considering non-motorised transport where use of speed attribution with algorithms alone may be misleading. The use of raw data attribution with secondary data, such as detailed census data for matching purposes have been proven to work (Ehrgott et al., 2012). This suggests that a visual approach where humans use their discretion based on additional detailed and reliable information – such as data from ordnance survey/OpenStreetMap/Google map/Bing map - could even be better when the temporal component is also visualised in a Space-Time Cube. However, for large-scale data collection, soft travel diaries such as the use of portable devices with integrated GPS sensors such as smart phones could be useful as demonstrated in San Francisco (Hood et al., 2011) and Portland (Broach et al., 2011); both examples from the US.

The use of GPS trackers and travel diaries in tracking daily mobilities offers an innovative means for gathering detailed information towards understanding transportation issues, especially when dealing with non-motorised transport. Approaches for tracking cyclists and the space-time cube based visual processing of data were discussed here. Despite the challenges we face, these approaches are promising and further research is needed. The outcome of such innovative approaches with detailed information can serve as an input to further transport related research such as non-motorised transport modelling. Challenging issues still remain: organisational and technical abilities; time and money among others. Daily mobilities are too important for all sorts of reasons to ignore (e.g. sustainable transport, employment exclusion, health for active living). In the 21st century, with all the technological advancement and technical knowledge, the DfT should be in a position to muster the resources and collect this type of data as it would significantly improve the explanatory power of our models in understanding daily mobilities for individuals and societies.

5.5 Exploratory Analysis using primary datasets

In the previous section on the exploration of available secondary data on cycling, it was pointed out that information on actual route choice preferences (for cyclists) is not collected in the UK, and a literature search confirmed this. We were therefore left with the possibility of collecting such datasets to aid in our understanding of urban cycling. In this instance, the effort made in data capture and refinement together with data analysis is considered. Local context is critical in understanding sustainable transport behaviour such as cycling. The absence of micro level mobility data results in researchers using rather crude ways of comparing and contrasting available information on transport behaviour (Susilo et al., 2012, p. 194). However, this chapter explores the collected micro level mobility data around the study area to enhance existing information on urban cycling behaviour. Descriptive statistics and spatial analysis techniques are applied on both the stated and revealed/actual preferences data of 79 adult utility cyclists to enable knowledge discovery via spatial information processing.

The exploratory analysis is undertaken in four stages looking at: the socio-demographic characteristics; stated preferences from travel diary; revealed preferences from GPS measured trips; and, perceptions and attitudes of regular adult cyclists.

5.5.1 Sample characteristics

It has been argued that sampling cyclists for a particular cycling research project is a challenging task for researchers (Krizek et al., 2009b). The idea behind the screening and sample size is to ensure the expected wide-range of activity and movement patterns (Van der Spek et al., 2009,

3052) is captured, as is relevant to the investigation given the findings from the explored secondary data along with the developed and selected instruments.

There were a total of 941 cycle trips by the sample of 79 adult cyclists, 319 trips of these made by females and 622 made by males. Weighted average distance per trip for both female and male were 3.5km and 5.4km respectively (Table 5-4). The average body mass index (BMI) for all the 79 cyclists was 23.3 kg/m^2 with a standard deviation of 3.4 kg/m^2. Average BMI for only female cyclists was 23.1 kg/m^2 and that of males was 23.5 kg/m^2.

Table 5-4: Gender versus number of cycle trips and distance travelled

Gender	**No.**	**Over one week period per person**					
		No. of Trips	Total distance km (weighted*)	Average km / trip (weighted*)	Average km/person (weighted*)	Min / Max (trip) km	Average BMI kg/m^2
Female	27	319	2137.4	3.5	41.1	0.25/13	23.1
Male	52	622	3373.0	5.4	64.9	0.12/36	23.5
Total	79	941	5510.4	4.5	53.0		23.3

* *Weighted by gender. Female distance value is weighted to control for gender imbalance using a factor of 52/27*

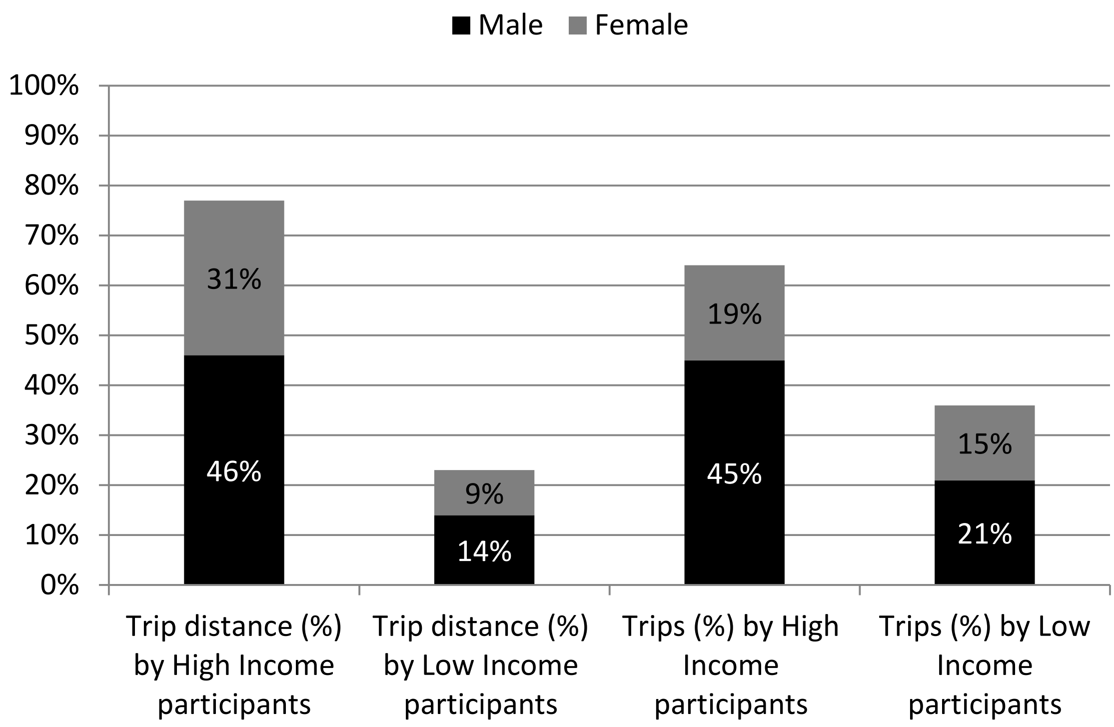


Figure 5-9: Percentages of distance and cycle trip by gender and income (High income is >£30,000 and low income is <=£30,000)

Note: £30,000 is based on rounded mean full-time gross weekly earnings for employees on adult rates from 2009 Annual Survey of Hours and Earnings (ONS, 2009, p. 11).

In this sample, cyclists with high annual income commuted more as shown in Figure 5-9. Despite the additional data collected for this research to deepen our understanding of urban cycling, a number of limitations similar to Dill (2009, p. s105) were also experienced here:

- most of the participants were everyday utility cyclists, suggesting that perhaps their route choices may differ from less experienced or occasional cyclists;
- the strategy used for the data collection may affect movement behaviour; limitations of the device in the form of battery life and urban coverage; and,
- forgetfulness on the part of some participants.

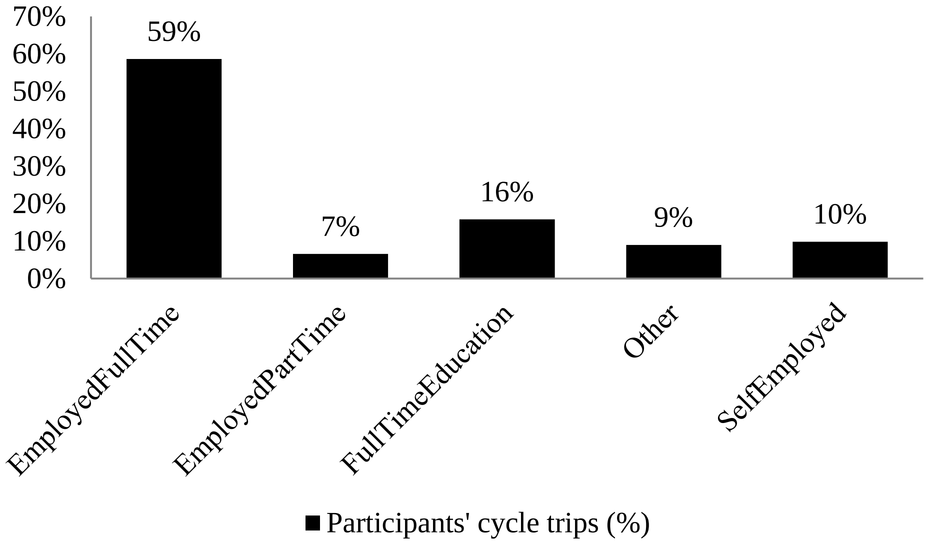


Figure 5-10: Cycle trips share per employment status from sample

The mean age was 38 years with a minimum of 23 years and a maximum of 67 years. In terms of employment, the highest percentage, 59%, of utility cycle trips were made by persons with full time employment status suggesting the possibility that full time employees were embracing cycling uptake within the study area (Figure 5-10). There was similar cycle trip share among married and single persons (Figure 5-11).

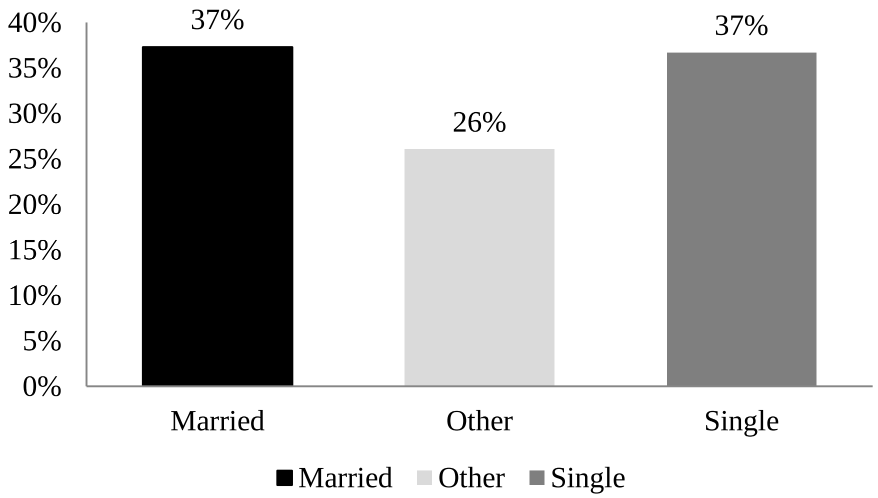


Figure 5-11: Cycle trips share per relationship status from sample

The mean years of cycling experience was 25.8 years ± 14 years. Apart from one participant who did not own a bike during the time of data collection, the entire sample owned a bike while about 58.2% owned a car. The average number of owned bikes was about 4 bikes with a standard deviation of 2.5. The type of bikes owned by the participants varied from folding bike (1.3%), hybrid bike (15.2%), mountain bike (11.4%), road bike (7.6%), and other various (64.6%) types comprising a combination of the previously stated ones with others.

Figure 5-12 shows that men in our sample cycle further than females confirming the weighted average distance per trip for both female (3.5km) and male (5.4km) as already shown in Table 5-4. The blue lines show movement behaviour of men in space and time while the red lines show behaviour of women. However, as it would be shown section 7.4.1 in Chapter 7, their relative cycling behaviour differences in terms of bike trip shares on/off/near the cycle network were quite similar.

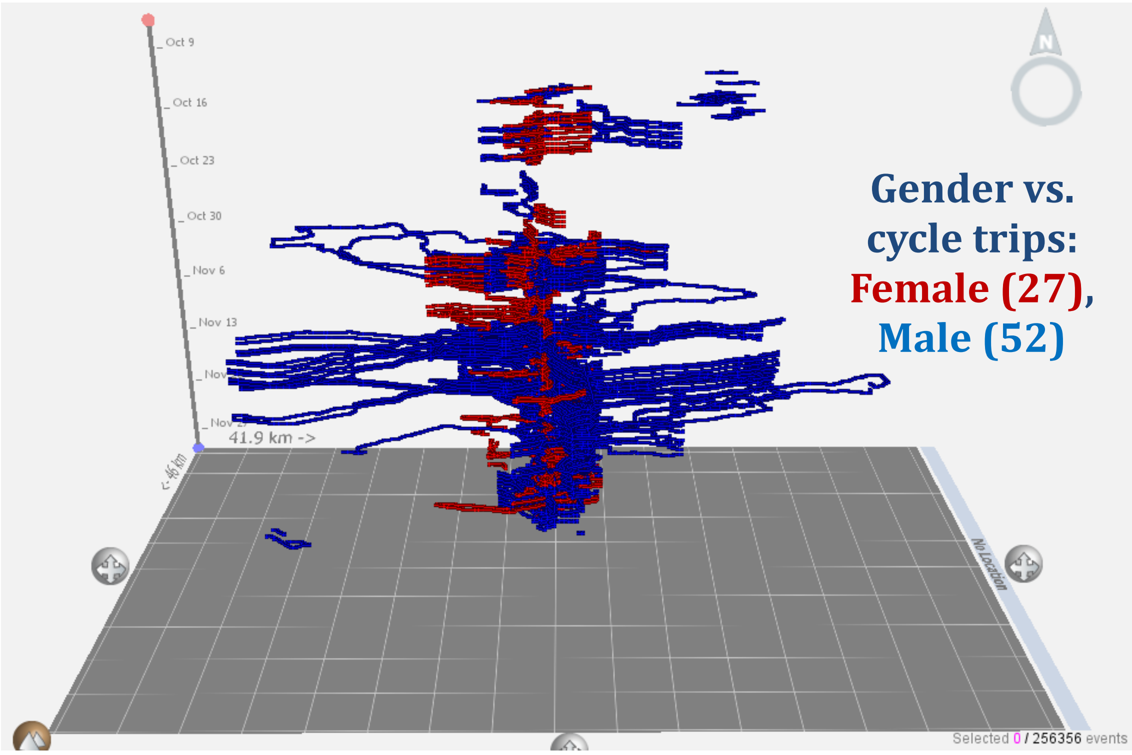


Figure 5-12: Space time representation of cycle trips based on gender categorisation

5.5.2 Overview of all travel diary trips

The reported travel modes by the participants have demonstrated that experienced cyclists may embrace integrated transport and are not always attracted to the use of the bicycle for several reasons. Out of the 2432 reported trips, 43% of participants' trips were actually reported to be cycle trips which are slightly less than combined trips for walking and car use (Figure 5-13). The *other* trips' mode comprised mainly motor bike, scooter, and running / jogging.

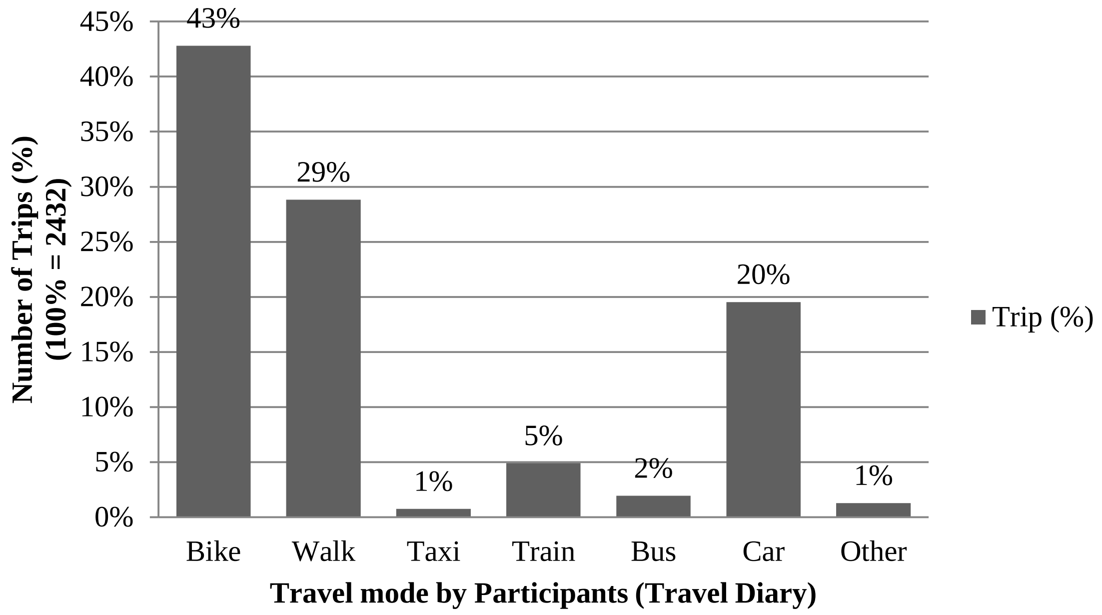


Figure 5-13: Reported travel mode by participants from travel diary

The total GPS logged points for the sample for the 7 day period were almost two and half million points using a log interval of 5 seconds. Thus, the smaller the logging interval the higher the likelihood of more point data which, if no careful consideration is given to data handling, can prove difficult in when it comes to data management and editing. For example, given a total 2,415,666 points in the case of this research, all merged data was impossible to be stored in MS Excel workbook given its limitation of 1,048,576 rows suggesting that without awareness, almost half of the point data will be lost in the course of editing or storage (Table 5-5).

Table 5-5: Summary of reported trips and logged GPS points

Item	Participants	All Diary trips	All GPS Points (Raw)	Only Cycle Trips (OCT)	OCT GPS points
Total	79	2,432	2,415,666	941	205,987

Given the fact that 941 trips were identified from the revealed route choice preferences (i.e. the GPS measured trips), 9.6% of the cycle trips reported in the travel diary were not recorded by the GPS device. The trend for reasons in data loss for cycle trips follow similar observations made by Dill (2009), suggesting that there are still challenges in the use of GPS technologies in capturing movement behaviours.

Any journey by a cyclist bounded by stops and identifiable in both a travel diary by reported journey purpose and GPS data by geometry is considered a cycle trip. The definition of utility cycling was discussed in section 1.2. The 941 trips comprise trip purposes such as:

- to work location (279),
- to work related task location (38),
- to food shopping location (46),
- to non-food shopping location (22),
- to school location (24),
- to a place to eat (15),
- to home location (361),
- to locations of social activities (30);
- to locations of friends and families (30),
- to other locations (66),
- and combination of such purposes but one purpose chosen as primary (30).

279 home to work commuting trips were identified using GPS tracks and diary (i.e. only trips made from home to work); 77 trips made by females and 202 trips by males. About 53.2% of the participants stated that they had “very good” health status. About 44.3% stated their health status was “Good” while 2.5% felt that theirs was “Fair”.

Table 5-6 shows the reported daily travel diary trips by mode of transport and suggest that the rate of cycling on Mondays, Tuesdays and Wednesdays were higher with 170, 189 and 183 trips respectively. The cycle trip rates in the weekends were comparatively lower than the weekdays with Saturday cycle trip rates being the lowest (i.e. 76 cycle trips). This low rate seems to have allowed use of car as a mode of transport during saturdays as the total trips by car was relatively higher (i.e. 117). However, this trend is not the case if all diary trips are considered. For all trips, Friday trips were more (i.e. 387) with Thursday closely following it with 382 multi-modal trips.

Table 5-6: Daily travel diary trip rates by mode of transport

Day of week	Cycle	Walk	Taxi	Train	Bus	Car	Other	Total Trips
Monday	170	88	2	8	10	65	3	346
Tuesday	189	90	1	15	4	39	9	347
Wednesday	183	102	0	17	5	51	3	361
Thursday	164	122	1	18	7	67	3	382
Friday	173	119	3	33	9	49	1	387
Saturday	76	98	9	16	8	117	7	331
Sunday	86	82	2	12	4	87	5	278
Total trips	1041	701	18	119	47	475	31	2432

Figure 5-14 shows a graphical perspective of daily travel for all modes of transport using the total number of 2432 trips as a base for calculating percentages for trip rates. Percentage of weekend car trips was more than weekdays. Trips by Bus tend to be relatively consistent throughout the week. Generally, preferred modes of transport by utility cyclists can be said to consist of mainly cycle, walk and car with few trips for train, taxi, bus among others.

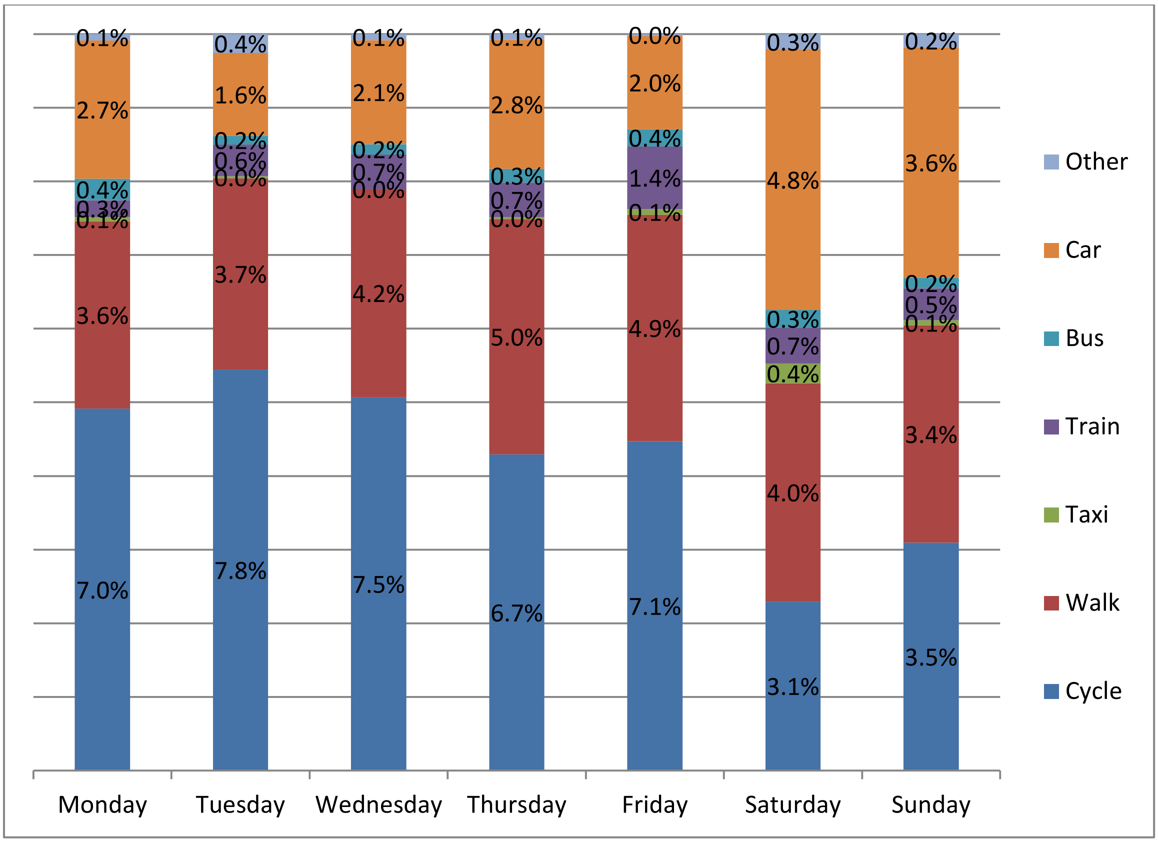


Figure 5-14: Percentage of daily trips by mode of transport

Table 5-7 and Table 5-8 show reported time (minutes) and distance (km) of daily diary trips by mode of transport respectively. The values show that variations in reported daily total time and daily total distance for cycle trips follow the trend for daily trip rates. As expected, reported daily distances for walking is relatively low and that of car and train was relatively high. Reported daily distances for travel by taxi and bus were relatively low; suggesting, perhaps, utility cyclists take these modes of transport only when it is necessary and at short distances. However, it could just be the case of reported low trip rates for these modes of transport.

Table 5-7: Reported time in minutes of daily diary trips by mode of transport

Weekday	Cycle	Walk	Taxi	Train	Bus	Car	Other	Total Trips
Monday	2,941	1,182	35	178	162	1,010	70	5,578
Tuesday	3,520	1,105	10	796	79	536	243	6,289
Wednesday	3,409	1,642	-	643	335	1,430	49	7,508
Thursday	3,046	1,660	17	1,091	125	1,572	105	7,616
Friday	2,803	1,557	35	1,241	158	1,137	20	6,951
Saturday	2,109	1,991	107	542	125	2,491	445	7,810
Sunday	2,220	2,812	21	370	60	2,983	115	8,581
Total trips	20,048	11,949	225	4,861	1,044	11,159	1,047	50,333

Table 5-8: Reported distance in km of daily diary trips by mode of transport

Weekday	Cycle	Walk	Taxi	Train	Bus	Car	Other	Total Trips
Monday	747	88	32	207	42	574	27	1,717
Tuesday	914	70	6	830	24	244	91	2,180
Wednesday	892	96	-	776	301	1,185	21	3,271
Thursday	774	114	10	1,855	41	1,268	416	4,478
Friday	685	136	15	3,258	54	855	5	5,009
Saturday	531	135	49	728	31	2,217	49	3,740
Sunday	471	185	9	607	16	2,592	24	3,904
Total trips	5,015	825	122	8,260	508	8,936	632	24,298

5.5.3 Central tendencies of cycling distribution from sample

Basic measures of central tendencies offer useful means of understanding quantitative datasets serving as a point of departure for further analysis. Although, admittedly, some of these measures such as mean and standard deviation have been used in the previous two sections, however the geometrical aspects of these measures were kept to be used in this section. Using the revealed route choice preference GPS data for the sample, measures of central tendencies (i.e. mean centre, median centre, central feature, linear direction mean, standard deviation, and standard deviational ellipse), already implemented in ESRI ArcGIS 10.0, are used to show standardised nature of the spatial distribution (Figure 5-15).

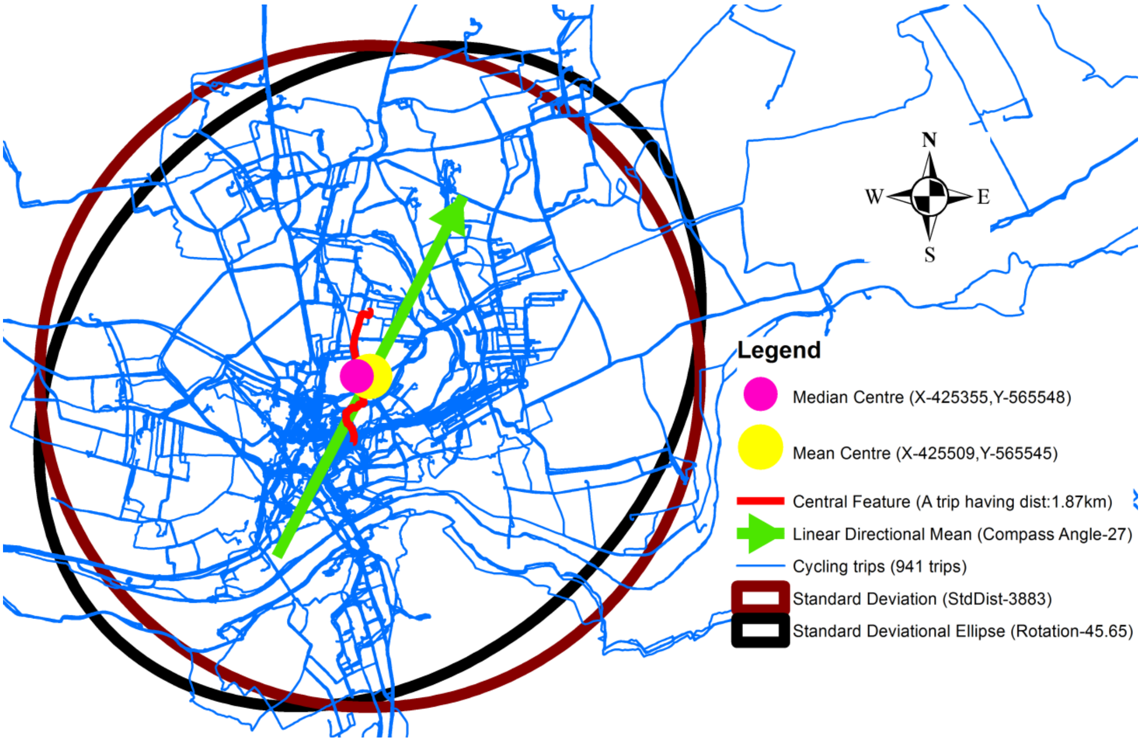


Figure 5-15: Overview of spatial distribution of participants' revealed preferences (GPS data)

The calculated mean linear directional cycling flow points to the north eastern part of Newcastle from the city centre (Figure 5-15). The standard deviation distance was 3.9km.

5.5.4 Perceptions and attitudes of utility cyclists

The baseline questionnaire (Form B of survey instruments) captures four groups of variables:

1. neighbourhood environment;

2. physical activity habits and past behaviour;

3. variables from the theory of planned behaviour (TPB) and related cognitions; and,

4. habit of using cycling.

These variables are used to explain perceptions and attitudes of the sampled cyclists, while a separate form captures their socio-demographic variables. The neighbourhood environment variables comprised of: residential density; land use mix (diversity); cycling facilities; traffic safety; and connectivity. The questions used to capture past behaviour of the cyclists (in 10 minutes minimum bouts) were informed by the recommendation for active transport for adults by UK Department for Health (DH, 2011). For capturing physical activity habits, the Self-Report Habit Index (SRHI) by Verplanken and Orbell (2003) which has been applied in the studying of active commuting habits by Lemieux and Godin (2009) as well as for studying physical habits by Verplanken and Melkevik (2008) informed the choice of questions. The socio-demographic factors comprise of age, gender, working/study status, body weight and height; using body weight and height to determine BMI.

The subjective nature of the inquiry on perceptions and attitudes demanded the level of measurement to be categorical responses coded as “ordinal” variables in SPSS. Likert type questions and scales were used in coding the data into SPSS (Section 5.1). Norman (2010, p. 631) summarises his study on Likert based measurements and statistical analysis as follows “*Parametric statistics can be used with Likert data, with small sample sizes, with unequal variances, and with non-normal distributions, with no fear of ‘‘coming to the wrong conclusion’*”. With this background, exploratory regression, a spatial statistical technique based on linear regression, is used to explore all captured variables later in this section. Each Likert-type question is treated as a response rather than as a Likert scale response (i.e. a score on the composition of Likert-type questions). All variables are treated as categorical ordinal (Boone Jr. and Boone, 2012), rather than continuous interval as a score and the outcome of the analysis is discussed below.

5.5.4.1 Cyclists’ perceptions about their neighbourhood environment

The majority (75.9%) of participants did not agree on the usage of sidewalks / pavements / footpaths for their cycling trips while agreeing (86.1%) that most of the streets in their neighbourhood had sidewalks / pavements / footpaths. Participants disagreed on availability of bicycle lanes (77.2%) and signage (51.9%) in their environment but remained somewhat undecided / agree (36.7%) when the question on whether it was safe to ride a bike was asked. Further measures on how they perceived safety from traffic was captured. The outcome suggests that about half of the sample (50.6%) agreed that there is not much traffic on the streets where they cycle. About half the sample (49.4%) agreed that the speed of the traffic is faster than 20mph, 57% of participants agreed that most drivers exceed their speed limits. On the presence of a lot of exhaust fumes from cars and busses within their neighbourhood, 59.5% of participants were in agreement.

Nearly half the participants in the sample (46.8%) disagree that the street design has few dead ends of cycling paths while two thirds (65.9%) agree there are many four-way road intersections in the neighbourhood. Regarding perception on residential density, they were of the view that the most common type of residence / building typology is row-houses (70.9%), followed by some apartments (53.2%), and then detached single-family residence (50.6%). For the majority of cyclists from the sample (96.2%), it takes less than 10 minutes to cycle to the nearest businesses/facilities from their home location. Examples of businesses/facilities they were instructed to imagine were grocery store, shopping centre, post office, library, bank, video store, bus stop, work and school. The majority of participants, 73.4%, have been living in the same neighbourhood for over 12 months. Finally, the majority of participants, 76%, reported that cycling constitutes about “61-100” % of their work/school trips and walking constitutes about “0-20”%.

5.5.4.2 Attitude, Norm, Behaviour, Intention, and Habit of utility cyclists

Most participants rated their attitudes on cycling regularly as satisfying (97.5%), energising (92.4%), pleasant (83.5%), advantageous (87.3%), and useful (95%). Three subjective norms were captured and they are as follows: The first suggests that 81% of participants agree if they were to use bicycle regularly. 64.6% of participants are of the view that most of the people who are important to them would recommend that they use the bicycle on a regular basis while 67% reported that their people would think they should use the bicycle on regular basis. In assessing participants’ perceived behavioural control, most of them agreed that: they are able to cycle on a regular basis (98.8%); it was up to them to cycle on a regular basis (98.7%); regular use of bicycle was easy (87.3%); they could easily cycle on a regular basis if they wanted (94.9%). As expected, the likelihood that most participants intended to (97.5%), would try to (98.7%), and would (93.7%), cycle on a regular basis within the normal week was high. The central tendency (i.e. mode) for all Likert item type questions asked on habitual status of participants is strong agreement. They agreed (i.e. agreed and strongly agreed) that using a bicycle to commute is something: they did frequently (96.2%); they did without having to consciously remember (84.8%); that made them feel weird if they do not cycle (62%); that would require effort if they do not cycle (46.9%); that belonged to their daily routine (84.8%); that they started doing before they realised they were actually commuter cyclists (53.1%); that they have no need to think of doing it (69.6%); that they think of as “typically me” (74.6%); they had been doing for a long time (81%). The higher scores on habit are in line with Lemieux and Godin (2009) study in Canada suggesting that habit plays an important role in cycling.

5.5.4.3 Assessing correlations with Exploratory Regression

As expected, given the nature of the sample and linearity of Ordinary Least Squares (OLS) and Moran's I (MI) spatial autocorrelation, none of the 57 explanatory variables passed all six criteria for the exploratory regression (ER). The ER approach was discussed in detail in section 3.11.3. Nevertheless, the results from the ER were useful in understanding explanatory variables that could be of significance and also assisted in reducing the number of variables to a smaller size. The dependent variable was determined as the frequency or number of utility cycling trips (i.e. uctrips) per participant over the one survey week period. Three models, with a specified min/max explanatory variables of 5, were found to have the highest adjusted coefficient of determination with R^2=0.39. This means that the three models in Table 5-9 explain 39% of the variation in frequency of cycling trips (the dependent variable).

All three models suggest that utility cycling in the area is significantly (p=0.01) correlated to habit, attitudes on satisfaction and energisation as well as past cycling behaviour. This finding partly confirms Lemieux and Godin's (2009) study on predicting active commuting behaviour and suggests that cycling behaviour correlates significantly with habits, intention and age with habit being the most significant predictor. Finally, Models 1, 2 and 3 suggest that significant correlations to actual (not stated preference) cycling behaviour relates to availability of cycle lanes, trip distance, and body mass index respectively. The findings also partly confirm Dill and Voros (2007) findings that positive perceptions of availability of cycle lanes are associated with cycling and the willingness to cycle more. Their project examined the interaction between community level environmental factors such as cycle lane and people's decision to cycle using intervening factors such as attitudes, perceptions of both subjective and objective factors, as well as socio-demographics. Dill and Voros (2007) survey was based on a random sample of adults in Portland (US). They concluded by pointing out that both subjective and objective measures of cycle behaviour needed to be explored further.

Table 5-9: Models showing Highest Adjusted R-Squared Results (*=is significant at 0.01)**

Model 1				
-Q0201*** (LanesAvailable)	-Q0802ORIG*** (PrevMonthTrips)	+Q0901*** (Attitude on satisfaction)	-Q0902*** (Attitude on energisation)	+Q1309*** (Habit)
Model 2				
-CALDIST*** (Calculated trip distance)	-Q0802ORIG*** (PrevMonthTrips)	+Q0901*** (Attitude on satisfaction)	-Q0902*** (Attitude on energisation)	+Q1309*** (Habit)
Model 3				
-CALCBMI*** (Calculated BMI)	-Q0802ORIG*** (PrevMonthTrips)	+Q0901*** (Attitude on satisfaction)	-Q0902*** (Attitude on energisation)	+Q1309*** (Habit)

5.6 Comparison of primary data with available secondary data

This section discusses the commonalities and differences of the primary data with available secondary data. Despite the deficiency in available data which do not permit comparison of actual route choices taken by the participants in this study, it is still possible to make some comparisons but at the descriptive level. It is important to suggest that this research does not claim full representation of the population. Houston (2014, p. 46) in examining the effect of the (south Los Angeles, California) built environment on moderate and vigorous physical activity using GPS and accelerometer, concluded by preceding their findings with a caveat that "Although the size and geographic and socio-demographic scope of the sample limit the generalizability of findings…." and suggested that placing findings in proper context matters. It is however useful to provide some perspective of how the sample relates to available secondary data to help the reader better understand the extent of generalizability of the findings.

We first (loosely) compare gender representation in the primary data with that of the UK 2011 Census analysis for cycling to work covering England and Wales (ONS, 2014). The released findings from the Census data analysis suggest that Newcastle recorded about 81% increase of number of people cycling to work over the decade (2001 to 2011) and the same source also suggest that "Males were more likely to cycle to work than females (3.9% of male workers compared with 1.6% of female workers)" (ONS, 2014, p. 1). This means that the ratio of women to men could be estimated as 0.4 (i.e. 1.6/3.9). This ratio is very close to the gender ratio in the primary data given that the ratio of number of women to men utility cyclists in the primary data is 1:2 (or 0.5 or 27/52). It is therefore possible to argue that the gender ratio of the primary data reflects the national gender ratio with slight over sampling of women. Perhaps it is the case that women tend to be oversampled as Broach et al. (2012, p. 3) study reported similar oversampling stating that "Although regular cyclists are more likely to be male (80% according to the phone survey), we oversampled women, resulting in a GPS sample composed of 44% females. Among all respondents, 89% were between the ages of 25 and 64." However, caution still needs to be taken given that we are considering commuters at the national level and utility cyclists (which include commuters based on the definition in this research) regarding the primary data. Furthermore, at the national level (i.e. Great Britain), the 2011 National Travel Survey, aside its " annual volatility in the cycling data because of the relatively small number of cyclists in the NTS sample" (DfT, 2012a, p. 4), reports that "Cycling is most prevalent among men than women (23 trips person per year compared to 8 trips)" (DfT, 2012a, p. 11). In terms of age, the peak age group cycling to work is younger than that of the primary data. According to the released findings "Cycling to work was most common among those aged 30 to 34 with 3.5% of workers in this age group cycling to work. Up to 60 years of age, the rate of cycling to work was above 2% for all age groups" (ONS, 2014). The primary data revealed a mean age of 38 years; slightly older but still within the thirties.

Another perspective is provided by comparing the primary data with already analysed Tyne and Wear Household Survey data which has been presented in Chapter 4. First of all, since the spatial analysis of the Tyne and Wear Household Survey data informed the choice of the study area, it is safe to argue that the primary data reflects the spatial variation of cycling within Tyne and Wear as can be seen in the plotted locations of the participants (Section 4.3). The spatial representation also reflects the analysis of the Newcastle Cycling Campaign 2010 Petition Survey data as well as the counter data (Section 4.2). Secondly, the Tyne and Wear Household Survey data reveals women to men ratio for only cycling mode as 0.3 (i.e. 160/540) suggesting that men cycle more than women and it is about three men to one woman ratio. This finding further explains the oversampling of women issue already discussed in this section. Thirdly, Tyne and Wear data analysis suggested that the 35-44 age group was the most frequent cycling activity in Tyne and Wear. The mean age of 38 years, computed from the primary data, falls in this age group suggesting that the primary data fairly reflects the cycling age for the area. The evidence so far also shows that the age group with most frequent cycling activity in Tyne and Wear is not same nationally (i.e. England and Wales) and that the group (i.e. 35-44 years) is older than the national age group (i.e. 30-34 years).

5.7 Systematic comparison of GPS data with travel diary data

The ability for this research to measure urban cycling behaviours both subjectively and objectively makes comparison of the two timely. The timely nature of such a comparative study is based on Mackett and Brown's (2011) observation that few studies have captured and explored both objective and subjective measurements within the context of physical activity such as cycling. Similar to Chen et al.'s (2010) conclusion, the analysis in this section will add to the palette of evidence on using GPS technology in travel surveys. The best way forward is to examine common properties of both the GPS data and the travel diary data.

Table 5-10 shows possible variables that could be used as bases for comparing GPS data and travel diary data. Chained Trip here means a concept of trip chaining as defined by US Department of Transport in their 2001 National Household Travel Survey which is "any travel between two anchors (we call this a tour, such as between home and work) that is direct or has an intervening stop of 30 minutes or less" (NHTS, 2001). Although comparing chained trip is possible in this research, the required time to extract and code all multimodal journeys from the GPS data to enable comparison with the travel diary data (which has been manually coded for all modes despite the tediousness) will make the research project impossible to complete within the time frame and is therefore considered as future work.

Table 5-10: Overview of possible variables for comparing GPS data and Travel diary data

Variable	GPS data	Travel diary data
Trip Distance (TD)	Measured distance	Perceived distance
Trip Time (TT)	Measured time	Perceived time
Trip Origin (TO)	Measured start location of journey	Reported start location of journey
Trip Destination (TD)	Measured end location of journey	Reported end location of journey
Single Journey/Trip (SJ/ST)	Measured trip trajectory	1) Euclidean/Manhattan distance between TO and TD 2) Distance generated from transport network using reported TO and TD
Chained Trip (CT)*	Measured chained trips	Reported chained trips

*Not considered in current study.

Table 5-11 shows the extent of use of both the GPS device and travel diary by all respondents. Overall, 73% (i.e. 100*(81/111)) of respondents, who were screened as utility cyclists, were interviewed face-to-face whilst 71% accepted GPS device at placement interview and used and completed a week travel diary (Table 5-11). Details of the recruitment process and GPS tracking of the cyclists have been discussed in sections 5.2 and 5.3. Since this research is more focused on utility cycling rather than all modes of transport, the comparison shown in Table 5-11 is about an overview of how cycle trips were captured using GPS device and travel diary by utility cyclists. However, extra effort was made to manually code all trips in the travel diary, but only cycle trips in the case of the GPS data as it was considered outside the scope of the research boundary and also would be time demanding considering the project timeline. Other cycling researchers who administer GPS devices in their survey design take some risks (such as high tendency to lose GPS device) to avoid collecting other data from other modes of transport. An example, Broach et al. (2012) study where participants clipped the portable GPS device on their bicycle suggesting that the GPS device is only used when participants use their bicycle to travel; thereby making trips made exclusively on bicycle available for analysis (Dill and Gliebe, 2008, p. 1). In this research, the pilot study suggested that mounting the GPS device on the bicycle was perceived to be too risky based on feedback from (pilot) participants suggest that the tendency of loss of (limited) GPS devices was high.

Anderson et al.(2009) GPS feasibility study, in the UK, suggests mixed findings regarding whether the total number of GPS trips should be more or less than the diary trips. In their study, they found that there were days in both data collection wave 1 and 2 where number of diary trips actually was more than GPS trips (Anderson et al., 2009, p. 48). In this study, as shown in Table 5-11, 91.6% (i.e. 954/1041 time 100) of cycle trips had GPS data suggesting that about 8.4% of reported cycle trips in the travel diary were not captured by the GPS device. Moreover, the line of distinction between their findings and that of this research is that of scope; whilst their analysis was multi-model in scope, the analysis in this section is precisely pointing to only utility cycling. That notwithstanding, evidence from Dill and Gliebe (2008)'s study, in Portland, which was about understanding and measuring bicycling behaviour using GPS with focus on only cycling trips (like this research) concluded that total number of cycling trips was underreported by about 8%. The findings in the study in Portland confirm the 8.4% underreporting found in this research. This is interesting as the research design was completely different in the sense that this research instructed participants to carry the GPS device the whole week logging all modes of transport and filling a hard-copy travel diary whilst that of Portland's study utilized GPS device with an interactive interface to input other information along with measuring cycling trips without consideration to any other mode of transport. Bringing these findings together provides profound empirical foundation for further research based on a different research design to ascertain whether the reverse of the findings can be reached.

Table 5-11: Overview of GPS device and Travel diary use by utility cyclists

Description	Total number of Respondents (R)	Total Number of cycle trips per R (GPS;Diary)	% of R interviewed	% of R completed diary	% of R used GPS
Utility cyclists screened from 108 email responses (and invited for face-to-face interview)	111	-	-	-	-
Attended interview (and collected and returned survey materials)	81	-	73%	-	-
Completed a travel diary in full	79	(954**;1,041)	71%	-	-
Accepted GPS device at placement interview (and used and completed a week travel diary)	79	(954**;1,041)	71%	100%	100%
Used GPS device (and completed travel diary) – but no GPS data due to faulty device	0	(0; 0)	0	0	0
Used GPS device for some days (and did not complete travel diary in full)	1	(ignored)	1%	1%	1%
Used GPS device, data received – but did not complete part of travel diary)	1	(ignored)	1%	1%	1%
Used GPS device for all cycle trips but device did not record 88 of the reported diary cycle trips	30	(394;481)	27%	38%	38%
Used GPS device for all trips without problems	79	(954**;1,041)	71%	100%	100%
Used GPS device for all trips without problems but some part of 8 cycle trips logged were incomplete.	6	(70;70)	5%	8%	8%
Base*	81		111	79	79

*Total number of respondents who were interviewed/completed a travel diary or used GPS device

**941 selected finally for analysis.

We now examine, in detail, the characteristics of weekday cycle trips recorded by comparing trip rates, distance, and time from the GPS data (i.e. complete trip capture) and travel diary. For the purposes of comparison of two types of datasets, all cycling trips were included in the analysis. Table 5-12 shows detailed comparison of GPS data and travel diary data using counts of daily cycling trips and respective distance and time. The findings suggest that cycle trips captured by the GPS device were under reported against the travel diary trips when day of week categorisation is considered.

Table 5-12: Comparison of GPS data and travel diary using total daily cycling trips with associated distance and time

	GPS			Diary			Difference (Diary-GPS)		
Day of week	Trip count	Distance (km)	Time (Min)	Trip count	Distance (km)	Time (Min)	Trip	Distance	Time
Monday	154	698	2,747	170	747	2,941	16	50	194
Tuesday	170	847	3,242	189	914	3,520	19	68	278
Wednesday	172	844	3,240	183	892	3,409	11	48	169
Thursday	153	732	2,887	164	774	3,046	11	42	159
Friday	158	667	2,661	173	685	2,803	15	18	142
Saturday	66	432	1,719	76	531	2,109	10	98	390
Sunday	73	270	1,342	86	471	2,220	13	202	878
Total	946	4,488	17,838	1,041	5,015	20,048	95	527	2,210

Table 5-13 shows that there was significant difference between stated distance and time expenditures against their corresponding GPS data for the cycle trips. This means that how the participants perceived distance and time was significantly poor; thus, it was unlikely that a participant would correctly estimate the actual distance or time of a particular trip if given one in twenty chances. This is further evidence that objective measures are needed to allow comparison with subjective measures. The findings also suggest that utility cyclists' perception (i.e. reported or stated time/distance) of time and distance is different from what was actually recorded. This could mean that completed reliance on findings related to utility cycling as bases for policy formulation may be problematic.

Table 5-13: Stated versus Revealed distance and time expenditure (Test Statistics[a])

	Revealed versus Stated distance (Measured vs. Recorded)	Revealed versus Stated time expenditure (Measured vs. Recorded)
Z	-6.501[b]	-14.739[b]
Asymp. Sig. (2-tailed)	.000	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

5.8 Discussion

The weighted average distances of the measured cycle trips were 3.5km for female and 5.4km for male cyclists. These distances together with the overall average single trip distance of 4.5km were slightly higher than reported average urban cycling journey of 3km and fall within the normal range of 1-5km in Britain from the standpoint of "neighbourhood planning" (Barton et al., 2010, p. 146). Given that the composition of cycle trips of our sample participants are utilitarian in nature, a loose comparison suggests that the computed average single trip distance of 4.5km is closer to a Dutch study where they found that the average single trip distance to work was 6.0km (Engbers and Hendriksen, 2010). In our case, the observed averages, however, fell below the reported maximum distance of 8km (Barton et al., 2010). The standard deviation of distance was 3.9km for all measured cycle trips. Participants with higher income (above £30K) constituted 65% of utility cycle trips amounting to 77% of total distance. The findings on cycle trip share by income group was similar to share by employment type suggesting that the facilities at workplace destinations as well as incentivisation schemes may be available, conducive and encouraging for employees to take up cycling to work.

The high correlations of cycling with availability of cycle lanes, BMI, distance, attitudes (i.e. satisfaction and energisation) as well as habitual cycling suggest the need for the provision of more bicycle lanes. In addition, the promotion of cycling as a means of transport with a health tag to facilitate the reduction in weight can support efforts to ameliorate obesity and its related diseases in communities. The BMI average of 23.3kg/m^2 with standard deviation (SD) of 3.4kg/m^2 for the sample (age range: 23 to 67) in this study was 1.3 points higher than Lemieux and Godin (2009) who reported BMI average of 22.0kg/m^2 (SD=3.4kg/m^2) for age range from 19 to 48 years and mean age of 24.0 ± 4.9 years. The mean ages for the two samples were however different. This study had mean age of 38 years (SD=10.3) with a minimum of 23 years and a maximum of 67. The older sample of our study explains the overall higher BMI; nevertheless, these findings suggest that cyclists tend to have an ideal weight according to the World Health Organisation (WHO) weight groupings according to BMI. According to Yang and French (2013), the WHO weight groupings according to BMI values could be defined as follows: “BMI < 18.5 kg/m^2” for underweight, “18.5 kg/m^2 ≤ BMI < 25.0 kg/m^2” for ideal weight, “25 kg/m^2 ≤ BMI < 30 kg/m^2” for overweight, and “BMI ≥ 30 kg/m^2” for obese. These values along with the findings clearly position cycling as a very attractive way of tackling obesity and promoting healthy lifestyles. The stated health status of the sample participants also confirms that cyclists tend to be healthier as nearly all the participants were of the view that they had good health. Despite the low uptake of cycling in the UK, it is considered as one of the “wonder drugs” and “miracle cures” in tackling health problems among the population, according to the Chief Medical Officer of the UK Department of Health (CMO, 2009). Recent investments in cycling indicate the seriousness being given to it by politicians too (DfT, 2013j).

The systematic comparison of GPS data and travel diary data in this chapter suggest 8.4% under reporting of the former.

Reflecting upon the experiences in this research and in relation to the decision by the DfT to stop using GPS trackers in the NTS from 2013 onwards, whilst our evidence (GPS data for cycling only) show that GPS data under reports by about 8.4% compared with travel diary data, we are concerned that this is likely to slow down advancements in GPS-enabled data collection, processing and analysis methods in this field as evidence of mixed findings exist (Section 8.6). The DfT has admitted that there is a lack of GPS based data processing and analysis methods, despite the claim that consultation respondents as well as DfT were in support of the GPS tracking approach (DfT, 2012d, p. 16).

The next two chapters will be focusing on specific aspects of the preliminary analysis presented in this chapter, employing more advanced analytical techniques such as profiling of activity spaces using space-time, action space theories and visual analytical framework (Chapter 6), statistical hypothesis testing and corridor space analysis (Chapter 7). Such in-depth empirical analysis is deemed necessary before conclusions are reached and policy implications and recommendations are discussed in the final Chapter 9.

CHAPTER 6. PROFILING AND VISUALISING ACTIVITY SPACES

6.1 Introduction

The main goal for visualising data in a scientific way by creating and viewing imagery derived from data is to increase human understanding of complex processes (Buliung and Morency, 2009, p. 120). Schonfelder and Axhausen (2010, p. 189) conclude that there is a likelihood of activity-space approach to physical-activity analysis (such as the analysis in this chapter) receiving much attention in the developed world. They argue that transport and urban planning are major actors in providing cycleable environments and activity-space approach to travel behaviour analysis can provide appropriate indicators of activity and movement to identify strategies that support physical activities such as cycling. Very little is known about the visualisation of actual urban cycling behaviours in available literature; particularly, when it comes to our understanding of individual level cycling behaviours in the British geographical context (Goodman, 2013). This is partly due to lack of spatio-temporal information which is needed as an input, and also due to the limited diffusion of innovative approaches for producing visualisation that add to the existing body of knowledge. This chapter contributes to the call for further research in detection and representation of activity spaces from portable GPS trackers, within the context of mobility pattern research (Thierry et al., 2013, p. 9). According to Andrienko and Andrienko (2013b), very little is known about the analysis of movement data in an explicit context. The term *context* is a vague and even versatile term in Visual Analytics (VA) since VA itself is quite broad. This thesis follows Tomaszewski and Maceachren's (2010) views on conceptualisation of *context* which makes the assumption that *context* is based on a fixed set of pre-determined descriptively well-defined terms used for processing and integrating information. Therefore, the contribution made in this chapter is the use of movement data from urban utility cyclists explicitly along with other terms which will be introduced in subsequent sections. The chapter applies techniques from VA in combination with concepts from space-time geography to examine movement behaviour of urban cyclists. The major concepts that the chapter draws on are the *activity space* and the *space-time cube*. These concepts have been discussed in the literature review (Sections 2.8, 2.8.4) and are described in the methods chapter (Section 3.4.5). To establish a link with those sections, the utility of STC in visualising event data is briefly discussed here.

From a space-time visualisation perspective, several questions have been raised about how complex data can be visualised in STC. Some of the questions raised by Kraak (2003) are “Can the user understand the cube when multiple Space-Time-Paths are displayed?” and “What should the STC interface look like?”. To enable meaningful visualisations, the approach taken in this chapter draws on the visualisation approach suggested by Kapler and Wright (2004) which provides several ways of generating graphs from spatio-temporal data. Their tools have been developed as commercial software called “GeoTime” and this is available to purchase at www.geotime.com. All graphs with a temporal dimension in this chapter have been developed using a 3D approach in GeoTime. Other related software exists but is not easily accessible or usable, except mostly used by the main developers and close collaborators as technical support and documentation is not easily available. Two such examples are the Activity Pattern Analyst (APA) developed by researchers from China and USA (Chen et al., 2011). The APA was used to explore some 19, 691 stationary activities derived from a stated preference survey of urban residents in the Beijing metropolitan area collected in 2007. Chen et al. (2011) developed a ‘‘space–time path generation’’ function to build individual space–time paths from the activity diary dataset, alongside basic filtering functions. *V-Analytics* software, also known as *CommonGIS* with prototypes available online: http://geoanalytics.net/and/demonstrators.html. The software contains several implementations of visual analytical techniques including the STC. Andrienko and Andrienko (2013a) provide examples of how CommonGIS could be used to visualise spatio-temporal movement data such as GPS trajectories of about 17,241 cars collected during one week in Italy. However, very little is known about the use of STC in visualising movement data of cyclists. Kraak (2003, p. 1988) suggests the creative use of STC because an alternative perspective of a dataset has the potential to “sparkle the mind with new ideas”. Because of the spatio-temporal characteristics of the STC, it is possible for one to examine, for example, the peak time estimates of an event along with its spatial orientation.

This chapter is to analyse, visualise and explain activity spaces of actual movement behaviours of urban cyclists using the primary dataset collected during the course of this research. Part of this chapter has been presented in the GIS Research UK 2014 (GISRUK2014) Conference by Alvanides and Yeboah (2014). VA provides the conceptual framework for the analysis and visualisation process. The results of the analysis in this chapter involve data abstraction and generalisation; Andrienko and Andrienko (2013a, p. 56, 81) in a study about *visual analytics framework for spatio-temporal analysis and modelling*-suggest that:

“It is now widely acknowledged that complex real-world data cannot be properly and/or efficiently analysed using only automatic computational methods or only interactive visualisations. […] From the statistical analysis and modelling perspective, we suggest a combination of visual, interactive and computational techniques supporting model building and

evaluation. From the perspective of spatio-temporal analysis, we suggest an approach to spatio-temporal modelling by decomposing the overall modelling task into spatial and temporal modelling subtasks."

This chapter draws on both suggestions. The activity space and space-time concepts are utilised to address the second of the suggestions which is from the perspective of spatio-temporal analysis, while Local Moran's I statistics were used to address the former.

