The impact of walking and cycling infrastructure on personal travel and carbon emissions:
the case of Cardiff Connect2



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Abstract

There is a growing recognition of the role that walking and cycling can make in reducing traffic congestion and air pollution whilst also contributing to improved personal health and wellbeing. While studies suggest that infrastructure is required to promote walking and cycling, there is a lack of evidence at the micro level on how interventions aimed at improving connectivity for walking and cycling influence travel behaviour and whether they promote a modal shift away from short car journeys.

The aim of this study was to investigate the extent to which the implementation of a high quality traffic free route, delivered by a recent programme targeted at everyday walking and cycling in the UK – the *Sustrans Connect2* Programme – influenced individuals' day-to-day travel decisions, changed the spatial and temporal nature of their journeys and impacted on overall carbon emissions from motorised travel. To achieve this aim an in-depth longitudinal panel study of a community of residents living next to a totemic *Connect2* scheme in Penarth, Cardiff, was conducted. A panel of purposively selected participants (N=50) were interviewed and asked to record their travel behaviour using personal GPS devices and travel diaries over two seasonally matching 7-day time periods in 2011 and 2012. This novel GPS based mixed-method approach provided a detailed account of participants' travel behaviour in the local area (n=2664 journeys) and a comprehensive understanding of how, why and for whom the Connect2 intervention was likely to influence travel behaviour and the longevity of effects.

The findings revealed that participants used the new *Connect2* scheme regularly during the period of the study (36% in 2011; 26% in 2012); however, the new scheme was likely to have a greater impact for recreational journeys rather than for everyday travel. Spatial data provided new insights into the complexities of walking behaviour and factors influencing cycling for everyday travel or recreation, including route choice decisions, destinations where activities were conducted and the role of the new *Connect2* infrastructure in

supporting this. Further findings support the potential of active travel in replacing short car trips (20%) and its impact on carbon emissions from personal travel (4.9% among the study sample). However, results suggest that the new *Connect2* scheme alone was unlikely to promote a significant change in travel behaviour and carbon emissions from (displaced) car journeys.

The study contributes to the debate on the effectiveness of interventions targeted at promoting walking and cycling and the importance of wider infrastructural improvements that may be required to encourage their wider uptake. The combination of methods for data collection developed and employed in this study also helps to inform future travel behaviour research.

Acknowledgments

I started cycling when I was 6. In the beginning I cycled for fun, with friends and as a way to explore my hometown and surrounding landscapes. Later on, cycling become a sport activity and an efficient, affordable and healthy mode for everyday travel. I am today truly passionate about this simple yet exciting method of travel and in exploring ways how cities can be redesigned to get more people to walk and cycle. Conducting this study and working alongside the iConnect research project and an engaged community was a fantastic opportunity to explore further the complexity of factors and relationships influencing day-to-day travel behaviour and in particular walking and cycling. As a landscape architect and urban designer, this endeavour proved to be a unique experience.

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Glossary and Terminology

Connect2	*A five-year infrastructural programme delivered by sustainable transport charity Sustrans (£138m) and aimed at increasing walking and cycling levels in the 84 communities around the UK by creating new bridges and crossings for pedestrians and cyclists that would help to overcome barriers to local walking and cycling journeys, such as busy roads, rivers and railways.*
CO_2	*Carbon dioxide*
CO_2e	*Carbon dioxide equivalent*
DEFRA	*Department for Environment, Food and Rural Affairs*
DfT	*Department for Transport*
EPSRC	*Engineering and Physical sciences Research Council*
GHG	*Greenhouse Gas*
GIS	*Geographic Information System*
GPS	*Global Positioning System*
iConnect	*Multi-disciplinary five-year study focused on the evaluation of the impacts on travel behaviour, physical activity and carbon emissions of three of the Sustrans Connect2 schemes.*
LSTF	*Local Sustainable Transport Fund*
NTS	*National Travel Survey*
NICE	*National Institute for Health and Clinical Excellence*
ONS	*Office for National Statistics*
Sustrans	*Sustainable transport charity in the UK responsible for delivery of walking and cycling infrastructure and travel behaviour change projects.*
Trip	*One-way course of travel with a single main purpose.*
Stage	*A new stage is defined when there is a change in the form of transport or when there is a change of vehicle.*
Tour	*Sequence of trips that started and finished at home.*
Walking or Cycling for Everyday Travel	*Journeys that involve daily activities such as going to work, school, grocery shopping, social activities and other 'necessary' purposes.*
Walking or Cycling for Recreation	*Journeys made for pleasure, leisure fitness or sport, including brisk walking, walking in the park/ countryside, dog walking, jogging, cycling touring and cycle racing (road and off road).*

1 Introduction

'At a time when fossil fuel, pollution and problems with climate and health are increasingly becoming a global challenge, giving higher priority to bicycle [and walking] traffic would seem like an obvious step to take. (…). Naturally, cyclists [and pedestrians] are welcome in support of the goal to promote lively, safe, sustainable and healthy cities' (Gehl, 2012)

1.1 The benefits of an increase in walking and cycling levels

There is growing recognition that walking and cycling can play a significant role as an alternative method of travel in urban areas where roads are often congested, public transport is either overcrowded or limited and a great part of trips are short (Butcher 2012; Pucher et al. 2010a; Gehl 2010). In the United Kingdom, cars and taxis alone account for 58% of UK Domestic transport greenhouse gas emissions[1] (DfT 2009) and the congestion cost (through wasted fuel, time, and the indirect cost added to consumer bills) in 18 of the largest towns and cities in the UK is estimated to be £4.4bn per year (Centre for Economics and Business Research 2012). While car travel is the most popular method of transport in England, at least 24% of these car trips are under 2 miles (DfT 2014a); and walking or cycling for some of these journeys could take only 15 to 30 minutes. Simultaneously, it is acknowledged that lack of physical activity and a greater reliance on car travel (rather than walking or cycling) are one of the underlying causes for the challenging obesity epidemic (National Health Service 2014). In the UK, obesity rates have increased by nearly 10% just over the last two decades (Health & Social Care Information Centre 2014). As major cities are increasingly being challenged by the need to enhance mobility and reduce congestion, accidents and pollution, it is acknowledged that promoting a change towards more efficient methods of

[1]Carbon dioxide (CO_2) is the predominant greenhouse gas emitted within the transport sector, accounting for 98.7 % of total GHG emissions (EEA, 2011a). CO_2 emitted varies per journey varies according to trip distance, speed, type of fuel used, vehicle type, weight and volume of goods transported or logistic efficiency (IEA, 2009).

travel should be one of the key strategies (alongside the need to reduce travel and encourage the use of public transport with increased load factors) (Banister 2008).

Walking and cycling are sustainable modes of transport as they to do not require the use of petrol or diesel, consume far fewer non-renewable resources than any motorised transport mode and cause virtually no noise or air pollution (Pucher & Buehler 2010). Energy expenditure from walking is negatively correlated with fossil fuel use from car driving (Frank et al. 2010; Brand et al. 2014) and lifecycle emissions from cycling are more than 10 times less than those from passenger cars (Blondel et al. 2011). Furthermore, as short car trips have higher per-mile fuel consumption and emissions rates than other journeys, replacing some of these car trips by active travel could have further positive impacts in terms of energy and carbon emissions mitigation (Beckx et al. 2013; Vagane 2007).

Walking and cycling are also one of the most space efficient, affordable and reliable methods of travel due to their simplicity, accessibility, minor equipment specialization and low cost. As cycling (and walking) require much less road space per passenger-mile than cars (Litman 2014b) and cycling parking provides an extremely efficient use of space in comparison to car parking, those two modes have the potential to reduce local traffic congestion and promote the liveability and attractiveness of streets and the urban environment (Bendiks & Degros 2013; Gehl 2010). Walking and cycling can also facilitate social interaction and access to urban opportunities for a larger group of people (including those with no access to a private car) as they are affordable methods of travel (Macmillen et al. 2009; Rauhala 2007; Cubukcu 2013). They can also promote retail activity, given that evidence suggests, for example, that pedestrians and cyclists shop more frequently in town centres than car drivers (Krag 2002; Macmillen et al. 2009; Whitehead et al. 2006). Cycling in particular has the potential to democratize the idea and appeal of flexible, individual and private mobility (Horton et al. 2007).

Finally, an extensive body of literature from the public health field has also shown positive relationships between active travel and health and wellbeing. Walking and cycling for daily

travel can provide valuable moderate-intensity physical activity levels with a wide range of health benefits and psychological wellbeing effects, such as a lower risk of ischemic heart disease, cerebrovascular diseases, depression, dementia, diabetes or obesity as an example (Andersen & Cooper 2011; Woodcock et al. 2009; Martin et al. 2014). Studies suggest that walking at a moderate pace of 5 km/hour (3 miles/hour) expends sufficient energy to meet the definition of moderate intensity physical activity (Ainsworth et al. 2000) and that the health benefits of bicycling far exceed the health risks from traffic injuries (as bicycling levels increase, cycling becomes safer and injury rates fall, providing larger net health benefits) (Rojas-Rueda & Nazelle 2011; Andersen et al. 2000; Elvik 2009; Pucher et al. 2010a).

In summary, there is a growing body of evidence suggesting that an increase in walking and cycling levels could play a role in improving personal health, quality of the urban environment, air pollution and other harmful impacts of car use and, as a result, the need to tackle some of these contemporary issues has led to the growing interest in walking and, in particular, cycling in recent years.

1.2 Promotion of walking and cycling in the UK

Successive governments in the UK have recognized the need to increase walking and cycling levels. Over the last two decades, a series of policy documents and initiatives have explored the options in terms of sustainable urban mobility and, more specifically, for the promotion of walking and cycling. Simultaneously, a wide range of organizations has campaigned at both local and national levels for better sustainable transport, influencing government policy or leading significant interventions. Activities related to cycling campaigning have been particular prominent in this respect.

Some of the most relevant strategy and guidance documents from, or commissioned by the government, include the first National Cycling Strategy (1996), the Action Plan for Walking and Cycling (DfT 2004b), Active Travel Strategy (DfT 2010a), Get Britain Cycling (All Party

Parliamentary Cycling Group & House of Commons 2013), and more recently, the Cycling Delivery Plan (DfT 2014b). Significant infrastructural and evaluation programmes include the on-going implementation of the National Cycle Network (delivered by the sustainable transport charity Sustrans), the Sustainable Travel Towns Programme (2005-2008), Cycling Demonstration Towns Programme (2005-2009), Safe Routes to School and more recently, the Sustrans Connect2 Programme (2008-2013) and the implementation of local schemes funded by the Local Sustainable Travel Fund/ Cycle City Ambition Grant (2011-2015). Along these initiatives, a range of soft measures, including training and promotion programmes such as Bikeability and Cycling to Work scheme have also aimed to increase cycling levels. Overall, greater resources have been put into promoting cycling rather than walking, which remains barely visible within society and more infrequently recognised in the planning of urban infrastructure (Pooley et al. 2014).

Despite these series of policies and programmes, walking and cycling levels are still low in the UK and there is little evidence of how some of these initiatives are effectively promoting walking and cycling as forms of everyday travel. England has still some of the lowest rates of cycling in Europe and while there are some exceptions at the local level, in cities such as Cambridge and Oxford, in England only 2% of trips are made by bicycle (DfT 2013b). This is comparatively low if compared to countries such as the Netherlands where cycling accounts for 26% of modal share (Fietsberaad 2009; DfT 2013b). Walking levels are not as low (23.4%), although they have been falling drastically (27% drop) when compared to figures from 1995/97 (DfT 2013b). While the government acknowledges that policy interventions have not yet delivered systematic increase in cycling and walking levels (Cabinet Office 2009), there is increasing criticism that the policy rhetoric is not met with the resources required to establish walking and cycling as the main modes of travel in urban areas (Golbuff & Aldred 2011; Horton & Jones 2015; Docherty & Shaw 2003; Pooley et al. 2013). On the other hand, there is still little understanding of the response to some of the more recent

targeted investment in walking and cycling initiatives and the extent to which they are influencing travel behaviour.

The aim of this thesis is therefore to develop a better understanding of the links between implementation of physical infrastructure targeted at promoting walking and cycling at local community level and the influence on personal travel behaviour and associated carbon emissions. In order to meet this objective and investigate with greater depth the impact of one of these infrastructural programs, this study follows a case study approach.

1.3 Case study: the Sustrans Connect2 Programme

Connect2 was a recent infrastructural project aimed at increasing walking and cycling levels in the UK (2008-2013). The project focused on creating new bridges and crossings for pedestrians and cyclists that would help to overcome barriers to local walking and cycling journeys such as busy roads, rivers and railways. Targeting 84 sites, the ambition of the programme was to transform everyday travel for local people in communities across the UK (Wistow 2008, Sustrans 2013). The Connect2 project was funded by the Big Lottery and Local Authorities (£138m) and administered by the transport organization Sustrans.

Founded in 1983, Sustrans is the leading sustainable transport charity in the UK responsible for delivery of walking and cycling infrastructure, as well as, travel behaviour change projects. While its aim is to promote sustainable transport more broadly it has a strong focus on cycling and the National Cycle Network has been since 1996 its flagship project. From the group of organisations promoting walking and cycling in the UK, Sustrans has been the most successful in winning funding and influencing government policy (Pooley et al. 2013) and nearly two thirds of its overall budget comes from local and central government (Sustrans, 2014b).

Each Connect2 scheme, delivered in one of 84 communities around the UK, comprised one flagship-engineering project plus improvements to feeder routes. The projects were tailored to individual sites and embodied a desire to create new routes for everyday local journeys on

foot or by bicycle and to create complementary links to NCN (Sustrans 2013). Sustrans anticipated therefore that the delivery of the Connect2 programme could transform not only local walking and cycling trips within each individual community but also contribute to greater growth in walking and cycling levels by providing some of the missing links in the NCN (Wistow 2008). Sustrans estimated that the Connect2 programme had the potential to transform local travel habits of six million people (10% of the UK population), to promote replacement of short car journeys with walking and cycling and to reduce local traffic congestion by removing 1 million car journeys from busy roads (Sustrans, 2013).

In order to evaluate the impact of the Connect2 Programme, Sustrans has developed a monitoring system based on route users' survey. Additionally, an independent multi-disciplinary group of researchers from eight universities in the UK – the iConnect consortium (www.iconnect.ac.uk) – conducted a five year study evaluating the impacts on travel behaviour, physical activity and carbon emissions of three of the Connect2 schemes (Ogilvie et al. 2012).

1.4 Limitations of existing research

1.4.1 Lack of evidence from in-depth studies on role of interventions that improve connectivity for pedestrians and cyclists

A growing body of literature acknowledges that a complex web of environmental, socio demographic and individual factors influence walking and cycling levels, and that built environment features which promote shorter distances between origin and destination (such mixed land use, higher density, connectivity, as an example) and enhance the experience of walking and cycling have a positive impact on walking and cycling (Saelens et al. 2003; Handy 2004; Banister 2007; Brown et al. 2007; Badland et al. 2008; Cervero et al. 2009; Banister 2009; Van Dyck et al. 2009; Heinen et al. 2010; Forsyth & Krizek 2010; Pucher & Buehler 2010; Boone-Heinonen et al. 2010; Timms & Tight 2010; Winters & Teschke 2010; Ogilvie et al. 2011; Goeverden & Godefrooij 2011; Susilo et al. 2012). Furthermore, studies

suggest that the presence of infrastructure and routes for pedestrians and cyclists are associated with walking and cycling (Ogilvie et al. 2011; Saelens et al. 2003; Handy 2004; Pucher et al. 2010a; Dill 2009; Forsyth & Krizek 2010). However, results are sometimes mixed. As an example, while some studies found connectivity to be significant for walking and cycling (Dill & Voros 2007; Cervero et al. 2009; Frank et al. 2004; Li et al. 2005; Ewing et al. 2008), empirical evidence from other studies could not support this association for neither walking (Cervero & Duncan 2003; Rutt & Coleman 2005; Lovasi et al. 2008) or cycling (Moudon et al. 2005; Zacharias 2005; Jones et al 2013). Moreover, reviewed intervention studies show little evidence that **changes to the built environment through infrastructure provision lead to an effective change in travel behaviour, a modal shift away from the car or influenced carbon emissions from personal travel.**

A further limitation of existing research in this field is that studies usually assess one of the behaviours alone, either walking or cycling, for one specific purpose (for example: utility cycling) or all in one (physical activity in general) (Adams et al. 2013; Heinen et al. 2010; Forsyth and Krizek 2010). Moreover, studies that have evaluated the impact of infrastructure for walking and cycling have rarely explored in detail the mechanisms and the context in which the interventions were (or were not) effective (Theatre 2010) or are biased towards North America and Australia. Likewise, a bias towards quantitative approaches may also contribute to a failure in understanding better constraints and circumstances that influence individual travel behaviour choices (Handy & Clifton n.d.; Pooley et al. 2013). Finally, studies that have analysed the impact of active travel on carbon emissions are usually speculative and based on scenarios (Lovelace et al. 2011; Woodcock et al. 2007) or not able to detect the possibility of small effects (Brand et al. 2014).

1.4.2 Difficulties in measuring walking and cycling behaviour:

This lack of more robust evidence within the field and some of the gaps identified could be partially attributed to the difficulty of measuring changes in walking and cycling behaviour

(Krizek, Handy, et al. 2009; Craig et al. 2008) alongside challenges in the evaluation of complex processes and in conducting natural experiments (Ogilvie et al., 2004; Garrad, 2007). Traditionally, travel behaviour data has been collected using travel surveys, travel diaries, telephone calls or counters but these methods are frequently limited by poor data quality on trips distance and duration or short trips, and crucially for the study of walking and cycling, they do not provide information on route choice.

In the UK, the National Travel Survey (NST) and Sustrans provide the primary sources of data on walking and cycling. NTS data is collected from a large sample of individuals each year (approximately 16,000) using face-to-face interviews, travel diaries and telephone surveys (DfT 2014a). However, NTS data underreports short trips and does not include information on trips that take place off the public highway, trips which are themselves a form of recreation and importantly, trips routes (DfT 2013a). Sustrans, on the other hand, uses Route User Intercept Surveys (RUIS) and manual or automatic counters to monitor and evaluate walking and cycling levels (Moore et al. 2006). This data is however aggregated, focused on users and does not provide depth at an individual level on how and why new interventions are likely to influence local residents travel behavior (e.g. promote a modal shift away from the car, an increase in walking and cycling levels or route substitution).

Following the limitations of traditional travel survey methods, studies of travel behaviour have recently started to explore the use of personal Global Positioning Systems (GPS) as a mean to record travel behaviour (Gong et al. 2012; Broach et al. 2011; Dill 2009; Bohte & Maat 2009; Duncan & Mummery 2007; Stopher, Swann, et al. 2007). GPS technology offers the ability to record accurate data on trip origin and destination, distance, duration speed and importantly, route taken (Wolf et al. 2003; Cho, Rodríguez, and Evenson 2010; Stopher 2006). Moreover, the fact that travel patterns are arguably becoming more complex in terms of time, space and modes (Bohte & Maat 2009) may suggest that new approahces that provide a greater detail and less burden for participants such as GPS tecnhology may be an advantage. However, there are also other challenges with GPS technology use that need to

be overcome. Those include the risk of missing data due to equipment failure (signal loss) or the complexity of processing and validating GPS raw data as GPS devices do not record trip mode and purpose.

1.4.3 Limited understanding at the micro level detail of the impact of schemes delivered by the Sustrans Connect2 Programme

Considerable effort, time and money has been spent developing and implementing the infrastructural Sustrans Connect2 programme, aimed at increasing walking and cycling in the UK through connectivity improvements for pedestrians and cyclists. At the same time, there is a lack of evidence at the micro level on whether these interventions can be effective in promoting a change in travel behaviour, for whom or in what context. The independent iConnect study set out to evaluate the effects of the Connect2 programme at a population level by developing a before and after panel study (N=1885) and using a postal questionnaire as main survey tool. This questionnaire (self-report instrument) recorded information on demographic and socioeconomic characteristics of participants, their overall travel behaviour (based in last 7-days travel), physical activity and psychosocial and environmental correlates of walking and cycling behaviour (Ogilvie et al. 2012). The study did not provide, however, a detailed account of participants travel behaviour over time at a trip level (including, for instance, trips routes, speed, origin and destination,) nor did it provide information on frequency of use of the Connect2 schemes (Goodman et al. 2013). Moreover, the study did not explore in detail how these new interventions were likely to influence individuals' complex everyday travel decisions either by promoting new trips, a modal shift away from the car or route replacement for some of the journeys.

In summary, there is lack of detailed knowledge on the effects of interventions that improve connectivity for pedestrians and cyclists. Moreover, there is limited understanding and spatial-temporal data available at the micro level, as to how and to what extent interventions delivered by the infrastructural Sustrans Connect2 are being effective in influencing individuals day to day travel decisions. The difficulty in measuring changes in walking and

cycling behaviour and recording spatial-temporal data using traditional methods is acknowledged as a limitation in current studies; however, use of GPS technology seems to open up new opportunities to fill this gap.

1.5 Research aims and objectives

This research aims to develop a better understanding of the links between implementation of physical infrastructure targeted at improving connectivity for walking and cycling at local community level and the influence on personal travel behaviour and associated carbon emissions.

More specifically in relation to the case study, the main research question leading this work is:

- **How and to what extent is local travel behaviour influenced in terms of mode, purpose and spatial-temporal characteristics, among a community served by a Sustrans 'showcase' Connect2 project and what is the overall impact on personal travel related carbon emissions?**

Four sub questions are constructed to address the main question:

1. **To what extent does a Connect2 scheme influence walking for everyday travel and recreation in terms of the nature of journeys and where these take place?**
2. **How does Connect2 influence cycling behaviour among cyclists and non-cyclists, including the nature of their journeys and route choice decisions?**
3. **What is the potential for replacing short car trips by walking and cycling within a community served by a Connect2 scheme and what are the impacts of such shift in carbon emissions levels from surface transport?**
4. **To what extent is use of a GPS based mixed method approach a feasible, reliable and valid method to collect travel behaviour data at the micro level?**

To achieve this aim and answer the research questions this study has the following research objectives:

- To develop a methodology for measuring and evaluating travel behaviour that accurately captures the spatial and temporal dimensions of travel at the micro level;
- To deploy this methodology amongst a local community served by a Connect2 scheme to measure their travel behaviour over time and evaluate changes in travel behaviour and associated carbon emissions;
- To investigate the spatial nature of walking and cycling in the local area and the extent to which the Sustrans Connect2 scheme may have influenced choice of route and time of day;
- To investigate the potential of walking and cycling to replace short journeys by car among a community served by Connect2 and calculate impact in carbon emissions from personal travel.

1.6 Overview of approach and methodology

To achieve the aims of this research a major case study of a 'flagship' Sustrans Connect2 scheme was investigated by developing and deploying a GPS based mixed method approach to observe travel behaviour and impute carbon emissions, at the detailed spatial and temporal level, of a panel of residents living nearby the Connect2 scheme, in Penarth and Cardiff, Wales. A case study approach has the capacity to deal with simple through complex phenomena, while taking into consideration how the phenomenon is influenced by the context within which it is situated (Baxter & Jack 2008; Feagin et al. 1991). The longitudinal panel approach provided an opportunity to explore the causal relationships and the dynamics of change in travel behaviour at an individual level.

In order to overcome some of limitations of traditional survey methods in measuring walking and cycling behaviour, this study has developed a novel mixed method approach to capture participants' overall travel behaviour based on use of GPS loggers (quantitative), travel

diaries (quantitative and qualitative) and contextual (qualitative and quantitative) data. While GPS technology has offered the ability to obtain precise and complete information on individuals' travel behaviour, including trip route, the use of travel diaries has validated data collected and improved the classification of trip purpose and mode (a current issue with GPS technology). Additionally, the collection of qualitative data enables to contextualize walking and cycling behaviour in the local area, changes in travel behaviour over time and the potential role of the new infrastructure. The benefits of a mixed method approach are therefore the opportunity to perform triangulation - which validates and provides greater credibility to the results - while providing a more comprehensive understanding of the relationships that cannot be uncovered when using quantitative or qualitative methods alone (Bryman 2006).

The case study selected to conduct this research was the Connect2 scheme in Penarth/Cardiff, one of the flagship schemes of the Connect2 Programme[2]. The scheme consisted of a new bridge and feeder routes for pedestrians and cyclists connecting the popular seaside resort town of Penarth, to Cardiff Bay, a large and cosmopolitan waterfront development. Cardiff, the capital of Wales, is the ninth largest city in the UK (figure 1.1).



Figure 1.1 - Overview of the core section of the Connect2 Cardiff project: Pont y Werin (source: author)

[2] As an example, the announcement that Sustrans' Connect2 has won the Best Environment Project category in the National Lottery Awards 2013 was made over the Pont-y-Werin, perceived as a showcase and high quality Connect2 scheme.

Participants in this study resided up to 2 miles away from the new Cardiff Connect2 scheme (they were purposively selected from a sub sample of iConnect core survey sample, see Ogilvie et al. 2012) and were invited to record their travel behaviour over periods of 7 days using a combination of GPS loggers and travel notebooks. A total of 50 participants provided completed travel data records (GPS, travel diary and interview) in the two consecutive years of the survey. Data was collected over the same period - April to July – of 2011 and 2012 - in order to minimize any seasonal effects. Collected data was cleaned and processed using a hybrid approach based on trip identification and inference of trip mode and purpose validated by travel diary data. This procedure has allowed the successful identification of 2664 geocoded trips that form the basis of the analysis performed. Travel data was analysed using Geographical Information Systems (GIS) and statistical software and focused on the evaluation of changes in travel behaviour over time, route analysis, assessment of journey transfer potential and calculation of carbon emissions profiles from personal travel. Qualitative data aided analysis and the interpretation of the results; moreover, it was vital in providing a comprehensive understanding of participants' travel decisions and the perceived impact of the Connect2 scheme in the community it served.

1.7 Contribution to knowledge

The results of this study provide detailed evidence on whether a major walking and cycling intervention, the Connect2 Cardiff project, has had the intended effect of transforming everyday travel within the local community. By exploring in detail the nature of journeys recorded and where and when these take place, the results provide new insights into the complexities of walking behaviour and contribute to a better understanding of barriers and enablers of cycling for everyday travel or recreation. Importantly, this study provides detailed methodology and evidence of whether these interventions are effective in influencing individual's everyday travel decisions, why and in what circumstances.

In policy terms this is significant, as it illustrates the effects of significant infrastructural interventions that delivery localised connectivity improvements and their success (or limitations) in encouraging walking and cycling or a modal shift away from the car. This can provide better information for planning practices on likely outcomes of similar interventions and contribute to weighing up such intervention against other alternatives under a similar budget. Moreover, it will contribute to a better understanding of other factors and measures that are likely to influence or enhance the impact of such interventions.

In methodological terms, the study provides an opportunity to demonstrate the advantages and challenges of using a GPS based mixed method approach to record the spatial complexities and dynamics of travel behaviour and which could be administered in other locales. The administration of this approach among a group of residents in a case study site demonstrates the willingness of the public to participate in this method of data collection and the analysis and comparison of the data collected to other sources will inform on its performance, validity and feasibility.

Finally, the tailored assessment for the potential for active travel to substitute short car trips and therefore reduce carbon emissions will contribute to evidence of the growing body of literature on the benefits of walking and cycling as an alternative and sustainable form of transport in our cities.

1.8 Summary and structure of the thesis

This chapter forms Part One of the thesis and has introduced the aim of this study, that is to better understand to what extent connectivity improvements for walking and cycling, namely delivered through the Sustrans Connect2 project, are likely to influence individuals' complex day-to-day travel decisions and carbon emissions from personal travel. The chapter started by outlining why promoting a change towards more energy efficient and healthy methods of travel such as walking and cycling should be a key strategy to enhance mobility and environment quality in urban areas. The chapter then established how government and

institutions have responded to this need in the UK but how successive policies and initiatives have failed to promote a significant increase in cycling or walking levels. The Sustrans Connect2 Programme, one of these recent infrastructural initiatives, was then introduced alongside its aim of transforming everyday travel in 84 communities in the UK by creating new routes that help to overcome barriers for pedestrians and cyclists. Following on the identified limitations of existing research and the significance of the Connect2 programme, the research questions leading this study were described alongside study overall approach. The remainder of the thesis comprises four parts covering literature and evidence review (Part Two), methodology (Part Three), results and analysis (Part Four) and synthesis and discussion of the main findings and recommendations (Part Five).

PART II – LITERATURE REVIEW

Chapter Two provides a comprehensive summary of the policy context for walking and cycling promotion in the UK, its aspirations and some of the key programmes and initiatives implemented over the last two decades. The chapter then explores the role of the leading sustainable transport charity Sustrans as a delivery agent for walking and cycling promotion in the UK and one of its more recent infrastructural flagship projects – the Connect2 Programme. The ambition and aims of the project are presented and its estimated impacts described. The chapter concludes by stressing that at the micro level there is still little understanding about how some of these initiatives, and in particular the Connect2 Programme, influence everyday travel behaviour and carbon emissions from personal travel in a local community.

Chapter Three provides an analysis of the literature reviewed to understand the complex web of factors influencing walking and cycling behaviour and the challenges surrounding its measurement. The first section provides an overview of the theoretical approaches developed to understand travel behaviour and the factors known to influence walking and cycling behaviour with a particular focus given to studies examining the role of infrastructure.

The second part of the chapter examines how walking and cycling behaviour are recorded in the UK and the limitations of the approaches used. It then explores the academic approaches and methods for measuring travel behaviour and the potential of GPS technology. The chapter concludes with a discussion of methodological challenges and knowledge limitations that this study aims to fill.

PART III – METHODOLOGY

Chapter Four introduces the research design and approach adopted in this study to evaluate the impacts of the provision of new infrastructure for pedestrians and cyclists on travel behaviour and carbon emissions in the case study location. The rationale behind a longitudinal panel study design and a mixed method approach for travel data collection is explained alongside the case study site selection process and its context. Finaly, the chapter provides a detailed account of participants' sampling criteria, recruitment and data collection strategies.

Chapter Five provides a detailed account of the methods developed in this study for processing and analysing travel data collected using a mix of personal GPS devices, travel diaries and panel interviews. The various steps of the hybrid approach developed for trip identification and classification are explained and illustrated in detail alongside the methods for data analysis, including carbon emissions calculations and route choice analysis. The chapter concludes by discussing the advantages, feasibility and challenges of using a GPS based mixed method approach to measure travel behaviour.

PART IV– RESULTS

Chapter Six describes the socio-demographic and spatial characteristics of a panel of 50 participants in the case study location and provides their overall travel behaviour over the period of the study, focusing on how, where and for what purpose participants have travelled

regularly. The aim is provide a better understanding of overall travel behaviour in the case study site and establish the context and scope for walking and cycling in the local area. Following on this, changes in overall travel behaviour detected between 2011 and 2012 are identified and reasons underlying such changes are identified across all modes of (local) transport.

Chapter Seven provides a detailed account of walking for everyday travel and recreation in the local area, its complexities and the extent to which the provision of the new Connect2 scheme was likely to have influenced walking in the local community. The chapter starts by contextualizing walking activities in the case study site, focusing on the diversity of travel patterns, perceived barriers and enablers. Following on this, it identifies who and how has used the Connect2 scheme during the period of the study and to what extent did this new route influenced walking activities or was the main reason underlying the changes in walking levels detected over time.

Chapter Eight explores the factors influencing cycling for everyday travel and recreation, the complex process of route choice and the extent to which the implementation of the Connect2 scheme may have influenced cycling behaviour amongst heterogeneous groups of cyclists and non-cyclists. The first part of this chapter contextualizes cycling activity in the local area and describes the characteristics and motivations of a group of 17 participants that have cycled during the period of study, including 3 new starters. The second part examines levels of use of the new Connect2 scheme, route choice decisions and changes in cycling levels over time. The chapter concludes with a discussion of the main findings.

Chapter Nine explores the potential of walking and cycling in contributing to a lower carbon transport system. For this purpose the detailed spatial and temporal data obtained are used to assess the potential for replacing short car trips with walking and cycling and the potential mitigation of carbon emissions associated with such modal shift. The second part examines the extent to which the high profile Connect2 intervention, set within the spatial context of Cardiff, is effective in supporting this shift and its real and estimated impacts.

PART V – SYNTHESIS AND CONCLUSION

Chapter Ten draws together the main findings of the research relevant to the research questions outlined in this chapter. It then discusses the wider policy implications for encouraging walking and cycling for everyday travel. The limitations of the research are acknowledged and discussed and suggestions as to how the research could be extended are provided.

A summary of the structure of the thesis is outlined in the following figure:

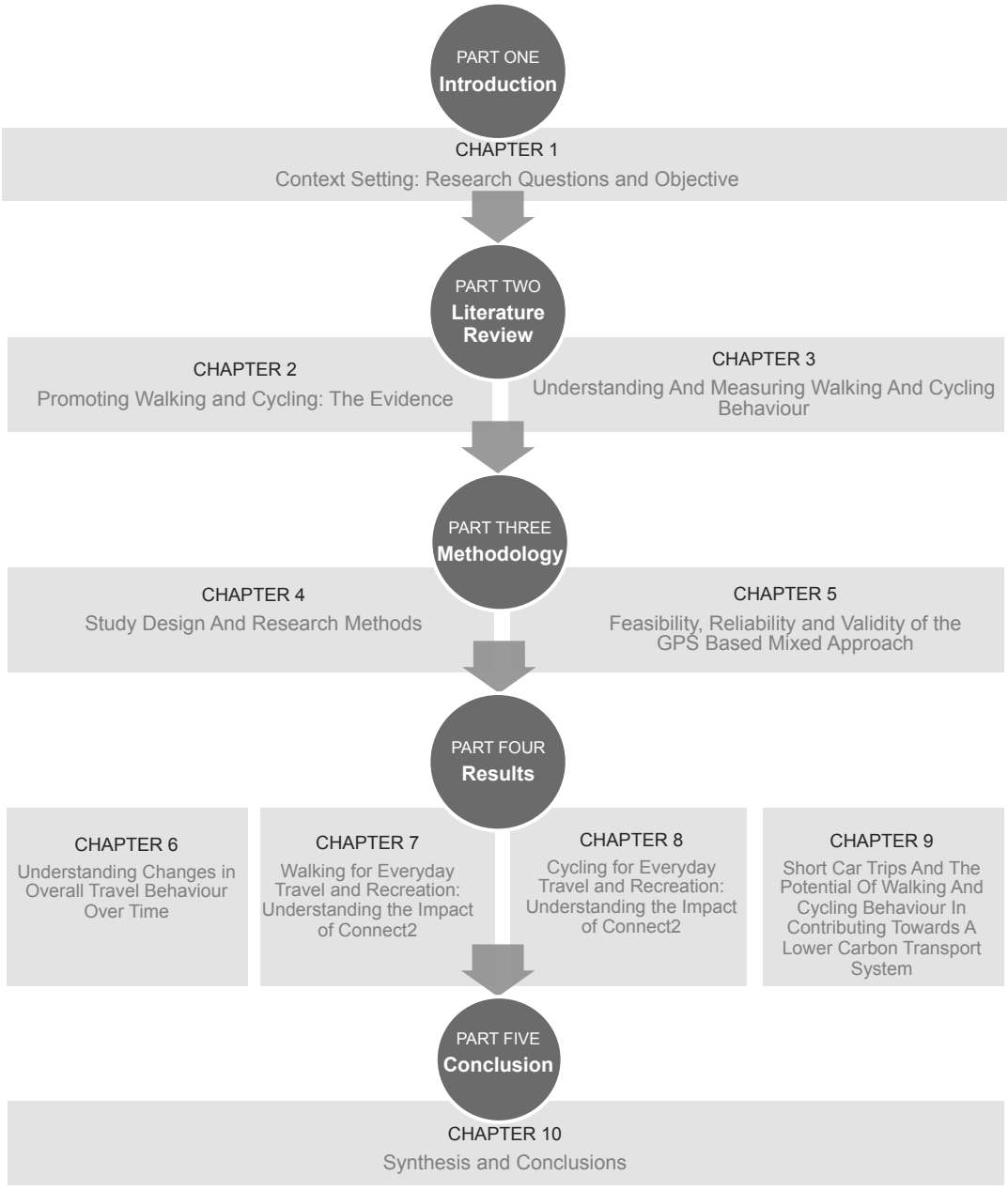


Figure 1.2 – Thesis structure

2 Promoting Walking and Cycling: The Evidence

2.1 Introduction

This chapter examines the context of walking and cycling promotion in the UK over the past 25 years. It investigates the key policies and programmes aimed at increasing walking and cycling levels and how such initiatives have (or have not) been successful in promoting such increase.

The chapter begins by reviewing the literature on the environmental, social and economic benefits of walking and cycling. It then explores the ways in which government, institutions and active groups have responded to these needs in the UK. This includes a summary of the policy context for walking and cycling promotion, its aspirations and some of the most relevant programmes and achievements. The relationship between walking and cycling levels in the UK and such approach are then examined. After this, the chapter focuses on the role of Sustrans, a sustainable transport charity in the UK and a main delivery agent of programmes and initiatives for walking and cycling, and its more recent flagship project – the Connect2 programme.

2.2 Cross sectorial benefits of promoting walking and cycling

Many commentators argue that the increasing evidence of the benefits of active travel in recent years is one of the reasons why government agencies and organizations are now more explicitly advocating walking and cycling as a way to improve population health but also reduce air pollution, carbon emissions, congestion, and other harmful impacts of car use (Pucher et al. 2010a; Pooley et al. 2013; Welsh Assembly Government 2013; NICE 2008; Davis & Cavill 2007; DfT 2010a; Association for Directors of Public Health 2008b; Golbuff & Aldred 2011). Before exploring how walking and cycling have been promoted in

the UK, this section outlines the wider environmental, economic and social benefits of walking and cycling.

2.2.1 Energy use, air pollution (noise pollution) and carbon emissions

Walking and cycling do not require the use of petrol or diesel, consume far fewer non-renewable resources than any motorised transport mode and cause virtually no noise or air pollution (Pucher & Buehler 2010). Energy expenditure from walking is negatively correlated with fossil fuel use (Frank et al. 2010; Brand et al. 2014) and despite cycling cannot be considered a 'zero-carbon emissions' mode of transport – due to energy losses associated with extraction and manufacturing of materials during bicycles and parts productions - lifecycle emissions from cycling are more than 10 times less than those from passenger cars (Blondel et al. 2011).

Table 2.1 – Life cycle analysis by travel mode (CO_2e/ passenger km)

Life cycle analysis by travel mode
(including emissions associated with production, operation and maintenaince phases)
source: adapted from Blondel et al (2011)

Travel mode	Walk	Bicycle	Electric bicycles	Bus	Passenger cars
grams of carbon dioxide equivalent (gCO2e) / passenger km	-	21*	22 **	101***	271***

** include estimated 16 g CO2e/km associated with cyclists required intake dietary*
*** include estimated 6 g CO2e/km associated with cyclists required intake dietary*
**** based on trips similar to those a bicycle would make*

Shifting from car travel to walking and cycling can be more energy efficient as short car trips have a high per-mile fuel consumption and emission rates. A 1% change in mileage from car to non-motorised modes tends to reduce energy consumption and emissions by 2 to 4% (Litman 2014a). Based on the experience from other European countries, there is evidence to suggest that share of journeys on foot or by bicycling can be higher. However, the literature reveals a lack of attention to non-motorised modes in reporting CO_2 emission reduction and climate policies (UK Energy Research Centre 2009).

2.2.2 Health

An extensive body of literature on public health has shown positive relationships between active travel and health. Walking and cycling for daily travel can provide valuable moderate-intensity physical activity with significant health benefits, including decreased risk of ischaemic heart disease, cerebrovascular disease, depression, dementia, and diabetes (Pucher & Buehler 2010; Troelsen 2008; Andersen & Cooper 2011; Woodcock et al. 2009). **Walking** at a moderate pace of 5 km/hour (3 miles/hour) expends sufficient energy to meet the definition of moderate intensity physical activity (Ainsworth et al. 2000). Moreover, walking is a free, convenient and popular form of exercise that can be incorporated into everyday life and sustained into old age (Ogilvie et al. 2007). Studies on **cycling** have also found a positive impact on levels of physical activity, cardiovascular health, morbidity or obesity rates (Butcher 2012; Pucher et al. 2010a; Lusk 2010; Davis & Cavill 2007; Andersen et al. 2000; Bassett David R et al. 2008) and that health benefits of bicycling far exceed the health risks from traffic injuries[4]. As bicycling levels increase, cycling becomes safer and injury rates fall, providing larger net health benefits (Rojas-Rueda & Nazelle 2011; Andersen et al. 2000; Elvik 2009; Pucher et al. 2010a).

2.2.3 Social

Walking and cycling are one of the most affordable methods of travel, due to its simplicity, accessibility, minor equipment specialization, efficiency, and low cost. A shift towards walking and cycling has the potential to reduce the socially divisive and inequitable effects of a transport system dominated by private car travel (Macmillen et al. 2009; Woodcock et al. 2007) and foster a heightened sense of neighbourhood and community (French et al. 2013; Wood et al. 2010). Cycling has the potential to fulfil similar needs of car use (such as freedom, independence as an example) but has also the potential to fulfil other aims and

[4] Andersen et al. (2000) have suggested that non-cyclists have an all-cause mortality 39% higher than those cycle to work and Rojas-Rueda & Nazelle (2011) estimated that health benefits from physical activity outweigh the risks by up to 77:1.

needs, such as combine transport independence with health, physical wellbeing and experience of rural and urban spaces (Troelsen 2008). For this reason, Horton et al. (2007) argues that cycling has also the potential to democratize the idea and appeal of flexible, individual and private mobility.

2.2.4 Economic

Findings from existing studies suggest that investment in walking and cycling are likely to provide low cost and high value options for many communities. A review of available cost benefit evidence in the UK and abroad (including peer reviewed and grey literature) found that most studies reported economic benefits of walking and cycling interventions to be highly significant (median result for all data was 13:1 and for UK data alone was 19:1) (Davis 2010). Other studies have also demonstrated a positive cost benefit ratio from investment in bicycle infrastructure in Netherlands (Fietsberaad 2011), Norwegian cities (Sælensminde 2004) or cyclists and pedestrians in the US (Garrett-Peltier 2011). Benefits include time gained, health, parking costs, employment, environmental benefits or positive economic return through increase retail (Macmillen et al. 2009; Whitehead et al. 2006). In the UK, it was estimated that the overall benefits of cycling would be 3.2 times the costs, and that an estimated 20% increase in cycling trips between 2005 - 2015 would release a cumulative saving of £523m' (SQW 2007). The HEAT tool, developed by the World Health Organization (WHO), estimates that the 'total value to society' from each additional cyclist is at an average of £590 per year (Golbuff & Aldred 2011; WHO 2011).

The empirical literature - mainly from health and physical activity studies - provides extensive evidence of the wider benefits of walking and cycling. However, the CO_2 emissions implications of a modal shift from motorised transport to active travel has received far less attention. The complex relationships between energy use, CO_2 and active travel promotion have been explored in general but active travel analysis is usually speculative, based on the generation of scenarios or not able to detect possibility of small effects. As an example,

Lovellace et al. (2011) concluded that pro-cycling interventions are likely to result in energy savings through reduced consumption of fuel and cars; however, these findings are based on the application of a simple model, borrowed from population ecology. Additionally, findings from one of the first studies to evaluate the impacts of new infrastructure for pedestrians and cyclists on CO_2 emissions from motorised travel in the UK suggested that effects of new infrastructure did not translate into sizeable CO_2 effects across the study population. This research contributes to providing empirical evidence on the real world distribution and effects of active travel promotion on CO_2 emissions from any mode shift away from motorised travel.