The next section proposes a visual analytical framework for the investigation of movement behaviour of cyclists based on suggestions from Andrienko and Andrienko (2013b) and related recent literature. This is followed by a section describing the specific datasets used for the analysis in this chapter. Section 6.3 discusses the profiling of activity spaces using areas frequently visited by the cyclists in the primary data. Sections 6.4 and 6.5 use Local Moran's I (LMi) statistics to explain statistically significant areas using the spatio-temporal attributes of the same dataset. Orellana and Wachowicz (2011) successfully utilised LMi as a statistical approach to explore movement data of pedestrians, such as urban outdoor gamers and visitors of a national park. Concepts like "movement vector" and "movement suspension" were used with the former being a directed line segment from an origin point and implicitly considered as a property of (activity) space. The latter represented the (activity) places where the pedestrians' movement is temporally suspended by physical restrictions such as the route choosing points of a park. The use of the term "movement suspension" rather than "stops" was to suggest the fact that reduction of speed associated with stopping behaviour had occurred. Similar notions were used in this chapter but with focus on cycling. Although STC was discussed by Orellana and Wachowicz (2011) it was not part of the results, limiting the outputs to two-dimensional visualisation in Euclidean space together with graphs from the LMi. This seems to be due to the fact that strict focus on LMi as an exploratory statistical approach was decided as part of their study design. The use of LMi together with STC for analysis and visualisation of movement data from cyclists is therefore a contribution of this thesis. This chapter concludes with a discussion of the major findings from profiling and visualising activity spaces of cyclists.

6.2 Data

The first step of developing a VA approach is to pre-process as well as transform all possible heterogeneous datasets in an input-ready status (Keim et al., 2010, p. 10). Four datasets are used in this chapter:

1. Cycle trips from the primary data collected in this study;
2. The 2011 Census Output Areas (OAs);

3. The 2012 electoral ward administrative boundaries from ONS; and,

4. All modes of transport from the utility cyclists sampled in this study.

The first dataset comprised of only the cycle trips extracted using the STC based processing technique already discussed in section 5.4, with the associated descriptive statistics presented in section 5.5. The second dataset was the 2011 Census OAs, the lowest official geographical unit in the UK, built from clusters of postcodes and designed to preserve confidentiality (ONS, 2013b). Despite the original use of OA areas for census statistics, it also provides sound bases for researchers to undertake low level data analysis without giving away sensitive individual information. For example, Daniel and Bright (2011) used the first wave of the Wealth and Assets Survey together with OA areas to provide an in-depth understanding of the geographical distribution of wealth and its related components. Areas exhibiting common demographic and socio–economic characteristics, from relatively high to low levels of aggregation while overcoming the disclose problem, were mapped, graphed and tabulated. Daniel and Bright (2011) concluded that OA based analysis further enhances our understanding of geographical trends. The 2012 electoral ward administrative boundaries from ONS covering the study area were the third dataset. Unlike the OA, the electoral ward is recognised as a spatial unit used for electoral purposes of local government councillors in districts and unitary authorities (ONS, 2013a). The use of such geographical units for cycling research has been employed elsewhere in a Bicycle Study in New Zealand where addresses of participants were aggregated into a mesh-block (Tin Tin et al., 2010, p. 55). The fourth dataset comprised all modes of transport taken by the tracked cyclists (i.e. bike, car etc.).

A brief description of the process used to clean the multi-mode dataset follows. The raw GPS data from the GPS devices were downloaded as a comma separated values (csv) file, and transferred to a Microsoft Access 2010 database. The raw data containing all modes of transport had some noise involving wrongly registered time stamps as shown in Figure 6-1. Such wrong registrations occurring in-between GPS fixes were removed except pointsets with dates that fell on October and November 2011 as shown in Figure 6-1. This was completed using the *sorting* together with the *copy* and *delete* functions in MS Access 2010.

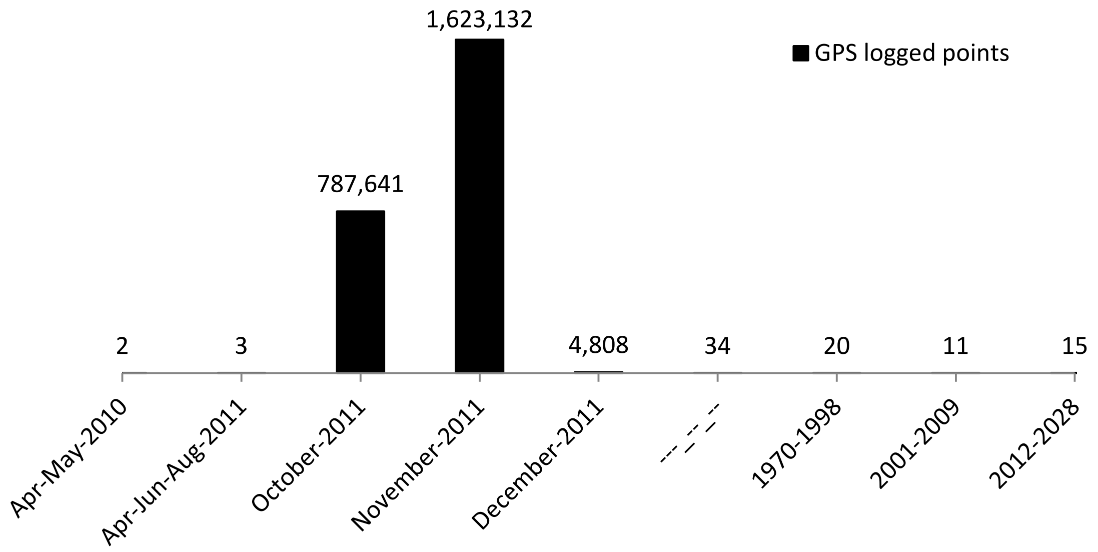


Figure 6-1: Total GPS points logged during data collection (*n= 2,415,666*)

The total number of logged points was 2,415,666, subsequently reduced to 637,447 based on suggestions from literature and own discretionary choices shown in Table 6-1. Ogle et al. (2002) suggest that positional dilution of precision (PDOP) and HDOP values greater than four are generally unreliable and so they were removed after random checks. Bohte and Maat (2009) found out that speed over 200 kmph was unrealistic in their dataset. Random checks in the dataset used for this study agreed with this finding and therefore points with speeds exceeding 200 kmph were removed. Logged points with speed attributes below 2kmph were assumed to be stationary points and were also removed, following Chung and Shalaby (2005) who suggested that general walking speed falls between 2~6kmph. All logged points with validity status of “NO FIX”, negative distance values, extreme values of height, longitude and latitude were also removed.

Table 6-1: Applied criteria for refining the fourth data in this chapter

Item	Number of points (Before)	Criteria	Number of points remaining (After)	Comment (including supporting literature where necessary)
Total points	2,415,666	Points from raw data of 79 cyclists	2,415,666	The original data
Only Oct.-Nov. points	2,415,666	Only Oct. & Nov. 2013. Also blanks and strange characters	2,410,773	No extra checks
Validity	2,410,773	NO FIX	2,408,877	No extra checks
PDOP Precision	2,408,877	"PDOP" >= 4	2,312,668	(Ogle et al., 2002) + random checks visually
HDOP Precision	2,312,668	"HDOP" >= 4	2,312,659	(Ogle et al., 2002) + random checks visually
Height	2,312,659	–ve/+ve values with extreme exponents (Exp $^{>+XX}$)	2,312,642	Sorting checks in database
Negative speed	2,312,642	Speed < 0 kmph	2,312,642	Sorting checks in database
Bad Lon/Lat values	2,312,642	Non-plottable / strange values with Exp $^{+2X}$. Also Lon/Lat=0	2,312,562	One lat. was 28675.78529
Unrealistic speed	2,312,562	Speed > 200 kmph	2,310,912	(Bohte and Maat, 2009)
Negative distance	2,310,912	Distance<0 km	2,310,912	Sorting checks in database
Stationary points	2,310,912	<2km/h	637,447	(Chung and Shalaby, 2005)

Flow of steps for the refinement

6.3 Profiling activity spaces from actual cycling flows

The aim of profiling activity spaces of actual cycling flows is twofold: first, to identify *stationary activity spaces (SAS)*; and, second, to find the *motile activity spaces (MAS) as shown in* Figure 6-2 and Figure 6-3. It is proposed here that these activity spaces should rely on basic geographic units of the area of study. Where these geographical units do not exist, equally gridded blocks of spaces may be considered. The fusion of spatially configured space (i.e. the basic geographical units) and the activities provide a practical way of identifying frequented areas interacted by cyclists.

The conceptualisation of space-time map is constrained by the potential path area (PPA) concept entrenched in Hägerstrand's space-time theory. As Golledge and Stimson (1997, pp. 267-268) note, the practical way of realising such a map is to "try and define bounded region of time and space and to treat everything in it as a space-time" activities … therefore permitting "the physical boundaries of space and time to be evaluated"…with an attempt "to capture [and examine] the complexity of interactions at the scale of the smallest unit". PPA has been discussed in section 2.8. The proposed case is that within these PPAs which serve as input to the formation of prisms of individual *activity space*, an *activity* could further be subdivided into *stationary* and *motile spaces*. At an aggregation level, the notion of significance of these two subdivisions of activity may be presented using standard confidence ellipses. Such ellipses are very useful in understanding spatial behaviour (Schonfelder and Axhausen, 2010).

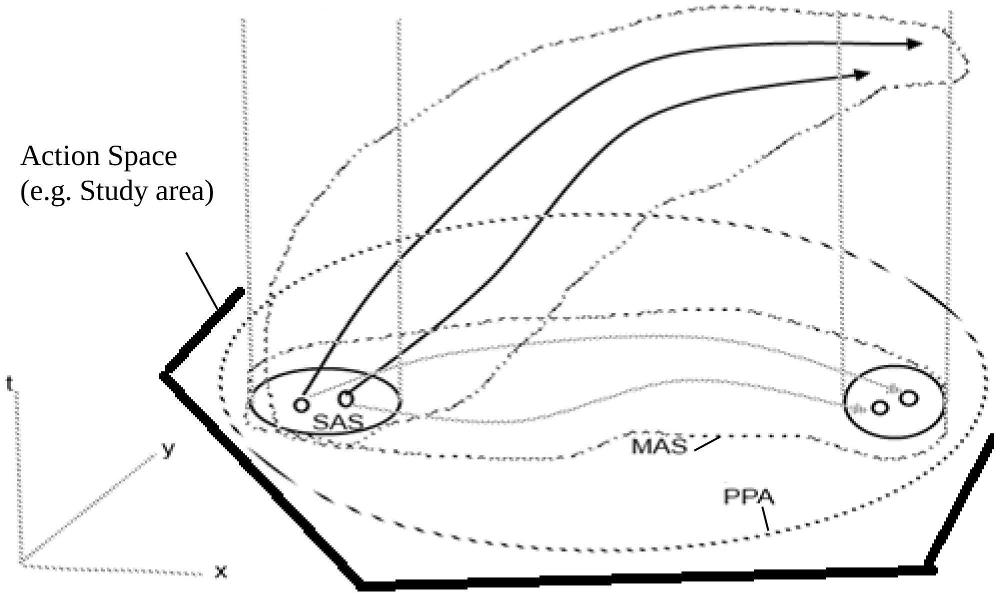


Figure 6-2: Stationary activity spaces (SAS) and Motile activity spaces (MAS)

Let us assume a given PPA and action space; potential *SAS* and potential *MAS* may be represented as presented in Figure 6-2. Unlike related concepts such as *perceptual space*, *action space*, *mental maps*, *space time prism*, *potential path areas* which usually suggest the description of an individual's travel potentials, the concept of activity-space describes the actual or observed or revealed use of space (Schonfelder and Axhausen, 2010, p. 122) and is deemed more appropriate here for addressing movement behaviour of cyclists.

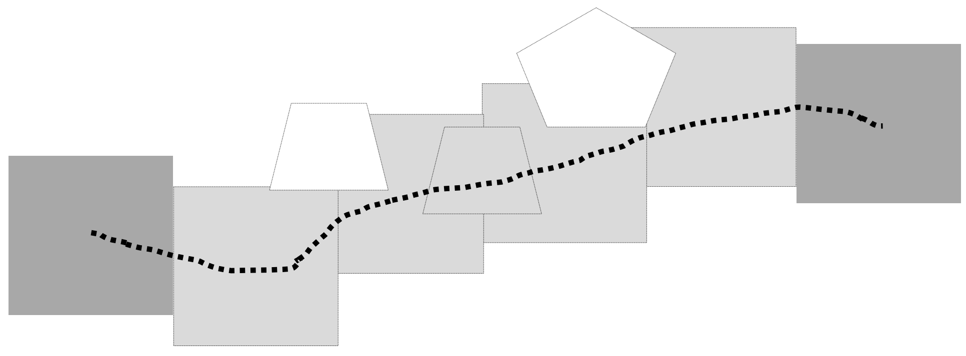


Figure 6-1: Conceptual diagram of stationary and motile activity spaces

Wherever gridded blocks are used, these should be carefully defined to allow easy communication of the findings. This way, the critique on place-based perspectives in favour of people-based perspectives is addressed in a methodological sense. Neutens (2010, pp. 14-16) argues that the place-based approach (i.e. use of either area/point geographical space) is limited by the modifiable areal unit (MAUP) problem and suggests some kind of people-based perspective (i.e. space-time accessibility measures) utilising the space-time prism concept. By definition, *accessibility* here means how easily the locations of activities (taken by an individual) can be reached from another location (Kwan and Weber, 2008). Neutens (2010, pp. 14-16) goes further to point out that the use of only space-time prism demands severe computational intensity and data requirements when it is being applied to large cross-sections of the population. From the perspective of space-time accessibility, Kwan and Weber (2008) studied the effect of geographical scale and MAUP for the analysis of the interaction with an individual's activity and frequented space. They used commercial and land parcels within the study area to represent (self-defined) opportunities, defined as the number of potential activity present in their PPA. The study also used a stated preference survey together with a detailed street network data due to lack of detailed revealed preference survey data (Kwan and Weber, 2008). It is suggested here that a fusion of both place-based and people-based perspectives is necessary so that the space, actual activity and time can be explained.

The easier the activity space is uniquely identifiable, the better the potential to disseminate the findings; for example to residents, councillors, policy makers to name a few. The considerations of these options bring to the forefront the issue about MAUP problem and the challenges it presents (Openshaw, 1984; Rogerson, 2006, p.16). The MAUP is concerned with the fact that outputs from statistical analyses with inputs derived from aggregated values based on a particular spatial configuration, a zoning system could be different if another spatial configuration was considered (Rogerson, 2006, p.16). This study draws on both the OA and ward areas due to the zonation, scale sensitivities and confidentiality of participants. Flowerdew et al. (2008, p. 1254) suggest that examining all the alternative spatial configurations is impractical and that consideration of at least two ways of aggregating the same data seems appropriate.

By definition in this thesis, stationary activity space (SAS) is defined as the actual stop's geographical space composed of either as a point of departure or arrival and defined by the chosen underlying spatial configuration. Similarly, a motile activity space (MAS) is defined as a region or area which exhibits cycling flow activity allowing cyclists to consume energy in the process. The idea of motility from biology informed this definition. Researchers in biological sciences define motility as the ability to move spontaneously and actively while consumption of energy takes place in the movement process (Baez, 2013; Davis et al., 2011). Given that cycling is a form of vigorous activity, the space where this activity occurs could be term as a *motile activity space (MAS)*. Schmitter et al. (2013) applied an image based analytical technique to measure the intensity at locations, its size and shape, by detecting and tracking fluorescently-tagged proteins. Motile structures in the form of rod-shaped cells of a bacterium were recorded in the used image.

Davis et al. (2011) utilised video microscopy to track behaviour of motile bacteria to get more understanding of their movement behaviour such as their speed and angular distributions. Two dimensional maps were used to explain the behaviour. Each line represented a bacterium as represented in the field of view in the microscope. Unlike the association of *motility* (i.e. motile bacteria) to bacteria in the study of movement behaviour of bacteria (Davis et al., 2011); *motility* is made a property of the cyclist's activity space once a spatially configured unit has been identified for that activity. This analysis considered activity spaces at both the ward and output area level within Newcastle upon Tyne. This decision was made due to the fact that the survey design was biased towards capturing actual cycling flows around Newcastle upon Tyne. The spatial information from activities performed by the participants and derived from the GPS trajectories were used to identify the activity spaces.

The departure and arrival points of all 79 cyclists derived from the GPS traces were used as an input to ESRI ArcGIS 10.0 software, where both departure and arrival maps were generated. This way, the computed aggregate values for each area (e.g. OA) were represented on the generated map as characteristics of that area, following the example of Andrienko et al. (2008). The next two sections adopt a bottom-up approach by starting from what is described earlier as level 4.

Figure 6-4 shows the general structure of presentation in this section and for analysing both MAS and SAS of the study area together with the characteristics of cycling flows.

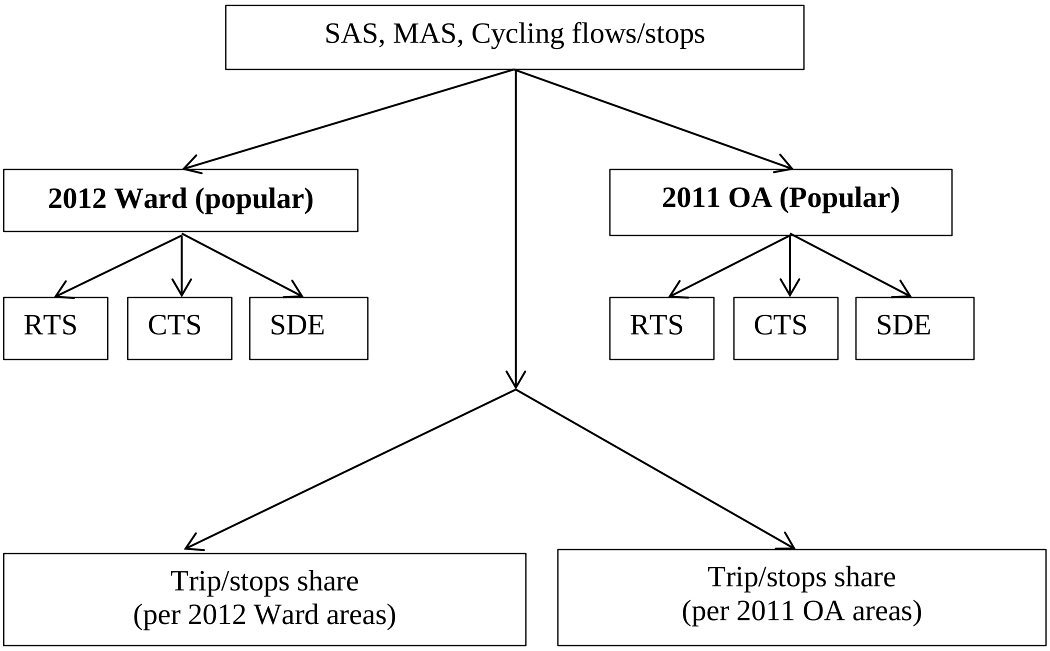


Figure 6-2: Overall presentation structure for SAS and MAS analysis

6.3.1 Stationary activity spaces from actual cycling flows

Figure 6-5 shows a map of departures for cycling flows from the sample, based on OAs from the 2011 census and the 2012 electoral administrative wards. From the viewpoint of the electoral wards shown in the figure, the most frequented departure spaces is Westgate ward. The second most frequented ward is South Jesmond. From the perspective of OAs, the most frequented OA, with code number *E00042583*, fell in South Jesmond ward. The second most frequented OA, with code number *E00042580*, fell in Westgate ward. The findings show how using at least two spatially configured activity spaces could give clues to where strategic investment of cycling could be directed. The findings also show how the influence of MAUP can influence analytical results. For presentation purposes, both the ward and the OA layers have been superimposed. The overlapping of OA over ward boundaries does not affect the estimated computed values as computation for each layer was done before the overlay.

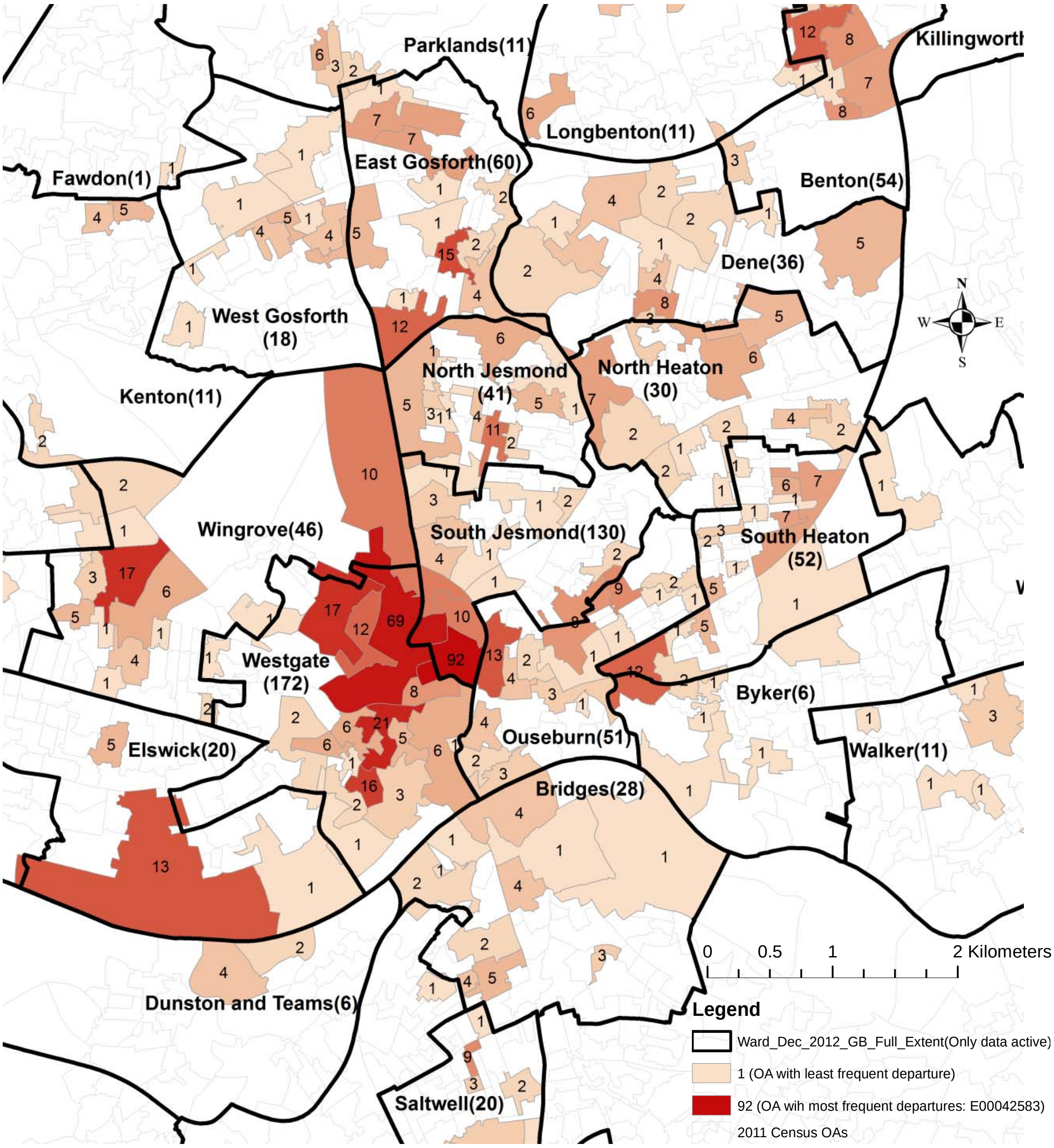


Figure 6-5: Departure map of actual cycling flows for 2011 Census OAs (2012 Wards also shown)

Figure 6-6 shows a map of arrivals for cycling flows from the sample based on the OAs from 2011 census and the 2012 ward areas. The two most frequented electoral wards for arrivals were identified as Westgate followed by South Jesmond. These findings make it clear that both Westgate and South Jesmond areas could serve as important places for the consideration of secure infrastructure for storing bicycles, for example, secure cycle parking. From the perspective of OAs, the most frequented OA, with code number *E00042583*, fell in South Jesmond ward. The second most frequented OA, with code number *E00042580*, fell in Westgate ward. These trends in the findings were same for the departures.

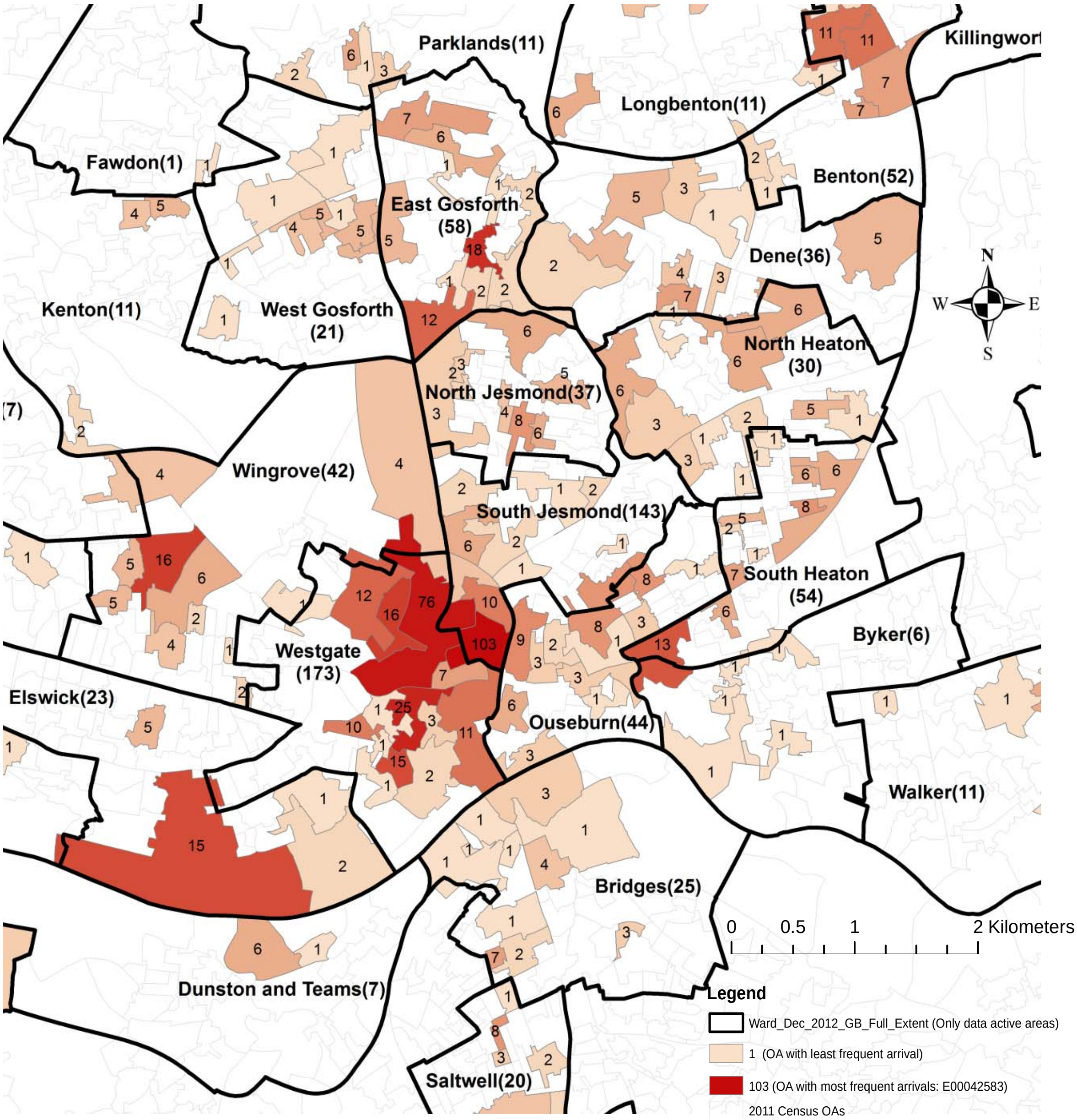


Figure 6-6: Arrival map of actual cycling flows for 2011 Census OAs and 2012 Wards

So far, attention has been on the most frequent SAS, as reported/logged without consideration to the temporal dimension of the SAS. The next step is to examine stationary time sequences associated with the stationary activity spaces using the logged time stamp status of each visit. The time sequence is conceptualised in two states: the realistic time status and the compressed time status (Figure 6-7). Mathematically, supposing there is a series of stationary points, time stamps, in their respective SAS spaces are denoted as $S = [S_1, S_2, \dots, S_{n-1}, S_n]$ where n equals number of SAS and $S_1 = [(O_1, D_1),(O_1, D_1),\dots,(O_{x-1}, D_{x-1}),(O_x, D_x)]$ such that O_k denotes departure time stamps while D_k arrival time stamps; x equals the total number of visits per stationary activity space but x equals k; and, the *realistic time status (RTS)* for departure could be defined as $[O_1, O_2, \dots, O_{k-1}, O_k]$. Similarly, RTS for arrivals could be represented as $[D_1,, D_2, \dots, D_{k-1}, D_k]$. The proposal here is that the compressed time status (CTS) spectrum can be left to the discretion of the analyst. In our case, CTS is a compressed form of RTS such that it could be transformed into an hourly time interval and dates collapsed into the date with the highest frequent activity.

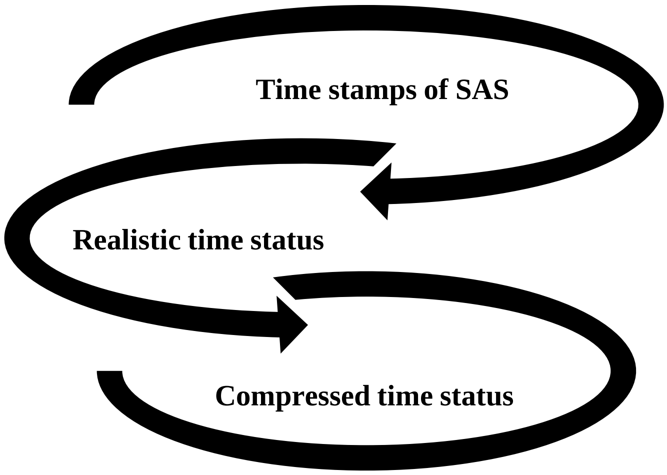


Figure 6-7: Conceptualisation of time sequence visualisation of activity spaces

The next step is to visualise stationary activities (i.e. departures and arrivals) within the most popular and frequented stationary activity spaces already identified as *Westgate* ward area together with the most popular OA using both RTS and CTS approaches. Figure 6-8 shows the realistic time status of arrivals' stationary activity spaces. The graphical presentation follows visualisation approaches proposed and implemented using the GeoTime software (GeoTime, 2013; Kapler and Wright, 2004; Kristensson et al., 2009).

All the stationary activities were grouped into *work related, work, non-food shopping, food shopping, home* and *other* (e.g. visits). The colour scheme for the activities was chosen as follows. Grey colour was used for work related activities. Black colour was used for work activities. Cyan was used for other activities. Blue and light-blue colours were used for food shopping and non-food shopping activities respectively. The home activity was colour coded as green. This colour scheme was chosen to enhance easy identification of activities on the graph. The two-dimensional graph showing Westgate boundary in the graph gives spatial dimension to the temporal dimensional space. The rough rings around each grouped activity indicate the temporal stationary activity space (TSAS) of those activities. TSAS is not necessarily the same as the spatial stationary activity space since the timing of activity dictates the structure whereas spatial SAS denotes a two dimensional Euclidean space without any consideration to timings of activities. RTS and CTS of TSAS give cues to the extent of freedom an individual has and provide the limited space available to the freedom of movement. We are able to know how cyclists spend their time in mandatory activities and more time-flexible activities. Looking at work and work related activities suggest that cyclists sampled cycle to work in both October and November with slight shift of work related cycling to November. Commuting by bike tend to generally mix with other cycling such as visiting a friend. Food shopping activities are more constrained in space and time and appear not so popular in this ward area.

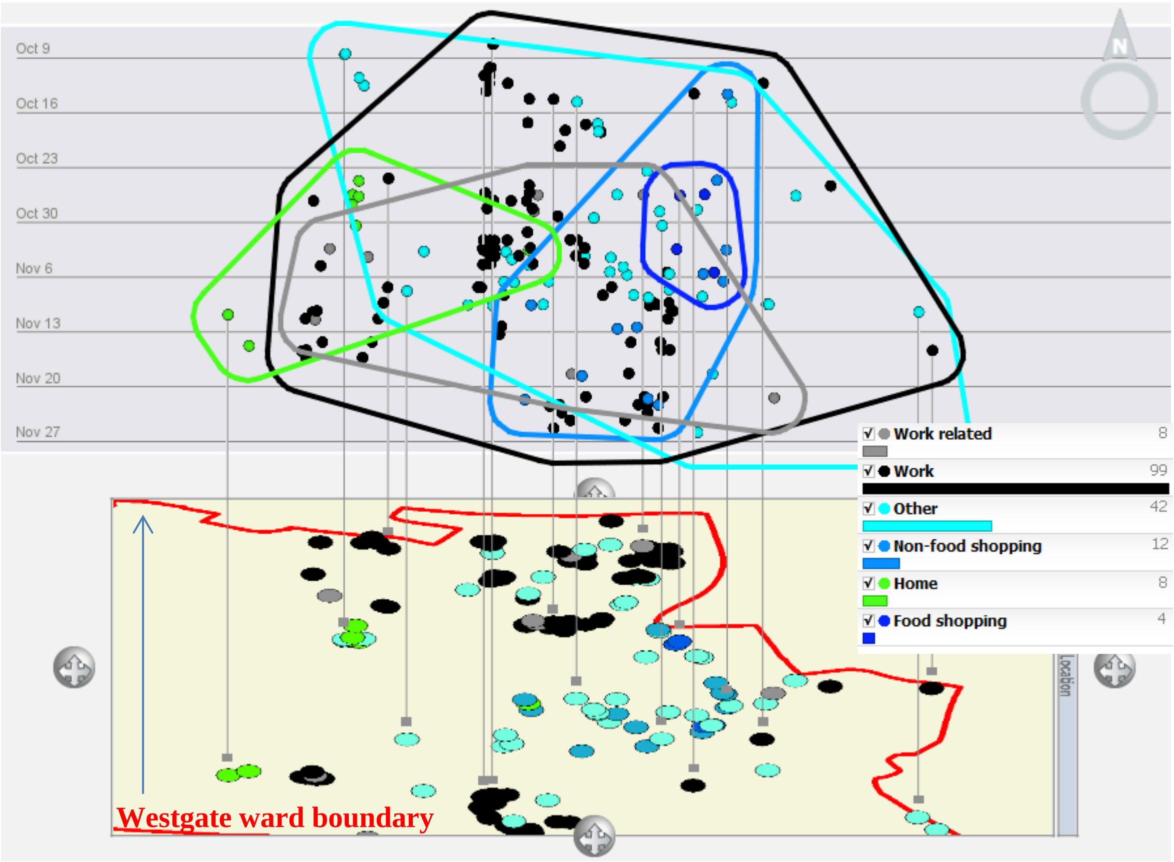


Figure 6-8: RTS for arrivals by purpose in most popular SAS (n=173)

By way of visual comparison, the compressed time status (CTS) stationary space closely matches its RTS counterpart spatial space size but changes the temporal boundary demarcation (Figure 6-8 and Figure 6-9). This is expected as the arrival location is dependent on its time stamp. The CTS provides a more detailed account of the activities in TSAS. As expected, work and work related activities fall within the traditional mandatory normal working hours which tend to be from around 8am to 5pm. There are several types of flexible working arrangements in the UK (GOV.UK, 2013). An example is the *flexitime* arrangements in which the employee agrees with the employer to start and end work where a certain range (i.e. core hours – 10am to 4pm) of time is mandatory (GOV.UK, 2013). This may explain the few black dots from 10am onwards as shown in Figure 6-9. Work related activities fall within the time frame for work activities as expected. The shift of arrival activities for home makes sense as they fall in the second half (i.e. post meridiem a.k.a. pm) of the day.

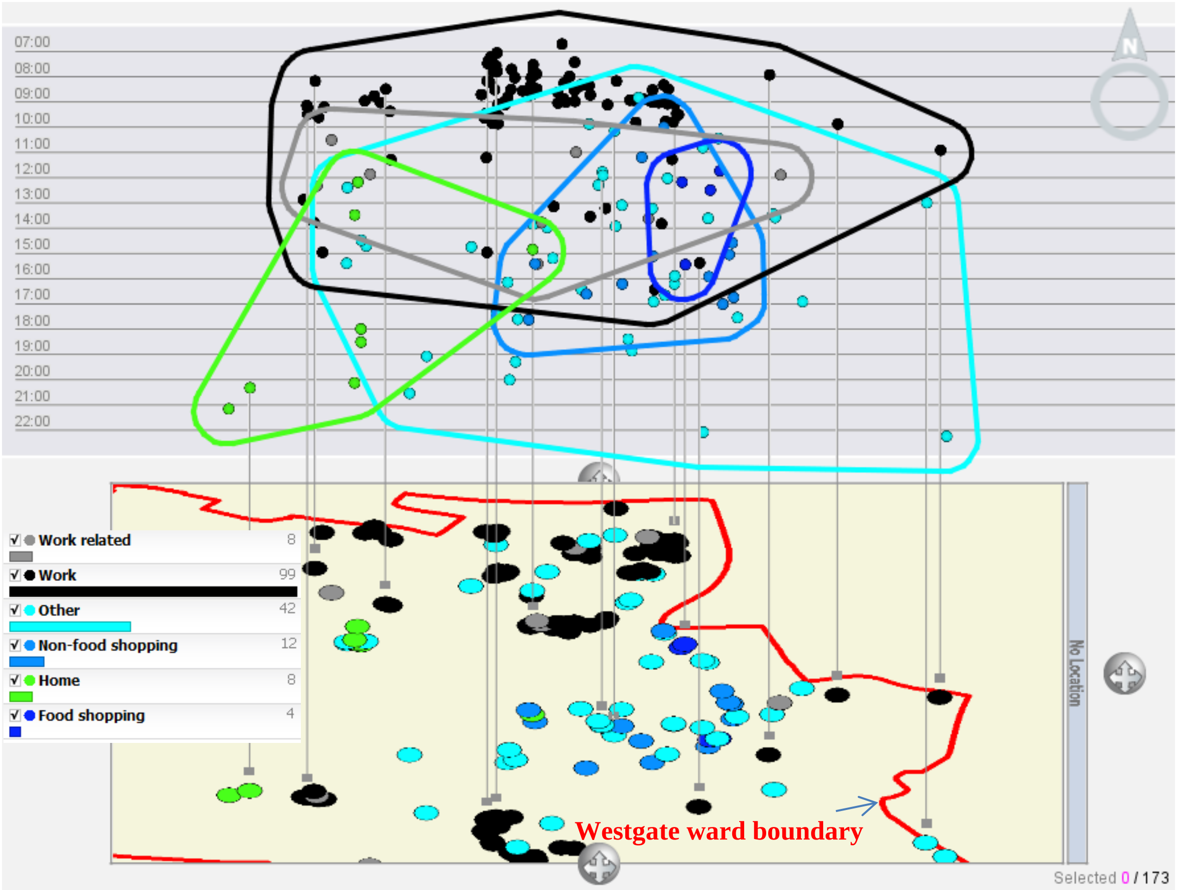


Figure 6-9: CTS for arrivals by purpose in most popular ward SAS (n=173)

Figure 6-10 shows gender based RTS and CTS for popular ward SAS. There are no clear differences between gender in terms of arrival activities in space and time. In this instance, the proposed framework for visualisation of cycling behaviour is being followed. The bottom-up approach direction was chosen and at level 2. Gender was only considered at this level. The goal was to take another look at the SAS by splitting the activity spaces by gender with time.

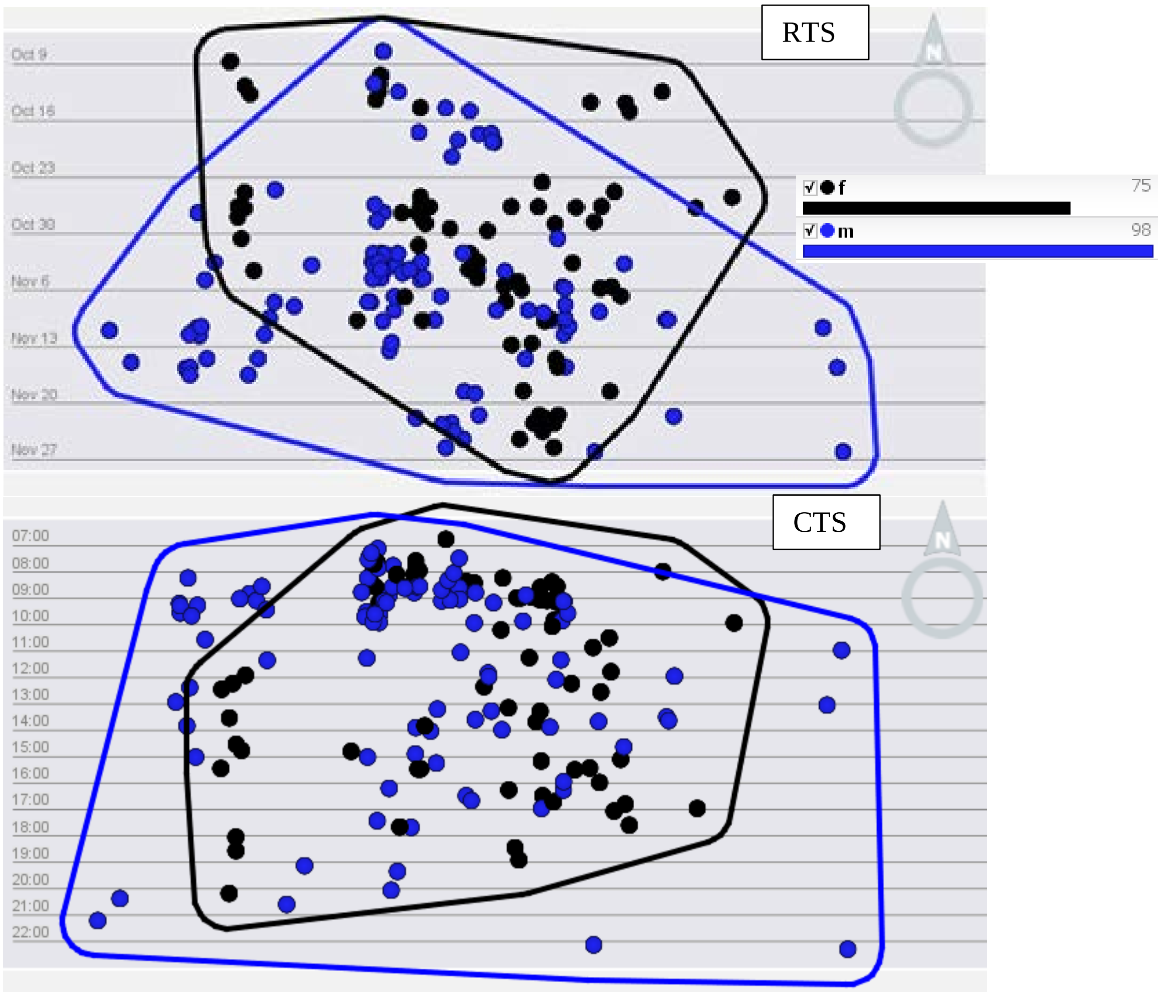


Figure 6-10: Gender based RTS and CTS visualisation of arrivals in most popular ward SAS

What follows is the visualisation of temporal dimensions of departures within the same most popular SAS but with respect to the departure activities in the ward area. The maps use the same colouring scheme as before for the arrival activity analysis: grey for work related activities, black for normal work activities, light blue for non-food shopping activities, blue for food shopping activities, green for home activities and cyan for other activities.

Figure 6-11 shows temporal spaces of departure activities in the most popular SAS and in the real time status. Most of the activities are home departure activities and spread over October and November. Temporal space for food shopping activity is spread wider than non-food shopping. The compressed time status stationary spaces closely matches its RTS counterpart spaces but change the temporal boundary demarcation (Figure 6-11 and Figure 6-12).

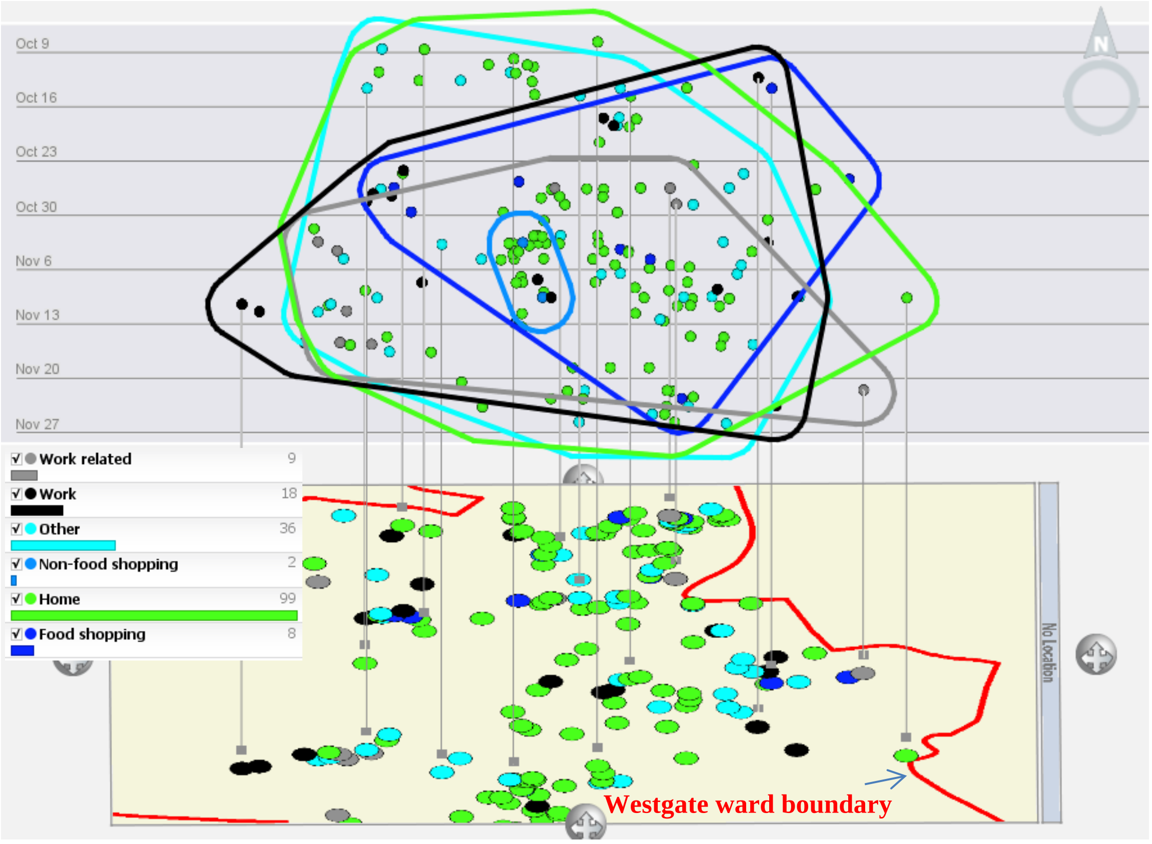


Figure 6-11: RTS for departures by purpose in most popular ward SAS (n=172)

Figure 6-12 shows the CTS for departures by purpose of activity in the most popular ward SAS area. Departure activities, with the aim of going home, cluster around 5.30pm which seem to be roughly around most official work closing hours. All other activities do not seem to follow any hourly pattern during the day. Spatio-temporal activity spaces for non-food shopping activities were relatively constrained to a small area.

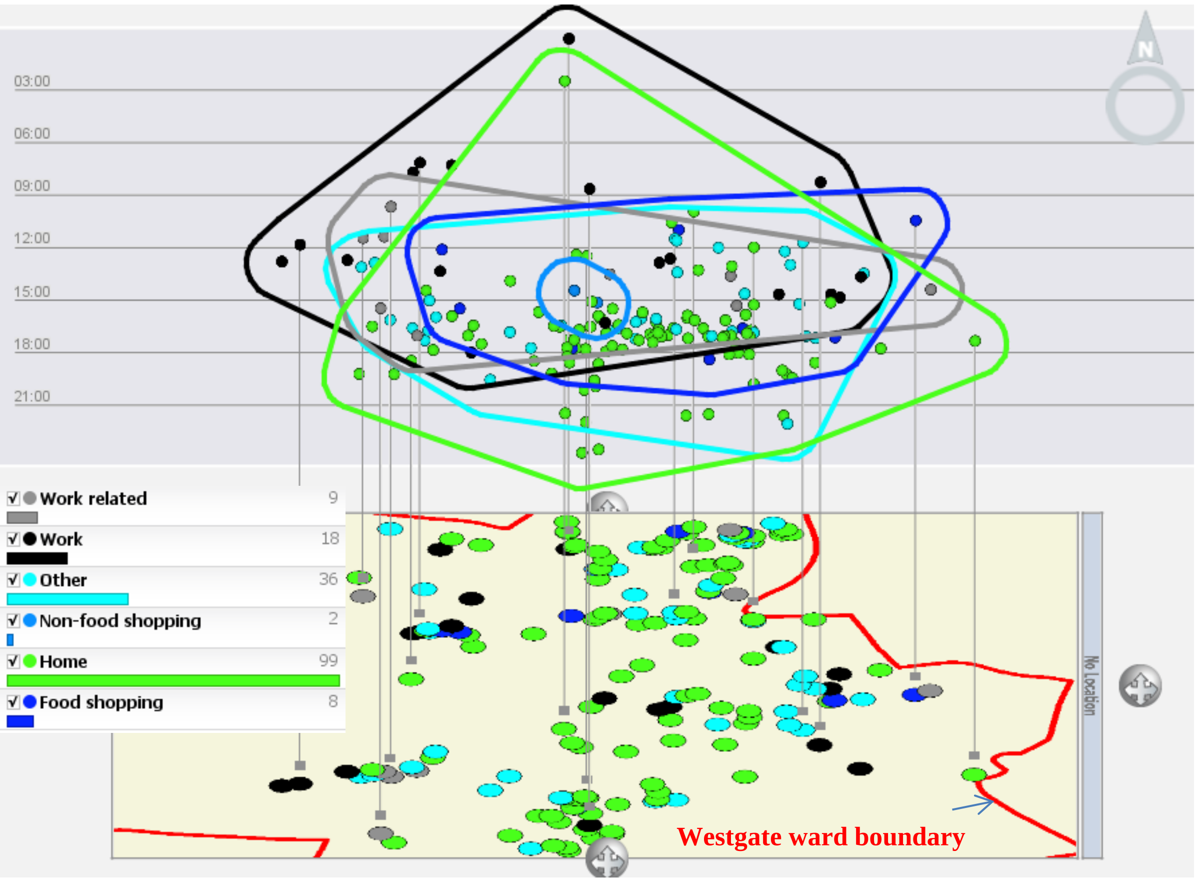


Figure 6-12: CTS for departures by purpose in most popular ward SAS (n=172)

The gender based RTS and CTS visualisation of departures in the most popular SAS is shown in Figure 6-13. There are no clear differences from the perspective of gender and departure activities.

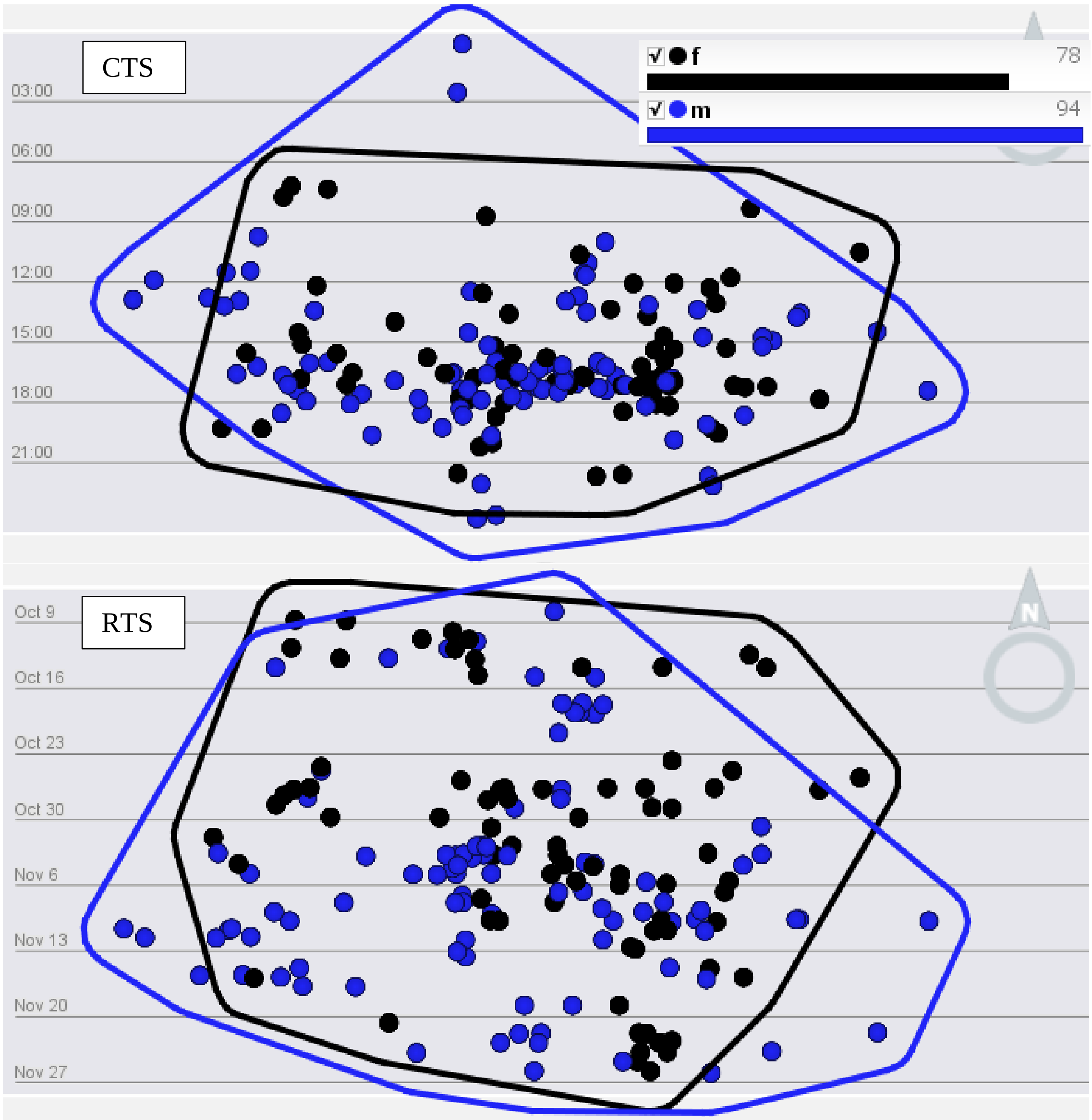


Figure 6-13: Gender based RTS and CTS visualisation of departures in most popular ward SAS area

Attention was given to the temporal dimensionality of the most popular OA area SAS. Only the most popular OA SAS with the code *E00042580* was visualised. This decision was made because it is the area which contains more activities than all other areas and therefore has the potential to give clues to activity patterns. The departures and arrivals were combined for OA, because the ward area, by definition, is larger than the output areas. The temporal differences for the most popular OA level SAS did not show any major difference visually at the RTS state but had a slight change at the CTS state (Figure 6-14). The use of RTS and CTS provides a unique way of viewing both short and long term perspective on cycling behaviour trends. SAS tend not to change drastically at OA area level for both RTS and CTS.