2.3 Policies and programmes to promote walking and cycling in the UK

Over the past 25 years UK governments at national (England, Wales, Scotland) and local (e.g. London, Bristol, Oxford) levels have increasingly recognised the above benefits of active travel (walking and cycling) for meeting everyday travel needs. As a result, a variety of strategy documents and initiatives have been published aimed at increasing active travel levels. Simultaneously, a wide range of organizations has campaigned at both local and national levels for better sustainable transport, influencing government policy or leading significant interventions. This section provides a summary of the policy context for walking and cycling promotion in the UK, its aspirations and some of the most relevant initiatives and their (claimed) achievements. Particular attention is given to the policies and activities aimed at promoting cycling levels, as this has been an area of increasing debate and prominent activities.

2.3.1.1 1990s - Cycling becomes visible in the policy discourse

Cycling became visible in the policy discourse in the UK during the 1990s. The first *National Cycling Strategy* was published in 1996 and aimed to quadruple levels of cycling by 2012. Despite criticism received on its high ambition, credibility and questionable effectiveness

(target dropped in 2004 White Paper), this strategy marked a 'breakthrough in UK transport thinking' as it was the first time Government had set objectives to promote cycling in the UK (Golbuff & Aldred, 2011). The launch of the *National Cycle Network (NCN)* was another significant cycling initiative at that time. NCN was delivered by the sustainable transport charity Sustrans, and its aim was to provide a network of 'quiet lanes, on-road routes and traffic- free paths' across the country for transport and recreational uses. While NCN represents a turning point in UK cycling infrastructure provision and its usage continues to increase (Sustrans 2014d), it is acknowledge that the infrastructure provided is variable (Golbuff & Aldred, 2011) and that NCN urban traffic-free cycle paths alone may be insufficient to encourage a shift from car to cycling for everyday travel purposes (Jones, 2012). Other initiatives taking place over that decade included the introduction of *Local Transport Plans* (and requirement for local highway authorities to produce a cycling strategy to facilitate long term thinking at a local level), the Government Cycle scheme or widespread of cycling infrastructure across urban areas in the UK (Headicar 2009). *The White Paper, A new Deal for Transport* (DETR 1998), was to some extent aligned with the growing environmental movement of the 1990's, recognizing the adverse impacts of transport related greenhouse gas (GHG) emissions and making a case for investment in public transport, improvement of infrastructure for pedestrians and cyclists and restrictions on car use (Pooley et al. 2013). The following table summarises some of the most significant policies and programmes aimed at promoting walking and cycling in the UK over the last 25 years. Sustrans Connect2 is highlighted in orange.

Table 2.2 – Relevant policies, programmes and initiatives to promote walking and cycling in the UK

YEAR	POLICY/ PROGRAMMES / INITIATIVES /	AIMS/ OUTPUTS/ TARGETS	OUTPUT	FUNDING
1995	**National Cycling Network** *(Sustrans)*	Create national network of on-road and off-road routes	14,700 miles of signed routes (2014)	Initial budget £42.5 m (estimated cost £200m)
1996	**National Cycling Strategy**	Strategy document to increase cycling levels in the UK (quadruple number of trips by 2012);	Cycling levels in 1996 were under 2% (similar figure today)	
1998	**White Paper,** ***A new Deal for Transport***	Embraced environment movement and recognized need for change; made case for investment on walking, cycling, public transport and reduce car use.		
1999	**Local Transport Plans (LTP) and Local Implementation Plans (LIP)**	Local highway authorities need to produce a cycling strategy plan;		
	Cycle to Work Scheme (to date)	Tax exemption for employers to loan cycles and cyclist safety equipment to employees to cycle to work;	25,000 employers; 120,000 bicycles (2009)	
2000	**Transport for a Ten Year Plan** *(DfT)*	Shift away from a full commitment to a more sustainable transport policy. Greater focus on road and rail.		
2004	**White Paper,** ***The Future of Transport***	Retained a commitment to sustainable transport and traffic management but more priority to road building.		
	The Sustainable Travel Towns / Smarter Choices (2004 - 2009)	Programme of 'smarter choice' measures to reduce car use in 3 towns. Interventions included travel planning, awareness campaigns, public transport marketing and promotion of walking and cycling.	Journeys by bike, foot or public transport increased in all 3 towns	£10 million in revenue funding over 5 years
	Action Plan for Walking and Cycling (DfT, 2004)	Emphasize importance of active travel and presented strategies to achieve goals: provision of routes, travel behaviour change, programmes and training.		
2005	**Cycling England** (2005- 2011)	Independent body funded by the DFT and which vision was to get 'more people cycling, more safely, more often'. Replaced National Cycling Strategy Board.	Cycling Cities, Cycling Towns; Bikeability; Journey Planner	£95m
	Cycling Demonstrations Towns (Cycling England) (2005 - 2008)	Innovate and trial programmes to get more people cycling through a variety of interventions; and demonstrate benefits of investment in cycling. 6 towns (2005-2008); 11 towns (2008 -2011)	Average 27% increase in cycling*(results being reviewed)	£7 m + £ 50m; £500,000 year per city; £10/ head
	Bikeability (Cycling England)	Cycling training; aim was to "give skills and confidence to cycle in modern road conditions"	482,890 school children (2012)	£11 m (2012) + £24m(2013/2014)
2008	**Cycling demonstration Towns**	Additional funding for projects to increase cycling levels in 11 new towns (2008)		£140 m
	Connect2 Programme *(Sustrans)* (2008-2013)	'Transform everyday travel for local people in communities across the UK' by overcoming barriers to walking and cycling.	Improved access to local destinations in 84 communities;	£50m (Big Lottery's) £115m (Local Authorities)
2009	**A walking and cycling Plan for Wales**	Action Plan to promote a walking and cycling culture in Wales and increase walking and cycling levels.		
2010	***Active Travel Strategy*** *(DFT/DoH,2010)*	"Cycling to be the preferred method of local transport in England in the 21st century". Greater emphasis on health benefits of cycling.		
2011	**White paper,** ***Creating growth, cutting carbon***	Shift in responsibility to Local level. Local initiatives to be supported by LSTF fund for which Local Authorities can bid for.		
	Local Sustainable Transport Fund *(DFT)* (to – 2015/16)	Funding to packages of transport interventions to be delivered by Local Authorities between 2011 and 2015/16	96 packages /77 authorities funded	£560m+£40m (2011/12) £64m (2015/16)
2012	**Cities Fit for Cycling**	Cycling safety Campaign/ Manifesto (The Times)		
2013	**Mayor's Vision for Cycling** (to 2021/2022)	New cycle routes or improvement to existing routes and junctions in London; increase safety; Cycling Superhighways, Quietways, Mini Hollands.		£913m
	Get Britain Cycling *(House of Parliament)*	Set of recommendations for central and local government, businesses, third sector to improve cycling		
2014	**Cycling Delivery Plan** *(Government)*	UK Government's 10-year strategy to increase cycling and walking across England. Ambition to double cycling levels and walking to school by 2025.		£10 person/ year by 2020/21 - by working with local government and businesses (aspiration)

2.3.1.2 A shift from infrastructure to soft measures

The start of new century had inaugurated a shift in focus from what had largely been infrastructure based cycling interventions to a variety of 'soft' and 'smarter' measures, focused on individual 'behaviour' through market research, individual travel planning, financial incentives and targeted promotional campaigns (Aldred 2012). Additionally, climate change and the health discourse became more embedded in policy making (Golbuff and Aldred 2011; Nice 2008; A Davis, Valsecchi, and Fergusson 2007; Association of Directors of Public Health 2008b). While there was a continuing commitment to walking and cycling, focus changed however to some extent towards road and rail, as visible in the publication of the *Transport Ten Year Plan 2000* (DfT 2000) and *White paper, the Future of Transport* (DfT 2004a). Example of policy documents that emphasized the importance of active travel for improving health, reducing congestion and community involvement and arguing the case for investment in soft measures included: *Walking and Cycling Action Plan* (DfT 2004b), *Active Travel Strategy* (DfT 2010a) and *NICE public health guidance on promoting walking and cycling* (NICE 2008; NICE 2012).

2.3.1.3 Is this decade the beginning of serious investment in active travel?

Following the change of administration in UK national government in 2010, there was some change in policy emphasis but as yet no significant change of direction in policy. The White Paper, *Creating Growth, Cutting Carbon* (DfT 2011a) stated that improving walking and cycling environment could dramatically improve local accessibility with positive benefits for growth, local economy and health. However, it shifted responsibility to the local level, through Local Sustainable Transport Funds (LTSF) and reserved only a few areas for national policy, such as the Bikeability schemes. Despite the LSTF fund distributed £560 million over 77 local authorities and 96 sustainable transport schemes, the impression was that government de-prioritised active travel. For example, it abolished Cycling England and ended funding for new speed cameras and focused instead on liberalising national policies on car parking and the promotion of low carbon vehicles (cars). Additionally, budget

allocated to LSTF was insignificant compared to other high profile schemes such as the High Speed 2 (HS2) rail project (£32.7- billion) (DfT 2012a).

The Times newspaper – *Cities for Cyclists safety* - campaign, launched in February 2012, arguably provided the catalyst for most of the attention given to cycling by Parliament because of growing concern about the increasing number of cyclists killed and seriously injured on London roads (Butcher 2012). In 2013, an initiative of the All Party Parliamentary Cycling Group, a cross party body with members in both the House of Commons and the House of Lords, interviewed and received written evidence from expert witnesses on the obstacles that must be overcome to enable more people across the UK to take up cycling. A set of measures to be undertaken by central and local government, as well as by world of business and the third sector, were published in a report entitled '*Get Britain Cycling – Summary and Recommendations*'(The All Party Parliamentary Cycling Group 2013). The document highlighted the need for transformation in towns and streets to support cycling, alongside the importance of an action plan and strong vision and leadership.

More recently, in October 2014, the government's 10 year Strategy Plan to increase cycling and walking levels across England was published - Cycling Delivery Plan (DfT 2014b). It featured a number of actions to meet the targets of doubling cycling levels by 2025 and increase the percentage of school children aged 5 to 10 years walking to school to 55% by 2025. Actions proposed include infrastructure development and cycle-proofing roads (DfT 2014b). This plan has however been already criticized for lacking both ambition and dedicated funding (Cyclists' Touring Club 2014; Sustrans 2014b).

2.3.1.4 Unrealised aspirations? Comparison of UK with other European Countries

Despite successive policies, programmes and initiative to promote walking and cycling in the UK, levels are still low and there is little evidence that these initiatives have been effective in promoting walking and cycling at a national scale. England has still some of the lowest rates of cycling in Europe and walking levels are declining.

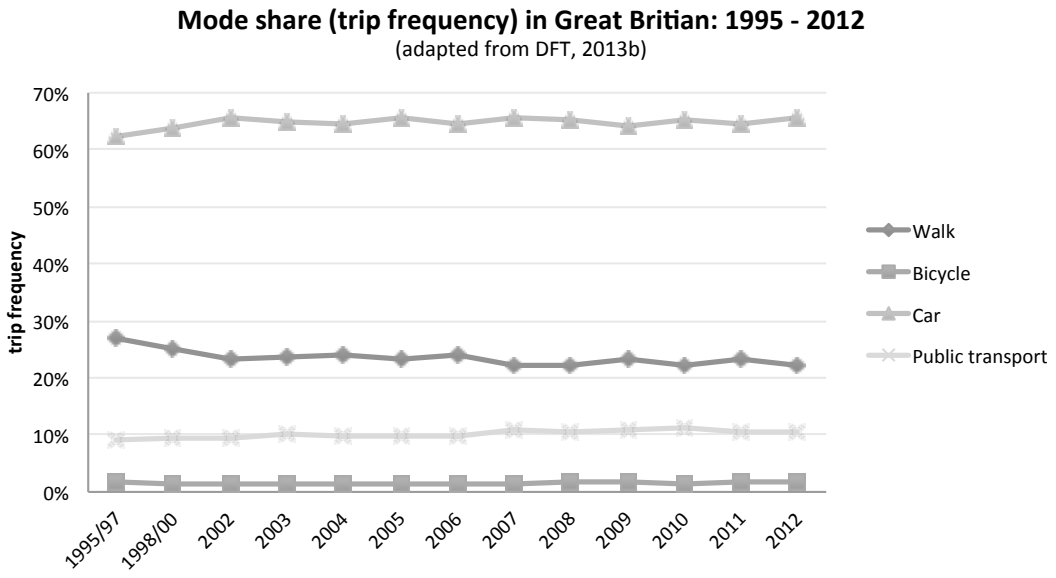


Figure 2.1 - Mode share in Great Britain between 1995-2012 – trip frequency

As shown in Figure 2.1, walking accounted for 22% of trips made in the UK in 2012 but levels have been declining since 1995/97 (DfT 2013b). Furthermore, recent statistics[5] provided by European Cycling Federation (ECF 2013) show that the United Kingdom is in seventh place from the bottom with regards to cycling as a main mode of transport (Figure 2.2). While there are some exceptions at local level, such Cambridge and Oxford[6], in England, only 2% of trips are made by bicycle (DfT 2013b). This is comparatively low, if compared to countries such as Netherlands or Denmark. These countries have invested in cycling over a longer period of time and have, therefore managed to develop a transport system where cycling has higher priority. As an example, in the UK, current spending on cycling is approximately £1-2 per head but the Dutch authorities spend approximately £20 per head and in Germany the figure varies across cities between £6 and £15 (Greater London Authority 2012).

[5] These figures are based on a European-wide survey rather than individual national government statistics.

[6] Cambridge (49%), Oxford (34%) and Richmond upon Thames (19%) exhibit relatively high shares of the population that cycle at least once a week (DfT 2014a).

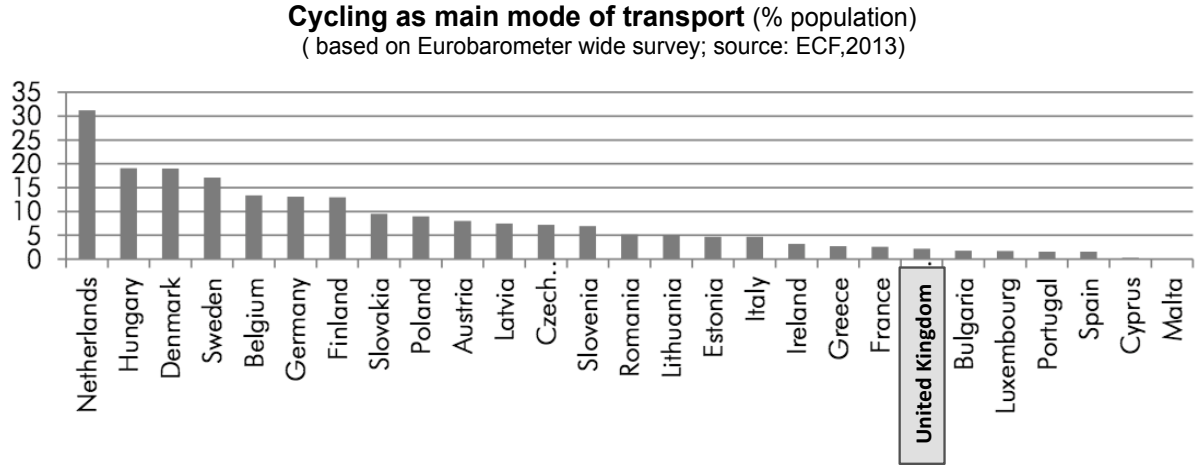


Figure 2.2 – Cycling as main mode of transport by country (% population)

Governmental bodies, such as the Department for Transport and the Cabinet Office, state that *'whole cycling levels have not increased in proportion with the quantity of public funding committed to it'*(DfT 2005: 1) and that '*policy interventions have not yet delivered systematic increases in cycling and walking'* (Cabinet Office 2009: 66). However, others argue that car dominance in British society, economy and transport policy (Pooley et al. 2013), a gap between political rhetoric and the realities of the policy process (Docherty & Shaw 2003; Horton & Jones 2015), lack of core fund, the outsourcing of cycling policy and implementation and a shift in policy governance away from the state and towards the responsible individual (Aldred 2012) are key. These low levels of walking and cycling may also suggest however that there is still a limited understanding on the factors influencing individuals and families complex day to day travel decisions and their poor response to some of these initiatives being implemented (Pooley et al. 2011).

2.4 Sustrans and the Connect2 programme

Alongside the official policies supporting the development of cycling outlined in the previous section are the activities of Sustrans. This section explores the role of the Sustrans in promoting walking and cycling and one of its more recent flagships projects: the Connect2 Programme.

2.4.1 Sustrans – a delivery agent for walking and cycling in the UK

Founded in 1983, Sustrans is a '*leading sustainable transport charity'* responsible for delivery of walking and cycling infrastructure and travel behaviour change projects in the UK. Its ambition is to enable '*people to travel by foot, bike or public transport for more of the everyday journeys'* by creating better conditions for walking and cycling, and to help people to think and change their travel choices (Sustrans 2014a: 1). While its aim is to promote sustainable transport more broadly it has a strong focus on cycling. From the group of organisations promoting walking and cycling in the UK (see Appendix A), Sustrans is the one with more notable success in winning funding and influencing government policy (Pooley et al. 2013).

The National Cycle Network (NCN) is Sustrans central project and it started in 1995 following a £42.5 million grant from the Millennium Commission. NCN has today over 14,200 miles of on road and off road routes with additional proposed routes planned covering both urban and rural areas and aimed at both transport and recreational uses (Sustrans, 2014c). It is claimed that 55% of UK homes are within a mile of a NCN route and usage of NCN continues to increase (Sustrans, 2014b). Sustrans estimates that 4.8 million people used the cycle network in 2013, saving a potential of 425,304 tons of CO_2 emissions from road transport (0.36% of total CO_2 emissions from road transport in the UK[7]) and bringing health benefits valued at £803 million (Sustrans, 2014b).

Beside the development of the NCN, Sustrans develops other projects that aim to increase levels of active travel among communities, workplaces or children and young people. These include Safe Routes to School, Safe Routes to Stations, Home Zones, Do It Yourself Streets, cycle training (Bike it), Travel Smart, Active Travel, Liveable Neighbourhoods, London Quietways and more recently the Connect2 Project. For most of these projects, Sustrans works in partnership with communities, policy makers and partner organizations,

[7] CO_2 emissions from road transport estimated to be 116.7 $MtCO_2$ in 2013 in the UK (Department of Energy and Climate Change 2014).

including local authorities, employers, schools, health sector, and government. Sustrans funding sources are therefore diverse and include charitable grants and trusts, supporter donations, sales but mainly local and central government, which account for nearly two thirds of overall budget, as seen in Figure 2.3 (Sustrans, 2014b).

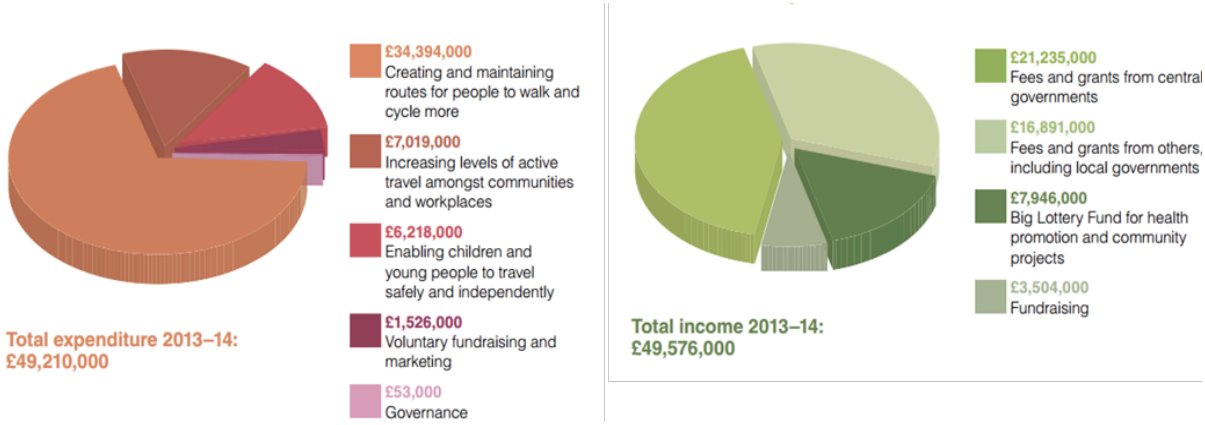


Figure 2.3 – Sustrans funding sources and total expenditure in 2013-2014 (source: Sustrans, 2014b)

While Sustrans' work - primarily the NCN project - represented a critical turning point in terms of cycling infrastructure provision in the UK, it is widely acknowledged that the infrastructure provided is variable (Golbuff & Aldred 2011). Additionally, Sustrans strategies or approaches have been sometimes criticized for focusing too much on traffic free paths (that are mainly used for recreation) and that provision of NCN urban traffic-free cycle paths alone might be insufficient in encouraging a shift from car to cycling for everyday travel purposes (Jones, 2012).

2.4.2 The Connect2 Programme – a recent UK wide infrastructural project

The Connect2 was a £138 million investment programme in walking and cycling infrastructure aiming to '***transform everyday travel for local people in communities across the UK'*** (Sustrans, 2013: 2). The project focused on creating new bridges and crossings for pedestrians and cyclists that would help to overcome barriers to local walking and cycling journeys such as busy roads, rivers and railways.

Sustrans launched the 'Connect2' project in August 2006 in a bid to win £50 million from the Big Lottery's '*Living Landmarks; The People's Millions*' competition. Connect2 was announced as the winning project on 12 December 2007. Following on this, Sustrans leveraged an additional £115 million from local authority partners. The Connect2 schemes were implemented in 84 sites across the country between 2008 and 2013 (Figure 2.4 – Location of Connect2 schemes in the UK

). Each Connect2 site compromised one flagship-engineering project plus improvements to feeder routes. Although the projects were tailored to individual sites, they embodied a desire to create new routes for everyday local journeys on foot or by bicycle (Sustrans 2013).



Figure 2.4 – Location of Connect2 schemes in the UK

Sustrans claimed that the Connect2 project had the potential to transform local travel habits of six million people (10% of the UK population) by creating 360 miles of predominantly

urban new routes and therefore facilitating access to work and local destinations in local communities. At least 2800 schools, 800 supermarkets, 1000 doctors surgeries and 3000 places of worship around the country were within one mile of a Connect2 scheme (Wistow 2008). Sustrans anticipated that the Connect2 programme could transform local walking and cycling trips and contribute to greater grow in walking and cycling as the programme delivered critical solutions to overcome significant barriers in local communities and provided some of the missing links of the NCN (Wistow 2008). To this end, Sustrans forecasted that Connect2 could support over 2000 million active travel trips by 2014 and a significant shift towards sustainable travel modes for short journeys. Sustrans figures suggest that in fact the Connect2 Programme has reduced traffic congestion as a third of people using the new routes could have used a car for their journey and at least one million car journeys were removed from busy roads (Sustrans, 2013b). Moreover, Sustrans estimates that the project brought a significant return on investment (£500m of economic benefit over 30 years) and helped to create jobs and benefits to the economy, mainly from improved health and savings to health budgets (ibid).

An evaluation of the travel, physical activity and carbon emissions impacts of the Connect2 programme was performed by the independent iConnect research consortium (www.iconnect.ac.uk) at three Connect2 sites[8]: Cardiff, Kenilworth and Southampton (Ogilvie et al. 2012). Findings from that study suggested that the Connect2 schemes were well used by local residents but that the schemes may have been more popular for recreation than for transport, and for walking rather than cycling activities (Goodman et al. 2014). The strategic evaluation indicated however that the Connect2 schemes had important health benefits and high benefit cost ratios, at an overall level (ibid). Findings suggested however that extra walking and cycling trips generated by the Connect2 schemes did not represent a modal

[8] The Connect2 Schemes evaluated in the iConnect study were selected based on implementation timetable, likelihood of measurable population impact and heterogeneity of overall mix of sites (Ogilvie et al. 2012).

shift away from motorised travel (Goodman et al. 2014) neither that changes detected could be translated into sizeable CO_2 effects (Brand et al. 2014).

Findings from the iConnect study were based on questionnaires[9] sent to local residents before and after the construction of the Connect2 schemes in 2010 (baseline), 2011 and 2012 (capturing infrastructure use). Sample of the study was 1796 adults in 2011 and 1465 adults in 2012. Questionnaires included one question with regards to the use of the Connect2 scheme and the main purpose for use. The 2010 baseline sample at Cardiff provided the sampling frame for this in-depth DPhil study.

2.5 Summary

This chapter provided the context of walking and cycling promotion in the UK over the last two decades. First, it has outlined evidence that suggests that an increase in walking and cycling has wider environmental, economic and social benefits and could play a role in improving personal health, quality of the urban environment, air pollution or other harmful impacts of car use. While the complex relationships between energy use (CO_2) and transport have been studied, analysis of CO_2 emissions impacts of active travel is usually speculative, based on scenario modelling and has the difficulty of detecting small effects within a heterogeneous population showing wide distribution of emissions.

Following on the identification of the benefits of promoting walking and cycling, this chapter then explored how government, institutions and campaign groups have responded to this need of increasing walking and cycling levels. Key strategy documents, programmes and initiatives were reviewed, alongside aspirations and achievements. From such analysis emerged that walking and cycling levels in the UK are still considerably low when compared to other European countries. While there is an increasing criticism that the policy rhetoric has

[9] The iConnect questionnaire collected data on demographic and socioeconomic characteristics, travel, physical activity and psychosocial and environmental correlates and mediators of these behaviours (Ogilvie et al. 2012).

not met with the resources required to establish walking and cycling as the main modes of travel in urban areas, these low levels of walking and cycling at national level also suggest that there is still little understanding of why people respond poorly to initiatives being undertaken and how these schemes are effective in influencing individuals' complex everyday travel decisions.

The chapter then focused on the role of Sustrans, a key sustainable transport charity in the UK responsible for the delivery of a variety of infrastructural and behaviour changes projects, and its recent flagship project – Connect2. The aims of the project were described and its estimated impacts examined; this included an analysis of the independent iConnect study findings, based on a large before and after postal questionnaire at three Connect2 case study sites. While results from that study suggest a positive impact of the new Connect2 schemes in influencing walking and cycling levels, there is little understanding at the individual level, how these interventions influenced complex everyday travel decisions and promoted (or not) more walking and cycling.

The next chapter provides a more in-depth review of the factors influencing walking and cycling behaviour, with a focus on the role of infrastructure.

3 Understanding and Measuring Walking and Cycling Behaviour

3.1 Introduction

This chapter presents the literature review that was undertaken to understand the key factors influencing walking and cycling behaviour and the extent to which the provision of facilities for pedestrians and cyclists are associated with walking and cycling levels.

The first section of the chapter provides an overview of the theoretical approaches developed to understand walking and cycling behaviour and the complex web of environmental, socio –demographic and individual factors associated with walking and cycling. The chapter then focuses on studies that examine the relationship between infrastructure and walking and cycling levels. The second part of this chapter examines the challenges surrounding the measurement of walking and cycling behaviour. It starts by exploring how walking and cycling behaviours are recorded in the UK and the limitations of the approaches used. It then focuses on academic approaches and methods for measuring travel behaviour and the increasing potential of GPS technology. The chapter concludes with a discussion of methodological challenges and limitations of knowledge base that this study aims to address.

3.2 Understanding walking and cycling behaviour

Walking and cycling have traditionally received little attention within the transport research field and have not been conferred the same status as motorised forms of transport. However, this has been gradually changing in recent years, as more studies are now exploring walking and cycling and factors influencing it. As a result, the existing literature on walking and cycling is gaining ground in terms of quality and breadth as it stems from

different approaches including traffic engineering, urban design, environmental studies, public health or socio-cultural perspectives on processes and experiences of mobility.

3.2.1 Theoretical approaches in travel behaviour research

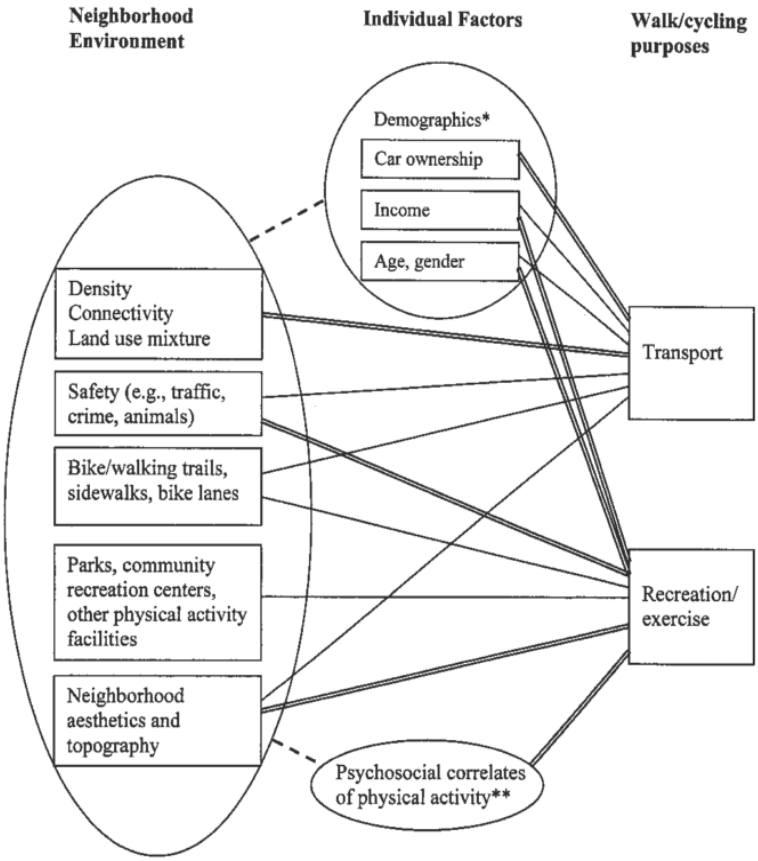
Different theoretical approaches and models have been developed for the purpose of understanding travel behaviour and explain why people choose to travel in different ways.

Theories derived from social psychology approach behaviour as a function of internal factors dominant to the individual. Theory of Planned Behaviour (TPB) (Netemeyer et al. 1991), a common theoretical input to travel behaviour research, states that intentions to perform behaviours can be predicted from attitudes towards the behaviour, subjective norms (perceived social pressure to perform a behaviour) and perceived behavioural control (evaluation of resources and skills to perform behaviour). This approach does not encompass, however, the influence of physical environment as assumes external factors to be mediated through these cognitive constructs. Additionally, it is argued that human behaviour is not always reasoned (Aarts et al. 1997), that having attitudes and values that identify with more sustainable travel does not mean that these beliefs are carried through into everyday life (Shove 2010) or that behaviour can also be influenced by habituation process and therefore decisions become automatic and less reasoned (Ajzen 2002). Early physical activity research in the the public health field focused on the psychology surrounding indidivual and their choice to be active (Adjei & Behrens 2012).

Utility maximizing theories (economic consumer theory choice), on the other hand, approach behaviour as a product of external factors and assume that individuals choose the option that maximizes their utility (Ben-Akiva & Lerman 1985). Utility is assumed to depend on cost, time and effort of a travel option; and an increase in any of these factors is likely to influence modal choice (Heinen et al. 2010; Krizek, Handy, et al. 2009). Travel behaviour researchers that have worked with this framework emphasized the role of environmental factors in influencing costs of travel. While research grounded on utility maximization theory

has revealed multiple associations between built environment characteristics and travel behaviour (Lee & Moudon 2006), the role of distance and quality of the environment seems to be particular relevant if extending this theory to the study of walking and cycling (Krizek, Handy, et al. 2009). Research in this field have not yet been clear, however, about the relationships between travel choices and individual characteristics or social environment factors.

Socio-Ecological models converge both of the above theoretical perspectives and posit that travel behaviour has multiple levels of influence that include intrapersonal, interpersonal and environmental levels (Sallis & Owen 1997). Based on this approach, Saelens et al. (2003) has developed a socio ecological model focused on walking and cycling as the behavioural outcomes of interest (Figure 3.1).



Source: Saelens, B.E., Sallis, J.F. & Frank, L.D., 2003. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, 25 (2); pp80-91. Figure 2.

Figure 3.1 – Saelens' ecological model of neighbourhood environment influence on walking and cycling

Using such framework, Saelens demonstrated that a complex web of environmental (infrastructure, street connectivity/layout, accessibility, land use mix, settlement size, topography), socio-economic (age, gender, income) and individual factors (beliefs, attitudes and perceptions) interact and influence walking and cycling, both as a mode of travel and as a recreational activity (Saelens et al. 2003).

This model underpins the applied ecological framework (Figure 3.2) developed by the iConnect study for the evaluation of the behavioural effects of interventions in the built environment to promote walking and cycling (Ogilvie et al. 2011). By specifying the key variables and causal pathways by which interventions are believed to work, the model developed by the iConnect study is useful for guiding analysis of interventions in heterogeneous and complex intervention sets.

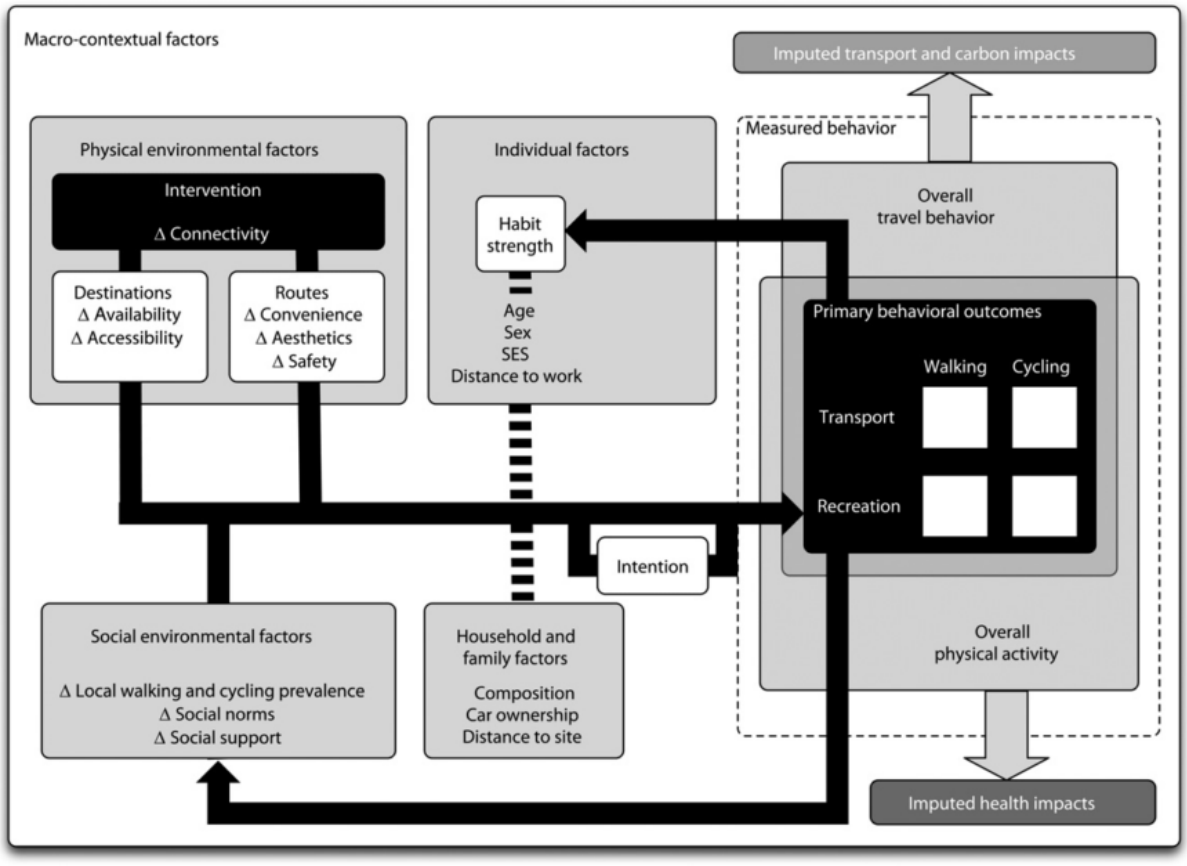


Figure 3.2 – Applied ecological framework developed by the iConnect study for evaluation of behavioural effects of interventions in the built environment to promote walking and cycling (source: Ogilvie et al. 2011)

This conceptual framework provides a simple explanatory model for how interventions that improve connectivity for pedestrians and cyclists are likely to work. The solid connectors indicate the primary causal pathway for the intervention; whereas the dotted connectors indicate the moderators of that causal pathway (Ogilvie et al. 2011). This study uses an adapted form of this conceptual framework to guide the research. Chapter 4 describes how the assumptions and concepts underpinning this theory were operationalized to investigate the behavioural effects of a new Connect2 scheme.

3.2.2 Environmental and individual factors influencing walking and cycling behaviour

Using a socio ecological modelling framework, this section gives a brief overview of the empirical work that has considered physical, environmental, social and individual factors as determinants of walking and cycling behaviour. The specific role of infrastructure is analysed in detail in the following section.

3.2.2.1 Physical Environment

The literature examining relationships between travel behaviour, including walking and cycling, and **land-use** characteristics is extensive (Pucher & Buehler 2010; Cervero et al. 2009; Moudon et al. 2005; Banister 2009; Ewing & Cervero 2010; Littman 2006). Most findings suggest that a mixed land use that directly influences locations of residences and workplaces relative to the city-level or metropolitan centre structure and provides a mixture of functions in a neighbourhood reduces travel distances and has, therefore, positive impacts on walking and cycling levels (Heinen et al. 2010; Forsyth & Krizek 2010; Badland & Schofield 2005; Goeverden & Godefrooij 2011). Equally, **density** is likely to influence travel behaviour and mobility patterns (Badland et al. 2008; Cervero et al. 2009; Rodríguez 2004) as in higher density urban areas, distances between locations are shorter, and can, be bridged more easily on foot or by bicycle (Heinen et al. 2010). **Accessibility,** which is determined by the characteristics of land-use system (where activities are located) and the

transportation system (how the locations of activities are linked) has also been associated with physical activity and/ or walking and cycling (Chin et al. 2008; Handy & Niemeier 1997; Cervero et al. 2009).

The relationship between **urban spatial structure** and travel behaviour have been extensively examined too (Naess 2006) and findings suggest that neighbourhoods with smaller residential lot sizes and gridded narrow streets have higher levels of walking, as an example (Brown et al. 2007; Van Dyck et al. 2009). Likewise, **settlement size** is also known to influence travel behaviour (Banister 2007) as it influences the proximity of destinations and this is particularly relevant for walking and cycling. In the Netherlands, small and medium-sized cities have, as an example, a highest bicycle share (Rietveld & Daniel 2004).

Neighbourhood characteristics - such as availability of safe routes and crossings, lighting, presence of parks, trees and shades, or convenience of nearby facilities - can also be associated with higher levels of walking and cycling or physical activity levels (Ogilvie et al. 2011; Saelens et al. 2003; Handy 2004; King et al. 2011; Boehmer & Hoehner 2006; Boone-Heinonen et al. 2010; Susilo et al. 2012). On the other hand, **quality and attractiveness** of the environment (including architectural aesthetics and activities in the street scene) are likely to stimulate active travel, as walking and cycling are slower speed modes and are more exposed to the environment (Timms & Tight 2010). Additionally, measures that influence traffic volume and speed, such as traffic calming measures, are likely to have positive impact on cycling levels too (Winters & Teschke 2010).

The **connectivity** of the built environment - defined by the directness of links and the density of connections in a network - has found to be significant in studies of **walking** (Li et al. 2005; Frank et al. 2004; Ewing et al. 2008), **cycling** (Dill & Voros 2007; Cervero et al. 2009) or both walking and cycling (Badland et al. 2008). Well-connected networks of paths have many short links and numerous intersections, providing, therefore, more route options and reducing distances between origin and destinations, which is particular beneficial for walking and cycling. Methods for systematically measuring connectivity of a given area have been

developed (Dill 2004, Tresidder 2005); however, results are sometimes mixed and the association between connectivity and walking and physical activity could not always be established. As an example, while some studies found connectivity to be significant for walking and cycling (Dill & Voros 2007; Cervero et al. 2009; Frank et al. 2004; Li et al. 2005; Ewing et al. 2008), empirical evidence from other studies could not support this association for neither walking (Cervero & Duncan 2003; Rutt & Coleman 2005; Lovasi et al. 2008) or cycling (Moudon et al. 2005; Zacharias 2005)**.** As a more recent example, in the UK, the Understand Walking and Cycling (UWAC) study (2009-2011) found a positive association between connectivity and walking but could not establish a similar association for cycling (Jones et al. 2013).

3.2.2.2 Natural Environment

Natural environment factors may not be a barrier for motorised transport, however, for walking and cycling, certain features are likely to influence travel behaviour decisions. Studies suggest that **hilliness** and slope are likely to increase the amount of effort that cyclists need to make (Rodríguez 2004; Parkin et al. 2007); however, topography is likely to be differently interpreted by individuals (Heinen et al. 2010; Stinson & Bhat 2005). Scarf and Grehan (2005) suggested that a 1 m of vertical travel on a bicycle can be considered to be equivalent to approximately 8 m of horizontal travel. **.Seasons and climate**, in particular cold or **wet conditions**, are also acknowledged to influence individuals level of comfort while travelling (Krizek, Forsyth, et al. 2009) and, as an example, influence odds of commuting to work by bicycle (Flynn et al. 2012). **Hours of daylight/ darkness,** which is also related to seasons, is also likely to impact on cycling commuting levels (Gatersleben & Appleton 2007; Winters, Davidson, et al. 2010). While the **wind** clearly influences the amount of effort made cyclists, little is known about its effect on cycling (Heinen et al. 2010) or walking. Furthermore, little is known about measures and facilities that lessen negative effects of weather (Heinen et al. 2010) or equipment and education programmes that alter perceptions of some of these features as barriers to cycling and walking (Krizek, Forsyth, et al. 2009).

3.2.2.3 Socio Demographic

Several studies have also established associations between some socio demographic factors, such as gender, age, income, employment status and cycling or walking activity. In general, studies suggest that men are likely to cycle more often and for longer distances that women (Dill & Voros 2007; Steinbach et al. 2011; Garrard et al. 2008) and that cycling levels are likely to decline with individuals age (Dill & Voros 2007; Zacharias 2005). In the UK, cycling is most prevalent among men (23 trips person per year compared with 9 trips by women) but walking rates are similar across gender (DfT 2013b). Also for walkers, there are far smaller differences between age groups than for cycling (DfT 2014a).

The relationship between physical active modes and income is however not clear. Goodman (2013) found that in England and Wales it is more common for socio-economically disadvantage groups to commute using physical active modes; however, for cycling, that association is weaker. In the US, Pucher, Buehler, et al. (2011) found that bicycling rates vary more significantly by purpose rather than by income level as low-income individuals cycle mainly for utilitarian purposes while high-income individuals cycle more for recreation and exercise.

Transportation cost has also an impact on modal choice. Cycling affordability is usually one of the reasons given by individuals commuting by bicycle (Bergström & Magnusson 2003). Inversely, petrol prices (Pucher & Buehler 2006) or free public transport are likely to reduce bicycle use (Bamberg et al. 2003). Car park cost and availability[11] can also influence active travel modes (Buehler 2012) and **car ownership** has a strong negative effect on cycling mode share (Parkin et al. 2007; Pucher & Buehler 2006; Goodman et al. 2012).

Employment status and household structure is also likely to influence active travel as some authors found that students, individuals without children and those in between jobs

[11] As an example, it was found that free car parking at work was associated with 70% smaller odds for bike commuting in Washington, DC (Buehler 2012)

were more likely to cycle, as an example (Ryley 2006; Moudon et al. 2005). Finally, associations have also been established between socio economic factors and choice of neighbourhood where to live, which indirectly influences travel choices (Pikora et al. 2003).

3.2.2.4 Individual Factors

Various associations have also been established between individual factors such as **attitudes, perceived values, habits, social norms** and likelihood of walking but more visibly, cycling. The importance that individuals attach to the health-related benefits of cycling (Gatersleben & Appleton 2007b), the negative perception of the consequences of car use (Stinson & Bhat 2005) and altruistic and ecological beliefs (Moudon et al. 2005) are likely to influence individuals decision to cycle. Moreover, cycling as a child increases the likelihood of cycling as an adult (Dill & Voros 2007) and cycling culture within a country or region is also acknowledge to influence cycling acceptance (Pucher et al. 1999). A person's evaluation of the possibility of performing certain behaviour (perceived behavioural control) also influences mode choice and, as an example, individuals who do not commute by bicycle perceive more barriers to commuting by bicycle than bicycle commuters (Gatersleben & Appleton 2007b).

Travel time and effort also influence choice for active travel modes. Wardman et al. (2007) suggests that travel time by bicycle is three times more unpleasant than travel time by other modes and Gatersleben & Appleton (2007b) argue that extra effort required generally results in a less positive attitude to cycling. Inversely, some cyclists choose to cycle precisely because of the effort needed - as an example those interested in sports or maintaining their health - and may therefore prefer longer commuting distances (Heinen et al. 2011). **Safety fears** have also frequently emerged as barriers to walking (Brown et al. 2007; Li et al. 2005) or often mentioned as a reason not to cycle (Pucher & Buehler 2006). Objective and perceived safety are important and can be influenced by environmental/social factors that might trigger fear of crime, traffic or distance (Chin et al. 2008). Danger and vandalism are

likely to be some of the most exogenous restrictions to cyclists (Fernández-Heredia et al. 2014).

The Understanding Walking and Cycling Project (UWAC) have recently examined the complexity of factors influencing everyday travel decisions in four English Towns (Leeds, Leicester, Worcester, and Lancaster). Findings from the study suggested that whilst attitudes to walking and cycling are usually positive or neutral, a combination of factors is likely to limit many people to engage in more active travel. Those include concerns about physical environment (especially safety), difficulty to fit walking and cycling into complex household routines and perception of walking and cycling as abnormal things to do (Pooley et al. 2011). The case study sites were selected to be broadly representative of a range of communities within the country and all urban areas had a number of interventions to promote more sustainable and active travel in recent years (Pooley et al. 2013). While the study employed an innovative multi-method approach for data collection, including collection of quantitative and qualitative data, it did not focused on the impact of a specific intervention for walking and cycling neither employed objective measurements strategies for recording changes in travel behaviour over time.

In conclusion, the literature suggests that a complex set of environmental, social and individual factors are associated with or influence walking and cycling behaviour. However, most studies examine only a limited number of factors at a time and focus on one mode of travel (either walking or cycling) or for one specific purpose (commuting, utility, leisure, etc.). Additionally, findings are sometimes mixed or limited. As an example, while some studies found connectivity to be significant for walking and cycling, empirical evidence from other studies could not support this association for either walking or cycling. Finally, there is little evidence from in-depth studies to support/ demonstrate that interventions in the built environment through connectivity improvements have led to changes in travel behaviour.

The next section explores in more detail the role of infrastructure in influencing walking and cycling behaviour.

3.2.3 The role of infrastructure

The availability of infrastructure is obviously related with travel behaviour; however, the role of walking and cycling infrastructure in transport choice has not been frequently evaluated. Existing studies support however the notion that availability of routes for walking and cycling are associated with patterns of physical activity in general, or walking (Ogilvie et al. 2011; Saelens, Sallis, and Frank 2003; Handy 2004) and cycling (Pucher, Dill, and Handy 2010a; Dill 2009; Forsyth and Krizek 2010) separately.

3.2.3.1 Cycling Infrastructure

Comparative studies suggest that countries with more cycling facilities have a higher modal split share of cycling and higher levels of bicycle safety (Pucher & Buehler 2008; Pucher et al. 2010a; Heinen et al. 2010) and that improving infrastructure for cycling (and community wide interventions) have the potential to increase cycling levels (Yang et al. 2010). Studies at a city level in Netherlands, Denmark, USA or Australia have detected or explained an increase in cycling levels due to cycle infrastructure provision.

In the **Netherlands,** a before-and-after study following the extensive provision of cycling infrastructure (bicycle paths, contra-flow lanes, bridges and underpasses or paths resurfacing) has detected a 1-3% increase in cycling levels and a 6% increase on average distance travelled over a period of 3 years (Wilmink & Hartman 1987). In **Denmark**, a controlled repeat cross sectional study comparing national travel survey data collected in Odense and in nearby cities between 1996-97 and 2002 found an increase in the proportion of all trips made by bicycle from 22.5% to 24.6% (Troelsen et al. 2004). Findings from revealed preference studies conducted in **USA** also found that cities with a greater provision of cycling infrastructure have also higher cycling rates (Buehler & Pucher 2011). Moreover, stated preference surveys in Boston, Gainesville and Portland also stated the lack of facilities are usually the main reason given by people for not commuting by bicycle (Dill & Gliebe 2008). In **Australia**, Melbourne and Sidney's difference in cycling levels has been

explained by faster and more integrated approach in cycling infrastructure provision (as well as cycling promotion) (Pucher, Garrard, et al. 2011).

In the **United Kingdom**, the Cycling Demonstration Towns programme found that number of adults cycling in a typical week increased by 14% over a period of 3 years[12] following improvements to infrastructure in 6 selected towns (alongside media campaigns, personalised travel planning, cycle repair and cycle training services) (DfT 2009). And more recently, the iConnect study reported a 5-12% increase in cycling levels in three communities where a new route for cyclists was implemented (Goodman et al. 2013).

There are different **typologies** of cycling infrastructure according to level of segregation from road traffic. Those include bicycle lanes, bicycle paths or on road shared with motor traffic (Figure 3.3). While there is an on-going debate on the advantages and disadvantages of segregation or a vehicular traffic approach to cycle infrastructure provision, it is commonly agreed that segregation between cars and bicycles is preferred where there is a large difference between speeds (Goeverden & Godefrooij 2011; Reid & Adams 2011). Moreover, it is also acknowledged that qualities and potentials of each typology should be considered depending on the context where infrastructure is implemented (Silva et al. 2011).



On-road shared with motor traffic | Bicycle lane | Segregated bicycle path

Figure 3.3 – Main typologies of cycling infrastructure (source: author)

[12] Net increases (between 2005 and 2008) in the proportion of residents who reported cycling for at least 30 min once per month (+2.78% or +1.89%) or 12 or more times per month (+0.97% or +1.65%) (Yang et al. 2010) .

Cycle paths (segregated from cars) are associated with a higher share or increase in cycling levels (Pucher & Buehler 2006; Barnes et al. 2006). Infrequent or less experienced cyclists are more likely to prefer bicycle paths to bicycle lanes (Hunt & Abraham 2006; Heinen et al. 2011); and potential users usually claim that they would cycle more often if there was a good provision of bicycle paths connected to desired destinations (Dill & Voros 2007; Heinen et al. 2011). The provision of **bicycle lanes** (painted lane/strip on road pavement) has also been associated with a positive and statistically significant relationship in cycling (Dill & Carr 2003; Nelson & Allen 1997; Parkin et al. 2007; Pucher et al. 2010a). However, some studies at disaggregate level could not established such association for at least cycling for transportation (Moudon et al. 2005; Dill & Voros 2007).

In streets where volume of motorised traffic is low and speeds are similar to cyclists, dedicated infrastructure may not be required (Goeverden & Godefrooij 2011). Existing evidence suggests however that cyclists felt most at risk on mixed traffic, regardless of age, gender or reason for cycling (Jensen 2007) and that both cyclists and non-cyclists usually preferred having bike lanes to riding in mixed traffic (Pucher et al. 2010a).

Provision of safe cycle parking infrastructure, presence of showers and changing facilities at work and junctions, traffic lights and number of stops along a route are also likely to influence cycling levels (Pucher et al. 2010a; Hunt & Abraham 2006; Litman et al. 2009; Heinen et al. 2010).

Preference for cycling facilities is likely to vary across individuals or journeys as inexperienced cyclists, women and younger cyclists usually find bicycle facilities more important than other users (Dill and Gliebe 2008; Pucher, Dill, and Handy 2010a; Emond, Tang, and Handy 2009). It is also argued that presence of cycle infrastructure may also influence route choice, as bicyclists are likely to detour to use bicycle facilities. Krizek et al (2007) found that bicyclists riding on a trail in Minneapolis were willing to travel, on average, 67% further to use the trail; and Dill (2009) found that almost half the miles recorded from 166 regular cyclists (1,800 trips) took place on roads with cycling infrastructure despite they

represented just 8% of existing road network. However, more experienced cyclists, such as bicycle commuters, seem to be less willing to sacrifice time to use dedicated bicycle facilities and tend to divert very little from shortest path (Dill & Gliebe 2008; Aultman-Hall et al. 1997).

In the UK, cycle specific infrastructure has been built in urban areas since the 1990s. However, it has been often criticized for its inconsistency, lack of connectivity, quality or directness (CEoGB 2014). It is also argued that cycling infrastructure usually appears as an add-on to a car system rather than a coherent system and that is usually implemented where it does not adversely impact with other modes of transport (Aldred 2012).

3.2.3.2 Walking infrastructure

In contrast to cycle infrastructure, it is usually assumed that basic provision of infrastructure for pedestrians should be enough to enable adults to walk (Krizek, Forsyth, and Baum 2009; Hoehner et al. 2005). Walking is the most common and preferred form of physical activity for the general population (Badland & Schofield 2005) and its popularity likely stems from its accessibility and negligible equipment specialization (Siegel et al. 1995).

Several studies suggest that footpaths are relevant and that people report to walk more if they perceive the environment as accessible and provided with high-quality sidewalks or paths (Brown et al. 2007; Saelens et al. 2003; Duncan et al. 2009; Giles-Corti & Donovan 2003; Krizek, Forsyth, et al. 2009). The connectivity of the paths is likely to be important (Li et al. 2005; Frank et al. 2004; Ewing et al. 2008) and the presence of footpaths is likely to improve perceived perception of safety (Krizek, Forsyth, et al. 2009).

Some authors suggest that other types of infrastructure, that are not dedicated exclusively to pedestrians, may also have a positive effect on walking levels. These include traffic calming measures that reduce traffic speed and that can therefore contribute to reduce number of accidents or its severity, as an example (Dumbaugh & Frank 2007). In some studies the association between footpath provision and utility walking could not be however established (Forsyth & Krizek 2010; Lee & Moudon 2006).

In conclusion, various studies have looked to the role of infrastructure in influencing walking and cycling levels; however methodologies vary widely between studies and there is a dominance of studies that used revealed preference methods and aggregated level analysis. While existing evidence supports the need for infrastructure, it is sometimes difficult to understand the effects of infrastructure provision on travel behaviour change and in particular for whom (potential users, experienced and inexperienced users) or what purposes (recreational or utility). Moreover, empirical evidence on the role of infrastructural connectivity is sometimes mixed (Dill & Voros 2007; Cervero et al. 2009; Frank et al. 2004; Li et al. 2005; Ewing et al. 2008; Jones et al. 2013); and its relationship with route choice decisions is limited. As an example, there is little evidence on how much, and for what reasons, people deviate from the shortest-path or the strategies that cyclists use to determine their route choice.

In conclusion, this section has highlighted the ways in which walking and cycling has been studied and the factors that are thought to influence whether people engage with them for everyday travel. Using a socio ecological framework, the complex web of environmental, socio demographic and individual factors associated with walking and cycling were reviewed. Existing literature suggests that built environment features that promote shorter distances and enhance the experience of walking and cycling are essential but that presence of infrastructure is also crucial, in particular for cycling. Studies reviewed suggested however that there are still some limitations in understanding the effects of continuity of infrastructure for walking and cycling or little evidence from interventions studies that show that changes to the built environment through infrastructure provision alone lead to a change in travel behaviour.

The next section explores the approaches used to measure walking and cycling behaviour.

3.3 Measuring walking and cycling behaviour

Some of the limitations on existing evidence are related with the difficulty in measuring walking and cycling behaviour, which has been recognized in both the transportation and the physical activity fields (Krizek, Handy, et al. 2009; Craig et al. 2008). As travel patterns are arguably becoming more complex in terms of time, space and modes of travel, seem to suggest that new approaches for travel data recording maybe required, in particular those that can provide a greater detail and less burden for participants (Bohte & Maat 2009).

This section examines how walking and cycling behaviour are recorded in the UK and surrounding issues. It then outlines academic approaches employed to measure travel behaviour and explore the increasing role and potential of GPS technology for this purpose.

3.3.1 The measures used in UK Policy

The National Travel Survey (NTS) and Sustrans monitoring provide the primary sources of data on walking and cycling in the UK.

The **National Travel Survey (NTS)** is a large scale survey delivered in England each year (16,000 individuals, in 7,000 households) and is designed to monitor long-term trends in personal travel and to inform the development of policy (DfT 2013a). NTS data is collected via face-to-face interviews and a one-week self-completed written travel diary; statistics on active travel are collected via an annual telephone survey of adults (Active People Survey (APS7), administered by Sport England (DfT 2014a). Some of the limitations of the NTS data in capturing walking and cycling behaviour are, however, that trips that take place off the public highway (open countryside or unsurfaced paths) or trips which are themselves a form of recreation are not included. Moreover, short walks are likely to be underreported in the NTS data as they are only recorded on the seventh day of the travel diary (DfT 2013a). Some argue that data generated by DfT may therefore fail to pinpoint clear trends in cycling and to reflect, as an example, the success of the National Cycle Network (Moore et al. 2006).

Sustrans uses a variety of tools for monitoring and evaluating walking and cycling. Most common are Route User Intercept Surveys (RUIS) and manual or automatic counts. RUIS capture data on trip type, modal selection, origin and destination and respondents profiling at selected sites (Moore et al. 2006). Automatic and manual counts record cycling and walking flows using either counter units at specific sites or commissioned repeated counts. Their practicality, sampling statistical power and validation or costs pose however some limitations (Cope 2011; Sustrans 2014a). Moreover, and more importantly, collected data is aggregated and focused on users of Sustrans routes. More recently, Sustrans has developed a methodology to estimate usage on route or network. The Whole Scheme Usage Estimate (WSUE) enables geographically distinct sources of data collected on a network of routes to be combined to provide an estimate of overall use (Sustrans 2014a). For sections of the schemes not covered by data, assumptions are however still performed and the risks of both under or over estimation are recognized (ibid).

3.3.2 Other measures

In general, researchers that conduct studies on travel behaviour have relied on **self reports, observation or instrumentation** to capture travel data. Data collected using observational or instrumental approaches are considered better quality and more accurate to those obtained by self-reported means. Self-report measures are however more accessible, easier to apply to larger samples and cheaper. Krizek, Handy, et al. (2009) argue that each one of these strategies have distinct advantages and disadvantages and are more or less appropriate for different dimensions of walking and cycling. As summarised Table 3.1, self-report strategies can capture individuals overall travel behaviour but are not able to provide detailed data on journeys route and distance.

Table 3.1 - Level of accuracy of different travel behaviour measurement strategies (adapted from Krizek et al, 2009)

Mesurement strategies	**Phenomenon or behaviour to mesure**				
	who does and does not walk or cycle	number of trips	distance	purpose and destination	route
Self report	+	✓	-	+	-
Observation	-	+	-	-	✓
Instrumentation	+	✓	+	-	+

\+ *is good at capturing this phenomenon/ behaviour*
✓ *fair*
\- *poor*

Travel surveys and travel diaries have been the conventional method for travel data collecting in transport research. Initially, travel behaviour data was collected through paper or phone recall surveys and participants were asked to describe or reconstruct their travel behaviour on an average day. In the late 1990s, the use of paper travel diaries become more popular. In those, participants were asked to record time, origin and destination, and the method and purpose of travel (Bohte & Maat 2009). In most countries, information about daily travel patterns at a national level is still captured using self-reported methods (written diary/survey, telephone retrieval or mail-back of diary forms).

Despite self-report instruments have been fundamental in recording travel behaviour, several issues and limitations have been recognized. They are likely to underreport short trips (Bohte & Maat 2009), overestimate or round off travel times (Dill and Gliebe 2008), overestimate trip distance and trip duration (Andersen, Abeywardana, Wolf, Lee, et al. 2009) and do not provide information on routes (Stopher et al. 2006). Furthermore, the completion of travel diaries can be onerous for participants, leading to increased likelihood of inaccurate completion or omission of important information (Bohte & Maat 2009; Gong et al. 2011). For walking and cycling behaviour, self-reporting might bring some other issues. First, travel surveys tend to undercount walking and cycling levels because many people fail to identify these as legitimate modes of travel (Krizek, Handy, et al. 2009). Secondly, the definition of what is a walking trip is not always clear to survey respondents and surveys may (or may

not) capture the diversity of walking trips (ibid). Thirdly, walking and cycling are considered by many as “good” behaviours and because of this, most people feel they should be walking and cycling more and therefore overestimate the degree to which they engage in such activities. The magnitude of this `halo effect', as it is often labelled, is however uncertain (ibid). Finally, in stated (or revealed) preference methods - frequent applied in cyclists route choice studies – participants are likely to misinterpret maps, data collection is limited to one trip or directional data is not included (Dill and Gliebe 2008).

Observing people’s activity, manually or using sensing equipment is another strategy that has been employed to measure and collect data on walking and cycling. Ethnographic studies have shown that researchers can embed themselves in participants environments and observe and record everyday travel decisions at close (Pooley et al. 2013). Mobile interviews have also been conducted recently for a better understanding of walking and cycling (Carpiano 2009). Potential challenges of such approach include however technical issues (example, feasibility of record a conversation whilst travelling, especially if in heavy traffic, time required to process data or potential of participant’s behaviour be influenced by the presence of the researcher (Pooley et al. 2013; Fincham, B. et al. 2009).

Automated methods, such as the use of counters, infrared sensors, or video cameras in specific locations to count pedestrians and cyclists, are also an alternative method of data collection. Main disadvantages include however dificulty to obtain individual data (such as gender and approximate age, in the case of video cameras as an example), cost (up to £5000 per unit) (Sustrans 2014b) or the fact that data is obtained only for those who are walking and cycling on specific facilities (Aultman-Hall et al. 1997; Willis et al. 2004). Some argue that while automated methods may provide a limited understanding of individuals decisions to walk or cycle, they can provide reliable data on measurements of changes in behaviour resulting from improvements to facilities or soft measures (Krizek, Handy, et al. 2009).

More recently, studies of travel behaviour studies have started to employ **personal global positioning systems (GPS)** devices to record travel behaviour and overcome some of the issues surrouding traditional survey methods (Gong et al. 2012; Broach et al. 2011; Dill 2009; Bohte & Maat 2009; Duncan & Mummery 2007; Stopher, Swann, et al. 2007).

3.3.3 Increasing role of GPS technology*:*

Travel surveys using GPS technology started to take place in late 1990's (Wagner 1997) but during a long period of time, employment of GPS technology was limited to a few and largely experimental studies or undertaken as supplementary survey to test accuracy of paper based surveys. Most of these surveys were also restricted to car use due to size of the devices and battery (Shen & Stopher 2014a).

Technology development, battery improvements and the introduction of lightweight devices improved GPS devices user friendliness and reliability over the years. As a result, an interest by government and research organizations has grown and GPS technology started to be incorporated in travel surveys in major cities and countries worldwide. Shen & Stopher (2014a) provide a comprehensively review of the development of GPS surveys, their current application in a number of transport fields and an extensive list of countries and studies that, for the past decade, have use GPS technology to undertake travel surveys.

In the UK, the first attempt to use GPS travel surveys as a replacement for the self-report National Travel Survey (NTS) travel diary took place in 2009. Accelerometer-equipped GPS units were delivered to a sample of 429 households and data was collected over a period of 7 days. The feasibility study demonstrated GPS technology to be promising but that a number of issues still needed to be resolved before a NTS style large-scale person-based study could be undertaken at a larger scale. The two main areas where further work was recommended was on regular reviews of new GPS devices reliability and user friendliness for person based surveys; and in disentangle levels of respondent error and devices error

(by conducting further studies using short travel diaries alongside GPS devices) (Andersen, Abeywardana, Wolf & Lee 2009).

3.3.3.1 GPS technology advantages

GPS technology offers the potential to overcome some of the issues related to self-reported instruments, including the ability to obtain precise information about a person or vehicle location at a given time (plus trip route, speed and exact origin and destination at accurate levels of plus or minus a few metres for location) (Stopher et al. 2006; Yen et al. 2007). They also offer the opportunity to map complex journeys and collect precise information on journeys distance, duration or context (Wolf et al. 2003; Cho et al. 2010). The use of GPS devices in travel surveys has also the potential to reduce sample sizes due to the accuracy of the collected data (Stopher & Kockelman 2008). Moreover, participants fatigue during a GPS based travel survey is expected to be lower, creating an opportunity to extend surveys from the traditional single day to multiple day data collection (Gong et al. 2012). Finally, GPS technology provides the potential to capture with greater accuracy short walking or cycling journeys, frequently missed in self report instruments.

3.3.3.2 GPS technology limitations

There are however some challenges associated with the use of GPS technology to record travel behaviour. Firstly, GPS devices do not collect data on the **mode or the purpose of travel**. Several studies have attempted to classify type of activity and travel mode using only GPS data or combination of GPS and accelerometer data (Chung & Shalaby 2005; Schantz & Stigell 2009; Stopher, FitzGerald & Xu 2007; Troped et al. 2008); however, results are still partially limited. Secondly, there is a risk of **data loss due to equipment failure or improper use.** The loss of satellite signal or degradation during warm start/ cold start is a common issue alongside GPS devices difficulty in logging position in built-up areas/ urban canyons (Stopher 2008a; Gong et al. 2012). GPS logging ability may also be influenced by travel mode as it appears to be most effective in recording car trips but less successful with

journeys made on foot or by public transport (Andersen, Abeywardana, Wolf & Lee 2009). Finally, there is a risk of devices misuse or of respondents forget to carry the devices (Yen et al. 2007). There are not significant or consistent[14] results that suggest that participant's behaviour is likely to be influenced by use of devices ('halo effect).

Overall, it can be argued that the fact that GPS technology can provide accurate distance, routes and speed data is a good trade-of for missing some trips (Murakami & Wagner 1999). Moreover, data errors on GPS based travel data are still small when compared to travel paper diary methods; and the use of the devices is likely to be less of a burden to participants (Bohte & Maat 2009).

3.3.3.3 GPS based surveys for measuring active travel

The use of GPS technology on studies of walking and cycling is fairly recent (Table 3.2). In some of these studies, researchers employed GPS technology to test the preference of cyclists regarding bike facilities in Portland, USA (Dill and Gliebe 2008; Broach, Dill, and Gliebe 2012), understand how far cyclists would be willing to travel (decay) to use a bicycle trail in Mineapollis, USA (Krizek et al. 2007), and to estimate cycling route choice models in Zurich and San Francisco (Menghini et al. 2010; Hood et al. 2011). In Denmark, individual GPS data was recently employed to examine the associations between neighbourhood and cycling activity (Madsen et al. 2013); and in the UK, GPS data collected from cyclists was used to explore behaviour and constraints in space-time of cycling in urban environments (Yeboah and Alvanides, 2015; Yeboah, Alvanides and Thompson 2015).

Studies on **walking** have used GPS technology to assess feasibility and improve methods in recording outdoor walking activity (Duncan & Mummery 2007; Cho et al. 2010; Ashley R. Cooper et al. 2010; Schantz & Stigell 2009), to explore the complexities of school journeys

[14] Stopher, FitzGerald, Zhang, et al. (2007) found no evidence of a halo effect from being asked to carry the GPS devices in a 28 days based GPS survey. Dill (2009) reported that in a study of 166 cyclists in Portland, survey responses suggested that 3.6% of the participants that were likely to have cycled more often or on different routes because of use of a GPS device.

and childrens travel behaviour (Mackett et al. 2007; Pooley et al. 2010) or to determine distance elderly people would be willing to walk (Prins et al. 2014). A greater number of these studies are within the public health field and have also combined GPS data with accelerometer to observe the behaviour of transport-related physical activities or to determine spatial location of physical activities (Rodríguez et al. 2005).

Table 3.2 - List of studies on walking and cycling behaviour using GPS technology

Walking			
(Cho et al. 2010)	Test algorithms to identify outdoor walking trips from GPS;	North Carolina, USA 35 person-days of data	Preferred algorithm in the calibration phase resulted in 90% of trips identified from the GPS data being found in the diary.
(Millward et al. 2013)	Evaluate frequency and length of walking episodes and investigate distance-decay functions for major destinations. *GPS only to increase accuracy of locations	Halifax, Canada n= 1790 walking episodes (collected using day after recall time diary)	All major destinations show strong distance-decay effects: most walks are shorter than 600m and very few exceed 1200m. Supports assumption that one should restrict the 'neighborhood of opportunity' to walking destinations within 1000m of the home.
(Duncan & Mummery 2007)	Examine utility of GPS to measure actual routes taken compared with GIS-estimated travel distance and barriers encountered.	Rockhampton, Australia 59 children who wore a GPS during the journey to school on a single occasion	Travel routes estimated by GIS are not representative of actual routes measured by GPS.
(Pooley et al. 2010)	Explore the complexity of the school journey and relate it to air pollution and physical environment.	Northern England, UK	For most children the journey to and from school is highly variable and contingent to other factors. Pupils who travelled independently (on foot, bicycle or bus) were most likely to engage with environment and small variations in route choice had significant effects on exposure to air pollution.
(Cooper et al. 2010)	Investigate whether GPS data recorded outdoors were associated with objectively measured physical activity.	1010 children, South West England, UK	Minute by minute patterning of GPS and physical activity data is feasible and may be a useful tool to investigate environmental influences on children's physical activity and to identify opportunities for intervention.
(Mackett et al. 2007)	Explore the concept of independent behavior by children.	Children aged 8-11Cheshunt, Hertfordshire, UK	Project CAPABLE (Children's Activities, Perceptions And Behaviour in the Local Environment); children's travel behaviour differs when they are with adults from when they are not.
Walking & Cycling			
(Prins et al. 2014)	Get insight into the number of trips walked and cycled by elderly within various buffer sizes using GPS measures	Spijkenisse, Netherlands (2011–2012)) N=120; total number of trips=337)	Elderly aged under 75 years and those with functional limitations walked and cycled shorter distances than those over 75 years and those without functional limitations. Males cycled shorter distances than females.
(Schantz & Stigell 2009)	Develop methods to determine route distance in physical active transportation	Stockholm, Sweden	When physically active commuters draw their commuting routes on maps, they create a valid and reproducible basis for route distance measurements

Author/ year	Aim	Location and sample size	Outputs
Cycling			
(Dill 2009) (Broach et al. 2012)	Test effect of different types of infrastructure, such as bicycle lanes or paths on bicycling	Portland, USA N=164 adult cyclists	60% of cyclists rode for more than 150 minutes per week and nearly all of the bicycling was for utilitarian purposes. A disproportionate share of the bicycling occurred on streets with bicycle lanes, separate paths or bicycle boulevards. Route preferences differ between commute and other utilitarian trips; cyclists were more sensitive to distance and less sensitive to other infrastructure characteristics for commuting trips.
(Menghini, Carrasco, Schu ssler, and Axhausen, 2010)	investigated cyclists' route choice and estimate a route choice model	Zurich, Switzerland N=2435	First route choice model for bicyclists estimated from a large sample of GPS observations.
(Krizek et al. 2007)	Understand propensity of using a trail based on distance	Minneapolis, USA	Decay function varies by trip purpose. Bicyclists travel, on average, 67% longer in order to include the trail facility on their route.
(El-Geneidy 2007)	Develop a model to predict travel speeds by bicyclists on various types of facilities	Minneapolis, USA (n=8) (315 study segments)	Model generated by the study provides an example of how it is possible to calculate bicycle travel time and impedances, which can then be used in generating accessibility measures specific to cycling.
(Hood et al. 2011)	Understand route choice and estimate a route choice model (GPS data collected from smartphone users)	San Francisco, USA N= 297	Calculated coefficients applied to a trip assignment model that will be used to evaluate prospective investments in bicycle infrastructure in San Francisco.
(Yeboah & Alvanides 2015)	Explore cycling in urban environments and understand constraints in space and time	N=79 (Tyne and Wear County, England)	Provided evidence on the use of the area's cycling infrastructure by utility cyclists and spatial variability of cycling in space and time
(Madsen & Schipperijn 2013)	Examine the associations between neighborhood walkability and cycling	Three Danish Cities, Denmark (n=123)	Built environment factors related to walking behavior are also applicable to cycling in Denmark.

Krenn et al. (2011) reviewed several GPS applications in physical activity and have concluded that GPS is a promising tool to obtain more reliable data. While the use of GPS devices and other new technologies may contribute to overcome some of the challenges inherent to measure walking and cycling behaviour, devices are however still expensive, bulky and require multiple battery charges facilities. Moreover, measuring walking and cycling behaviour are still a challenge and the bottom line is that *'measuring walking and cycling is in no way a simple task'* (Krizek, Handy, et al. 2009: 734).

3.4 Limitations of knowledge base and methodological challenges

The literature reviewed suggestted that a complex set of environmental, socio-demographic and individual factors are likely to influence walking and cycling behaviour and that presence of infrastructure plays an important role (Ogilvie et al. 2011; Saelens et al. 2003; Handy 2004; Pucher et al. 2010a; Dill 2009; Forsyth & Krizek 2010). However, it was found that there is limited evidence at the micro level on how infrastructural interventions that improve connectivity for pedestrians and cyclists influence travel behaviour and reduce carbon emissions from personal travel. Given the inherent challenges in measuring walking and cycling behaviour or in conducting natural experiments, existing literature is also frequently limited by methodological issues, sample bias or influence of cultural and geographical context. More specifically, the following gaps in the literature were identified.

Firstly, while some studies found connectivity of the infrastrucutre to be significant for walking and cycling (Dill & Voros 2007; Cervero et al. 2009; Frank et al. 2004; Li et al. 2005; Ewing et al. 2008), empirical evidence from other studies could not support this association for neither walking (Cervero & Duncan 2003; Rutt & Coleman 2005; Lovasi et al. 2008) or cycling (Moudon et al. 2005; Zacharias 2005).

Secondly, there is little evidence from existing research and actual interventions studies to show that changes to the built environment through infrastructure provision have led to a change on travel behaviour and increase in walking and cycling levels (Ogilvie et al. 2004; Krizek, Forsyth, et al. 2009; Badland & Schofield 2005; Lin Yang et al. 2010; Ogilvie et al. 2007). Moreover, there is a lack of evidence from in-depth studies on the impacts of these interventions in influencing individuals day to day travel decisions and the context in which the interventions are (or are not) effective, for whom and for what purposes.

Thirdly, while it is widely assumed that walking and cycling for everyday travel can be a substitute for motorised travel and therefore reduce CO_2 emissions (de Nazelle et al. 2010; DfT 2011a; Blondel et al. 2011; Ogilvie et al. 2004; Brand et al. 2014), there is limited

evidence to show how provision of infrastructure for pedestrians and cyclists promotes a modal shift away from the car and impacts on carbon emissions from displaced motorised travel.

Finally, despite provision of infrastructure, in particular for cycling, is recognized as crucial to support an increase in active travel (Ogilvie et al. 2011; Saelens et al. 2003; Handy 2004; Pucher et al. 2010a; Dill 2009; Forsyth & Krizek 2010), it is sometimes difficult to understand its effects in users with different skills or levels experience and in influencing individuals route choice decisions (Winters, Teschke, et al. 2010; Hunt & Abraham 2006). Furthermore, although walking behaviour is complex and diverse, it has been studied as a rather simplified concept in most urban planning and design studies (Saelens et al. 2003; Lee & Moudon 2006a; Choi 2013).

Some of the limitations of studies on walking and cycling behaviour and impact of interventions reflect however methodological challenges and measurement problems.

- First, only a small number of natural or longitudinal studies have been conducted to evaluate the effects of infrastructural improvements on walking and cycling (Merom et al. 2003; Fitzhugh et al. 2010; Burbidge & Goulias 2009). Measurement of walking and cycling behaviour prior to and following a change in the built environment is likely one of the best approaches for establishing causality (Krizek, Handy, et al. 2009; Heinen et al. 2010), however, manipulating environmental change for experimental purposes is a main difficulty (Ogilvie et al. 2012).
- Second, there is usually a reliance on self-report survey tools or simple counts of users that may provide a limited record of travel behaviour. **Self report mesures** tend to underreport short trips (Bohte & Maat 2009), overestimate or round off travel times (Dill and Gliebe 2008), overestimate trip distance and trip duration (Andersen, Abeywardana, Wolf, Lee, et al. 2009) and do not provide information on routes taken (Stopher et al. 2006). Moreover, in travel surveys, walking and cycling levels are usually undercount because many people fail to identify these as legitimate modes of

travel (Krizek, Handy, et al. 2009). Contrariwise, some individuals may overestimate the degree to which they engage in such activities as walking and cycling are considered by many as 'good' behaviours. The magnitude of this `halo effect', as it is often labelled, is uncertain (Krizek, Handy, et al. 2009). In stated (or revealed) preference methods - frequent applied in cyclists route choice studies – other factors such as participant misinterpretation of maps, data collection limited to one trip or not inclusion of directional data may also limit records obtained (Dill and Gliebe 2008). It is acknowledged that data collected using **observational or instrumental** approaches have the potential to provide records that are more accurate than those obtained by self-reported means.

- Third, most studies assess either walking or cycling, for one specific purpose (commuting cycling, as an example) or only one behavioural outcome (e.g. total physical activity) (Adams et al. 2013; Heinen et al. 2010; Forsyth and Krizek 2010). A more clear distinction between modes and purposes (recreational, utility) is then likely to enhance understanding of factors influencing walking and cycling behaviour in different contexts. Furthermore, existing studies on walking, and in particular cycling, are frequently limited by sample size or bias. As walking and cycling are uncommon activities, even in large mode choice studies, desired levels of statistical significance may limit results derived. Furthermore, sampling selection bias is a frequent issue, particularly on cycling studies, as participants are often regular and enthusiastic bicyclists rather than random samples of individuals (Dill and Gliebe 2008; Pucher et al. 2010a; Forsyth & Krizek 2010). Therefore, it may be argued that understanding travel behaviour decisions of a more diverse group (users and non-users) would be key (Dill & Gliebe 2008).
- Fourth, walking and cycling behaviour are strongly related with the socio cultural context and built and natural environment where they occur but this change significantly between cities and countries. Current literature on this field is

geographical biased to some extent towards countries such as USA or Australia. Perspectives from other countries, in particular from the UK may offer a more nuanced picture of the effect of infrastructure on bicycle use, as an example, (Adams et al. 2013; Badland & Schofield 2005; Heinen et al. 2010).

To summarise, the review of existing literature suggests that there is limited understanding at the micro level of the impacts of provision of infrastructure for pedestrians and cyclists on individuals everyday travel behaviour and carbon emissions from personal travel. Moreover, findings suggest that a clear distinction between modes (walking and cycling), purposes (travel or recreation) alongside a better understanding of the context in which an intervention is delivered and inclusion of a diverse sample of users is crucial to provide enhanced evidence. While measurement of walking and cycling behaviour and evaluation of interventions for pedestrians and cyclists is still limited by methodological challenges, the use of GPS technology in providing a detailed account of travel behaviour (including spatial features) has the potential to overcome some the current issues.

These are the gaps identified in existing literature that this study aims to fill and that lead to the research questions formulated in Chapter 1. The aim of this study is therefore to develop a better understanding of the links between implementation of physical infrastructure targeted at improving connectivity for walking and cycling at local community level and the influence on personal travel behaviour and associated carbon emissions. For a detailed understanding of the problem, walking and cycling, either for recreation or utility purpose should be measured independently and using alternative survey methods that enable to capture spatial dimension of travel and overcome limitations of traditional survey methods.

3.5 Summary

The literature review section of this thesis was presented in two parts. The first chapter provided an overview of walking and cycling promotion in the UK and explored how despite current policies and initiatives, levels of walking and in particular cycling are still very low.

While some reasons could be attributed to this unrealized aspiration in the UK, this also suggest that there is still limited understanding of individuals' poor response to some of these initiatives or how they influence individual travel decisions on a day-to-day basis and under complex arrangements. Within this context, the aims of the recent and large infrastructural Sustrans Connect2 Programme were examined but a lack of detailed evidence on how this programme has transformed everyday travel in the communities it served was identified.

This chapter presented the literature review that was undertaken to understand the web of factors influencing walking and cycling behaviour and the extent to which the provision of facilities for pedestrians and cyclists are associated with walking and cycling levels. The review of existing evidence suggested that presence of infrastructure influences walking and cycling behaviour; however, results are some times mixed or limited with regards to the role of interventions that provide new routes or improve connectivity for pedestrians and cyclists. The chapter then explored the limitations of the main sources of travel data on walking and cycling in the UK and how there is a growing recognition of the potential of GPS technology in overcoming some of the challenges related to traditional survey methods. The chapter concluded by highlighting the gaps in current research and linking them to this study aims.

This thesis turns now to the methodology used to investigate whether, at the individual level, the provision of connectivity improvements in infrastrutcure for pedestrians and cyclists, namely the Sustrans Connect2 project, is helping to promote a change in travel behaviour and in mitigating carbon emissions levels from surface transport

4 Study Design and Research Methods

4.1 Introduction

This chapter presents and justifies the research design, data collection and analysis methods used to achieve the aims of this study. The chapter is divided into six sections. Section 4.2 discusses why the study adopts a mixed methods (quantitatively driven) research strategy and a longitudinal panel study of a Connect2 site as main research design. Section 4.3 describes the research methods employed for travel data collection and the advantages (and disadvantages) of using a combination of GPS loggers, travel diaries, and qualitative observation. Section 4.4 then provides a comprehensive description of the Cardiff Connect2 scheme - the selected case study site to conduct this research – and its local context. Section 4.5 describes the strategy for selection and recruitment of participants in the case study site, including sample criteria, study sample size and responses rates achieved during two waves of the survey. Finally, section 4.6 explains the data collection procedures conducted in the study site between 2011 and 2012.

The methods developed for data processing and analysis – a challenging phase of this research– and evaluation of the feasibility of using GPS technology to record travel behaviour data at the micro level – one of the objectives of this study - are discussed separately in Chapter 5.

4.2 Overall research approach and design

4.2.1.1 Research strategy: a mixed method approach with emphasis on quantitative methods

Qualitative and quantitative approaches have evolved from very different scientific traditions; however, it is today acknowledged that both have their strengths and weaknesses (Bryman, 2012). Quantitative approaches investigate an observable

phenomenon via statistical measurement or numerical quantification, have a deductive orientation and enable testing of theory. Qualitative approaches, on the other hand, focus in gathering an in-depth understanding of human behaviour and the reasons that govern such behaviour (via interviews, observations, group discussions or analysis of documents), have an inductive orientation and are more focused on the generation of theory (Bryman 2008). More recently, however, it has been questioned the extent to which such approaches should be divide into such distinct camps, in particular in social research, and increased permissiveness seems to be rising towards mixing approaches (Alasuutari et al. 2008). **Mixed method approaches** comprise therefore the mixing of qualitative and quantitative research strategies. According to Johnson et al. (2007), three broad classes of mixed method research studies can be defined, depending on what it is its core and added as a supplement: quantitatively driven approaches, qualitatively driven approaches and interactive or equal status design.

This study follows a **mixed method approach** with emphasis on quantitative measurement of travel behaviour around a Connect2 scheme but where qualitative data is added to supplement and provide a deeper understanding of the quantitative results, including a meaning to why travel behaviour may or may not have changed. Such approach provides a more comprehensive understanding of the phenomena being studied, its context and causal relationships, which could not easily be uncovered using a single approach. Moreover, this approach provides an opportunity to perform triangulation of results, which contributes to greater validity and credibility of findings (Bryman 2006). Some potential risks of mixed methods approaches include however the potential for 'selective searching' (Sale et al. 2002) or being more expensive and time consuming than other methods (Bryman 2008).

4.2.1.2 Research design: a longitudinal panel study

Research designs can generally be classified into two broad categories on the basis of whether they obtain repeated observation of the same variables over time; longitudinal

surveys do and cross-sectional surveys do not (Sharp & Murakami 2002). Because longitudinal studies track the same variables/individuals over time, they provide a more robust method for measuring behaviour change and are more accurate in smaller samples (Sharp & Murakami 2002; Stopher 2008b). While longitudinal studies have been widely used in fields such as medicine, psychology, health sciences or economics, their use in transport studies is however more recent (Stopher & Greaves 2007). Longitudinal studies can be categorized as either cohort or panel studies, depending if they sample a group experiencing some event in a selected time period and study it at intervals through the time (cohort) or sample a cross section and survey it at regular intervals (panel).

This study adopted a **longitudinal design approach of a panel of residents** in a local community served by a Connect2 scheme as the main research design to evaluate whether interventions that provide physical infrastructure for pedestrian and cyclists, namely the Connect2 Programme, influence local residents everyday travel behaviour. This approach was found as the most appropriate research design in meeting the objectives of this study as it provided the opportunity to accurately measure changes in travel behaviour over time and evaluate, at individual and panel levels, the causal relationships underlying any changes detected, namely the role of the new intervention. This approach provides more than a snap shot perspective of local residents travel behaviour in the local area and has the potential to detect more subtle changes that might result or influence individuals everyday travel. Finally, it also provides an opportunity to assess the longevity of any of the changes detected.

There are however some disadvantages inherent to longitudinal panel studies, mainly with regards to respondent burden and panel attrition (due to the intensity of contact with participants increasing the likely fatigue and drop-out rate, as an example) (Deng et al. 2013; Stopher & Stecher 2006). Other potential challenges include response bias (due to respondent conditioning), cost of tracking respondents that have moved away,

and the more complicated weighting and estimation process of results (Stopher & Greaves 2007; Sharp & Murakami 2002). Some strategies can however be employed to minimize effects of attrition, such as oversample in the first wave of the survey, or refreshment samples of new, randomly sample respondents.

4.2.1.3 Research scope: a case study approach

In the definition of the scope of this study, it was important to be clear whether the research focus was to understand the overall impact of the UK wide Connect2 programme or, alternatively, to focus on an in-depth study of a particular Connect2 scheme. The first approach would have required a sample of Connet2 schemes to be drawn that were broadly representative of the Connect2 Programme as a whole. Due to the large sample size required to produce meaningful results, this would not have been feasible or even possible due to lack of resources within a research degree project. Furthermore, such approach would have replicated to some extent the work developed by the iConnect project consortium. Therefore, this study focussed on an in-depth study of a single Connect2 case study site.