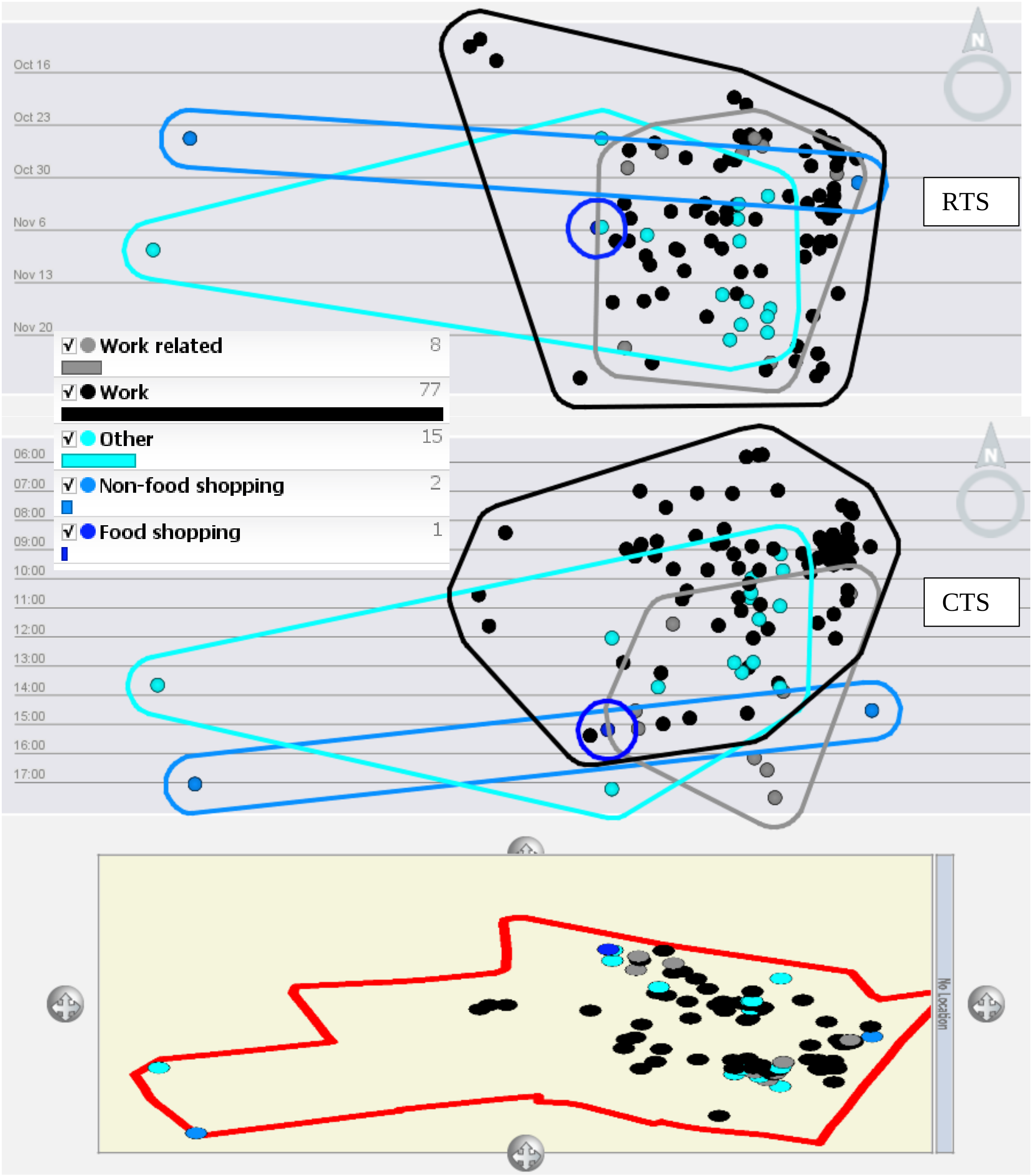


Figure 6-14: Arrivals RTS and CTS for most popular OA SAS (n=103)

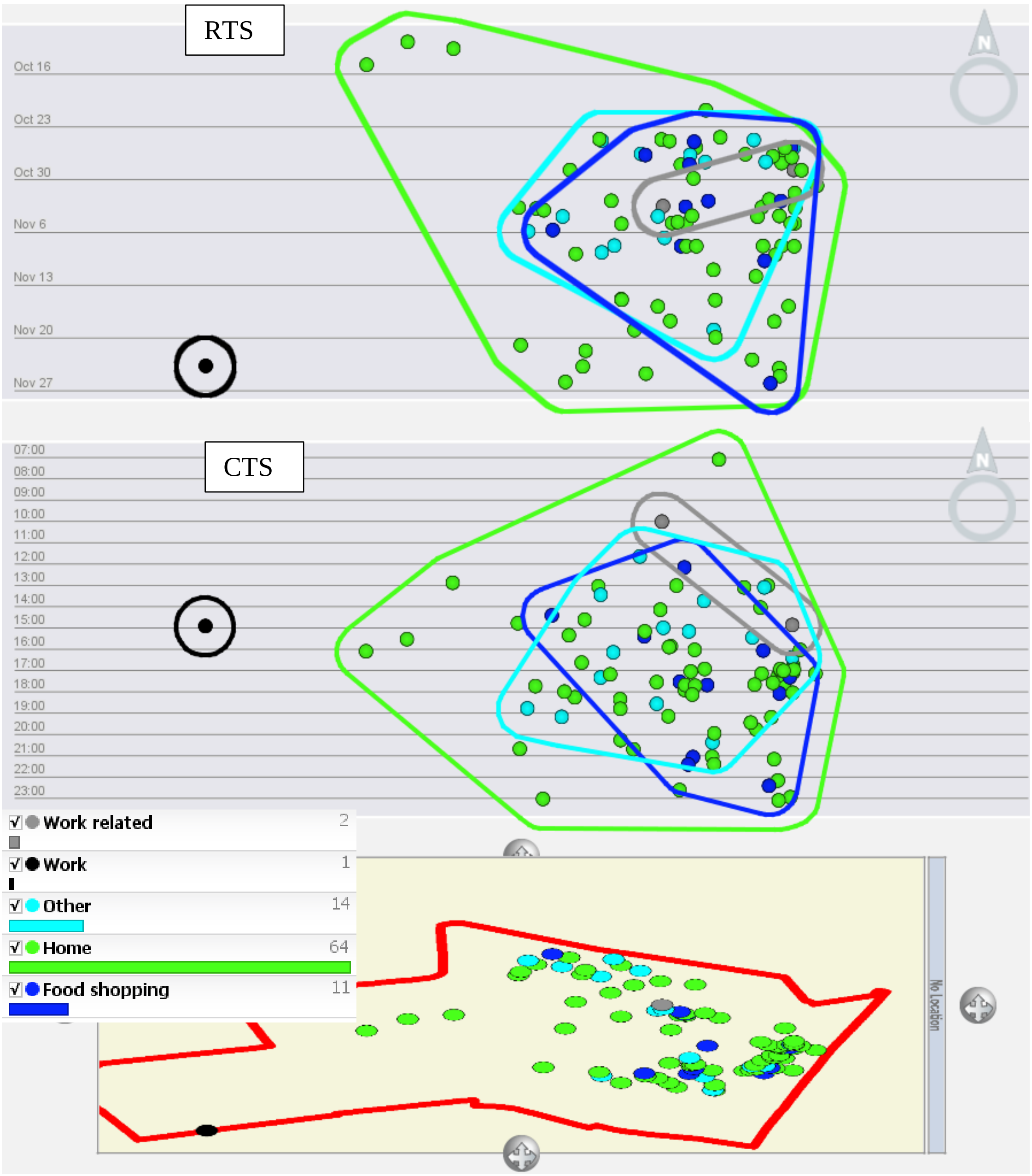


Figure 6-15: Departures RTS and CTS for most popular OA SAS (n=103)

In order to identify standard trends within the already identified most popular wards and output areas, standard deviational ellipses for stationary activities (i.e. departures and arrivals activities) were generated and overlaid on cycle infrastructure data such as cycle parking locations provided by Newcastle City Council. Figure 6-16 shows these ellipses denoting directional trend of stationary activities for areas within the most popular SAS areas. The method for calculating the standard deviational ellipses are discussed in section 3.4.5. The orientation of confidence ellipse indicates the actual size of the (stationary) activity space (Schonfelder and Axhausen, 2010). The use of ellipses to explain trends in spatial behaviour permits analysis to be done beyond just a purely descriptive level (Schonfelder and Axhausen, 2010, pp. 132-135, p. 184). Figure 6-16 shows trends of departure stationary activity spaces by purpose and with locations of cycle parking facilities for public use and are managed by the Newcastle City Council. The figure shows the trend of activities for both popular ward and OA areas. Activities shown in the figure are those having at least six departure activity locations. This was easier to compute based on the implemented tool in ArcGIS 10.0 software. The outside grey boundary shows the 2012 electoral ward with name Westgate. The work departure stationary activity spaces hold about seven of the cycle parking facilities. Food shopping departure activity spaces for both ward and OA areas appear to follow the same directional distribution. There is evidence in the figure that the activity spaces (i.e. the computed ellipses) have some cycle parking facilities, but assessing whether these provisions are enough for the respective activity spaces demands a bigger study outside the scope of this thesis. Nevertheless, the analysis presented here could serve as a useful point of departure.

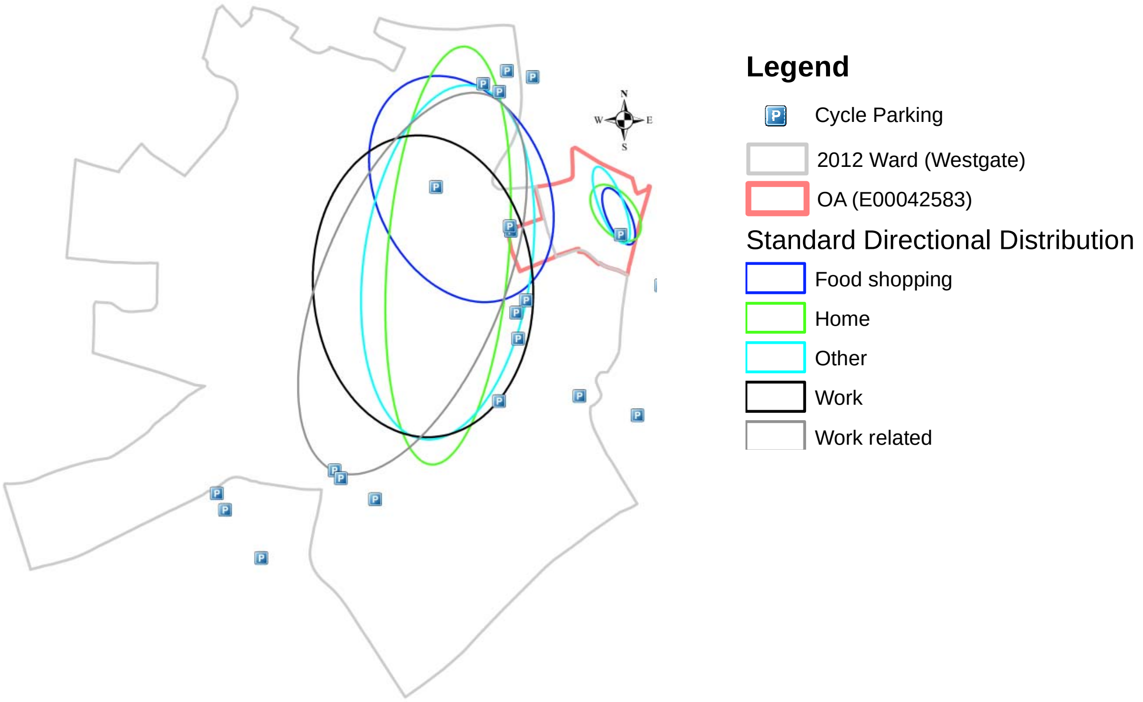


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Figure 6-16: Trend (Standard Deviational Ellipse) for departure activities for most popular ward and OA areas

Figure 6-17 shows arrival activity spaces for the same ward and OA areas together with the spatial locations of cycle parking facilities. The OA boundary is in light red while that of the ward is the larger grey boundary. Arrival activities for the purposes of food shopping are virtually non-existent in the popular areas. Arrival activities for the purposes of work appear visible in both the most popular ward and OA areas. These findings can be useful in considering daily accessibility issues within this area, such as access to secure parking locations.

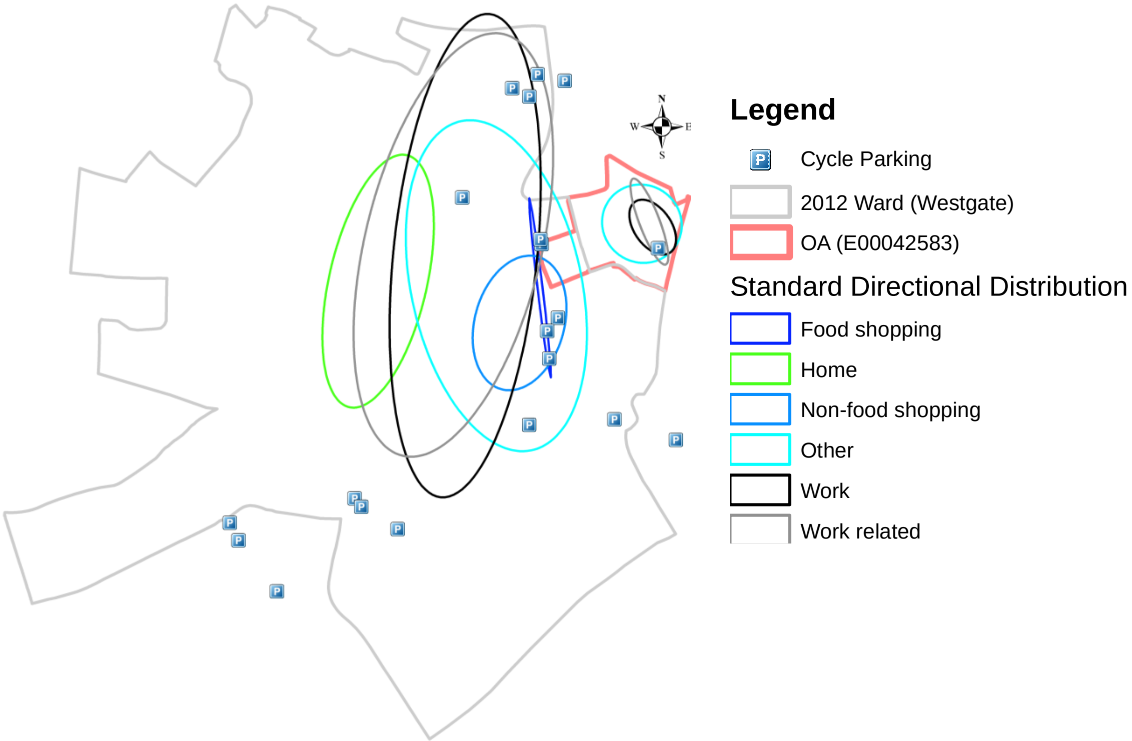

Figure 6-17: Trend (Standard Deviational Ellipse) for arrival activities for most popular ward and OA areas

6.3.2 Motile activity spaces from actual cycling flows

Based on the two selected geographies, Wards and OAs, it is possible to determine areas exhibiting motility by using the actual cycling flows as input. We define a geographical space G so that it consists of areas $A_i = [A_1, A_2, \ldots, A_{n-1}, A_n]$ that share adjacent boundaries. We also have motile activity across these areas A (Figure 6-3) defined as $T_i = [T_1, T_2, \ldots, T_{n-1}, T_n]$. A set of motile activity spaces (MAS) can be represented as $A_T = [A_{T1}, A_{T2}, \ldots, A_{Tn-1}, A_{Tn}]$ on the condition that T crosses A. The A_T with the highest frequency of motile activities becomes the most popular MAS and therefore deserves further attention in order to visualise motile activity spaces from actual cycling flows.

The total number of motile activities within each MAS, for ward and output areas, were aggregated to identify the highest frequent activity value. The refined GPS point datasets representing the isolated cycle trips and for each identified MAS were extracted to aid in the visualisation of the temporal dimension of activities. The activities in the selected MAS areas were then visualised in Space-Time Cube using both RTS and CTS approaches. GeoTime software from Oculus was used for the visualisation. Once the MAS with highest frequency of motile activity were detected, the pointsets were used to extract the spatio-temporal information for the visualisation. Each ward/OA polygon was given a summary of the numeric attributes of the polylines (i.e. trip segments or entire trip) that spatially intersect it and a count field that shows how many polylines intersected it. Based on the count field, the highest total count was selected and its corresponding code checked to trace the area name per the census given codes. For the most popular MAS, South Jesmond emerged first followed by Westgate with 473 and 472 total mobility traces respectively. Figure 6-18 shows the CTS and RTS of motile activities of the most popular ward. The findings also suggest that cyclists are active during working hours as seen from the time scale on the left hand side of the figure.

Figure 6-18: CTS and RTS for popular ward MAS and trip purpose

The top graph of Figure 6-18 shows spatial and temporal structures of how hourly and monthly motile activity patterns emerge within South Jesmond ward. Morning peak time of motile work activities appears to be around 9am for daily patterns within the popular MAS. Evening peak time of same activity is around 5.30pm when most of them appear to be home activities as shown in Figure 6-18.

To further understand areas within South Jesmond where significant motile activities occurred, standard directional ellipses were generated based on purpose namely *work*, *work-related*, *food shopping, non-food shopping, home* and any *other (e.g. home, visit etc.)*. Figure 6-19 shows the standard distributional trends based on activity purposes suggesting that non-food shopping activity trends within the area are different from actual food shopping activities. It is also clear in this image that non-food cycling behaviours deviate geographically from all other cycling behaviours within the most popular ward MAS area.

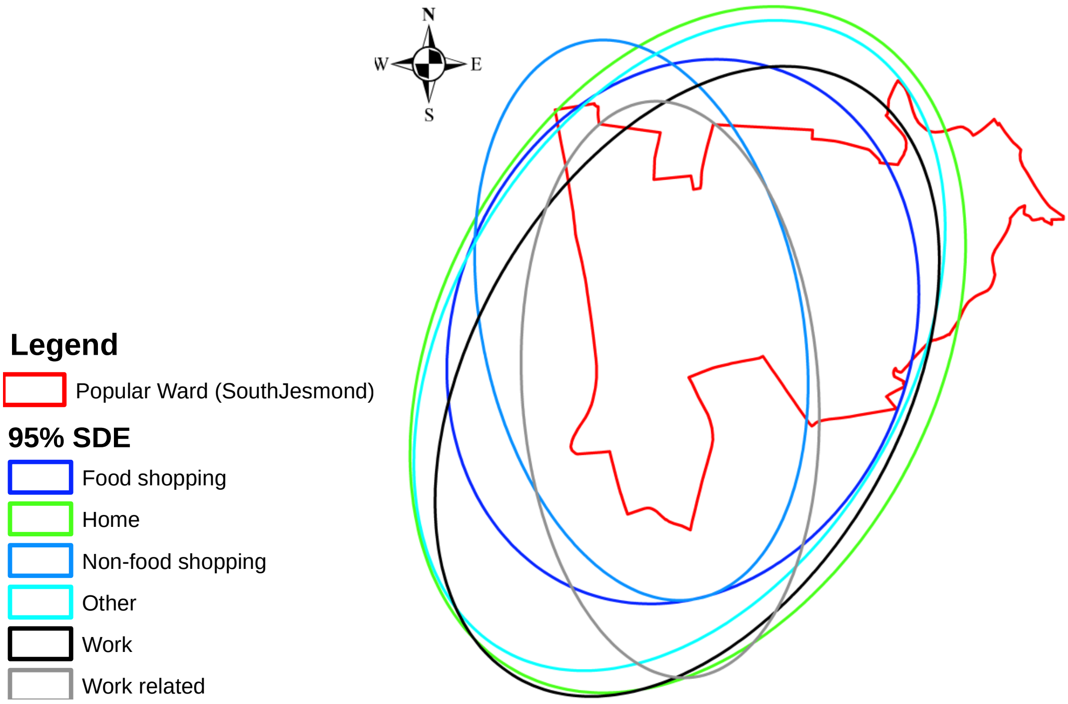

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Figure 6-19: Standard directional distributions of popular MAS ward

Figure 6-20: CTS and RTS for popular OA MAS and trip purpose (n= 334)

The most popular OA (code E00042580) was also in South Jesmond with a total count of 334 motile activities. Figure 6-20 shows the two dimensional views of most popular OA MAS area using both RTS and CTS respectively. Similar to the ward area pattern, cycling to work daily peak times were found to be around 9am while a similar pattern followed later around 5.30pm. It is suggested here that most of the peak cycling activities around 5.30pm represented return journeys back home with a few for other purposes. In order to understand the “utilitarian” activities within the identified MAS areas, the computation of standard directional distribution by generating ellipses based on trip purpose namely *work*, *work-related*, *food shopping*, *non-food shopping* and any *other (e.g. home, visit etc.)* were generated to show varying spatio-temporal structures of these activities. The findings suggest that non-food shopping activities within the area deviate from all other trends with different purposes at the OA level (Figure 6-21). Similar characteristics of purposed-based activity trends occurred at the ward level in Figure 6-19.

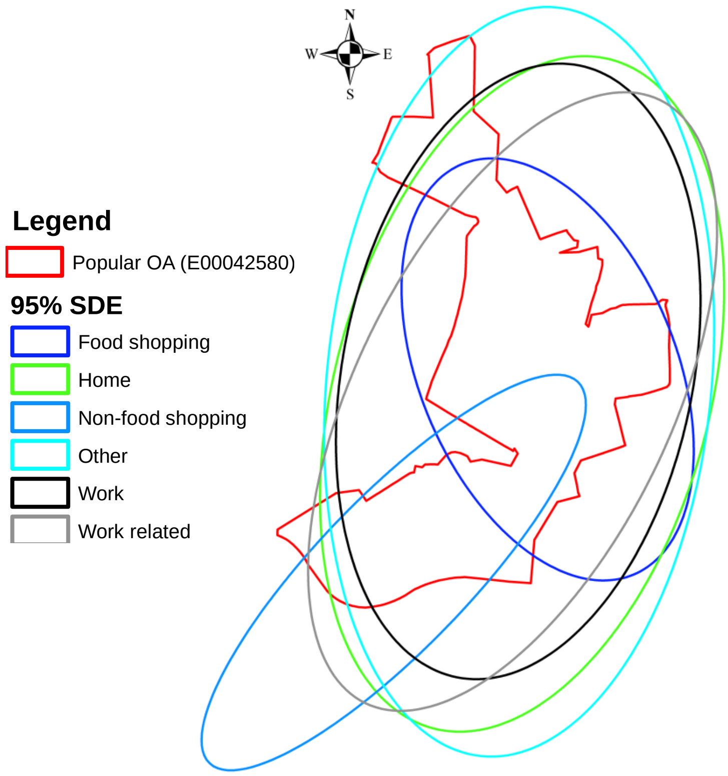

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Figure 6-21: Standard directional distributions of popular OA MAS

6.3.3 Visualising all SAS and MAS from ward and OA perspectives

So far, only the most popular SAS or MAS areas have been investigated. Attention is shifting here to SAS and MAS for the whole study area for the visualisation of only all used spaces in terms of frequencies of counts of stationary or motile activities. Graduated colouring and point symbology were used together with the Jenks Natural Breaks algorithm (a univariate classification scheme) as well as variance minimisation classification (de Smith et al., 2013; Mitchell, 1999, pp. 58-62). Darker colours were used to represent “high” frequency of activities as most people appear to interpret darker colours to mean “greater” or “more” (Mitchell, 1999, p. 60). The Jenks Natural Breaks algorithm assumes that one first selects the count variable and the number of classes required at the first instance. The count variable, c, by definition is the frequency of activities per ward or OA unit area. The classes, *n*, are the defined groupings such that there are clearer differences between groups for the purpose of visualisation. Based on this, a set of "*c-1*" uniform or random values are generated showing both minimum and maximum ranges which are used as class boundaries initially. The mean value is computed for each initial class. The differences between the squared deviations of values from the computed mean value is calculated and later summed together. All the squared deviations are then added and stored. The last stage of the algorithm, an iterative process, checks if the stored squared deviations value could be reduced by consistently assigning the values of individual classes to adjacent classes by way of adjusting the class boundaries (de Smith et al., 2013). Since an ultimate optimisation of the iteration process is not assured, the discretion of the analyst is for manipulating the *n* values subjectively. The number of classes was kept to less than seven as people tend to distinguish up to seven colours (Mitchell, 1999, p. 60). ESRI ArcGIS version 10.0 was used for this analysis. Figure 6-22 shows two ways of visualising cycling flows, per our sample, across the study area using the 2011 OA areas. The left image in the figure indicates the use of the OA geographies with five classes defined using the Jenks Natural Breaks algorithm. The darker areas show places with higher frequencies of activities. The right image shows the use of proportional symbology based on the counts frequency per OA geographical unit. The larger the black circles the higher the occurrence of cycling flows for the OA area. They all show that the central part of Newcastle upon Tyne exhibits higher frequencies of motile activities.

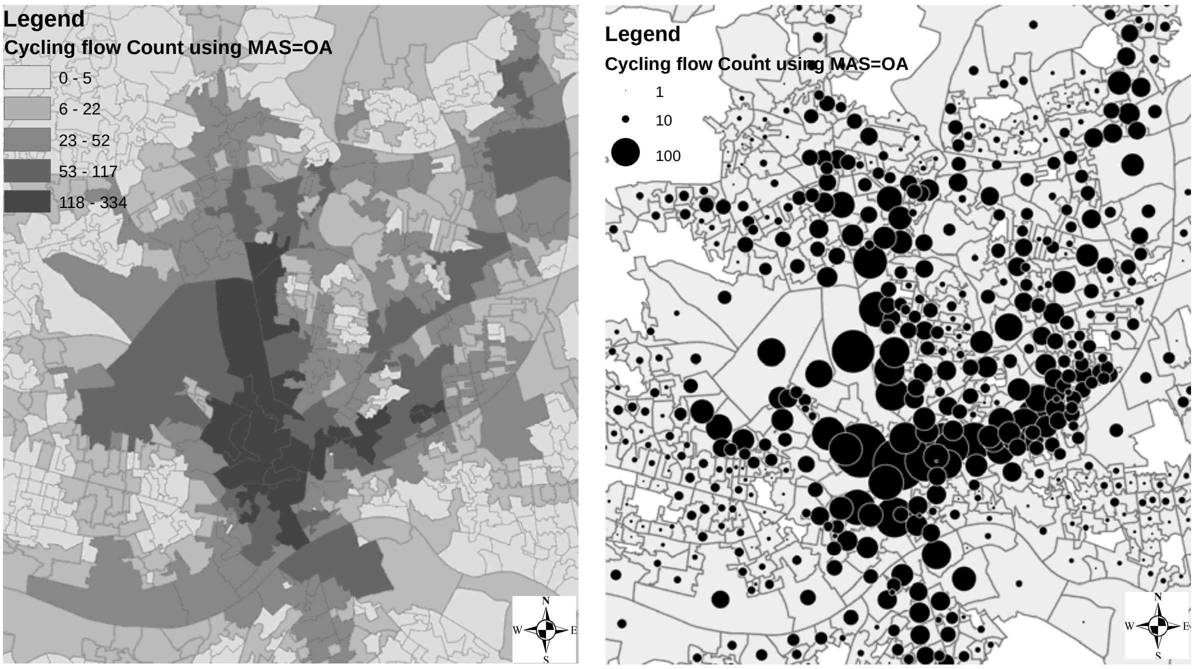


Figure 6-22: OA based MAS cycling flows

Similarly, Figure 6-23 shows two ways of visualising cycling flows, per our sample, across the study area using the geographies of 2012 electoral ward administrative boundaries. Both the left and right images in the Figure 6-23 show more or less a summarised form of the relative images in the Figure 6-22.

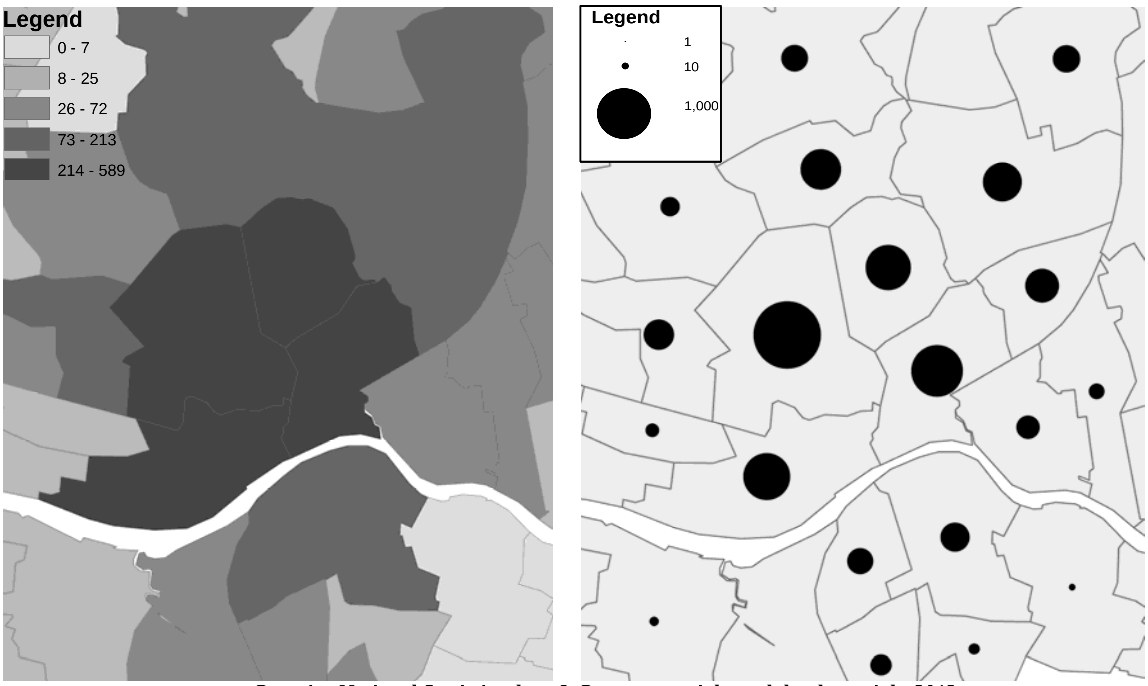


Figure 6-23: Ward based MAS cycling flows

Finally, for the SAS areas, Figure 6-24 shows the variability of stationary activity distribution across the study area. Because stationary activity spaces comprise both departures and arrivals, the two extracted layers for departures and arrivals were first merged and used as a single input to count stationary points.

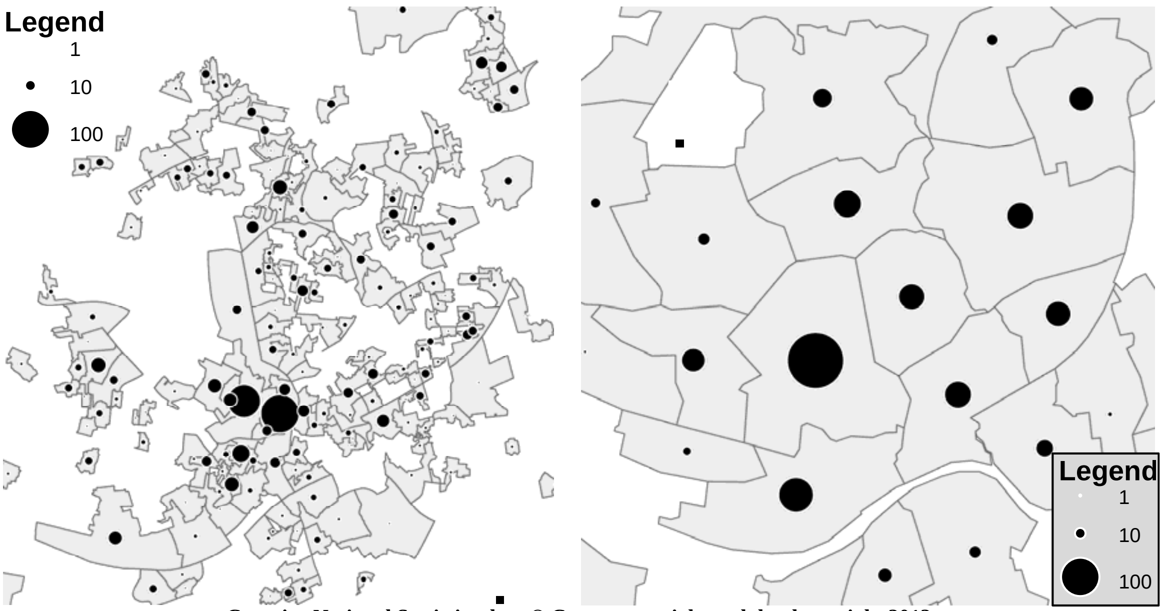


Figure 6-24: OA (left) and Ward (right) based SAS pattern

6.4 Significant Low and High Motile Activity Spaces using cycling speed

So far, the emphasis was on activity spaces with frequent occurrence of stationary and motile activities. This section examines the cycling behaviour based on speed of the cyclists. Here, a kind of inferential statistics called Local Moran’s I (LMi) statistics, is used to map activity spaces with statistically significant low and high speeds clusters. This algorithm has been proven to be useful in exploring and explaining movement behaviour (Orellana and Wachowicz, 2011). Of particular interest here would be activity spaces having statistically significant low speeds and high speeds. Significant Low Motile Activity Space (SLMAS) will mean MAS areas that are statistically significant at p=0.05 based on LMi statistics where low speed is the main characteristic. Likewise, Significant High Motile Activity Space (SHMAS) will mean MAS areas that are statistically significant at p=0.05 based on LMi statistics where high speed is the main characteristic. According to Orellana and Wachowicz (2011), the advantages for using the algorithm is that:

- No *a priori* knowledge is needed to establish stringent threshold values for time, space and speed. Thus, knowledge about the data collection process is not a major requirement.
- It can be applied to messy GPS tracking data without the need to address positional errors which could change global distribution of speed values present in data and as a result having an impact on the local statistics.

Until now, very little has been stated in the literature about the application of this algorithm to the analysis of detailed GPS tracking data about cyclists with the aim of understanding movement behaviour in space and time. Table 6-2 shows the description of clusters based on measured speed attribute and Local Moran’s I (Orellana and Wachowicz, 2011). Figure 6-25 shows how the Local Moran's I p-values and z-scores are associated with the normal distribution. The significance testing by Local Moran’s I is based on the null hypothesis that the data for the study area has many possible versions of complete spatial randomness (Ebdon, 1985, p. 156). The null hypothesis is rejected when a significance value (p-value) for clusters is reached or exceeded.

Table 6-2: Description of clusters based on measured speed

Standard deviation with sign (z-score)	Significance value (p-value)	Mean Speed (MS) (kmph)	Cluster description
>+1.96	0.05	<MS	**LL** Clusters: **L**ow speed points having other **L**ow speed points as neighbours
<-1.96	0.05	<MS	**LH** Clusters: **L**ow speed points having other **H**igh speed points as neighbours
<-1.96	0.05	>MS	**HL** Clusters: **H**igh speed points having other **L**ow speed points as neighbours
>+1.96	0.05	>MS	**HH** Clusters: **H**igh speed points having other **H**igh speed points as neighbours
<+1.96 & >-1.96	(>0.05)		**R** Clusters: Random and insignificant points

Source: Adapted from Orellana and Wachowicz (2011)

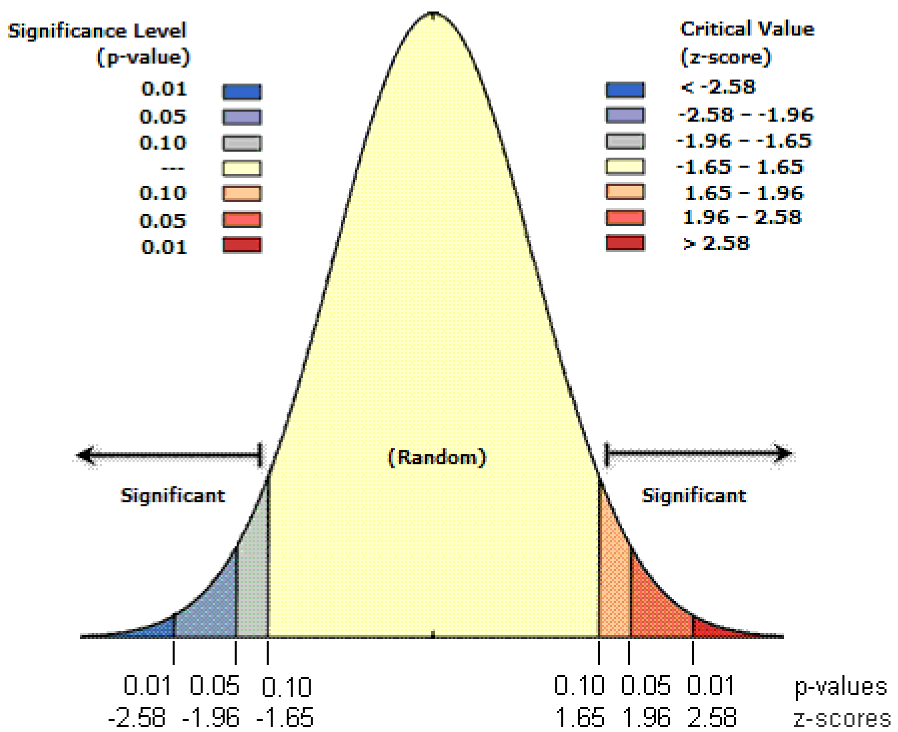


Figure 6-25: Local Moran's I p-value and z-score association with normal distribution

Source: ESRI ArcGIS 10.0 Documentation (ESRI, 2011)

Using the LMi statistics, the concentration was on cluster type labelled LL which indicated point features with high statistical significance of spatial association and low speed values – identified as SLMAS. Also, HH which indicated High speed values–identified as SHMAS were visualised together using Ordnance survey open data stream as a base-map.

Figure 6-26 shows a scatterplot graph of the z-scores versus the movement speed. The mean speed for cycling was around 14 kmph (SD=9). Accurate estimation of speed levels of cycling for particular groups such as utility cyclists helps in the determination of energy expenditure by the group. For example, a report from UK Department of Health (2004) suggests that a 30 minute cycling activity with a metabolic rate (intensity) of 8.0 and at a speed of 19-22.5kmph for a person with a weight of 60kg results in an energy expenditure of 240kcal. Similarly, a 30 minute cycling activity with intensity of 6.0 and at a speed of 16-19kmph results in an energy expenditure of 180kcal. Herrmann (2011) provides compendium of estimates of energy expenditure for various levels of cycling suggesting that these estimates, however, do change from study to study. The estimates of rate of energy expenditure serve as an input towards policies that aim to confront health problems such as obesity. As discussed in Chapter 2, obesity is a major issue in UK Public Health and particularly so for local policies around the study area.

Furthermore, the mean speed value falls within the normally distributed speed range for cyclists pointed out by Taylor and Mahmassani (2000); between 12.9kmph and 32.2kmph. This range takes into account differences among cyclists in relation to desires, physical fitness, strength, skill (i.e. bicycle proficiency in the UK) together with the associated bicycle maintenance and technology. Figure 6-27 shows a map of both statistically SLMAS in red and SHMAS clusters in green which are significant low and high speed clusters. The clusters indicate that cyclists often ride at low speed around the central part of Newcastle upon Tyne and tend to increase their speed once they get out of that area. Also, the low speed areas occur at built up areas when one compares the low speed clusters with the basemap.

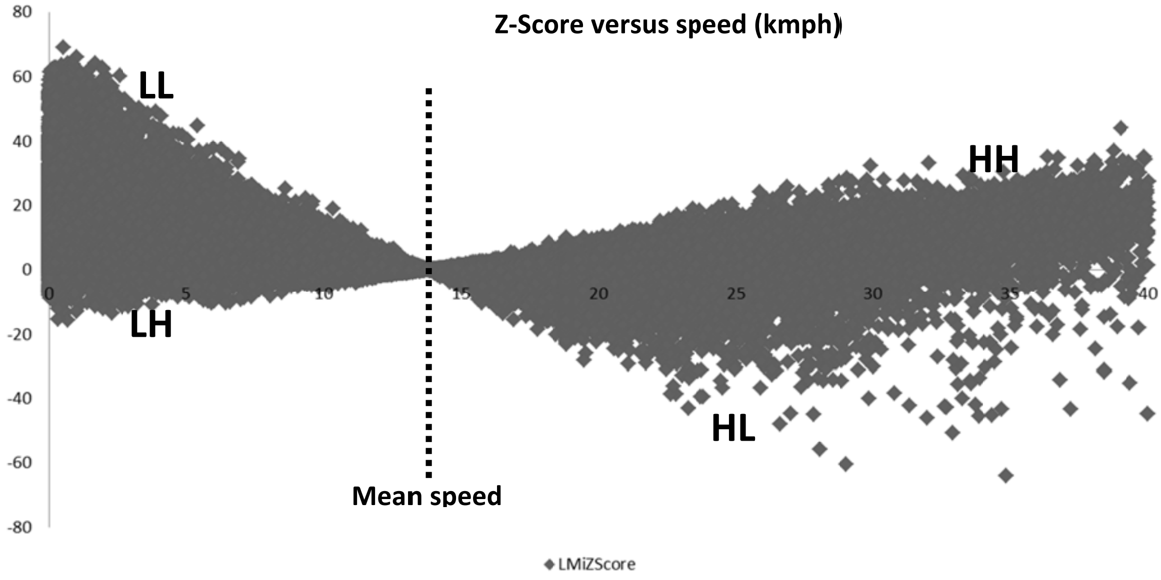


Figure 6-26: Z-score versus movement speed for only cycle trips

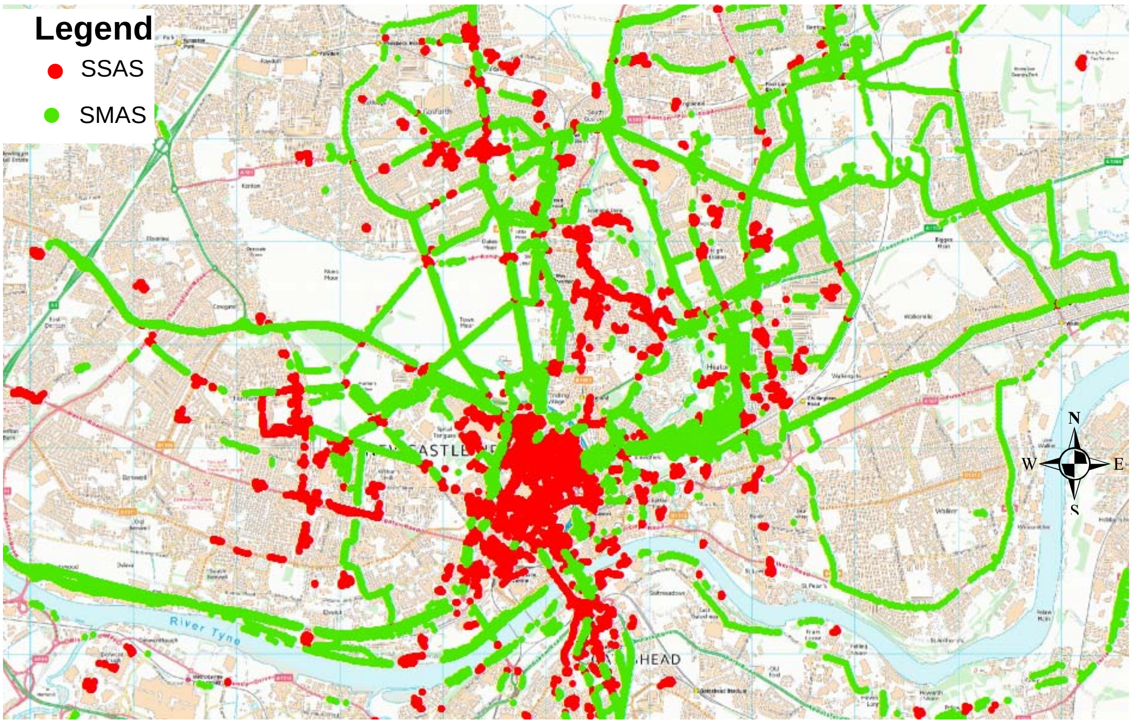


Figure 6-27: Significant SAS and MAS clusters for only cycle trips

Source of basemap: OS Open Data on openstream.edina.ac.uk

6.5 Significant Low and High speed MAS from multi-mode perspective

This section devotes attention to the entire multi-mode route choice information and associated visualisation. Here, the LMi was also used in a similar manner to the previous section. GPS data of cyclists with actual stationary activities removed were used as input to the LMi statistics calculation. Thus, points with speed lower than 2kmph were removed as discussed in the data preparation section. The data was projected from the World Geodetic System version 1984 to the UK National Grid Coordinate System.

Figure 6-28 shows a scatterplot graph of the z-scores (vertical axis) versus the movement speed in kmph (horizontal axis). The mean speed is estimated to be around 11kmph for all modes combined, which is lower than the mean speed for cycling (14kmph with SD=9). This reduction was influenced by the walking mode which usually has low speed. Additionally, the reported walk mode share is about 29% of total reported trip share and therefore can influence the mean speed for all modes.

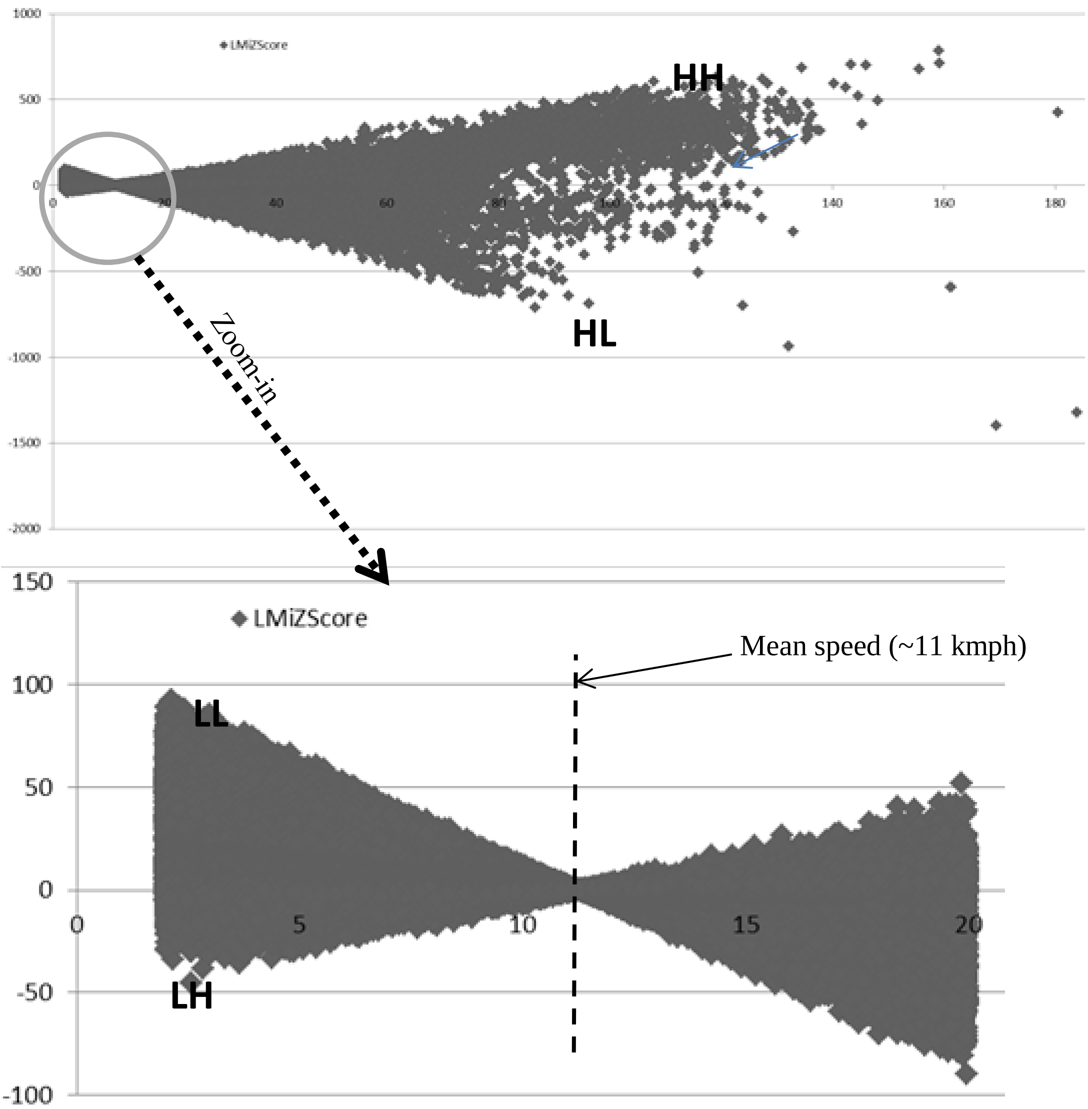


Figure 6-28: Z-score (y-axis) versus movement speed (x-axis) for all modes

A map of significant LMAS clusters which are low speed clusters for all modes is shown in Figure 6-29. The LMAS cluster is characterised by a calculated mean speed of 4kpmh with a standard deviation of 1.9kmph. With this mean speed falling within the general walking speed range of 2~6kpmph, it is fair to infer that the cluster areas denote walking friendly areas for the sampled cyclists.

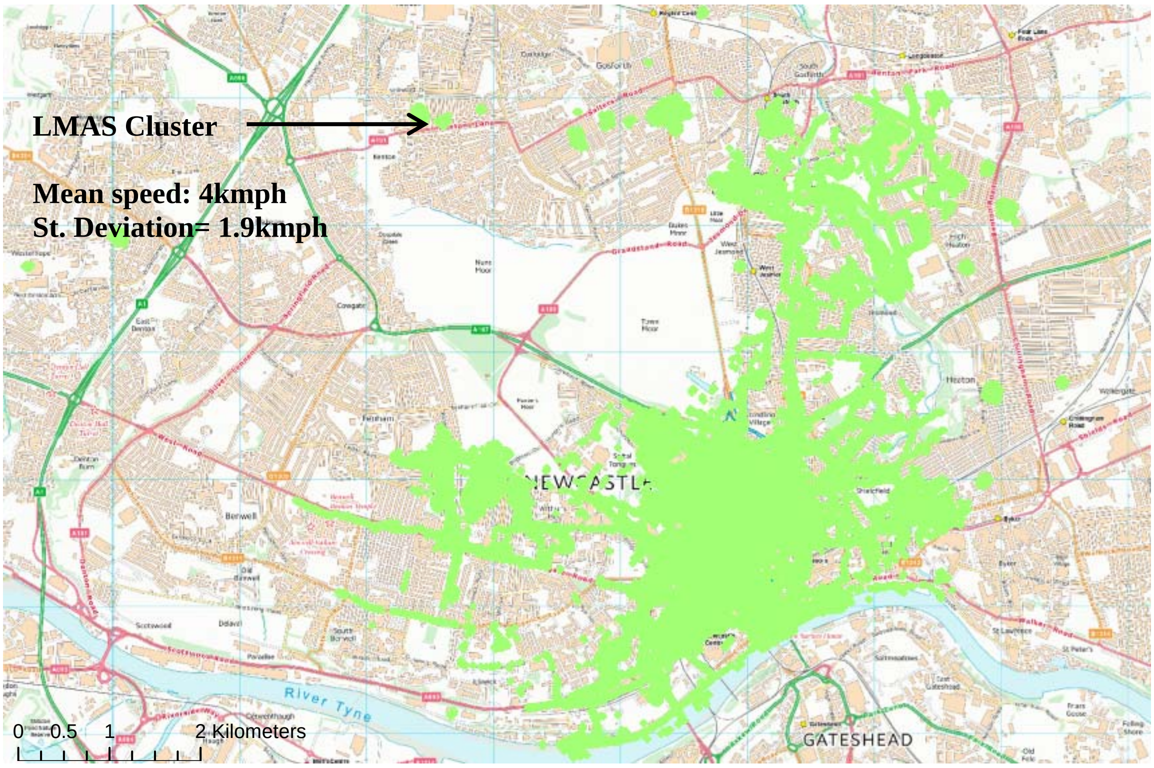


Figure 6-29: Significant LMAS clusters for all modes

Source of basemap: OS Open Data from openstream.edina.ac.uk

One of the computed cluster types from the LMi can also be used to determine clusters of HMAS areas. As defined in Table 6-2, the HH clusters have the characteristics of a motile activity space and therefore could be termed to be the parameter for significant HMAS. Similar to the analytical approach used earlier in identifying the significant LMAS, same is shown for significant HMAS. Figure 6-30 shows significant HMAS clusters for all modes. The HMAS is characterised by a mean speed of 29kmph with a standard deviation of 17kmph.

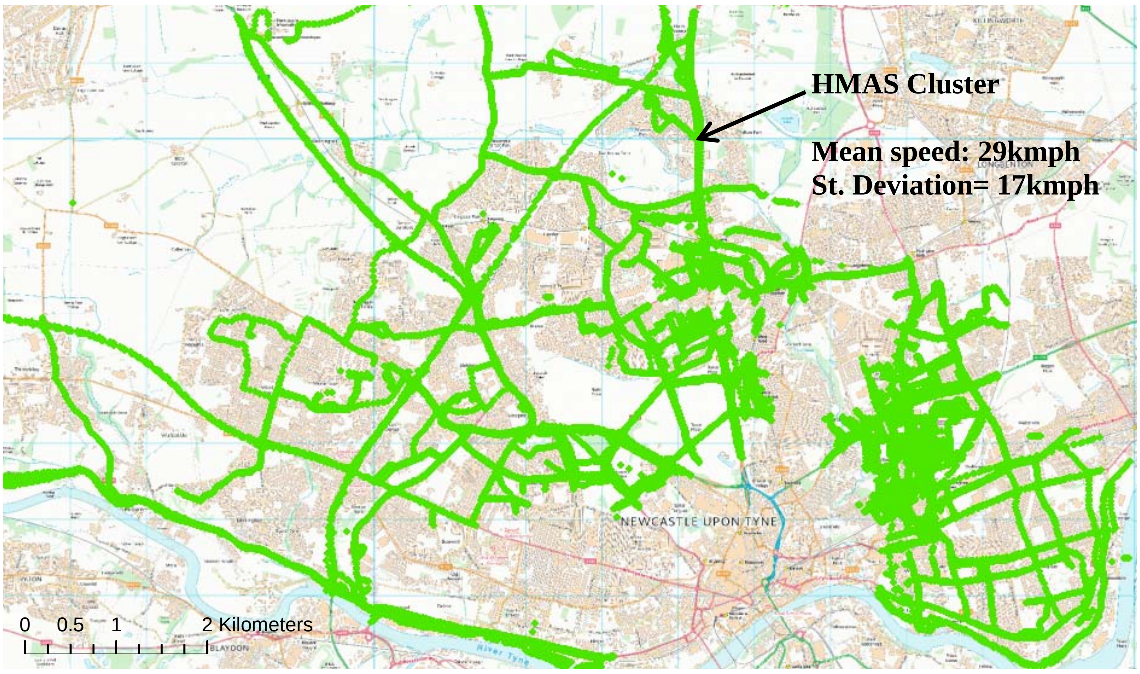


Figure 6-30: Significant HMAS clusters for all modes
Source of basemap: OS Open Data from openstream.edina.ac.uk

6.6 Discussion

In this chapter, it has been demonstrated how cycling behaviours can be analysed and visualised in a meaningful way. First, the chapter has contributed towards the visualisation of spatio-temporal aspects of cycling behaviours, thus adding to an existing body of knowledge on the use of visual analytical techniques for understanding travel behaviour (Andrienko et al., 2008; Schonfelder and Axhausen, 2010; Schönfelder and Samaga, 2003; Van der Spek et al., 2009). In addition, insights into travel behaviours of urban cyclists within the British context and around the study area have been explored, adding to our understanding of actual travel behaviours of urban cyclists. Both *stationary* and *motility* were considered as activities and their activity spaces were identified for Wards and Output Areas (OAs) as defined by the 2011 census geographical units. These two geographical levels were used for two reasons. OAs as the smallest areas that census data is provided while preserving confidentiality, can be useful when comparing values from the census. Wards, as basic administrative blocks where councillors are elected can help create awareness among policy makers about what to do in order to improve cycling uptake.

Following on from Broach et al.'s (2012) study in Portland Oregon, this study has demonstrated that there are differences in route and destination choice decision making between commuting and other utilitarian trips among utility cyclists in the North East of England. This comparison is done loosely given the different geographical contexts as well as sample characteristics along with research design characteristics within the two studies.

The novel use of SAS and MAS as a means of profiling activity spaces adds to the current body of knowledge on activity-based analysis as well as on space-time geography. In a broader sense, the available concepts in the visual analytics framework have also been expanded. Significant low speed clusters referred to as significant SAS areas were found to be located around built-up areas. The use of OAs may be useful for future research where census estimates for identified activity spaces could be further investigated. The analysis performed in this chapter has also added to analytical approaches for investigating detailed movement trajectories based on GPS data by demonstrating how LMi could be used to explore movement behaviour of urban cyclists. The chapter has shown that LMi is also useful and applicable to understanding cycling behaviours. This adds to what already existed on the use of LMi in understanding movement behaviour of pedestrians in an outdoor gaming and national park environment (Orellana and Wachowicz, 2011).

The next substantive chapter will perform route choice analysis at two different scales. On the one hand, the corridor space analytical technique will be used to understand whether these cyclists ride on, near, or off the designated cycle network. On the other hand, two statistical hypothesis testing techniques will be applied to test the null hypothesis - that transport network do not have any restrictions impact bicycle commuting.

CHAPTER 7. ROUTE CHOICE ANALYSIS OF CYCLING BEHAVIOURS

7.1 Introduction

The aim of this chapter is threefold. First, to identify in the relevant literature specific variables tested in cycling related route choice studies. Second, to use the identified variables as input to route choice analysis. The route choice model will test the hypothesis that network restrictions (i.e. one way, turn restrictions and access) do not have any significant influence on the movement of commuter cyclists. The third objective is to determine bike trip shares using the corridor space analytical technique. The findings of these analyses will be discussed in the last section of the chapter.

The neglect of non-motorised transportation options in transport planning and demand modelling is gradually changing in UK in a positive way. For example, the DfT has recently allocated funding for the improvement of cycling in cities through a cycling ambition programme and for improving the transport infrastructure in the UK (DfT, 2013f, i). In route choice research there has been, in recent years, a trend away from modelling hypothetical situations towards field-testing (Papinski and Scott, 2011). This is partly due to the effective use of emerging GPS technologies for gathering travel behaviour data in "wild" urban spaces, making it possible to observe realistic situations (Gong and Mackett, 2008, p. 3). Such detailed travel behaviour data offers possibilities for further research, especially in the non-motorised transportation arena.

Globally, there is increasing interest in the development of cyclists' route choice models using revealed preference GPS data from various geographical and local contexts with same, different or mixed methodological approaches in a variety of studies usually in a western context. However, very little knowledge of detailed cyclists' route choice preferences exist within the British geographical and local contexts; especially for cities in North East England where there are various attempts to promote cycling uptake. The previous chapter has shown how cycling behaviours could be mined, visualised and explained by employing visual analytical techniques. This chapter further examines cycling behaviours based on the newly acquired route choice information at two discrete but related levels of spatial analysis. First, by looking at the corridor space level, and second, by analysis at the network level for trips from home to work. Hence, the chapter fills a knowledge gap by analysing actual home-to-work route choices of commuter cyclists around Newcastle upon Tyne derived from the primary data collected for this study.

The application of a route choice modelling approach in understanding usage of transport infrastructure is considered quite challenging but very rewarding (Bierlaire and Frejinger, 2008; Harvey et al., 2008; Papinski and Scott, 2011). The challenges revolve around the lack of detailed information about the users of the infrastructure, in addition to limited availability of accurate data on the infrastructure itself. Perhaps a more pertinent emerging concern is how to determine and use the necessary variables to better understand the relationship between the collected data on the one hand and the infrastructure on the other hand. Even when the relevant variables are identified, accurate calculation of their values may take a significant amount of time, thus adding to the demands of the research. To this effect, Papinski and Scott (2011) developed a toolkit to generate relevant variables, with the aim of improving variable-generation-time. They used 237 home-to-work GPS-based observed routes of car drivers in Halifax (Nova Scotia, Canada) and developed the toolkit in ArcGIS with the *NetworkAnalyst* extension and VBA (visual basic for applications) programming language. Unfortunately, the toolkit is not available to the research community due to licensing issues, in addition to lack of functionality with more recent version of ArcGIS (Papinski and Scott, 2011). However, Papinski and Scott's (2011) study provides useful knowledge both on the process and on the generated variables themselves which could be applied to non-motorised route choice modelling.

7.2 Contextual background

In the last decade, cycling related studies aiming at route choice data and analysis have been undertaken; but studies remain limited in the British context. As contextual background, a brief discussion of cycling related studies follows.

Aultman-Hall's (1996) study analysed urban cycling behaviours using a GIS with time and distance variables as a fundamental part of the investigation. Although the behaviours were described as "*actual*" this may not necessarily be the case as participants had to draw/show/state their route on a prepared map of the study areas around Guelph, Toronto and Ottawa (Canada). This prepared map was an integral part of the survey instruments for the data collection and the stated routes were subsequently geocoded. In other words, GPS devices were not used to log the actual movement of the participants. The collected routes from participants were then compared with their shortest path alternatives while investigating other variables such as distance, time, signage, turns, slope, age, gender amongst others. Using multinomial logistic regression modelling, the study found that age, gender and winter cycling were significant factors in route preferences of the cyclists sampled and within the study area. Also, off-road paths, although of high-quality, were rarely used. The study suggested that the analysis of cyclists' route choice preferences has the potential to allow transportation planners and engineers to better serve the needs of cyclists.

Harvey et al.'s (2008) study used data from a stated preference survey together with a GPS based survey for 49 cyclists in Minneapolis (US). They found that mean distance of the preferred routes of commuter cyclists was significantly longer than the computed shortest possible route on a network without implementing any kind of choice model. In other words, the study compared preferred routes to their shortest path alternatives. In their shortest path computation, all roads with restrictions for cycling were removed prior to the computation. They also used network attributes, such as street, on-street bicycle lane, off street path and compared them between preferred and shortest routes for each commuter cyclist. A study in Texas (US), based on a web-enabled stated preference survey of cyclists, investigated how some set of variables influenced route choice preferences of cyclists (Sener et al., 2009). The study examined demographic characteristics of cyclists, on street parking, types of bike facilities along with roadway physical, operational (e.g. travel time) and functional (e.g. traffic volume) characteristics. The findings suggested the importance of demographic characteristics and route-related attributes in route choice analysis and decision making. They emphasised that the commuting time and motorised traffic volume are the most important variables for consideration and they also mentioned that the signage, speed, on-street parking, and availability of bike facilities en-route were other important variables.

Unlike the reported study by Sener et al. (2009), Menghini et al. (2010) used secondary GPS data of cyclists' route choice preferences as an input to route choice analysis in Zurich, Switzerland. The study used a representative sample of 2,435 residents, but without recording residents' demographic information. As such, only distance, observed routes and their relevant but unique alternatives were analysed as part of the modelling. The findings suggest that policies towards the improvement of cycling uptake should aim towards the provision of direct and marked bike paths for cyclists within the study area. Data limitations, such as navigable street-level network, forced the researchers to address a useful but limited set of variables. Menghini et al. (2010) suggest that future work should also take into account environmental attributes such as traffic volume, as well as socio-demographics of respondents such as age, gender, BMI and their aversion to risk.

Similar to Sener et al. (2009), Larsen's (2011) study used a web enabled stated preference survey together with other secondary data such as origin-destination information to investigate location allocation and prioritisation of bike facilities based on defined grid-cells across the study area in Montreal, Canada. The choice of grid-cell approach was based on the biasness of generated routes towards arterial roads. The use of disparate data sources presented many challenges which the analyst had to confront and decide on; especially when, for example, a network for analysis is not cycling friendly. Both observed and potential trips were generated using the shortest path algorithm and later rasterised to fall within the 300m grid-like corridors. Variables considered were time, origin, destination, turns, and weather. They concluded that the grid-cells method is not appropriate for detailed analysis of cyclists' actual route choice preferences. Additionally, they emphasised the importance of cycling infrastructure and the fact that methods assisting objective revelation of priority areas are essential to provide the evidence needed as input to effective use of finite resources allocated to the building and improvement of cycling infrastructure. They concluded by stating that objective evaluation of past projects are necessary to ensure greater transparency in transportation planning which eventually leads to an improved cycling network.

Hood et al. (2011) designed a revealed preference survey; they used a GPS based smartphone enabled survey to understand the route choice decisions of cyclists in San Francisco (US). This is the only cycling study found in the literature that has used smartphone enabled GPS data collection. The measured trips were instantly, at the point of logging, filtered for the detection of purpose and mode as well as map-matching to the transport network. Shortest path alternatives were considered as part of the analysis. The study suggested that traffic volume, count of lanes, crime, speed of traffic, and nightfall had no effect on route choice decisions while length and turns were found to have a negative effect. Also, frequent cyclists did not value bike lanes more than infrequent cyclists.

Broach et al. (2012) found that the information and analysis from the revealed route choice preferences suggests a significant difference between all other utilitarian purposes and commuting purposes among cyclists in Portland, Oregon (US). Also, distance, frequency of turns, slope, off-street bike paths, traffic signage at intersections, bridges, and volume of traffic played a role in cyclists' route choice decision making. Ehrgott et al. (2012) suggested variables such as time and traffic speed and volume, bike lanes, and gradient among others as input to the development of a route choice model. Snizek et al. (2013) used a web enabled stated preference survey, not GPS based, for collection of route choice information from the participants. Although similar to Aultman-Hall's (1996) study, they used a web enabled map rather than a paper map. The study suggested that cyclists enjoy riding near bike facilities, as well as near bodies of water or green areas. Almost all of these cycling related studies have also relinquished the visual aspect of the captured cycling behaviours, focusing on only route choice modelling. Several ways of visualising the captured behaviour, as presented in Chapter 6, can provide insight on the nature of the captured data and enable data exploration from different perspectives.

Table 7-1 lists the most recent cycling related studies that have analysed adult cyclists' route choice preferences. Essential explanatory variables used in these studies are cross-referenced in the table. The next section discusses these variables further and justifies their selection for analysis in this research.

Table 7-1: Variables used in studies for cycling related route choice studies

Study area	Copenhagen	Auckland	Portland	San Francisco	Montreal, Quebec	Zurich	Texas	Minneapolis	Ottawa, Guelph&, Toronto
Variables used/discussed	(Snizek et al., 2013)	(Ehrgott et al., 2012)	(Broach et al., 2012)	(Hood et al., 2011)	(Larsen, 2011)	(Menghini et al., 2010)	(Sener et al., 2009)	(Harvey et al., 2008)	(Aultman-Hall, 1996)
Travel time		✓					✓	✓	✓
Travel distance	✓	✓	✓	✓	✓	✓	✓	✓	✓
Origin, Destination	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bike lane	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quantitative information	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nodes/turns			✓	✓	✓				✓
Weather		✓		✓			✓		✓
Safety/Crime	✓			✓	✓			✓	✓
Traffic lights / signal	✓	✓	✓			✓	✓		✓
Gradient / Slope		✓	✓	✓		✓	✓		✓
Socio-demography		✓			✓		✓	✓	✓
Trip purpose		✓	✓				✓		✓
Route familiarity	✓						✓		✓
Route complexity			✓	✓	✓		✓		✓
Congestion	✓								
Level of service	✓					✓			
Traffic volume		✓	✓	✓			✓		✓
Route detours/ directness	✓							✓	✓
intersections	✓	✓	✓						
Comfort	✓	✓						✓	✓
Speed/Velocity		✓		✓		✓	✓		✓
Marked bike path						✓		✓	
Bridge			✓						✓

Crossings			✓				✓		✓
En-route stops or delays	✓								
Parkings	✓	✓					✓		
Natural areas	✓								

Table 6-1 (continued). Quantitative information is usually secondary data. Natural areas may include forest, parks, cemeteries, bodies of water, wetlands, and green spaces

7.3 Variable and Route generation for route choice analysis

Route choice researchers are normally confronted with two main challenges in route choice analysis (Papinski and Scott, 2011, p. 436). The first challenge is the generation of feasible alternative routes connecting departure and arrival locations to enable comparison with observed routes. The second is the identification and evaluation of network and non-network attributes that govern route choosing by the traveller. This section discusses how contextual variables, alternative and observed routes were generated as an input to the route choice analysis in this chapter. The observed routes used for the analysis were the only home-to-work commuting trips from the study sample.

7.3.1 Contextual variables

The contextual variables were derived from the cycling related route choice studies identified in the literature as listed in Table 7-1. Apart from Harvey et al.'s (2008) study, it was not clear how the shortest path was computed/generated from the network used by the other studies with respect to whether the restrictions on the network were released or maintained before the computation (Table 7-1). A shortest path generation based on network with restricted paths may be different from one based on network with unrestricted paths. Also, the measure of directness of a route, route efficacy, seems important enough to be considered. A cue taken from Harvey et al. (2008) findings, is that the more experienced bicyclists manoeuvre from point A to point B, especially in heavy traffic conditions, the more unlikely the willingness to travel extra distances. Nevertheless, such findings should be properly considered in relation to the purpose of riding as differences-in-preferences of different types of cyclists – such as recreational, commuter, utilitist are reported by Harvey et al. (2008). Despite the large number of variables that could be considered as input to route choice analysis, the reported studies have demonstrated that the decision to incorporate such variables is somewhat based on data availability and quality, methodology, line of inquiry, and the context of usage of variables. Based on the above studies and what could be computed given the available data and tools, thirteen variables were selected for analysis in this chapter. Larsen (2011) suggests that the characteristics of multiple datasets and methodological issues play an important role in the selection of factors to study cycling infrastructure. The available multiple datasets, chosen methods, and knowledge of the analyst informed the selection of variables for analysis in this research, as shown in Table 7-2. The OpenStreetMap (OSM) roads and their types were used, rather than the OS MasterMap® Integrated Transport Network Layer™, because of the difficulty in updating the transport network offered by the latter to reflect the captured route choice preferences. The OSM was easier to update and reflected more of the captured route choice preferences from the sampled cyclists.

Table 7-2: Contextual variables selected for analysis

Variable	Definition
Distance	Travelled distance of a trip or trip segment
Time	Network travelled time of a trip
Straight line distance	Euclidean distance between the points of departure and arrival
Route efficacy	Actual travelled distance divided by computed straight-line distance
Used road types from OpenStreetMap (OSM, 2012)	
Tertiary	Busy unclassified through roads. Roads wide enough to allow two cars to pass safely and having adequate road markings. *OSM tag: highway=tertiary*
Primary	A roads having OSM tags: *highway=primary;highway=primary_link*
Secondary	B roads having *OSM tags: highway=secondary; highway=secondary_link*
Residential	Residential roads. (Used only on roads that have no other function other than for residential purposes). *OSM tag: highway=residential*
Service	Service roads. (driveways, carpark entrance roads, private roads, bus-only roads, etc.). *OSM tag: highway=service*
Cycleway	A cycle track which may or may not follow a road. OSM tags used: *highway=cycleway; highway=track; highway=bridleway; highway=path*
Footway	A path mainly for walking. OSM tags: highway=footway; highway=pedestrian
Unclassified	Country lanes. OSM tag: highway=unclassified
Unknown	Unknown categories. OSM tags: highway = null; highway=road

7.3.2 Generating routes

The cycle network infrastructure used for the generation of constrained routes was OSM. The OSM network dataset was extracted from the parent/global planet.osm file using the BBBike.org web service (Figure 7-1). The use of this service provided a time-convenient way for the extraction of the needed data from the huge layer of OSM covering the entirety of earth. ArcGIS Editor for OSM 2.1 was used for the conversion from OSM data format to ArcGIS Network Analyst data format. To ensure that the converted data as input to ArcGIS Network Analyst is optimally configured for cycling, the OSM network data configuration file, in eXtensible Markup Language (XML) format "*CycleGeneric.xml*" was used as part of the input in the conversion process.

Name: NEEngland

Coordinates: -1.895,54.842 x -1.333,55.145

Script URL: http://extract.bbbike.org/?sw_lng=-1.895&sw_lat=54.842&ne_lng=-

1.333&ne_lat=55.145&format=osm.bz2&coords=-1.538%2C54.842%7C-
1.438%2C54.844%7C-1.333%2C54.867%7C-1.338%2C54.923%7C-
1.352%2C54.975%7C-1.394%2C55.022%7C-1.454%2C55.135%

7C-1.631%2C55.145%7C-1.788%2C55.106%7C-1.895%2C55.045%7C-
1.808%2C54.942%7C-1.78%2C54.905%7C-1.753%2C54.863%7C-
1.668%2C54.861%7C-1.606%2C54.842&city=NEEngland

Square kilometre: 1,212

Granularity: 10,000 (1.1 meters)

Osmosis options: omitmetadata=true granularity=10000

Format: osm.bz2

File size: 4.7 MB

SHA256 checksum:
e65b6666c894331ade14af53cdf3740ce4655c000d68909ba78369940f6c01da
Last planet.osm database update: Fri Mar 29 19:31:02 2013 UTC

License: OpenStreetMap License

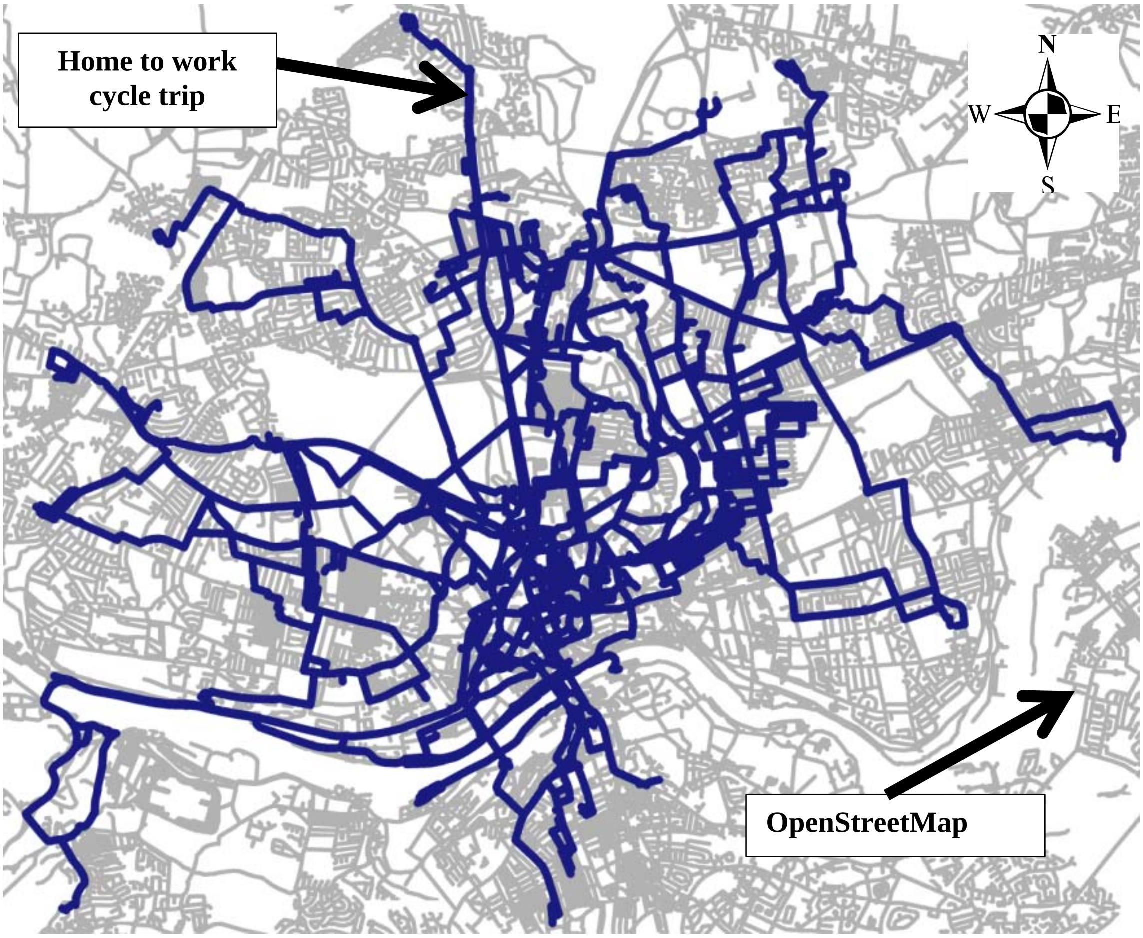
Figure 7-1: Extracted area parameters by BBBike.org

This file was provided as a downloadable file and is used if one requires a cycle routing network for analytical purposes. Further, the file contains information on the following OSM tag definitions:

- *highway:* *cycle navigable roads*
- *access:* *road access restrictions*
- *barrier:* *cycle barrier restrictions / time penalties*
- *oneway:* *turn restrictions onto oneway roads*
- *surface:* *paving of tracks, cycle ways and footways*
- *smoothness:* *drive time penalty for rough roads*
- *bicycle:* *restrictions on bicycle traffic*

The generated network was subsequently updated using the actual route choices from the primary data to ensure that the network constrained routes could easily be generated using the method proposed by Papinski and Scott (2011). Although the proposed method was originally applied to motorised transport networks, it can be extended for cycle networks if the underlying routes reflect the observed paths. The aim was to ensure that the provided network reflects the cycle network infrastructure. The outcome of this process was that the OSM network was updated to reflect cycle path infrastructure provision in the study area, although the update process was very time consuming and tedious.

The four-step method for generating routes, as described in section 3.9, was used to generate routes on the OSM transport network. The method which was originally proposed by Papinski and Scott (2011) provides an alternative to the use of map-matching techniques to align the extracted home to work trips from the GPS data to the OSM cycle network. The method generates network routes which reflect the GPS measured route choice preferences from the sample cyclists and allow network level analysis to be performed. For visualisation purposes, the observed routes, in blue, were superimposed on the OSM network, shown as grey lines in Figure 7-2.



Credit: © OpenStreetMap contributors & ODbL

Figure 7-2: Generated observed home-to-work routes with updated OSM network dataset in the background

In addition, using only the origin and destination information, the shortest path routes were computed for both applied restrictions on the network and released restrictions on the network. In total, the three sets of network data were used as part of the inputs to the statistical model:

- the observed constrained routes (OCR);
- the network restricted routes (NRR); and,
- the network unrestricted routes (NUR)

7.4 Analysis and results

7.4.1 Corridor space analysis based on cycle trips only

Apart from the administration of the detailed sample characteristics and visualisation of cycling behaviours from our sample, the aim of this section is to present a comparative geographical analysis of primary tracks on everyday utility cycling, in comparison to "official" cycling network data of the study area. Rather than using 300m grid-like corridors, as was in the case of

Larsen (2011) study, “corridor space analysis”, already explained in the methods chapter (Section 3.7) is used here for analysis. The analysis was intended to provide substantive empirical evidence on the use of the area’s cycling infrastructure by commuter cyclists, by estimating the cycle-miles/kilometres on the cycling network as a percentage of the total, for the given sample.

In adopting the concept of corridor space to compare route choice preferences of participants, two spatial analytical functions were used: buffer; and overlay (*identity*) analyses, following steps in ESRI ArcGIS. First, two sets of buffers were created around the Tyne and Wear Cycle Network, at 10/20 metres on each side of the network. As argued in Methods section 3.8.1, these values were used based on the outcome of the on/near/off estimates with the near value estimate used as a trade-off measure in the settlement of both on/off estimates. Second, the ArcGIS *identity* function was applied to overlay the buffers with the primary GPS data. Both the selected point-sets forming cycle tips and the subsequently generated cycle trips in the form of polylines were used. The *identity* function computes the spatial intersection of features (points, lines, buffers) and merges their respective attributes. Finally, the ArcGIS spatial statistics functions were used to compute various distances and database queries were used to extract trips of interest for further space-time-cube categorisation and visualisation.

What follows are the actual results from the corridor space analysis covering only home to work cycle trips, all cycle trips except home to work trips, and all cycle trips. All percentages were derived from weighted distances to account for gender.

Figure 7-3 shows trip shares for the off/on/near regions for all cycle trips. Findings from the corridor space analysis suggests that 57.4% of cyclists’ trips were found on the cycle network whilst 33.8% cycles outside the cycle network with 8.8% near the cycle network (Figure 7-3). Also, for all cycle trips, men tend to dominate in cycling *on* and *near* the cycle network. Both the males and females tend to use the cycle network more than *off* the network for utility trips. Table 7-3 shows the details of the weighted distances for each of the corridor regions (i.e. on/off/near regions). Due to quantisation/round-off error, the total weighted distances were slightly different between Table 7-3 and the previous Table 5-4 suggesting a limitation in this analytical approach, but the information loss is minimal at 0.04% of the total distance of trips.

Table 7-3: All Trips: Gender & Cycling with Off/On/Near Network - Corridor space characteristics

All Trips	Off/On/Near Network - Corridor space characteristics (Weighted distance travelled in km / %)			Total (km)
	Outside buffers (off network) km (% of *)	10m buffer (on network) km (% of *)	10-20m buffer (near network) km (% of *)	
Female	695 (12.6%)	1,262 (22.9%)	179 (3.3%)	2,136
Male	1,167 (21.2%)	1,900 (34.5%)	305 (5.5%)	3,372
Total	1,862 (33.8%)	3,162 (57.4%)	484 (8.8%)	5,508*

Source: Adapted from Yeboah et al. (In press)

Figure 7-3 shows a summarised form of Table 7-3 using a histogram. The percentage differences between male and female bike trips falling within the "on" regions, (34.5 - 22.9 = 8.6)% is almost the same as the percentage of bike trips falling within the "off" region (21.2-12.6 = 11.6)% suggesting some similarities in cycling behaviours based on gender. The addition of the trade-off region, the "near" region (5.5 – 3.3 = 2.2)%, estimates to the "on" estimates, making it about 10.8%, even increases the degree of similarities between "on" and "off" intra-differences. Figure 7-4 shows the temporal dimension of all the cycle trips per the on/off/near regions.

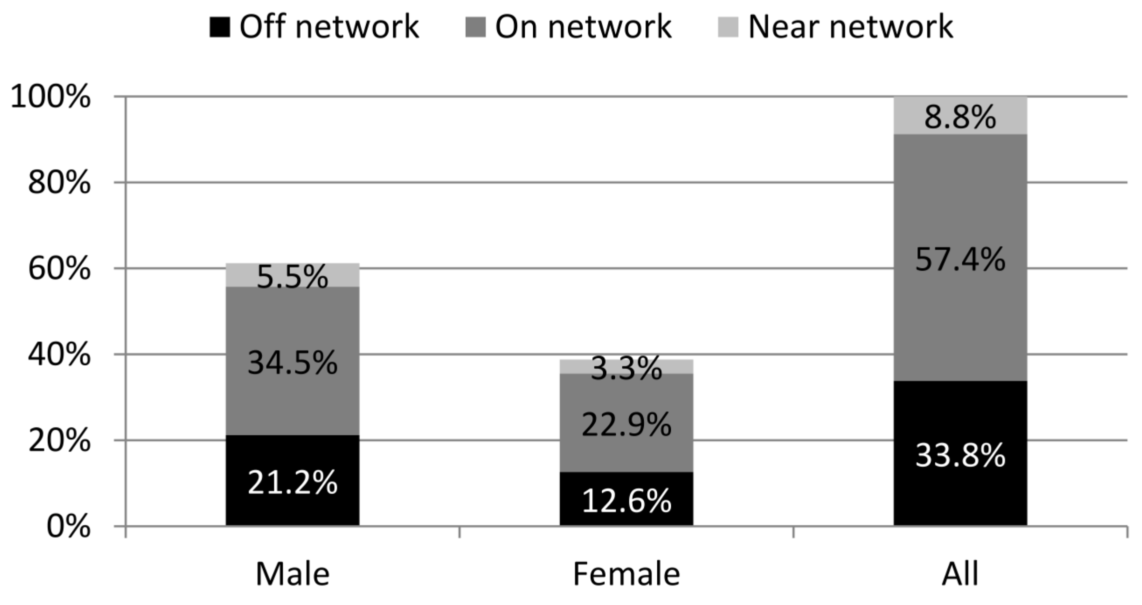


Figure 7-3: All Trips - Gender & Cycling with Off/On/Near Network - Corridor space characteristics

Source: (Yeboah et al., In press)

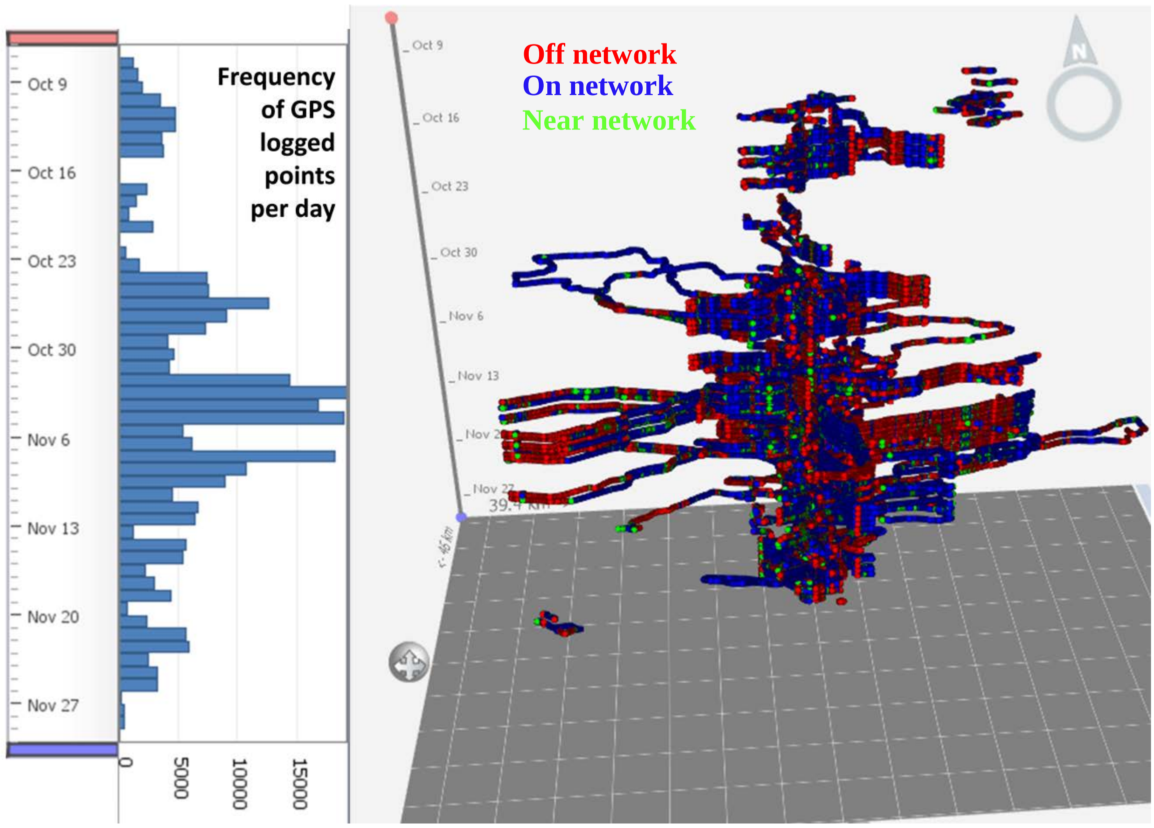


Figure 7-4: All Trips in Space and Time: Gender & Cycling with Off/On/Near Network - Corridor space characteristics

Source: (Yeboah et al., In press)

Only home to work trip trend follows similar characteristics for *all trips shares* and *all other trips shares*. For *only home-to-work cycle trips,* 56% is found *on* the network (Figure 7-5, Figure 7-6 and Table 7-4). The peak hours was found to be within the *ante meridian* confirming findings in section 6.3 where peak was around 9am in the CTS state for most popular activity spaces.

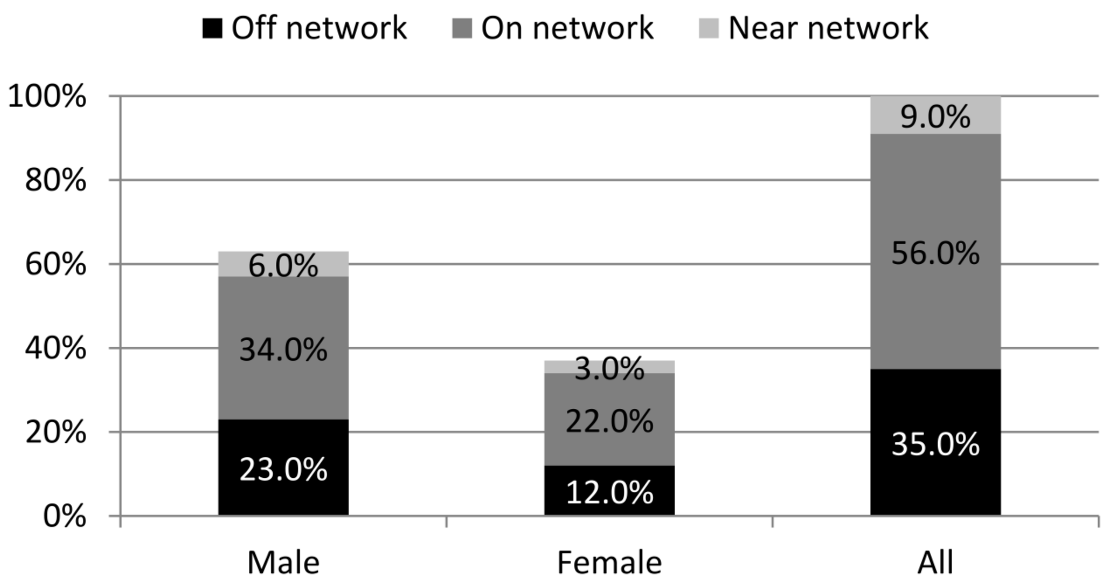


Figure 7-5: Only Home-to-Work Trips: Gender & Cycling with Off/On/Near Network - Corridor space characteristics

Source: (Yeboah et al., In press)

Table 7-4: Only Home-to-Work Trips table: Gender & Cycling with Off/On/Near Network - Corridor space characteristics

Only home to work trips	Off/On/Near Network - Corridor space characteristics (Weighted distance travelled in km / %)			Total (km)
	Outside buffers (off network) km	10m buffer (on network) km	10-20m buffer (near network) km	
	f: 20, m:49	f: 20, m:50	f: 20, m:50	
Female (f)	260 (32.8%)	470 (59.3%)	63 (7.9%)	793
Male (m)	493 (36.3%)	741 (54.6%)	123 (9.1%)	1,357
Total	753 (35%)	1211 (56.3%)	186 (8.7%)	2,150

Source: (Yeboah et al., In press)

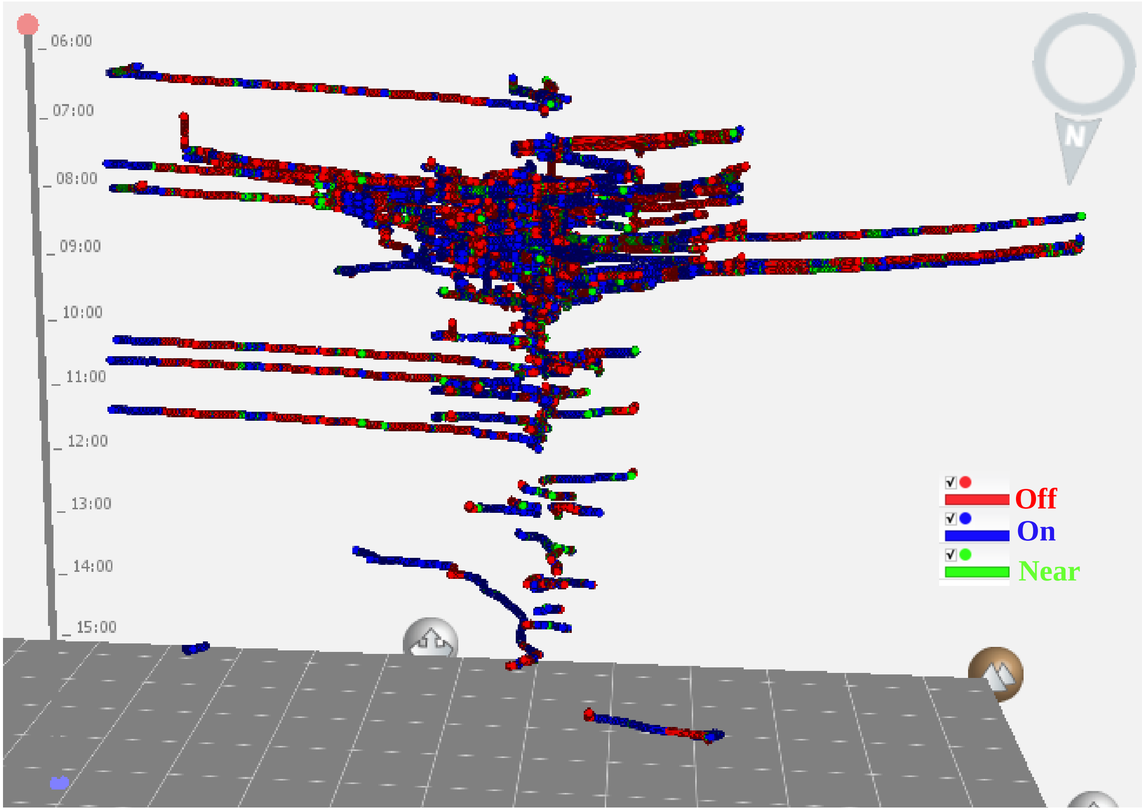


Figure 7-6: Only Home-to-Work Trips in Space and Time: Gender & Cycling with Off/On/Near Network - Corridor space characteristics

Figure 7-7 and Figure 7-8 show the corridor space characteristics for all other trips except home-to-work cycle trips in the form of histogram and space-time representation respectively. Table 7-5 shows the actual computed but weighted distance values for all other trips. Figure 7-8 shows the rush-hour time being moved to the *post meridiem* confirming findings in section 6.3 where peak was around 5.30pm in the CTS state for most popular activity spaces.

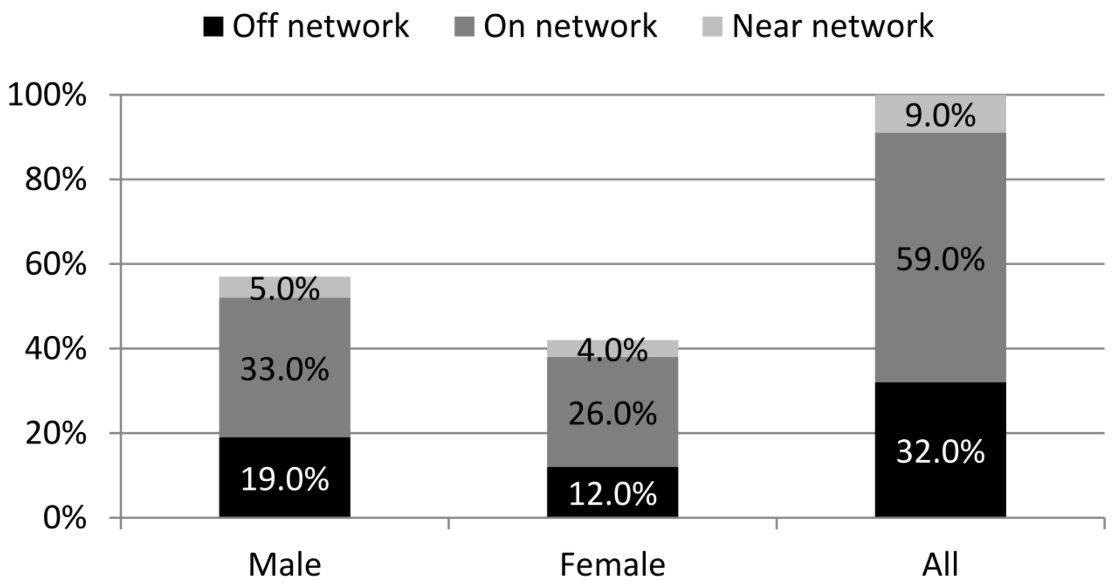


Figure 7-7: All Other Trips histogram: Gender & Cycling with Off/On/Near Network - Corridor space characteristics

Source: (Yeboah et al., In press)

Table 7-5: All Other Trips: Gender & Cycling with Off/On/Near Network - Corridor space characteristics

All Other Trips	Off/On/Near Network - Corridor space characteristics (Weighted distance travelled in km / %)			Total km
	Outside buffers (off network)	10m buffer (on network) km	10-20m buffer (near network) km	
Female	433 (29.6%)	901 (61.5%)	131 (8.9%)	1,465
Male	674 (34.4%)	1,159 (57.5%)	182 (9.0%)	2,015
Total	1,107 (33.1%)	2,060 (58.0%)	313 (8.9%)	3,480

Source: (Yeboah et al., In press)

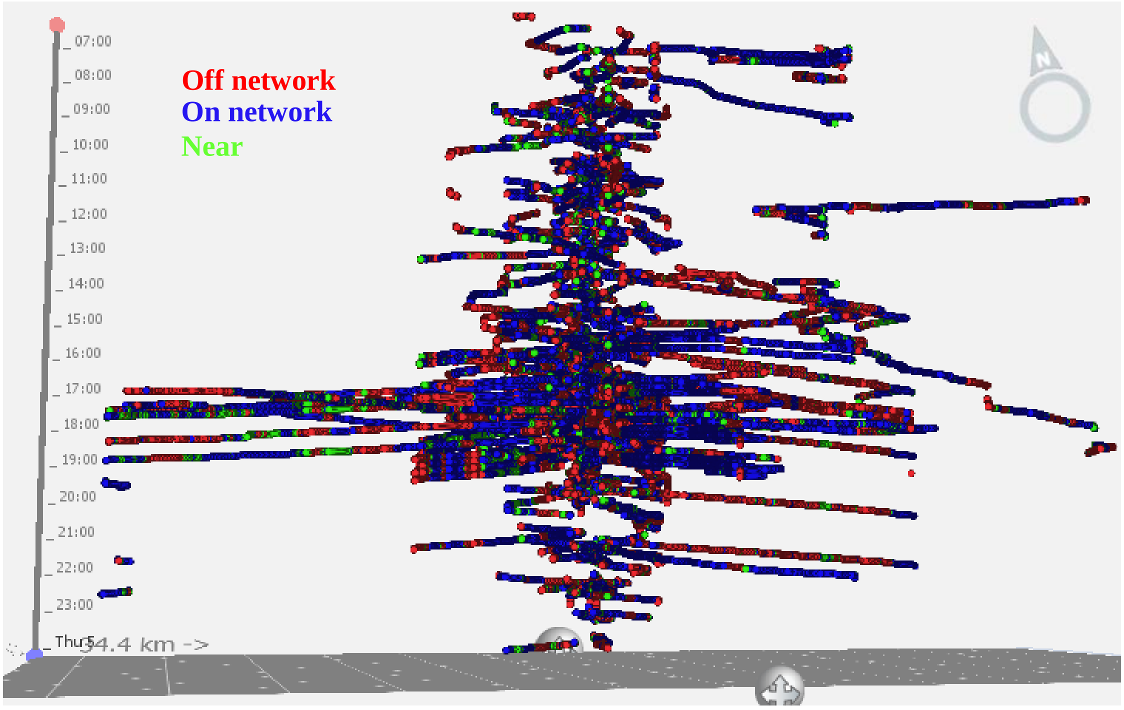


Figure 7-8: All Other Trips in Space and Time: Gender & Cycling with Off/On/Near Network - Corridor space characteristics

Source: (Yeboah et al., In press)

However, these differences of gender and cycling corridor network infrastructure usage are not so significant. With 42.6% of cyclists still cycling outside the designated cycle network, it is imperative that policy initiatives are aimed towards investing in cycling research and infrastructure (i.e. lanes, parking, crossings, etc.). The frequencies of male cyclists who cross cycle crossings are almost four times (i.e. 3.8 times) that of female cyclists; suggesting that female cyclists may tend to avoid cycle crossings.

7.4.2 Corridor space analysis with parkings and crossings

Two more layers of cycle infrastructure data are considered here: cycle parking layer and cycle crossing layer vis-à-vis the given sample's route choice preferences. Here, rather than using the cycle network infrastructure, the actual route choices/trips which were tracked during the GPS survey are used as the reference point for the buffering to detect both parkings and crossings locations (Figure 7-9). Locations of parkings and crossings within the *near* and *off* regions were not considered since they could not be of immediate or potential reach by the sampled cyclists. In total, 44 parking facilities out of 224 within the corridor space were found 20m near the actual route choice preferences of the sample. Also, 206 crossings were identified within the corridor space; of these 120 were labelled as pelican crossing and 81 as toucan crossing, while the remaining 5 were bikeshops in the list of crossings. These findings give an indication of the available infrastructure for the cyclists for immediate use.

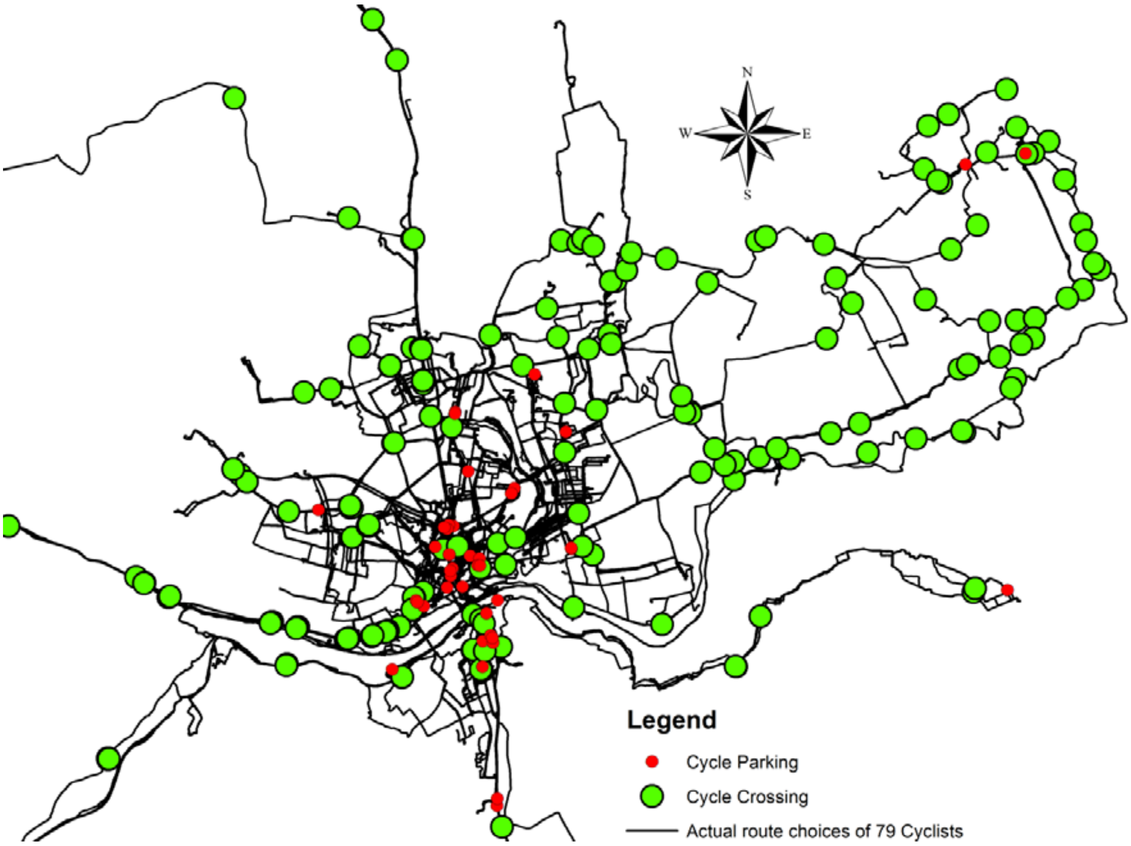


Figure 7-9: Map showing corridor crossings and parking with actual route choices of 79 Cyclists only cycling trips

Secondary data source: Parking and crossing data is from Newcastle City Council.

7.4.3 Hypothesis testing: Restricted versus Unrestricted Network

Little is known about how restrictions on the cycle network influence cycling behaviours. This knowledge gap is even stronger when the British context is considered. The statistical analysis tests the hypothesis that urban transport network restrictions (i.e. one way, turn restrictions, and access) do not have any significant influence on movement of commuter cyclists. Paired samples t-test was used to compare the attributes of the observed constrained route (OCR) to that of the network restricted routes (NRR) and network unrestricted routes (NUR). Similarly, as a way of checking robustness and triangulation of evidence given that the sample variables are not normally distributed. Wilcoxon Signed Ranked t-test was also used for the same datasets and the results compared. Summary statistics of contextual variables were manually generated (Table 7-6).

Table 7-6: Route attribute summary statistics for observed routes and shortest paths alternatives based on distance impedance and network restrictions (n = 219)

Variable	Observed constrained Route (mean ± std.)	Network Restricted Route (mean ± std.)	Network Unrestricted Route (mean ± std.)
Time	16.8 ± 8.0	15.4 ± 7.6	14.7 ± 7.1
Distance	4463.4 ± 2100.0	4036.2 ± 1913.7	3925.5 ± 1896.0
Straight line distance (SLD)	3192.5 ± 1553.6	3187.2 ± 1551.7	3192.3 ± 1553.5
Route Efficacy	1.4 ± 0.2	1.3 ± 0.1	1.2 ± 0.1
Percentage of route based on OSM road type			
% of distance on Tertiary	70.24 ± 137.40	135.35 ±162.05	131.57 ± 163.34
% of distance on Primary	81.52 ± 194.35	113.68 ± 162.77	102.72 ± 166.67
% of distance on Secondary	34.51 ± 86.29	99.86 ± 148.71	89.37 ± 141.25
% of distance on Residential	56.55 ± 94.73	105.69 ± 115.44	107.52 ± 113.52
% of distance on Service	31.28 ± 70.44	35.90 ± 53.75	44.17 ± 61.09
% of distance on Cycleway	69.92 ± 201.02	184.57 ± 319.26	189.32 ± 298.78
% of distance on Footway	22.09 ± 61.72	63.41 ± 96.00	68.60 ± 129.29
% of distance on Unclassified	28.11 ± 60.58	65.98 ± 71.61	61.11 ± 69.93
% of distance on Unknown	140.80 ± 480.41	369.66 ± 648.51	388.67 ± 696.56

Figure 7-10 shows box plots of the time component of the three commuting datasets suggesting that there were no instances of extreme outliers. Unlike the first three items from the left side, the last two box plots show the symmetrical variations of time differences between the OCR and the NRR as well as the NUR. Figure 7-11 and Figure 7-12 show box plots of observed and computed distances. Figure 7-11 show that the median of the observed routes dataset was higher than their generated shortest path routes but has a slight variation in the differences as the arrival points were moved to the point of restriction towards the destination. For example, if a cyclist cycles from point A to C via B and there was a restriction such that cycling was not possible on the network from B to C, the point B was considered the arrival point; as such, the observed point at C is moved to B manually. This is to ensure that the effect of network restrictions in movement is properly reflected in the generated routes for NRR. In general, the straight line distance between origin and destination for all three commuting datasets are very close (Figure 7-12). Figure 7-13 shows the route efficacy/directness index box plots. The figure also shows some pattern of differences and was assumed to be appropriate given that the variables used to compute the index were both showing no outliers (Figure 7-11 and Figure 7-12).

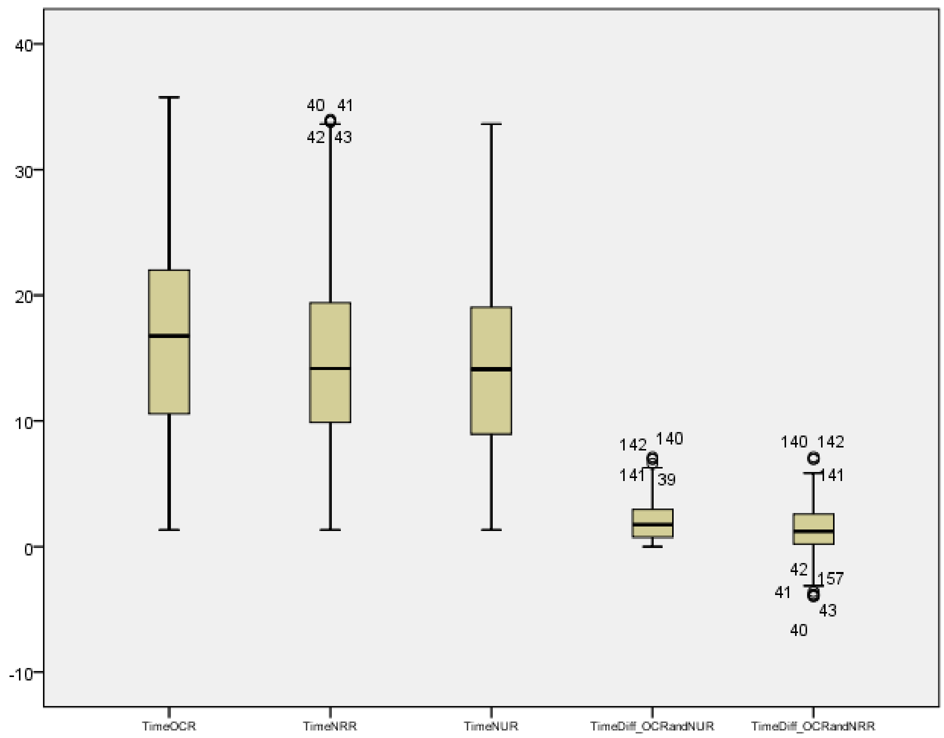


Figure 7-10: Time variable box plots of commuting datasets

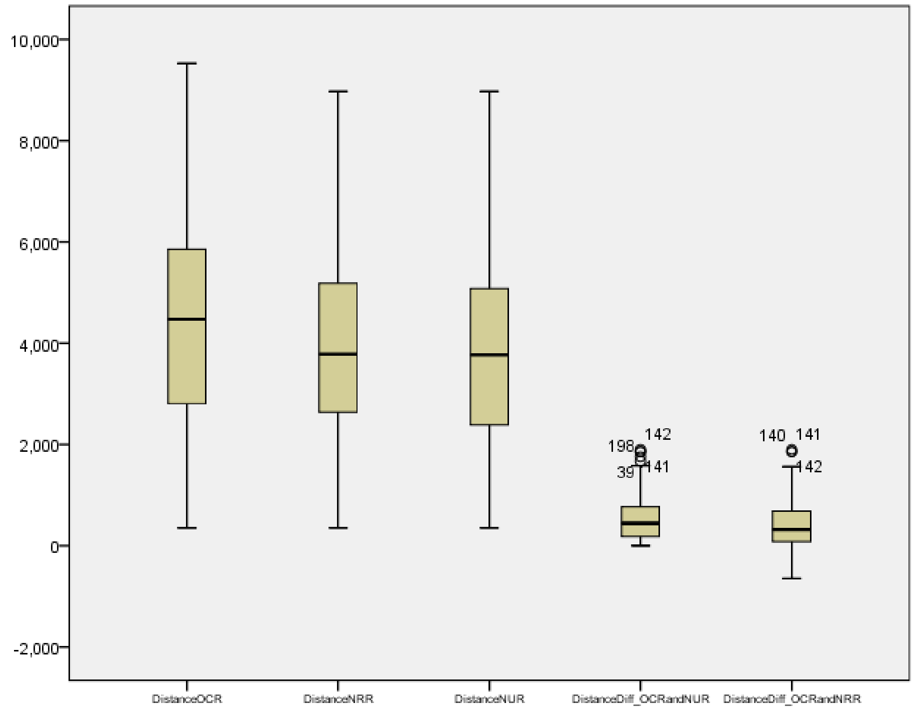


Figure 7-11: Distance variable box plots of commuting datasets

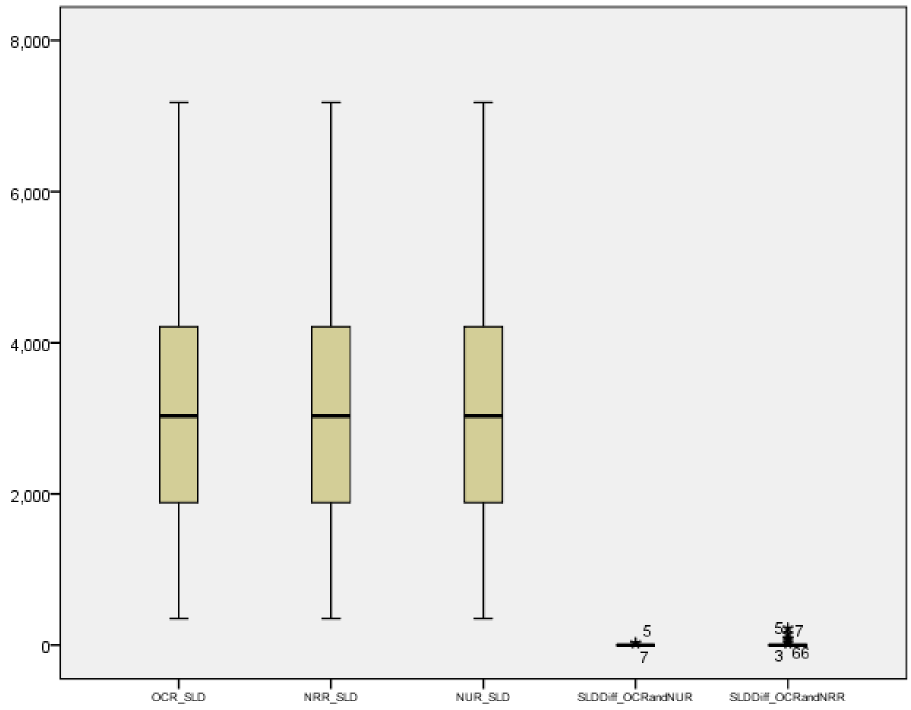


Figure 7-12: Straight Line Euclidean Distance variable box plots of commuting datasets

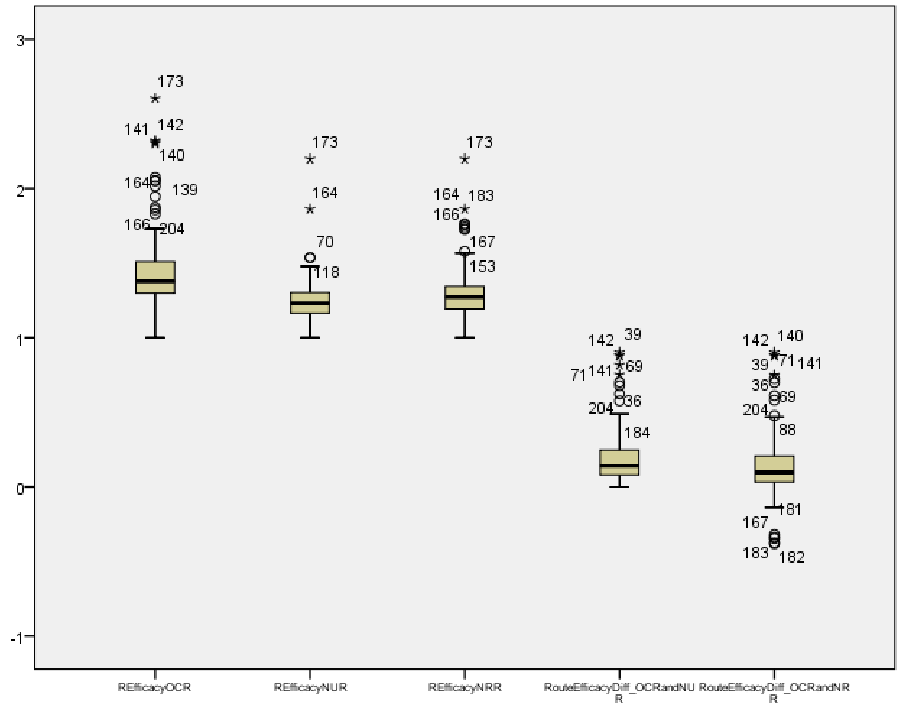


Figure 7-13: Route efficacy variable box plots of commuting datasets

Figure 7-14 and Figure 7-15 show the time differences between the OCR and NUR/NRR datasets in the form of histograms and normal distribution curves. The knowledge of this variability served as input to not only in understanding the commuting datasets but the determination of appropriate statistical techniques. From the figures, the normal distribution of time differences between the NRR and OCR appears more normal and symmetrical than that of OCR and NUR.