A case study approach is useful when a holistic, in-depth investigation is required about a particular phenomenon (Feagin et al. 1991). It enables the researcher to answer “how” and “why” type questions, while taking into consideration how a phenomenon is influenced by the context within which it is situated (Baxter & Jack 2008). Advantages of case study include the ability to uncover new dimensions of relationships and the ability to examine a certain event in greater depth. Cases studies can be explanatory, exploratory or descriptive; design adopted can be of single or multi case studies; and methods applied can be qualitative, quantitative or mixed (Yin 2009).

For these reasons it was decided that a **case study approach** was the most appropriate in meeting the objectives of this study. This approach enabled to investigate with greater depth how a new Connect2 scheme influenced individuals’

travel behaviour and to examine the complexities of everyday live. Moreover, the aim of this study was not to generalise the results to the wider population (to Wales or the UK, or to the entire Connect2 programme of 84 interventions) but to be able to articulate and generalise findings to theoretical propositions, as the contemporary phenomena to be explored were embedded in real life contexts, with complex boundaries existing between the two. Potential disadvantages of a case study approach include however selection bias and the fact that findings cannot be generalised under specific circumstances (Bryman 2008).

4.3 Methods of data collection

The two main data collection methods employed in this study were a GPS based 7-day travel survey (using a combination of GPS loggers and travel diaries) and collection of contextual data (through an exit interview and qualitative observations).

4.3.1 Background

Travel surveys are the most common method employed for travel data collection in travel behaviour studies. However, traditional travel surveys or travel diaries are frequently limited by poor data quality on journey distance and duration and, more importantly for this study, lack reporting of short trips by active travel modes and on route choice. In recent years, increasing interest has been around the use of GPS devices as they provide the ability to record accurate data on trip time and distance, speed and route taken. This has been described in section 3.3.3. However, while hardware, software and processing techniques continue to advance, there are still issues that need to be addressed in order for GPS based surveys to fulfil their potential. Some of these challenges include improve trip mode and purpose identification techniques, increase battery life over longer survey periods, reduce signal loss and risk of equipment failure or improve public acceptance. Additionally, GPS

measurements also fail to understand constraints and circumstances that influence individual's travel behaviour options and that are particularly important in the context of walking and cycling.

In order to overcome some of these issues, this study employed a combination of personal GPS devices and customized travel diaries to record travel behaviour data. GPS technology offers the ability to obtain complete and precise information on trip distance, trip origin and destination, duration, travel speed and importantly, route. These features provide a comprehensive understanding of spatial dimension of travel, including an opportunity to assess the level of use of the new intervention, and are crucial for the accurate measurement of changes in travel behaviour over time. The use of self-completion travel diaries, on the other hand, enabled to overcome some of the weaknesses of GPS technology, mainly the incapacity to record trip mode or purpose, and to improve the quality of the data collected. In the travel diaries, participants were invited to record trips purpose, mode and origin and destination, and useful contextual data regarding their journeys. All this information is fundamental to cross check and validate data recorded by the GPS devices.

Additionally, contextual data was collected via an exit interview and qualitative observations, contributing to a more comprehensive understanding of the role of the new intervention in influencing individuals everyday travel behaviour and unveiling the reasons for detected changes in travel behaviour over time.

4.3.2 GPS travel recorder

The personal GPS travel recorder (or GPS logger) used in this study was the Qstarz BT – Q1000 XT device (Figure 4.1), which was obtained through the core EPSRC *iConnect* study. This relatively small user-friendly instrument is able to log up to 400,000 waypoints and records route taken, distance, trip duration, elevation and speed. Due to its lower power consumption Li-ion battery and the vibration sensor

(which makes the start/ stop logging an automatic procedure based on movement), this device can operate for a maximum of 42 hours between charges. The log interval used in the design of this research was “5” seconds based on device memory capacity, battery life and research scope.

Although this device is easy to use, a leaflet with instructions about its operation was designed and delivered to participants. This leaflet (see *Appendix E*) included instructions on the device management (charging, switching on and off or checking device status) along with answers to frequent asked questions, such as when and where to use the device or the procedure to follow in case of equipment failure. The information contained in the leaflet was also discussed with participants in person to address any issues or concerns prior to field surveys taking place.

Data collected from the Qstarz BT – Q1000 XT devices can be visualized and extracted as CVS, GPX, KML, KMZ or ITM format files in purpose-built software (Qtravel). However, for a more comprehensive analysis of the data – such as trips mode and purpose identification, it is required other GIS (Geographic Information System) software. This GPS device had a cost of £85 per unit and it was made available by the funding body (EPSRC) through the iConnect project (grant agreement EP/G00059X/1).



Figure 4.1 - GPS device used in this this study for travel data collection and example of participant wearing it according to this study protocol (source: author)

The reliability and accuracy of these devices was tested by the researcher at various locations (including Oxford, London and Cardiff) during months prior to fieldwork

commencing. A formal one-week pilot test with 14 participants took also place between 2 and 9th of August 2010 in Oxford *(see section 4.3.5)*. No significant anomalies were detected with regards to devices accuracy and ability to record trips by different modes or battery capacity.

4.3.3 Travel diary

In order to overcome the present issue with trip mode and purpose identification from GPS raw data[16], an adapted version of a seven-day travel diary was also developed for this study. This travel diary was designed with several important aspects in mind. Firstly, it focused on capturing trip features required to validate GPS data such as trip mode and trip purpose but did not capture trip distance (the latter is a variable that participants usually struggle to correctly fill in traditional travel surveys). Secondly, this travel diary provided a dedicated section for recording contextual information that could enhance understanding of trips recorded, such as atypical conditions influencing journeys made. Thirdly, the design element of the travel diary aimed for clarity and minimization of written entry. For example, travel modes were recorded by marking a cross on a dedicated column of symbols representing different transport modes. Additionally, there was no need to repeatedly write the start point of the journey as it was assumed that the previous journey destination was also the origin of the journey that followed. Finally, the supplementary use of travel diary also acted as a backup for the collection of data that the accompanying GPS fails to record.

Traditional travel diaries and travel surveys for adult and young persons, including the travel diaries in use by the UK National Travel Survey were reviewed prior to development of this travel diary (Taylor et al. 2012). Based on this information but also

[16] As mentioned previously, GPS devices can give very accurate information regarding trip route, distance, speed and duration; however, they do not record trip mode or purpose. Recent studies have been looking at potential ways of deriving this information from GPS raw data but it is still nowadays difficult to process the enormous amount of data generated and to efficiently derive mode and purpose with total certainty relying exclusively on GPS data.

on the measurement tool main objective – complement GPS collected data – four different diaries were produced. Please refer to Appendix D for a copy of other travel diaries layouts designed for this study. Following comments received from peers and participants in the feasibility and reliability testing (see section 4.3.5), it was decided to use layout D which was more easily interpreted by participants and provided a comprehensive record of travel data (Figure 4.2).

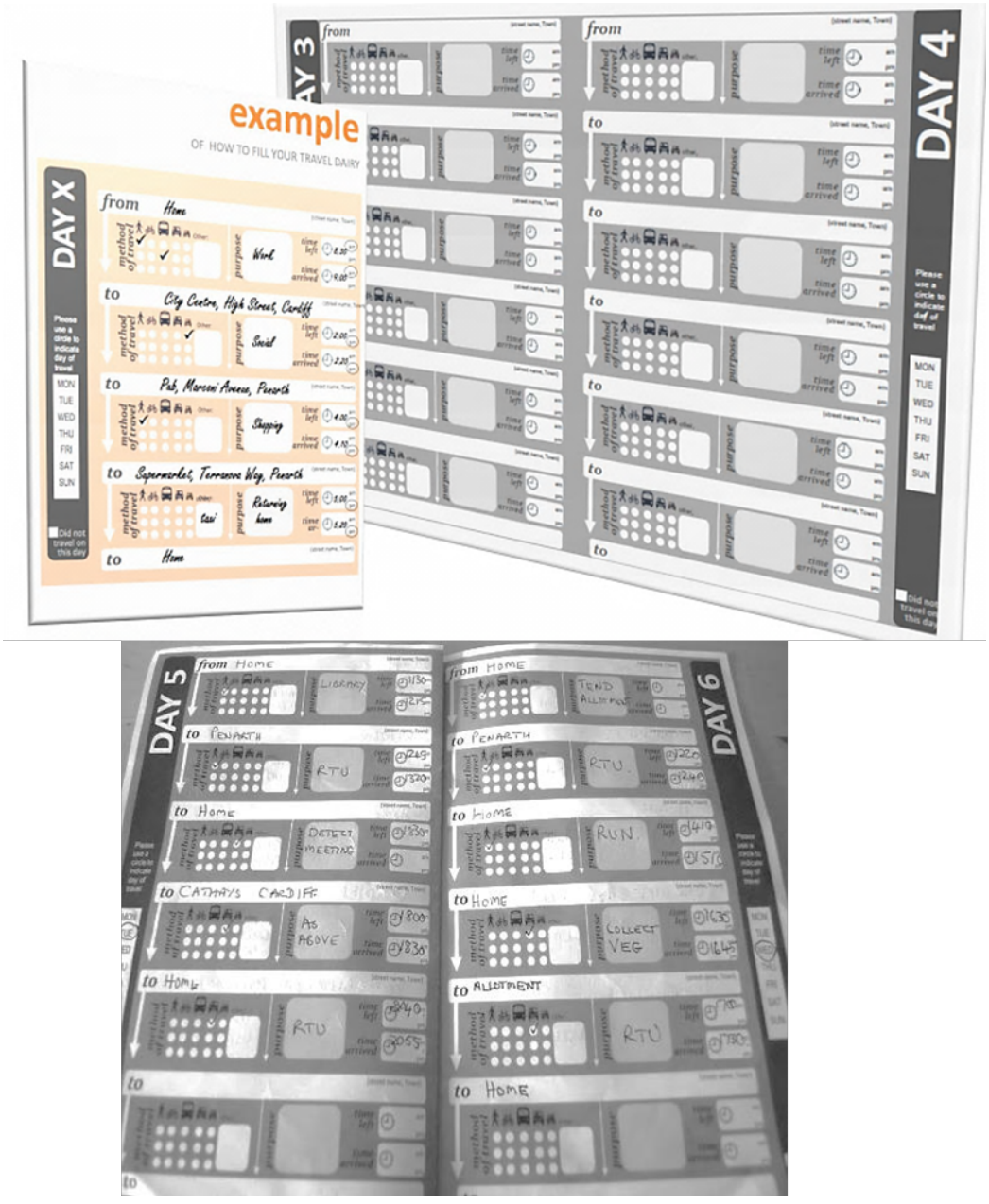


Figure 4.2 – Travel diary designed for this study (above) and snapshot of a filled in travel diary

4.3.4 Contextual data collection: Semi structured exit interview and observations

Whilst GPS loggers and travel diaries provide an 'objective' measurement of travel behaviour, they do not collect data on participant's experiences of everyday travel, motivations for travelling on foot or by bike or underpinning factors driving individual travel patterns. Thus, it was defined that collection of contextual data – mainly through an exit semi structured interview - was crucial to enhance understanding of participants travel behaviour, perceptions and opinions on walking and cycling facilities in the area and the significance of the Connect2 scheme in particular.

A semi structured interview is a method of research used in social sciences where an interview is open, allowing researcher to tailor questions to the interview context and situation and allowing new ideas to be brought in as a result of what the interviewee says. Semi structured interviews are usually guided by a framework of themes to be explored (Bryman 2008).

In this study, the **exit interview** was administered to participants on the last of four meetings and was guided by a questionnaire (see Appendix F) focused in capturing participant's views on the following themes:

a) Perceived change in overall travel behaviour (by mode, purpose, frequency, distance or route substitution) and underlying reasons (environmental, socio economic, individual);
b) Perceived role of walking and cycling in everyday travel behaviour at an individual and local community level; attitudes, motivations and perceived constraints;
c) Perceptions about walking and cycling facilities in the area and significance of the new Connect2 scheme in influencing walking and cycling levels (individual and community levels); Connect2 scheme advantages and issues.

As the semi structured interview was open, it allowed the researcher to tailor his questions to the interview situation and it allowed different perspectives to be brought as a result of what the interviewee said. The objective was to understand the respondent's point of view rather than generalise about behaviour. The participants' names were anonymised for the presentation of results and discussion in later chapters.

The **informal collection of data** during other meetings with participants (total of four meetings over period of study) and **observations** conducted in the case study completed this contextual data collection strategy. These observations were conducted by the researcher at key locations in the case study site and over different periods of time using a digital photographic camera. Relevant notes were kept in a diary and later transcribed to a word processor for subsequent analysis. Photos taken were organized by date, location and theme and provided a visual summary of active travel behaviour in the local community. Some of this contextual information was feed to the exit interview.

As mentioned in Chapter 3, this study uses an adapted form of the applied ecological framework developed by the iConnect study (Ogilvie et al. 2011) for the evaluation of the behavioural effects of interventions to promote walking and cycling. Figure 4.3 summarises how the constructs of this framework were operationalized in this study using the methods defined for data collection.

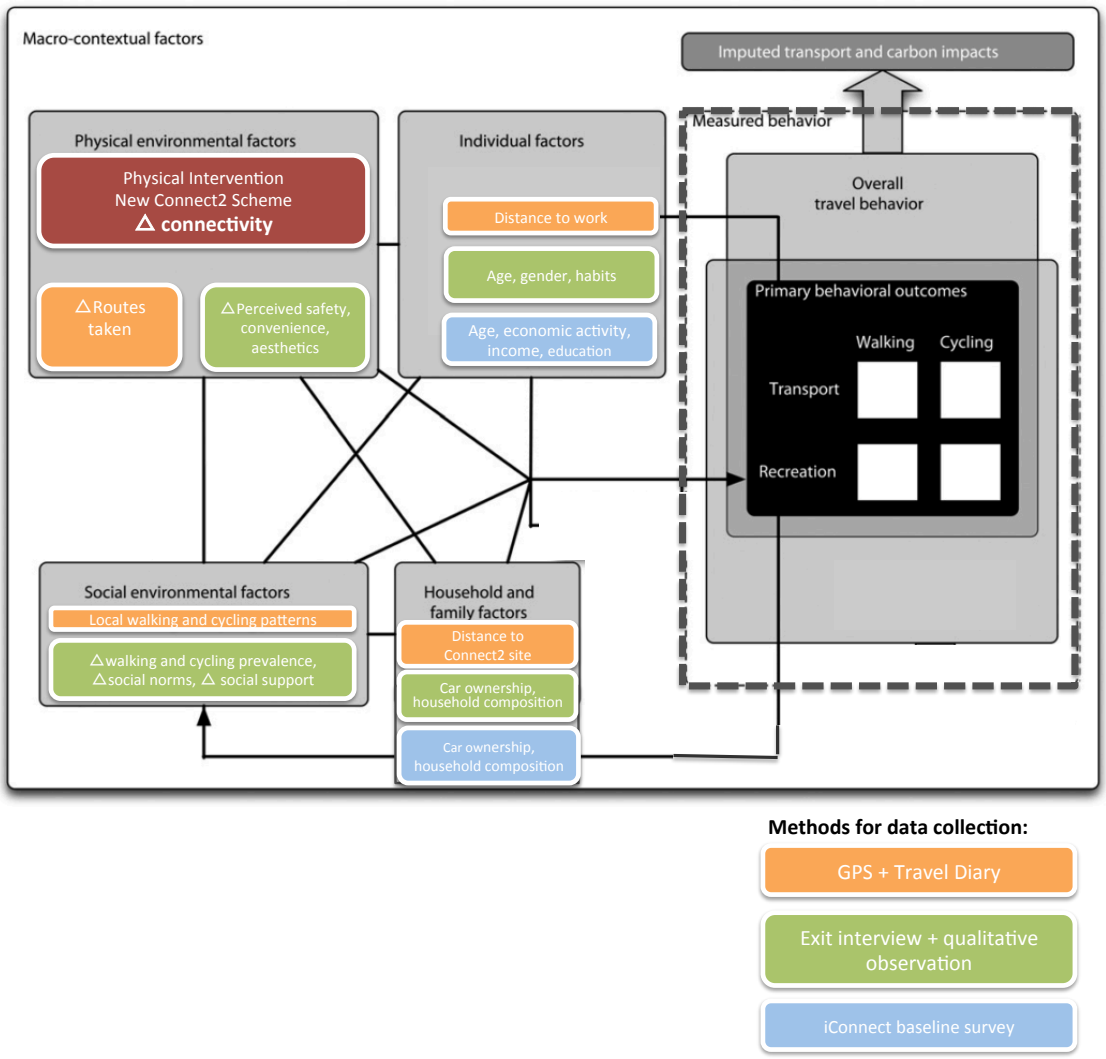


Figure 4.3 – Diagram representing how the applied ecological framework from Ogilvie et al. (2011) was operationalized in this study

In summary, the aim of the **methods developed for travel data** collection in this study and that involves the **use of GPS devices, travel diaries and exit interviews**, was to provide a detailed and comprehensive record of travel behaviour that could not be uncovered when using one of these instruments alone, as summarised in detail in table 4.1. Such approach had the potential to provide a more accurate and comprehensive understanding of the impact and significance of the new Connect2 scheme in influencing walking and cycling levels among the local community.

Table 4.1 – Travel attributes recorded using mixed method approach developed in this study

	Mesurement methods		
Attributes recorded	***GPS diary***	***Travel diary***	***Exit interview***
trip origin/ destination	++	+	-
trip route	++	-	-
trip start/ end time (duration)	++	+	-
trip distance	++	-	-
trip speed (average speed, maximum speed)	++	-	-
trip purpose	*	+	-
trip mode	*	+	-
trip context	*	+	+
reasons underlying changes in travel behaviour	-	-	+
attitudes, motivations and perceveid barriers towards walking and cycling in the local area	-	-	+
perceived significance of the Connect2 Scheme	-	-	+

++	objectively measured
+	subjectivley measured
-	not provided
*	attribute derived

4.3.5 Testing feasibility and reliability of data collection methods

A pilot study for testing the feasibility and reliability of the data collection methods was conducted in Oxford during August 2010. The objectives of this pilot study included the assessment of the survey tools performance in recording travel behaviour, their user friendliness and acceptance alongside evaluation of participant's fatigue along the week and feasibility of a seven days travel survey approach.

The participants for this pilot study were invited from a group of work colleagues and friends. The fourteen participants selected were equally distributed in terms of gender and were aged between 23 and 55 years; they lived in Oxfordshire and use a variety of modes of transport for their everyday journeys, including walking, cycling, car or public transport.

Participants were asked to wear a GPS device and an actigraph[17] and to fill in a travel diary during a period of four or seven days. At the end of this period, a meeting was arranged to collect the devices, travel diaries and to discuss data collection protocol.

The evaluation process was focused in getting perceptions and suggestions of users and peers on the following aspects:

- Feasibility of a 4 days or 7 days long travel survey;
- Legibility of support materials produced and instructions provided;
- Travel diary legibility;
- Ease of use of the devices and any related issues;
- Feasibility of the overall process (fatigue, burden, other suggestions).

The feedback received allowed reflection on the methods used. Following this, materials and protocol were adjusted to reflect some of these comments. Overall, it was found that a seven day travel survey was a feasible option for most of the participants and that the research protocol was clear for the majority of the group, although explanations provided should be adjusted to participants. The instructions sheets were also improved to include more details on equipment use and researcher contact details. Finally, the travel diary was re-designed to improve its legibility and allow more trip details to be recorded (Appendix D).

4.4 The Case Study: Connect2 Cardiff

The focus of this study was the Connect2 programme, administered by the sustainable transport organization Sustrans, and one of the most significant infrastructural programmes to encourage walking and cycling in the UK in recent years. The selection

[17] As part of the work with the iConnect consortium, participants were asked to carry an actigraph along the use of a GPS device. The GT3X Tri-Axis Actigraph Monitor measured participants' physical activity levels, including activity counts, energy expenditure, steps taken and activity intensity.

of one of these Connect2 sites, where new infrastructure for pedestrians and cyclists was implemented in a local community, provided the natural experimental setting for this in-depth study.

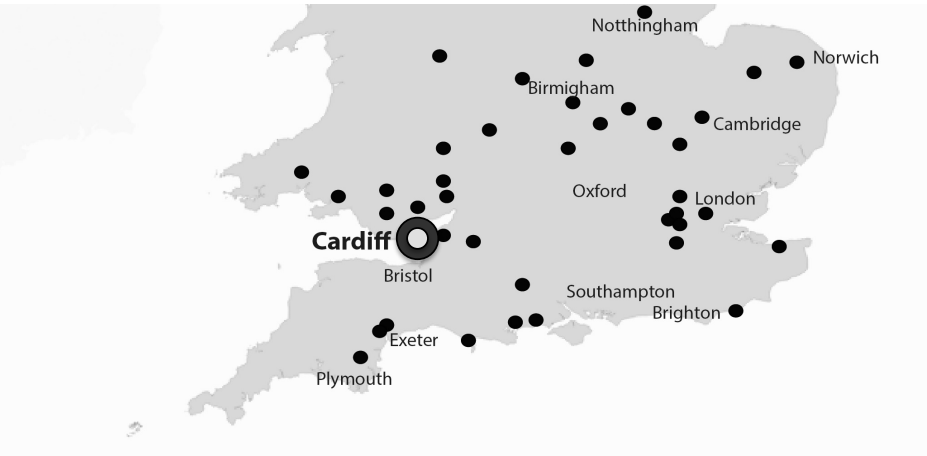


Figure 4.4 – Map of Connect2 intervention sites and location of the Connect2 Cardiff scheme

4.4.1 Case study selection:

The decision to choose the Connect2 Cardiff scheme as a case study site was determined by the fact that this scheme was one of the larger (and 'iconic') Connect2 projects to be implemented and therefore with potentially larger effect size to be expected. Furthermore, as Cardiff Connect2 was one of the three iConnect2 study core sites[18] that provided an opportunity to use core data collected through the iConnect baseline survey in 2010, conduct in-depth research already covered by existing ethics approval (University of Southampton Research Ethics Committee, CEE200809-15) and receive support with participants' recruitment. Finally, its proximity to Oxford and delivery schedule (2010-2013) was also taken into account during the appraisal process. For further reference on the iConnect core sites selection please refer to Ogilvie et al. (2012).

[18] From the 84 available sites, the iConnect study has selected three case studies sites using a combination of criteria such as accessibility to researchers, likelihood of measurable population impact, heterogeneity overall mix sites, risk that the scheme would not be implemented and expected timetable for implementation of the scheme. The three core study sites defined were Cardiff, Kenilworth and Southampton (Ogilvie et al. 2012).

4.4.2 Case study site: context

Cardiff is the capital of Wales and the 10th largest city in the United Kingdom with an estimated population of 346,100 inhabitants (Office for National Statistics 2012). Cardiff was a small town until the early 19th century but its prominence as major port and trading hub during early 20th contributed to its rise as major city. Following a period of subsequently decline, Cardiff has seen significant development since the 1990s. The new waterfront area at **Cardiff Bay** (1,100 hectares), previously a derelict industrial site, is one of these areas that received significant regeneration and investment in the form of new residential, retail, entertainment and sport facilities. Cardiff city centre is relatively flat but is bounded by hills on the outskirts of town towards east, north and west. The Cardiff Urban Area covers a slightly larger area outside the county boundary and includes the towns of Dinas Powys and Penarth, two of the suburbs served by the Connect2 Cardiff (Figure 4.5).

Penarth (20400 inhabitants) is a seaside resort town located 5.2 miles southwest from the city centre of Cardiff. While during Victorian Times it was a popular holiday destination, the town is today a popular residential area for retired people, young families and commuters to Cardiff, with house prices significantly higher than the average. The town is located on the top of the Penarth Cliffs, lying on at the southern end of Cardiff Bay. **Cogan and Llandough** are two suburbs of Penarth that resulted of the expansion of the city towards northwest since the 50s and are mainly residential areas. **Penarth Marina** is both a marina for boats and an area of modern housing located on the west bank or river Ely.



Figure 4.5 - Location of Cardiff, Penarth and the Cardiff Connect2 scheme

Public transport provision in the case study site is relatively good (Figure 4.6). The local area is served by two branches of the Vale of Glamorgan Railway Line that runs from Cardiff, the largest railway station in Wales with 10 million passengers a year. The closest train stations to the Connect2 scheme are Penarth, Dingle Station and Cogan. Bus services in the local area are equally frequent and cover a large area of the case study site. Penarth falls into the Cardiff fare zone for Cardiff bus fares. Additionally,

there is a waterbus service that crosses Cardiff Bay hourly during the day and that links Penarth Marina to the Mermaid Quay on Cardiff waterfront.

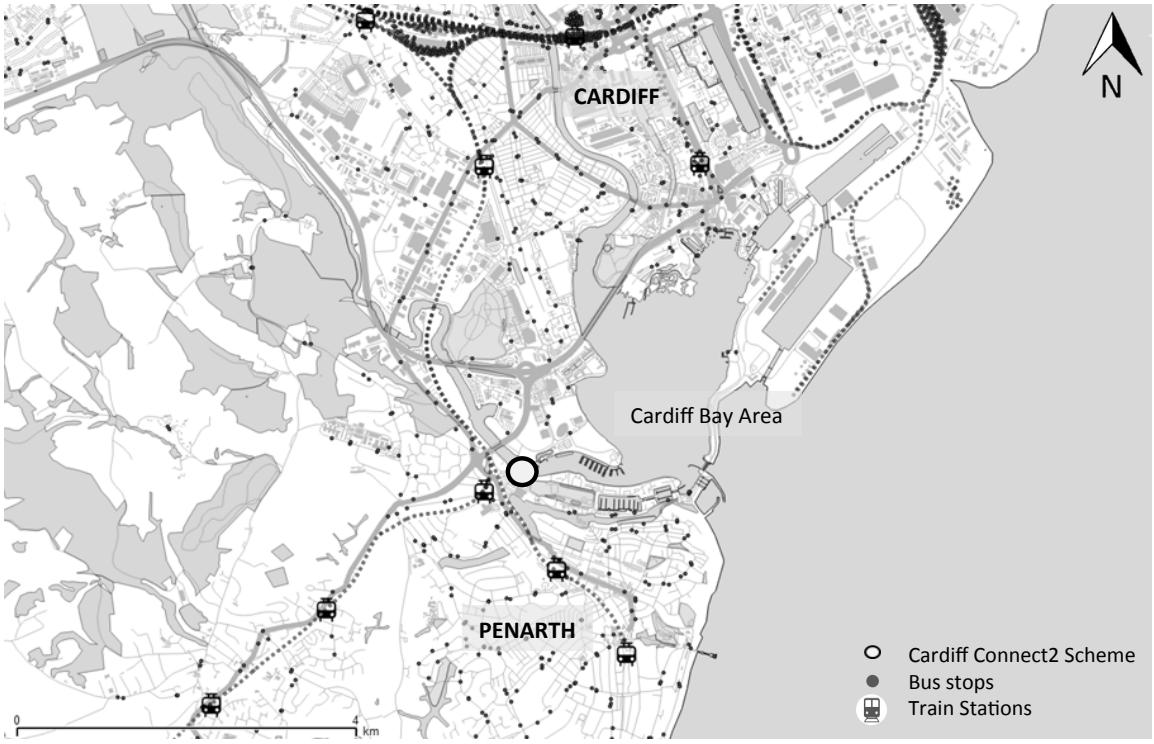


Figure 4.6 – Public transport provision in the case study site (© OpenStreetMap contributors)

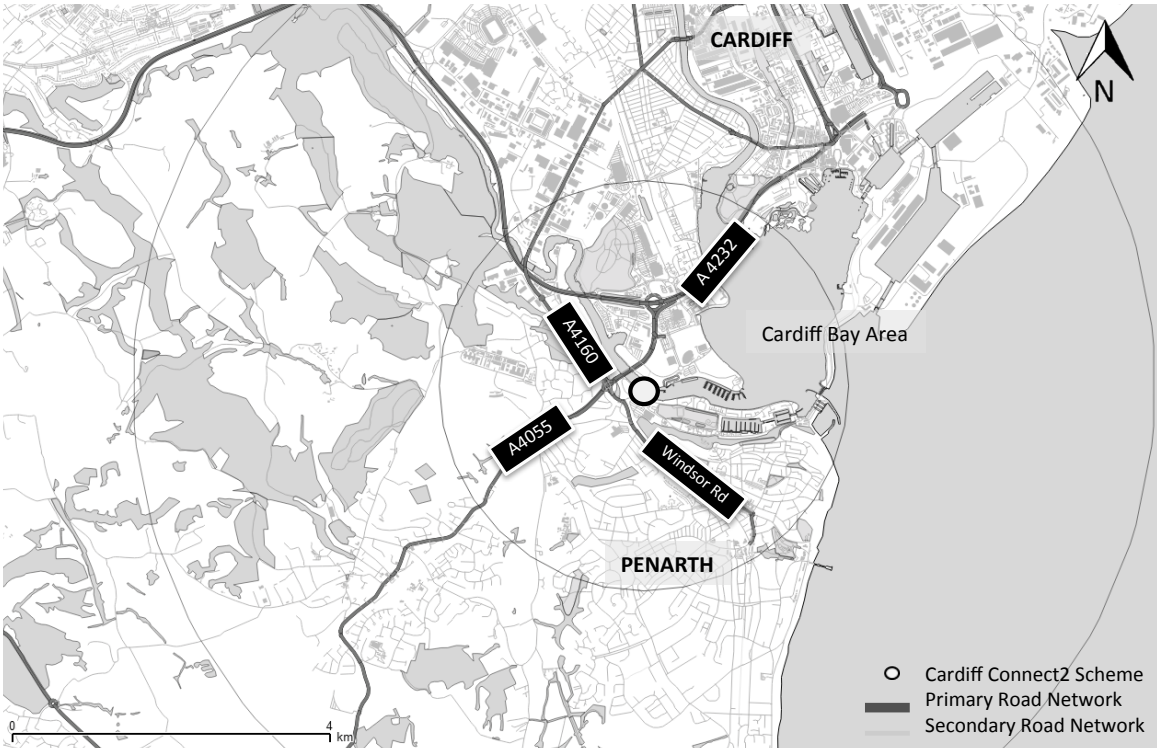


Figure 4.7 – Primary road network in the case study site (© OpenStreetMap contributors)

The primary road network in the case study site is formed by Windsor Road (main road access to Penarth and where main local shops are located), A4160 road (old road connecting Penarth to Cardiff) and A4055 road (main road link between Cardiff Bay, Penarth and Barry) (Figure 4.7). Traffic congestion is regularly observed on Windsor Road, Cardiff Road (A4055) and Penarth Road (A4160), particularly at peak times.

Cycle infrastructure in the local area is limited to some cycle paths or cycle lanes that are usually not well connected and do not provide an extensive, functional or safe network for cycling. While the Cardiff Cycle Network (north of river Ely) is 58 miles long, segregated cycle infrastructure in Vale of Glamorgan (south of river Ely) is limited to a few sections of road and a disused railway track. Recent figures (2011) suggest however that 3.9% of residents in Cardiff commute to work by bicycle and that cycling levels have increased by 65% in the last 10 years (Office for National Statistics 2014).

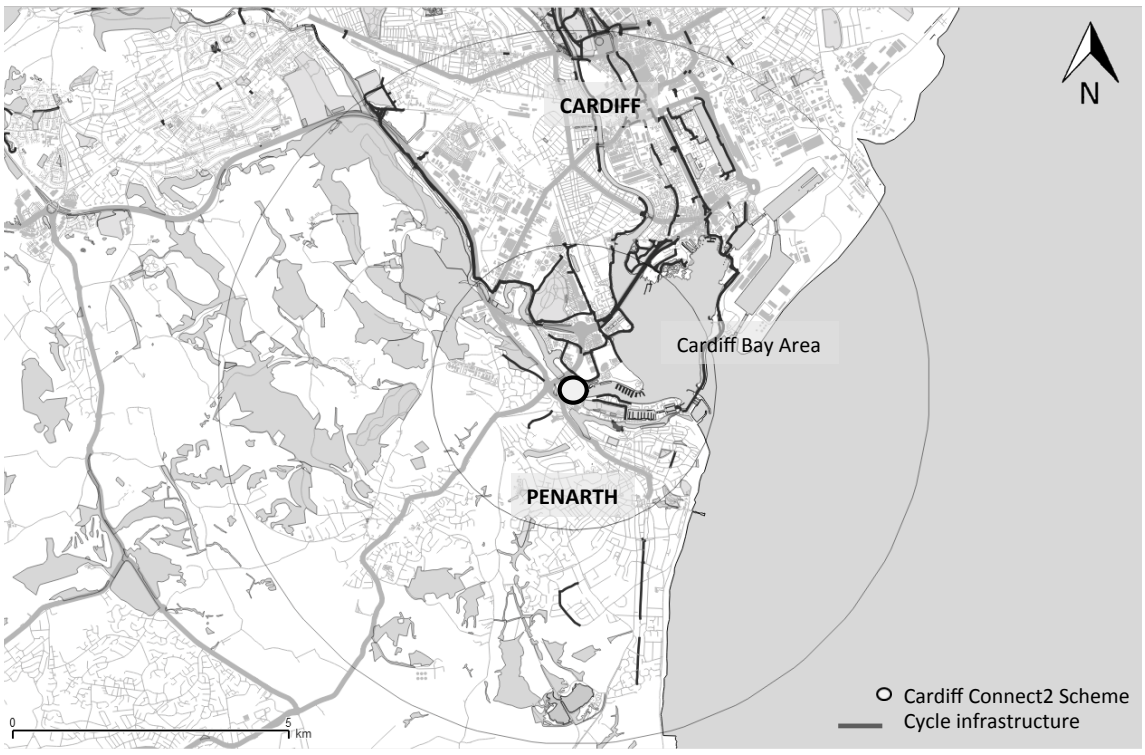
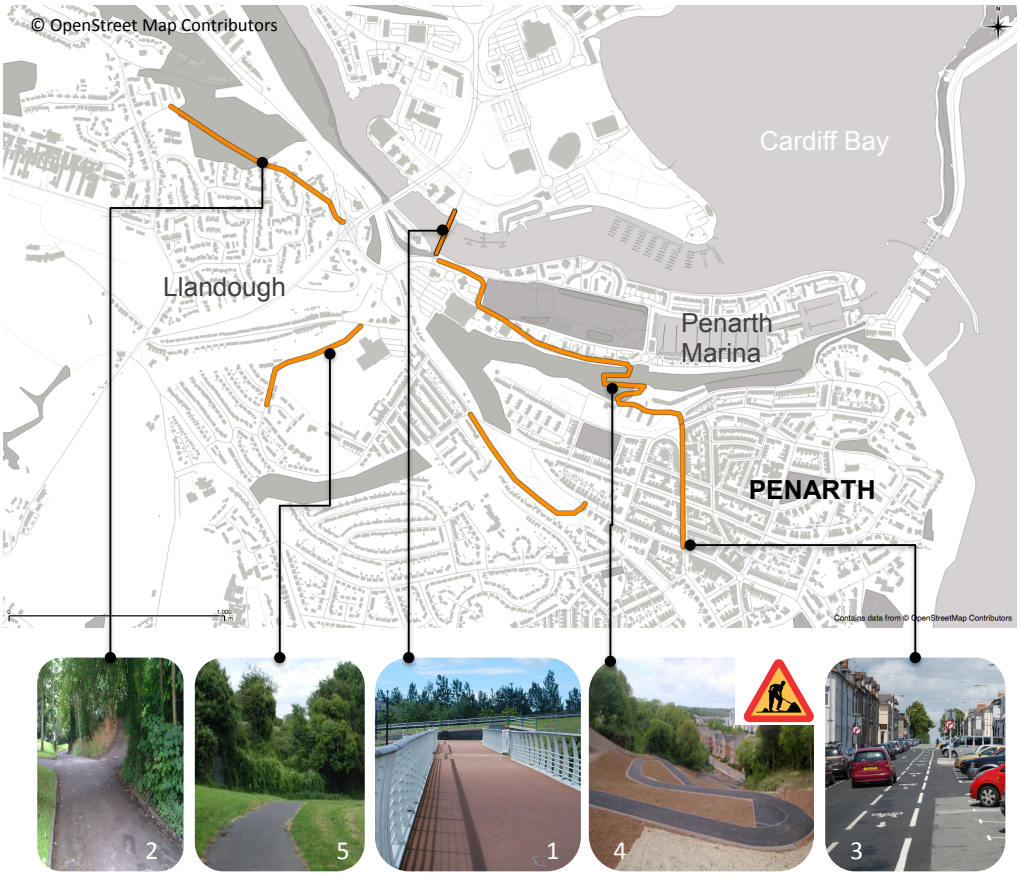


Figure 4.8 – Cycling infrastructure provision in the case study site (© OpenStreetMap contributors)

The case study site area lies within the north temperate zone and has an essentially maritime climate characterised by mild weather, which can be cloudy, wet and windy (Met Office 2013).

4.4.3 The Connect2 scheme

The Cardiff Connect2 scheme consists of a traffic free bridge over the river Ely – Pont y Werin (or People's Bridge) and improved link routes for pedestrians and cyclists that connect Penarth to Cardiff Bay Area facilities and Cardiff City Centre (Figure 4.9). The aim of the scheme was to enable commuters to walk or cycle from Penarth into Cardiff (or the opposite way) and local residents to access the leisure and commercial facilities in the Bay and in Penarth without need to travel by car. Additionally, the bridge completed a popular 10.5km circular trail around Cardiff Bay (PTRC 2012).



	Type of Infrastructure	Location	Implementation
1	**Bridge**	River Ely	July 2010
2	**Traffic free path**	Cogan Pill Road, Llandough	Re surfaced in 2012
3	**Contra flow lane**	Penarth Town Centre	April 2012
4	**Traffic free path**	Penarth – Penarth Marina	2013 (after period of the study)
5	**Traffic free path**	Windsor Road Dingle	Partially re surfaced in 2012 and finished in 2013

Figure 4.9 - Elements of the Connect2 Cardiff scheme and implementation timeline

The Cardiff Connect2 scheme consisted of five elements. The core infrastructural component was the 140m traffic-free pedestrian cycle bridge (Figure 4.9). The construction of the bridge[19] started in July 2009 and the bridge opened in 14th July 2010. The estimated cost of implementing the Pont y Werin was £4.6million – one of the most significant investments of the entire Connect2 programme.

The Cardiff Connect2 scheme was comprised of four other elements, mainly feeder routes to and from the Pont y Werin Bridge to facilitate its access and use. Those include a contra flow lane implemented in the city centre of Penarth in 2010 (Figure 4.11) and three segregated footpaths in Dinas Powys, Windsor Dingle and Llandough that were re-surfaced in 2012. A new access route for pedestrians and cyclists linking the Pont y Werin Bridge to Riverside Walk and a cycle lane over Plassey Street were also implemented in the local area during 2012 (Figure 4.12).

A crucial element of the Connect2 scheme was the "zig zag" route (Figure 4.13), a traffic free section linking the new Pont Y Werin Bridge and the Penarth Marina to the top of the hill and Penarth town centre. However, this element was not implemented until May 2013, one year after the conclusion of data collection for this study[20]. For implementation timeline of the Cardiff Connect2 scheme please refer to Appendix G.

The Connect2 scheme in Cardiff was funded by Sustrans (£1.15million), Welsh Assembly Government (£1.6 million), Cardiff City Council (£1.3 million), Vale of Glamorgan (£200,000) and Cardiff Harbour Authority (£250,000) (PTRC 2012).

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[19] The bridge itself consists of a bascule bridge with four sections, (each weight between 38 and 46 tonnes) and a 20 metre opening section that allows river traffic to pass through.

[20] The fact that an important element of the Cardiff Connect2 scheme was not implemented during this study survey period was likely to have influenced local residents' perceived accessibility to the Pont y Werin. The impacts of this limitation are discussed in Chapter 10.



Figure 4.10 – Pont Y Werin over river Ely in Cardiff Bay - implemented in July 2010 (source: author)



Figure 4.11 – Contra flow lane in Arcot Street - implemented during spring 2011 (source: author)



Figure 4.12 – New path on River Walk (left); new bicycle lane on Plassey Street (middle) and re surfaced path on Windsor Dingle (right)- implemented in 2012 (source: author)



Figure 4.13 – Zig Zag route linking Penarth Marina to top of the hill in Penarth – implemented in 2013 (source: https://penarthnews.files.wordpress.com)

4.4.3.1 *Conditions for walking and cycling prior to the provision of the Connect2 scheme*



Figure 4.14 – Existing routes over river Ely linking Penarth to Cardiff prior to the implementation of the new Connect2 scheme

Before the implementation of the Cardiff Connect2 scheme, access for pedestrians and cyclists between the two banks of the river Ely was limited to three alternative routes (Figure 4.14):

(1) The Cogan Spur was a four lane road, with a high volume of traffic, no provision of cycling infrastructure for cyclists and pedestrian access restricted.

(2) Penarth Road provided a long detour from local destinations and was perceived as an unfriendly environment for pedestrians and cyclists due to high volume and speed of traffic.

(3) The barrage route was a good quality traffic free path, further east from iConnect scheme, and that linked Penarth to Cardiff Docks. This route was however not open 24 hours a day; did not provide a direct access between Penarth Marina and closest facilities in the north bank of the river Ely; and it was more exposed to the weather conditions, in particular wind.

4.5 Sample of participants

This section describes the panel of participants of this study, how they were purposively selected and how they were recruited from an existing sample of the iConnect core survey sample. The aim of the selection process was to select a group of residents served by the new Connect2 scheme as diverse as possible; however, it was considered that attitude towards travel behaviour change and the proximity to Connect2 (i.e. 'exposure') should set the parameters for purposive sample selection which is further outlined below. As described in detail in Chapter 7, the final panel of participants in this study (N=50) was equally distributed in terms of gender and was diverse with respect to age (26 – 71 years old). From those, 17 participants have cycled at least once during the period of the study, either for utility or recreational purposes.

4.5.1 Background: the iConnect study sample

As part of the data collection strategy of the iConnect project, in April 2010, survey packs were mailed to 22500 adults living in a radius up to 5 km of a Connect2 Intervention in Cardiff, Kenilworth and Southampton; participants were randomly selected using the edited electoral register. The iConnect survey collected data on demographic and socioeconomic characteristics of participants alongside their travel behaviour, physical activity levels and psychosocial and environmental correlates and mediators of these behaviours (Ogilvie et al. 2012). The survey included also information on respondent's willingness to take part in further research[22]. Respondents to the iConnect survey (n=3516) appeared to be broadly representative in their demographics, socio economic and travel characteristic of local population in the three

[22] As part of the survey and its consent form, respondents were asked if they accepted "to be approached later to be invited to participate in optional follow up studies on the basis of information gained from the current study". This in-depth study was thus covered by the core survey ethics approval (University of Southampton Research Ethics Committee, CEE200809-15).

case study sites. However, comparisons with local and national figures suggested that respondents were likely to be older, had a somewhat higher level of education attainment and better health (Adams et al. 2013).

The fact that an initial contact with respondents was already established in Cardiff and that some basic information that could improve sample framing was made available beforehand provided a unique opportunity to this study. This enabled a more targeted and purposive approach to participants' recruitment that reduced burden over local population and expedited the recruitment process.

The iConnect baseline survey in Cardiff generated a total of 1020 responses. From this group, 659 respondents had agreed to be contacted in the future for further research.