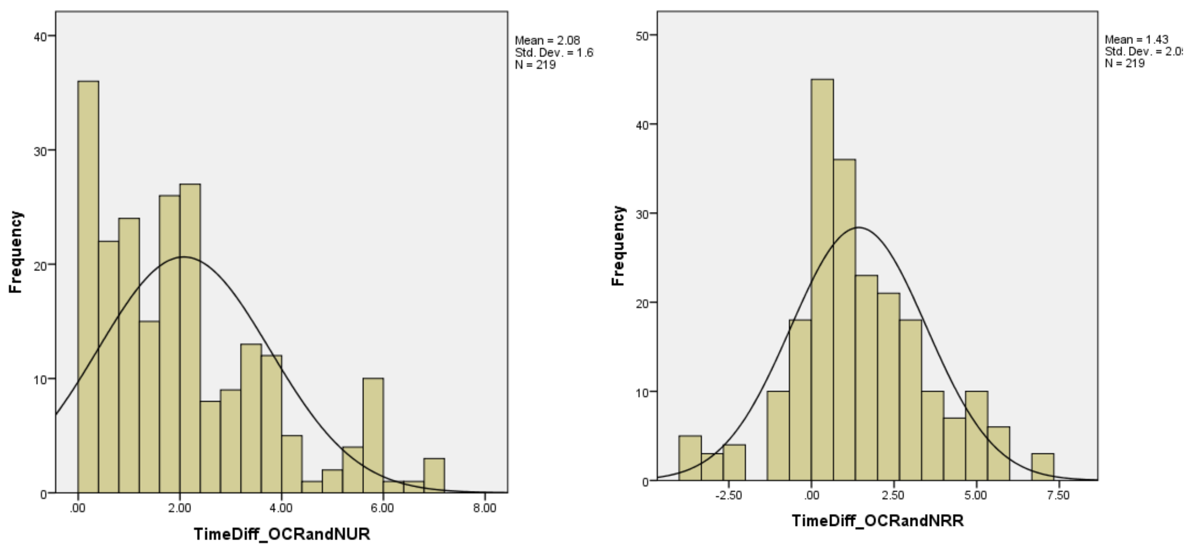


Figure 7-14: Histograms and normal distributions of time differences between OCR and NUR/NRR.

Comparatively, the same trend followed for the cases of differences in distance and route efficacy between the OCR dataset and the NUR or NRR (Figure 7-15 and Figure 7-16). Figure 7-15 shows variations in the differences in the distances between the OCR and either the NUR (left histogram) or NRR (right histogram) datasets. These variations were compared with the normal distribution graphically. The variation was expected as some of the arrival points in the NRR datasets were moved to the point of termination of the related observed trip route due to the restriction from that point to the actual destination.

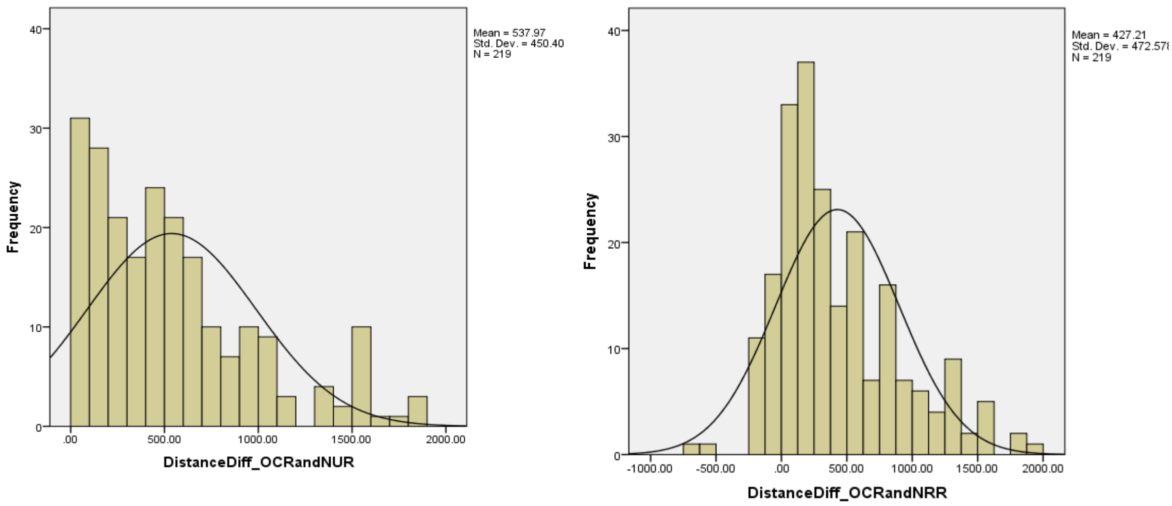


Figure 7-15: Histograms and normal distributions of distance differences between OCR and NUR/NRR

Figure 7-16 shows the normal histograms and normal distributions of route efficacy differences between OCR and NUR/NRR commuting datasets.

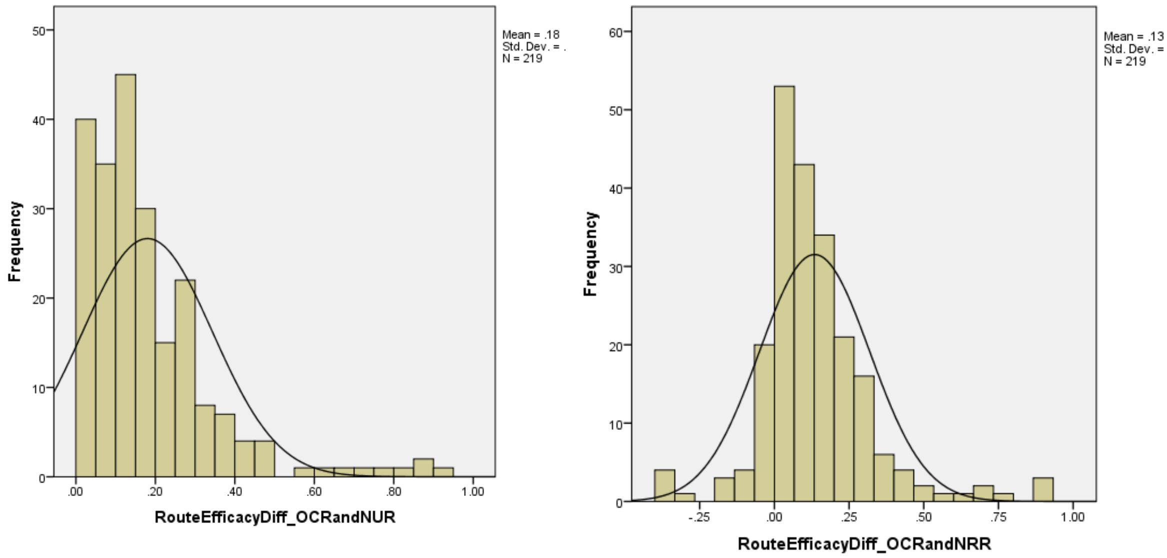


Figure 7-16: Histograms and normal distributions of route efficacy differences between OCR and NUR/NRR

The contextual attributes of observed routes compared to their shortest-path alternatives via paired-samples t-tests are shown in Table 7-7, using the test statistics and their p-values (in brackets). The values in bold indicate differences significant at the 0.05 significance level (n = 219).

Table 7-7: Attributes of observed routes compared to their shortest-path alternatives using the paired-sample t-test (n = 219)

Contextual variable	OCR versus NUR	OCR versus NRR
Time (minutes)	**18.136 (0.000)**	**10.309 (0.000)**
Distance (metres)	**17.676 (0.000)**	**13.378 (0.000)**
Straight line distance (SLD)	1.367 (0.173)	**2.849 (0.005)**
Route Efficacy	**16.274 (0.000)**	**10.769 (0.005)**
Percentage of route based on OSM road type		
% distance on Tertiary	**-4.106 (0.000)**	**-4.338 (0.000)**
% distance on Primary	**-3.782 (0.000)**	**-2.097 (0.036)**
% distance on Secondary	**-7.943 (0.000)**	**-7.598 (0.000)**
% distance on Residential	**-8.990 (0.000)**	**-10.844 (0.000)**
% distance on Service	-0.047(0.963)	-0.504 (0.615)
% distance on Cycleway	**-3.882 (0.000)**	**-4.547 (0.000)**
% distance on Footway	**-5.329 (0.000)**	**-4.985 (0.000)**
% distance on Unclassified	**-6.651 (0.000)**	**-4.579 (0.000)**
% distance on Unknown	-1.741 (0.084)	**-2.017 (0.046)**

The contextual attributes of observed routes compared to their shortest-path alternatives, using the Wilcoxon Signed Ranked test, are shown in Table 7-9 based on the sign of the ranks and their p-values in brackets.

Table 7-8: Observed routes compared to their shortest-path alternatives using the Wilcoxon Signed Ranked t-test (n = 219)

Contextual variable	OCR versus NUR	OCR versus NRR
Time (minutes)	**-12.801b (0.000)**	**-9.381b (0.000)**
Distance (metres)	**-12.801b (0.000)**	**-11.187b (0.000)**
Straight line distance (SLD)	-1.342b (0.180)	**-2.934b (0.003)**
Route Efficacy	**-12.831b (0.000)**	**-10.525b (0.005)**
Percentage of route based on OSM road type		
% distance on Tertiary	**-8.036 b (0.000)**	**-7.531b (0.000)**
% distance on Primary	**-10.424 b (0.000)**	**-8.437b (0.000)**
% distance on Secondary	**-12.176 b (0.000)**	**-13.245b (0.000)**
% distance on Residential	**-11.291 b (0.000)**	**-12.880b (0.000)**
% distance on Service	**-2.526 b (0.012)**	**-3.057b (0.002)**
% distance on Cycleway	**-7.558 b (0.000)**	**-10.253b (0.000)**
% distance on Footway	**-10.188 b (0.000)**	**-11.294b (0.000)**
% distance on Unclassified	**-10.359 b (0.000)**	**-9.253 b (0.000)**
% distance on Unknown	**-2.617 b (0.009)**	**-2.483 b (0.013)**

Note: The bolded values shown in Table 7-8 are significant differences at the 0.05 significance level (n = 219); b means based on positive ranks.

7.5 Discussion

The research reported in this chapter partly confirms the findings by Hood et al. (2011) in San Francisco that frequent cyclists (in our case experienced cyclists) tend to make full use of cycle lanes. Our research took into consideration the suggestions by Menghini et al. (2010) to incorporate socio-demographic variables such as age and gender in understanding cycling behaviours. We found that there are no significant differences between males and females cycling on/near/off the cycle network. Home-to-work trips alone constituted a total weighted distance of 2150km; while all other trips (excluding home-to-work) constituted a weighted distance of 3480km. The findings suggest that only home-to-work trips differ from all other trips including return from work-to-home. The differences in negotiating other routes beside "only home-to-work" routes confirms comments in the literature that the use of the transport network for non-home-to-work purposes may differ greatly from routes chosen for only home-to-work purposes (Yiannakoulias et al., 2012, p. 171). There are, however, policy implications at three different levels: for city planners, employers, and for employees/utility cyclists. City planners may have to aim at providing routes (cycle paths/lanes) alongside workplace parking, crossings, and signage. Planners and politicians should consider providing and promoting an enabling environment through policies as well as cycling proficiency training. Employers, including cycle shop/maintenance owners, may have to actively provide "employer place cycle infrastructure" in addition to cycling related schemes targeting the comfort of employees who decide to cycle. Employees/utility cyclists should therefore take advantage of these enabling environments and ensure they pay attention to cycling proficiency and provide feedback when needed. However, there are limitations as to how far the use of bicycles could reach. It is therefore suggested that the objective should not only be to focus on cycling but on an integrated quality transport system where cycling is well integrated in the whole system. Policy makers in the UK have emphasised that cycling is at the heart of transport and health strategies (DH, 2010), but cyclists are yet to experience this on the ground as investment on cycling infrastructure is now being declared three years after such statements (DfT, 2013i; Siddique, 2013; Walker, 2013a).

The research design developed here has only been implemented in a few published cycling studies. There were no significant differences between gender and use of cycling "corridors". Reasonable use of current cycling networks (more than half of trips take place within a buffer of 10m of cycling paths) is evident in respondents' travel behaviours. Also, there is potential for better use of cycling networks (e.g. parallel streets). However, there seems to be a need to improve the cycling network for the ⅓ of trips taking place "off" the network implying policy implications issues such as a reconsideration and assessment of the designated cycle network routes. It is argued that space-time analysis can provide insights on day/time differences for cyclists and usage of the cycling network.

In the UK, there seems to be a gradual decline in the use of main roads for cycling over the last decade (DfT, 2013l). As Figure 7-17 shows, those using any space other than the main road network to cycle appear to be on the increase over the last decade which is from 2002 to 2012. Could it be that the enhancement of the road infrastructure is not right while awareness of the usefulness of cycling is on the increase nationally? The downward trend of cycling on main roads in the UK over a decade may be due to the unfriendly nature of the transport network for cycling. While people cycling on pavements, cycle paths, road in parks, open country and private land was on the increasing trend, main-road cycling appears to be decreasing over the last decade with a slight increase in 2012 (DfT, 2013l).

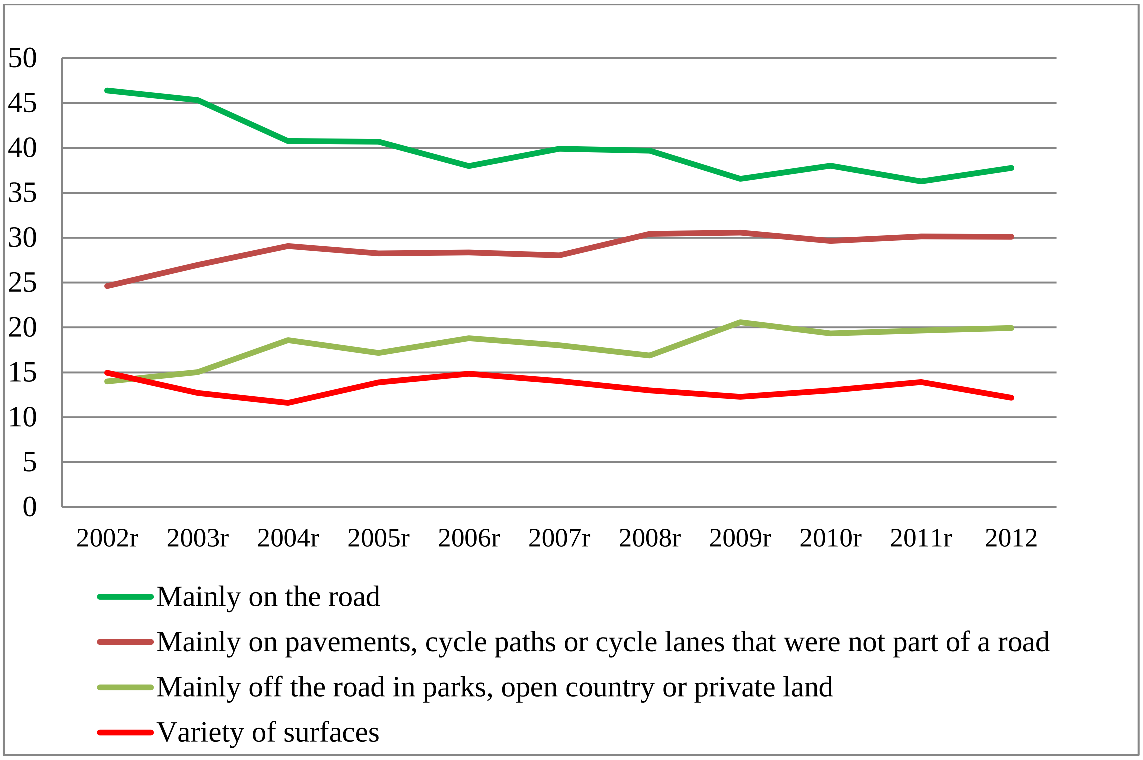


Figure 7-17: Where usually cycled in the last 12 months in the UK

Data source: National Travel Survey 2002 to 2012 (DfT, 2013l)

This claim could be supported by the recent announcement by politicians to invest about £77 million of public money into cycling in England with the aim of improving the transport network at 14 locations on the trunk road network (Siddique, 2013; Walker, 2013a). Although the funds have been made available, knowing where to invest in a practical sense is the key to getting better value for the money. This is necessary because it has been pointed out that major roads pose various obstacles to journeys by bike (Siddique, 2013). The eight cities mentioned to benefit from this investment were Newcastle, Leeds, Manchester, Oxford, Norwich, Birmingham, Bristol, and Cambridge. The shares of investment of public funds for the cities are shown in Figure 7-18. There was an additional £17 million in investment funds to cover national parks; South Downs (£3.8), New Forest (£3.6m), Peak District (£5m) and Dartmoor (£4.4) (Westcott, 2013). Although this recent policy shift is positive, more is needed as the declared investment still does not match other EU countries such as the Netherlands where they fund about £24 per person per year (Peck, 2013). Even when the entire funding for investments in cycling is combined in the UK, the budget is estimated to be only around £18 per person per year (DfT, 2013k).

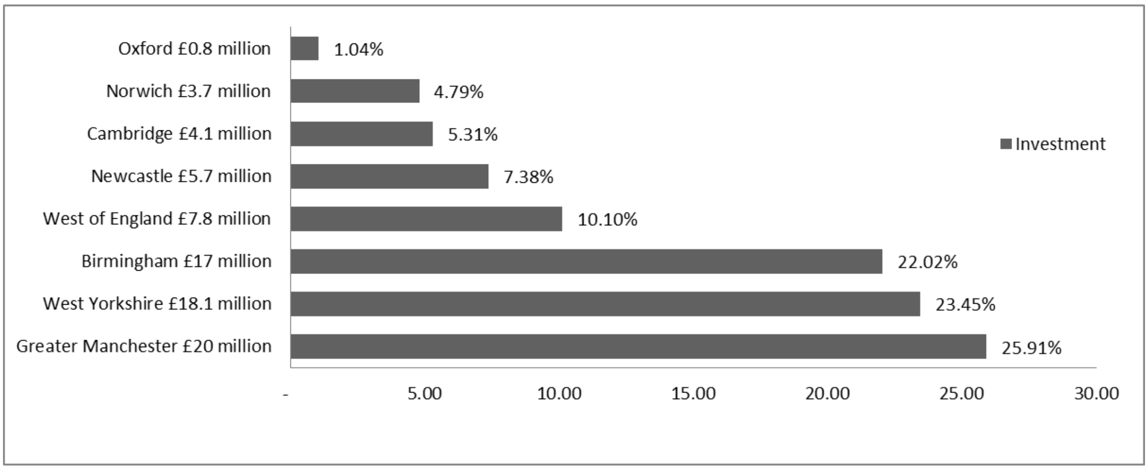


Figure 7-18: Share of investment in cycling for 8 cities in England

Data source: Press release - Government shifts cycling up a gear (DfT, 2013j)

Despite the apparent effort and financial commitment by the UK government in improving cycling, there is considerable criticism. For example, Walker (2013b) argues that the government is not doing enough for the realisation of UK becoming one of the "cycling nations" in Europe. The basis of this argument is that the long awaited DfT response to the "Get Britain Cycling Inquiry" recommendations was far below expectation and seem not to offer any hope by linking responses to already existing nationwide projects (DfT, 2013k; Goodwin, 2013; Walker, 2013b). The MP for Newcastle Central, Chi Onwurah, has also argued for better national leadership and backing for cyclists in the study area during a recently held (Get Britain Cycling) debate in parliament (Pearson, 2013). This political campaign suggests that there is more to be done than just a well formulated local plan as in the Tyne and Wear area. Strategic policies should be put in place to connect on and off-road cycle lanes by improving the completeness of the cycle network. In addition, key hubs and trip generators should be linked together with the cycle network with the aim of improving the everyday cycling experience (LTP3, 2011, p. 160). The findings in this chapter also suggest that cycling from home to work journeys tend to be on residential roads and then footways as shown in Figure 7-19. Footways, according to the coding system of OSM and even as its name implies, are meant not for cycling but it appears the only way, for cyclists in this study, to get to work on time and safely, as cyclists chose to use them in an attempt to minimise exposure to tertiary and primary roads.

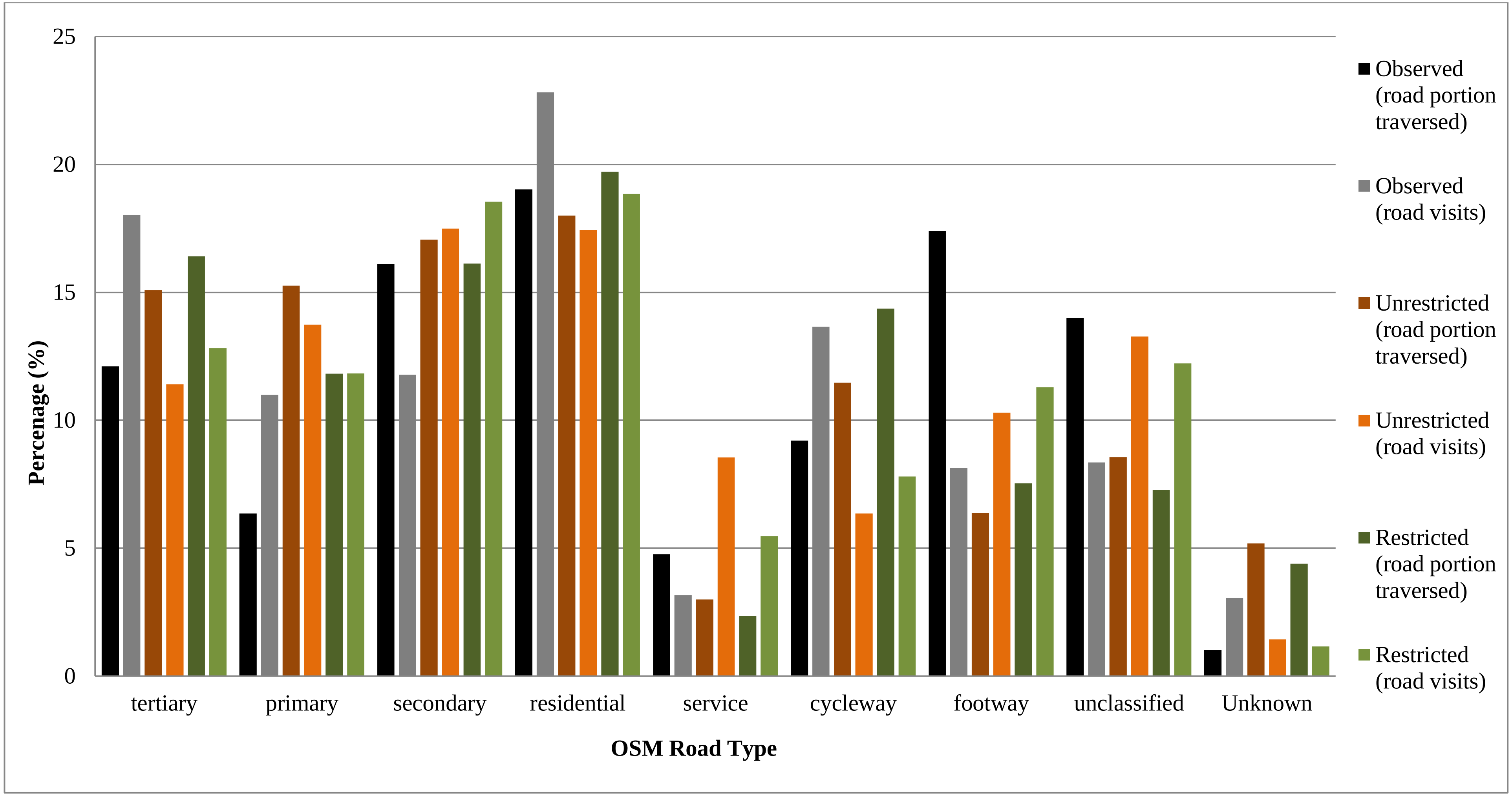


Figure 7-19: Percentage of route based on road type

In order to follow the interpretation and discussion of the results from the network level analysis, an example of hypothesis testing is given in Table 7-9. From this example, the null hypothesis that there is no significant difference between Time OCR (cycle time from observed routes) and TimeNUR (cycle time from network unrestricted routes) is rejected because the difference between their medians is significant (i.e. p=0.001 < 0.05). Therefore, the Wilcoxon T test indicated a significant difference between the two conditions (i.e. Time NUR and Time OCR) with T (N=219) = t-value indicated, p= p-value indicated.

Table 7-9: An example of hypothesis test summary using Wilcoxon T-test

Null Hypothesis	Test	Sig.	Decision
The median of differences between *TimeOCR* and *TimeNUR* equals 0	Related-Samples Wilcoxon Signed Rank Test	.001	Reject the null hypothesis

The statistical findings from the comparison of observed routes against shortest routes based on distance suggest that observed routes were significantly longer than their shortest path alternatives. The only exception was the straight line distance between the observed bike routes and the unrestricted network routes, where the difference was not statistically significant. For all the other contextual variables/conditions, both the parametric and non-parametric outputs from the statistical analysis showed significant differences and the null hypothesis was rejected in favour of the alternative. This means that urban transport network restrictions (i.e. one way, turn restrictions and access) appear to have significant influence on the daily movement of commuter cyclists. Therefore, minor changes in the configuration of the network which in part constitute the built environment may or may not support cycling uptake. In order to see an increase in cycling uptake, the network structure needs to support higher destination accessibility (i.e. closer to a value of one for the route efficacy measures) with bike lanes supporting greater connectivity between local streets. The ease-of-travelling to a destination is what is generally considered destination accessibility (Zhao, 2013). The route efficacy, the directness of routes, for both observed and shortest paths was found here to be significant suggesting that route directness is an important factor to be considered for restricted and unrestricted networks.

The findings reported here are in agreement with the “follow your nose” hypothesis tested by Conroy-Dalton (2001, p. 11), where she defines route angularity as “*the phenomenon of judging a route that contains many changes of direction to be longer than a straighter route of identical length.*” Conroy-Dalton (2001) tested the hypothesis that “*an individual subject will follow as straight a route as possible with minimal angular deviation (from a straight line) on condition that this choice always approximates the direction of their final destination*.” The finding was that people tend to steer a linear path as an unconscious strategy to minimise navigation complexities. The study of strict route angularity per se was deemed outside the scope of the thesis. However, future work to randomly sample route choices from the data collected for this thesis and experiment with route angularity to further compare the findings from the virtual world settings as performed by Conroy-Dalton (2001) could be interesting. The GPS device logged the headings or angular movement of directions which could also be computed from the polylines representing the routes together with the street network for verification.

Finally, the outcome of the route choice analysis suggests that shortest paths do not accurately represent observed bike routes for the home-to-work commute. It is important to also state that the shortest path determination was based on distance. It was found that using time-impedance for the shortest path with the OSM cycle network was same as the distance-impedance. This may be due to the lack of posted speed values on the cycle network. It is likely that the shortest path cycle trips generated would have been different given posted speed values integration with OSM. The differences for the paired-samples t-tests are computed as observed route attribute minus the shortest path attribute. This means that if the statistic is positive, the observed route is longer, while if the statistic is negative, the shortest path attribute is longer.

CHAPTER 8. DISCUSSION OF KEY FINDINGS AND METHODOLOGICAL ISSUES

This section draws on the results and discussions from the previous chapters and summarises the key findings while pointing out some of the methodological implications. This is the first study in the UK that combined detailed collection and analysis of adult cyclists' route choice preferences and perceptions in an urban environment, bringing substantive empirical evidence for understanding daily urban cycling behaviours in space and time (Alvanides and Yeboah, 2012a, b, 2014; Henderson, 2013; Northumbria, 2013; ScienceDaily, 2013; Yeboah, 2013; Yeboah and Alvanides, 2013; Yeboah et al., In press; Yeboah et al., 2012). Very few published studies in this field have implemented the research design developed for this research offering the possibility to understand detailed actual/revealed route choice preferences within the study area. Schonfelder and Axhausen (2010, p. 181) concluded in their longitudinal study that the combination of travel diary data and GPS observations shows great potential for future work. Until now little evidence was available about revealed cycling behaviours in a scientific manner and this study has filled the knowledge gap in the British context. In addition, the triangulation of evidence using available secondary data further deepens the existing understanding of cycling patterns and infrastructure within the study area. The thematic strands discussed in the conceptual framework for this research are revisited here to synthesise the key findings of the research.

8.1 Cycling data capture, refinement and analytical issues

This research developed a number of tools for data capture and refinement of cycling behaviour data. First, the use of state-of-the-art portable GPS trackers along with detailed travel diary and other questionnaires to capture cycling behaviours is innovative in the British context. Second, several cycling related datasets were identified for the study area providing useful baseline information for this study. For example, from the analysis of the secondary datasets such as the Tyne and Wear Household Travel Survey from 2003 to 2011, it became evident that cycling activity concentrated in the central part of Newcastle upon Tyne. This finding helped in informing the definition of the study area for this research. Chapter 3, discussing the methods used in this study, showed both existing and new approaches for analysing and visualising cycling behaviours.

The novel use of STC as a visual technique for data processing has the potential of allowing anyone who is familiar with the neighbourhood to easily clean the GPS dataset without any algorithmic knowledge of complex toolkits. By using STC this way, the usability of the cube achieves a complete cycle of GPS data cleaning, analysis and visualisation as conceptualised in Figure 8-1. This conceptualisation extends discussions made in sections 2.8 and 2.14.1. The analytical flexibility offered by the analytical tool (GeoTime) allowed the idea of using the space-time cube as a data processing tool conceivable. Proulx and Canfield (2013) recently report on the latest challenges and opportunities within the GeoTime analytical framework which points to the integration of web technologies. With a well-developed web enabled platform, the potential for processing cycling data using cloud computing is possible.

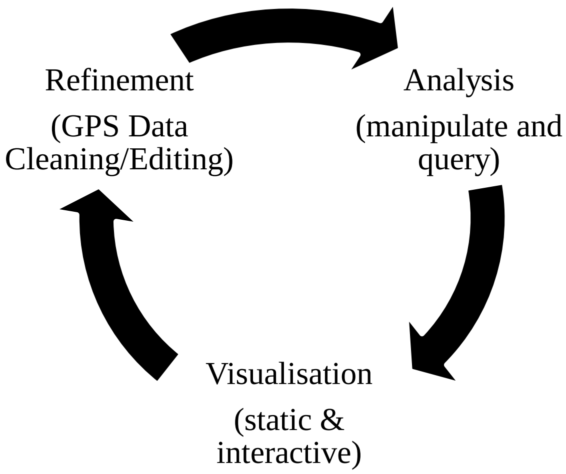


Figure 8-1: The Space-Time-Cube (STC) usability cycle
Source: Adapted from Yeboah et al. (In press)

Another novel concept introduced here is the corridor space approach for spatial analysis which offers a unique insight for understanding cyclists' interactions with the built environment when the cycling infrastructure is fragmented. Finally, an innovative approach for profiling activity spaces of cyclists was introduced in Chapter 3 and operationalised in Chapter 6 for identifying popular and significant areas where cyclists stopped or moved. The stepwise semi-manual application of flow mapping techniques in generating flow maps may lead to automated analytical tools for performing such tasks. The challenge faced, at the time of data analysis, in identifying appropriate tool in commercial GIS packages such as ArcGIS is recently confirmed by Maddox et al. (2013) who argue that undertaking flow mapping tasks within such packages is quite challenging. The basic symbol-set that they have developed in ArcGIS, although not tested for its capability or usefulness, may serve as input to further work in relation to understanding cycling behaviours using flow mapping approach.

8.2 Subjective behaviours of cyclists

The findings from the analysis of the questionnaires among adult cyclists suggest that utility cycling in the area is significantly ($p=0.01$) correlated to habit, attitudes on satisfaction and stimulus as well as past cycling behaviour. This finding partly confirms Lemieux and Godin's (2009) study, based on stated preference survey to predict active commuting behaviour, where cycling behaviour correlates significantly with habits, intention and age (with habit being the most significant predictor). From the view point of the theory of planned behaviour (Section 2.7), the findings here suggest that cyclists sampled are in favour (i.e. attitude) of doing the behaviour (cycling) and are not under any significant social pressure (i.e. subjective norm) to cycle. Furthermore, in the current study, significant correlations to actual (not stated preference) cycling behaviour relates to lane availability, trip distance and BMI respectively.

8.3 Temporal behaviours of cyclists

The temporal analysis of the Tyne and Wear Household Travel Survey, suggests that peak departure cycle trips occurred between 7.45am to 8.45am. The afternoon/evening peak departure cycle trips occurred between 4pm to 6pm. For the arrival cycle trips, morning peak occurred between 7.55am to 9am and afternoon peak occurred between 4pm to 6.20pm. Comparatively, there is a slight shift in the morning timings for departures and arrivals. This may be due to duration of cycle trips as the computed average time expenditure per cycle trip is about 15 minutes. This shift is not evident for afternoon/evening timings of departures and arrivals.

In addition, the profiling of activity spaces of adult cyclists in this research suggests that:

- The mean speed for cycling around the study area is about 14 kmph. This is below the recommended average speed (19.3kmph/12mph) set out by the initial working group working on strategic routes for the area (Section 2.10.7).
- There is more clarity in temporal trends of stationary and motile activities when (hourly-daily) compressed time status approach is assumed. However, this may be equally so for a bigger sample size for (monthly) real time status approach.
- Motile and stationary work activities tend to peak around 9am and 5.30pm daily. Work activities along with home activities exhibited strong dominance among utilitarian activities and confirm similar findings from Schonfelder and Axhausen (2010, p. 182).
- Cycling activities were found to peak on Tuesdays and Wednesdays.

8.4 Spatial behaviours of cyclists

Exploration of the secondary data related to the study area suggests the following five key findings:

1. The analysis of Tyne and Wear Household Travel Survey from 2003 to 2011 suggests that the density of cycling is more visible around Newcastle city centre and specific parts of the Tyneside.

2. The analysis of survey data from Newcastle Cycling Campaign suggests that the minimum distance to cycle from a household to another household was found to be around 578 meters while the maximum distance was about 7km. The standard directional distribution of household locations suggests that cyclists reside in all five districts in Tyne and Wear but concentrate in Newcastle upon Tyne.

3. The analysis of AAWT within Tyne and Wear from 2004 to 2012 suggests that Newcastle upon Tyne registered more AAWT than all other districts in the region with the exception of 2010 and 2012 when Gateshead took the lead.

4. The district level analysis of 2001 and 2011 Census travel to work data across North East England suggests that dissimilarity of cycling is increasing over the last decade with indices 5% and 11% for 2001 and 2011 respectively.

5. The sub-district level analysis at LSOA level found Dissimilarity indices of 26% and 25% for 2001 and 2011 for North East England respectively. This shows that dissimilarity is higher at the sub-district level for both years.

The Dissimilarity index for 2011 at the district level is about twice that of 2001 clearly showing a difference of 6%. However, although the dissimilarity indices are higher at the LSOA level for both 2001 and 2011, the difference in dissimilarity over the ten year period is about 1%. This amount (1%) agrees with town-wide study by Goodman et al. (2013b) which suggests that cycling to work prevalence among about 1.3 million commuters in 18 intervention English towns has risen from 5.8% in 2001 to 6.8% in 2011 resulting in the same difference of 1% (6.8-5.8) despite these towns being different from the study area in this thesis.

These findings confirm the need to address cycling related issues in Newcastle upon Tyne in order to maintain and promote cycling uptake. The findings also add to the use of existing knowledge and spatial data in understanding cycling behaviours leading to better promotion of use of bicycles around the study area. Such a stand agrees with a recent study in Vancouver in Canada where existing spatial data and knowledge are used to identify areas where cycling is more or less prevalent albeit mainly based on a stated preference survey and not actual route choice preferences (Winters et al., 2013). The recent selection of Newcastle upon Tyne for cycling investment funding in addition to seven other cities in Britain confirms the important role the city needs to play in promoting cycling in the Tyne and Wear region (DfT, 2013i; Siddique, 2013).

In this study, it was found that weighted average distance of the measured cycle trips for both female and male was 3.5km and 5.4km respectively. Utility cyclists in the study area are typically white and of higher income group. This finding did not agree with the conclusion from Goodman's (2013) national level analysis which suggests that it is more common for those with lower income to take up active transport such as cycling. The thesis addresses some of the limitations discussed by Goodman (2013) for example, the need for individual level analysis of cycling behaviours together with local and regional levels of analyses. The findings reported here have the potential to facilitate feasible solutions for improving the urban cycling infrastructure and encouraging more people to cycle as part of their daily commute.

This research is one of the few studies that have examined the urban built environment association with utility cycling behaviours. The findings suggest that improvements to cycling infrastructure should not be designed and executed in isolation because several personal and environmental factors are interlinked. Similar conclusions within the British context were reached by Adams et al. (2013) who based their study on the iConnect project baseline (not GPS based survey). They examined the associations of perceptions of the environment and four specific behaviours and concluded that improvements to cycling infrastructure in future transport and planning policy should consider additional factors such as access to destinations, land use mix, environmental quality among others (Adams et al., 2013). A new layer of knowledge in understanding everyday cycling behaviours is now available and can serve as a point of departure for further studies. However, there are still limitations in this study in terms of scope and generalisability of findings and conclusions. Such limitations call for further studies at different geographical locations within the British context; particularly regarding the acquisition, refinement, analysis and visualisation of detailed actual and perceived route and destination choice preferences.

8.5 Spatio-temporal behaviours

A major aspect of this research was the spatio-temporal analysis of activity spaces, as part of cycling behaviours. This approach agrees with Winters et al. (2013) Vancouver study conclusion suggesting that mapping cycling behaviours provides a powerful visual aid for planners and policy makers to identify areas for improvement and strategic investment in support of sustainable transport. As discussed in Chapter 6, the novel methods for the generation of profiles of activity spaces of urban cyclists have shown that a variety of activity spaces can be distinguished: popular stationary activity spaces and significant activity spaces. Additionally, the spatial variability of cycling flows by geographical areas, based on electoral wards and OAs shows potential for estimating and quantifying human activity spaces. Such an approach offers a direct link and comparison with data from other secondary sources. For example, the use of electoral ward boundaries enables better communication to politicians. Moreover, such evidence could also be used to suggest improvements of cycling infrastructure depending on the spatial orientation of arrivals, departures and route choices as measured by a range of spatial statistics within the confines of the stationary activity spaces (SASs) and motile activity spaces (MASs). The outcome of the profiling analysis suggests that such identified activity spaces tend to be constrained by home, work, work related, food and non-food shopping among others. The findings made clear that:

- The spatio-temporal structure of daily arrival and departure activity choices varies both at electoral ward and OA geographical levels.

- The dynamics of spatio-temporal distributions of arrivals' and departures' stationary activities are different when the same spatial extent is considered.

- The central part of Newcastle upon Tyne experiences generally lower cycling speeds.

- The spatial orientation of food and non-food shopping activity spaces is different at both ward and OA geographical levels. All other activities tend to follow a relatively standard directional distribution trend. There is potential for examining the effect of other spatially configured spaces such as the use of LSOAs.

- Findings from the identification of most popular SAS for departures/arrivals followed the same trend. The most popular SAS is identified as Westgate electoral ward with the second in ranking being South Jesmond ward. From the perspective of OAs, the most frequented OA, with code number *E00042583,* fell in South Jesmond ward. The second most frequented OA, with code number *E00042580,* fell in Westgate ward. These findings suggest that these areas could serve as important places for the consideration of secure infrastructure for storing bicycles such as secure cycle parking.

- The most popular MAS is identified as South Jesmond (Ward level).

It is worth mentioning here that although significant activity spaces were deduced, their interpretation should still be limited to the sample size as the findings cannot be directly generalised to the larger population. This limitation is similar to the work by Schonfelder and Axhausen (2010, p. 182) who later concluded that "*clearly, some features of the datasets diminished the significance of the results*". Examples of some of the features they cited were lack of socioeconomic information of the data and sample size. Although this research captured socioeconomic information, the particular characteristic of the convenience sample only permit limited generalisability of results.

The route choice analysis in Chapter 7 provided evidence on the utilisation of the cycleway infrastructure of the study area. About 57% of the cycle trips appeared to be on the designated cycleway. The remaining trips tend to be on other road types which may pose danger to other road users and even the cyclists themselves. It is an interesting coincidence that around the time that this study was ending, the UK government made a significant policy shift to invest about £94 million in public funds for the improvement of cycling infrastructure which will benefit the study area. In the case of Newcastle upon Tyne, which is one of the selected cities in England to receive funds for improving cycling infrastructure, this research could serve as useful information in pointing out some of the areas for infrastructural investment given that the investment strategy was to target those who are already cycling.

The corridor space analysis suggests that 57.4% of the cycle trips from this sample take place on the cycle network whilst 33.8% are outside the cycle network with a smaller percentage (8.8%) taking place near the cycle network. With a total of 42.6% cycle trips still taking place outside the designated cycle network, it is imperative that policy initiatives are aimed towards investing in cycling behavioural research and infrastructure such as cycle lanes, parking and crossings (Henderson, 2013; Northumbria, 2013; ScienceDaily, 2013). Finally, the findings from this research suggest that observed routes tend to be significantly longer than their shortest path counterparts. Therefore, the use of shortest path algorithms in route planning systems, especially online services, is likely to be problematic and unlikely to serve the interests of cyclists around the study area.

8.6 Systematic comparison of GPS data and Travel diary data

The systematic comparison of GPS data and travel diary data in this chapter suggest 8.4% under reporting of the former. That notwithstanding, evidence from study, in Portland, which was about understanding and measuring bicycling behaviour using GPS with focus on only cycling trips (like this research) concluded that total number of cycling trips was underreported by about 8% . The findings in the study in Portland confirm the 8.4% underreporting found in this research (Dill and Gliebe, 2008). The Portland study was about understanding and measuring bicycling behaviour using GPS with focus on only cycling trips with different research design.

However, there is mixed findings regarding whether the total number of GPS trips should be more or less than the diary trips (Anderson et al., 2009).

CHAPTER 9. CONCLUSION, IMPLICATION, LIMITATION AND FUTURE RESEARCH

9.1 Research aims and objectives: Re-visited

This section re-visits the research aim and objectives stated in Chapter 1. It also reflects on the work completed in this thesis to justify that the aim and objectives have been addressed. This section also adds to the threefold contribution to knowledge pointed out and discussed in section 1.5 of Chapter 1: theoretical contribution; empirical contribution; and, methodological contribution. The aim of this research was to understand how the built environment constrains or supports the space-time movement behaviour of cyclists in urban environments. Four discrete but linked objectives were devised in order to achieve the overall aim, as discussed in section 1.4. So far, this thesis has:

(A) Reviewed the literature on cycling as active transport; space-time geography and behavioural geography; sustainable urban mobility studies, GPS, GISc and GIS technologies, stated versus revealed route choice preference studies; modelling, visual analytical techniques, and in general terms the linkage between transport and health.

(B) Contributed to the knowledge lacuna about empirical evidence of urban cycling behaviours within the British context through the collection and refinement of detailed adult cyclists' route choice preference data.

(C) Utilised a variety of novel techniques in space-time geography, statistics, spatial analysis, and visual analytics to provide understanding of urban cycling behaviours.

(D) Explored the relevance of the study towards sustainable urban transportation and policy by suggesting possible strategies towards improving urban cycling.

Objective A was mainly addressed in Chapter 2 along with other critical discussions on previous studies and policies in all the chapters with methods underlying the study presented in Chapter 3. The identified literature provided the needed evidence to facilitate meaningful and critical discussions of the findings from this study. The review pointed out three main areas for further research which helped define the subsequent objectives. These three areas comprise of: the extension of the usability of space-time cube; sensing of urban cycling behaviours in new geographical spaces; and the novel use of old and new methodologies in broaden our understanding of urban cycling to aid in well designed and functioning built environment which support safe urban cycling.

The area definition for the study towards the provision of empirical evidence on revealed preferences of urban cyclists became more evident as pointed out from the findings from the comprehensive exploratory data analysis of existing cycling related datasets in Chapter 4. Chapter 5 addressed the needed evidence (objective B) on revealed preferences by collecting, refining, and describing newly acquired layers of knowledge on utility cycling within the British built (urban) environment.

The availability of new layers of knowledge gathered as part of the early chapters of the thesis provided the opportunity for the introduction of new methodological approaches in analysing and visualising cycling behaviours. The methods used were presented in sections 3.4 through to 3.11 and applied in Chapter 4, Chapter 5, Chapter 6 and Chapter 7 with further discussion in Chapter 8. All main methods used in this thesis were enumerated in Table 3-1. The utilisation of these novel methods to examine cycling behaviours addressed the third of the research objectives (objective C).

Finally, section 9.2 discusses some policy implications that could be drawn from this study (objective D). The policy suggestions points out to the need for integrating sustainable transport, strategic investment due to limited budgetary allocations, special attention to minority groups, student population, the aged, and the strategies for promoting urban cycling via slogans.

In brief, the primary data collection, analyses and discussion along with the sourced secondary datasets and survey, ensure the achievement of the defined research objectives.

9.2 Implications for policy, society, and cycling behaviour

Although two thirds of all journeys in the UK are less than five miles, practical alternatives are often not available (DfT, 2011a, p. 7), despite the acknowledged importance of cycling in the UK (DfT, 2011a, 2013d, f, i; DH, 2010). It is worth pointing out here that in the sample in this study, all bike trips were less than five miles or 8km (Section 5.5.1).

The study has shown that almost half of the sample bike trips were not on the designated cycle network provided by the Newcastle City Council. Although the bias in the research design is noted, this finding serves as evidence for further investigation of the impact of the strategic routes in promoting uptake of cycling in the city.

9.2.1 Need for Integrated Sustainable Transport policy

The findings from this research have shown that urban cyclists from the sample did not patronise only cycling as a means of transport. Even though about 43% used their bicycle for travel, the remaining trips were a mix of other modes of transport with walking (29%), car (20%) and train

(5%). The four districts in Tyneside conurbation should work closely to ensure the realisation of well integrated cycling network rather than each district embarking on their own agenda. The LTP strategy, for the study area, to maximise use of existing and emerging datasets needs greater attention (LTP3, 2011, p. 160). The use of geospatial technologies for capturing and analysing these datasets are vital to inform "spatial reasoning" in policy formulation.

9.2.2 Invest, but where? Strategic investment in cycling infrastructure

Strategic investment is not necessary where enough public funds are available to ensure that every corner of the study area gains from five benefits mentioned previously: safe, comfortable, direct, coherent, and attractive cycling infrastructure. This is normally not the case due to pressure on available public funds for various kinds of development that a city requires. Therefore, the allocated funds for the improvement of cycling infrastructure needs strategy to facilitate the realisation of maximum returns without comprise on the five stated benefits. This strategic plan needs to be informed by empirical evidence in order to make realistic plans. Such plans can be made available to the public as part of a participatory planning process. As a first step, monitoring and evaluating the need of active cyclists seems to be a logical choice. For example, by monitoring movement of utility cyclists around the study area, the study has showed most frequently used areas which could lead to the identification for potential areas for investment by way of provision of secure parking, crossings, lanes or lights. Otherwise, just building in the hope that people may cycle can be a big gamble for limited budgets.

9.2.3 Targeting minority ethnic groups, student population, the elderly, and low income groups

The fact that most of the cyclists in the sample were typically white and of higher income status suggest that the potential for growth still remains for men and women within the ethnic minority groups as well as those of lower income status. Moreover, the findings have the potential to facilitate feasible solutions for improving the urban cycling infrastructure and encouraging more people to cycle as part of their daily commute – particularly the student population. In Newcastle upon Tyne alone, about 15% of the entire population are students during the academic year period. At the moment, it is still unclear as to the percentage of students who are utility cyclists. A strategic policy by both the universities as well as the local authorities across Tyne and Wear could be to specifically target students and encourage them to cycle. The findings in this study suggest that cycling decreases with age. Therefore, the policy considerations aiming to promote cycling should include students and younger people, so that they would be able to integrate cycling into their lifestyle with the hope that they would even take it to their working life at a later stage. Another important policy consideration should also be given to the elderly and people with special needs.

9.2.4 Promoting urban cycling

Adoption and promotion of urban cycling strategic policies need creativity and humour in addition to factual evidence as an input to decision making. Jones (2012) concludes that a multi-faceted approach to the promotion of cycling is needed and should include social marketing vis-à-vis physical measures (Jones, 2012). This section discusses the notion of *slogans* as a way of promoting urban cycling. A World Bank driven study, on cycling inclusive planning and promotion in urban areas, suggests that the use of a slogan like "*Reclaiming street*" could be the right approach to the improvement of *liveability* as the creation of pleasant road environment for cycling may potentially contribute to the enhancement of the quality of public space (Godefrooij and Schepel, 2010, p. 26). Hansmann et al. (2009) examination on the effective use of slogans estimates that "slogan effectiveness was positively related with ratings for good and ecological argumentation, creativity, humour, and easy comprehensibility". What follows are some suggestions of *thematic slogans* as a consideration for promoting urban cycling. Actual systematic testing of these slogans is considered to be outside the scope of this thesis.

Slogan one: Cycling is a catalyst for business.

The reviewed literature has partly shown that cycling is good for business accounting, increasingly contributing to over £2.9 billion to the British economy as discussed in sections 1.1.2 and 2.1. Given that the level of cycling is still low in Britain, many potential opportunities still exist for the cycling industry to boost the economy. In this study, majority of utility cyclists were those with higher economic status and also appears to cycle for shopping activities. These findings make cycling therefore attractive for business. The more people cycling, the more the need for bike shops, sharing services together with possibly inclusion of other modes of transport, web services to facilitate route planning and related tasks, touring services to name a few.

Slogan two: Cycling – a modern way of reducing car traffic congestion.

Sections 2.1, 2.2, 2.3, and 2.9.3 discussed aspects of motorised traffic congestion and how cycling as a means of transport could serve as part of the solution to the reduction of traffic congestion. Increasingly, many local authorities in charge of urban areas have recognised the need for the reduction of traffic congestion as it is becoming costly to business, the environment, and well-being of urban dwellers. Car traffic congestion and poor air quality together with other factors is known to cost about £10 billion yearly in urban areas in Britain. This study has made substantive evidence in support of the fact that most short journeys of about 5 miles could be taken using a bike. Nationally, it is also the case that about two-thirds of all journeys are less than 5 miles according a policy document on improving local transport by DfT (DfT, 2012b).

Slogan three: Cycling, a lifeline for Transport, Health, and Environment.

This study has reviewed literature suggesting that cycling has the potential to address major problems facing urban areas such as the study area. In addition, this research has also shown that the average BMI of cyclists tend to fall within the ideal weight category as defined by the WHO. Given that BMI constitutes one of the ways of measuring one's health status, it would be fair to conclude that cycling is healthy and therefore improves quality of life and well-being. As already discussed in this section, the fact that cycling also contributes to the reduction of car traffic congestion as well as serving as a catalyst for the improvement of air quality, it could also be said to serve the preferred solution for transport and environmental problems. The strong link that cycling provides to Transport-Health-Environment (THE) makes cycling the lifeline for these three important areas of concern in urban THE policy formulation.

9.3 Research limitations

9.3.1 Challenges in spatio-temporal data collection, processing and analysis

Despite the contributions of this thesis, the challenges in spatio-temporal data collection, processing and analytics are still an on-going problem. The emergence of new datasets from GPS devices and virtual globes has brought about challenges surrounding computation issues. According to recent spatial computing 2013 reports looking at the future directions of research and associated challenges, it has been noted that spatio-temporal datasets are increasingly exceeding spatial computing technologies and these pose enormous challenge in relation to data processing, analytics, capacity and validation (CCC, 2013). This observation also agreed with the decision of DfT's not to use portable GPS devices in the National Travel Survey in the near future starting from 2013 (DfT, 2012d).

In this study, it was observed that data processing of spatio-temporal data was time consuming. Several other challenges were also encountered as follows. Prior to the data collection, device testing and procurement became critical as the deadline for funding of GPS devices got closer. Therefore, it is suggested here that in-terms of planning, the following should be carefully considered:

- Planning issues: device procurement timing, size, cost, customer support; sample size, potential for some devices to get stolen or break down, spatial distribution of trajectories.

- GPS device issues: battery life and the means to charge/re-charge; horizontal and or vertical accuracy; memory capacity for storing logged points; and fix time.

- Data quality assessment.

In the case of the fix time, the faster the better; mostly less than or equal to 35 seconds was found to be normal. The software for downloading and possible initial viewing of the data also needs to be considered. Where necessary, it is recommended that the researcher avoids the use of proprietary software, unless there are no other options as the license of the software may restrict the multiple installation and at times re-installation delays. Novel approaches for data processing have been found to be another challenge. In this thesis, the discussion has mainly categorised the approaches into twofold: non-algorithmic and algorithmic approaches. This thesis contributed to the non-algorithmic approach paradigm by proposing and demonstrating the use of space-time cube as a data processing tool. However, this approach is still limited and requires a travel diary as well as supporting secondary datasets. It seems convenient for small to medium datasets. Several algorithms for post-processing spatio-temporal data (from portable GPS devices) on cycling were identified but issues surrounding the standardisation of the algorithms to allow transferability and easy application to datasets in different coordinate systems and structure are still unsolved. This brings to the fore data quality issues and the reliability of the datasets as no additional information exists in most cases. At the moment, there seem to be no generic algorithmic tools.

9.3.2 Research limitation: A retrospective view

This section gives retrospective views of this research by highlighting some of the limitations observed in this work, as well as how this research could have been done differently. The section also adds to the discussion in Chapter 1. The conduct of this research is also tacitly a process of learning and this experience has brought awareness to several layers of the whole process.

The philosophical viewpoint taken as part of the methodology together with the specific methods, theories and technologies influenced the way and manner that this research has been conducted. The chosen paradigm would have made it possible, for example, to use *video* as a way to account for utility cyclists' journeys in a qualitative sense. The use of video could have been combined with GPS tracking along with travel diaries to capture the nuances of the journeys. Such a decision would have had several serious implications. These implications borders on the following:

- added complications of using a video camera,

- re-consideration of financial resource,
- the use of technology and associated analytical expertise,
- inclusion of qualitative methods and theories around ethnographic studies, and
- the scope and timing of the research process.

Moreover, the use of *video* as a method in cycling behaviour research is already being pursued in the UK. Spinney (2009) makes a case for broadening available methods in video based cycling research in order to "*highlight the often fleeting and ephemeral meanings that can contribute significantly to what movement means*". Spinney (2009) discusses cycling behaviour research within the context of ethnography while Hammersley and Atkinson (2007) give a general methodological foundations and practical applications in ethnography in social research. The use of video as a main method of qualitative inquiry often falls within *Ethnographic research.* Characteristics of Ethnographic research are quite broad and it is considered outside the scope of this research.

Additionally, on the technical side, any transformation errors and on-the-fly geo-referencing of spatial datasets used were ignored. It was assumed that the implemented algorithms in the software used were correct ones. The only check done was to superimpose a newly transformed data layer onto another data layer having the new coordinate system in order to check whether they conform. For example, to visualise the newly collected primary data with cycling infrastructure which is in the UK National Grid Coordinate System, the primary data is projected from the World Geodetic System (WGS84) to the UK National Grid Coordinate System with the same done for OpenStreetMap street network. The expectation is that the OpenStreetMap data layer should reasonably conform to the cycling infrastructure data layer when they are superimposed and viewed in ArcGIS. The convenient random sampling approach adopted here in tracking cyclists imposed limits on the generalisability of the findings and conclusions that relates to the primary datasets collected as part of the study.

9.4 Future research

Cycling behaviour research within the British context is still an emerging and exciting field. It is therefore the hope of the author that the findings from this study will have an impact on future research in cycling behaviour analysis in general but especially within the British utility cycling context. This section discusses some of the potential areas and ideas for future research as follows.

9.4.1 Development of online mobile platforms for sensing cycling behaviours

New location aware technologies together with geospatial technologies are now permitting an unprecedented rate of spatial data capture (Wilson, 2013) at different spatio-temporal scales and recently been argued to hold promise in relation to making available new level of details with the potential to advance everyday mobility research (Pangbourne and Alvanides, 2013). New tracking technologies can make some tasks in mobility research simpler but more work is needed towards how it can be well integrated into research design. In this study no mobile platform was used as part of the data collection process. Although promising, the use of online mobile platforms presents several challenges which need to be addressed. Some of the challenges are, but not limited to:

- battery life span for mobile devices,
- adequate memory for storage,
- communication cost for online data transfer to servers,
- stability/robustness of "apps" as human-device interactive interface,
- privacy issues as mobile devices often contain personal data and sensitive usage information.

Among these, the most prominent one is the battery life as most mobile devices, at the time of writing, in 2013, were unable to maintain battery life span even under normal usage for 24 hours continuously. Thus, the acquisition of multi-day data could be challenging but promising as it is possible with the hope that new technologies emerge. The latest mobile devices such as Apple iPhone5 using iPhone operating system (iOS) platform has a daily battery life span of about 10 hours maximum, without necessarily using the GPS feature (http://www.apple.com/iphone/features/). The other latest mobile device, Samsung S4, which reportedly won a battery life testing experiment (Goldhill, 2013); and, using a different operating system platform, Google's Android operating system, could maintain about 1,000 minutes of battery life for making calls only without use of GPS features. The use of such devices, at the moment, will demand frequent charges on the part of participants increasing their responsibility.

Future research could consider the development of mobile platforms for the collection of spatio-temporal information about movement of cyclists within the British context. Very little is known in this area, even globally; with exception to the work in San Francisco, California in the USA, where a mobile platform was developed as part of sensing cycling behaviours (Hood et al., 2011). So far, this platform has been used in the USA context and there is no evidence on usage within the British context. Additionally, the demands for systematic data collection for the purposes of research do present several challenges which need to be addressed. Moreover, there appear to be several cycling mobile-apps: those for fitness such as *MapMyRide*, *BikeMateGPS, Cycle Meter*; for safety such as *CycleStreets, Bike Hub Cycle Journey Planner*; for maintenance such as *BikeDoctor*; for alteration such as *Bicycle Gear Calculator*; and purposely made apps for those cycling in urban centres such as London such as *London Bike*, *Cycle Hire (Observer, 2012)*. Very little is known about the use of such apps for research purposes. One issue could be the cost of the devices and at times hidden cost from the service providers as to data transfers. Another useful starting point could be the use of APISENSE (http://www.apisense.fr/) participative platform (Haderer et al., 2013); which is being developed to assist scientists to collect realistic datasets such as the kind collected in our study. It is important to note that the capacity to collect the data should be equated to the ability to post-process using either non-algorithmic approaches and/or algorithmic approaches which what works best are still on-going (Thierry et al., 2013). Also, emphasis should be placed on the effort/time ratio on both the researcher/analyst who will post-process the data and the respondent who will supply the data.

9.4.2 Comparative analysis of agent based models of bicyclists' behaviour

Some level of consensus on the usefulness of agent based modelling and simulation in cycling research is gradually emerging among researchers (Section 2.11). Although this is the case, the step-by-step approach together with concepts are needed to enable full implementation of agent based models; especially in relation to using actual route choice parameters and cycle networks and facilities as inputs. The emerging importance of bicycling and its associated non-linear travel behaviour have now prompted researchers to turn to the application of agent based modelling and simulation techniques to create platforms to further understand behaviour of cyclists. The on-going development, at the time of writing, of Copenhagen Agent Based Model of bicyclists' experiences (in short CopenhagenABM) as part of the Bikeability.dk project in Denmark is typical (Snizek et al., forthcoming). Future research should use datasets in different geographical contexts and adopt some or all of the methodological approaches used in the CopenhagenABM to enable easy comparison of models, thereby allowing testing of variants of hypotheses and existing theories. The detailed dataset collected in this thesis could serve as a potential for the development of NewcastleABM together with comparative analysis of common variables alongside the CopenhagenABM. There are several realistic ideas and assumptions that can now be made based on the work done in this thesis which could serve as an input to NewcastleABM:

- Exit points for the model could adapt the significant SAS areas or simply use the extracted stops for the cycle trips. Extra work will be needed if all exact stops were to be used for the model which is possible with the use of the space time cube for the extraction process.

- The refined openstreetmap transport network could serve as the initial network for routing to allow movement of agents

- The spatial extent of where cycling is prevalent could be estimated with some realistic spatial reasoning given the new layer of knowledge about movement of cyclists shown in this thesis.

- With the identified revealed preferences of cyclists with respect to road types on the transport network, the possibility of simulating congestion with and without cycling for the next decade may seem useful for the study area as local authorities through the LTP3 strategy from 2011 to 2021 with the aim to increase cycling uptake to tackle congestion. Several scenarios could be conceptualised and simulated to inform transport policy for the region.

The reproducibility and technical challenges of ABMs have not been left alone. The emerging solutions and future prospects are inconclusive at the time of writing, especially when it comes to cycling research. Efforts such as published proposal for the scientific committee to adopt "ODD" (Overview, Design concepts, and Details) protocol (Grimm et al., 2006; Grimm et al., 2010) as well as hosts of various user groups of different ABM toolkits or platforms (e.g. NETLogo, RePAST, and MATSim) are all evidence to emerging solutions and future prospects (Yeboah, 2012a). The ODD framework appears to be the cure to the reproducibility challenge; published in 2006 (Grimm et al., 2006) and further published with updates in 2010 (Grimm et al., 2010); suggesting that its development is evolutionary. The ODD protocol offers seven basic elements around which a model can achieve clarity for the end user and the reader (Grimm et al., 2010, p. 2761); and, to some extent, clarity for the modeller for future use of the model in terms of updates and extension.

Aside from these aforementioned challenges, ABM still has the potential to offer the possibility to model, explore as well as predict multiple futures or the past stochastically in combination with existing theories or testing hypotheses rather than what traditional modelling which offers one deterministic future or past in combination with existing theories (Batty et al., 2012, p. 95, 99, 129, 136, 339, 349, 352, 412). The emerging solutions to challenges facing the use of ABM are gaining momentum. Therefore, the prospects for the future in terms of usage of ABM in virtually every discipline where understanding complex phenomena exist are just a matter of time. More importantly the paradigm shifts in cycling related policies (as discussed in Section 2.10) may demand and draw on ABM for exploring and understanding interventions and policies governing the promotion and encouragement of increasing cycling uptake levels in communities. Given the increasing level of micro data with detailed statistics on cycling, the stage is being set for generating possible hypotheses which can then be incorporated into ABMs for purposes of further stochastic testing and theory generation. Most expected changes in the future may come from new sources of micro data, such as the primary data from this research, and therefore "*a change in focus from what in the past has been meso-level approaches to the truly micro – local – and the macro – global – is possible. Dealing with routine fine scale spatial and temporal behaviours is more closely matched to ABM than location predictions of the more aggregate kind, while at the global level; the policy context is ripe to be informed by insights for a new class of aggregate ABM. These can combine the individualistic behaviours in such models with aggregates or groups treated as individuals at the highest levels.*" (Batty et al., 2012, p. 745). Just as physical activity such as cycling has been described as a "miracle cure" (CMO, 2009, p. 21; DH, 2010, p. 1); ABM could be a "miracle platform" for understanding complex behaviours of cyclists' in the near future although our understanding of this behavioural complexity must first be established in different geographical areas such as that of the UK (Yeboah and Alvanides, 2013). Moreover, comparison of different ABM platforms is also necessary to determine the most robust available technology for easy implementation (Yeboah, 2012a).

9.4.3 Multi-disciplinary approach: Combining geography, physical health and psychology

The lessons learnt from conducting this research suggest that more emphasis should be placed on multi-disciplinary approach to problem solving, suggesting that an integrated solution based on a combination of public health and transportation approaches where the combined use of GPS and accelerometer datasets are at the core of the research design process (Chaix et al., 2013). These approaches are not without challenges such parameterisation of algorithms, imputation of exact nature of purposeful journeys among others (Chaix et al., 2013). Although, further theoretical and empirical clarifications both at the local and global context are needed to further our understanding of causal links between psychological, social, spatial factors, and travel behaviour (Friman et al., 2013; Gehlert et al., 2013); this should be pursued by drawing on the strength of the body of knowledge in geography, health and psychology. This section further underpins Schonfelder and Axhausen (2010, p. 189) concluding remarks in their study about urban rhythms and travel behaviour suggesting that activity-space approach to data analysis within the context of physical activity research offers a promising opportunity for cooperation between travel behaviour analysis and public health research.

9.4.4 The Newcastle Cycle City Ambition Bid: Recently awarded project

At the time of writing, the Newcastle Cycle City Ambition Bid (NCCAB) had been submitted to the UK Department of Transport Cycling City Ambition fund in April 2013 (NCCAB, 2013) and had been successful in August 2013. It is therefore hoped that some of the analysis performed in this study could serve as input to the data analysis and subsequent output of the project. The submission followed the announcement of a £62 million investment in cycling by Norman Baker, an MP, on January 30 2013 (DfT, 2013i); and subsequent release of proposal guidance documentation on 15th February with updates on 15th April 2013 (DfT, 2013f). It is fair to argue that, in addition to efforts by various stakeholders in promoting cycling in the study area and prior to this announcement; a significant amount of publicity has been made by the work done in this thesis both locally via Newcastle Cycling Campaign annual meetings; nationally via UK Parliamentary and Scientific Committee through an invited presentation at the House of Commons at Westminster on 18th March 2013 (Yeboah, 2013), as well as a couple of news articles (Henderson, 2013; ScienceDaily, 2013); and, nationally through an international workshop on cycling data challenge (Alvanides et al., 2013). This study closed on a good note with recent announcement of a £77 million investment in cycling in England in which Newcastle upon Tyne was among the selected eight British cities to benefit (Siddique, 2013; Walker, 2013a). Therefore, a viewpoint based on data analysis and experiences gained in the course of this PhD research is justifiable as both the research and the NCCAB fit the main aim of aiding strategic investment in cycling. A SWOT analysis is used to summarise the viewpoint on the NCCAB proposal.

Strength: The immediate focus on urban core of the proposal for the first few years within the ten year plan is quite positive and confirms some of the findings in this thesis. For example, the analysis of the Tyne and Wear Household Travel Survey data from 2003 to 2011 suggests that the Newcastle city centre area has more concentration of cycling prevalence.

Weakness: The scope of the project is well defined and vision clearly stated; thus, to achieve 12% mode share for trips under 5 miles. This, for now, or next ten years, may be feasible. However, given that there were *everyday cycling flows* in this research from the city centre of Newcastle upon Tyne to other neighbouring districts, especially within Newcastle-North Tyneside corridor, it is important that the proposed strategic routes fit well with, at least, other proposals from districts within the Tyneside conurbation (i.e. Newcastle upon Tyne, North Tyneside, South Tyneside, and Gateshead).

Opportunities: The proposal should serve as an opportunity to embrace collaboration with other districts within Tyne and Wear (i.e. North Tyneside, South Tyneside, Sunderland, and

Gateshead). Even the consideration of Durham would not be a bad idea given that some participants, in this research, were cycling from Durham to Newcastle although those trips were considered outliers in most of the analyses made in this thesis.

Threat: Bike theft is a potential threat although careful and strategic investment of secure parkings and storage facilities can ameliorate this situation, if not eliminate it completely.

9.4.5 Comparative study: OpenStreetMap and Ordnance Survey cycling datasets

We found out that authoritative data sources to enable detailed network level analysis of cycling behaviours needed extra information to allow useful investigation. In this study, we used an updated openstreetmap network and therefore were unable to use both time and distance impedances to generate, for example, shortest path alternatives to the observed routes as was in the case of Papinski and Scott (2011). A careful update of the Ordnance Survey ITN data was necessary but was difficult and time consuming; hence, left for a future study. However, because the cycle network infrastructure from Newcastle City Council was used, it may be useful to use the updated network in this study as a point of departure. This data was only used for the corridor space analysis but was not useful when it came to the network level analysis as extra updates to connect thousands of junction nodes needed to be done. We relied on cycle network infrastructure from OpenStreetMap, with some update, in order to perform the network level analysis regarding the route choice analysis of home to work trips. Therefore, a more detailed comparative study to study these two disparate data sources in relation to understanding cycling behaviours is proposed. Graser et al. (2013) recent work has developed an open source toolbox for the comparison of street networks. They conclude that their technique which is developed using Sextante (sextantegis.com) Quantum GIS affect low ranking streets in favour of high ranking streets. Based on motorised traffic and usually high speed limits, high ranking streets appear not appropriate for cycling. Cycle street networks exhibit low street ranking characteristics such as residential streets or streets with about 20 mph maximum traffic speeds (Section 7.5). Graser et al. (2013, p. 17) agree with this section by suggesting that future work should consider techniques aiming at cycle networks. Full implementation of open source tools in the generation of network variables has the potential to be useful in future research; a point of departure could be the use of pgRouting with QuantumGIS (QGIS) and PostGIS. In the case of using QGIS, Sextante which is an application programming interface (API) for spatial data processing may prove useful in such a study. This will be useful because all its components are under open source license as reported by Graser et al. (2013). A well-refined cycle network – for example, well connected cycle lanes – can also serve as input to ABMs.

9.4.6 Understanding route-angularity and eco-routing for sustainable transportation

The findings from this study suggest that preferences for observed/revealed routes were significantly different from routes generated on transport networks using shortest path algorithm. This might mean that existing systems that rely on the use of shortest path algorithms in providing route planning services might be deficient in meeting demands for sustainable transport such as cycling in urban spaces. It was therefore interesting to note those other spatial computing researchers and companies are reported to have started experimenting with “eco-routing” (CCC, 2013). Eco-routing is a term for a kind of route optimisation that results in the reduction of fuel consumption. It has been argued that an intelligent routing that avoids left-turns saves millions of gallons of fuel annually and also causes a reduction in greenhouse gas emissions (CCC, 2013; LOVELL, 2007). The combination of our understanding of turns (as in transport network restrictions) within the context of an integrated transportation where both motorised and non-motorised options were considered and optimised can provide future solutions in addressing fuel consumption, greenhouse gas emissions and also tackle obesity. The study of turns in routing could also be merged with the well-known “follow your nose” hypothesis partly discussed in section 7.5. According to (Conroy-Dalton, 2001), people tend to steer a linear path as an unconscious strategy to minimise navigation complexities. It seems this hypothesis has been tested only in walking as a mode of transport. However, it appears if motorists were to “follow their nose,” which will lead to less left turns, they could be contributing to a reduction in greenhouse gas emissions and savings in millions of gallons of fuel annually. Moreover, conducting a “follow your nose” experiment about cycling could provide a useful input to enhancing the development of agent-based modelling of cycling behaviours which has the potential of serving as a decision making platform (also see section 2.11 and 9.4.2 for discussion on agent-based modelling). That notwithstanding, for one to properly study these *route-angularity* and *eco-routing* demands well refined detailed datasets of which some are still yet to be collected; some of the ideas were discussed in section 9.4.6 although biased to data collection on cycling behaviours. A broader discussion of collection, fusion and curation of space-time persistent monitoring of large areas can be found in a recent 2013 report on spatial computing (CCC, 2013).

9.4.7 Do *pay-as-you-go bike renters* use designated cycle network?

Understanding data from bike sharing systems are useful in generating insights into sustainable and integrated transport systems (O’Brien et al., 2013). Such a shared system provides, for example, a convenient means for one to combine the use of the cycle and public transport (Martens, 2007). The primary data collected in this research did not cover utility cyclists who are inclined to use pay-as-you-go bike rental/share systems. Finding ways to capture actual routes of "pay-as-you-go bike renters" was time consuming and expensive within the scope of this research. This limitation makes this area a very fertile ground for future research. Ideally and preferably, the data capture needs to be integrated in the bike-share system. ScratchBikes (scratchbikes.co.uk), a leading bike sharing provider around the study area do not (confirmed in Feb. 2013) have a facility to track cyclists who use their bikes. Once data from hiring schemes are available, it will be possible to provide more meaningful information on cycling behaviours around the area. Some possible analysis with such data could be the exploration of gendered cycling behaviours as discussed by Beecham and Wood (2013) and the role of bike sharing systems in normalising the image of cycling (Goodman et al., 2013a). At the time of writing, research about bike sharing systems appeared to focus on areas around London due to availability of data. It is also possible to use ethnographic research design (e.g. using video/mobile interviews) to capture the ephemeral and subjective behaviours similar to studies discussed by Spinney (2009).

9.4.8 Slogans as strategies for promoting urban cycling

Some suggestions towards the use of slogans in promoting urban cycling have been suggested in this chapter (Section 9.2.4). Unlike the case in Godefrooij and Schepel (2010) study where slogans were actually tested in the field, these suggested slogans have not been tested in the field. The argument being made in this section is that the development and operationalisation of slogans for the purpose of promoting urban cycling may have an important role to play in the quest for cycling friendly policies and politics. One cure to soliciting themes for slogan could be from the first paragraphs of report summaries and introductions. This idea has been inspired by a recent regional study on how cycles could be used as a mode of transportation in Latin America (Baumann et al., 2013). Baumann et al. (2013) report on the study start their summary with "*Cycling is one of the most sustainable methods of urban transportation*" and proceed to an introductory heading "*In the Grand Tour of urban transportation methods, cycling leads the pack.*" It may be possible to draw on such ideas as part of the slogan testing. In another case, the recent Get Britain Cycling inquiry summary and recommendation report captures some slogans such as "*Cycling makes life better for all*" and one heading suggesting "*Cycling in Britain: The Potential for Growth*" (APPCG, 2013b). The former is highlighted in the introductory chapter of this thesis suggesting how inspiring these slogans can be to researchers. It will be interesting to actually test how effective these slogans are in the British context. Further research in this area is proposed to increase our understanding of the effectiveness of slogans in promoting urban cycling. It is also important to note that promoting cycling goes with equally providing cycle lanes. Whitehorn (2013) argues that more cycle lanes are needed everywhere and for tricycles too for those having balancing problem riding the bicycle. It seems appropriate to end this section with one of the three quotes cited in the beginning of Chapter 1 to somewhat reiterate the need for promoting cycling; "*Cycling for daily travel can provide a wide range of benefits that far outweigh the costs of cycling infrastructure, equipment, and programs*" (Pucher and Buehler, 2012, p. 347).

REFERENCES

Abbott, A., Cyranoski, D., Jones, N., Maher, B., Schiermeier, Q., Van Noorden, R., 2010. Do metrics matter? Nature 465, 860-862.

Abley, S., 2005. Walkability Scoping Paper, Final ed, Christchurch, New Zealand. Retrieved July 31 2011, from http://www.levelofservice.com/walkability-research.pdf

Adams, E., Goodman, A., Sahlqvist, S., Bull, F., Ogilvie, D., 2013. Correlates of walking and cycling for transport and recreation: factor structure, reliability and behavioural associations of the perceptions of the environment in the neighbourhood scale (PENS). International Journal of Behavioral Nutrition and Physical Activity 10, 87.

Adams, J., 2010. Prevalence and socio-demographic correlates of "active transport" in the UK: Analysis of the UK time use survey 2005. Preventive Medicine 50, 199-203.

Adams, M., Ryan, S., Kerr, J., Sallis, J., Patrick, K., Frank, L., Norman, G., 2009. Validation of the Neighborhood Environment Walkability Scale (NEWS) items using Geographic Information Systems. J Phys Act Health 6, 113 - 123.

Aditjandra, P.T., Mulley, C., Nelson, J.D., 2013. The influence of neighbourhood design on travel behaviour: Empirical evidence from North East England. Transport Policy 26, 54-65.

Alderson, F., 1972. Bicycling: A History. David & Charles Limited, South Devon House Newton Abbot Devon, Great Britain, Newton Abbot.

Aldred, R., 2013. Who are Londoners on Bikes and what do they want? Negotiating identity and issue definition in a 'pop-up' cycle campaign. Journal of Transport Geography 30, 194-201.

Alemu, G., Stevens, B., Ross, P., 2011. Towards a conceptual framework for user-driven semantic metadata interoperability in digital libraries: A social constructivist approach. New Library World 113 38 - 54.

Allan, R., 2010. Survey of Agent Based Modelling and Simulation Tools (Technical Report). Daresbury Laboratory. Retrieved June 13 2011, from http://purl.org/oai/oai:epubs.cclrc.ac.uk:work/50398 / http://epubs.cclrc.ac.uk/bitstream/5601/DLTR-2010-007.pdf

Allen, E., 2012. Petrol prices will rise again as motorists must accept higher taxes to help clear Britain's debt, insists Transport Minister, DailyMail. Retrieved June 25 2012, from Retrieved from http://www.dailymail.co.uk/news/article-2164264/Transport-Secretary-Justine-Greening-says-petrol-prices-rise-help-clear-UK-debt.html#ixzz1ypbUoQlJ

Alvanides, S., Yeboah, G., 2012a. Cycling in the city: Understanding urban cycling behaviours and constraints in space-time, In: Alvanides, S., Pangbourne, K., Wilson, A.M. (Eds.), RGS-IBG Annual International conference, University of Edinburgh.

Alvanides, S., Yeboah, G., 2012b. Talk to us, say North East cyclists, Annual Conference Media Coverage. Royal Geographical Society (with Institute of British Geographers) Edinburgh. Retrieved July 12 2012, from http://www.rgs.org/NR/rdonlyres/6A596F54-5509-421D-A596-691F8607599B/0/120705AlvanidesCycling.pdf

Alvanides, S., Yeboah, G., 2014. Profiling and visualizing activity spaces of urban utility cyclists, GIS Research UK 2014 (GISRUK2014) Conference, Wednesday 16th April to Friday 18th April 2014. GISRUK2014, University of Glasgow, UK.

Alvanides, S., Yeboah, G., Leyendecker, K., Prospect, C., Dodds, B., 2011. 8-spoke city: a radial cycling route system for Newcastle. UK Ordnance Survey Geovation Challenge 2011. Theme: "How can we improve transport in Britain". Retrieved April 21 2011, from http://www.geovation.org.uk/wordpress/wp-content/uploads/2012/02/GeoVation-Challenge-Ideas-and-summary-transport.pdf

Alvanides, S., Yeboah, G., Van der Spek, S., Van de Weghe, N., 2013. Tracking daily mobilities: GPS based bicycle data collection, processing, and analysis snapshots, Understanding Urban Cycling: A Data Challenge (CDC2013). A pre-AGILE 2013 Conference Workshop. CDC2013 Organizers, Leuven, Belgium.

Amaratunga, D., Baldry, D., Sarshar, M., Newton, R., 2002. Quantitative and qualitative research in the built environment: application of "mixed" research approach. Work Study 51, 17-31.

Ampt, E., 2003. Respondent Burden, In: Jones, P., Stopher, P.R. (Eds.), Transport Survey Quality and Innovation, 1st ed. Pergamon, Oxford.

Ampt, E.S., Richardson, A.J., Brög, W., Wermuth, M.J., 1983. Collection of household travel and activity data: Development of a survey instrument, In: Ampt, E.S., Richardson, A.J., Brög, W. (Eds.), New survey methods in transport: 2nd International Conference Hungerford Hill, Australia, 12-16 September 1983, Volume 1983, Hungerford Hill, Australia.
Anderson, B.J., Smith, R.E., 1994. Natural orbital environment definition guidelines for use in aerospace vehicle development. Retrieved April 21 2011, from http://thehuwaldtfamily.org/jtrl/research/Space/NASA-TM-4527,%20Natural%20Orbital%20Environment%20Guidelines.pdf
Anderson, T., Abeywardana, V., Wolf, J., Lee, M., 2009. National Travel Survey GPS Feasibility Study - Final Report Final ed. By NatCen & GeoStats for DfT, London.
Andrienko, G., Andrienko, N., Kopanakis, I., Ligtenberg, A., Wrobel, S., 2008. Visual Analytics Methods for Movement Data, In: Giannotti, F., Pedreschi, D. (Eds.), Mobility, Data Mining and Privacy: Geographic Knowledge Discovery. Springer Berlin Heidelberg.
Andrienko, N., Andrienko, G., 2005. Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach, 2006 ed.
Andrienko, N., Andrienko, G., 2013a. A visual analytics framework for spatio-temporal analysis and modelling. Data Min Knowl Disc 27, 55-83.
Andrienko, N., Andrienko, G., 2013b. Visual analytics of movement: An overview of methods, tools and procedures. Information Visualization 12, 3-24.
Anselin, L., 1995. Local indicators of spatial association-LISA. Geographical Analysis 27, 93-115.
APPCG, 2013a. All Party Parliamentary Cycling Group (APPCG). Retrieved January 23 2013, from http://allpartycycling.org/inquiry/
APPCG, 2013b. Get Britain Cycling - Summary and Recommendations. Retrieved April 24 2013, from http://www.ctc.org.uk/sites/default/files/get_britain_cycling.pdf
Argyrous, G., 2005. Statistics for research: with a guide to SPSS, 2nd ed. ed. SAGE, London.
Aultman-Hall, L.M., 1996. Commuter Bicycle Route Choice: Analysis Of Major Determinants And Safety Implications, Civil Engineering. McMaster University.
Axelrod, R., 1997a. Advancing the art of simulation in the social sciences, In: Conte, R., Hegselmann, R., Terna, P. (Eds.), Simulating Social Phenomena. Springer, Berlin, pp. 21-40.
Axelrod, R., 1997b. Advancing the art of simulation in the social sciences. Complexity 3, 16-22.
Bachu, P., Dudala, T., Kothuri, S., 2001. Prompted Recall in Global Positioning System Survey: Proof-of-Concept Study. Transportation Research Record: Journal of the Transportation Research Board 1768, 106-113.
Baez, M., 2013. Motility. Retrieved July 19 2013, from https://www.healthtap.com/#topics/motility
Barton, H., Grant, M., Guise, R., 2010. Shaping Neighbourhoods for local health and global sustainability, Second ed. Routledge.
Batty, M., See, L.M., Heppenstall, A.J., Crooks, A.T., 2012. Agent-based models of geographical systems. Springer, Dordrecht, London.
Bauman, A.E., Murphy, N., Matsudo, V., 2013. Is a Population-Level Physical Activity Legacy of the London 2012 Olympics Likely? Journal of physical activity and health 10, 1 – 4.
Baumann, C., Bojacá, M., Rambeau, M., Wanner, Z.l., 2013. Biciudades 2013: Regional study on the use of the bicycle as a mode of transportation in Latin America, First ed. American University School of International Service.
BBC, 2010. Cycling surges in the land of the automobile. Retrieved April 15 2011, from http://www.bbc.co.uk/news/world-us-canada-11415660
Beecham, R., Wood, J., 2013. Exploring gendered cycling behaviours within a large-scale behavioural data-set. Transportation Planning and Technology, 1-15.
Bergmann, L., Sheppard, E., Plummer, P.S., 2009. Capitalism beyond harmonious equilibrium: mathematics as if human agency mattered. Environment and Planning A 41, 265-283.
Berrigan, D., Pickle, L., Dill, J., 2010. Associations between street connectivity and active transportation. International Journal of Health Geographics 9, 20.
Bierlaire, M., Frejinger, E., 2008. Route choice modeling with network-free data. Transportation Research Part C: Emerging Technologies 16, 187-198.

BMA, 2012. Healthy transport = Healthy lives. Retrieved July 17 2012, from http://bma.org.uk/-/media/Files/PDFs/Working%20for%20change/Improving%20health/healthytransporthealthylives.pdf

Bohte, W., Maat, K., 2009. Deriving and validating trip purposes and travel modes for multi-day GPS-based travel surveys: A large-scale application in the Netherlands. Transportation Research Part C: Emerging Technologies 17, 285-297.

Bonabeau, E., 2002. Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences of the United States of America 99, 7280-7287.

Boone Jr., H.N., Boone, D.A., 2012. Analyzing Likert Data. Journal of Extension 50.

Bopp, M., Kaczynski, A.T., Besenyi, G., 2012. Active commuting influences among adults. Preventive Medicine 54, 237-241.

Boston-University, 2013. The Theory of Planned Behavior. Retrieved August 06 2013, from http://sph.bu.edu/otlt/MPH-Modules/SB/SB721-Models/SB721-Models3.html

Braun, M.T., Oswald, F.L., 2011. Exploratory regression analysis: A tool for selecting models and determining predictor importance. Behav Res 43, 331-339.

Briggs, M., 2012. London mayor election: who is the greenest choice? The Ecologist.

Brignall, M., King, M., 2012. Budget 2012: Osborne disappoints motorists over fuel price increase, Guardian.

Broach, J., Dill, J., Gliebe, J., 2012. Where do cyclists ride? A route choice model developed with revealed preference GPS data. Transportation Research Part A: Policy and Practice 46, 1730-1740.

Broach, J., Gliebe, J., Dill, J., 2009. Development of a Multi-class Bicyclist Route Choice Model Using Revealed Preference Data, 12th International Conference on Travel Behavior Research, Jaipur, India.

Broach, J., Gliebe, J.P., Dill, J., 2011. Bicycle route choice model developed using revealed preference GPS data Transportation Research Board 90th Annual Meeting. Transportation Research Board, Washington DC.

Brown, M., 2012. Metro bosses reject call to allow bikes on trains. Chronicle.

Brownson, R.C., Hoehner, C.M., Day, K., Forsyth, A., Sallis, J.F., 2009. Measuring the Built Environment for Physical Activity: State of the Science. American Journal of Preventive Medicine 36, S99-S123.e112.

Buliung, R., Roorda, M., Remmel, T., 2008. Exploring spatial variety in patterns of activity-travel behaviour: initial results from the Toronto Travel-Activity Panel Survey (TTAPS). Transportation 35, 697-722.

Buliung, R.N., Morency, C., 2009. "Seeing Is Believing": Exploring Opportunities for the Visualization of Activity–Travel and Land Use Processes in Space–Time, In: Páez, A., Gallo, J.L., Buliung, R.N., Dall'erba, S. (Eds.), Progress in Spatial Analysis - Methods and Applications. Springer.

Burgoine, T., Alvanides, S., Lake, A.A., 2011. Assessing the obesogenic environment of North East England. Health & Place 17, 738-747.

Burt, J.E., Barber, G.M., Rigby, D.L., 2009. Elementary statistics for geographers, 3rd ed. Guilford Press, New York.

Buttimer, A., 1976. GRASPING THE DYNAMISM OF LIFEWORLD. Annals of the Association of American Geographers 66, 277-292.

CabinetOffice, 2009. The wider costs of transport in English urban areas in 2009. Retrieved August 20 2013, from http://webarchive.nationalarchives.gov.uk/+/http:/ www.cabinetoffice.gov.uk /media/307739/wider-costs-transport.pdf

CCC, 2013. From GPS and Virtual Globes to Spatial Computing - 2020: The Next Transformative Technology. Retrieved August 19 2013, from http://cra.org/ccc/files/docs/Spatial_Computing_Report-2013.pdf

Cerin, E., Conway, T., Saelens, B., Frank, L., Sallis, J., 2009. Cross-validation of the factorial structure of the Neighborhood Environment Walkability Scale (NEWS) and its abbreviated form (NEWS-A). Int J Behav Nutr Phys Act 6, 32.

Cervero, R., 1996. Mixed land-uses and commuting: Evidence from the American Housing Survey. Transportation Research Part A: Policy and Practice 30, 361-377.

Chaix, B., Méline, J., Duncan, S., Merrien, C., Karusisi, N., Perchoux, C., Lewin, A., Labadi, K., Kestens, Y., 2013. GPS tracking in neighborhood and health studies: A step forward for environmental exposure assessment, a step backward for causal inference? Health & Place 21, 46-51.

Charlesworth, A., 2012. Boris' bike scheme goes live tomorrow. Retrieved June 25 2012, from http://www.businessgreen.com/bg/news/1805995/boris-bike-scheme-goes-live-tomorrow
Chen, C., Gong, H., Lawson, C., Bialostozky, E., 2010. Evaluating the feasibility of a passive travel survey collection in a complex urban environment: Lessons learned from the New York City case study. Transportation Research Part A: Policy and Practice 44, 830-840.
Chen, J., Shaw, S.-L., Yu, H., Lu, F., Chai, Y., Jia, Q., 2011. Exploratory data analysis of activity diary data: a space-time GIS approach. Journal of Transport Geography 19, 394-404.
Christie, N., Kimberlee, R., Towner, E., Rodgers, S., Ward, H., Sleney, J., Lyons, R., 2011. Children aged 9–14 living in disadvantaged areas in England: Opportunities and barriers for cycling. Journal of Transport Geography 19, 943-949.
Chung, E.-H., Shalaby, A., 2005. A Trip Reconstruction Tool for GPS-based Personal Travel Surveys. Transportation Planning & Technology 28, 381-401.
Chung, K.-R., Hyeong, J., Choi, C.-H., Kim, S.-Y., Hong, G.-S., 2009. A Study on the Design Strategy for Promotion of Bicycle Use, International Association of Societies of Design Research (IASDR 2009) Conference, Coex, Seoul KOREA.
CIVITAS, 2013. The CIVITAS Initiative. Retrieved June 02, 2013, from http://www.civitas-initiative.org/index.php?id=69
Clark, A., 2011. Draft Newcastle Cycling Strategy for consultation. Retrieved Feb. 14 2012, from www.newcastle.gov.uk/wwwfileroot/legacy/regen/plantrans/DraftCyclingStrategyJuly2011.pdf
Clifford, N., Valentine, G., French, S., 2010. Key Methods in Geography. SAGE.
CMO, 2009. Annual Report of the Chief Medical Officer 2009. Retrieved Nov. 29 2012, from http://www.fcrn.org.uk/sites/default/files/2009_Annual_Report_of_Chief_Medical_Officer.pdf
Cole, R., Burke, M., Leslie, E., Donald, M., Owen, N., 2010. Perceptions of representatives of public, private, and community sector institutions of the barriers and enablers for physically active transport. Transport Policy 17, 496-504.
Commission, E., 2010. Clean transport. Retrieved March 01 2011, from http://ec.europa.eu/transport/urban/urban_mobility/urban_mobility_actions/cycling_en.htm
Committee, E.E.a.S., 2010. European cycling lexicon, p. 80.
Conroy-Dalton, R., 2001. The secret is to follow your nose: route path selection and angularity, 3rd International Space Syntax Symposium, Atlanta, Georgia, USA.
Conti, G., Magliocchetti, D., Devigili, F., DeAmicis, R., 2012. The role of SDIs as enablers of next generation intelligent transport systems, In: Cerbova, K., Cerba, O. (Eds.), SDI, Communities and Social Media. Czech Centre for Science and Society.
Conway, E., 2008. What's in a Name? Global Warming vs. Climate Change. Retrieved July 29 2013, from http://www.nasa.gov/topics/earth/features/climate_by_any_other_name.html
Cope, A., Nair, S., Torrance, J., Allan, W., Wilson, A., 2011. Cycling in the city regions: Delivering a step change. Retrieved July 07 2012, from http://www.sustrans.org.uk/assets/files/rmu/110411_Cycling_in_the_city_regions_Sustrans_PTEG_report_final.pdf
Coppock, J.T., Rhind, D.W., 1991. The History of GIS. In P. A. Longley, M. F. Goodchild, D. J. Maguire & D. W. Rhind (Eds.), Geographic Information Systems (First ed., Vol. 1, pp. 21-43): John Wiley & Sons.
Council, N.C., 2006. CITY CENTRE AREA ACTION PLAN - KEY ISSUES AND DEVELOPMENT OF OPTIONS. Retrieved June 15 2011, from http://www.newcastle.gov.uk/wwwfileroot/cxo/casino/1Keyissues.pdf
Crampton, J.W., 2001. Maps as Social Constructions: Power, Communication and Visualization (reprinted and revised version). Progress in Human Geography 25, 235-252.
Creedy, J., 1998. The dynamics of inequality and poverty: comparing income distributions. Elgar, Cheltenham.
Crooks, A., Castle, C., Batty, M., 2008. Key challenges in agent-based modelling for geo-spatial simulation. Computers, Environment and Urban Systems 32, 417-430.
Crotty, M., 1998. The Foundations of Social Research. Meaning and perspective in the research process. SAGE Publications, London, Thousand Oaks, New Delhi, pp. 1-17.

Daley, M., Rissel, C., 2011. Perspectives and images of cycling as a barrier or facilitator of cycling. Transport Policy 18, 211-216.

Daniel, E., Bright, G., 2011. Exploring the geographical distribution of wealth using the output area classification. Economic & Labour Market Review 5, 59-78.

Davis, M.L., Mounteer, L.C., Stevens, L.K., Miller, C.D., Zhou, A., 2011. 2D motility tracking of Pseudomonas putida KT2440 in growth phases using video microscopy. Journal of Bioscience and Bioengineering 111, 605-611.

de Smith, M., Goodchild, M.F., Longley, P.A., 2013. Geospatial Analysis, Fourth ed.

Deshpande, N., Chanda, I., Arkatkar, S.S., 2011. Accident Mapping And Analysis Using Geographical Information Systems. International Journal of Earth Sciences and Engineering 4, 342-345.

DfT, 2006. The Eddington Transport Study. The case for action: Sir Rod Eddington's advice to Government. Retrieved Aug. 21 2013, from http://webarchive.nationalarchives.gov.uk/20090104005813/http://www.dft.gov.uk/162259/187604/206711/executivesummary.pdf

DfT, 2008a. Cycle Infrastructure Design (Local Transport Note 2/08). Retrieved April 14 2011, from http://www.dft.gov.uk/pgr/roads/tpm/ltnotes/ltn208.pdf

DfT, 2008b. Making Personal Travel Planning Work: Practitioners' Guide, London.

DfT, 2011a. Creating Growth, Cutting Carbon: Making Sustainable Local Transport Happen. Retrieved July 02 2013, from https://www.gov.uk/government/publications/creating-growth-cutting-carbon-making-sustainable-local-transport-happen

DfT, 2011b. In Confidence - National Travel Survey (Questionaire form), Presentation on behavioural responses to Disruption. Dft with National Centre for Social Research (NatCen), London. Retrieved June 29 2011, from http://www2.dft.gov.uk/pgr/statistics/datatablespublications/nts/technical/adulttrcrd.pdf

DfT, 2011c. A public consultation on the future design of the National Travel Survey (DfT-2011-16). Retrieved June 29 2011, from http://assets.dft.gov.uk/consultations/dft-2011-16/dft-2011-16-consultation-document.pdf

DfT, 2011d. Research to explore perceptions and experiences of Bikeability training amongst parents and children. Retrieved July 31 2011, from http://www2.dft.gov.uk/pgr/sustainable/cycling/bikeabilitytraining/pdf/bikeabilitytraining.pdf

DfT, 2012a. National Travel Survey: 2011 Statistical Release.

DfT, 2012b. Policy: Improving local transport. Retrieved August 20 2013, from https://www.gov.uk/government/policies/improving-local-transport

DfT, 2012c. Proportion of urban trips under 5 miles taken by (i) walking or cycling (ii) public transport. Department for Transport. Retrieved July 22 2013, from https://www.gov.uk/government/publications/proportion-of-urban-trips-under-5-miles-taken-by-i-walking-or-cycling-ii-public-transport

DfT, 2012d. Public Consultation on the Future Design of the National Travel Survey: Summary of Responses.

DfT, 2012e. Table CW0111: Proportion of residents who cycle (any length or purpose) at a given frequency: England, from 2010/11.

DfT, 2013a. Bikeability Delivery Statistics Clarification Note and Summary. Retrieved July 20 2013, from http://www.dft.gov.uk/bikeability/download/100

DfT, 2013b. Bikeability: Cycling Proficiency for the 21st century. Retrieved July 20 2013, from http://www.dft.gov.uk/bikeability/what-is-bikeability/

DfT, 2013c. Door to Door: A strategy for improving sustainable transport integration. Retrieved July 02 2013, from www.gov.uk/government/uploads/system/uploads/attachment_data/file/142539/door-to-door-strategy.pdf

DfT, 2013d. Evaluation of the Cycling City and Towns programme. Retrieved Oct. 16 2013, from https://www.gov.uk/government/publications/evaluation-of-the-cycling-city-and-towns-programme

DfT, 2013e. Guidance: Cycle city ambition grants. Retrieved June 02 2013, from https://www.gov.uk/government/publications/cycle-city-ambition-grants

DfT, 2013f. Local area walking and cycling statistics: England 2011/12. Retrieved Oct. 16 2013, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/185738/local-area-walking-and-cycling-england-2011-12.pdf
DfT, 2013g. Local Sustainable Transport Fund Annual Report 2011/12. Retrieved July 29 2013, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/206369/lstf-annual-report-2011-12.pdf
DfT, 2013h. Minister announces record £62 million investment in cycling. Retrieved June 01 2013, from https://www.gov.uk/government/news/minister-announces-record-62-million-investment-in-cycling
DfT, 2013i. Press release - Government shifts cycling up a gear. Retrieved August 12 2013, from https://www.gov.uk/government/news/government-shifts-cycling-up-a-gear?dm_i=6EB,1RI71,3DY6U8,6AE0L,1
DfT, 2013j. Response to the ‘Get Britain cycling’ report published by the All Party Parliamentary Cycling. Retrieved April 24 2013, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/232611/appcg-response.pdf
DfT, 2013k. Table NTS0315: Where usually cycled in the last 12 months: Great Britain, 2002 to 2012. Department for Transport.
DfT, 2013l. Transport Statistics notes and guidance: National Travel Survey. Retrieved July 21 2013, from https://www.gov.uk/transport-statistics-notes-and-guidance-national-travel-survey
DH, 2004. At least five a week. Evidence on the impact of physical activity and its relationship to health: A report from the Chief Medical Officer. Retrieved April 11 2011, from http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_4080981.pdf
DH, 2010. Active Travel: The Miracle Cure? A guide for the NHS on raising physical activity levels through your local transport plan. Retrieved Sept. 17 2013, from http://www.corporatecitizen.nhs.uk/data/files/resources/269/Active-Travel-The-Miracle-Cure.pdf
DH, 2011. UK physical activity guidelines (Fact sheet 4: Adults (19-64 years)). Retrieved July 11 2011, from http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_127931
Dijst, M., Vidakovic, V., 2000. Travel time ratio: the key factor of spatial reach. Transportation 27, 179-199.
Dill, J., 2009. Bicycling for Transportation and Health: The Role of Infrastructure. J Public Health Pol 30, S95-S110.
Dill, J., Gliebe, J., 2008. UNDERSTANDING AND MEASURING BICYCLING BEHAVIOR: A FOCUS ON TRAVEL TIME AND ROUTE CHOICE (Final Report). Oregon Transportation Research and Education Consortium (OTREC), Portland.
Dill, J., Voros, K., 2007. Factors Affecting Bicycling Demand: Initial Survey Findings from the Portland, Oregon, Region. Transportation Research Record: Journal of the Transportation Research Board 2031, 9-17.
Docherty, I., Shaw, J., 2008. Traffic jam: ten years of 'sustainable' transport in the UK. Policy Press, Bristol.
Dodds, B., 2012. Newburn to city centre working group notes. Retrieved Oct. 16 2013, from http://www.newcastle.gov.uk/sites/drupalncc.newcastle.gov.uk/files/wwwfileroot/parking-roads-and-transport/cycling/cycling_forum_working_group_21_february.doc
Du, J., Aultman-Hall, L., 2007. Increasing the accuracy of trip rate information from passive multi-day GPS travel datasets: Automatic trip end identification issues. Transportation Research Part A: Policy and Practice 41, 220-232.
Duffy, T.M., Jonassen, D.H., 1992. Objectivist and Constructivist: Conceptions of learning and instruction, In: Duffy, T.M., Jonassen, D.H. (Eds.), Constructivism and the Technology of Instruction: A conversation. Lawrence Erlbaum Associates, Hillsdale, NJ.
Duncan, M.J., Mummery, W.K., 2007. GIS or GPS? A Comparison of Two Methods For Assessing Route Taken During Active Transport. American Journal of Preventive Medicine 33, 51-53.
Ebdon, D., 1985. Statistics in geography, 2nd ed., revised with 17 programs. ed. Blackwell, Oxford.
EC, 2011. Future of transport - Analytical report, Flash EB Series #312. Flash Eurobarometer 312 – The Gallup Organization, Hungary. Retrieved Sept. 11 2013, from http://ec.europa.eu/public_opinion/flash/fl_312_en.pdf

EDINA, 2013. UKBORDERS becomes UK Data Service Census Support. Retrieved Sept. 03 2013, from http://edina.ac.uk/news/newsline18-1/censussupport.html
Ehrgott, M., Wang, J.Y.T., Raith, A., van Houtte, C., 2012. A bi-objective cyclist route choice model. Transportation Research Part A: Policy and Practice 46, 652-663.
Ellegård, K., Vrotsou, K., 2006. Capturing patterns of everyday life - presentation of the visualization method VISUAL-TimePAcTS, In IATUR - XXVIII Annual Conference, August 16-18, 2006. Linköping University, Copenhagen, Denmark.
Engbers, L., Hendriksen, I., 2010. Characteristics of a population of commuter cyclists in the Netherlands: perceived barriers and facilitators in the personal, social and physical environment. International Journal of Behavioral Nutrition and Physical Activity 7, 89.
Epstein, B., 2011. Agent-Based Modeling and the Fallacies of Individualism, In: Humphreys, P., Imbert, C. (Eds.), Models, Simulations, and Representations. Routledge, New York, pp. 115-144.
ESRI, 2011. What is a z-score? What is a p-value?, ESRI ArcGIS 10.0 Documentation ed. ESRI. Retrieved Oct. 11 2013, from from http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//005p00000006000000
ESRI, 2012. Exploratory Regression (Spatial Statistics). ESRI. Retrieved Jan. 01 2013, from http://resources.arcgis.com/en/help/main/10.1/index.html#/Exploratory_Regression/005p00000050000000/
ESRI, 2013. Cluster and Outlier Analysis (Anselin Local Moran's I) (Spatial Statistics). Retrieved July 31 2013, from from http://resources.arcgis.com/en/help/main/10.1/index.html#/Cluster_and_Outlier_Analysis_Anselin_Local_Moran_s_I/005p0000000z000000/
EU, 2013. Innovation in urban mobility - Policy making and planning. European Union, Bulgaria. Retrieved from April 24 2013, from http://www.transport-research.info/Upload/Documents/201304/20130417_132707_15935_PB03ENWEB.pdf
Eurostat, 2012. Introduction to NUTS classification. Retrieved from July 31 2013, from http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction
Fagiolo, G., Valente, M., Vriend, N.J., 2007. Segregation in networks. Journal of Economic Behavior & Organization 64, 316-336.
Fernández-Avilés Calderón, G., 2009. Spatial Regression Analysis vs. Kriging Methods for Spatial Estimation. Int Adv Econ Res 15, 44-58.
Fernández Heredia, Á., Monzón de Cáceres, A., 2010. Cyclists' Travel behaviour, from theory to reality, 12th World Conference on Transport Research Society 2010. World Conference on Transport Research Society, Lisboa, Portugal.
FHWA, 2000. An Investigation of The Use of Global Positioning Sytem (GPS) Technology and Its Augmentations Within State and Local Transporation Departments. U.S. Department of Transportation, Virginia (VA), USA. Retrieved March 02 2011, from http://www.fhwa.dot.gov/publications/research/operations/its/00093.pdf
Field, A.P., 2009. Discovering statistics using SPSS, 3rd ed. SAGE, Los Angeles.
Flowerdew, R., Manley, D.J., Sabel, C.E., 2008. Neighbourhood effects on health: Does it matter where you draw the boundaries? Social Science & Medicine 66, 1241-1255.
Flowerdew, R., Martin, D., 2005. Methods in Human Geography: A guide for students doing a research project, Second ed. Pearson Prentice Hall, Harlow.
Foresight, 2007a. Tackling Obesities: Future Choices - Project Report. Retrieved Jan. 16 2011, from http://www.bis.gov.uk/assets/bispartners/foresight/docs/obesity/17.pdf
Foresight, 2007b. Tackling Obesities: Future Choices – Visualising the Future: Scenarios to 2050. Retrieved Jan. 16 2011, from http://www.bis.gov.uk/assets/foresight/docs/obesity/09.pdf
Foresight, 2008. Tackling Obesities: Future Choices. One-Year Review (October 2007-November 2008). Retrieved Nov. 16 2011, from http://www.bis.gov.uk/assets/bispartners/foresight/docs/obesity/obesity_review_final_jp_110310.pdf
Foresight, 2012. Tackling Obesities: Future Choices. Mid-Term Review November 2008 – September 2010. Retrieved Sept. 07 2013, from http://www.bis.gov.uk/assets/foresight/docs/obesity/12-1210-tackling-obesities-mid-term-review
Forester, J., 1983. Bicycle Transportation. MIT Press, London.

Forsyth, A., Krizek, K., 2011. Urban Design: Is there a Distinctive View from the Bicycle? Journal of Urban Design 16, 531-549.
Fotheringham, A.S., Brunsdon, C., Charlton, M., 2002. Geographically Weighted Regression: The Analysis of Spatially Varying Relationships. Wiley.
Fotheringham, A.S., Charlton, M., 1994. GIS AND EXPLORATORY SPATIAL DATA ANALYSIS: AN OVERVIEW OF SOME RESEARCH ISSUES. Geographical Systems 1, 315-327.
Francis, J.J., Eccles, M.P., Johnston, M., Walker, A., Grimshaw, J., Foy, R., Kaner, E.F.S., Smith, L., Bonetti, D., 2004. CONSTRUCTING QUESTIONNAIRES BASED ON THE THEORY OF PLANNED BEHAVIOUR - A MANUAL for HEALTH SERVICES RESEARCHERS. Centre for Health Services Research, Newcastle upon Tyne.
Freeman, T.W., Snodgrass, C.P., 1966. Tyneside, The Conurbations of Great Britain, 2 ed. Manchester University Press.
Friman, M., Fujii, S., Ettema, D., Gärling, T., Olsson, L.E., 2013. Psychometric analysis of the satisfaction with travel scale. Transportation Research Part A: Policy and Practice 48, 132-145.
GAPA, 2010a. NCD Prevention: Investments that Work for Physical Activity. Global Advocacy Council for Physical Activity (GAPA), Toronto. Retrieved April 21 2011, from http://www.globalpa.org.uk/pdf/investments-work.pdf
GAPA, 2010b. The Toronto Charter for Physical Activity: A Global Call to Action. Global Advocacy Council for Physical Activity, Toronto. Retrieved April 21 2011, from http://www.globalpa.org.uk/pdf/torontocharter-eng-20may2010.pdf
Gatersleben, B., Appleton, K.M., 2007. Contemplating cycling to work: Attitudes and perceptions in different stages of change. Transportation Research Part A: Policy and Practice 41, 302-312.
GCF, 2013. Gateshead Cycling Forum, Gateshead. Retrieved Oct. 09 2013, from from http://www.gatesheadcycling.org.uk/
Gehlert, T., Dziekan, K., Gärling, T., 2013. Psychology of sustainable travel behavior. Transportation Research Part A: Policy and Practice 48, 19-24.
GeoTime, 2013. OPEN UP THE DIMENSION OF TIME WITH GEOTIME FOR ARCGIS. Oculus. Retrieved Aug. 27 2013, from from http://www.geotime.com/Product/GeoTime-(1)/GeoTime-for-ArcGIS.aspx
Gewin, V., 2013. Climate change gets clocked, Nature News. Nature Publishing Group. Retrieved from Oct. 15 2013, from Retrieved from http://dx.doi.org/10.1038/nature.2013.13922
Gibson, J., McKenzie, D., 2007. Using Global Positioning Systems in Household Surveys for Better Economics and Better Policy. The World Bank Research Observer 22, 217-241.
Gilbert, K., McCarthy, M., 1994. Deaths of cyclists in London 1985-92: the hazards of road traffic. BMJ 308, 1534-1537.
Gilbert, N., Troitzsch, K.G., 1999. Simulation for the social scientist. Open University Press, Buckingham, Philadelphia.
Glennon, A., 2010. Creating and Validating Object-Oriented Geographic Data Models: Modeling Flow within GIS. Transactions in GIS 14, 23-42.
Godefrooij, T., Schepel, S., 2010. Co Benefits for Safe, Clean and Affordable Transport Strategy in Urban Areas, The Example of Cycling Inclusive Planning and Promotion, Final draft January 2010 ed. World Bank, Utrecht.
Goetz, A.R., Vowles, T.M., Tierney, S., 2009. Bridging the Qualitative–Quantitative Divide in Transport Geography∗. The Professional Geographer 61, 323-335.
Goldhill, O., 2013. Which?: Galaxy S4 wins battery life test. The Telegraph. Retrieved July 01 2013, from Retrieved from http://www.telegraph.co.uk/technology/mobile-phones/10145537/Which-Galaxy-S4-wins-battery-life-test.html
Golledge, R.G., Stimson, R.J., 1997. Spatial Behavior: A Geographic Perspective. Taylor and Francis (Guilford Press).
Gong, Y., Mackett, R., 2008. Visualizing Children's Walking Behaviour Using Portable Global Positioning Units (GPS) and Energy Expense Monitors, Virtual Geographic Environments, The Chinese University of Hong Kong, China.
Goodchild, M.F., 2010. Twenty years of progress: GIScience in 2010. Journal of Spatial Information Science 1, 3–20.