4.5.2 Sample frame criteria

The main criteria used to pre select participants for this study was (a) an indication by the participant that s/he intended to conduct more journeys on foot or by cycle to travel from place to place or for recreation over the coming months[23] and (b) household proximity to the new Connect2 infrastructure. Socio demographic characteristics were not used as selection criteria; however it was decided that if the random selection performed would not delivery the desired mix sample of participants these would be added as criteria (c). The selection process is illustrated in figure 4.15.

The aim of using *intention towards walking and cycling (a)* as a criterion for sample selection was to guarantee that at least some of the participants would be positive (or predisposed) to change their active travel levels in the near future and that therefore potential change could be studied. This "near market" strategy was particularly important, as the sample of the study was expected to be relatively small. It should

[23] Participants that stated to disagree or strongly disagree with the question: 'Do you intend to walk or cycle more over the next few months?' were excluded.

bear in mind however that 80.1% of all respondents stated to have “moderate to high intention to do more walking and cycling for travel or recreation over the next months” .

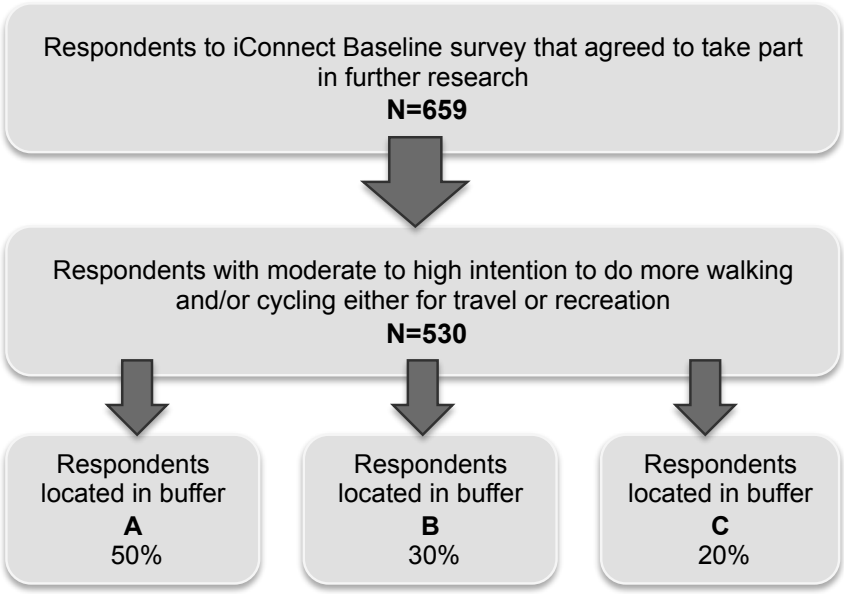


Figure 4.15 - Diagram representing application of sample criteria

The justification for *using household proximity to infrastructure (b)* as one criterion for selection was to guarantee that the influence of the new infrastructure could be assessed and that observed changes in participants living nearer and further away to the Connect2 site could be investigated. Three buffer areas based on distance to the Connect2 scheme were defined to draw the sample from: 50% of participants were randomly selected from buffer A (1mile); and 25% of participants were selected from both buffer B and buffer C (2 and 3 miles, respectively away from the Connect2 scheme. The selection process is illustrated in the figure below.

In summary, the iConnect baseline survey in Cardiff generated a total of 1020 responses. From this group, 659 respondents agreed to be contacted in the future for further researcher. Following the sample criteria application, respondents that revealed no intention towards walking and cycling were excluded. From the 530 available respondents, 400 were randomly selected and an invitation sent to their households.

4.5.3 Sample size

The panel of participants in this study comprised 50 participants (Figure 4.16). While there was an initial ambition of having a larger sample of participants in this study, the main limitations were twofold. Firstly, the sample size was limited by response rate achieved during recruitment of participants (described in the following section) and attrition levels (participants' dropout during the period of the study which is typical in longitudinal studies). Secondly, technical limitations related to limited number of GPS devices available and data collection workload imposed restrictions on the feasibility of a larger sample size.

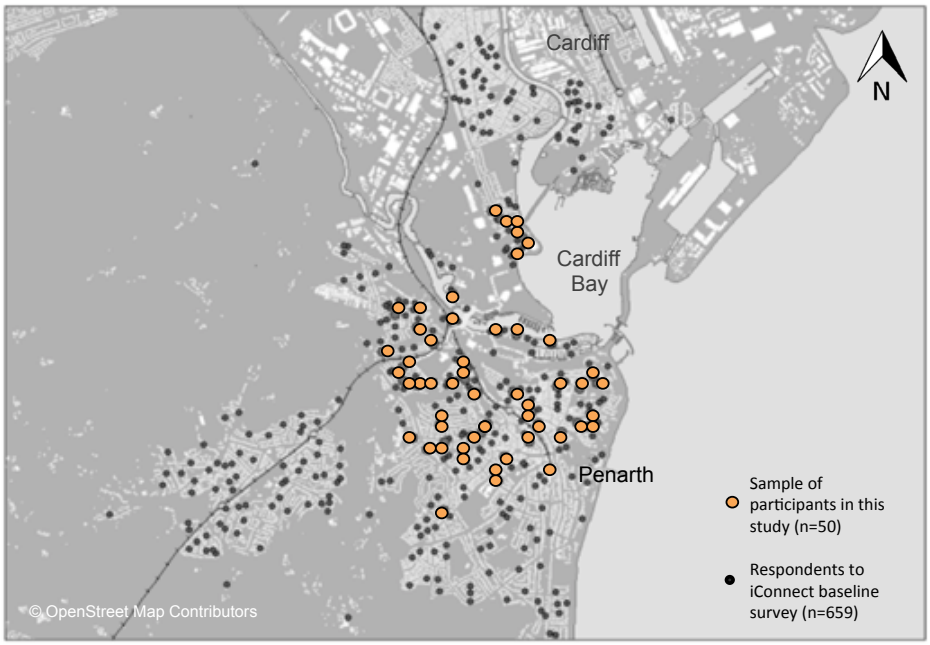


Figure 4.16 - Location of respondents to iConnect baseline survey and participants in this study (N=50)

The main limitations of a relatively small sample are a lack of representation of the local population; therefore generalizations for the general population cannot be established with any degree of certainty[24]. However, this study is focused on the

[24] A sample of at least 378 participants would have been required to allow for the results of the study to be generalised to the population of Penarth (circa 23,000) with a confidence level (CL) of 95% and confidence interval (CI) of 5% (i.e. if the experiment is repeated on a random sample of the population, the probability to get the same result is +/-5%, 95 times out of 100) (http://www.surveysystem.com/sscalc.htm#one).

exploration of mechanisms influencing walking and cycling behaviour and their relationship with new infrastructure; the statistical representativeness of the quantitative findings gathered is not assumed as a key objective. Moreover, it is the panel design approach that allows for intra subject changes to be explored (addressing one of the main aims of this study).

4.5.4 Recruitment of participants, response rate and incentives

Invitations to take part in this study were mailed[25] to the selected sample of four hundred respondents. The invitation package contained an advance letter, a participant information sheet and a pre-paid self-return postcard on which the respondent could indicate whether or not they were interested in taking part in the study (see Appendix B). Invitations were sent in two waves rather than one to make ensure that the researcher was not oversubscribed with willing participants. Figure below summarises the various stages of the recruitment process.

[25] It should be noted that the joint recruitment of participants for this study was done in partnership with another PhD student working alongside the iConnect project and focusing her study at the same case study site.

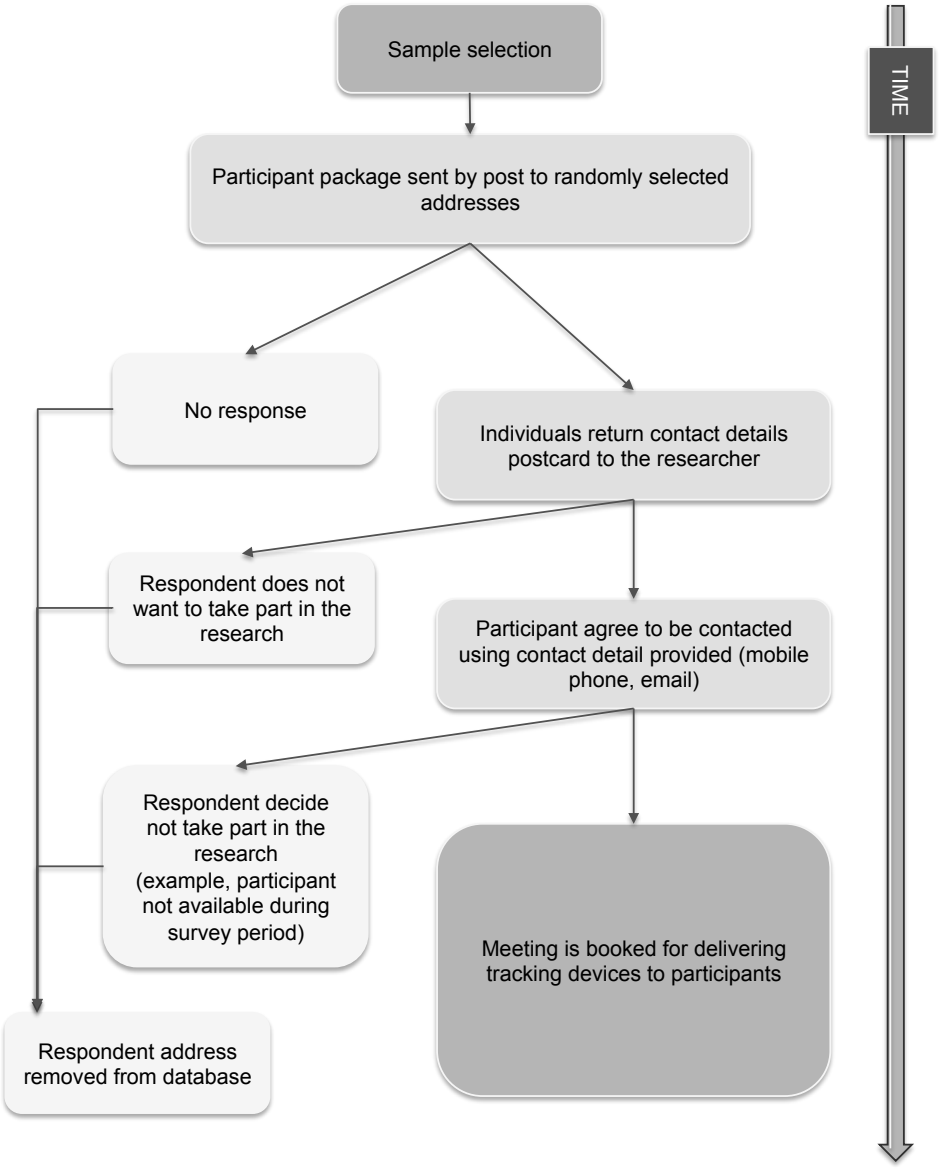


Figure 4.17 - Recruitment process diagram

4.5.4.1 Response rate

In 2011, 23% of the 400 respondents contacted confirmed their willingness to take part in this study. These people were contacted shortly after by phone or email to confirm their interest and to arrange an initial visit to their homes to commence the study. A total of 71 participants agreed to take part in the travel survey during 2011 (Table 4.2).

In 2012, those participants that took part in the study in the previous year and from whom travel data records were valid (N=69) were invited to take part in the study again. A positive response rate of 73.9% was achieved in this second year of the survey. The main reason for general dropout between waves was that participants had

moved away from the case study site (N=5) or were unwilling to take part in the follow up survey (N=11). Additionally, due to a failure of one GPS device during the survey period in 2012, records from one participant were also excluded from dataset Therefore, the final panel sample size of this study was N=50.

Table 4.2 – Overall Sample population and response rates

	Individuals	Response Rate
iConnect Cardiff survey - questionnaires sent	7200	
iConnect Cardiff survey - questionnaires received	1020	13.6%
iConnect Cardiff survey - respondents agreed to be contacted	659	
Sample available for this study	**659**	
Sample after frame selection criteria	530	
YEAR 1 - addresses randomly selected and invitations sent	400	
YEAR 1 - sample response	71	17.8%
YEAR 1 - successful travel data records	69	
YEAR 2 - invitations sent	69	
YEAR 2 - sample response	51	73.9%
YEAR 2 - successful travel data records	50	
Final sample	**50**	

4.5.4.2 Incentives

As a way of compensating participants for their time they were offered a £10 gift voucher if they managed to complete the first phase of the study. By making payment of the incentive conditional on the return of the GPS device also limited the risk of the non-return of the devices.

As a reference, in the National Travel Survey UK, respondents are given a £5 high street voucher if the CAPI interview is completed and all household members provide a fully completed travel diary. In the NTS GPS Feasibility Study (DfT, 2009), a £10 high street voucher was offered for full participation if the respondent fully completed a travel diary and accepted and returned a GPS device.

4.6 Data collection

The collection of travel data in the case study site was conducted in two waves in 2011 and 2012. A total of 14 weeks were spent in the local area meeting participants, delivering and picking up devices and collecting contextual data. The researcher met each participant on four different occasions and conducted observations at the case study site during the fieldwork process (Figure 4.18).

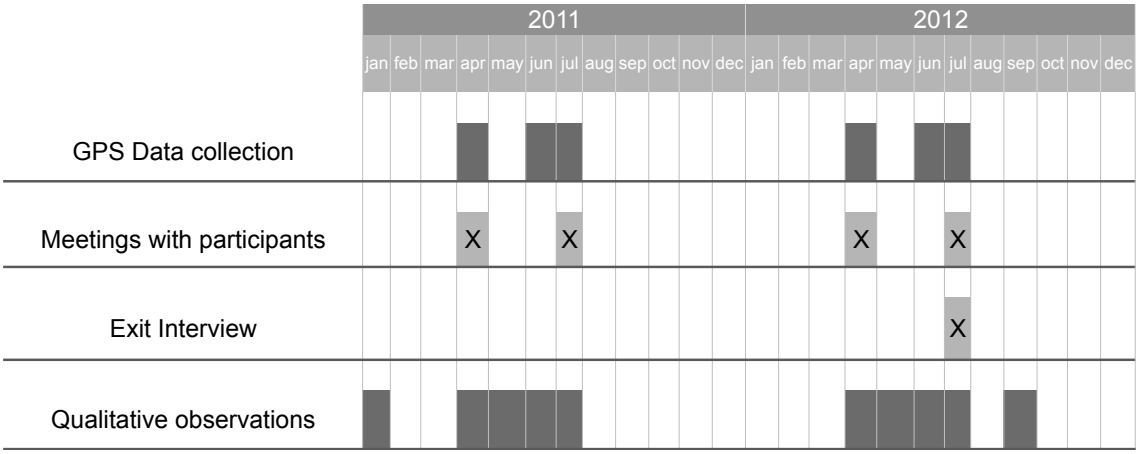


Figure 4.18 – Timeline for collection of travel behaviour data in the case study site

4.6.1.1 First wave - 2011

The first wave survey took place between April 2011 and July 2011. The researcher arranged an initial meeting with participants to explain the research protocol and delivery the survey instruments (GPS device, charger and travel diary). A leaflet with instructions was also provided (see Appendix E) and any concerns or issues regarding the use of devices were discussed with the participants. Participants were asked to take the GPS devices with them for all travel outside home, no matter how long or short, and no matter what the purpose was; and reminded to carry on their normal activities and travel patterns during the travel survey week and to record any events that were atypical.

Usually 1 to 2 weeks after the initial meeting, the researcher visited participants again to collect the measurement tools. Participants were asked to report any problems with

the devices or to raise any other issues that they had during the travel survey period. On the receipt of the devices, any faults were also recorded.

During encounters with participants, the researcher recorded participants' comments in a notebook to be able to return to these when examining participants travel patterns. At the end of the meeting, participants were offered a £10 high street gift voucher to compensate for their time.

4.6.1.2 Second wave - 2012

In 2012, a similar procedure was followed. An initial meeting with participants took place to delivery devices; however, this time, the meeting was usually shorter as participants were already familiar with the research protocol. During the final meeting to collect the devices, the researcher conducted an exit semi structured interview. In this interview, the researcher asked participants questions about their perception on travelling around the local area, barriers to walking and cycling, changes in travel behaviour over time and significance of the new Connect2 scheme in influencing everyday travel. At this stage, participants were also asked to provide feedback on the travel survey conducted, instruments and their use. All the comments were recorded on a notebook. Data from the devices together with scanned data from travel diaries was uploaded and stored securely on a desktop computer in accordance with University data protection policy.

Alongside the semi structured exit interview, the researcher also collected other contextual data while meeting up with participants and conducting qualitative observations in the local area during 2011 and 2012. As an example, meeting up with the participants, to delivery survey instruments, revealed as an excellent opportunity to engage in informal discussions and to get participants views, critiques or suggestions regarding their local area and travel behaviour. Having the privilege to go into participants' homes provided a unique opportunity to learn from participant's accounts.

Furthermore, during the time spent in the local area, the researcher conducted a series of qualitative observations in key sites in the local area, as such the Pont y Werin Bridge, the Barrage, Penarth town centre or Cardiff bay area. During these observations, the researcher used a digital camera and notebook to record travel movements, mobility patterns or as an example, the number of cyclists and pedestrians crossing the Pont Y Werin bridge over a determined period of time. Overall, this provided useful insights of the local context, contributing to the much-needed interpretation of the travel in the area.

4.7 Summary

This chapter has described the rationale for the research strategy adopted in this study and the methods developed for data collection. The chapter started by justifying how this study followed a mixed method quantitative driven approach, as at its core was the quantitative measurement of travel behaviour around a Connect2 scheme but where qualitative data was added to supplement and provide a more comprehensive understanding of the quantitative results and the phenomena being studied – the impact of new infrastructure for pedestrians and cyclists in individuals everyday travel behaviour. The advantages behind the adoption of a longitudinal study of a panel of residents served by a Connect2 scheme as the main research design for this study were then explained. These included the opportunity to accurately measure participants' travel behaviour over time, detect more subtle changes that may have influenced individuals' everyday travel alongside opportunity to explore the causal relationships and longevity of any of the effects detected. The novel combination of methods developed for data collection was then described alongside the advantages of such approach. Personal GPS devices have the capacity to provide detailed information on travel patterns, including route taken, which is crucial to assess the level of use of the new scheme and to objectively measure changes in travel over time. The

use of self-completion travel diaries, on the other hand, enables to overcome some of the current issues with GPS data processing and to cross check and validate data recorded by the GPS devices. Additionally, the collection of contextual data provides a meaning to the quantitative results obtained and contributes to a better understanding of the significance of the new infrastructure in influencing (or not) individuals' travel behaviour.

This chapter has also introduced the case study selected to conduct this research: the Connect2 Cardiff. This is one of the most iconic Connect2 schemes and consists of new routes and a 140m dedicated bridge over the river Ely, in Cardiff Bay. The scheme enables commuters to walk or cycle from Penarth into Cardiff and local residents to access leisure and commercial facilities in Cardiff Bay without the need to travel by car. By focusing on a single case study, the aim was to be able to evaluate with greater depth the role of a Connect2 scheme in influencing local residents' travel behaviour while taking into consideration the context within the scheme was situated. Following on this, the chapter described how the panel of participants in this study (N=50) was selected and how they were recruited from an existing sample of the iConnect core survey sample. The collection of data in the case study was conducted in two waves in 2011 and 2012 and was described in the last section of the chapter.

The methods developed in this study for data processing and analysis are described in detail in the next chapter alongside a discussion of the feasibility and challenges of using a GPS mixed method approach to measure travel behaviour - one of the aims of this study.

5 Feasibility, Reliability and Validity of the GPS Based Mixed Method Approach

5.1 Introduction

Following the outline of the research objectives, conceptual framework, methodology and participants recruitment in Chapter 4, this chapter evaluates the feasibility, reliability, internal validity, participant acceptance and challenges of using a GPS based mixed method approach for travel data collection – a core objective of this study. The various steps and tools involved in data cleaning and processing are then described in detail in section 5.3, as this was a challenging stage of the research and is still a critical process in GPS based studies. Finally, in section 5.4, the methods employed for data analysis, including evaluation of changes in travel behaviour over time, route analysis and carbon emissions from personal travel calculations, are explained in detail.

5.2 Feasibility of a GPS based mixed method approach

One of the aims of this study was to assess the feasibility of a GPS based mixed method approach for travel data collection. Based on the experience gained from the application of this methodology in the case study site, among a group of 50 participants and over two survey waves in 2011 and 2012, this section describes the reliability of the survey instruments, its acceptance by the public and their overall performance.

5.2.1 Reliability of the survey instruments

The majority of the 42 GPS devices available for data collection performed well during the survey period. However, in 2011, 2 units failed to record any data and 6 units recorded only up to 5 days of travel. In 2012, only one GPS unit failed to record any data though. All the participants, with exception of two, have returned the GPS units, chargers and filled in travel diaries following the survey period. In 2011, one participant

failed however to return his travel diary and in 2012, one participant failed to return both survey instruments. This participant was excluded from the sample study.

Other travel surveys using GPS technology have also reported equipment failures. As an example, in the NTS GPS feasibility study conducted in the UK it was found that 5 out of 60 devices were faulty, 2 devices developed faults whilst they were with respondents and 32 devices lost their configuration settings due to a software issue (Andersen, Abeywardana, Wolf & Lee 2009). Overall, this corroborates that as with any technology, there is always a risk of equipment failure.

Alongside these technical issues (including GPS signal scattering, signal loss or failure to record a section of a journey), participants' misuse of the devices was also likely to have influenced travel records. Most common reasons include participants forgetting to carry the GPS device, turning it on or charging it. As a result, at least 28% of the participants have reported the likelihood of one or more journeys conducted during the travel survey period not being recorded on the GPS devices. However, 22% of the travel diaries contained as well missing data with regards to journeys conducted (journey start and end time were the most frequently incomplete field).

5.2.2 Feasibility and public acceptance of the survey instruments

In general, participants found the survey instruments to be user friendly. Despite the diversity of the participants in the study in terms of age (28-76), gender, background or skills and aptitudes, most of them found the GPS devices relatively easy to use and the overall survey process relatively straightforward. As in the second year of the survey participants were more familiar with the survey methodology and overall GPS performance has improved, this may suggest however that participant's experience of the survey procedure is beneficial. Additionally, this may highlight one of the advantages of panel surveys – the fact that participants have the opportunity to train a specific survey protocol and that can potentially reduce the error of measurement in

next waves (Stopher, Kockelman, et al. 2008). It should be noted that a small group of participants found the need to fill in the travel diary as a small burden. This may suggest that opportunity to record that travel data using a digital or integrated platform with GPS device may be preferred, at least by some individuals.

5.2.3 Level of accuracy of GPS data

An approximate total of 1,120,000 geo-coded points were recorded during the survey period. The level of detail in raw GPS data was impressive in most cases and a clear identification of trip routes, mode of travel or activity conducted at destination could be easily inferred. Additionally, the identification of walking and cycling trips conducted over the new Connect2 scheme was straightforward in the majority of the cases. Figure 5.1 shows some examples of the level of accuracy found in GPS raw data.



Figure 5.1 - Raw GPS data – examples (source of basemap: Map Data © 2014 Google)

5.2.4 GPS devices and travel diaries: cross-validation of travel activity data

In this study, personal GPS devices and travel diaries were designed to be complementary to each other. However, in order to explore the completeness and performance of the GPS devices, this sub-section examines the number of trips recorded by both instruments. It could be assumed that if the GPS devices functioned correctly, and were correctly used/ carried by respondents, all trips that were recorded in the travel diary should have been present within the GPS data.

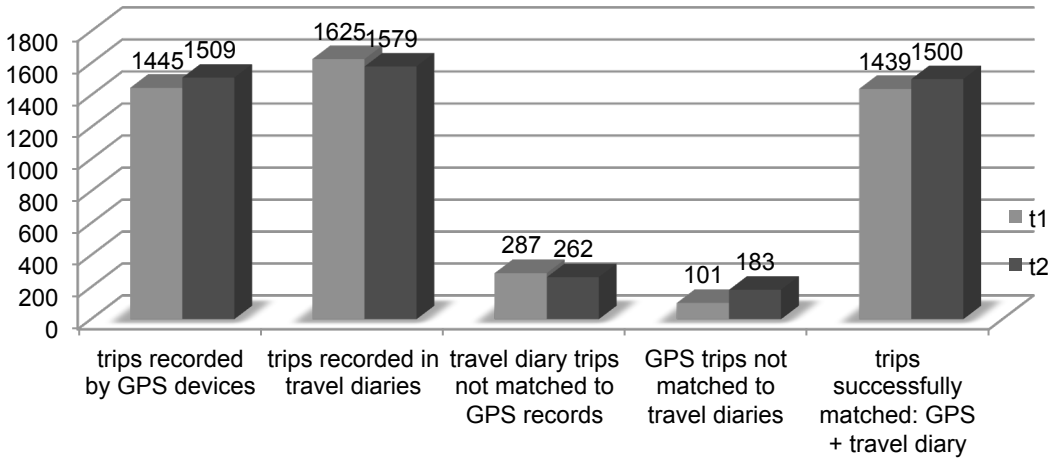


Figure 5.2 - Stages recorded on GPS devices and travel diaries in both years of the survey

Overall, 92 % of travel diary trips were matched by the GPS data; i.e. similar trip in terms of origin and destination and start/end times were detected in both the GPS and travel diary. However, GPS weekly stage rate was lower than the comparable travel diary stage rate (29.5 and 32.0 respectively) as travel diaries recorded **9% more stages**[26]. It should be noted that 284 **stages recorded by the GPS** devices were not reported on the travel diaries. Additionally, a comparison between years suggests that

[26] In this study, 2954 stages were identified in the GPS data and 3204 stages reported in the travel diaries. The DfT GPS Feasibility Study (Andersen, Abeywardana, Wolf & Lee 2009) reported however that a higher number of trips were recorded in the GPS data rather in the travel diaries (8 per cent more). It should be noted that the averages recorded by participant in the DfT study are lower to results obtained in this study: GPS weekly trip rate was 19.0 in the DfT study (28.9 in this research) and the travel diary weekly rate was 17.6 in DfT report (30.2 in this research).

difference between GPS and travel diaries records is lower in the second year of the survey (weekly rate are 30.1 and 31.6, respectively). This may suggest an increase in GPS recording performance in the second wave of the survey, likely to be related with participant's increased awareness of the devices and its correct use.

The use of **travel diaries** provided, however, to be extremely useful in addition to the GPS devices. Trip details and contextual notes recorded in the notebooks provided valuable information on trip purpose and trip mode validation. Furthermore, it should be noted that nearly one third of the participants used the travel diary to add extra notes regarding their travel behaviour options. Comments made included clarification of journeys mode of travel, route travelled or issues with the GPS device, such as forgetting to turn on the device or lack of battery during a specific journey.

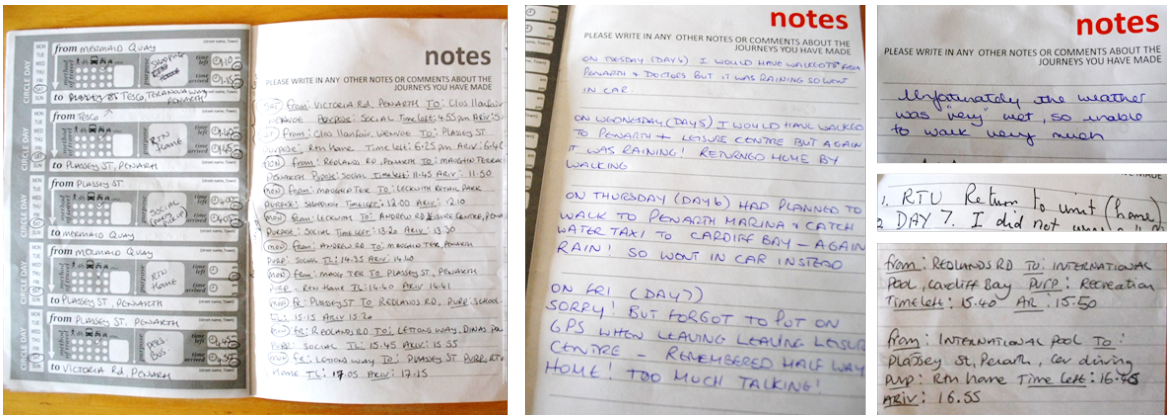


Figure 5.3 - Example of contextual notes left by participants on the travel diaries

5.2.5 Section summary: advantages and challenges

This brief evaluation suggests the potential of GPS technology in collecting an impressive and amount of detail with regards to travel behaviour patterns. However, the comparison of GPS and travel diary data recorded demonstrated that GPS devices captured trips that respondents have not reported in the travel diary but that the opposite was also true, as there was a considerable proportion of travel diary trips being unmatched by GPS data. As explained, this could be partially explained by misuse of the devices (participants forgetting to carry the devices, turning them on or

charging) or some sort of technical issues (signal loss, equipment failure, software issue or lack of battery). Additionally, cold start issues (i.e. time that GPS device takes to reach satellite signal when is turned on) may explain why some trips, usually starting at home, were incomplete for the first 200-400m. As with any technology, there is always a risk of equipment failure, however, this seems to be a minor issue if compared to the quality and the quantity of the data gathered. Moreover, a great advantage of this mixed method approach to travel data collection (GPS + travel diary), was the opportunity to triangulate data collected, increasing accuracy and validity of the results obtained.

5.3 Data processing

The procedure developed in this study for GPS data cleaning and processing was based on a **hybrid approach** that relied on trip identification and inference of trip mode and purpose validated by travel diary data. This section provides a detailed description of the actions and tools employed to perform this procedure. As exemplified in Figure 5.4, this was a challenging and complex phase of the study due to the amount of data collected (nearly 11 million GPS points) and processes involved in cleaning, processing and correctly coding the data.



Basemap: © OpenStreetMap contributors

Figure 5.4 - Example of GPS raw data complexity

5.3.1 Background

There is a growing body of literature focused on the exploration of techniques and rule-based algorithms to allow inference of trip purpose and trip mode from raw GPS data. However, results obtained are still exploratory, are not 100% reliable and frequently require manual checks, suggesting that further development is still required (Stopher 2008a; Lee et al. 2008; Schuessler & Axhausen 2009; Bohte & Maat 2009; Gong et al. 2012; Shen & Stopher 2014a).

The basic procedure for **trip identification** involves the correct definition and identification of trip end and trip start. Travel data is divided into trips, based on the concept that trip is all travel between two activity nodes[28]. Most researchers use rule based algorithms to perform trip/segment identification; however, a wide range of problems frequently challenges results obtained. These include valid definition of dwell time between activities, identification of short stops, spurious trips and missing trips, influence of signal loss or signal noise, as an example (Shen & Stopher 2014a).

For **trip mode and purpose** classification based on GPS data, the most frequently used methods are ***Inference, Recall Surveys or Travel Diaries***. These are summarised in Table 5.1. **Trip mode identification** usually relies on ad hoc rules that combine x and y coordinates and timestamps in the GPS logs with average speed, maximum speed, acceleration, and information from a GIS database (Bohte & Maat 2009; Stopher et al. 2008). The ratio of successful identification is in average 80%[29]. Hit ratios for car trips may be as high as 95% but cycling and walking trip ratios vary between 65%- 80%, with an exceptional 98% for walking trips reported by (Chung & Shalaby 2005). While deterministic methods are still struggling with the ambiguity of

[28] As an example, Gong et al. (2011) defined activity nodes as cluster of points that are less than 50 meters or more than 200 seconds from each other.

[29] Gong et al (2011) developed a GIS algorithm that automatically processes GPS based travel survey data and was able to detect 5 modes of travel (walk, car, bus, subway, commuter rail) - the success achieved was 82,6 %.

identifying similar trip modes such as bicycle or buses; probabilistic methods have the limitation of being subject to either long training procedures or a lack of required 'ground truth' data (Shen & Stopher 2014a).

Table 5.1 – Strategies for deriving trip mode and purpose from GPS traces

Inference	Consists in Inspecting GPS traces using formulated ad hoc rules to associate scores to particular variables with a specific transport mode; this involves formal data mining and statistic models, which can be deterministic or probabilistic. The main critic to an Inference approach is that there is no confirmation of correctness by the participants.
Recall	Consist in contacting participants after the data has been collected and request them to validate the trips made. This can be made as an example by printing travel maps and ask participants to manually identify and correct assumptions made on trip purpose classification or using an online application. This is considered the best approach for data validation, however this can be also time consuming and likely to increase respondent burden. Web based post validation surveys have the disadvantage of being restricted to some groups of the population.
Travel diaries	Consist of self-report instruments that participants fill in the trip purpose and trip mode of each trip they have made during the same period of time when they were using GPS devices. The researcher uses than manual inspection of mapped traces against the imputed purpose and mode.

Trip purpose is typically imputed on the basis of land-use information (Axhausen et al. 2003; Wolf et al. 2001) or a combination of land-use and personal information (e.g. home address) (Bohte & Maat 2009; Stopher 2008a). While recall and travel diaries provide a more accurate approach for trips classification and validation, such approach can be however time consuming and likely to increase respondents burden. For an extensive summary of approaches for trip mode and purpose identification and accuracy rates refer to Shen & Stopher (2014a).

5.3.2 Approach adopted for processing data in this study

The procedure adopted for GPS data cleaning and processing in this study relies on a **hybrid approach** that is based on trip identification and inference of trip mode and purpose validated by travel diary data. Other alternatives considered for data cleaning and processing included the development of ad hoc rules, use of the web application

Personal Activity Location Measurement System (PALMS/ University of San Diego)[30], or outsourcing with a GPS data specialist at Sidney University and a private company GeoStats[31]. After a period of testing, these options were ruled out due to different issues (accuracy of final outputs, need for manual validation, time involved or cost).

A summary of the overall approach adopted in this study for data processing is provided in the figure below.

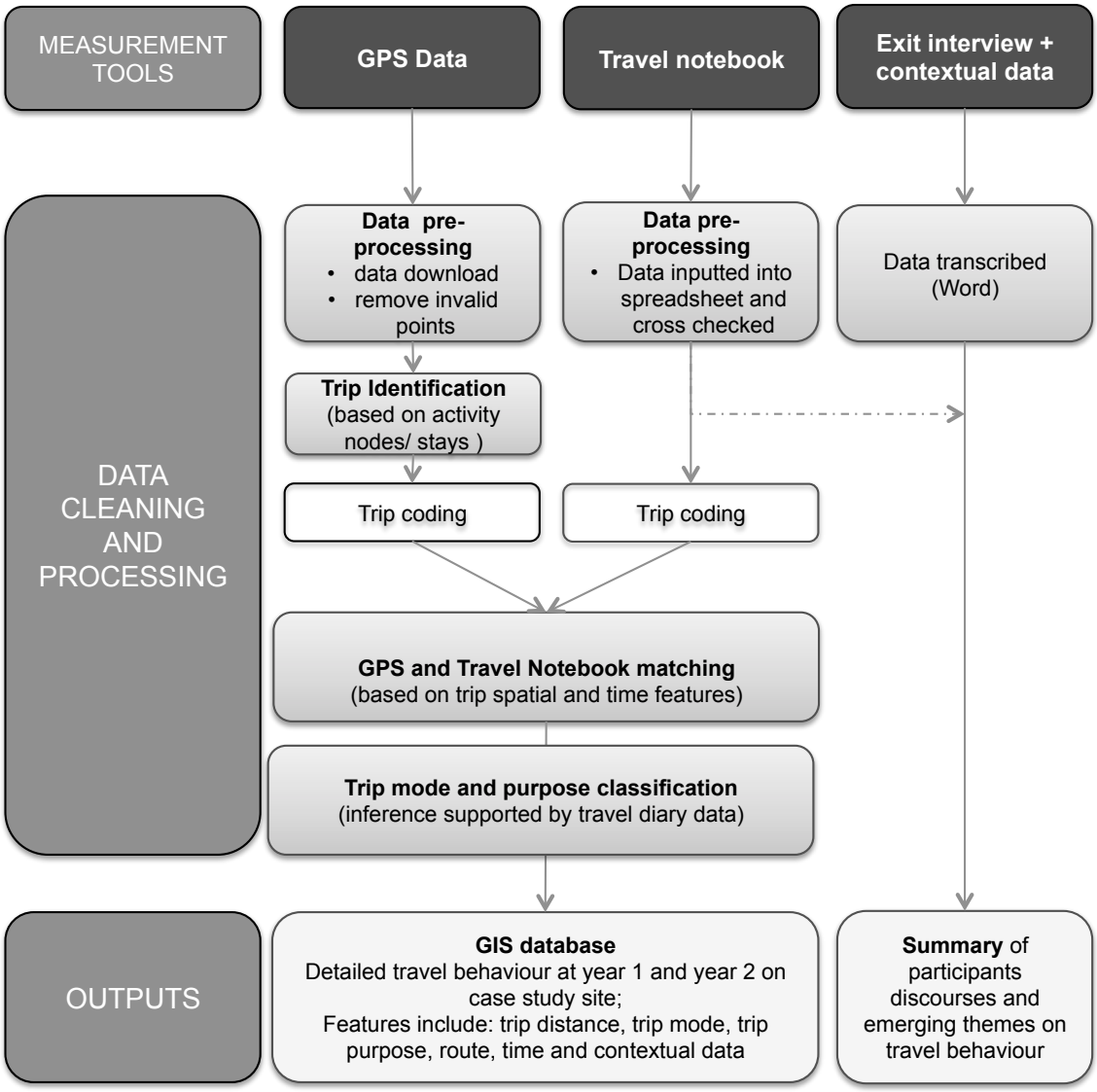


Figure 5.5 – Summary of approach adopted in this study for data processing

[30] Source: http://ucsd-palms-project.wikispaces.com

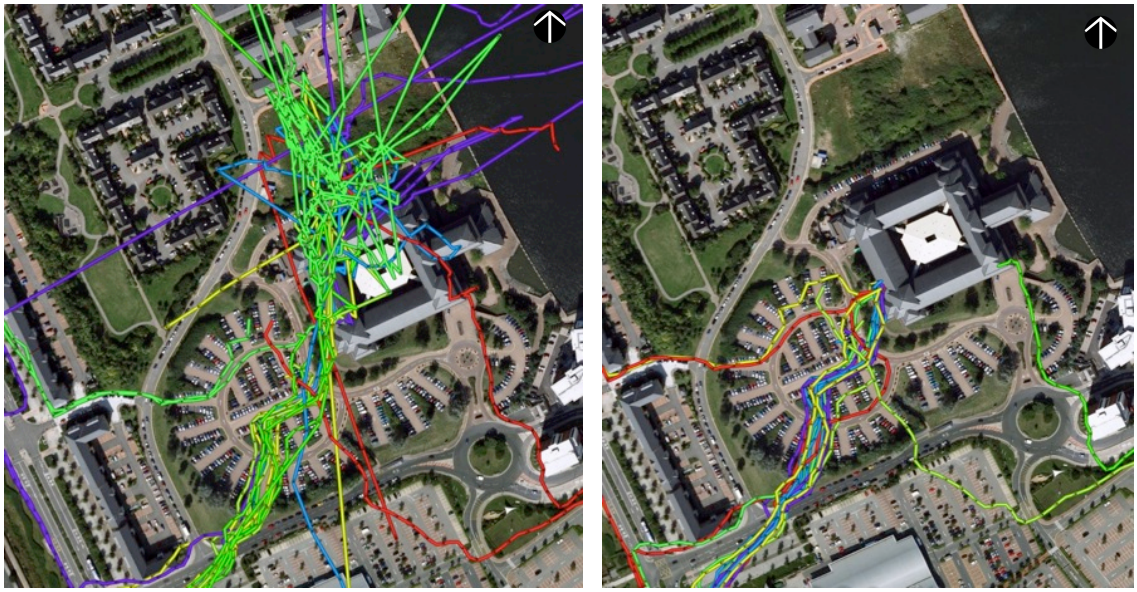
[31] GeoStats (Tias - Trip Identification and analysis systems custom software's developed by GEOSTATS. source: http://www.geostats.com/service_swdev.htm

5.3.3 Data pre processing

The first operation of this procedure was to download data from the GPS devices, validate their quality and export data into GPX and CSV format, using the Qstarz Qtravel software. The self-reported data in the travel diaries was also transcribed into an Excel spread sheet organized by trips (rows) and trip attributes (columns). The trip features recorded were trip start/destination, trip start/end time, trip mode and trip purpose. Trips destinations were double-checked using online tool www.showmystreet.com - this enabled a quick visualisation of any given address details based on postcode or address. This database contained also a column with the contextual notes recorded by the participant on the travel diary. This included quotes such “change plan due to illness or weather” or “forgot to turn off GPS device on trip 2”, as an example. Approximately, 30% of the participants in this study have used the travel diary to record notes and comments. Some of these notes were later followed up in the interview. The spread sheet produced contained 2952 rows of data (refer to Appendix I for a snapshot of the database).

5.3.4 Data cleaning

This first step involved cleaning invalid points from the travel set. Those included stationary points representing no movement (recorded, as an example, when participants were inside buildings) and linear path scattering (series of points travelling along a linear path ignoring the obstacles). Data points with excessive speed values (more than 150km/ h) were also checked and removed at this point (Figure 5.6).



Basemap: Map Data ©2014 Google

Figure 5.6 - Example of GPS data before and after removing stationary points or linear path scattering

5.3.5 Trip identification

Trips were identified based on the concept that trip is all travel between two activity nodes. Activity nodes were defined as cluster of points that were less than 50 meters or more than 200 seconds from each other. For stay classification, it was assumed that 7+ adjacent points within ± 2 min and 60 meters distance were a stay. This is aligned with thresholds applied in current literature (Gong et al. 2012; Sorgenfri et al. 2009).

Trip identification was performed using a GPX Editor application (ADZE – 1.3.3). This software enables one to split GPS tracks based on rest time (minutes) and buffer area (meters). The filters applied were however adjusted frequently, as thresholds defined did not fit in every occasion. In addition, during this stage, it was detected that the position of the GPS points that defined a track were sometimes not aligned with road network. In this case, data points were spatially adjusted to the actual alignment on the ground and transport network (map matching). Examples of this procedure are illustrated in Appendix H.

5.3.6 GPS and travel diary records matching

The next step of this data procedure was to match trips identified in GPS data with trips recorded in the travel notebook[32]. This procedure was performed in GIS software (Cartographica) and required a match of spatial and temporal trips features in both datasets. Three outputs were derived from this operation:

1) A GPS trip was matched to a trip recorded in travel notebook (92.4% of trips);
2) A GPS trip could not be matched to any trip recorded in travel notebook (8.9% of trips);
3) A trip recorded in travel notebook trip could not be matched to any GPS trip (17.1% of trips).

The comparison and matching provided some form of internal cross-validation. The figures obtained suggest a relatively good match and validity of the hybrid approach. Travel diary trips that could not be matched to GPS trips (3) were however excluded from final dataset as for these trips routes taken were not available.

5.3.7 Trip mode and purpose classification

Trip mode and purpose classification was performed using a **mix approach of inference supported by travel diary data.**

Trip mode was deduced from the GPS file based on average speed, maximum speed and route taken. Deduced trip mode was validated with data from travel diary. In case of conflict, other features were assessed, such as transport infrastructure network or past behaviour.

[32] As an example, in the NTS GPS feasibility study it was defined that trips from GPS and travel diary could be matched if they fell within 12.5 minutes of each other; alternatively, trip end locations could be automatically matched if they fell within 100m of each other (DfT et al. 2009).