Goodman, A., 2013. Walking, Cycling and Driving to Work in the English and Welsh 2011 Census: Trends, Socio-Economic Patterning and Relevance to Travel Behaviour in General. PLOS ONE 8.
Goodman, A., Green, J., Woodcock, J., 2013a. The role of bicycle sharing systems in normalising the image of cycling: An observational study of London cyclists. Journal of Transport & Health.
Goodman, A., Panter, J., Sharp, S.J., Ogilvie, D., 2013b. Effectiveness and equity impacts of town-wide cycling initiatives in England: A longitudinal, controlled natural experimental study. Social Science & Medicine.
Goodwin, P., 2013. Get Britain Cycling - Full Report from the Inquiry, London.
GOV.UK, 2013. Guide Flexible working. Retrieved Aug. 27 2013, from from https://www.gov.uk/flexible-working/types-of-flexible-working
Graser, A., Straub, M., Dragaschnig, M., 2013. Towards an Open Source Analysis Toolbox for Street Network Comparison: Indicators, Tools and Results of a Comparison of OSM and the Official Austrian Reference Graph. Transactions in GIS, n/a-n/a.
GreenerJourneys, 2011. A step change for Britain's buses Maximising the economic, social and environmental potential.
Gregory, D., Johnston, R., Geraldine, P., Watts, M.J., Whatmore, S., 2009. The Dictionary of Human Geography, 5 ed. John Wiley & Sons Ltd.
Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S.K., Huse, G., Huth, A., Jepsen, J.U., Jørgensen, C., Mooij, W.M., Müller, B., Pe'er, G., Piou, C., Railsback, S.F., Robbins, A.M., Robbins, M.M., Rossmanith, E., Rüger, N., Strand, E., Souissi, S., Stillman, R.A., Vabø, R., Visser, U., DeAngelis, D.L., 2006. A standard protocol for describing individual-based and agent-based models. Ecological Modelling 198, 115-126.
Grimm, V., Berger, U., DeAngelis, D.L., Polhill, J.G., Giske, J., Railsback, S.F., 2010. The ODD protocol: A review and first update. Ecological Modelling 221, 2760-2768.
Grous, A., 2011. The British Cycling Economy - '‘Gross Cycling Product’ Report. Retrieved Nov. 27 2012, from http://corporate.sky.com/documents/pdf/press_releases/2011/the_british_cycling_economy
Gu, Y.-G., Wang, Z.-H., Lu, S.-H., Jiang, S.-J., Mu, D.-H., Shu, Y.-H., 2012. Multivariate statistical and GIS-based approach to identify source of anthropogenic impacts on metallic elements in sediments from the mid Guangdong coasts, China. Environmental Pollution 163, 248-255.
Guell, C., Panter, J., Jones, N.R., Ogilvie, D., 2012. Towards a differentiated understanding of active travel behaviour: Using social theory to explore everyday commuting. Social Science & Medicine 75, 233-239.
Guensler, R., Wolf, J., 1999. Development of a Handheld Electronic Travel Diary for Monitoring Individual Tripmaking Behavior, Proceedings of the 77th Annual Meeting of the Transportation Research Board, Washington DC.
Güting, R., de Almeida, V., Ding, Z., 2006. Modeling and querying moving objects in networks. The VLDB Journal 15, 165-190.
Guting, R.H., 2007. How to Build Your Own Moving Objects Database System, Mobile Data Management, 2007 International Conference on, pp. 1-2.
Guy, S., Marvin, S., 2000. Models and Pathways: The Diversity of Sustainable Urban Futures, In: Williams, K., Burton, E., Jenks, M. (Eds.), Achieving sustainable urban form. Taylor and Francis, London.
Haderer, N., Rouvoy, R., Seinturier, L., 2013. A preliminary investigation of user incentives to leverage crowdsensing activities, 2nd International IEEE Workshop on Hot Topics in Pervasive Computing (PerHot).
Hägerstrand, T., 1970. What about people in Regional Science? Papers in Regional Science 24, 6-21.
Hammersley, M., Atkinson, P., 2007. Ethnography: principles in practice, 3rd ed. ed. Routledge, London.
Handy, S., 2005. Does the built environment influence physical activity? Examining the evidence; Transportation Research Board (TRB) Special Report 282, Critical Assessment of the Literature on the Relationships Among Transportation, Land Use, and Physical Activity. Transportation Research Board (TRB) Washington, DC, USA.
Handy, S.L., Boarnet, M.G., Ewing, R., Killingsworth, R.E., 2002a. How the built environment affects physical activity: Views from urban planning. American Journal of Preventive Medicine 23, 64-73.
Handy, S.L., Boarnet, M.G., Ewing, R., Killingsworth, R.E., 2002b. How the built environment affects physical activity: Views from urban planning. American Journal of Preventive Medicine 23, 64-73.

Hansmann, R., Loukopoulos, P., Scholz, R.W., 2009. Characteristics of effective battery recycling slogans: A Swiss field study. Resources, Conservation and Recycling 53, 218-230.
Hargrove, W., Westervelt, J., 2012. An Implementation of the Pathway Analysis Through Habitat (PATH) Algorithm Using NetLogo, In: Westervelt, J.D., Cohen, G.L. (Eds.), Ecologist-Developed Spatially-Explicit Dynamic Landscape Models. Springer US, pp. 211-222.
Harker, J., 2011. TERRITORY REPORT: Denmark. Retrieved Nov. 06 2011, from http://www.bikebiz.com
Harvey, F., Krizek, K.J., Collins, R., 2008. Using GPS Data to Assess Bicycle Commuter Route Choice. Transportation Research Board, 20p.
Hazell, L.C., Brodie, G., 2012. Applying GIS tools to define prehistoric megalith transport route corridors: Olmec megalith transport routes: a case study. Journal of Archaeological Science 39, 3475-3479.
Heinen, E., Van Wee, B., Maat, K., 2009. The impact of work-related factors on levels of bicycle commuting. Journal of the Transportation Research Board TRB 2009 Annual Meeting CD-ROM - Paper revised from original submittal.
Henderson, T., 2013. Cycling research on Tyneside shows more are getting on bikes. The Journal. Retrieved May 29 2013, from Retrieved from http://www.journallive.co.uk/north-east-news/todays-news/2013/03/16/cycling-research-on-tyneside-shows-more-are-getting-on-bikes-61634-32999526/#ixzz2UgV7hmsQ
Herrmann, S., 2011. 2011 Compendium of Physical Activities Reference List Category 1 - Bicycling, 2011 Compendium of Physical Activities and additional resources. Arizona State University
Hill, D., 2012a. Ken Livingstone is streets ahead of Boris Johnson in mayoral cycling policy race. Retrieved June 25 2012, from http://www.guardian.co.uk/politics/davehillblog/2012/apr/06/ken-livingstone-jenny-jones-boris-johnson-london-cycling-policies
Hill, D., 2012b. London mayor: your ideas on cycling and walking. Guardian. Retrieved June 25 2012, from http://www.guardian.co.uk/commentisfree/2012/mar/15/london-mayor-cycling-walking
Hood, J., Sall, E., Charlton, B., 2011. A GPS-based bicycle route choice model for San Francisco, California. Transportation Letters: The International Journal of Transportation Research 3, 63-75.
Hopkinson, P., Wardman, M., 1996. Evaluating the demand for new cycle facilities. Transport Policy 3, 241-249.
Horner, M.W., Zook, B., Downs, J.A., 2012. Where were you? Development of a time-geographic approach for activity destination re-construction. Computers, Environment and Urban Systems 36, 488-499.
Houston, D., 2014. Implications of the modifiable areal unit problem for assessing built environment correlates of moderate and vigorous physical activity. Applied Geography 50, 40-47.
Hull, A., 2005. Integrated transport planning in the UK: From concept to reality. Journal of Transport Geography 13, 318-328.
Icek, A., 1991. The theory of planned behavior. Organizational Behavior and Human Decision Processes 50, 179-211.
IEA, 2011. International Energey Agency. Retrieved July 29 2013, from http://www.iea.org/index_info.asp?id=1959
IEA, 2013. REDRAWING THE ENERGY-CLIMATE MAP: World Energy Outlook Special Report. INTERNATIONAL ENERGY AGENCY (IEA). Retrieved Sept. 07 2013, from http://www.iea.org/publications/freepublications/publication/RedrawingEnergyClimateMap_2506.pdf
Johnson, D.L., Ambrose, S.H., Bassett, T.J., Bowen, M.L., Crummey, D.E., Isaacson, J.S., Johnson, D.N., 1997. Meanings of environmental terms. J. Environ. Qual. 26, 581-589.
Johnston, R.J., Gregory, D., Geraldine, P., Watts, M., 2000. The Dictionary of Human Geography, 4 ed. Blackwell Publishing.
Jones, A., Bentham, G., Foster, C., Hillsdon, M., Panter, J., 2007. Tackling Obesities: Future Choices – Obesogenic Environments – Evidence Review. Government Office for Science.
Jones, A., Coombes, E., Griffin, S., van Sluijs, E., 2009. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. International Journal of Behavioral Nutrition and Physical Activity 6, 42.
Jones, P., 2011. What future for Britain's road network?, Britain in 2011: Annual magazine of the Economic and Social Research Council. ESRC.

Jones, T., 2012. Getting the British back on bicycles—The effects of urban traffic-free paths on everyday cycling. Transport Policy 20, 138-149.

Jones, T., Pooley, C.G., Scheldeman, G., Horton, D., Tight, M., Mullen, C., Jopson, A., Whiteing, A., 2012. Moving around the city: discourses on walking andÿcycling in English urban areas. Environment and Planning A 44, 1407-1424.

Kaplan, M., 2013. Speed test for wild cheetahs. Nature.

Kapler, T., Wright, W., 2004. GeoTime Information Visualization, Information Visualization, 2004. INFOVIS 2004. IEEE Symposium on, pp. 25-32.

Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J., Melançon, G., 2008. Visual Analytics: Definition, Process, and Challenges, In: Kerren, A., Stasko, J., Fekete, J.-D., North, C. (Eds.), Information Visualization. Springer Berlin Heidelberg, pp. 154-175.

Keim, D., Kohlhammer, J., Ellis, G., Mansmann, F., 2010. Mastering the Information Age Solving Problems with Visual Analytics. Eurographics Association.

Keim, D.A., Mansmann, F., Schneidewind, J., Ziegler, H., 2006. Challenges in Visual Data Analysis, Information Visualization, 2006. IV 2006. Tenth International Conference on, pp. 9-16.

Kelly, J., 2011. BBC News - Is dangerous cycling a problem?, BBC News Magazine, 13 April 2011 Last updated at 10:28 ed. British Broadcasting Corporation (BBC), London.

Kerr, J., Duncan, S., Schipperjin, J., 2011. Using Global Positioning Systems in Health Research: A Practical Approach to Data Collection and Processing. American Journal of Preventive Medicine 41, 532-540.

Knight, A., Ruddock, L., 2008. Advanced Research Methods in the Built Environment, 1st ed. Wiley-Blackwell 2008, Oxford.

Kobayashi, T., Miller, H., Othman, W., 2010. Analytical methods for error propagation in planar space–time prisms. Journal of Geographical Systems, 1-28.

Kochan, B., Bellemans, T., Janssens, D., Wets, G., 2006. Dynamic activity-travel diary data collection using a GPS-enabled personal digital assistant, Proceedings of the ninth International Conference. AMER SOC CIVIL ENGINEERS, pp. 319-324.

Kraak, M.-J., 2003. The space-time cube revisited from a geovisualization perspective, 21st International Cartographic Conference (ICC), Durban, South Africa, 10-16 August 2003.

Kraak, M.-J., Huisman, O., Kveladze, I., 2012. EU MOVE-COST WG4 Workshop on Analysis and visualization of movement data. What can the Space-Time-Cube do for you? University of Twente, Netherlands, Twente, Netherlands.

Kristensson, P.O., Dahlback, N., Anundi, D., Bjornstad, M., Gillberg, H., Haraldsson, J., Martensson, I., Nordvall, M., Stahl, J., 2009. An Evaluation of Space Time Cube Representation of Spatiotemporal Patterns. Visualization and Computer Graphics, IEEE Transactions 15, 696-702.

Krizek, K.J., Handy, S.L., Forsyth, A., 2009a. Explaining changes in walking and bicycling behavior: challenges for transportation research. Environment and Planning B: Planning and Design 36, 725 - 740.

Krizek, K.J., Handy, S.L., Forsyth, A., 2009b. Explaining changes in walking and bicycling behavior: challenges for transportation research. Environment and Planning B: Planning and Design, 725-740.

Kuha, J., Firth, D., 2011. On the index of dissimilarity for lack of fit in loglinear and log-multiplicative models. Computational Statistics & Data Analysis 55, 375-388.

Kveladze, I., Kraak, M.-J., 2012. What do we know about the space-time cube from cartographic and usability perspective?, AutoCarto 2012. The Cartography and Geographic Information Society (CaGIS), Columbus, Ohio, USA - September 16-18, 2012.

Kwan, M.-P., 1998. Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-based Framework. Geographical Analysis 30, 191-216.

Kwan, M.-P., Weber, J., 2008. Scale and accessibility: Implications for the analysis of land use–travel interaction. Applied Geography 28, 110-123.

Kwan, M.P., Schwanen, T., 2009. Critical quantitative geographies. Environment and Planning A 41, 261-264.

Larsen, J., Patterson, Z., & El-Geneidy, A., 2011. Build it. But where? The use of geographic information systems in identifying locations for new cycling infrastructure. International Journal of Sustainable Transportation.

Layendecker, K., 2010. Newcastle cycling petition - safe cycling in the city centre, Newcastle upon tyne.

LCC, 2013. London Cycling Campaign.
Lee, C., Moudon, A.V., 2006. The 3Ds+R: Quantifying land use and urban form correlates of walking. Transportation Research Part D: Transport and Environment 11, 204-215.
Lemieux, M., Godin, G., 2009. How well do cognitive and environmental variables predict active commuting? International Journal of Behavioral Nutrition and Physical Activity 6, 12.
Lenntorp, B., 1999. Time-geography – at the end of its beginning. GeoJournal 48, 155-158.
Leshem, S., Trafford, V.N., 2002. Starting at the End to Undertake Doctoral Research: Predictable Questions as Stepping Stones. Higher Education Review 35, 31-49.
Leslie, E., Saelens, B., Frank, L., Owen, N., Bauman, A., Coffee, N., Hugo, G., 2005. Residents' perceptions of walkability attributes in objectively different neighborhoods: a pilot study. Health Place 11, 227 - 236.
Leszczynski, A., 2009. Quantitative Limits to Qualitative Engagements: GIS, Its Critics, and the Philosophical Divide. The Professional Geographer 61, 350-365.
Lichter, M., Felsenstein, D., 2012. Assessing the costs of sea-level rise and extreme flooding at the local level: A GIS-based approach. Ocean & Coastal Management 59, 47-62.
Longley, P.A., 2000. The academic success of GIS in geography: Problems and prospects. Journal of Geographical Systems 2, 37-42.
Lorek, H., Sonnenschein, M., 1999. Modelling and simulation software to support individual-based ecological modelling. Ecological Modelling 115, 199-216.
LOVELL, J., 2007. Left-Hand-Turn Elimination, The New York Times Magazine.
LTP3, 2011. LTP3: The Third Local Transport Plan for Tyne and Wear Strategy 2011 - 2021. Tyne and Wear Integrated Transport Authority, Tyne and Wear.
LTSA, 2004. CYCLE NETWORK AND ROUTE PLANNING GUIDE. Land Transport Safety Authority, New Zealand. Retrieved Aug. 24 2011, from http://www.nzta.govt.nz/resources/cycle-network-and-route-planning/docs/cycle-network-and-route-planning.pdf
Lwin, K.K., Murayama, Y., 2011a. Modelling of urban green space walkability: Eco-friendly walk score calculator. Computers, Environment and Urban Systems 35, 408-420.
Lwin, K.K., Murayama, Y., 2011b. Modelling of urban green space walkability: Eco-friendly walk score calculator. Computers, Environment and Urban Systems In Press, Corrected Proof.
Mackett, R., 2011. Improving health through walking and cycling. Logistics & Transport Focus 13, 22 - 25.
Mackett, R.L., Brown, B., 2011. Transport, Physical Activity and Health: Present knowledge and the way ahead. Centre for Transport Studies, University College London, London, UK. Retrieved July 19 2013, from http://www.ucl.ac.uk/news/pdf/transportactivityhealth.pdf
Maddox, C., Corcoran, J., Liu, Y., 2013. Mapping spatial flows over time: a case study using journey-to-work data. Journal of Spatial Science 58, 147-159.
Maguire, D.J., 1991. An overview and definition of GIS, In: Longley, P.A., Goodchild, M.F., Maguire, D.J., Rhind, D.W. (Eds.), Geographic Information Systems, First ed. John Wiley & Sons, pp. 9-20.
Martens, K., 2007. Promoting bike-and-ride: The Dutch experience. Transportation Research Part A: Policy and Practice 41, 326-338.
Martin, J., 2007. The 17 Great Challenges of the Twenty-First Century. Futurist 41, 20-24.
McClure, W.R., Bartuska, T.J., 2007. The built environment: a collaborative inquiry into design and planning. John Wiley & Sons.
McCormack, G., Masse, L., Bulsara, M., Pikora, T., Giles-Corti, B., 2006. Constructing indices representing supportiveness of the physical environment for walking using the Rasch measurement model. International Journal of Behavioral Nutrition and Physical Activity 3, 44.
Menghini, G., Carrasco, N., Schüssler, N., Axhausen, K., 2009. Route choice of cyclists in Zurich: GPS-based discrete choice models. Arbeitsberichte Verkehrs- und Raumplanung 544, IVT, ETH Zurich, Zurich.
Menghini, G., Carrasco, N., Schüssler, N., Axhausen, K.W., 2010. Route choice of cyclists in Zurich. Transportation Research Part A: Policy and Practice 44, 754-765.
MetOffice, 2013a. UK actual and anomaly maps - November 2011 Days of snow lying Actual. metoffice.gov.uk.
MetOffice, 2013b. UK actual and anomaly maps - November 2011 Days of thunder Actual. metoffice.gov.uk.

MetOffice, 2013c. UK actual and anomaly maps - November 2011 Lightning strikes Actual. metoffice.gov.uk.
MetOffice, 2013d. UK actual and anomaly maps - November 2011 Mean temperature Actual. metoffice.gov.uk.
MetOffice, 2013e. UK actual and anomaly maps - November 2011 Rainfall Actual. metoffice.gov.uk.
MetOffice, 2013f. UK actual and anomaly maps - November 2011 Sunshine Actual. metoffice.gov.uk.
MetOffice, 2013g. UK actual and anomaly maps - October 2011 Days of snow lying Actual. metoffice.gov.uk.
MetOffice, 2013h. UK actual and anomaly maps - October 2011 Days of thunder Actual. metoffice.gov.uk.
MetOffice, 2013i. UK actual and anomaly maps - October 2011 Lightning strikes Actual. metoffice.gov.uk.
MetOffice, 2013j. UK actual and anomaly maps - October 2011 Mean temperature Actual. metoffice.gov.uk.
MetOffice, 2013k. UK actual and anomaly maps - October 2011 Rainfall Actual. metoffice.gov.uk.
MetOffice, 2013l. UK actual and anomaly maps - October 2011 Sunshine Actual. metoffice.gov.uk.
Meyer, M.S., 2011. Presentations from the Bikeability Seminar: December 2 2010. bikeability.dk, pp. video, audio and the powerpoint slides presented at the first International Bikeability Seminar on December 2nd 2010.
Miller, G.A., 1994. The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychological Review 101, 343-352.
Miller, H., 2007. Place-Based versus People-Based Geographic Information Science. Geography Compass 1, 503-535.
Miller, H.J., 1991. Modelling accessibility using space-time prism concepts within geographical information systems. International Journal of Geographical Information Systems 5, 287-301.
Miller, H.J., 2004. Activities in Space and Time, In: Stopher, P., Button, K., Haynes, K., Hensher, D. (Eds.), Handbook of Transport Geography and Spatial Systems. Pergamon/Elsevier Science.
Mitchell, A., 1999. The ESRI guide to GIS analysis, Vol.1, Geographic patterns and relationships, 1st ed. ed. Environmental Systems Research Institute (ESRI), Redlands, Calif.
Mitchell, A., 2005. The ESRI Guide to GIS Analysis. ESRI Press.
Mitchell, R., Popham, F., 2008. Effect of exposure to natural environment on health inequalities: an observational population study. The Lancet 372, 1655-1660.
Moiseeva, A., 2013. Experience the City: Analysis of Space-Time Behaviour and Spatial Learning, Department of the Built Environment. Eindhoven:Technische Universiteit Eindhoven, Eindhoven.
Moudon, A.V., Lee, C., 2003. Walking and Bicycling: An Evaluation of Environmental Audit Instruments. American Journal of Health Promotion, Inc. 18.
Moudon, A.V., Lee, C., Cheadle, A.D., Collier, C.W., Johnson, D., Schmid, T.L., Weather, R.D., 2005. Cycling and the built environment, a US perspective. Transportation Research Part D: Transport and Environment 10, 245-261.
Murray, A.T., McGuffog, I., Western, J.S., Mullins, P., 2001. Exploratory Spatial Data Analysis Techniques for Examining Urban Crime: Implications for Evaluating Treatment. British Journal of Criminology 41, 309-329.
NCC, 2011a. Improvement suggestion document from Newcastle cycling campaign. Retrieved July 29 2013, from http://newcycling.org/news/2011Ncl_CllrTodd_01.12.2011.pdf
NCC, 2011b. Seven Strategic Cycle Routes into the Heart of Newcastle. Retrieved Oct. 16 2013, from http://newcycling.org/news/20130929/ccaf-september-2013
NCC, 2012. Newcastle Cycling Campaign. Retrieved July 17 2013, from from http://www.newcycling.org/
NCCAB, 2013. Cycle City Ambition Fund Bid. Newcaslte City Council. Retrieved June 02 2013, from http://www.newcastle.gov.uk/parking-roads-and-transport/cycling/cycle-city-ambition
Ned, L., 2010. CrimeStat: A Spatial Statistics Program for the Analysis of Crime Incident Locations (v 3.3), July, 2010 ed. Ned Levine & Associates, Houston, TX, and the National Institute of Justice, Washington, DC.
Nelson, T.A., Boots, B., 2008. Detecting spatial hot spots in landscape ecology. Ecography 31, 556-566.
Neutens, T., 2010. Space, time and accessibility: analyzing human activities and travel possibilities from a time-geographic perspective. Ghent University. Faculty of Sciences.
Neutens, T., Delafontaine, M., Scott, D.M., De Maeyer, P., 2012. A GIS-based method to identify spatiotemporal gaps in public service delivery. Applied Geography 32, 253-264.

Neutens, T., Van de Weghe, N., Witlox, F., De Maeyer, P., 2008. A three-dimensional network-based space–time prism. Journal of Geographical Systems 10, 89-107.
NewcastleCityCouncil, 2013a. Criteria for strategic routes. Retrieved Oct. 17 2013, from http://www.newcastle.gov.uk/sites/drupalncc.newcastle.gov.uk/files/wwwfileroot/parking-roads-and-transport/cycling/strategic_cycling_routes_criteria.doc
NewcastleCityCouncil, 2013b. Strategic cycle routes. Retrieved Oct. 16 2013, from http://www.newcastle.gov.uk/parking-roads-and-transport/cycling/strategic-cycle-routes
NHS, 2008. Physical activity and the environment - Costing report - Implementing NICE guidance, NICE public health guidance 8. Retrieved Nov. 29 2012, from http://www.nice.org.uk/nicemedia/live/11917/38990/38990.pdf
NHTS, 2001. FAQ - What is trip chaining? Retrieved March March 12 2014, from http://nhts.ornl.gov/2001/pub/tripchaining.pdf
NICE, 2012. Walking and cycling: local measures to promote walking and cycling as forms of travel or recreation, NICE public health guidance 41. Retrieved Nov. 28 2012, from http://guidance.nice.org.uk/PH41/Guidance/pdf/English
Norman, G., 2010. Likert scales, levels of measurement and the “laws” of statistics. Adv in Health Sci Educ 15, 625-632.
Northumbria, 2013. Cycling in the city, Impact Magazine, Summer 2013 ed. Northumbria University, Newcastle upon Tyne, pp. 18-19.
O'Sullivan, D., Haklay, M., 2000. Agent-based models and individualism: is the world agent-based? Environment and Planning A 32, 1409-1425.
O’Brien, O., Cheshire, J., Batty, M., 2013. Mining bicycle sharing data for generating insights into sustainable transport systems. Journal of Transport Geography(0).
Observer, 2012. Top cycling apps, The Observer.
Ogilvie, D., Bull, F., Cooper, A., Rutter, H., Adams, E., Brand, C., Ghali, K., Jones, T., Mutrie, N., Powell, J., Preston, J., Sahlqvist, S., Song, Y., 2012. Evaluating the travel, physical activity and carbon impacts of a ‘natural experiment’ in the provision of new walking and cycling infrastructure: methods for the core module of the iConnect study. BMJ Open 2.
Ogilvie, D., Bull, F., Powell, J., Cooper, A.R.P., Brand, C., Mutrie, N., Preston, J., Rutter, H., 2011. An Applied Ecological Framework for Evaluating Infrastructure to Promote Walking and Cycling: The iConnect Study. American Journal of Public Health 101, 473-481.
Ogilvie, D., Griffin, S., Jones, A., Mackett, R., Guell, C., Panter, J., Jones, N., Cohn, S., Yang, L., Chapman, C., 2010. Commuting and health in Cambridge: a study of a 'natural experiment' in the provision of new transport infrastructure. BMC Public Health 10, 703.
Ogle, J., Guensler, R., Bachman, W., Koutsak, M., Wolf, J., 2002. Accuracy of Global Positioning System for determining driver performance parameters. Transportation Research Record, 12–24.
ONS, 2008. 200 years of the census. Retrieved June 28 2011, from http://www.ons.gov.uk/census/census-history/200-yrs-census/index.html
ONS, 2009. Annual Survey of Hours and Earnings - 2009 Results. Retrieved Sept. 13 2013, from http://www.ons.gov.uk/ons/rel/ashe/annual-survey-of-hours-and-earnings/2009-revised/index.html
ONS, 2011a. 2011 Census ad-hoc tables. Retrieved Sept. 19 2013, from http://www.ons.gov.uk/ons/guide-method/census/2011/census-data/2011-census-ad-hoc-tables/index.html
ONS, 2011b. 2011 Census ad-hoc tables: CT0050 - Method of travel to work (alternative) - National to Output Areas.
ONS, 2011c. Output Areas (OA): Modification of Output Areas in England and Wales. Retrieved Sept. 18 2013, from http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/census/output-area--oas-/index.html
ONS, 2013a. Electoral Wards/Divisions. Retrieved Aug. 09 2013, from http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/administrative/england/electoral-wards-divisions/index.html
ONS, 2013b. Output Areas (OA). Retrieved July 03 2013, from http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/census/output-area--oas-/index.html
ONS, 2013c. Table CT0015EW Method of travel to work (alternative), local authorities in England and Wales, 13 February 2013 ed. ONS.

ONS, 2014. 2011 Census Analysis - Cycling to Work (Changes in cycling to work in England and Wales since 2001). Retrieved April 08 2014, from http://www.ons.gov.uk/ons/dcp171776_357613.pdf
Openshaw, S., 1984. The Modifiable Areal Unit Problem. Elsevier Science Geo Abstracts.
Orellana, D., Wachowicz, M., 2011. Exploring Patterns of Movement Suspension in Pedestrian Mobility. 行人移动停靠模式的探索性分析. Geographical Analysis 43, 241-260.
OSM, 2012. United Kingdom Tagging Guidelines. Retrieved Aug. 11 2013, from http://wiki.openstreetmap.org/wiki/UK_public_rights_of_way#Classic_vs_Alternative_tagging_schemes
Palazzo, D., Steiner, F., 2011. Urban Ecological Design: A Process for Regenerative Places. Island Press, Washington.
Paliament, 2011a. Cycling: Safety, House of Commons Hansard Written Answers for 10 Mar 2011 (pt 0001): Column 1197W.
Paliament, 2011b. Dangerous and Reckless Cycling (Offences): House of Commons Hansard Debates for 22 Mar 2011 (pt 0002). Motion for leave to bring in a Bill (Standing Order No. 23), 22 Mar 2011 : Column 875.
Pangbourne, K., Alvanides, S., 2013. Towards intelligent transport geography. Journal of Transport Geography.
Pank, P., 2013. Budget cuts put safer cycle lane project at risk, The Times. July 20 2013 Issue.
Panter, J., Griffin, S., Dalton, A.M., Ogilvie, D., 2013. Patterns and predictors of changes in active commuting over 12 months. Preventive Medicine.
Papinski, D., Scott, D.M., 2011. A GIS-based toolkit for route choice analysis. Journal of Transport Geography 19, 434-442.
Parkin, J., Wardman, M., Page, M., 2008. Estimation of the determinants of bicycle mode share for the journey to work using census data. Transportation 35, 93-109.
Patel, R.S., 2012. Statistical techniques for data analysis: basic book, to understand statistical techniques & useful for data analysis in research work for education & psychology. LAP LAMBERT Academic, Saarbrücken. Retrieved Sept. 12 2013, from http://capitadiscovery.co.uk/northumbria-ac/items/1615939
Pearson, A., 2013. Newcastle MP calls for national backing for city's cyclists, Chronicle Live. Retrieved Sept. 05 2013, from http://www.chroniclelive.co.uk/news/local-news/call-greater-cycling-support-newcastle-5837012
Peck, C., 2013. Get Britain Cycling report recommends £10 per head, per year funding for cycling. Retrieved April 23 2013, from http://www.ctc.org.uk/news/get-britain-cycling-report-recommends-%C2%A310-head-year-funding-for-cycling
Perkins, C., 2009. Mapping, Philosophy, In: Editors-in-Chief: Rob, K., Nigel, T. (Eds.), International Encyclopedia of Human Geography. Elsevier, Oxford, pp. 385-397.
Pikora, T., Giles-Corti, B., Bull, F., Jamrozik, K., Donovan, R., 2003. Developing a framework for assessment of the environmental determinants of walking and cycling. Social Science & Medicine 56, 1693-1703.
Pooley, C.G., Horton, D., Scheldeman, G., Tight, M., Jones, T., Chisholm, A., Harwatt, H., Jopson, A., 2011. Household decision-making for everyday travel: a case study of walking and cycling in Lancaster (UK). Journal of Transport Geography 19, 1601-1607.
Posselt, J., 2011. MergeTransport planning and Design of Cities:Transurban Planning, making cities for people …. Gehl Architects, Copenhagen, Denmark. Retrieved Feb. 20 2012, from http://gehlcitiesforpeople.dk/author/jogehl/
Pouliot, V., 2007. “Sobjectivism”: Toward a Constructivist Methodology. International Studies Quarterly 51, 359-384.
Prato, C.G., 2009. Route choice modeling: past, present and future research directions. Journal of Choice Modelling 2.
Pratt, C.E., 1891. A sketch of American bicycling and its founder, Outing.
Proulx, P., Canfield, C., 2013. The beneficial role of the VAST Challenges in the evolution of GeoTime and nSpace2. Information Visualization.
Pucher, J., Buehler, R., 2008. Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. Transport Reviews 28, 495-528.

Pucher, J., Buehler, R., 2012. Promoting Cycling for Daily Travel: Conclusions and Lessons from across the Globe, In: Pucher, J., Buehler, R. (Eds.), City Cycling. MIT Press, Cambridge, pp. 347-362.
Pucher, J., Dill, J., Handy, S., 2010. Infrastructure, programs, and policies to increase bicycling: An international review. Preventive Medicine 50, S106-S125.
Qstarz, 2011. Qstarz BT-Q1000XT GPS device features. Retrieved Aug. 02 2013, from http://www.qstarz.com/Products/GPS%20Products/BT-Q1000XT-F.htm
Rapoport, A., 1982. The meaning of the built environment: a nonverbal communication approach. SAGE Publications.
Rietveld, P., Daniel, V., 2004. Determinants of bicycle use: do municipal policies matter? Transportation Research Part A: Policy and Practice 38, 531-550.
RITA, 2009. Serving the nation as a leader in global multimodal transportation innovation. RITA, U.S. Department of Transport. Retrieved March 01 2011, from http://www.volpe.dot.gov/infosrc/docs/yir09.pdf
Rivas Perez, M., Hodgson, F., 2011. Travelling to work: the differing employment geographies of households in neighbourhoods of low and high deprivation in North and South Tyneside. Environment and Planning A 43, 2779-2780.
Rogers, S., 2011. Indices of multiple deprivation: find the poorest places in England. Retrieved April 01 2011, from http://www.theguardian.com/news/datablog/2011/mar/29/indices-multiple-deprivation-poverty-england
Rogerson, P.A., 2006. Statistical Methods for Geography: A Student's Guide, Second ed. SAGE Publications Ltd.
Rose, G., 1993. Feminism and geography : the limits of geographical knowledge. Polity Press, Cambridge.
Rosenshein, L., Scott, L., Pratt, M., Esri, 2011a. Exploratory Regression - A tool for modeling complex phenomena, ArcUser Winter 2011. ESRI.
Rosenshein, L., Scott, L., Pratt, M., Esri, 2011b. Finding a Meaningful Model, ArcUser Winter 2011. ESRI.
Saarloos, D., Kim, J.-E., Timmermans, H., 2009. The Built Environment and Health: Introducing Individual Space-Time Behavior. International Journal of Environmental Research and Public Health 6, 1724-1743.
Schmitter, D., Wachowicz, P., Sage, D., Chasapi, A., Xenarios, I., Simanis, V.V., Unser, M., 2013. A 2D/3D image analysis system to track fluorescently labeled structures in rod-shaped cells: application to measure spindle pole asymmetry during mitosis. Cell Division 8.
Schönfelder, S., 2006. URBAN RHYTHMS – MODELLING THE RHYTHMS OF INDIVIDUAL TRAVEL BEHAVIOUR. EIDGENÖSSISCHEN TECHNISCHEN HOCHSCHULE ZÜRICH, Zurich. Retrieved Dec. 05 2012, from http://www.ivt.ethz.ch/oev/ped2012/vpl/publications/reports/ab426.pdf
Schonfelder, S., Axhausen, K.W., 2010. Urban Rhythms and Travel Behaviour. Ashgate Publishing Limited.
Schönfelder, S., Samaga, U., 2003. Where do you want to go today? - More observations on daily mobility, 3rd Swiss Transport Research Conference, Monte Verità / Ascona, March 19-21, 2003.
Schuurman, N., 2002. Reconciling Social Constructivism and Realism in GIS. ACME: An International E-Journal for Critical Geographies 1, 73.
ScienceDaily, 2013. Cycling in the city. Retrieved May 29 2013, from http://www.sciencedaily.com/releases/2013/03/130315074518.htm
Scottish-Government, 2009. Monitoring and Evaluation of the Smarter Choices Smarter Places Programme - Baseline Report (Annex K – Kirkwall Findings). Scottish Government, Kirkwall.
Sener, I.N., Eluru, N., Bhat, C.R., 2009. An analysis of bicycle route choice preferences in Texas, US. Transportation 36, 511-539.
Shankleman, J., 2012. Boris Johnson: 'I delivered every single one of my green pledges'. Retrieved June 25 2012, from http://www.businessgreen.com/bg/interview/2171102/boris-johnson-delivered-single-green-pledges
Shephard, R., 2008. Is active commuting the answer to population health? Sports Med 38, 751 - 758.
Siddique, H., 2013. David Cameron to announce largest ever investment in cycling. Retrieved Aug. 12 2013, from http://www.theguardian.com/lifeandstyle/2013/aug/12/david-cameron-largest-investment-cycling
Silverman, B.W., 1986. Density estimation for statistics and data analysis. London: Chapman and Hall.

Simms, A., Potts, R., 2012. The New Materialism. Retrieved Oct. 11 2013, from http://www.edialogue.co.uk/upload/New_Materialism_24%2011%2012.pdf
Skinner, D., Rose, P., 2007. Hell is other Cyclist: rethinking transport and identity, In: Horton, D., Rosen, P., Cox, P. (Eds.), Cycling and Society. Ashgate Publishing Ltd, Aldershot, UK, pp. 83-96.
Sloman, L., Cavill, N., Cope, A., Muller, L., Kennedy, A., 2009. Analysis and synthesis of evidence on the effects of investment in six Cycling Demonstration Towns: Report for Department for Transport and Cycling England Department for Transport and Cycling England. Retrieved April 14 2011, from http://www.dft.gov.uk/cyclingengland/site/wp-content/uploads/2010/03/analysis-and-synthesis-report.pdf
Smith, R.C., Harkey, D.L., Harris, B., 2001. IMPLEMENTATION OF GIS-BASED HIGHWAY SAFETY ANALYSES: BRIDGING THE GAP. Retrieved Aug. 11 2012, from http://www.fhwa.dot.gov/publications/research/safety/1039.pdf
Snizek, B., Sick Nielsen, T.A., Skov-Petersen, H., 2013. Mapping bicyclists' experiences in Copenhagen. Journal of Transport Geography, 30(0), 227-233.
Snizek, B., Skov-Petersen, H., Alexander Sick Nielsen, T., Yeboah, G., van de Weghe, N., forthcoming. copenhagenABM: An Agent Based Model of Bicyclists' Experiences. Journal of Transport Geography.
Speisser, N., Stopher, P.R., 2011. Evaluation of GPS Device Properties for a Possible Use in Future Household Travel Surveys (Poster), 90th Annual Meeting of the Transportation Research Board TRB 2011, Washington, D.C., United States.
Spinney, J., 2009. Cycling the City: Movement, Meaning and Method. Geography Compass 3, 817-835.
Spokes, 2013. Cycle campaigns – Scotland. Retrieved July 17 2013, from http://www.spokes.org.uk/wordpress/links/cycle-campaigns-scotland-uk-international/
Stewart, H., 2012. Olympics 2012 marketing hype poses the question: how much is enough? Retrieved June 25 2012, from http://www.guardian.co.uk/business/2012/jun/10/olympics-2012-marketing-capitalism
Stinson, M.A., Bhat, C.R., 2004. Frequency of Bicycle Commuting: Internet-Based Survey Analysis. Transportation Research Record, 122-130.
Stopher, P., Bullock, P., Jiang, Q., 2002. GPS, GIS and personal travel surveys: an exercise in visualisation, 25th Australian Transport Research Forum Incorporating the BTRE Transport Policy Colloquium, Canberra, Australia. Retrieved March 08 2011, from http://www.patrec.org/web_docs/atrf/papers/2002/1390_Stopher,%20Bullock%20&%20Jiang%20(2002).pdf
Stopher, P., Clifford, E., Swann, N., Zhang, Y., 2009. Evaluating voluntary travel behaviour change: Suggested guidelines and case studies. Transport Policy 16, 315-324.
Stopher, P., FitzGerald, C., Zhang, J., 2008a. Search for a global positioning system device to measure person travel. Transportation Research Part C: Emerging Technologies 16, 350-369.
Stopher, P., Kockelman, K., Greaves, S., Clifford, E., 2008b. Reducing Burden and Sample Sizes in Multiday Household Travel Surveys. Transportation Research Record: Journal of the Transportation Research Board 2064, 12-18.
Stopher, P., Prasad, C., Zhang, J., 2010a. CAN GPS REPLACE CONVENTIONAL TRAVEL SURVEYS? SOME FINDINGS Australasian Transport Research Forum Canberra, Australia. Retrieved March 08 2011, from Retrieved from http://www.patrec.org/web_docs/atrf/papers/2010/1940_034%20-%20Stopher%20Prasad%20Zhang.pdf
Stopher, P., Prasad, C., Zhang, J., 2010b. Comparing GPS and prompted recall data records Working Papers 2010. Institute of Transport and Logistics Studies, Sydney. Retrieved March 09 2011, from http://sydney.edu.au/business/__data/assets/pdf_file/0007/86713/itls-wp-10-24.pdf
Stopher, P., Swann, N., FitzGerald, C., 2007. Using an Odometer and a GPS Panel to Evaluate Travel Behaviour Changes, 11th TRB National Transportation Planning Applications Conference, Daytona Beach, Florida.
Stopher, P.R., 1998. A review of separate and joint strategies for the use of data on revealed and stated choices. Transportation 25, 187-205.
Stopher, P.R., Speisser, N., 2011. Evaluation of GPS Device Properties for a Possible Use in Future Household Travel Surveys, 90th Annual Meeting of the Transportation Research Board TRB 2011, Washington, D.C., United States.

Susilo, Y.O., Williams, K., Lindsay, M., Dair, C., 2012. The influence of individuals' environmental attitudes and urban design features on their travel patterns in sustainable neighborhoods in the UK. Transportation Research Part D: Transport and Environment 17, 190-200.
Sustrans, 2011. About Sustrans. Retrieved July 29 2013, from http://www.sustrans.org.uk/about-sustrans
Tang, Y., Ye, X., Tang, N., 2010. Temporal Information Processing Technology and Its Applications. Springer.
Tashakkori, A., Teddlie, C., 1998. Mixed methodology: combining qualitative and quantitative approaches. Sage, London.
Taylor, D., Mahmassani, H., 2000. Coordinating Traffic Signals for Bicycle Progression. Transportation Research Record: Journal of the Transportation Research Board 1705, 85-92.
Taylor, E., Humphrey, A., Pickering, K., Tipping, S., 2013. National Travel Survey 2012: Technical Report. Retrieved July 31 2013, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/49692/nts2012-technical.pdf
Taylor, M.A.P., 2007. Voluntary Travel Behavior Change Programs in Australia: The Carrot Rather Than the Stick in Travel Demand Management. International Journal of Sustainable Transportation 1, 173 - 192.
Taylor, M.A.P., Ampt, E.S., 2003. Travelling smarter down under: policies for voluntary travel behaviour change in Australia. Transport Policy 10, 165-177.
Thierry, B., Chaix, B., Kestens, Y., 2013. Detecting activity locations from raw GPS data: a novel kernel-based algorithm. International Journal of Health Geographics 12, 14.
Thomas, J.J., Cook, K.A., 2006. A visual analytics agenda. Computer Graphics and Applications, IEEE 26, 10-13.
Thornton, L., Pearce, J., Kavanagh, A., 2011. Using Geographic Information Systems (GIS) to assess the role of the built environment in influencing obesity: a glossary. International Journal of Behavioral Nutrition and Physical Activity 8, 71.
Tight, M., Timms, P., Banister, D., Bowmaker, J., Copas, J., Day, A., Drinkwater, D., Givoni, M., Gühnemann, A., Lawler, M., Macmillen, J., Miles, A., Moore, N., Newton, R., Ngoduy, D., Ormerod, M., O'Sullivan, M., Watling, D., 2011. Visions for a walking and cycling focussed urban transport system. Journal of Transport Geography 19, 1580-1589.
Tilahun, N.Y., Levinson, D.M., Krizek, K.J., 2007. Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. Transportation Research Part A: Policy and Practice 41, 287-301.
Timmermans, H., Arentze, T., Joh, C.-H., 2002. Analysing space-time behaviour: newapproaches to old problems. Progress in Human Geography 26, 175–190.
Tin Tin, S., Woodward, A., Thornley, S., Langley, J., Rodgers, A., Ameratunga, S., 2010. Cyclists' attitudes toward policies encouraging bicycle travel: findings from the Taupo Bicycle Study in New Zealand. Health Promotion International 25, 54-62.
Todd, N., 2011. Delivering Cycling Improvements in Newcastle A ten year strategy 2011-22. Retrieved Feb. 14 2012, from http://www.newcastle.gov.uk/sites/drupalncc.newcastle.gov.uk/files/wwwfileroot/parking-roads-and-transport/cycling/newcastle_cycling_strategy_2011.pdf
Tomaszewski, B., Maceachren, A.M., 2010. Geo-Historical Context Support for Information Foraging and Sensemaking: Conceptual Model, Implementation, and Assessment, IEEE Conference on Visual Analytics Science and Technology (IEEE VAST 2010), pp. 139-146.
Torjman, S., 2005. What is Policy? Caledon Institute of Social Policy, Ottawa, Ontario, Canada.
Triggle, N., 2012. Cycle and walking 'must be norm' for short journeys. Retrieved Nov. 28 2012, from http://www.bbc.co.uk/news/health-20499005
TWITA, 2011. Press release – Tyne and Wear wins £4.9m for active and sustainable travel initiatives. Retrieved July 29 2013, from http://www.tyneandwearltp.gov.uk/congestion/successful-bid-to-lstf/
TWJTWG, 2011. The Tyne & Wear Household Travel Survey 2003 to 2011. Tyne and Wear Joint Transport Working Group (TWJTWG), Newcastle-upon-Tyne.
TWLTP, 2006. Tyne and Wear Household Travel Survey. Retrieved Aug. 02 2013, from http://s3.amazonaws.com/zanran_storage/www.newcastle.gov.uk/ContentPages/18656453.pdf

UNECE, 1993. Convention on Road Traffic of 8 November 1968, incorporating the amendments to the Convention which entered into force on 3 September 1993. Inland Transport Committee of the United Nations Economic Commission for Europe UNECE, Geneva. Retrieved Oct. 27 2013, from Retrieved from http://www.unece.org/fileadmin/DAM/trans/conventn/crt1968e.pdf

UNSW, 2012. Four is the 'magic' number. ScienceDaily. Retrieved Oct. 23 2013, from http://www.sciencedaily.com/releases/2012/11/121128093930.htm

Van der Spek, S., Van Schaick, J., De Bois, P., De Haan, R., 2009. Sensing Human Activity: GPS Tracking. Sensors 9, 3033-3055.

Van Dyck, D., Deforche, B., Cardon, G., De Bourdeaudhuij, I., 2009. Neighbourhood walkability and its particular importance for adults with a preference for passive transport. Health & Place 15, 496-504.

Verplanken, B., Melkevik, O., 2008. Predicting habit: The case of physical exercise. Psychology of Sport and Exercise 9, 15-26.

Verplanken, B., Orbell, S., 2003. Reflections on Past Behavior: A Self-Report Index of Habit Strength1. Journal of Applied Social Psychology 33, 1313-1330.

Vrotsou, K., Coooper, M., 2006. Interactive visual exploration of time-use data (Poster), 10th International Conference on Information Visualisation (IV'06), July 5-7, 2006. Linköping University, London, UK. Retrieved April 29 2014, from http://webstaff.itn.liu.se/~katvr62/IV06-Poster-Vrotsou-A4.pdf

Wagner, D.P., 1997. Global Positioning Systems for Personal Travel Surveys. Lexington Area Travel Data Collection Test: FINAL REPORT, Columbus, Ohio. Retrieved March 08 2011, from http://www.fhwa.dot.gov/ohim/lextrav.pdf

Wahlgren, L., Schantz, P., 2011. Bikeability and methodological issues using the active commuting route environment scale (ACRES) in a metropolitan setting. BMC Medical Research Methodology 11, 6.

Walker, P., 2013a. David Cameron's 'cycling revolution' is barely off the starting blocks. Retrieved Aug. 14 2013, from http://www.theguardian.com/environment/bike-blog/2013/aug/12/david-cameron-cycling-revolution-investment

Walker, P., 2013b. Despair, cyclists: Britain will not be a 'cycling nation' in your lifetime. Retrieved Sept. 02 2013, from http://www.theguardian.com/environment/bike-blog/2013/aug/30/government-cycling-policy-failed

Warburton, D., 2011. Tyneside street speed limits curbed at 20mph. Retrieved Aug. 03 2013, from http://www.chroniclelive.co.uk/news/north-east-news/tyneside-street-speed-limits-curbed-1408382

Weber, J., Kwan, M.-P., 2003. Evaluating the Effects of Geographic Contexts on Individual Accessibility: A Multilevel Approach. Urban Geography 24, 647-671.

Wells, H.G., 1896. The Wheels of Chance - A Bicycling Idyll. Breakaway Books, New York.

WEO, 2011. World Energy Outlook 2011. Retrieved July 29 2013, from http://www.worldenergyoutlook.org/

Westcott, R., 2013. Cycling gets £94m push in England. Retrieved Aug. 12 2013, from http://www.bbc.co.uk/news/uk-23657010

Whitehorn, K., 2013. Why we need more cycle lanes. Retrieved October 29 2013, from http://www.theguardian.com/lifeandstyle/2013/oct/27/why-we-need-more-cycle-lanes

Wilson, A.G., 1974. Urban and regional models in geography and planning. John Wiley and Sons, London.

Wilson, A.G., 1981. Geography an the environment; Systems analytical methods. John Wiley and Sons (Wiley-Interscience), London.

Wilson, A.M., Lowe, J.C., Roskilly, K., Hudson, P.E., Golabek, K.A., McNutt, J.W., 2013. Locomotion dynamics of hunting in wild cheetahs. Nature 498, 185-189.

Wilson, M.W., 2013. Geospatial technologies in the location-aware future. Journal of Transport Geography.

Winters, M., Brauer, M., Setton, E., Teschke, K., 2010. Built Environment Influences on Healthy Transportation Choices: Bicycling versus Driving. Journal of Urban Health 87, 969-993.

Winters, M., Brauer, M., Setton, E.M., Teschke, K., 2013. Mapping bikeability: a spatial tool to support sustainable travel. Environment and Planning B: Planning and Design 40, 865-883.

Winters, M., Davidson, G., Kao, D., Teschke, K., 2011. Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transportation 38, 153-168.

Witten, K., Pearce, J., Day, P., 2011. Neighbourhood Destination Accessibility Index: a GIS tool for measuring infrastructure support for neighbourhood physical activity. Environment and Planning A 43, 205-223.

Wood, Z., 2012. Olympics fever will help to make 2012 the year of the bike, The Observer, 29th Jan. 2012 Issue, 21-22.
Woodforde, J., 1970. The Story of the Bicycle. Routledge & Kegan Paul Limited, London.
Xie, Z., Yan, J., 2008. Kernel Density Estimation of Traffic Accidents in a Network Space. Computers, Environment and Urban Systems 35, 396-406.
Yang, J., French, S., 2013. The travel - obesity connection: discerning the impacts of commuting trips with the perspective of individual energy expenditure and time use. Environment and Planning B: Planning and Design 40, 617-629.
Yano, K., 2000. GIS and quantitative geography. GeoJournal 52, 173-180.
Yeboah, G., 2012a. Exploring Agent-based modelling technique for cycle track modelling. European Union MOVE COST Grant ID: ECOST-STSM-IC0903-051112-023655-23655. University of Copenhagen, Denmark.
Yeboah, G., 2012b. Space cube as a data processing tool - a visual approach to gps data processing, EU MOVE-COST WG4 Workshop on Analysis and visualization of movement data. What can the Space-Time-Cube do for you?, University of Twente, Netherlands.
Yeboah, G., 2013. Everyday cycling in urban environments: Understanding behaviours and constraints in space-time, SET for BRITAIN Engineering Exhibition 2013, Terrace Marquee, House of Commons at UK Paliament.
Yeboah, G., Alvanides, S., 2013. Everyday cycling in urban environments: Understanding behaviours and constraints in space-time, GIS Research UK 2013 Conference, University of Liverpool, UK.
Yeboah, G., Alvanides, S., Emine, M.T., in press. Everyday cycling in urban environments: Understanding behaviours and constraints in space-time, In: Helbich, M., Jokar Arsanjani, J., Leitner, M. (Eds.), Computational Approaches for Urban Environments. Geotechnologies and the Environment. Springer, New York.
Yeboah, G., Alvanides, S., Thompson, E.M., 2012. Methodological perspective on understanding cycling behaviours of commuters, Cycling and Society Symposium 2012, University of East London Stratford Campus, UK. Retrieved Oct. 01 2012, from http://www.cyclingcultures.org.uk/C&S12/posters/Yeboah-poster.pdf
Yiannakoulias, N., Bennet, S.A., Scott, D.M., 2012. Mapping commuter cycling risk in urban areas. Accident Analysis & Prevention 45, 164-172.
Zhao, P., 2013. The Impact of the Built Environment on Bicycle Commuting: Evidence from Beijing. Urban Studies.

APPENDICES

Appendix A: Sample of Questionnaire for Individual Participants

Questionnaire for Individual Participants

In Confidence

Everyday Cycling (Travel) Survey

(You are helping towards understanding cycling in the city of Newcastle upon Tyne)

This questionnaire has pass through rigorous check by the Research Committee of Northumbria University. The purpose is strictly for research.

Please use black or blue ink if possible

Thank you very much for your help

Given ID:	**1110XT11500997**	
Travel week	Start day:	Finish day:
	Start date:	Finish date:
Interviewer / contact person:	Will call again on	
	Day:	Day:
	Date:	Date:
	Time:	Time:

Table 1: Things to remember when filling the questionnaire – form

<table>
<tr>
<td>A
What was the purpose of your journey?
Please give a simple description such as “to eat” which will mean selecting and circling the number eight (8). If it is nine, state the purpose in the box. <u>To:</u>
1=Work; 2=Visit(friends,family,.); 3=Work related task; 4=Food shopping; 5=Non-food shopping; 6=School(Student);
7=Entertainment (e.g. cinema, disco, etc.);
8=Eat (Lunch, drink,..)
9=Home; 10= Other (specify; e.g. sports, leisure, etc.). Sports=competitive cycling etc.</td>
<td>B/C
What time did you leave/arrive?
Write in hours and minutes (e.g. 9.15). Please tick am or pm to show the time of day.</td>
<td>D/E
Where did you start/go to? (Tick “Home” or give the name of the village, town or area but commonly identifiable by third person)
Please write down the name of the place where your journey started and finished. If this was a large town or city give the name of the area. If you went to a shopping centre or visitor attraction please tell us its name. Please be as precise as possible. If you journey started or finished at home, you only need to tick “Home”.</td>
<td>F
What method of travel did you use for each stage of your journey?
Use a different line for the method of travel you used at each stage of your journey (e.g. bike, car = 1,4) by using the numbers:
1=Bike; 2=Walk; 3=Taxi; 4=Train; 5=Bus;
6=Car; 7=Other (specify)</td>
<td>G
How far did you travel? (Miles)
Please give us the distance you travelled in miles or metres (e.g. 3 miles, 0.5 miles, 300 metres).</td>
</tr>
<tr>
<td>H
How long did you spend travelling? (Minutes)
Please note the amount of time you spent travelling and do not include any time you spent waiting for public transport.</td>
<td>I
How many people travelled including you?
Please write in the number of people, including yourself, who set out together. Only include people who were with you for at least half the distance of your journey.</td>
<td>J
Where did you lock your bike?
Please tell us where you locked you bike:
1=Safe place
2=Unsafe place
3=Inside my house / a house
4=An enclosed storage facility
5=A bike rack
6=Locked and walked to destination
7=Other(specify

You can list numbers as many as applicable separated by commas.For example: 1, 3 (which means you locked the bike in a safe place which is inside your house or a house)</td>
<td>K
How would you describe the journey? Write down letters (one or more separated by comers) as you see appropriate. The options are:
1=Took shortest route known
2=Uncertain of cycling routes
3=Unsafe (heavy traffic)
4=Safe and enjoyed it
5=Used a map as an aid
6=Bad weather
7=Attractive green vegetation
8=GPS charged before trip
9=Other (specify)</td>
<td>L
Which care or other motor vehicle did you use?
Please tell us which vehicle was used if it belongs to your household (e.g. Toyota). If you travelled in someone else’s vehicle, please tell us that (e.g. friend’s car).</td>
</tr>
<tr>
<td>M
Where you the driver (D) or a passenger (P)?
Please tick “D” if you were the driver or “P” if you were the passenger of the vehicle.</td>
<td>N
How much did you pay for parking?
Enter how much you paid for parking. Please tick the box marked “Nil” if you did not pay anything.</td>
<td>O
How much did you pay for road tolls/congestion charges?
Please tell us the amount you paid for road tolls or congestion charges. Tick the box marked “Nil” if you did not pay any charges. If you are exempted from charges please write in “Exempt”.</td>
<td>P
What type of ticket did you use?
Write here the type of ticked you used. Tell us if it was a single, a return, a season ticket or a one day travelcard. If you used an oyster card please tell us whether it was a pre-pay or a season ticket.</td>
<td>Q
How much did you ticket cost?
Please tell us the amount you actually paid. If your journey was covered by a season ticket, tick/enter “Nil”. If you bought a return ticket or travel card write the total amount next to the first journey you used it for.</td>
</tr>
<tr>
<td colspan="3">R
How many times did you board?
Write here the number of different trains or buses you used at each stage of your journey (e.g. if you used two separate buses enter “2”)</td>
<td colspan="2">S
How much did your share of the taxi cost?
Enter the amount you paid for your share of the taxi fare. Tick/enter “Nil” if you paid nothing.</td>
</tr>
<tr>
<td colspan="5">T
Why did you change your travel mode in journey 1, 2, 3, 4, 5, etc.?
Circle the numbers assigned - as many as applicable: 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; 7=other specify: e.g N/A
Note: If you, for example, bicycled in Journey 1 but walked in Journey 2, you may choose to answer question T for Journey 2 as “1” being “1=short distance”</td>
</tr>
</table>

Table 2: Questionnaire to be filled by participant

DAY (1, 2, 3, ... 7):............... Mon Tues Wed Thur Fri Sat Sun Date: .... Given ID:.........................1110XT11500997......................................

STAGES – These columns are for entering details of each stage of your journey. Help with filling form – see notes.

JOURNEYS – Please record each journey on a new row. Include very short ones and return journeys. Include all **bike journeys and other travel mode journeys over 100m**.												**Only** fill in these columns if you used a CAR or OTHER MOTOR VEHICLES				**Only** fill in these columns if you used **PUBLIC TRANSPORT**			**Only** fill in these columns if you used a TAXI
A What was the purpose of journey? **To:** **1**=Work **2**=Visit (friends, etc..) **3**=Work related task **4**=Food shopping **5**=Non-food shopping **6**=School(Student) **7**=Entertainment **8**=Eat (Lunch, etc.) **9**=Home **10**=Other (specify; e.g. sports, bank,etc.)	**B** What time did you leave?	**C** What time did you arrive?	**D** Where did you start your journey? (Tick Home or give the name of building or identifiable name with postcode)	**E** Where did you go to? (Tick Home or give the name of building or identifiable name with postcode)	**stage**	**F** What mode of travel did you use for each stage of your journey? **1**=Bike **2**=Walk **3**=Taxi **4**=Train **5**=Bus **6**=Car **7**=Other (specify)	**G** How far did you travel? (Km)	**H** How long did you spend travelling? (Minutes)	**I** How many people travelled including you?	**J** Where did you lock your bike? **1**=Safe place **2**=Unsafe place **3**=Inside my house / a house **4**=An enclosed storage facility **5**=A bike rack **6**=Locked and walked to destination **7**=Other(specify)	**K** How would you describe the journey? **1**=Took shortest route known **2**=Uncertain of cycling routes **3**=Unsafe (heavy traffic) **4**=Safe and enjoyed it **5**=Used a map as an aid **6**=Bad weather **7**=Attractive green vegetation **8**=GPS charged before trip **9**=Other (specify)	**L** Which car or other motor vehicle did you use? (e.g. Toyota or friend's car)	**M** Were you the driver (D) or a passenger (P)?	**N** How much did you pay for parking? (£)	**O** How much did you pay for road tolls / congestion charges?	**P** What type of ticket did you use? **1**=single/ one way **2**=return **3**=season ticket **4**=1 day **5**=Oyster **6**=Nexus **7**=Other (specify)	**Q** How much did your ticket cost? (£)	**R** How many times did you board?	**S** How much did your share of the taxi cost?
Journey 1	Time ☐am ☐pm	Time ☐am ☐pm	☐Home	☐Home	1								☐ D ☐P						
					2								☐ D ☐P						
					3								☐ D ☐P						
T Why did you change your travel mode in journey 1? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; 7=other specify:																			
Journey 2	Time ☐am ☐pm	Time ☐am ☐pm	☐Home	☐Home	1								☐ D ☐P						
					2								☐ D ☐P						
					3								☐ D ☐P						
T Why did you change your travel mode in journey 2? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; 7=other specify:																			
Journey 3	Time ☐am ☐pm	Time ☐am ☐pm	☐Home	☐Home	1								☐ D ☐P						
					2								☐ D ☐P						
					3								☐ D ☐P						
T Why did you change your travel mode in journey 3? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; 7=other specify:																			
Journey 4	Time ☐am ☐pm	Time ☐am ☐pm	☐Home	☐Home	1								☐ D ☐P						
					2								☐ D ☐P						
					3								☐ D ☐P						
T Why did you change your travel mode in journey 4? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; 7=other specify:																			
Journey 5	Time ☐am ☐pm	Time ☐am ☐pm	☐Home	☐Home	1								☐ D ☐P						
					2								☐ D ☐P						
					3								☐ D ☐P						
T Why did you change your travel mode in **journey 5**? (*circle as applicable*): **1**=short distance; **2**=long distance; **3**=No bike racks at destination; **4**=dangerous to cycle; **5**=group pressure; **6**=tired; **7**=other specify:																			
Use this space for anything else you want to tell us->																Extra journeys add more sheets / contact researcher			

FORM A:
PLEASE FILL THIS FORM IN ADDITION TO THE DAILY TRIP DATA COLLECTION
(Given ID: 1110XT11500997)

Question 1:
Is the GPS device easy to use? (Circle one of these): Yes or No.

Please indicate any problem you encountered using the GPS device or filling the questionnaire (including this form):
____
____

Question 2:
What aids do you often use to assist you in knowing your travel routes?
A) Google maps on my phone
B) Other (Specify): ____

Question 3:
Do you think the maps (to be shown by the researcher) as show by the GPS device confirms your trips for the data collection week? Circle one of these: Yes or No.

Question 4:
Do you own any of the following items? Tick as applicable: ☐Bike ☐Car
If you ticked bike, what **type** of bike and **how many bikes** are in your household?
(Please circle or give details):
Type of bike: Hybird, Road, MTB, BMX, or details:__________________________
Number of bicycles in your household:__________________________________

Question 5:
In your view will Oyster card be relevant in Tyne & Wear?? Or is it a NEXUS card?
(Circle one or both and give your reason for your selection)
1. Oyster card will be relevant in Tyne & Wear
2. NEXUS card is relevant in Tyne & Wear
3. ***Your reason:***

____
____

Question 6:
Your current relationship status (circle all that apply):
Single MarriedOther (describe) ___________________________

Question 7:
Would you like us to contact you again for a similar one week travel survey or an online survey? Yes or No

Question 8:
How is your health in general? Circle any one of these:
1. Very good 2. Good 3. Fair 4.Bad 5.Very bad

(PLEASE TURN OVER)

FORM A: (Given ID: 1110XT11500997)

Question 9:
What is your year of birth? (Please specify, for example 1948):_________________

Question 10:
To which of the following groups do you consider you belong? (please select one only)

- White – British, Irish or any other White background
- Asian or Asian British or Any other Asian background
- Mixed – White & Black or Any other Mixed background
- Other ethnic group (Please specify): ___________________
- Black or Black British – Caribbean, African & Any other Black background

Question 11:
Which of these activities best describes what you are doing at present? (please select one only)

- Employee in full-time job (30 hours or more a week)
- Full-time education at school, college or university
- Employee in part-time job (under 30 hours a week)
- On a government supported training programme (e.g. Modern Apprenticeship/Training for Work)
- Self-employed, full or part-time
- Doing something else (Please specify): _______________________

Question 12:

What is your current annual household income (gross)?

- Low income (Under £10,000)
- Medium income (£10,000 - £30,000)
- High income (Above £30,000)

Question 13:
What is your height (in metres) and weight (in kg)?: Height(m):_____Weight(kg):_____

Question 14:
How long (in years) have you been cycling? _____________ years.

Question 15:
Do you have anything to share with me regarding this survey? If so please comment below:
:

<u>FORM B</u>: Environment, attitude, behaviour, norm, intention, and habit. (Neighbourhood definition: domain of bicycling activities). Given ID: 1110XT11500997

Availability and use of sidewalks / pavements / footpaths

♉ There are sidewalks/pavements/footpaths on most of the streets in my neighbourhood.
Underline only one: Strongly disagree / disagree / neutral / agree / strongly agree

♉ I often cycle using the sidewalks/pavements/footpaths.
Underline only one: Strongly disagree / disagree / neutral / agree / strongly agree

Availability of bicycle lanes and signs

♉ There are bicycle lanes on most of the streets in my neighbourhood.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

♉ It is safe to ride a bicycle in or near my neighbourhood.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

♉ I often see traffic signage for cycling in my neighbourhood.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

Perceived safety from traffic

♉ There is so much traffic along the street I live on or nearby that it makes it difficult or unpleasant to bicycle in my neighbourhood.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

♉ The speed of traffic on the street I live on nearby is usually slow (20 mile per h or 32 km/h or less).
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

♉ Most drivers exceed the posted speed limits while driving in my neighbourhood.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

♉ When cycling in my neighbourhood, there are a lot of exhaust fumes (such as from cars, buses).
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

Connectivity

♉ The street design in my neighbourhood has few, if any, dead ends of cycling paths.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

♉ There are many four-way road intersections in my neighbourhood.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

Residential density

♉ How common is each type of residence listed below in your immediate neighbourhood?

Detached single-family residence
Underline only one: None / some / a lot

Row house (terrace, linked house or townhouse)
Underline only one: None / some / a lot

Apartment
Underline only one: None / some / a lot

Diversity

♉ About how long would it take to get from your home to the nearest businesses or facilities listed below if you are to cycle to them?
List of facilities in mind: grocery store, shopping centre, post office, library, bank/credit union, video store, bus stop, work, school

Underline only one: 1-5 / 6-10 / 11-20 / 21-30 / >30 minutes

Time in the neighbourhood

♉ How long have you lived in your current neighbourhood?
Underline only one: ≤ 3months / 4-12 months / > 1 year

For commuting

♉ In the past 4 weeks, how many times (for a period of at least 10 minutes) did you walk to get to your workplace or your school?
Underline only one: about 10% / 20% / 30% / 40% / 50% / 60% / 70% / 80% / 90% / 100%

♉ In the past 4 weeks, how many times (for a period of at least 10 minutes) did you bicycle to get to your workplace or your school?
Underline only one: about 10% / 20% / 30% / 40% / 50% / 60% / 70% / 80% / 90% / 100%

(PLEASE TURN OVER)

<u>FORM B</u>: Please answer the questions whilst thinking of the period of your participation.
ID: 1110XT11500997

Attitude

♉ For me, to regularly cycle would be…
Underline only one: Very unsatisfying / unsatisfying / neutral / satisfying / very satisfying
Underline only one: Very tiring / tiring / neutral / energising / very energising
Underline only one: Very unpleasant / unpleasant / neutral / pleasant / very pleasant
Underline only one: Very disadvantageous / disadvantageous / neutral / advantageous / very advantageous
Underline only one: Very useless / useless / neutral/ useful / very useful

Subjective norm

♉ If I was to use bicycle regularly, most of the people who are important to me would…
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
♉ Most of the people who are important to me would recommend that I use bicycle on a regular basis.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
♉ The people who are most important to me think I should use bicycle on regular basis.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

Perceived behavioural control

♉ I think I am able to cycle on a regular basis.
Underline only one: Strongly disagree / disagree / neutral / agree / strongly agree
♉ It is up to me to cycle on a regular basis.
Underline only one: Strongly disagree / disagree / neutral / agree / strongly agree
♉ For me, regular use of bicycle would be…
Underline only one: Very difficult / difficult/ neutral / easy / very easy
♉ If I wanted, I could cycle on regular basis.
Underline only one: Very unlikely / unlikely / neutral / likely/ very likely

Intention

♉ I intend to cycle on a regular basis.
Underline only one: Very unlikely / unlikely / neutral / likely/ very likely
♉ I will try to cycle on a regular basis.
Underline only one: Very unlikely / unlikely / neutral / likely/ very likely
♉ I will cycle on a regular basis.
Underline only one: Very unlikely / unlikely / neutral / likely/ very likely

Habits

♉ Using bicycle to commute is something:
– I do frequently.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– I do automatically.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– I do without having to consciously remember.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– that makes me feel weird if I do not do it.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– that would require effort not to do it.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– that belongs to my daily routine.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– I start doing before I realize I'm doing it.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– I would find hard not to do.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– I have no need to think about doing.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– that is typically "me".
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree
– I have been doing for a long time.
Underline only one: Strongly disagree / disagree / neutral /agree / strongly agree

FILLED QUESTIONNAIRE SAMPLE

DAY (1, 2, 3, ... 7): 3 Mon Tues Wed (Thur) Fri Sat Sun Date: AUGUST 29 2011 Given ID: 2210XT11500966

STAGES – These columns are for entering details of each stage of your journey. Help with filling form – see notes.

JOURNEYS – Please record each journey on a new row. Include very short ones and return journeys. Include all bike journeys and other travel mode journeys over 100m.												Only fill in these columns if you used a CAR or OTHER MOTOR VEHICLES				Only fill in these columns if you used PUBLIC TRANSPORT			Only fill in these columns if you used a TAXI
A What was the purpose of journey? To: 1=Work 2=Visit (friends, etc.) 3=Work related task 4=Food shopping 5=Non-food shopping 6=School(Student) 7=Entertainment 8=Eat (Lunch, etc.) 9=Home 10=Other (specify; e.g. sports, bank,etc)	B What time did you leave?	C What time did you arrive?	D Where did you start your journey? (Tick Home or give the name of building or identifiable name with postcode)	E Where did you go to? (Tick Home or give the name of building or identifiable name with postcode)	stage	F What mode of travel did you use for each stage of your journey? 1=Bike 2=Walk 3=Taxi 4=Train 5=Bus 6=Car 7=Other (specify)	G How far did you travel? (Km)	H How long did you spend travelling? (Minutes)	I How many people travelled including you?	J Where did you lock your bike? 1=Safe place 2=Unsafe place 3=Inside my house / a house 4=An enclosed storage facility 5=A bike rack 6=Locked and walked to destination 7=Other(specify)	K How would you describe the journey? 1=Took shortest route known 2=Uncertain of cycling routes 3=Unsafe (heavy traffic) 4=Safe and enjoyed it 5=Used a map as an aid 6=Poor Air Quality 7=Attractive green vegetation 8=GPS charged before trip 9=Other (specify)	L Which car or other motor vehicle did you use?	M Were you the driver (D) or a passenger (P)?	N How much did you pay for parking? (£)	O How much did you pay for road tolls / congestion charges?	P What type of ticket did you use? 1=single/ one way 2=return 3=season ticket 4=1 day 5=Oyster 6=Nexus 7=Other (specify)	Q How much did your ticket cost? (£)	R How many times did you board?	S How much did your share of the taxi cost?
Journey 1 1	Time 9:52 ☑am ☐pm	Time 10:10 ☑am ☐pm	☑Home 29 Grosvenor Place NE2 2RD	☐Home Wynne Jones Building NE1 8ST	1	1	5	18	1	1,5			☐D ☐P						
					2								☐D ☐P						
					3								☐D ☐P						
T Why did you change your travel mode in journey 1? (circle as applicable): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; (7)=other specify: N/A																			
Journey 2 3	Time 10:30 ☑am ☐pm	Time 10:40 ☑am ☐pm	☐Home Wynne Jones Building NE1 8ST	☐Home Northumberland Building NE1 8ST	1	2	0.4	10	1	7(N/A)	1,4		☐D ☐P						
					2								☐D ☐P						
					3								☐D ☐P						
T Why did you change your travel mode in journey 2? (circle as applicable): (1)=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; 7=other specify:																			
Journey 3 1	Time 10:45 ☑am ☐pm	Time 10:54 ☑am ☐pm	☐Home Northumberland Building, NE1 8ST	☐Home Wynne Jones Building, NE1 8ST	1	2	0.4	9	1	7(N/A)	1,4		☐D ☐P						
					2								☐D ☐P						
					3								☐D ☐P						
T Why did you change your travel mode in journey 3? (circle as applicable): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; (7)=other specify: N/A																			
Journey 4 10 (Bank)	Time 11:00 ☑am ☐pm	Time 11:08 ☑am ☐pm	☐Home Wynne Jones Building, NE1 8ST	☐Home Lloyds, Haymarket	1	1	2	8	1	1,5,6	1,4		☐D ☐P						
					2								☐D ☐P						
					3								☐D ☐P						
T Why did you change your travel mode in journey 4? (circle as applicable): 1=short distance; (2)=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; 7=other specify:																			
Journey 5 1	Time 11:18 ☑am ☐pm	Time 11:27 ☑am ☐pm	☐Home Lloyds, Haymarket	☐Home Wynne Jones Building, NE1 8ST	1	1	2	9	1	1,5	1,4		☐D ☐P						
					2								☐D ☐P						
					3								☐D ☐P						
T Why did you change your travel mode in journey 5? (circle as applicable): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; (7)=other specify: N/A																			
Use this space for anything else you want to tell us->	see back page for continuation																	Extra journeys add more sheets / contact researcher	

Table 2: Questionnaire to be filled by participant

3

FILLED QUESTIONNAIRE SAMPLE

DAY (1, 2, 3, ... 7):......3...... Mon Tues Wed (Thur) Fri Sat Sun Date: ....AUGUST 29 2011.... Given ID:.......... 2210XT11500966

STAGES – These columns are for entering details of each stage of your journey. Help with filling form – see notes.

JOURNEYS – Please record each journey on a new row. Include very short ones and return journeys. Include all **bike journeys and other travel mode journeys over 100m.**

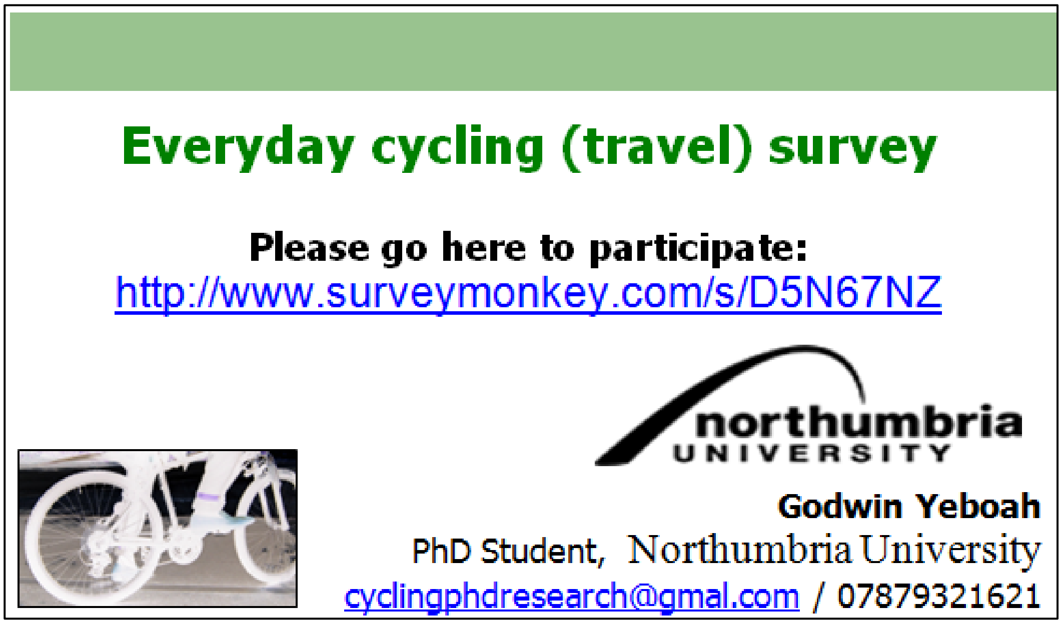
A What was the purpose of journey? To: 1=Work 2=Visit (friends, etc.) 3=Work related task 4=Food shopping 5=Non-food shopping 6=School(Student) 7=Entertainment 8=Eat (Lunch, etc.) 9=Home 10=Other (specify; e.g. sports, bank,etc)	B What time did you leave?	C What time did you arrive?	D Where did you start your journey? (Tick Home or give the name of building or identifiable name with postcode)	E Where did you go to? (Tick Home or give the name of building or identifiable name with postcode)	stage	F What mode of travel did you use for each stage of your journey? 1=Bike 2=Walk 3=Taxi 4=Train 5=Bus 6=Car 7=Other (specify)	G How far did you travel? (Km)	H How long did you spend travelling? (Minutes)	I How many people travelled including you?	J Where did you lock your bike? 1=Safe place 2=Unsafe place 3=Inside my house / a house 4=An enclosed storage facility 5=A bike rack 6=Locked and walked to destination 7=Other(specify)	K How would you describe the journey? 1=Took shortest route known 2=Uncertain of cycling routes 3=Unsafe (heavy traffic) 4=Safe and enjoyed it 5=Used a map as an aid 6=Poor Air Quality 7=Attractive green vegetation 8=GPS charged before trip 9=Other (specify)	L Which car or other motor vehicle did you use? (*Only* fill in these columns if you used a CAR or OTHER MOTOR VEHICLES)	M Were you the driver (D) or a passenger (P)?	N How much did you pay for parking? (£)	O How much did you pay for road tolls / congestion charges?	P What type of ticket did you use? 1=single/ one way 2=return 3=season ticket 4=1 day 5=Oyster 6=Nexus 7=Other (specify) (*Only* fill in these columns if you used PUBLIC TRANSPORT)	Q How much did your ticket cost? (£)	R How many times did you board?	S How much did your share of the taxi cost? (*Only* fill in these columns if you used a TAXI)
Journey 1 8	Time 2:19 ☐am ☑pm	Time 2:28 ☐am ☑pm	☐Home Wynne Jones Building NE1 8ST	☐Home Get stuffed 10 St. Mary's	1	1	0.3	9	1	2,7(structure)	1,4,8		☐D☐P						
					2								☐D☐P						
					3								☐D☐P						
T Why did you change your travel mode in journey 1? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; (7)=other specify: N/A																			
Journey 2 1	Time 3:15 ☐am ☑pm	Time 3:25 ☐am ☑pm	☐Home Get stuffed, 10 St. Mary's	☐Home Wynne Jones B., NE18ST	1	1	0.3	10	1	1,5	1,4		☐D☐P						
					2								☐D☐P						
					3								☐D☐P						
T Why did you change your travel mode in journey 2? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; (7)=other specify: N/A																			
Journey 3 3	Time 5:00 ☐am ☑pm	Time 5:38 ☐am ☑pm	☐Home Wynne Jones Building, NE18ST	☐Home 34 Grainger Park Road	1	1	10	38	1	1,7(pole)	1,5,3,2,7,8		☐D☐P						
					2								☐D☐P						
					3								☐D☐P						
T Why did you change your travel mode in journey 3? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; (7)=other specify: N/A																			
Journey 4 1	Time 6:00 ☐am ☑pm	Time 6:25 ☐am ☑pm	☐Home 34 Grainger Park Road	☐Home Wynne Jones B. NE18ST	1	6	10	25	3	4,7(in car)	2, ~~8~~ 9 (cycle lanes occupy by cars on Brighton Groove)	~~Sal~~ Saloon	~~☐D~~☐P						
					2								☐D☑P						
					3								☐D☐P						
T Why did you change your travel mode in journey 4? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; 5=group pressure; 6=tired; 7=other specify:																			
Journey 5 9	Time 8:45 ☐am ☑pm	Time 9:00 ☐am ☑pm	☐Home Wynne Jones Building, NE1 8ST	☑Home	1	2	0.5						☐D☐P						
					2	4	15	25	1	7(N/A)			☐D☐P			1,6	3	1	
					3	2	0.4						☐D☐P						
T Why did you change your travel mode in journey 5? (*circle as applicable*): 1=short distance; 2=long distance; 3=No bike racks at destination; 4=dangerous to cycle; (5)=group pressure; 6=tired; 7=other specify:																			
Use this space for anything else you want to tell us-> I was not the one driving. I was sitting at the back!																		Extra journeys add more sheets / contact researcher	

Table 2: Questionnaire to be filled by participant

4

Appendix B: Samples – Flyer, Brochure and Poster for notice boards

Sample of Flyer



Everyday cycling (travel) survey

Please go here to participate:
http://www.surveymonkey.com/s/D5N67NZ

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Godwin Yeboah
PhD Student, Northumbria University
cyclingphdresearch@gmal.com / 07879321621

Sample of Brochure (Outside/cover)

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Thank you for your time. We will contact you soon.

If you are unsure about your eligibility then please contact the research team and we can discuss any issues or ambiguity.

Contact information:
Godwin Yeboah, PhD Researcher
School of the Built and Natural Environment
Room 209, Wynne Jones Building,
Northumbria University,
Newcastle upon Tyne,
NE1 8ST, UK.

Office Tel. number: +44 (0) 191 227 4301
Mobile number: 07879 321621
Email for correspondence:
cyclingphdresearch@gmail.com

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INVITATION

Everyday cycling (travel) survey

"The main aim of this three (3) years PhD study is towards understanding of how the built environment support or serve as barrier to cyclists and potential cyclists. We hope to measure traces of movement of our participants and how they perceived cycling within Newcastle."

PhD work being conducted by Godwin Yeboah, Northumbria University

Supervisors:
Dr. Seraphim Alvanides
Dr. Emine Mine Thompson

Note: Please collect more flyers to give to friends.

Sample of Brochure (inside)

Dear Potential Participant

I am currently looking for volunteers for GPS based everyday cycling (travel) survey on bicycling in Newcastle.

The study involves 3 visits or contacts:

- ***First Visit***: Training session which will take place as per arrangement with participant. This session will last approximately 40 minutes.

- ***Second Visit***: Participant to be given a small pocket size GPS device and questionnaire form to fill during a week. This is a self reporting session and depends on participant filling the form.

- ***Third Visit***: Participant to return the small pocket-size GPS device with the questionnaire forms.

By way of compensation for your time and inconvenience we will enter your participation ID into a random draw which will be announced at the end of field work. The winner will receive a voucher of £50.

This study has received approval from the Ethics committee from the School of Built and Natural Environment, Northumbria University.

Please go to the next page to continue if you want to volunteer/participate.

Note: For online survey please go to this link:
http://www.surveymonkey.com/s/DZ98JPK

Please fill the questionnaire below

Please answer the following questions to enable us prepare to meet you for further discussion.

***1. Are you a male or female?**

○ Female
○ Male

***2. Which age group do you belong to?**

○ 19-22 years ○ 23-26 years ○ 27-30 years ○ 31-34 years ○ 35-38 years ○ 39-42 years ○ 43-46 years ○ 47-50 years ○ 51-54 years ○ 55-58 years ○ 59-62 years ○ 63-66 years ○ 67-70 years ○ Less or equal to 18 years ○ More than 70 years

***3. How many times do you cycle in a week and why?**

○ Not at all but would like to cycle
○ One or more weekdays or weekends to and from work,visit friends and relatives, shops, entertainment, lunch,
○ Only on weekends for sports / recreation / holidays
○ Please specify if none of the above:

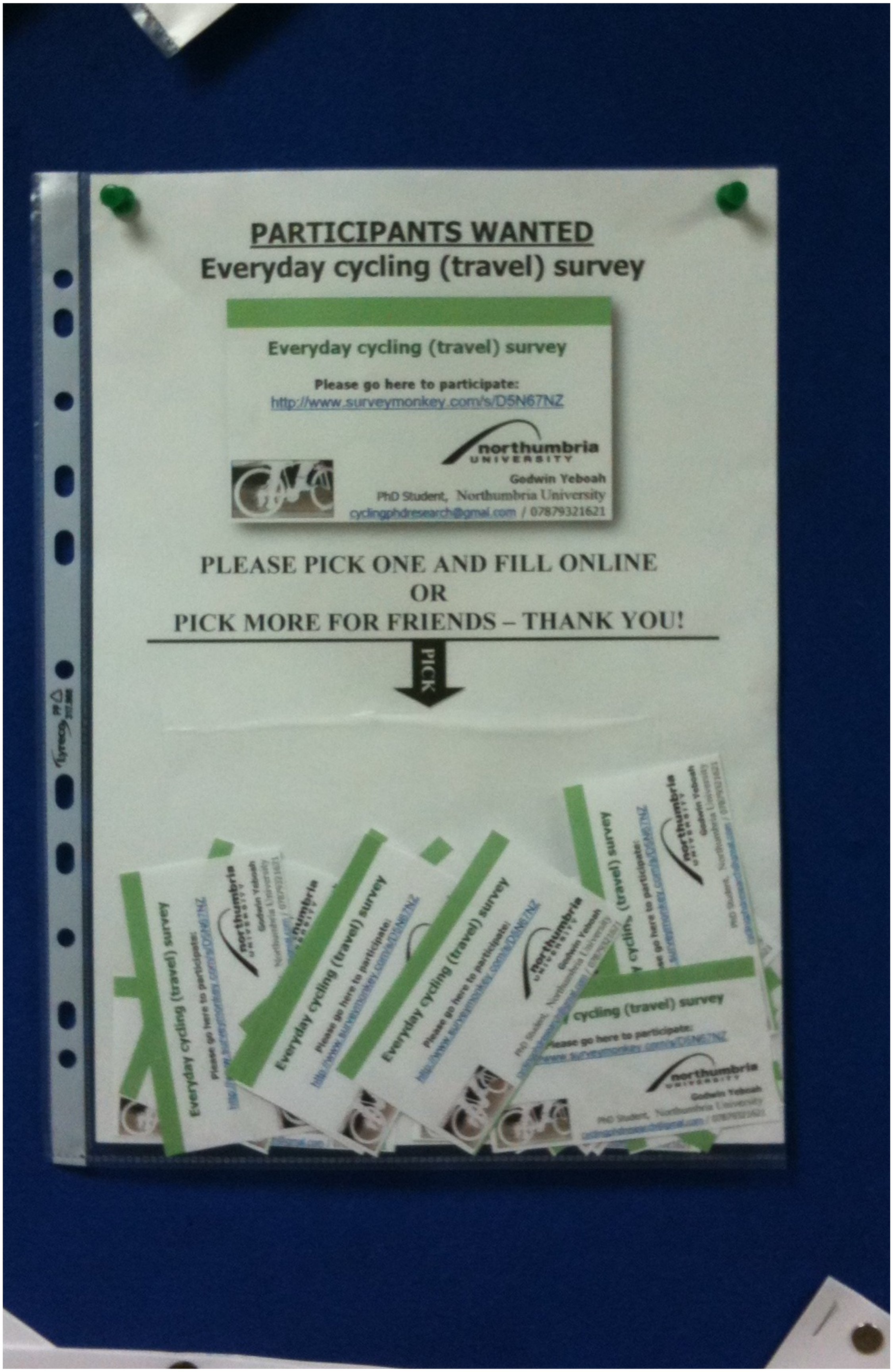
***4. Why do you cycle? (Select as many as apply)**

☐ For commuting from and to work/school/visit/shop/lunch/Bank
☐ For leisure
☐ For sports
☐ I do not cycle but would like to cycle.

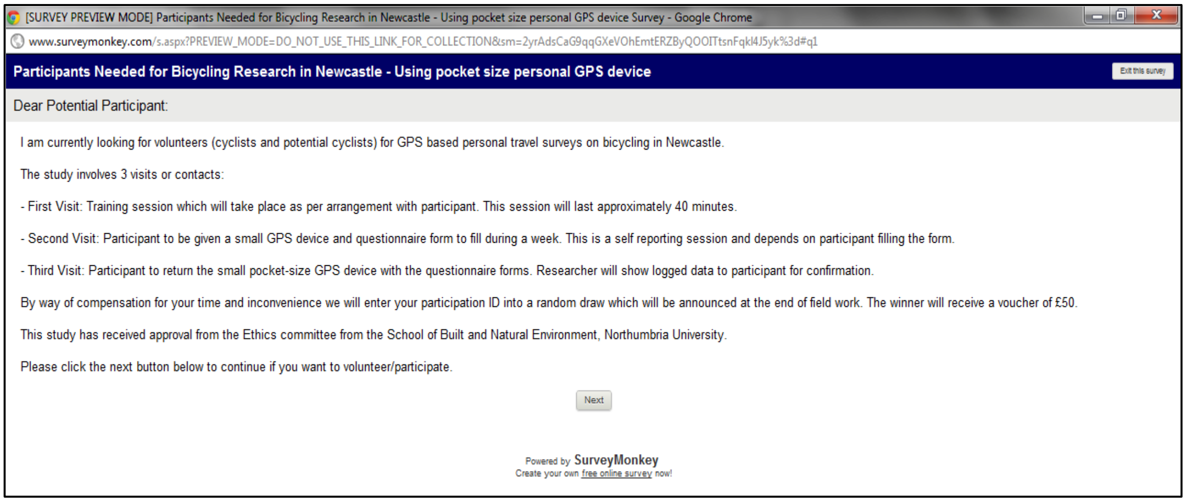
Other (please specify)

***5. Please enter your contact (Email / Telephone) information that you would want us to use to reach**

Sample of Poster for notice boards



Appendix C: Sample of three web pages designed using Survey Monkey


[SURVEY PREVIEW MODE] Participants Needed for Bicycling Research in Newcastle - Using pocket size personal GPS device Survey - Google Chrome

www.surveymonkey.com/s.aspx?PREVIEW_MODE=DO_NOT_USE_THIS_LINK_FOR_COLLECTION&sm=2yrAdsCaG9qqGXeVOhEmtERZByQOOITtsnFqkl4J5yk%3d#q1

Participants Needed for Bicycling Research in Newcastle - Using pocket size personal GPS device Exit this survey

Dear Potential Participant:

I am currently looking for volunteers (cyclists and potential cyclists) for GPS based personal travel surveys on bicycling in Newcastle.

The study involves 3 visits or contacts:

- First Visit: Training session which will take place as per arrangement with participant. This session will last approximately 40 minutes.

- Second Visit: Participant to be given a small GPS device and questionnaire form to fill during a week. This is a self reporting session and depends on participant filling the form.

- Third Visit: Participant to return the small pocket-size GPS device with the questionnaire forms. Researcher will show logged data to participant for confirmation.

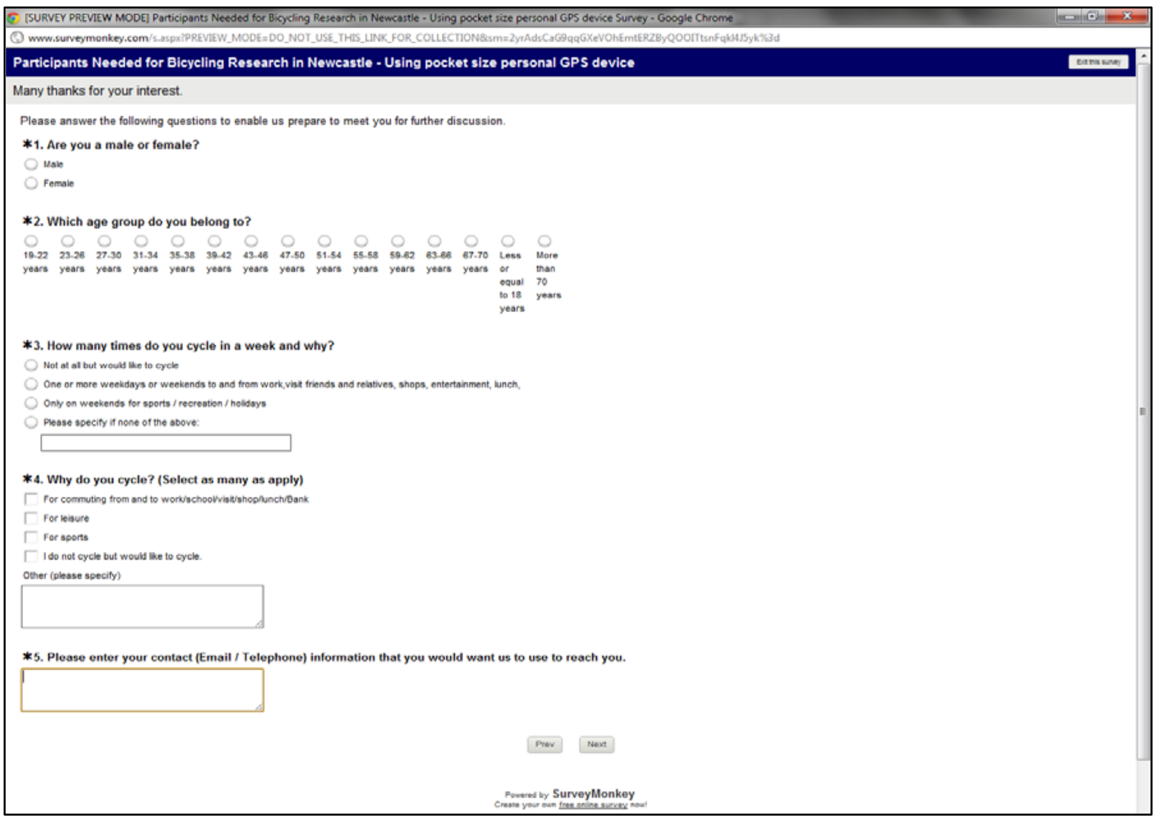
By way of compensation for your time and inconvenience we will enter your participation ID into a random draw which will be announced at the end of field work. The winner will receive a voucher of £50.

This study has received approval from the Ethics committee from the School of Built and Natural Environment, Northumbria University.

Please click the next button below to continue if you want to volunteer/participate.

Next

Powered by SurveyMonkey
Create your own free online survey now!


[SURVEY PREVIEW MODE] Participants Needed for Bicycling Research in Newcastle - Using pocket size personal GPS device Survey - Google Chrome

www.surveymonkey.com/s.aspx?PREVIEW_MODE=DO_NOT_USE_THIS_LINK_FOR_COLLECTION&sm=2yrAdsCaG9qqGXeVOhEmtERZByQOOITtsnFqkl4J5yk%3d

Participants Needed for Bicycling Research in Newcastle - Using pocket size personal GPS device Exit this survey

Many thanks for your interest.

Please answer the following questions to enable us prepare to meet you for further discussion.

***1. Are you a male or female?**

- Male
- Female

***2. Which age group do you belong to?**

19-22 years, 23-26 years, 27-30 years, 31-34 years, 35-38 years, 39-42 years, 43-46 years, 47-50 years, 51-54 years, 55-58 years, 59-62 years, 63-66 years, 67-70 years, Less or equal to 18 years, More than 70 years

***3. How many times do you cycle in a week and why?**

- Not at all but would like to cycle
- One or more weekdays or weekends to and from work,visit friends and relatives, shops, entertainment, lunch,
- Only on weekends for sports / recreation / holidays
- Please specify if none of the above:

***4. Why do you cycle? (Select as many as apply)**

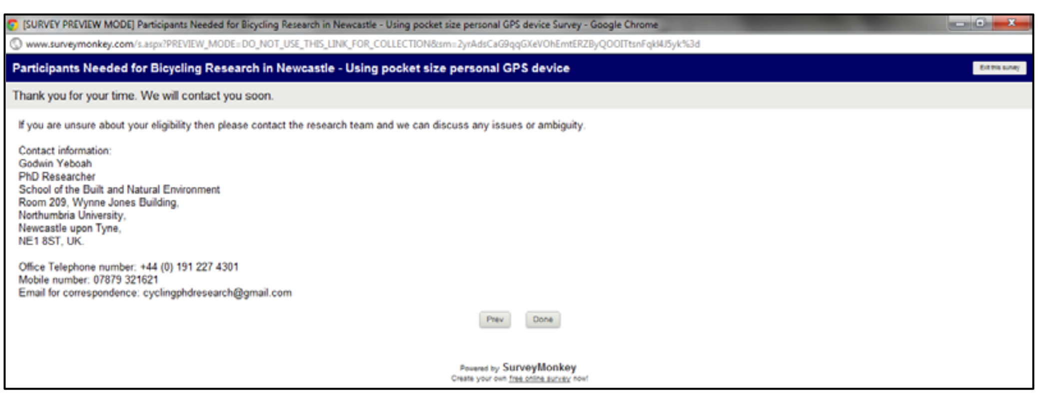
- For commuting from and to work/school/visit/shop/lunch/Bank
- For leisure
- For sports
- I do not cycle but would like to cycle.

Other (please specify)

***5. Please enter your contact (Email / Telephone) information that you would want us to use to reach you.**

Prev Next

Powered by SurveyMonkey
Create your own free online survey now!


[SURVEY PREVIEW MODE] Participants Needed for Bicycling Research in Newcastle - Using pocket size personal GPS device Survey - Google Chrome

www.surveymonkey.com/s.aspx?PREVIEW_MODE=DO_NOT_USE_THIS_LINK_FOR_COLLECTION&sm=2yrAdsCaG9qqGXeVOhEmtERZByQOOITtsnFqkl4J5yk%3d

Participants Needed for Bicycling Research in Newcastle - Using pocket size personal GPS device Exit this survey

Thank you for your time. We will contact you soon.

If you are unsure about your eligibility then please contact the research team and we can discuss any issues or ambiguity.

Contact information:
Godwin Yeboah
PhD Researcher
School of the Built and Natural Environment
Room 209, Wynne Jones Building,
Northumbria University,
Newcastle upon Tyne,
NE1 8ST, UK.

Office Telephone number: +44 (0) 191 227 4301
Mobile number: 07879 321621
Email for correspondence: cyclingphdresearch@gmail.com

Prev Done

Powered by SurveyMonkey
Create your own free online survey now!

Appendix D: Examples of email messages

Email message for the first call

***Subject**: First meeting arrangement – Everyday cycling (travel) survey*

***Email content**:*

Dear Potential Participant:

I am currently looking for volunteers (cyclists and potential cyclists) for GPS based personal travel surveys on bicycling in Newcastle.

The study involves 3 visits or contacts:

- *First Visit: Training session which will take place as per arrangement with participant. This session will last approximately 40 minutes.*

- *Second Visit: Participant to be given a small GPS device and questionnaire form to fill during a week. This is a self-reporting session and depends on participant filling the form.*

- *Third Visit: Participant to return the small pocket-size GPS device with the questionnaire forms. Researcher will show logged data to participant for confirmation.*

By way of compensation for your time and inconvenience we will enter your participation ID into a random draw which will be announced at the end of field work. The winner will receive a voucher of £50.

Please click the next web-link below to continue if you want to volunteer/participate (you can also forward this email to others):
http://www.surveymonkey.com/s/DZ98JPK

This study has received approval from the Ethics committee from the School of Built and Natural Environment, Northumbria University.

Contact information:
Godwin Yeboah
PhD Student
School of the Built and Natural Environment
Room 209, Wynne Jones Building,
Northumbria University,
Newcastle upon Tyne,
NE1 8ST, UK.

Office Telephone number: +44 (0) 191 227 4301
Mobile number: 07879 321621
Email for correspondence: cyclingphdresearch@gmail.com

Email message for the mid-week follow up

***Subject**: Follow-up check: How you are faring.*

***Email content**:*

Dear [name of participant],

I would like to find out how you are faring with charging and carrying the GPS devices as well as filling the forms.

Any difficulties?

Thanks for your support.
[name of researcher]

Email message for end of week follow up and meeting

***Subject**: Follow-up: next meeting date and time.*
***Email content**:*

Dear [name of participant],

My records suggest you started on the 22nd Oct. which means the week for the data collection will end by end of Fri. 28th Oct.. Please double check your recorded travel week in the form if you started on 22nd. If this is the case, I suggest you switch the GPS device off if it is still on whilst we arrange to meet.

Is it possible to meet tomorrow at 7.30pm same venue as previous meeting?

Many thanks for your support.
[name of researcher]

Appendix E: GPS FAQ leaflet for participants

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Question: Why data collection using GPS device?
Answer: Data from GPS device help researchers to understand travel patterns which go a long way in helping to suggest better alternatives and improvements to transport infrastructures.

Question: How is the information going to be handled?
Answer: The data will be transferred securely to a well protected computer being used by the research team and provided by the University. Data will be processed using the diary and the transferred data and used by the research team towards understanding barriers to cycling in Newcastle.

Question: Is this research confidential?
Answer: Yes. Research team is bound by the Data Protection Act and Northumbria University Code of Ethics. Your voluntary contribution is used only for research purposes. Names, addresses, telephone numbers would not be part of the results.

Question: Is it compulsory to participate using the GPS?
Answer: No. We are only counting on your goodwill and voluntary cooperation for the success of this survey. We hope to have many people participating to enable us come to a good conclusive results. That said, you are free to withdraw from the study at any time.

Question: How do you expect me to use the GPS device?
Answer: Please take the device with you whiles taking any journey from one place to another. If you are on a bike, please place the device in your pocket or top compartment of your bag. If you are not cycling, kindly keep it in your pocket or top compartment of your bag or hook it on your belt or key-holder, dashboard of car. You do not need to keep the device on you whiles indoors for a long time but kindly wear device if you intend to leave the place and it is likely you might forget taking the device with you.

Question: What do I get for participating?
Answer: You will be entered into a draw with the possibility of wining £50 voucher.

Question: How do I get my questions answered?
Answer: We have prepared further instructions for participants. Please see attachment. Moreover, you can contact us using the following email address: cyclingphdresearch@gmail.com

Godwin Yeboah, PhD Student, (contact: ***cyclingphdresearch@gmail.com / 07879321621)***
School of the Built and Natural Environment, Room 209, Wynne Jones Building, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK.

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A) GPS device usage guide for participants

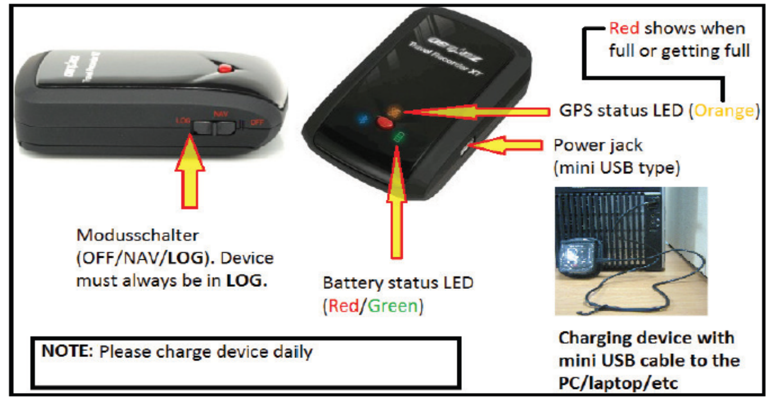

Figure 1: Basic features you should know about the device

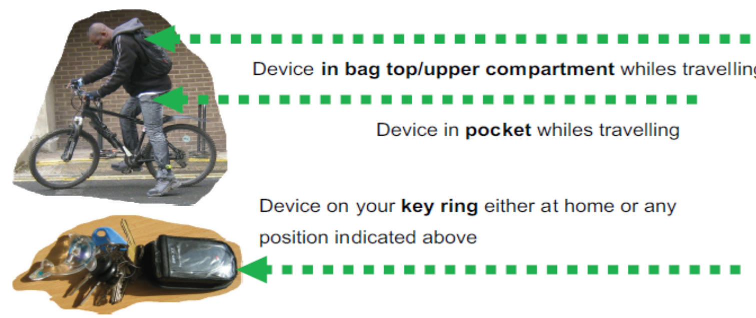

Figure 2: Recommended places you could place the GPS device

Godwin Yeboah, PhD Student, (contact: ***cyclingphdresearch@gmail.com / 07879321621)***
School of the Built and Natural Environment, Room 209, Wynne Jones Building, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK.

LED Status		Flash	ON	OFF
Power (Red/Green)		Low Power (Red)	Recharging (Green)	Fully charged
GPS (Orange)		GPS position is fixed, Navigation	Detecting Satellite, GPS position not fix	GPS not powered
Log (Red)		Log Mode is on Flash per 2 sec: Low memory (20%) Flash 3 times: POI(Point of Interest) is recorded	Memory is full	GPS not powered

Figure 3: What to know about LED indicators of the GPS device. (Source: GPS device manual)

How do I charge the GPS device?
Use the provided mini USB cable and connect to your PC or laptop. See Figure 1 and Figure 3 above. Please note that the device must always be in the **LOG** mode always. It goes to idle mode when it remains idle for about 10 minutes; orange colour goes off.

What should I do if it rains?
You may temporarily place the device inside your clothing or bag. Please see Figure 2

Should I switch the device off to save battery life when I am indoors for hours?
The device must always be on during the data collection week. There is an in-built motion detection functionality that puts the device off when it is idle for ten (10) minutes. It re-activates when the device is moving. This helps in saving battery life but please endeavour to charge the device daily.

Please contact Godwin Yeboah using this email address / Telephone for any questions: cyclingphdresearch@gmail.com / 07879321621

Godwin Yeboah, PhD Student, (contact: ***cyclingphdresearch@gmail.com / 07879321621)***
School of the Built and Natural Environment, Room 209, Wynne Jones Building, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK.

B) GPS Leaflet for participants-Frequently Asked Questions (FAQ)

Question: Can the device cause harm to me?
Answer: No. The GPS device can not harm you. It has been purposely made for personal use.

Question: Do I have to carry the device only when I am cycling?
Answer: No. Please carry the device everywhere you go during the day. You can fix the device on your key ring, slot in your pocket or any upper compartment of your bag. Please see Figure 2.

Question: What will happen to me if I lose the GPS device?
Answer: The device is very expensive and we trust that you will not lose it. Please do your utmost best to keep it safe. You will not be responsible for any lose. What will happen is that we will find it difficult to complete the research.

Question: I am not good with technologies; what makes you think I can use this GPS device?
Answer: The GPS device is as simple to use as using a mobile phone. All you have to do is to switch it on and off, charge, and place on your bike-handlebar or bag or pocket making sure it is more expose to the sky for good signal reception.

Question: Why do you want me carry a GPS device and fill a diary simultaneously?
Answer: We want to avoid putting so much burden on you so with the GPS an accurate speed, distance, and time of your movement is recorded passively whiles you only use some few minutes to fill the form.

Question: Can someone track and monitor where I go whiles keeping the device?
Answer: No one can track you whiles keeping this device. We have ensured that this will not happen. The data on the device is only usable when the device is returned. Even that, we will make sure it will not be possible to identify you to the data.

Question: Is the device for only cyclists?
Answer: No. A non-cyclist who is interested in cycling but want to make known his or her barriers to cycling can also carry the device whiles filling the form.

Question: What is a GPS device?
Answer: It is a Global Positioning System (GPS) gadget which receives signals sent by GPS satellites high above the earth. Similar to how a mobile phone, with say a chip from Vodafone, will receive signal from Vodafone Mobile Service. The signal is converted to points, speed, distances, and time.

Godwin Yeboah, PhD Student, (contact: ***cyclingphdresearch@gmail.com / 07879321621)***
School of the Built and Natural Environment, Room 209, Wynne Jones Building, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK.

Appendix F: Consent form and research statement for participants

School of the Built and Natural Environment

RESEARCH STATEMENT

TO: Participants
Date: 1st October 2011
Project Title: Understanding Urban Cycling in Space and Time
Academic Supervisors: Dr Seraphim Alvanides, Dr Emine Mine Thompson
PhD Student Researcher: Mr. Godwin Yeboah

1. Purpose and Background
This study seeks to understand urban cycling behaviours in space and time.

2. Participation
We are asking you to take part in this research because you are a utility cyclist in the city. The participation process has three stages:

- First meeting: Training session which will take place as per arrangement with participant. This session will last approximately 40 minutes.
- Second meeting: Participants will be given a small GPS device and questionnaire form to fill –in during a typical week.
- Third meeting: Participant to return the small pocket-size GPS device with the questionnaire forms. The researchers will show logged data to participant for confirmation.

By way of compensation for your time and inconvenience we will enter your participation ID into a random draw which will be announced at the end of field work. The winner will receive a voucher of £50.

3. Privacy, Confidentiality and Disclosure of Information
The information gathered in this study will be secured so that it is accessible only to the research team. The analysis will be done in a way that prevents the identification of individuals. Any information obtained in connection with this project and that can identify you will remain confidential. This research is for academic purposes only and will not be used commercially or publicly.

4. Results of Project
Please let us know whether you wish to be informed when the results of the research become available.

13. Further Information, Queries or Any Problems
If you require further information concerning this project please contact one of the following researchers:

Dr Seraphim Alvanides, Reader Wynne-Jones Building (WJ114), Built and Natural Environment, Northumbria University, Newcastle NE1 8ST s.alvanides@northumbria.ac.uk s.alvanides@gmail.com	Dr. Emine Mine Thompson BA MA MSc PhD Senior Lecturer in Visualisation *0191 227 4867* *School of the Built and Natural Environment, University of Northumbria,* *Ellison Building* *Newcastle upon Tyne, NE1 8ST*	Godwin Yeboah, PhD Researcher, BSc MSc MSc School of the Built and Natural Environment Room 209, Wynne Jones Building, Northumbria University, Newcastle upon Tyne,NE1 8ST, UK. +44 (0) 191 227 4301

School of the Built and Natural Environment
RESEARCH PARTICIPANT CONSENT FORM

GIVEN ID:______________________ 1110XT11500997_____________________________

Name of participant	
Organisation / Company / Institution	
Researcher's name	**GODWIN YEBOAH**
Title of research project/dissertation	**Understanding Urban Cycling in Space and Time**
Programme of study *[Only if researcher is a student]*	**Full time PhD programme**
Supervisors' name *[Only if researcher is a student]*	**Dr. Seraphim Alvanides; and,** **Dr. Emine Mine Thompson**

Standard statement of participant consent (please tick as appropriate)*

I confirm that:

I have been briefed about this research project and its purpose and agree to participate* ☐

I have discussed any requirement for anonymity or confidentiality with the researcher** ☐

I agree to being audio taped / videotaped during the interview ☐

**Please tick collected items:* ☐One *GPS device* ☐*One USB cable* ☐*Questionnaire forms* ☐*Mount*

* *Participants under the age of 18 normally require parental consent to be involved in research.*

****Specific requirements for anonymity or confidentiality (if any)**

Signed .... **Date** ....

Your full home postcode:...

Your full work postcode:..

(Your name will not be used for any publication or given to any third party)

Standard statement by researcher
I have provided information about the research to the research participant and believe that he/she understands what is involved.

Researcher's signature ……………………………………….
Date ……………………………………

Appendix G: Publications

The following items show the publications resulting from this research.

Peer reviewed and edited book chapter:

Yeboah, G., Alvanides, S., Emine, M.T., (In press). Everyday cycling in urban environments: Understanding behaviours and constraints in space-time, In: Helbich, M., Jokar Arsanjani, J., Leitner, M. (Eds.), Computational Approaches for Urban Environments. Geotechnologies and the Environment. Springer, New York.

Yeboah, G., Alvanides, S., (Submitted). Route choice analysis of urban cycling behaviours using OpenStreetMap: Evidence from a British Urban Environment, In: Jokar Arsanjani, J., Zipf, A., Mooney, P., Helbich, M. (Eds.), OpenStreetMap in GIScience: experiences, research, applications. Springer.

Peer review publication/conference/workshop:

Yeboah, G., Alvanides, S., (Submitted). Examining Urban Utility Cycling using Space-Time Cube, GPS, Travel Diary and Agent-Based Modelling techniques: Possibilities, Challenges, Emerging Solutions. Journal of Applied Spatial Analysis and Policy.

Yeboah, G., Alvanides, S., (Submitted). Profiling and visualizing activity spaces of utility cyclists: Evidence from a British Urban Environment. Journal of Applied Spatial Analysis and Policy.

Alvanides, S. and Yeboah, G., (2014). Profiling and visualizing activity spaces of urban utility cyclists. Paper presented at the GIS Research UK 2014 Conference, University of Glasgow, UK.

Yeboah, G., and Alvanides, S. (2013). Everyday cycling in urban environments: Understanding behaviours and constraints in space-time. Paper presented at the GIS Research UK 2013 Conference, University of Liverpool, UK.

Yeboah, G. (2013). Everyday cycling in urban environments: Understanding behaviours and constraints in space-time. Poster presented at the SET for BRITAIN Engineering Exhibition 2013, Terrace Marquee, House of Commons at UK Parliament.
(Special competitive invitation from UK Parliamentary and Scientific Committee)

Alvanides, S., and Yeboah, G. (2012). Cycling in the city: Understanding urban cycling behaviours and constraints in space-time. Paper presented at the RGS-IBG Annual International conference, University of Edinburgh.

Yeboah, G., Alvanides, S., and Thompson, E. M. (2012). Methodological perspective on understanding cycling behaviours of commuters. Poster presented at the Cycling and Society Symposium 2012, University of East London Stratford Campus, UK.

The author of this thesis also co-organised an international workshop on cycling data challenge, in Belgium, with three experienced European researchers together with a mix of other experts and early – career researchers. Also, a web site was developed for the workshop: https://sites.google.com/site/cdc2013workshop/workshop-presentations

Media release, other presentation and blog:

Northumbria, 2013. Cycling in the city, Impact Magazine, Summer 2013 ed. Northumbria University, Newcastle upon Tyne. Retrieved from http://www.northumbria.ac.uk/static/5007/pr/340465_Impact_Spring13.pdf

ScienceDaily. (2013). Cycling in the city. Retrieved from http://www.sciencedaily.com/releases/2013/03/130315074518.htm

Yeboah, G. (2012). Space cube as a data processing tool - a visual approach to GPS data processing. Oral presentation at the EU MOVE-COST WG4 Workshop on Analysis and visualisation of movement data. What can the Space-Time-Cube do for you?, University of Twente, Netherlands. Received travel grant from MOVE-COST. Available at http://www.move-cost.info/index.php?option=com_content&view=article&id=111&Itemid=97

RGS-IBG (2012). Talk to us, say North East cyclists, Royal Geographical Society (with Institute of British Geographers) Media Release. Retrieved from http://www.rgs.org/NR/rdonlyres/6A596F54-5509-421D-A596-691F8607599B/0/120705AlvanidesCycling.pdf

A research blog was also created in 2011 to create awareness for the research and is available at http://godwinyeboah.blogspot.co.uk