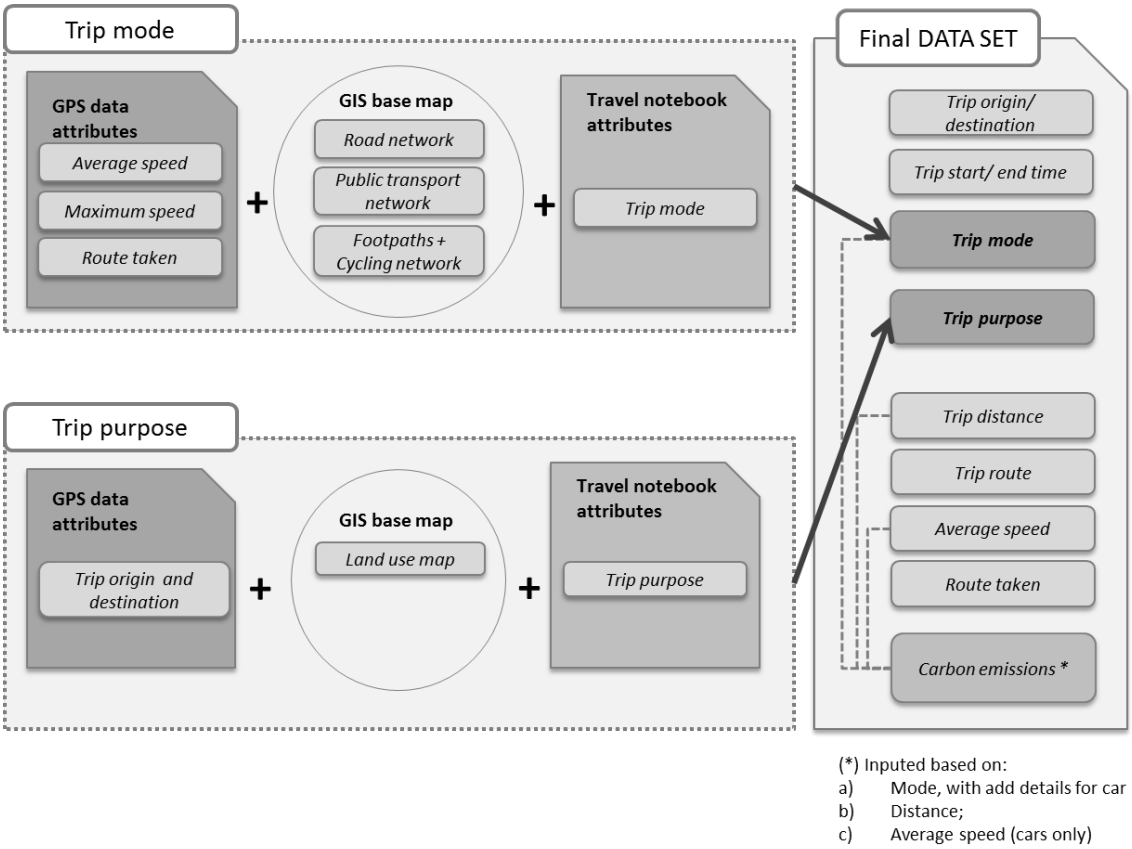


Figure 5.7 – Strategy developed for trip mode and trip purpose classification

Journeys purposes were classified as follow:

a) **Commuting** - trips to and from usual place of work;

b) **Business** - trips in course of work;

c) **Escort and Education** - trips to school or college by students, or used when the participant had no purpose of his or her own, other than to escort or accompany another person. An example of a frequent escort trip was picking up a friend from the station or a child from the nursery.

d) **To and from shopping or personal business:** all trips to shops or from shops to home, even if there was no intention to buy; trips to visit services (most common were bank, post office, hairdresser, library and church); trips for medical consultations or treatment (local GP surgeries, dentist and hospital);

e) **Social and visit friends:** trips to visit and meet friends, relatives, or acquaintances, both at someone's home or at a pub, restaurant; trips to all types of entertainment, clubs, and voluntary work;

f) **Recreation:** walking trips for pleasure or exercise along public highways, including taking the dog for a walk and jogging; cycling trips for sport or recreation;

g) **Other leisure:** trips made to access leisure and sport activities, including gyms, sport centres, leisure centres, parks or places where recreation activity takes place. Also included is scenic driving.

5.3.8 Web Map services and software

Three primary web map services were utilised to aid in the editing of the collected GPS tracks and to present the results over the following chapters. These include Google Maps, OpenStreetMap and BingMaps. The Google Maps interface is an integral part of the Qtravel software[33] that comes as a package with the Qstarz BT-Q1000XT GPS device. This is the only custom software that enables to download GPS logged data from Qstarz devices and provides an initial visualization of data. Google Maps interface was also used with the Adze software[34], a GPX data editor for Mac OS X that was employed to edit track points, automatically split tracks at rest-stops and optimize away redundant data. Openstreetmap and Bing Maps were used with ArcGIS[35], Cartographica[36] and QGIS[37]. Data of the local area presented in the maps (road

[33] http://www.qstarz.com/Products/Software%20Products/QTravel-F.html
[34] http://kobotsw.com/
[35] https://www.arcgis.com/features/
[36] https://www.macgis.com/
[37] http://www.qgis.org/en/site/

network, transport interfaces, buildings, services and facilities, parks and green areas, rivers, or other points of interest (POI) were adapted from OpenStreetMap[38].

A list of software used in this study to process data collected is presented in the table below.

Table 5.2 – List of tools used to process collected travel data in this study

Software/ Tools	Function/ used for	File formats
Qtravel Qstarz	Download data from GPS devices and export as data CSV and GPX files.	CSV GPX
Showmystreet.com	online tool used to validate address details while manually inputting data from travel diaries to travel database.	
Adze 1.3.3	GPX editor for Mac OS X; enabled trip identification based on rest stop time (minutes; adjustable) and buffer area (meters; adjustable); provided live preview of any editing; discard rest stops; trips coding; route optimization based on different strength levels and % of points removed; indication of track direction.	GPX
Cartographica 1.4	GIS software for Mac OS X; main features include easy importation and analysis tools. Use for merging CVS files (travel diary database) with GPX files (data recorded by GPS devices) and export merged files as Shapefile (for ArcGIS) and as CSV (for SPSS).	GPS SHP
ArcGIS 10 and QGIS 2.6	Spatial analyses and visualization of travel data; plot maps.	SHP
Microsoft Excel	Input data collected through travel diaries.	
SPSS 19.0	Statistical analysis.	

This section has explained why in the absence of an automatic procedure to clean and process GPS raw data, this study developed a hybrid approach for trip identification and classification. This approach was based on trip identification and inference of trip mode and purpose validated by travel diary data. The various steps of this procedure were detailed in this section alongside tools used in each part of the process. Overall, this approach provided an accurate and cross-validated travel data set that could not be obtained by relying exclusively on rule-based algorithms. The procedure was, however, time consuming and is unlikely to be replicable for much larger data sets unless sufficient resources are provided (e.g. in national surveys).

[38] OpenStreetMap data is available under the Open Database License and the cartography is licensed as CC BY-SA - http://www.openstreetmap.org/copyright.

5.4 Data analysis

The methods employed for travel data collection and data processing provided the successful identification of 1010 tours, 2664 trips and 463 stages and 17760.9 miles of travel recorded over a period a 7 days in both 2011 and 2012 (Table 5.3). This section describes the methods employed for data analysis, including the definition of unit of travel, route analysis, carbon emissions calculations and journey transfer potential from short car trips to walking and cycling.

Table 5.3 Tours, trips and stages recorded in 2011 and 2012

		2011	2012
Tours		513	497
Trips		1340	1324
	single trips	1209	1172
	multimodal trips	72	116
	round trips	59	36
Stages		1439	1500

5.4.1 Definition of unit of analysis

In this study, travel data was coded using three different units of analyses/ level of hierarchy, in order to better describe the complexities and the context of the journeys captured (table 5.4).

Table 5.4 – Units of analysis

Stage	most basic unit of travel; A new stage was defined when there was a change in the form of transport or when there was a change of vehicle requiring a separate ticket (DFT 2012).
Trip	One way course of travel with a single main purpose. • **Single trip** - trips that have one stage only • **Multimodal trip** - trips that have 2 or more stages; it assumed that the longest stage is the main stage of a multimodal trip • **Round trip** – trips that start and finish at the same location.
Tour	sequence of trips that start and finish at home.

Trip, defined as a *'one way course of travel with a single main purpose',* is the most common unit of analyse adopted in travel studies (DfT 2011b). However, for the study of walking and cycling, **stage** is usually a better measure then number of trips. The

reason is that these modes of travel, in multi modal journeys, account usually for the shortest leg of the journey and are therefore likely to be missed if only trips are considered. Trips with two or more stages were defined as *Multimodal Trips*. Those trips where the origin and the destination were the same and where there was no discernible break in their travel were classified as *round trips*.

For a better understanding of the context of the trips within a journey, a third level of classification was applied. **Tour or trip chain** was therefore applied to define a sequence of trips that have started and finished at participants' household. The figure below summarises the strategy adopted in this study for unit of analysis classification.

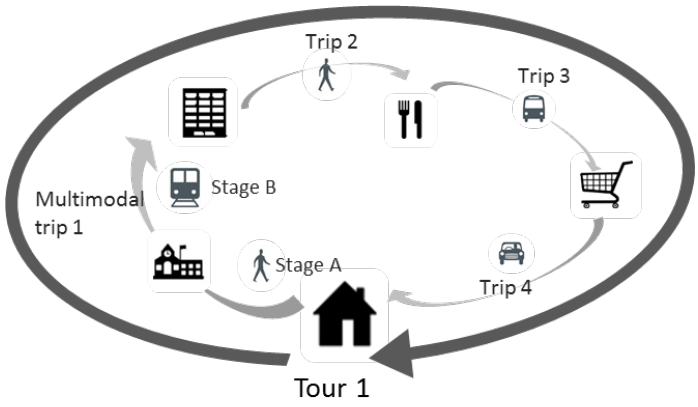


Figure 5.8 – Example of a tour with 4 elements: 3 single trips and one multimodal trip with 2 stages.

In **Chapter 6**, results are analysed at a trip level, as the objective of the chapter is to explore changes in overall travel behaviour over time for all modes of transport. Additionally, this approach enables to compare obtained figures to local and national averages for a contextualization of the results obtained. In **Chapter 7 and Chapter 8**, data is presented at a stage level as the aim is to investigate in detail the role of walking and cycling behaviour in the local area, and as explained above, stage provides a better measurement for these modes of travel. Finally, in **Chapter 9**, data is presented at a trip and tour level as the aim of the chapter is to assess the potential of walking and cycling in replacing short car journeys.

5.4.2 Outcome measures:

The main quantitative outcome measures of this study are summarised in the table below. These include trip frequency and distance travelled disaggregated by mode and purpose and CO_2 emissions from motorised travel also disaggregated by trip mode and purpose.

Table 5.5 – List of main outcome measures

	Distance travelled	**Trip frequency**	**CO_2 emissions per trip/ participant**
Utility walking	✓	✓	*
Utility cycling	✓	✓	*
Recreational walking	✓	✓	
Recreational Cycling	✓	✓	
Car Travel	✓	✓	✓
Public Transport	✓	✓	✓

✓Outcome measure
** Calculated*

Annual estimates (when presented) were obtained by multiplying the weekly total by 47 (and not 52 weeks). As the survey period fell outside these periods, this approach of discounting 5 weeks of time away from home (example school holidays, public holidays) seemed appropriated. A similar approach has been used by Brand et al. (2013).

A weighting adjustment that could have potentially corrected sample bias of this study was initially considered but then rejected due to the small sample size and the fact that some groups were under represented (as an example, there was only 5 participants in the plus 65 group). Furthermore, this study focuses on understanding individual's response to new routes for pedestrians and cyclists at a micro level rather than generalise conclusions to the overall population. Collected travel data was not also weighted either to take into account variables that may affect travel, such as weather. It is acknowledge that this may have implications for year on year comparisons and that particular caution should be considered when attempting to draw conclusions from small percentage points.

5.4.3 Evaluating changes in travel behaviour - statistical tests

Changes in travel behaviour over time are evaluated at both the overall and individual level in Chapter 6. Additionally, the level of use of the Connect2 scheme is examined in detail in Chapters 7 and Chapter 8. For this evaluation, a series of statistical tests were performed to compare means and to test for significance of changes detected over time. The table below describes the assumptions of the two statistical tests used for data analysis in this study: Paired Sample t-test and Wilcoxon Signed Rank Test.

Table 5.6- Statistical tests

Test	Description and Assumptions	Used for
Paired sample t-test	Used to determine whether the ***mean*** difference between paired observations was significantly different from zero. Assumptions: • Continuous dependent variable • Independent variable that consisted of two matched pairs • No significant outliers • Distribution is normal	• total trip frequency • trip frequency by mode • walking stage frequency and distance • cycling stage frequency
Wilcoxon Signed Rank Test (non-parametric)	Used to determine whether there was a ***median*** difference between paired or matched observations. It was used when distribution was non normal. Assumptions: • Continuous dependent variable; • Independent variable is categorical with two related groups • Distribution of the differences between the two related group are symmetrical in shape	• distance travelled (total and by mode) • cycling stage distance • walking and cycling stage frequency over Connect2 Scheme • total carbon emissions levels from surface transport

The Wilcoxon signed-rank test is the nonparametric test equivalent to the Paired t-test but it does not assume the normality in the data. Therefore, it was used when this assumption was violated and the use of the paired t-test was inappropriate.

5.4.4 Route and deviation from shortest path analysis

The objective of the spatial analysis performed in this study was focused on the identification of patterns of overall travel behaviour in the local area, including its context, main routes, popular destinations and its characteristics (trip route, trip distance, trip mode and trip purpose). Walking and cycling activities were analysed with a greater level of detail. For walking, analysis performed focused on exploring the complexities of walking for everyday travel and recreation, its relationship with features

of built environment and evaluation of level of use of the new Connect2 scheme. For cycling, analysis performed focused on the exploration of cyclists' route choices decisions, including deviation from shortest path for utility journeys and level of use of the Connect2 scheme or alternative routes. The route analysis was performed in QGIS software using the Road Graph Plugin[39], a C++ plugin that calculates the shortest path between two points on any polyline layer and plots this path over the road network (Figure 5.9). The likelihood of other attributes of the road network to have influenced cyclists' route choice, such as presence of cycling infrastructure, gradient, number of junctions along the route, or environmental quality of the routes was assessed based on spatial visualization and cross validation with contextual data collected.

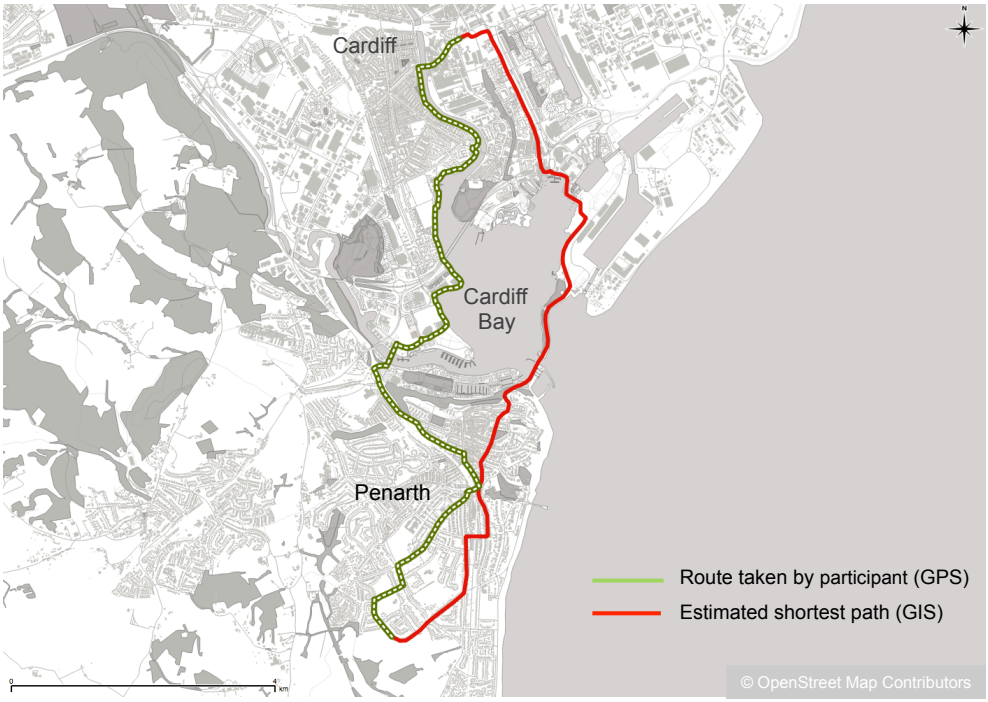


Figure 5.9 - Example of shortest route analysis performed in QGIS

[39] http://docs.qgis.org/1.8/en/docs/user_manual/plugins/plugins_road_graph.html

5.4.5 Assessment of potential replacement of short car trips by active travel/ journey transfer potential

One of the aims of this study was also to understand potential of walking and cycling in replacing short car trips and the extent to which the new Connect2 scheme would facilitate such shift. The assessment of journey transfer potential in this study was based on **trip distance, trip purpose and context of trip within a tour.**

It is frequently argued that walking and cycling can replace short car trips. However, an assessment of journey transfer potential based on trip distance alone may be limited. Trips are usually connected with other trips and only few are in fact isolated events. Furthermore, travel mode choice is frequently made on the basis of the whole chain. As an example, if a 1-mile car trip is just an element in a longer chain of several longer trips, car use may be a more reasonable option. A chain-based approach to analyse short trips, instead of a more fragmented perspective where all trips are treated equally is therefore likely to provide a more comprehensive understanding of the journey transfer (Davidson et al. 2007; Vagane 2007; Beckx et al. 2013). Following this rational, in this study it was defined that short car trips (<3miles) that were part of a home-based tour longer than 8 miles (12.8km) would not be considered as being potentially replaceable by walking and cycling.

However, it is not just the distance and the complexity of the trip chain that explains why car is usually preferred as mode of travel over short distances; in fact, the **purpose of the trip** is also likely to influence mode choice. Therefore, in this study it was assumed that for those short car trips (< 3miles) where participant was not the driver or that involved escorting to and from a place would be excluded[40]. Additionally, shopping trips to large retail areas were also filtered out, as it is assumed that need to

[40] Trips as car passenger were not considered as car passengers usually get a lift in a car that is already on the road; it can be argued that their mode choice has a different basis. Despite escort trips were as well excluded, it is acknowledged that there are feasible alternatives to carry 1 or 2 children on a bicycle (child seat, child trailer, cargo bicycle) or on foot (push chair, scooter, walking).

carry heavy goods and groceries may limit the feasibility of walking and cycling as an alternative mode of travelling. Short car trips to local shops and personal business were however considered, as when shopping in local shops, people tend to shop more frequently but in less quantity at each time and therefore need to carry lighter goods. Additionally, it may also be argued that the use of shopping trolleys, bike racks, panniers or cargo bicycles have the potential to facilitate walking or cycling over short distances while carrying goods. The table below summarises the attributes considered for the journey transfer potential assessment in this study.

Table 5.7 – Criteria for journey transfer potential assessment

Filters applied
Short car trips (<3 miles)
Short car trips part of tours < 8miles
Short car trips as a driver
Short car trips (escort trips removed)
Short car trips (shopping to large retail areas removed)

Results of journey transfer potential from short car trips to walking and cycling are presented in Chapter 9.

5.4.6 Carbon emissions calculation

The carbon emissions associated with participants travel activity were calculated for both waves of the survey period. Alongside the potential of the new Connect2 scheme in mitigating carbon emissions from personal travel, these are presented in Chapter 9.

A common approach employed for estimation of carbon emissions from surface transport is to apply mode and vehicle specific carbon emissions factors to travel activity data (Brand & Boardman 2008; Brand et al. 2014; NETCEN 2009). These conversion factors enable to convert travel activity data, such as distance travelled by mode, into kilograms of carbon dioxide equivalent (CO_2e) for each leg of a journey (DEFRA 2009; DEFRA 2011). In this study, CO_2e emissions from passenger cars were calculated using distance travelled by trip purpose (obtained from the GPS and travel

log data) and converted to emissions by applying conversion factors that take into account car size (with engine size as a proxy), fuel type (petrol, diesel, hybrid electric, other), average vehicle speed, vehicle age and the number of 'cold' starts (which causes excess emissions due to suboptimal fuel burn). The calculations applied in this study were based on speed-emissions[41] factors underlying the National Atmospheric Emissions Inventory[42] (NAEI) and obtained from DEFRA (NETCEN, 2009).

In this study, all emissions were allocated to the car driver, following a method originally developed by Brand & Boardman (2008). Car technology details and age were obtained from the iConnect core survey datasets (Brand et al. 2014; Ogilvie et al. 2012). Emissions from taxis were calculated using a conversion factor that is based on average GHG emissions of medium and large cars and occupancy of 1.4. For vans, motorcycles and public transport (bus and rail), average emissions factors for the specific regions were used, based on current GHG reporting guidelines (DEFRA 2011).

The CO_2 emission mitigation potential of utility walking and cycling was estimated by simulating a similar trip by car (origin and destination) and deriving associated CO_2 emissions. The car details of each participant (engine size, fuel type, vehicle age) and an assumed mean speed of 40 km/h for cars in urban areas (DfT 2014d) were used to perform these calculations. Final estimates also took into account cold and hot emissions.

For an estimation of annual CO_2 emissions levels, weekly totals were multiplied by 47 weeks, instead of 52. As travel data collection took place between April and July in each year, it seems that this approach of discounting five weeks' time away from home

[41] The underlying speed-emissions curves are polynomial functions of emissions as a function of average speed, by vehicle type, fuel type, engine size and vehicle age. 'Cold' start emissions are dependent on the ambient air temperature, average trip lengths and the share of the trip length running 'cold' (Brand, 2012).

[42] These factors are usually used by local authorities for environmental impact assessments and by national government for reporting on national greenhouse gas emissions to the UNFCCC.

(e.g. school holidays, public holidays) might be appropriate. This approach was applied in similar studies (Brand et al. 2013).

The analytical software packages used to perform the calculations was Microsoft Excel v2010 (for computation of emissions) and SPSS v19 (for descriptive analysis).

5.4.7 Qualitative data interpretation

Qualitative data collected during exit interview and contextual notes recorded over all the period of the study were initially transcribed into a Word Document. Participant responses were manually (i.e. unaided by Computer Assisted Qualitative Data Analysis Software) sorted into categories in order to undertake content analysis: context of travel in the local area (including main barriers, constraints and facilitators), perceptions of walking and cycling, significance and impact of the Connect2 scheme, and rationales for changes in travel behaviour. The content of each statement was then analysed further and through an iterative process emerging themes were highlighted. This information was crosschecked with travel data records (GPS + travel diaries). Exemplar statements were selected and are presented in Chapter 6, 7, 8 and 9 to provide explanatory power to general quantitative data. Participants' names have been anonymised and when quotes are presented, pseudonyms are used instead.

5.5 Summary

This chapter has examined the feasibility of the GPS based mixed employed in this study for travel data collection and described in detail the procedures developed for data processing and analysis. An examination of the travel data records suggests the potential of GPS technology in collecting an impressive amount of detail with regards to travel behaviour (section 5.3.2). Results have however demonstrated GPS loggers did not capture all trips, likely due to equipment failures or participants misuse of the devices, GPS loggers did not capture all trips made by participants (the same was also

true for the travel diaries). Nevertheless, 92% of the trips recorded in the travel diaries could be matched to GPS records.

The use of travel diaries was very useful in addition to the GPS devices as it provided an opportunity to triangulate data collected, increasing accuracy and validity of the results obtained. Moreover, journeys details and contextual notes recorded provided valuable information for trip purpose and mode validation and in interpreting atypical events or travel patterns. Despite a strand of research is currently focusing on the singular use of GPS technology in travel studies (Gong et al. 2012; Shen & Stopher 2014a), findings suggest the advantages of a mixed GPS-diary approach. This conclusion is aligned with findings from the DfT GPS Feasibility Report (Andersen, Abeywardana, Wolf & Lee 2009). The contextual data collected through interviews and meetings with participants was essential to provide an in-depth understanding of the reasons underlying particular patterns of travel behaviour and detected changes over time. The micro level detail gathered using this GPS mixed method approach would be less useful without the qualitative data.

The procedure developed in this study for data cleaning and processing was also described in detail in this chapter as up to date there is no automatic procedure to clean and process GPS raw data and this a critical stage in studies involving GPS technology. The hybrid approach developed was based on trip identification and inference of trip mode and purpose validated by travel diary data. This approach delivered a high level of accuracy to the final travel data set that could not be obtained by relying exclusively on rule-based algorithms. This was however a very time consuming process and may not be replicable in larger studies. The methods employed for data analysis, including statistical tests performed, route analysis, calculation of carbon emissions and journey transfer potential were also described alongside the issues surrounding definition of unit of analysis.

The following chapter describes the characteristics of the sample of participants in this study (N=50) and their overall travel behaviour during the two years of the survey period. Its aim is to provide a better understanding of travel behaviour in the case study site and define the context and scope for walking and cycling in the local area.

6 Understanding Changes in Overall Travel Behaviour over Time

6.1 Introduction

The results of this study and their analysis are presented over the following four chapters. This chapter describes the socio-demographic and spatial characteristics of a panel of 50 participants in Cardiff, their overall travel behaviour recorded over the period of the study and whether and why it changed between 2011 and 2012. Chapter 7 will then focus on the role of walking for everyday travel and recreation in the local area and the impact of the provision of the new Connect2 scheme in influencing walking levels over the period of the study. Similarly, Chapter 8 focus on the current role of cycling around the case study site, perceived barriers, route choice decisions and the impact of the provision of the new Connect2 scheme in promoting cycling for everyday travel or recreation. Finally, Chapter 9 investigates the potential of walking and cycling in replacing short car trips, the role of the Connect2 scheme in supporting this modal shift and detected changes in carbon emissions levels from surface transport.

The data presented and analysed over the following chapters is based on a total of 1010 tours, 2664 trips and 463 stages successfully recorded during the period of the study (2011 – 2012). Travel data is comprehensively coded and includes detailed spatial and temporal information. Results are presented in tabular or graph format and in the form of maps, allowing for comparisons and spatial contextualization. Quotes from participants and illustrations are also provided where these are considered to aid analysis and the interpretation of the results. In this chapter, data is analysed at a trip level, defined as one-way course of travel with a single main purpose.

6.2 Sample description

This section describes the socio demographic and spatial characteristics of sample of participants in this study (N=50). The aim is to provide a context to the group of residents in the local community served by a Connect2 scheme and the extent to which they relate to the local population.

6.2.1 Sample socio demographic characteristics

The group of respondents in this study was equally distributed in terms of gender (50%) and was heterogeneous with respect to age (26 – 71 years old). Comparisons with local and national figures suggest however that the sample of participants may have been younger than the average local population. The 65 plus age group was likely to be underrepresented (18.7% local level and 10.0% in this study) while the 50 - 64 age group was over represented (19.7% at local level compared to 34.0% in this study).

The sample of participants was highly qualified as almost two thirds of the group had a degree or equivalent (76%) compared to the average of 30% of the population with similar qualifications (CENSUS, 2011). Nearly three quarters (74%) of the participants were working either full time or part time, and 22% were retired. Annual household income was, within the sample, greater than £40,000 for at least half (56%) of the participants (table 6.1).

Car ownership levels of the sample were higher than for local population. While 20.2% of the local population does not have access to a car in the household (25.6% of households in England and Wales (DfT, 2011), in the study sample, only 4% of the respondents did not have a car.

In summary, while for gender and economic activity sample distribution was aligned with local figures, it was found that the study sample was likely to show bias towards

younger people, higher levels of education, income, car ownership and home ownership.

Table 6.1 - Socio demographic characteristics of the sample of participants in the study (N=50)

			Panel Study Sample (n=50)		Local population County level (a)	England and Wales
			2011		CENSUS 2011	CENSUS 2011
Domain	**Variable**	**level**	***n***	***(%)***	***%***	***%***
Demographic	Sex	female	*25*	50.0%	51.3%	50.9%
		male	*25*	50.0%	48.7%	49.1%
	Age	18-34 years	*15*	30.0%	20.1%	26.5%
		35-49 years	*13*	26.0%	20.3%	28.0%
		50-64 years	*17*	34.0%	19.7%	23.9%
		> 65	*5*	10.0%	18.7%	16.0%
	Ethnicity	White	*49*	98.0%	98.8%	86.0%
		Other	*1*	2.0%	1.2%	14.0%
	any child under 16	no	*36*	72.0%	66.2%	55.6%
		yes	*14*	28.0%	33.8%	44.4%
					0.0%	0.0
Socio Economic	Education	Degree	*38*	76.0%	30.0%	27.2%
		A-level	*3*	6.0%	12.2%	12.3%
		GCSE	*8*	16.0%	33.4%	34.3%
		no formal	*1*	2.0%	24.6%	26.3%
	Annual household income	> £40,000	*28*	56.0%	.	.
		£20,001-40,000	*15*	30.0%	.	.
		<=£20,000	*7*	14.0%	.	.
	Housing tenure	home owner	*46*	92.0%	71.2%	64.0%
		renting	*4*	8.0%	27.5%	36.0%
	Employment Status	full time	*30*	60.0%	44.5%	48.2%
		part-time	*7*	14.0%	17.3%	13.7%
		student	*0*	0.0%	7.9%	9.2%
		retired	*11*	22.0%	15.8%	13.3%
		home duties	*2*	4.0%	3.7%	4.3%
		other	*0*	0.0%	10.9%	10.8%
		economically active	*37*	74.0%	61.8%	77.6%
		economically inactive	*13*	26.0%	38.2%	22.4%
Car and bike access	cars in the household	no cars	*2*	4%	20.2%	25.6%
		1 car in the household	*28*	56%	43.0%	42.2%
		2 or more cars in the h	*20*	40%	36.9%	32.1%
	any adult bike in the household	yes	*34*	68%	.	.
		no	*16*	32%	.	.

a) population estimates are based on Vale of Glamorgan and Cardiff Boroughs CENSUS data, adjusted to similar proportion as study sample (92% Vale of Glamorgan and 8% Cardiff)

Population of Vale Galmorgan Borough (126,831) and of Cardiff (348,493)

Data Source: CENSUS 2011, Office for National Statistics

6.2.2 Sample spatial distribution

Participants in this study lived at maximum distance of 3 miles from the new Connect2 scheme and were distributed across Penarth and Cardiff Bay Area, as seen in Figure 6.1.

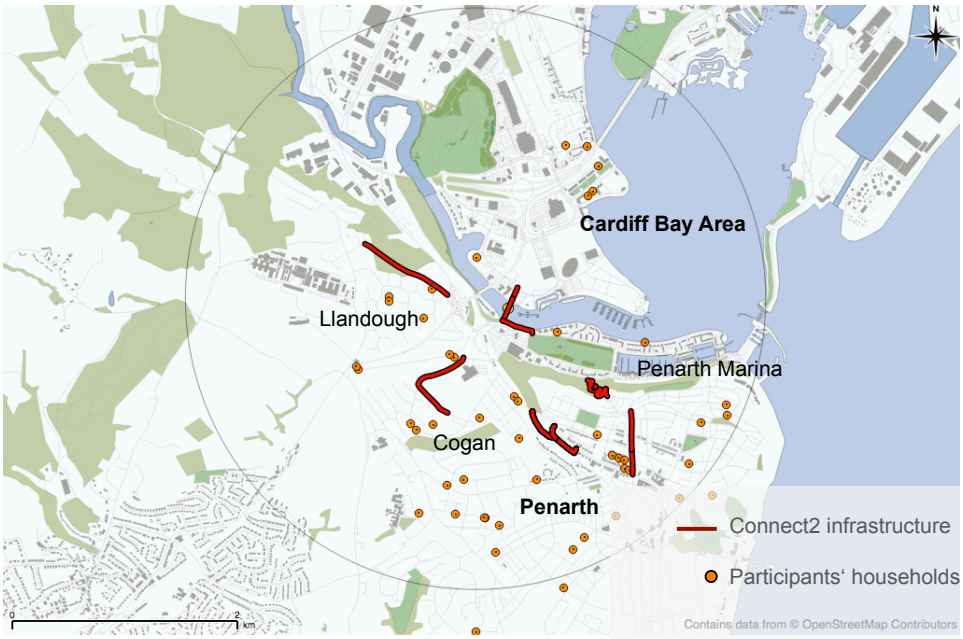


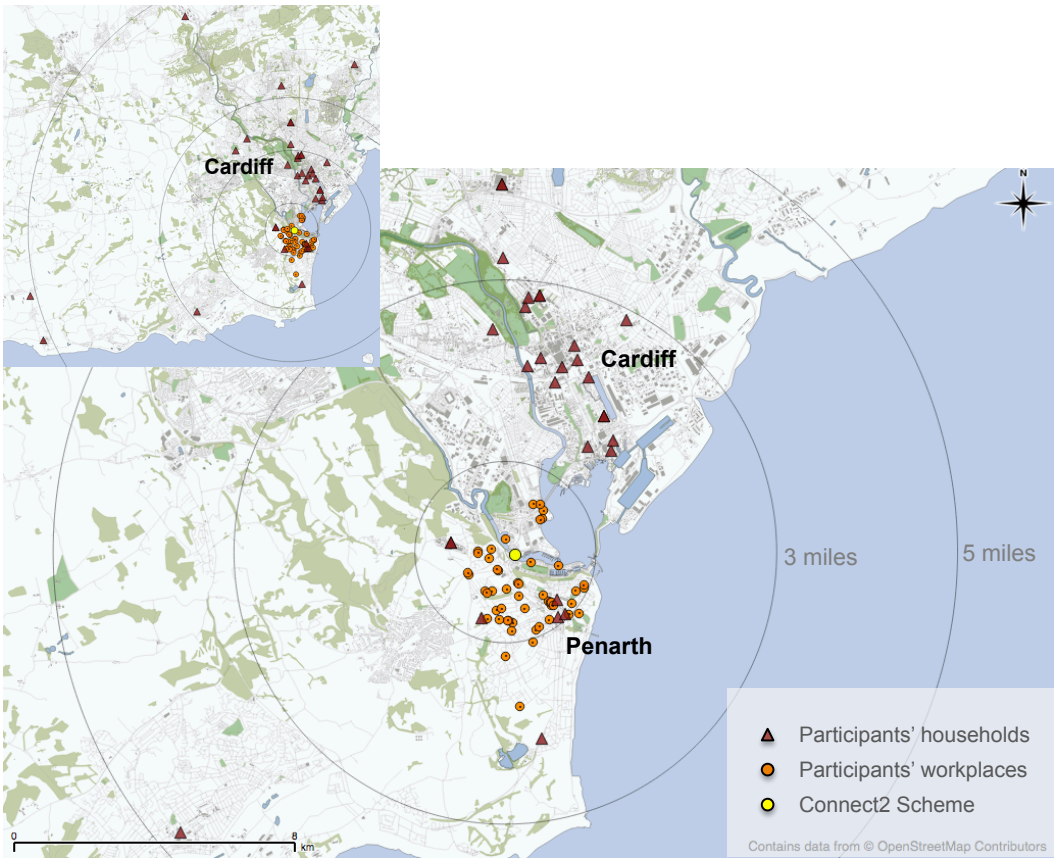
Figure 6.1 - Household location of participants in this study (N=50)

A vast majority of participants (N=27) lived in **Penarth**, located on the top of the Penarth Cliffs and lying on at the southern end of Cardiff Bay. One third (N=13) lived in **Cogan and Llandough,** two residential suburbs on northwest of Penarth; and 10 participants lived in **Penarth Marina** and **Cardiff Bay Area**, areas of medium density modern housing surrounding the bay. A comprehensive description of each of these neighbourhoods is provided in section 4.4.

6.2.2.1 Participant's workplace location

Nearly two thirds of the participants (N=37) work either full time or part time. From this group, 54% worked less than 5 miles away from home. The majority of the workplaces were also located around Cardiff and in the north bank of river Ely; this contrasts with

majority of participants' household location around Penarth and in the south bank of the river Ely (Figure 6.2).

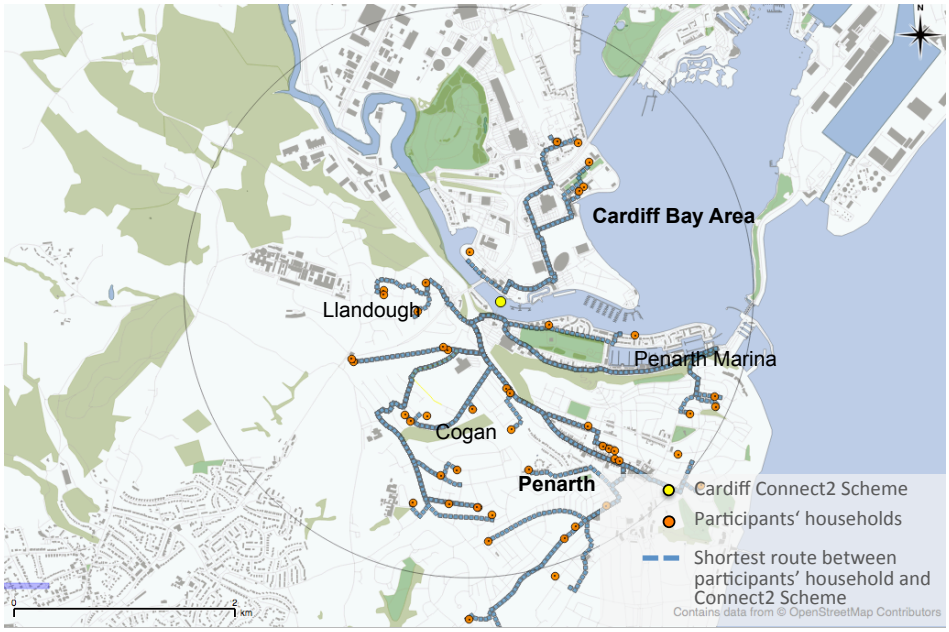


Network distance Home - Work	Frequency (N=37)
< 3 miles	11
3 to 5 miles	9
5 to 10 miles	9
10 to 20 miles	4
> 20 miles	4

Figure 6.2 – Household and workplace location of participants economically active (N=37)

6.2.2.2 Network distance between household and new Connect2 scheme

The majority of the participants (60%) live less than 1 mile away from the new Connect2 scheme, 30% of the participants live between 1 to 1.5 miles away of the new infrastructure and 10% of the participants lived between 1.5 to 2.5 miles away from the new walking and cycle infrastructure (Figure 6.3).



Distance home – new walking and cycling Connect2 Bridge *(shortest route)*	**Frequency** *(number of participants)*
< 0.5 miles	7
0.5 to 1 miles	23
1 to 1.5 miles	15
> 1.5 miles	5

Figure 6.3 - Shortest route path between participants' homes and the new Connect2 Bridge.

6.2.3 Sample socio demographics characteristics – changes between 2011 and 2012

As this is a longitudinal study, any changes in participants' individual circumstances or socio economic variables were recorded over the time horizon of the study (2011 and 2012). More relevant changes detected were related to socio economic profile of a few participants.

In 2012, full time employment rate dropped by 10% relatively to 2011. Two participants have retired, one participant became full time student, another participant changed to a part time job position and finally, another became unemployed during 2012. Therefore, there are some changes in annual household income of some participants, namely a 12% increase in the share of participants in the income category £20,000 - £40,000.

It is here also worth reporting that during 2012, two participants got a new job and two participants were reallocated to a different workplace or city. These changes implied that some commuting trips needed to be readjusted (mode of travel, trip distance or route). Table 6.2 summarises the variables that have changed the most over the period of the study: employment status and annual household income.

Table 6.2 – Changes in socio economic and vehicle access variables over the period of the survey (2011 – 2012)

			Study Sample (n=50)			
			2011		2012	
Domain	**Variable**	**Level**	***n***	***(%)***	***n***	***(%)***
Socio Economic	Employment Status	full time	30	60%	25	50%
		part-time	7	14%	8	16%
		student	0	0%	1	2%
		retired	11	22%	13	26%
		home duties	2	4%	2	4%
		other	0	0%	1	2%
	Annual household income	> £40,000	28	56%	24	48%
		£20,001-40,000	15	30%	21	42%
		<=£20,000	7	14%	5	10%
Car and Bike access	cars in the household	no cars	2	4%	2	4%
		1 car	30	60%	29	58%
		2 or more cars	18	40%	19	38%
	any adult bike in the household	yes	36	68%	39	*78.0%*
		no	14	28%	11	*22.0%*

Car ownership levels changed for five participants during the period of the study. Four have increased number of vehicles in the household (from 1 to 2 cars or from 2 to 3 cars) and one participant has sold 1 out of 2 two cars in the household motivated by a need to cut family expenses. Adult bicycle ownership increased in 2012, as three participants bought new bicycles in that same year.

In conclusion, the sample of participants in the study was well distributed in terms of age and gender but was likely to show a bias towards younger people, higher levels of education, income, car ownership and home ownership. Most of the participants (90%) lived less than 1.5 mile away from the Connect2 scheme and from those economic active 54% live less than 5 miles away from their workplace. Most significant changes

detected over the period of the study were related to change in jobs or economic activity.

6.3 Overall travel behaviour at baseline

In order to understand participants travel behaviour in the case study site and explore the context and scope of walking and cycling in the local area, this section examines how, why, where and when did participants travelled during the first year of the survey (2011).

The majority of the trips made by the participants in this study took place around Cardiff Area and were less than 5 miles long (77.1%). Trips over 25 miles represented just 4.6% of all the trips made but 52.6% of all the distance travelled. The main trip destinations outside the local area include North Wales, London, Southampton, Plymouth, Milton Keynes, Brighton, Guildford or Reading (Figure 6.4).

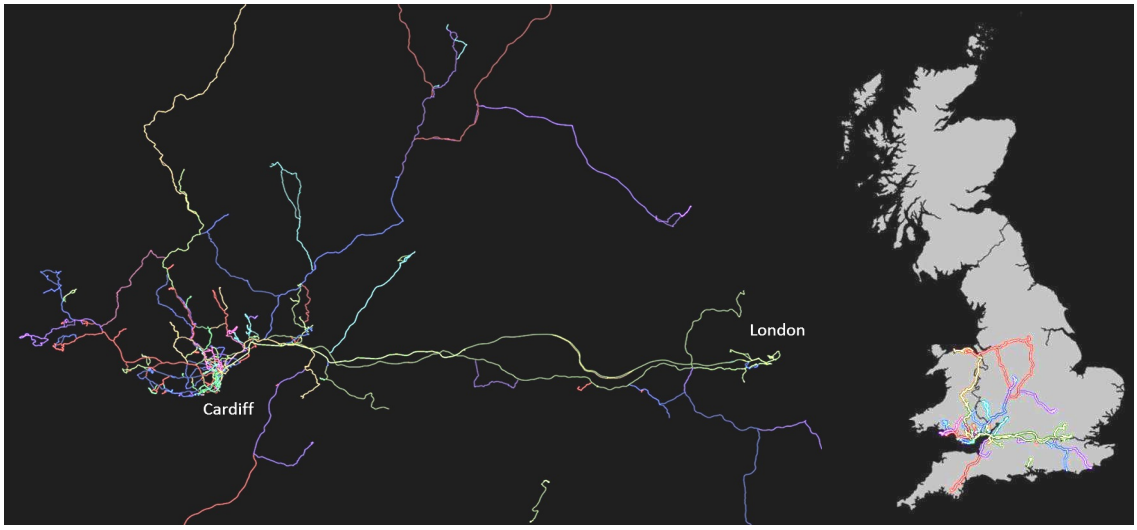


Figure 6.4 - Spatial distribution of trips made by participants over the period of the study

The participants living around the new Cardiff Connect2 scheme did on average 27 (±3.0 95% CI) trips per week and travelled an average of 164.3 miles (± 48.0 95% CI) over similar period of time (results presented show mean figures and interval estimated at a 95 % confidence level (CI)). Annual estimates suggest that participants in this study did in average 1245 trips per year and did travel a total of 7720 miles per year.

Please refer to Appendix J for a description of weekly and annual estimates of trip frequency and distance travelled by participants over the period of the study.

6.3.1 How did people travel (mode)?

Car travel was the most popular method of travel among the sample of participants, accounting for the largest share of trips and distance travelled during the period of the study. In 2011, travelling by car, either as driver or a passenger accounted for 61% of all trips made and for 81% of all distance travelled (Figure 6.5). Travelling by **public transport**, in contrast, was the mode of transport participants used less frequently (4%). **Walking** accounted for 29% of all trips made and **cycling** ranked third in terms of total trip frequency (6%) and distance travelled (6%).

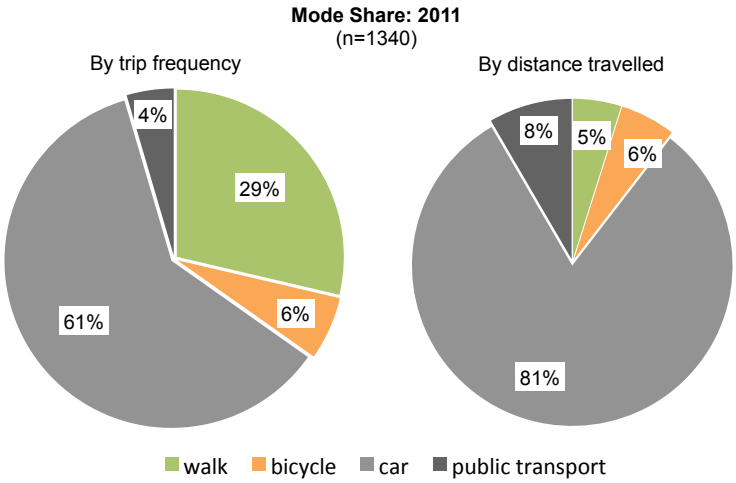


Figure 6.5 - Mode Share by trip frequency and distance travelled in 2011

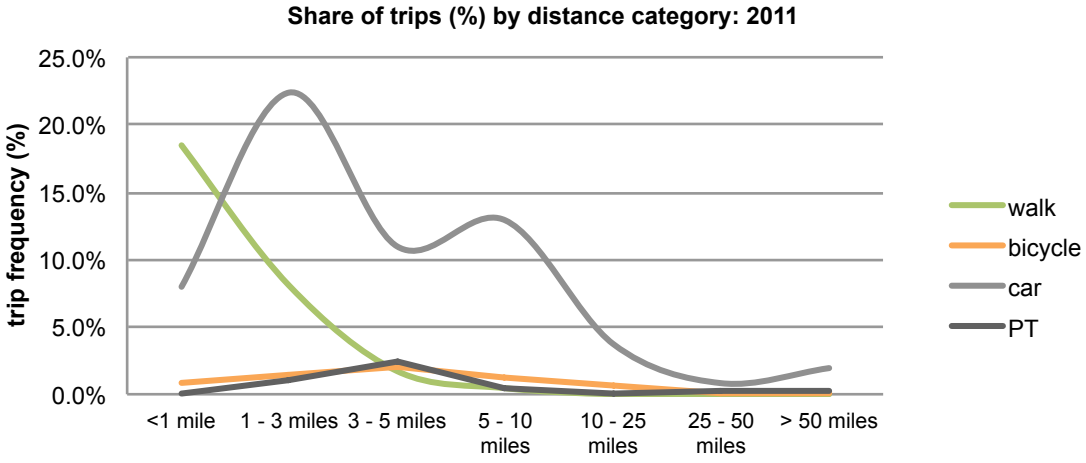


Figure 6.6 - Trips by distance by mode

Walking was the main mode chosen for trips less than 1 mile (18.4%) but travelling by car was the most frequent method of travel for all other journeys length (Figure 6.6). It should be noted however that 69.3% of all car trips were less than 5 miles.

A comparison with Great Britain national figures, obtained from National Travel Survey 2011) (DfT 2012b) suggest that **car travel** results are aligned with national averages both in terms of trip frequency and distance. Public transport use and distance travelled seem however below national averages as seen in Table 6.3.

For **walking**, and in particularly **cycling**[43], figures obtained are considerably above national figures. Within the sample, cycling accounts for 6.1% of trips made (1.7% national average) and 5.6% of distance travelled (1.0% national average). It should be noted however that figures reported in this study include both utility and recreational activities, which are not accounted for in the UK National Travel Survey.

Table 6.3 – Trip and distance modal share: comparison to NTS GB (2011)

	Annual Estimates	**Trip Modal Share**		**Distance Modal Share**	
	count (trips per participant) (n=50)	n=50	NTS GB	n=50	NTS GB
	2011	**2011**	**2011**	**2011**	**2011**
walk	*361*	28.7%	22.3%	4.9%	3.0%
bicycle	*77*	6.1%	1.7%	5.6%	1.0%
car	*764*	60.7%	64.4%	81.1%	78.0%
public transport	*57*	4.6%	11.7%	8.4%	19.0%

6.3.2 Why did people travel (purpose)?

Travelling while commuting to work accounted for the largest share of distance travelled (30.8%). Economically active participants did in average 9.7 (± 1.4 95% CI) trips to work per week and the average length of commuting trips recorded was 7.2

[43] Annual estimates for cycling suggest that participants have ridden their bicycles 75 times and during 423 miles during 2011. It As a reference, UK national figures suggest an average of 16 trips by bicycle per year and an estimated annual distance of 49 miles by bicycle (DfT 2012b).

miles long. Travelling for **shopping or personal business** was however main purpose for a larger share of the trips (31.6%). In average, participants did 9.2 (± 1.4 CI 95%) trips per week for that purpose and the average short trip length (3.0 miles) suggest the local character of most of these journeys.

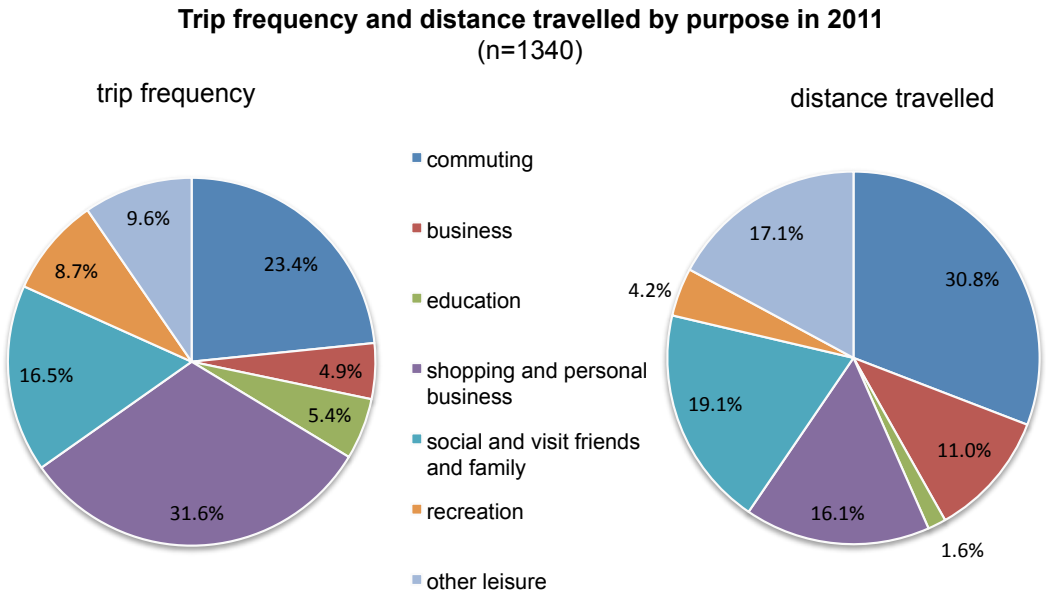


Figure 6.7 - Trip frequency and distance travelled by trip purpose in 2011

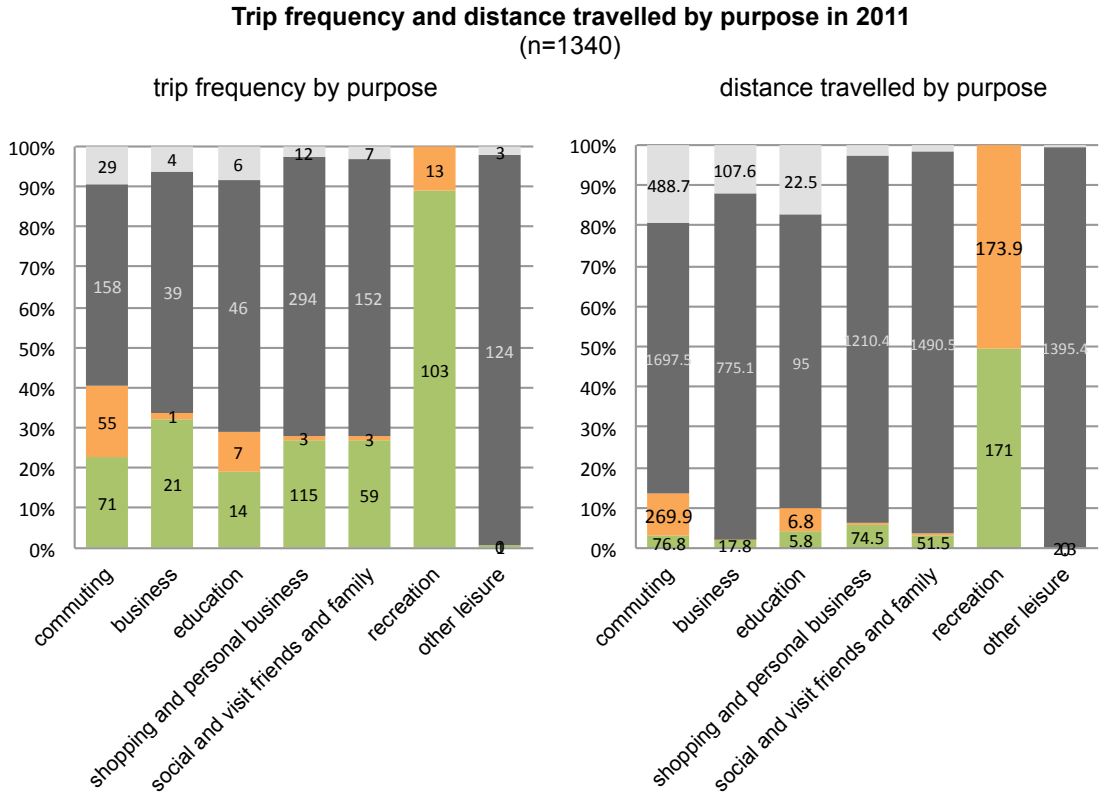


Figure 6.8 - Trips and distance travelled disaggregated by purpose and mode (n=1340)

Travelling for social purposes and travelling for accessing leisure activities were also popular reasons to have travelled further (19.1% and 17.1% of all distance travelled, respectively). **Recreational trips**, instead, accounted for less than 9% of all trips made and were in average short (2.9 miles per trip).

As seen Figure 6.8, car travel dominated all the trips made for every main purpose, both in terms of trip frequency and distance travelled. This also includes trips to access fitness and leisure activities ("other leisure"), such as the local sports centre, the beach or local recreational parks; it should be noted that 62.4% of these car trips were shorter than 3 miles (111out from 178). Despite low share of public transport use, it is here evident that it plays a more relevant role in commuting journeys (19.3% of the total distance travelled for commuting). Walking, as the second most popular method of travel, was more relevant for shopping and personal business trips and recreational activities. Cycling as a method of travel was also more significant for commuting to work journeys (10.9% of all distance travelled for that purpose).

A comparison with NTS figures, suggest that the results obtained are to some extent comparable with national trends. In the UK, in 2011, shopping and personal business trips were also the main reason to have travelled more frequently (40% modal share) and shopping trips were also shorter than the average (4.4miles). Furthermore, commuting to and from work (19%), other leisure (22%) and visiting friends (19%) accounted for a higher proportion of the average distance travelled, similarly to the sample in this study. While car travel dominates across all trip purposes, at a national level, rail is also more relevant for commuting journeys and walking for shopping, personal business and recreational trips (DfT 2012b).

6.3.3 Where did people travel?

The main destinations to where participants have travelled more frequently during the period of the study are identified in this section. This data provides useful information

on patterns of travel behaviour in the local area and potential of the new Connect2 scheme in facilitating some of these journeys (see Chapter 9).

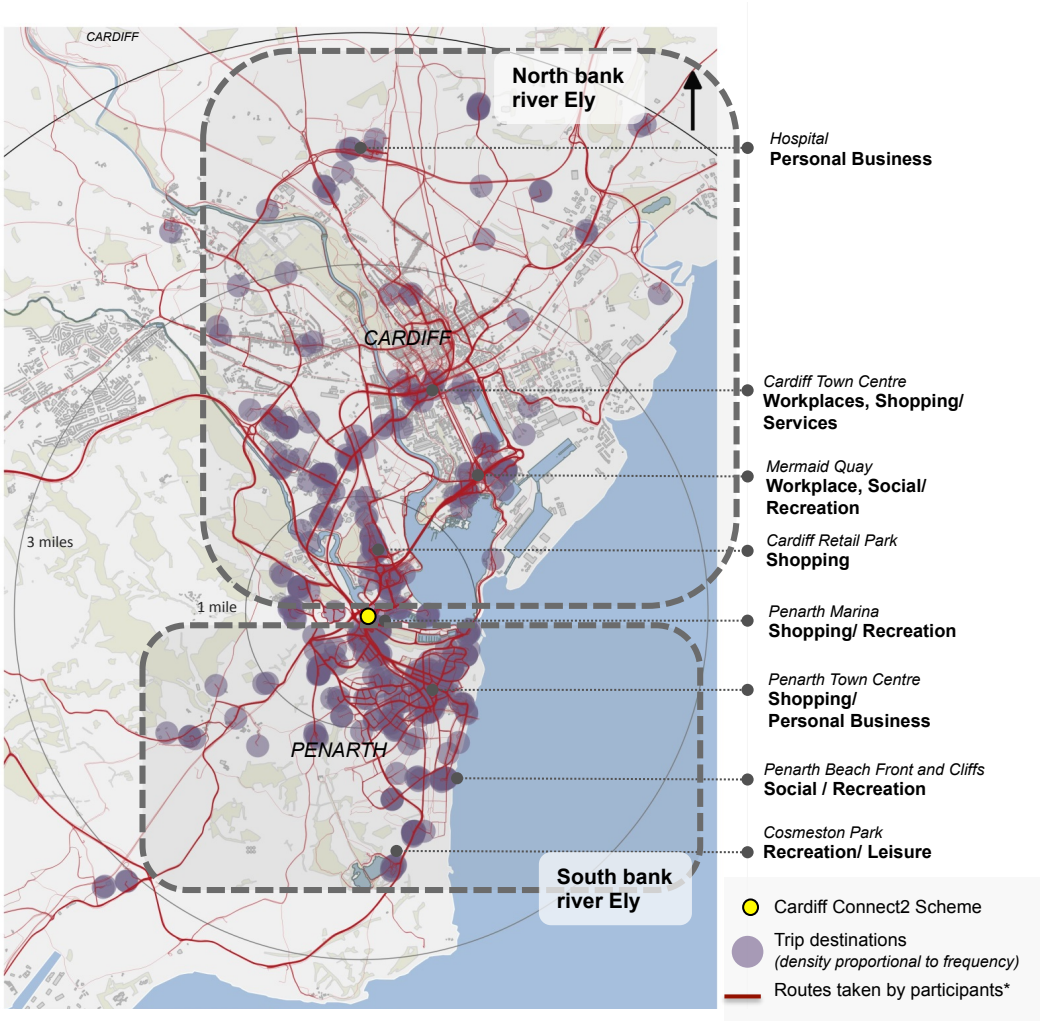


Figure 6.9 – Main routes and destinations around the local area; density of lines and dots represent trip frequency

As seen in Figure 6.9, participants in this study travelled more frequently to services and facilities in the south bank of river Ely. Some of those include shops in Penarth Town Centre, a large supermarket in Penarth Marina, Cosmeston Park or Penarth Cliffs and beachfront. The majority of the participants (N=46) also live in the south bank of the river Ely (Penarth), as described in section 6.2.2. However, a majority of workplaces and also popular services, shopping and entertainment facilities are located in Cardiff City Centre, Mermaid Quay, Cardiff Bay or Cardiff Retail Park (north bank of river Ely). As the Connect2 scheme provides a link between the south and north bank

of the river Ely, this may suggest the potential of the new Connect2 scheme in facilitating some of these local journeys.

Analysis of routes taken by participants suggested that higher volumes of traffic were recorded on Windsor Road and the junction A4160/A4055 (Figure 6.10). This is particularly relevant, as Windsor Road provides the most direct access route to the Connect2 scheme (from Penarth) and the junction A4160 /A4055 is a main barrier for pedestrians and cyclists to access the new Connect2 scheme from Llandough.

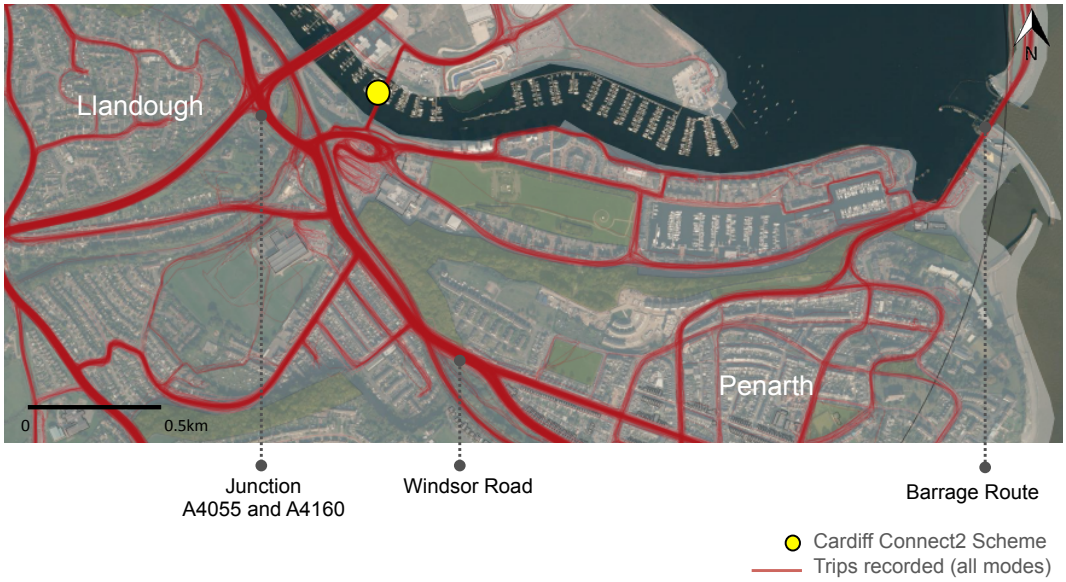


Figure 6.10 - Example of routes with higher volume of traffic and potential conflict with accessibility to new Connect2 scheme (source of basemap: Map Data © 2014 Google)

Further analysis of most popular routes, disaggregated by trip purpose (Figure 6.11), suggest that commuting trips tend to use either the quickest route (main roads/dual carriage way or motorway) or shortest path between home and workplace. Additionally, shopping and personal business journeys have a local character. In Chapter 9, this origin-destination information is used to assess the potential of walking and cycling in replacing short car trips in the local area and the potential of the Connect2 scheme in supporting such modal shift.

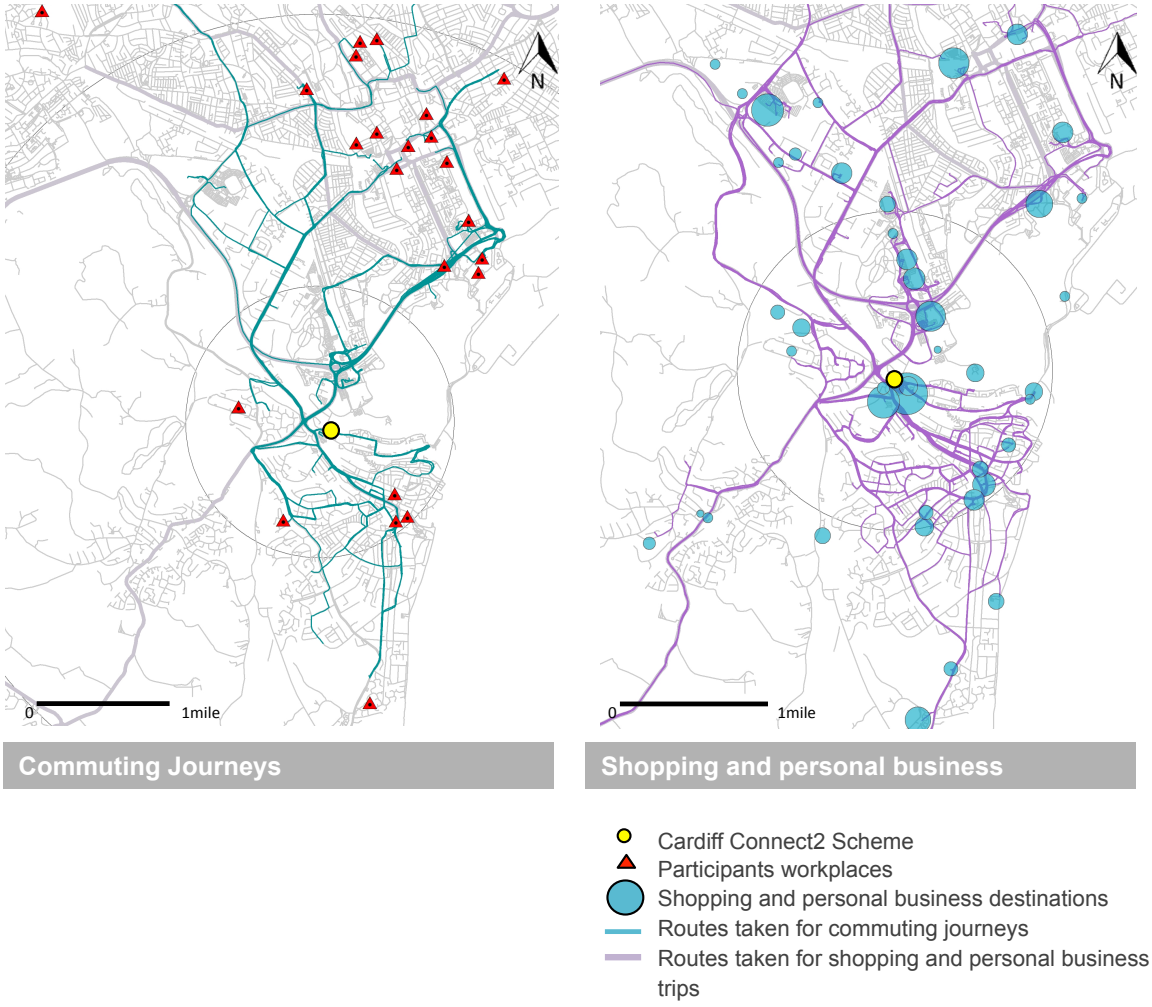


Figure 6.11 – Commuting journeys and shopping or personal business trips: spatial distribution.

6.3.4 When did people travel?

In average, participants travelled more frequently during weekdays than on weekend (Figure 6.12). A larger share of trips was recorded on Thursday and Friday (n= 213 and 201, respectively) and Sunday's were in general when participants travelled less. These figures are comparable with national averages, as according to the NTS 2012, '*over the 5-year period 2008 to 2012, on average, the busiest day of the week in terms of the number of trips was Friday with 150 trips per person per year*' (DfT, 2012).

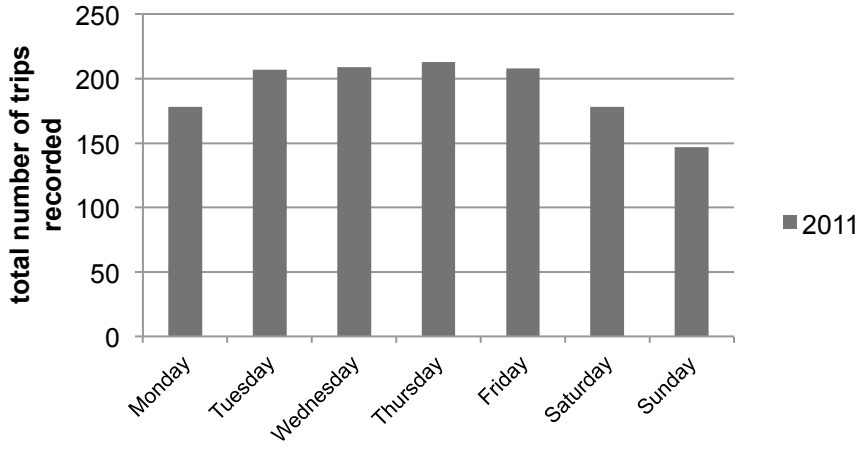


Figure 6.12 –Total number of trips recorded by day of the week in 2011 (n=1340)

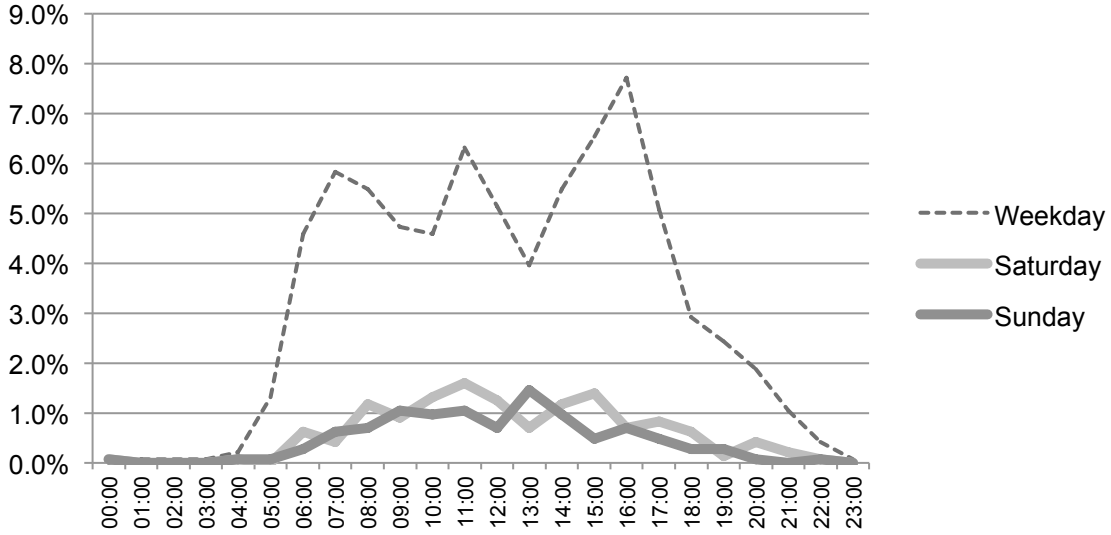


Figure 6.13 –Total number of trips recorded over a 24 hours period in 2011 (n=1340)

In Figure 6.13, trips are also described in terms of progress over the course of 24 hours. This graph shows that there are mainly two peak hours registered: the first, in the morning, between 9:00 and 11:00 am; and the second one, in the afternoon, between 15:00 and 16:00 pm. The three peaks of travel during weekdays were mainly related with (1) commuting journeys, (2) shopping and personal business journeys (at lunchtime), (3) returning home, shopping and social activities at the end of the day. Over weekend, journeys were more equally spread during the day.

6.4 Changes in overall travel behaviour between 2011 and 2012

This section describes participants' travel behaviour in 2012 (t2), one year after the first survey was conducted (t1) and examines most relevant changes detected over time. In section 6.5, reasons leading to some of these changes are described at an individual level.

Overall it was not detected that trip frequency and distance travelled by the 50 participants in this study changed significantly between 2011(t1) and 2012 (t2). The results of paired samples t-test indicated that there was no significant difference ($t_{(49)}$=0.20, p=0.84) in trip frequency between t1 and t2; and a Wilcoxon Signed Rank[44] test indicated also that no significant increase in the mean rank of the distances travel from t1 to t2 could be detected (Z= -1.65, p<0.10).

In order to investigate in further detail potential changes in travel behaviour over time, the following sub-sections describe changes in trip frequency and distance travelled by participants in the study disaggregated by mode of travel and trip purpose.

6.4.1 Changes in trip frequency and distance travelled disaggregated by mode of travel

Mean figures suggest that **car travel** levels were relatively similar across the period of the study but that use of public transport (trip frequency and distance travelled) seem to have doubled in 2012 (Table 6.4). As the mean is pulled in the direction of the extreme scores (skewed distribution), this may suggest however that a small minority might be responsible for the large share of the total. Mean figures also suggest that **walking and cycling levels** fell slightly in 2012; however, the presence of a few outliers and a large confidence interval suggest that these changes may not be significant.

[44] As the distribution for distance travelled was non-normal and there were extreme outliers in the sample, Wilcoxon Signed Rank test were performed to test for significance, as this test does not make the assumptions of normality and outliers.

Table 6.4 - Trip frequency and distance travelled by mode between 2011 and 2012 (N=50)

Trip frequency

	2011					***2012***				
	Total *n=1340*		***By participant*** *N=50*			**Total** *n=1324*		***By participant*** *N=50*		
	Count	***%***	**Mean**	**CI 95%**	**Median**	***Count***	***%***	**Mean**	**CI 95%**	**Median**
Walk	384	28.7%	7.7	*(6; 9.4)*	6.0	343	25.9%	6.6	*(5.1; 8)*	5.0
Bicycle	82	6.1%	1.6	*(0.6; 2.7)*	0.0	49	3.7%	1.0	*(0.3; 1.7)*	0.0
Car	813	60.7%	16.3	*(13.1; 19.4)*	13.5	818	61.8%	16.8	*(13.6; 19.9)*	14.0
Public Transpor	61	4.6%	1.2	*(0.7; 1.8)*	2.0	114	8.6%	2.1	*(1.21; 3.03)*	1.0
Total	1340		26.8	*(23.7; 29.9)*	25.0	1324		26.5	*(23.8; 29.1)*	27.0

Trip distance (miles)

	2011					***2012***				
	Total *n=1340*		***By participant*** *N=50*			**Total** *n=1324*		***By participant*** *N=50*		
	Miles	***%***	**Mean**	**CI 95%**	**Median**	***Miles***	***%***	**Mean**	**CI 95%**	**Median**
Walk	399.7	4.9%	8.0	*(5.7; 10.2)*	4.5	332.5	3.5%	6.5	*(4.8; 8.2)*	4.7
Bicycle	459.7	5.6%	9.2	*(0.9; 17.5)*	0.0	279.2	2.9%	5.6	*(1.6; 9.5)*	0.0
Car	6664	81.1%	133.3	*(85.1; 181.4)*	85.5	7097	74.3%	142.1	*(88.5; 195.7)*	111.2
Public Transpor	689.9	8.4%	13.8	*(0.9; 26.7)*	0.0	1839	19.3%	36.8	*(3.8; 69.7)*	4.6
Total	**8213**		**164.3**	*(115.0; 213.5)*	117.1	**9548**		**191.0**	*(130.7;251.2)*	133.9

Results of the **paired t-test** comparing 2011 and 2012 in terms of the frequencies of each travel mode revealed a marginally significant increase in the number of trips participants travelled by public transportation ($t_{bus\ (49)}$= 2.28, $p<0.05$). However, the number of trips by other modes of travel did not significantly defer from t1 to t2 ($t_{bike\ (49)}$ =1.54, p=0.13; $t_{walk\ (49)}$=-0.10, p=0.17; $t_{car\ (49)}$=-0.10, p=0.92).

Regarding the length of trip, the results of a **Wilcoxon Signed Rank test** shown a marginally significant **increase** for travel by public transportation between t1 and t2 (Z_{bus} =2.03, $p<0.05$). For other modes of transport, including walking and cycling, no significant changes in distance travelled were detected between t1 and t2 at an aggregate level.

6.4.2 Changes in distance travelled disaggregated by trip purpose

This section describes changes in distance travelled by car and public transport disaggregated by trip purpose. Changes in walking and cycling trips are analysed in detail in Chapter 7 and Chapter 8.

Mean figures in Table 6.5 suggest that participants in this study may have travelled further by **public transport** for commuting and social purposes during 2012; however, a skewed distribution suggests that a small minority might be responsible for the increase detected. Additionally, figures suggest that distance travelled by car was likely to have increased for education/ escort and dropped for social purposes in 2012.

Table 6.5 - Distance travelled by car and public transport by purpose between 2011 and 2012

Mean trip distance travelled by public transport by purpose week (miles) (N=50)						
	2011					
	mean	**CI 95%**	**median**	**mean**	**CI 95%**	**median**
Commuting	**9.8**	(1.0; 25.1)	0.0	**22.5**	(4.5; 58.1)	0.0
Business	**2.2**	(0.0; 6.2)	0.0	**4.0**	(0.4; 10.7)	0.0
Education	**0.5**	(0.0; 1.2)	0.0	**0.1**	(0.0; 0.4)	0.0
Shopping and personal business	**0.0**	(0.1; 0.4)	0.0	**1.1**	(0.3; 2.1)	0.0
Social and visit friends and family	**0.5**	(0.1; 1.1)	0.0	**7.0**	(0.7; 16.9)	0.0
Other leisure	**0.0**	(0.0; 0.6)	0.0	**2.0**	(0.0; 4.9)	0.0

Mean trip distance travelled by car by purpose week (miles) (N=50)						
	2011					
	mean	**CI 95%**	**median**	**mean**	**CI 95%**	**median**
Commuting	**34.0**	(12.9; 64.4)	6.5	**33.7**	(14.9; 57.6)	6.5
Business	**15.5**	(1.0; 36.7)	0.0	**19.9**	(3.3; 44.1)	0.0
Education	**1.8**	(0.7; 3.2)	0.0	**7.6**	(1.9; 15.3)	0.0
Shopping and personal business	**24.3**	(16.3; 34.7)	14.4	**29.5**	(18.1; 43.8)	14.6
Social and visit friends and family	**29.8**	(17.8; 44.9)	4.6	**5.1**	(3.3; 7.2)	2.2
Other leisure	**27.9**	(13.9; 45.5)	3.9	**19.0**	(8.9; 30.7)	0.0

In order to compare the frequencies and distances of travel by purpose and mode between 2011 and 2012, two series of Wilcoxon tests were performed. The results indicated that none of the travel modes had made significantly longer or shorter distances between 2011 and 2012 for different trip purposes. Results of the test are presented in Appendix J.

In conclusion, at an overall level, it could not be detected any statistically significant change in trip frequency and distance travelled by the 50 participants in this study between 2011 and 2012. At a disaggregated level, mean figures seem to suggest however some variation in distance travelled by mode, however, skewed distributions and wide confidence intervals suggest that a small minority are likely to be the main responsible for these changes. The statistical tests performed at a disaggregated level found only a marginally significant increase in the number of trips and distance travelled by public transport between 2011 and 2012. In the next section, the reasons and motivations underpinning some of these changes are investigated at an individual level. While the GPS data was crucial to measure changes in travel behaviour over time, the contextual data collected provides an explanation for the changes detected.

6.5 Understanding the dynamics of change in overall travel behaviour at the individual level

This section describes the context, causes or motivations that have influenced changes in overall travel behaviour over time at an individual level. Those cases where more relevant changes were identified ("outliers") are contextualized based on qualitative data collected from the participants. In Figure 6.14, difference in distance travelled by participants between 2011 and 2012 is plotted at an individual level and outliers are highlighted.

In general, findings suggest that most relevant changes detected could be partially explained by changes in life circumstances (related to job/ workplace changes, economic activity status or family responsibilities) or year on year variability. Examples are summarised in table 6.14 and expanded further over the next section. A comprehensive list of individual changes detected in travel behaviour over time is presented in Appendix K.

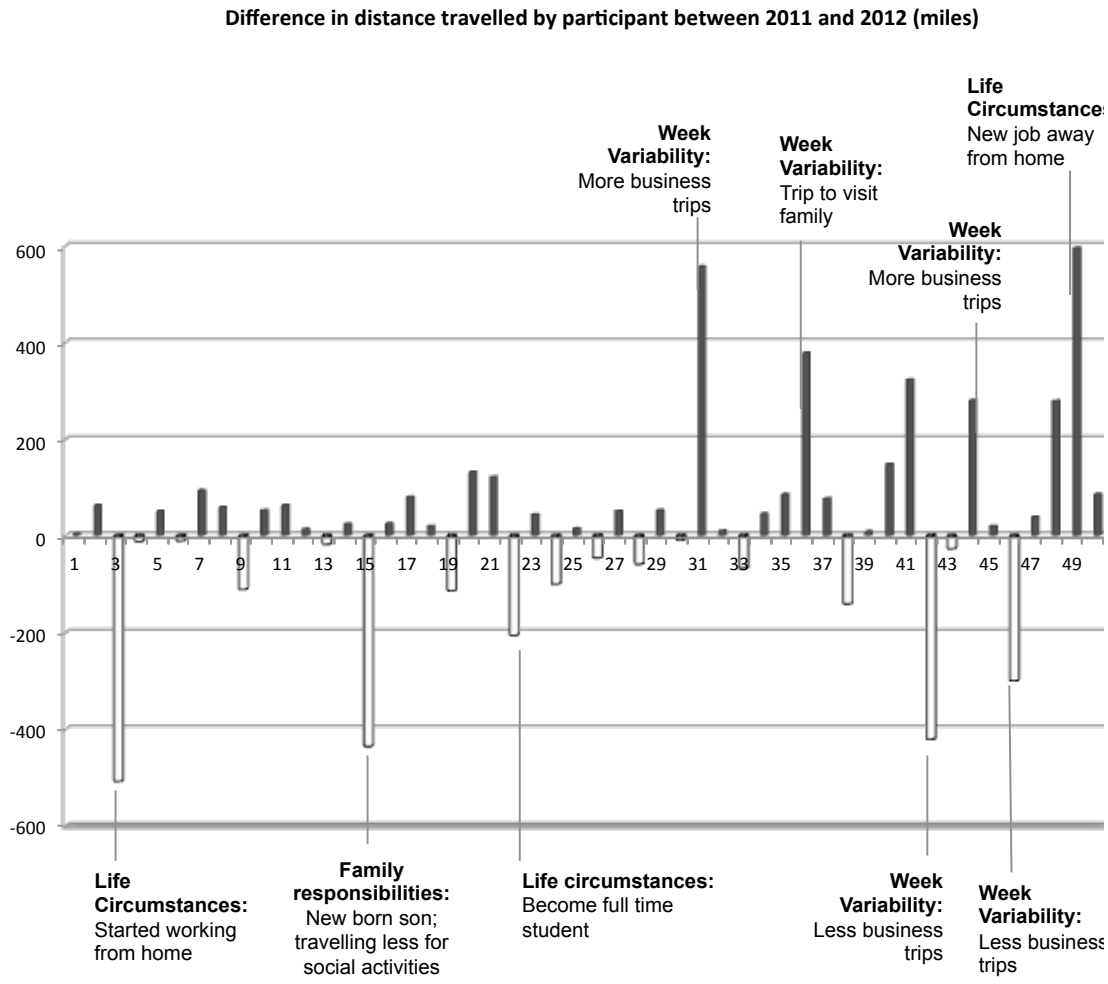


Figure 6.14 - Difference in distance travelled by participant (N=50) between 2011 and 2012 and contextual reasons underpinning most relevant changes detected (unit: miles)

Table 6.6 – Main reasons underlying relevant changes detected in distance travelled over time

	examples
Changes in life circumstances	Got new job further away from home (n=1); Starting to work from home (n=1); Workplace reallocated (n=2)
	Change in economic activity (retired, full time student, leaving maternity leave) (n=4)
	Family responsibilities (n=2)
	Change in car ownership (n=2)
Atypical events or year to year variability	Long business or work related trips recorded during just one year of the survey (n=3)
	Leisure or social (visit relatives) trips recorded during only in one year of the survey (n=2)
Additional for walking and cycling (described further in Chapter 7 and 8)	Weather conditions; New bicycle/ bicycle stolen; Peers influence; Desire to be physically more active; Replacing principal physical activity (gym membership); Dog died; Connect2 Scheme (residual).

6.5.1 Travel behaviour changes influenced by changes in life circumstances:

- **Example of impact of changes in job or workplace reallocation**

id	participant					miles
70	*Douglas*	-1.1	0.0	-151.9	**748.0**	**595**

> Douglas, 31 years old, married, in full time employment. Douglas used to travel by car to work as his workplace was just 6 miles away from home and public transport provision was poor in the area. In 2012, Douglas got a new job 65 miles away from home and started to commute by train, as this became a more convenient and cheaper option (fuel, tolls, parking). Additionally, Douglas employee partially supports rail seasonal ticket.

The majority of trips recorded from this participant during the period of the survey in 2011 and 2012 were commuting trips. Therefore, this is the main reason distance travelled by car decreased in the second year of the survey and distance travelled by public transport increased by 748 miles in 2012. Douglas is the participant for whom, distance travelled per week changed more dramatically during the period of the study.

id	participant					miles
4	*Angelina*	-0.3	0.0	-506.5	0.0	**-507**

> Angelina, 30 years old, married, no children, in full time employment. Angelina's workplace is 73 miles away from home. In 2012, she started working from home three out of five days a week. The opportunity to work from home became available in her company on that same year.

Angelina was the participant from whom distance travelled by car fell the most between years (-506 miles). The reason underlying this change is related with a change in commuting journeys but lead in this case by an opportunity to work from home and therefore, need to travel less.

id	participant					miles
12	*Katherine*	-8.3	0.0	-117.1	15.4	**-110**

Katherine, 33 years old, works full time and used to commute to work by car, as this was the most convenient and quicker travel option. In 2012, her workplace was reallocated to Central Cardiff, which is closer to home (2.5 miles). As car-parking facilities are expensive and limited at the new workplace, she started to commute to work by bus instead.

- **Examples of changes in economic activity influencing travel behaviour**

id	participant					miles
53	*Rodrigo*	3.3	0.0	-118.8	**192.5**	**77**

Rodrigo, 64 years old, worked full time during the first wave survey in 2011 but retired prior to the survey in 2012. In the second year of the survey, Rodrigo's drove 119 miles less than in the previous year (less commuting journeys) but has, during a similar period of time, travelled further by public transport.

For this participant, a change in economic activity status was a key explanation for changing travel behaviour patterns. As Douglas was not commuting to work anymore, his need to travel by car was substantially reduced by the second year of the survey. Simultaneously, as this participant had more free time, he started to travel more often for recreational purposes and often by bus.

id	participant					miles
26	*Amelie*	1.2	6.4	-200.7	**80.2**	**-113**

Amelie, 31 years old, has given up her job in 2012 to become a full time postgraduate student. Records show that Amelie travelled 200 miles less by car over a period of a week in 2012 but had, during the same period of time, travelled further by public transport. Amelie lives 0,5 mile away from closest train station and the fact that she will have no income over the next couple of years is making her to consider selling her car.

For this participant, change in travel was associated with replacement of daily commuting journeys to work by car with travelling to university. As the place of study of

this participant is located in Central Cardiff, public transport provides a quicker and cheaper alternative to car travel.

id	participant					miles
48	*Celina*	-6.6	0.0	56.2	36.2	**86**

Celina, 34 years old, was on maternity leave during the survey period in 2011. During that year, she mainly travelled around the local area, frequently on foot (with a push chair). In 2012, Celine returned to work and distance travelled by car and public transport increased as result of commuting journeys. As Celina spends now less time at home, she also walks less frequently around the local area.

- **Family responsibilities**

id	participant					miles
17	*Alexandra*	-1.3	0.0	49.1	-22.6	**25**

Alexandra, 29 years, works full time and her workplace is 6 miles away from home. She usually commutes by public transport but that journey can take up to 1 hour. .She has access to a car in the household but her husband is the frequent driver. In 2012, Alexandra got pregnant of twins. Ahead of future changes to household routines, she bought a car for herself and start commuting to work by car instead as this was quicker and more practical.

id	participant					miles
18	*Christian*	0.0	0.0	-418.6	0.0	**-435**

Christian, 30 years old, became a father during 2012. In the previous year, Christian travelled frequently over the week to his hometown (60 miles away from Penarth) for band practice and music gigs. Due to family care responsibilities and time constraints, Christian did not engage in similar activities in the year after, and therefore, travelled less by car in that same year.

In these two examples, expecting or having a new baby in the family, was the reason associated with a change in car travel between years. In the first case, the convenience and comfort offered by car travel influenced a mum to be to replace public transport commuting journeys by car travel and, therefore, to increase distance travelled by car.

In the second example, family care responsibilities with new-born baby limited amount time available to engage in other recreational activities, and therefore reduced need to travel.

6.5.2 Examples of variability on year to year events that influenced measured changes in travel behaviour over time

The following cases exemplify participants for whom changes in travel behaviour detected were mainly related to year-to-year variability, i.e., some long distance trips were recorded over one year of the survey but not on the following year or vice-versa. Some of the trips for business or social purposes (visit friends and family) would usually follow into this category.

- **Business trips**

						miles
67	*Martha*	-1.7	0.0	-12.1	-285.4	**-299**

Martha, 48 years old, works in Cardiff central (5 miles away from home) but travels occasionally to London for business meetings (145 miles journey). One of these journeys was recorded during survey period in 2011 but not in 2012. Martha is the participant that registered a greater drop in distance travelled by public transport during the period of the study (-285 miles).

id	participant					miles
43	*Lizzie*	1.1	0.0	562.7	-7.3	**122**

Lizzie, 50 years old, works full time but her job involves either working from home or travelling around the country in business trips. During the survey period in 2011, Lizzie worked mostly from home but during the survey week in 2012, Liz did a total of 8 business trips, including a long trip to Plymouth and Reading. Lizzie is the participant that recorded a largest increase in distance travelled by car.

- **Leisure/ social trips**

id	participant					miles
31	*Chris*	**9.6**	-24.6	137.2	0.0	**122**

Chris, 55 years old, has travelled 137 miles further by car in the second year of the survey as he did in 2011. Such difference in distance travelled by car could be explained by one day of commuting to work by car (instead of by bicycle – 13 miles) plus a trip to a caravan holiday park in the west coast of Wales. Although this is not an atypical event on Chris travel behaviour, this sort of trip was not recorded in 2011. Hence the main reason for difference detected between years.

id	participant					miles
50	*Therese*	-3.9	0.0	381.6	0.0	**378**

Therese, 64 years old, retired. She usually travels around the local area for leisure, shopping or social activities. However, from time to time she goes to visit her family in the south of England. During the survey period in 2012, one of these trips to visit family and relatives was recorded and therefore, the difference in distance travelled recorded.

In Chapter 7 and Chapter 8 relevant changes in walking and cycling levels over time are reported and main reasons unveiled, including the extent to which the Connect2 scheme was likely to have played a role. However, for the all the cases highlighted in this section, findings suggest that the implementation of the Connect2 scheme was not the main reason behind a relevant change in travel behaviour or a modal shift. Additionally, no relationship could be established between a drop in distance travelled by car and an increase in walking and cycling levels, as seen in Table 6.7 and tested by a linear regression.

A linear regression of difference in distance travelled by car as dependent variable and distance travelled by walking and cycling as an independent variable was run. R=0.696 indicates a medium degree of correlation and value of r2 suggests that only 48.4% of the variance in distance travelled by car could be explained by walking, cycling or

difference in public transport. It could not be determined that there was a significance on the relationship (p>0.5).

Table 6.7 – List of participants that have travelled less further by car during the period of the study and distance travelled by other modes of transport, including walking and cycling during similar period of time.

id	participant					miles
4	*Angelina*	-0.3	0.0	-506.5	0.0	**-507**
18	*Christian*	0.0	0.0	-418.6	0.0	**-435**
61	*Julia*	-1.3	0.0	-418.6	0.0	**-420**
26	*Amelie*	1.2	6.4	-200.7	**80.2**	**-113**
70	*Douglas*	-1.1	0.0	-151.9	**748.0**	**595**
54	*Laurence*	.	0.0	-128.6	-8.0	**-140**
53	*Rodrigo*	3.3	0.0	-118.8	**192.5**	**77**
12	*Katherine*	-8.3	0.0	-117.1	15.4	**-110**
34	*Karen*	1.0	0.0	-99.7	0.0	**-99**
40	*Cindy*	-6.4	0.0	-67.0	15.8	**-58**

6.6 Discussion of the main findings

The aim of this chapter was to provide a better understanding of travel behaviour in the case study site, contributing therefore to define the context and scope for walking and cycling around the local area. This section provides a synthesis of the results presented in this chapter.

6.6.1 Local travel behaviour and comparison with national figures

Annual estimates based on weekly counts suggested that participants in this study were likely to have travelled more frequently and further than the national average (see section 6.3). At a disaggregated level, results suggested that walking and car trip rates were aligned with national averages both in terms of trip frequency and distance travelled but that public transport modal share was lower than national average while cycling rates were considerable higher (6.0% in this study and 2% at national level) (DfT 2012b). While a comparison between study population travel behaviour and national figures is useful to contextualize and validate findings obtained in this study, one should bear in mind potential limitations of this assessment. First, the sample in

this study was not representative of the local/ regional population due its size and bias towards age, education, higher income, car ownership and urban context. Secondly, data presented was collected using different methodologies: self-report instruments in National Travel Survey and GPS technology and travel diaries in this study – it is acknowledged that the use of GPS technology provides the ability to capture more accurate information on trips made (Stopher & Greaves 2007; Andersen, Abeywardana, Wolf, Lee, et al. 2009). Thirdly, recreational trips and short walking trips were recorded in this study and are not captured in the UK National Travel Survey.

6.6.2 Travelling around the local area: dominance of car travel and role of walking and cycling

The majority of trips recorded during the period of the study took place in the local area and nearly three quarters were less than 5 miles. **Car** travel was the predominant mode of transport and accounted for the largest share of trips made and distance travelled. These figures were aligned with national trends as in Great Britain, in 2011, car travel accounted for 64% of all journeys made and 79% of all distance travelled (60% and 80%, respectively, in this study). (DfT 2012b). A great part of these car journeys were however less than 5 miles (69.3%), which is slight above the national figure of 57% (DfT 2014c). Reasons underpinning car travel, and in particular over short distances, are explored in detail in Chapter 9.

Walking was the second most popular mode of transport in terms of trips frequency in this study, accounting for approximately one quarter of all trips made during the period of the study. However, as walking trips are usually short, they represent just 5% of all distance travelled, which yet is slightly above the national average of 3%. Participants were likely to walk more frequently while on their way to shopping, personal business or recreational activities, which is also aligned with national trends. The average walking trip length was 1.0 mile, marginally above the national average of 0.7 miles (DfT 2012b).

Cycling levels in this study were higher than national trend as cycling represented 6% of all distance travelled (1% national average) and 6% of modal share (2% national average) (DfT 2012b). This may suggest that at least among some participants, cycling was a popular mode of transport for everyday travel or recreation. This figure may be aligned to some extent with recent statistics that indicated an increased popularity of cycling in Cardiff - cycling levels have increased by 65% between 2001 and 2011 in Cardiff and 3.9% of residents commute to work by bicycle (Office for National Statistics 2014). It should be noted that car ownership levels were also very high across the study population and all those who have cycled (except one participant) were also frequent car drivers.

6.6.3 Spatial analysis and potential of the Connect2 scheme

Results showed that 90% of the participants lived less than 1.5 miles from the new Connect2 scheme; and 92% lived on the south bank of the river Ely – a major barrier for pedestrians and cyclists that the new infrastructure helped to overcome. Spatial analysis of travel data collected has showed that a great number of local destinations and poles of attraction, including workplaces, were located in the north bank of river Ely; and that 54% of economically active participant lived less than 5 miles away from work. The Connect2 scheme location linking both banks of river Ely, the distribution of activities around the local and share of short trips suggest therefore that the Connect2 scheme may play a role in facilitating walking and cycling journeys across the area. The actual role of the Connect2 scheme in supporting walking and cycling is examined in detail in Chapter 7 and 8.

6.6.4 Understanding the reasons underlying changes in travel behaviour over time

Results suggested that there were no statistically significant changes in trip frequency and distance travelled by mode during the period of the study, except for public

transport use, that recorded a marginally significant increase in trip frequency ($t_{bus\ (49)}$= 2.28, $p<0.05$) and in distance travelled (Z_{bus} =2.03, $p<0.05$) between 2011 and 2012. A skewed distribution suggested however that potential changes could be attributed to a small minority of the sample.

The reasons influencing a relevant change in motorised travel behaviour over time were described in section 6.5. Findings derived from qualitative data collected suggested that changes in life circumstances were usually the main reason for relevant changes in motorised travel behaviour; those included job changes, working from home, becoming economically inactive (retired, unemployed, full time student) or family responsibilities. Year to year variability was, however, also likely to have influenced some of the detected changes in travel behaviour over time in some cases, usually due to long trips being recorded in one year of the survey but not in the other one (frequently business or leisure/ family related trips). One may argue however that if an independent cross-sectional survey approach at each time of measurement have been followed, the error in measurement would have been likely higher (due to random error of an independent sample survey or errors of the representativeness of the sample). This fact highlights therefore an advantage of panel studies.

For the all cases highlighted in this chapter and that explored the reasons influencing a relevant change in travel behaviour over time, findings did not suggest however that the implementation of the Connect2 scheme played a key role. Additionally, at an overall level, findings could not establish a relationship between a decrease in distance travelled by car and an increase in walking and cycling levels (table 6.7). In those cases where distance travelled by car has declined, that was more likely due to a reduced need for travel or an increase in public transport use. Changes detected over time were unlikely to be attributed to data collection and processing methodology, as the devices and procedures were the same between the years of the survey.

6.7 Summary

This chapter has described the main socio demographic characteristics of the sample of participants in this study (N=50) and their overall travel behaviour during the two years of the survey period. Its aim was to provide a better understanding of travel behaviour in the case study site, contributing therefore to define the context and scope for walking and cycling around the local area and the potential role of the new Connect2 scheme in facilitating some of these journeys. A comparison with local population suggested that the sample in this study was well distributed in terms of gender and age but likely to show a bias towards younger people, higher levels of education, income and in particular car ownership (96%). While the majority of the trips made by the participants took place around the case study site and were less than 5 miles long (77.1%), travelling by car was the dominant mode of transport in the local area. However, walking, and in particular cycling rates, were quite significant among the study sample and slightly above national average. Results shown there were no statistical significant changes in overall travel behaviour between 2011 and 2012 among the study sample, with an exception of an increase in public transport use related to changes in life circumstances of a small group of participants. In fact, changes in life circumstance (such as change in jobs, economic activity, family responsibilities, etc.) were usually the main reason for most relevant changes in motorised travel levels detected over time. It could not be established however that the implementation of the new Connect2 scheme played a significant role in those cases.

The next chapter explores with a greater level of detail (and at a stage level) walking behaviour in the case study site, the levels of use of the new Connect2 scheme and the extent to which the new scheme was likely to have influenced participants' walking behaviour.

7 Walking for Everyday Travel and Recreation: Understanding the Impact of Connect2

'While walking is basically a linear movement that brings the walker from place to place, it is also much more. Walkers can effortlessly stop underway to change direction, manoeuvre, speed up or slow down or switch to a different type of activity such as standing, sitting, running, dancing, climbing or lying down (…). Walking is a form of transport, but is also a potential beginning or an occasion for many other activities' (Gehl 2010)

7.1 Introduction

Following on from the analysis and interpretation of overall travel behaviour, this chapter focuses on the role of **walking for everyday travel and recreation** in the case study site, its complexities and the extent to which the new Connect2 scheme had influence travel behaviour, for whom and in what circumstances. It aims therefore to address sub research question 1:

> **To what extent does a Connect2 scheme influence walking for everyday travel and recreation in terms of the nature of journeys and where these take place?**

In order to address this objective, this chapter starts by examining the context of walking behaviour in the case study site. This includes the identification of where and how walking activities take place and an exploration of participants' motivations and perceived barriers towards walking in the local area. Following this, levels of use of the Connect2 scheme during the period of the study are examined alongside participants' views on the significance of the new infrastructure in influencing or facilitating walking activities for the local community. Reasons influencing detected changes in walking behaviour over time are subsequently analysed. The chapter concludes with a discussion of the main findings.

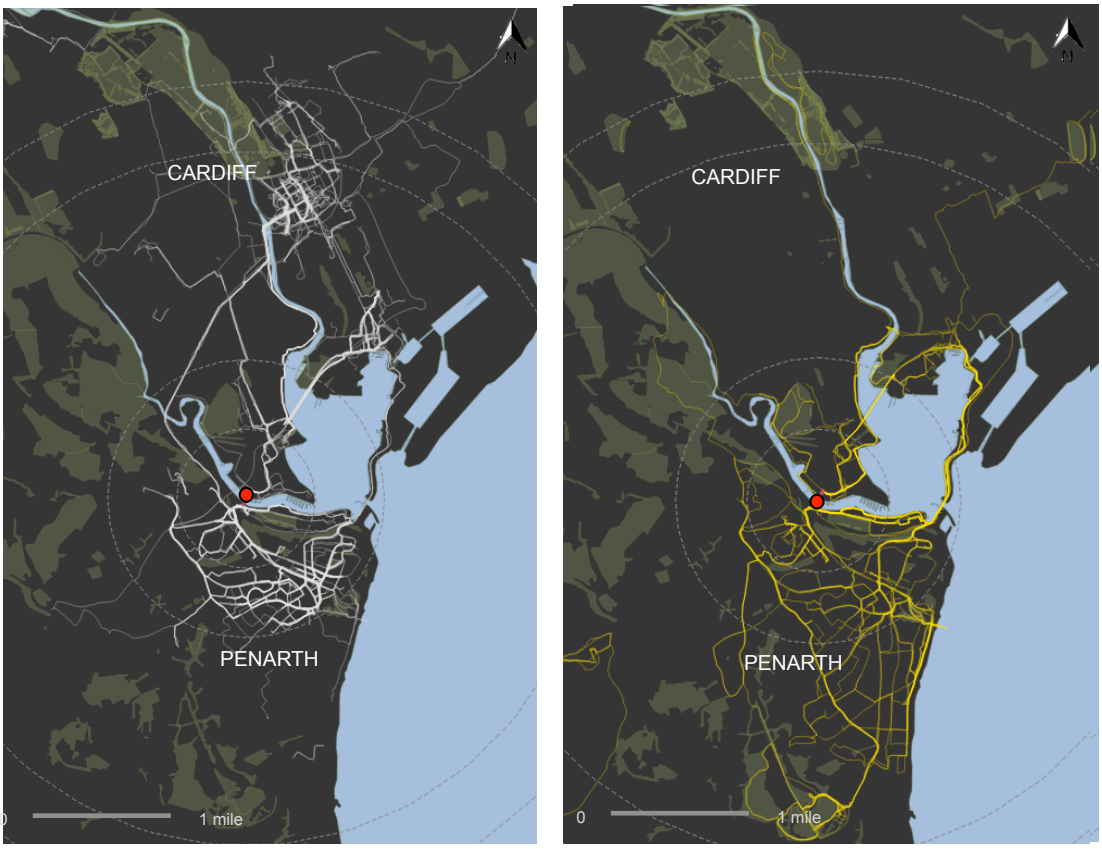
The data presented in this Chapter is based on **971** walking stages collected among 49 participants and recorded in two survey weeks in both 2011 and 2012 in the case study site. Data in this chapter is presented at stage level rather than trip level. This approach provides a greater level of detail to the analysis as 25.8% of walking stages recorded in the study were part of multi modal trips (and would not be considered if examined at trip level - see section 5.4).

7.2 Context of walking in the local area: for what purpose, how, where and why?

This section examines the context to walking for everyday travel and recreation in the case study site. This provides a background to understand better the impact of the Connect2 scheme in the local area. In this chapter, walking journeys are grouped into **everyday travel (79.6%)** and **recreational** stages **(20.4%)**, depending on their purpose and destination.

7.2.1 Walking for everyday travel

The largest share of walking stages recorded (79.2%; n= 770) were part of **utilitarian walking journeys,** defined in this study as journeys that involve daily activities such as going to work, school, grocery shopping and other 'necessary' purposes. These trips took place most frequently on streets and built areas with a large provision of services and facilities, higher number of pedestrians and higher level of non-residential use at a ground level. The origin and destination of utilitarian journeys was more fixed, compared to recreational walking trips; and the shortest distance/ route between origin and destination was usually favoured, as efficiency in the movement seems to be a key factor while walking for everyday travel. Utilitarian walking stages were usually shorter (mean 0.5-0.8 miles) than recreational trips (mean 1.6 miles). Figure 7.1 highlights some further differences between walking for everyday travel and walking for recreation in the local area.



Walking – everyday travel	Walking - recreation
Short (in average 0.5-0.8 miles)	Longer (in average 1.6 miles)
Built up areas, good provision of services and facilities and mix of activities	Local parks, green areas, sites close to open water; scenic views; described by participants as pleasant places
More fixed routes	More circular routes

Figure 7.1 – Spatial distribution of utility and recreational walking trips in the local area (contains data from ©OpenStreetMap contributors)

Participants walked more frequently for everyday travel while commuting to/ and from work. While 12% of the participants would walk the entire journey (distance up to 1.5miles), for others, walking was usually a part of a multimodal journey. In this case, participants would walk from their household to nearest train or bus stop, travelling then by public transport for the longest leg of the journey (Figure 7.2). A more unusual type of walking stage recorded were however associated with commuting journeys by car. In this case, participants would drive their car to a site close to their workplace and then would walk for the last leg of the journey (some of these walking stages were up to 1.4

miles long – see Figure 7.3). Cost or availability of car parking at the workplace was usually a key reason for this travel pattern.

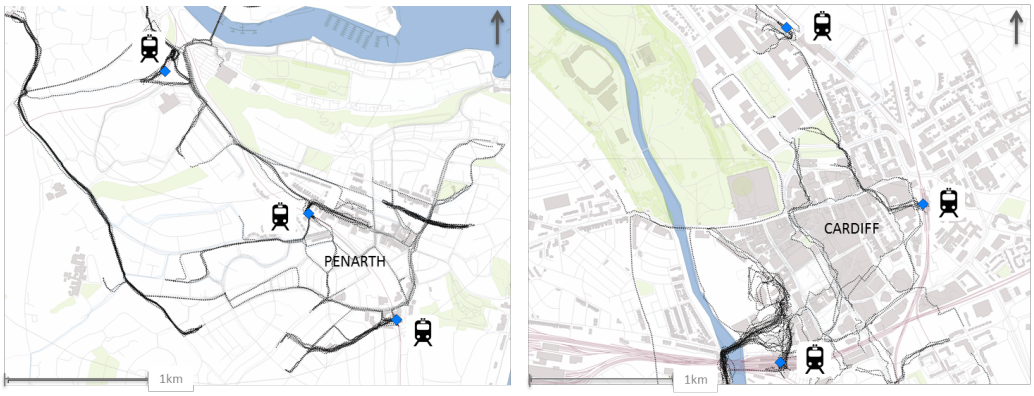


Figure 7.2 – Walking as part of a multimodal journey - access public transport (contains data from ©OpenStreetMap contributors)



Figure 7.3 – Walking as part of a multimodal journey to work (following journey by car) (contains data from ©OpenStreetMap contributors)

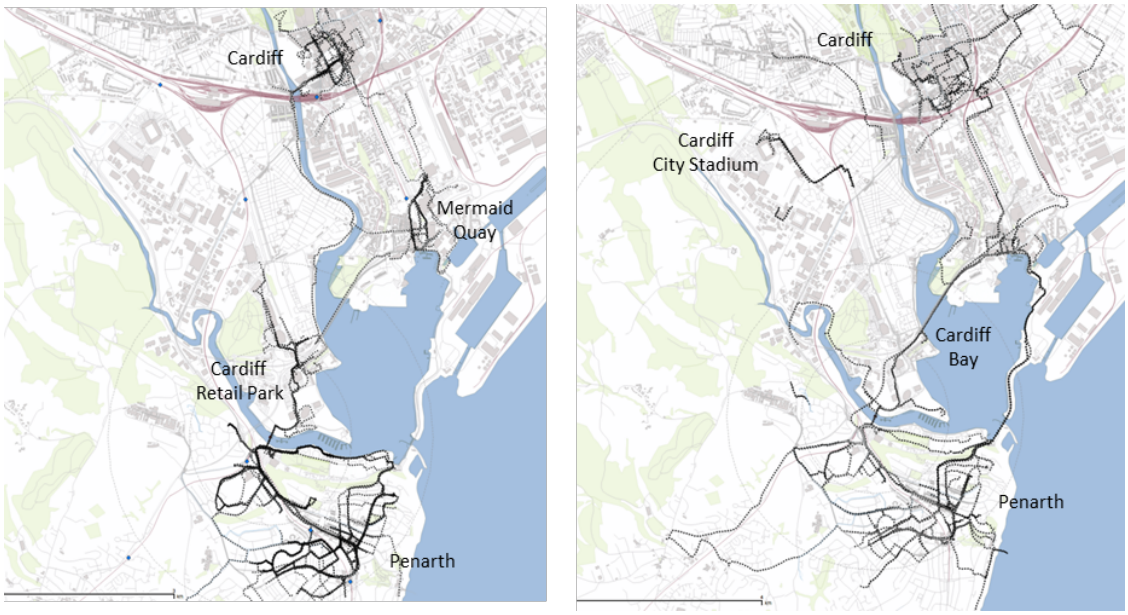


Figure 7.4 – Walking for shopping and personal business activities (left map) and social purposes (right map) (contains data from ©OpenStreetMap contributors)

The second most frequently purpose of utilitarian walking trips was going for ***shopping or personal business activities*** (35.4% of total utility stages). These journeys were usually conducted around Penarth Town Centre, Cardiff Bay Retail Area, Mermaid Quay and Cardiff City Centre, where most of the shops, services or facilities are located (Figure 7.4). Household location, availability of car parking in town centre or convenience of large retail stores in the outskirts of town were however likely to influence some of these journeys (Box 7.1).

Box 7.1

I found it very difficult to park the car now in Penarth town centre. It is awful. So walking ends up being a more convenient alternative; in fact, it takes me just 10min to walk to the shops as we live very close. (Julia, 52 years old)

I used to walk to Penarth town centre for daily shopping but since my children were born that I started to drive to the large retail area outside Penarth. I found this a practical alternative as I can seat my children on the shopping trolley and then do all the shopping in one go. Shopping locally as I used to do would just take forever these days. (Paul, 38 years old)

While many of the local schools were in walking distance from participants' households, it was found that walking to school, education or escort represented just 4.6% of all walking journeys recorded (28% of the participants had children less than 16 years old at the household). For a great part of these journeys participants would travelled by car instead as they found it more practical, convenient and/or quicker (Box 7.2).

Box 7.2

I usually pick up my kids from school and then we walk home. That is actually part of our daily routine and a nice part of the day. (Paul, 38 years old, part time worker, two children)

I usually walk with my daughter to the school as we live very close by. I then cycle to work. However, my wife always does the school run by car, as she is

usually on her way to/ from work and finds it more convenient. (Tim, 33 years old, full time work, two children)

I have three children and I drop them off and pick up from nursery, school, leisure centre and other activities on a daily basis. For use it would be just impossible to link all these activities without driving. Most of these journeys are in fact short trips but driving definitely makes things easier when you have small children and are short in time. (Jennifer, 35 years old, three children)

7.2.2 Walking for recreation

Nearly 20% (n=201) of all walking trips recorded during the period of the study (2011 and 2012 combined) were made for pleasure or recreational reasons. These walking trips, excluding walking for exercise, were generally conducted at a lower speed and with more flexibility between moving and stopping. The route choices for these activities were also distinct from the utilitarian journeys, as the destinations were less fixed, loop patterns were more frequent and movement was not always directed by shortest distance between start and destination.

Participants have walked for leisure and pleasure more often in urban parks, off road tracks, in in the countryside and along the coast. Each four in five recreational trips took place in the local area (3 miles buffer). Participants would usually walk with other family members, friends or in some cases, with a dog. Popular locations for recreational walking in the local area included Cosmeston Park, Penarth Pier or Cardiff Bay Area (Figure 7.5). For one third of the recreational walks (32.6%), participants have however relied on car travel to access the destination where the walking activity was going to take place. One of the reasons for this behaviour was that recreational walking was frequently associated with natural environments, scenic views and pleasurable routes and such destinations were usually located further away from the local area. Coast paths, forests, mountains or national parks in the region, such as the Brecon Beacons, were popular destinations for recreational walking activities outside the case study site (Figure 7.6).

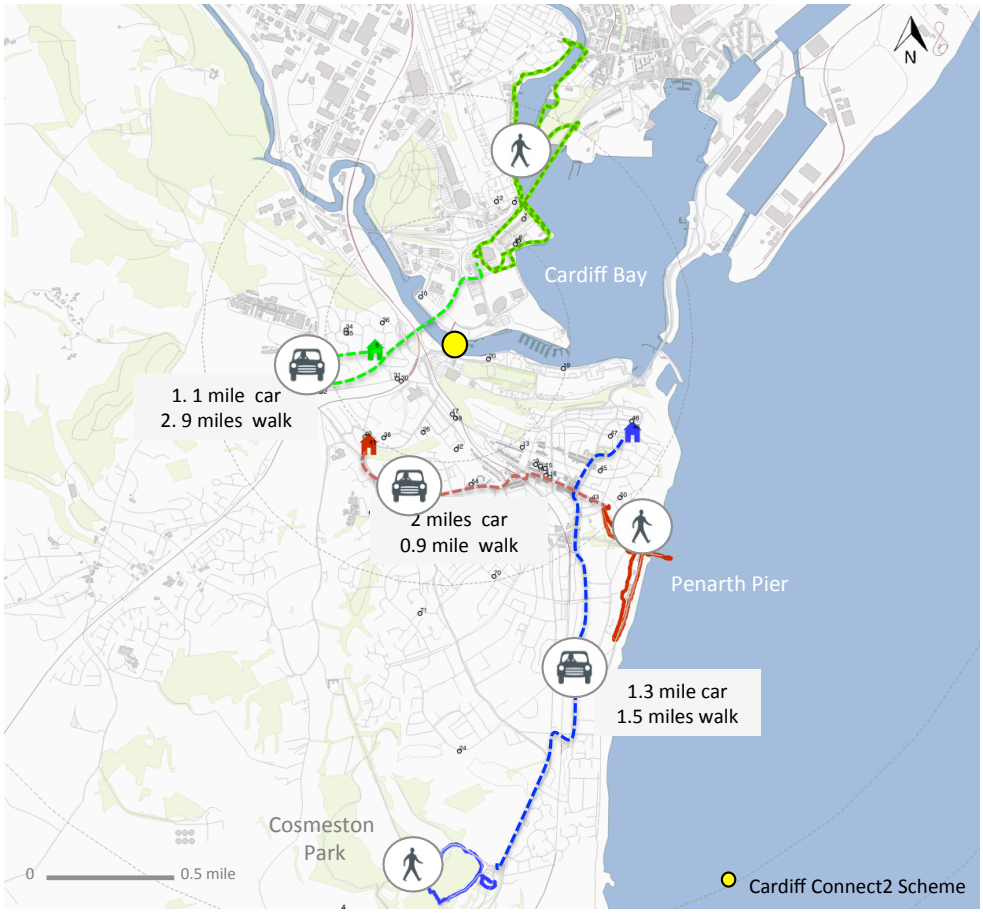


Figure 7.5 - Example of recreational walking in the local area (within 3 mile buffer) (source of basemap: Map Data ©2014 Google)



Figure 7.6 - Example of recreational walking journeys associated with car travel outside the local area (source of basemap: Map Data ©2014 Google)

While walking for recreation in the local area, participants did also travel often by car (39.4% of recreational walks in the local area were associated to a car trip). Figure 7.7 exemplifies some of these journeys.



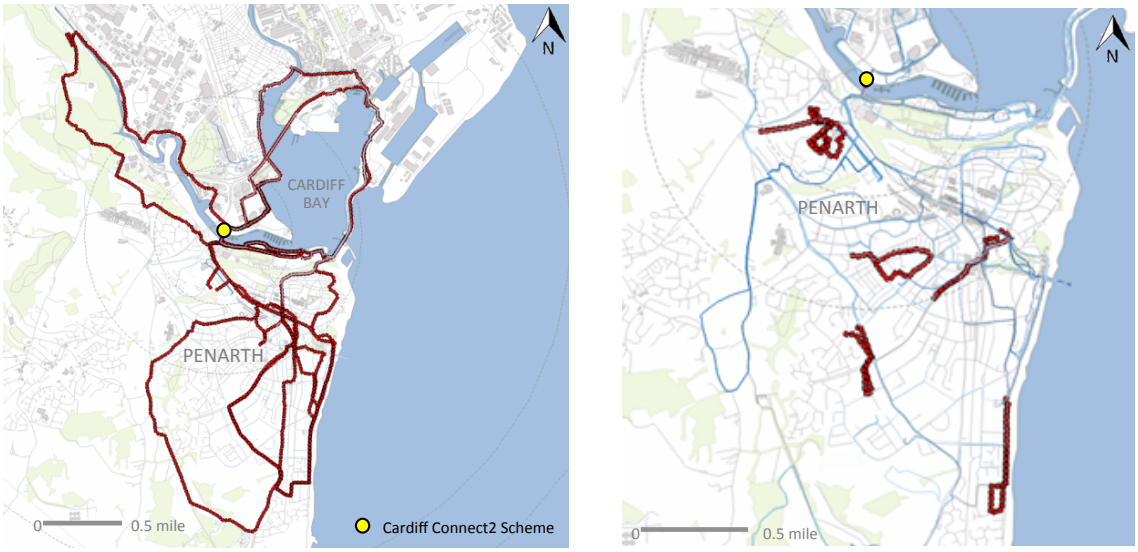
(contains data from ©OpenstreetMap contributors)

Figure 7.7 – Example of recreational walking trips conducted in the local area and associated with short car journeys

The majority of participants walked for recreation and pleasure purposes, however, others walked as a form of sport and fitness activities (15.4%). **Jogging trips** were usually longer (3.4 miles average distance) and were made at a higher speed (5.8 miles/ hour). Additionally, they frequently had a loop pattern and start/finished at participants' home. Popular destinations for jogging in the local area included Cosmeston Park and Cardiff bay Area.

Dog walking (n=29/ 14.4%) was other purpose for recreational walking around the local area. Participants usually described these trips as a mean to provide daily exercise regime needed to keep the dog healthy as well as providing exercise and companionship for the walker**.** These trips usually took take place very close to participants household, they were in average short (0.7 miles) and made at a moderate pace (2.7 miles/ hour), involving frequent stopping and staying during the walking

activity. Occasionally, participants would also drive somewhere further away to go for a walk with their dogs. Figure 7.8 highlights the distinctive patterns of jogging and dog walking trips.



Contains data from ©OpenstreetMap contributors

Figure 7.8 - Example of circular pattern of jogging trips (left) and short dog walk walking trips (right)

7.2.3 Walking around the local area: motivations and barriers

For most of the participants in this study, walking was frequently associated with general feelings of health, wellbeing, independence and engagement with the environment. Walking for utility trips was also motivated by necessity, convenience, proximity, cost or lack of alternative in some cases (Box 7.3).

Box 7.3

I feel that walking is good to get fitter and important to improve my health and wellbeing in general. (Rebecca, 60 years old)

I walk as a way to improve my fitness levels but also because I really enjoy the experience of walking. It just seems that you "see" [experience] more when you walk. (Juliette, 63 years old)

I have started to walk more frequently as driving is becoming more expensive and we have just one car available in the household now. (Thomas, 48 years old)

As I need to get fitter, walking is just good for me. Also, as traffic is increasing so much, walking - and then taking the public transport whenever needed - is a great alternative for my daily commuting by car. (Olga, 53 years old)

I would like my children to be active and to walk more often; however, we just travel by car everywhere as it is so practical and there are no other choices left. (Jennifer, 35 years old, three children)

In general, participants were very positive about conditions to walk in the case study site. They found that there were many opportunities around the local area for a recreational walk and that there were was a good diversity of services and facilities available in the town centre where they could walk to, if required, for shopping, for going for a meal or meeting up with some friends and socialize. The fact that there was a good provision of public transport in the local area, including three train stations and bus stops within walking distance, and frequent services to and from Cardiff City Centre was also a factor supporting walking and use of public transport as an alternative to car travel.

Crime rates in the local area were low and in general, participants did not feel that was unsafe to walk in most of the areas and streets and at different periods of day and night. Most participants agreed that pavements and footpaths were in general of good quality, cleaned and comfortable. Occasionally, some noted a few conflicts with cyclists in the pavement, however, the impact of this issue with participants walking behaviour was not found to be relevant.

The main perceived barriers to walking more in the case study site were however local topography, poor connectivity and safety of some desired routes (e.g., due to lack of safe crossings on roads with heavy traffic and busy junctions). As an example, *Jocelyne and Juliet* live less than 0.5 miles walk away from local supermarket but both travel by car (2 miles), as they perceived the A4055/A4160 junction as an unsafe crossing for pedestrians (Figure 7.9).

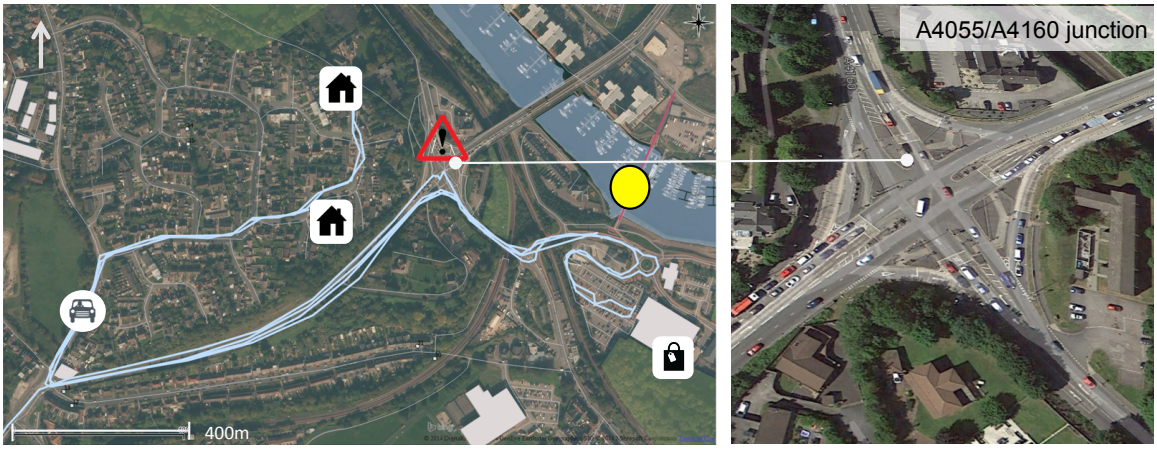


Figure 7.9 – Example of short car trips to local supermarket motivated by a perceived lack of connectivity and safety for pedestrians (basemap: Map Data ©2014 Google)



Figure 7.10 – Alternative route to the new Connect2 scheme (road A4055) - pedestrians were not allowed (source: Google Street View (2008, 2009)

Furthermore, the **lack of connectivity for pedestrians between Cogan (Penarth) and the other bank of the river Ely** was also noted by some participants as a barrier to walk into Cardiff Bay (see section 4.4.2)**.** Prior to the implementation of the new Connect2 scheme the only route available linking these two sites was the busy A4055, however pedestrians were not allowed on this section of the road (Figure 7.10).

The next section explores the extent to which the implementation of the Connect2 scheme over the river Ely impacted on local residents walking behaviour.

7.3 Walking and the Connect2 scheme

This section describes how and who has used the Connect2 scheme during the period of the study and to what extent did this new route influenced or facilitated walking activities for the local community.

7.3.1 Walking over the Connect2 scheme: how frequently and for what purpose?

A total of 48 journeys (46 single stage trips and 2 multimodal stage trips) were recorded over the Connect2 scheme during the period of the study, representing a share of **4.9%** of all walking trips recorded between 2011 and 2012. The number of trips recorded over the Connect2 scheme was higher for recreational purposes (n=29) than for everyday travel (n=19); and at a year level, more trips were recorded in 2011 (n=25) rather than in 2012 (n=23) (Table 7.1).

Walking trips recorded over the new bridge were usually **longer** than trips using other routes. Recreational trips over the Connect2 scheme were in average 2.8 miles long (1.6 miles in the study at an overall level) and utility trips were 1.8 miles long (0.7 miles in the study, respectively).

Table 7.1 – Frequency and average length of stages recorded over the Connect2 scheme in 2011 and 2012

		2011				**2012**			
		Trip frequency			**Distance**	**Trip frequency**			**Distance**
		Count (n=472)	*Freq by total (%) (n=472)*	*Freq (%) by trip purpos*	Average trip length (miles)	*count (n=499)*	*Freq by total (%) (n=499)*	*Freq (%) by trip purpos*	Average trip length (miles)
Recreation		14	3.0%	12.8%	2.8	15	3.0%	18.5%	2.8
Utility		11	2.3%	3.0%	1.5	8	1.6%	1.9%	2.2
	Shopping	5	-	-		2	-	-	
	Social	3	-	-		4	-	-	
	Commuting	3	-	-		2	-	-	
Total		**25**	5.3%			**23**	4.6%		

Trips recorded over the Connect2 scheme took place mainly during daytime. Figures suggest that the peak for utility trips was around 9am; and that more recreational trips took place both in the morning (8am) and in early afternoon (1pm). One of the advantages of the new scheme compared to the Barrage route (alternative route B) is that the Pont y Werin is well lit at night. Maybe for this reason, the latest trip recorded over the scheme has started at 8pm, as seen in Figure 7.11.

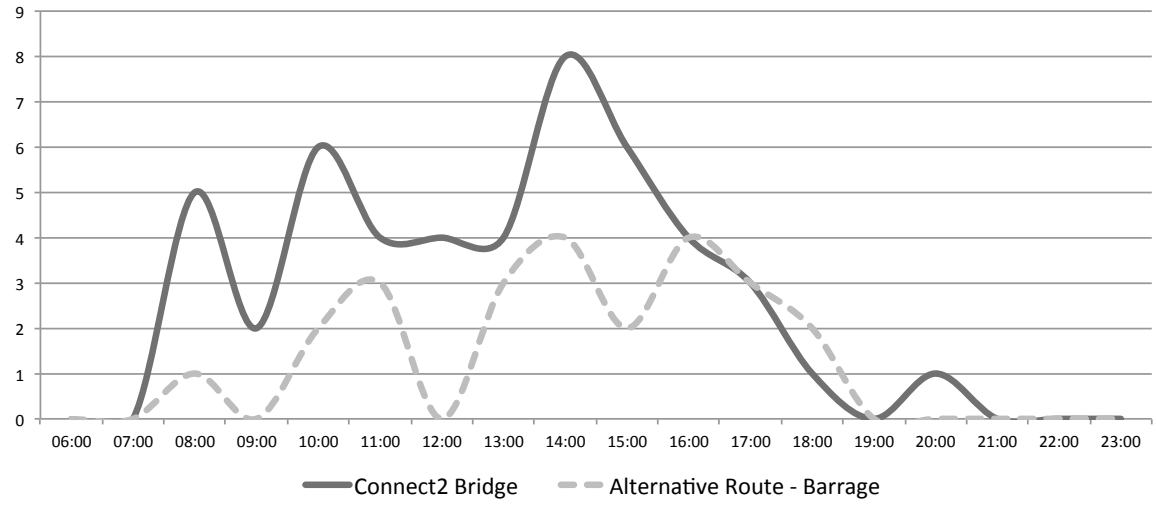


Figure 7.11 –Frequency of walking trips recorded over new Connect2 scheme and alternative route (barrage) over a 24 hours period.

7.3.1.1 Utilitarian walking over the Connect2 scheme

From the 19 utility walking trips recorded over the Connect2 Bridge between 2011 and 2012, only **5 were part of a commuting journey**; and they were all made by just one participant that lives 0.3 miles away from the Pont y Werin.

> David, 41 years old, works in Central Cardiff (2 miles away from home). As David has a sedentary job, he likes to walk to work in order to introduce physical activity levels into his daily life routine. David used to walk to work along the busy A4160 road but following the implementation of the Connect2 scheme in 2010, David started to walk more frequently and always over the new Connect2 scheme. The new Connect2 scheme provided a shorter and more pleasant route to work to this participant.

There were **7 trips** recorded over the bridge that were part of **social activities.** Examples included travelling to local pubs on both sides of the river Ely, visiting a friend that lives in Cardiff Bay Area or travelling to an event in Cardiff Bay Area.

> Julia, 52 years old, states that the new Connect2 scheme has enabled her to access a friend's house in Cardiff Bay without being dependent on a lift by car from her husband. Julia does not drive and therefore she feels now more independent to travel to that part of town whenever she likes.

The Connect2 scheme as also improved connectivity to large retail shops in both sides of the river Ely and seven trips were recorded over the new bridge as part of **shopping or personal business activities.** However, convenience offered by car travel and need to carry groceries was seen as a deterrent to walk more frequently over the new scheme for that purpose.



Figure 7.12 – Walking for everyday travel over the new Connect2 scheme (source: author)

7.3.1.2 Recreational Walking over the Connect2 scheme

Nearly two thirds of the trips recorded over the new scheme were part of a recreational trip (n=29), representing 9.5% share of all recreational walking trips recorded during the period of the study. Journeys recorded over the scheme were essentially of two kinds: leisure walking (n=15) and jogging trips (n=14). In both cases, route scenic quality, proximity to waterfront and proximity from household were main features influencing participants to use it (Box 7.4). Two thirds of these trips started or finished at home and one third (11 trips) of them were round trips (Figure 7.14). The new

Connect2 scheme has completed a popular circular and recreational route around Cardiff Bay.



Figure 7.13 – Walking for recreation over the new Connect2 scheme (source: author)

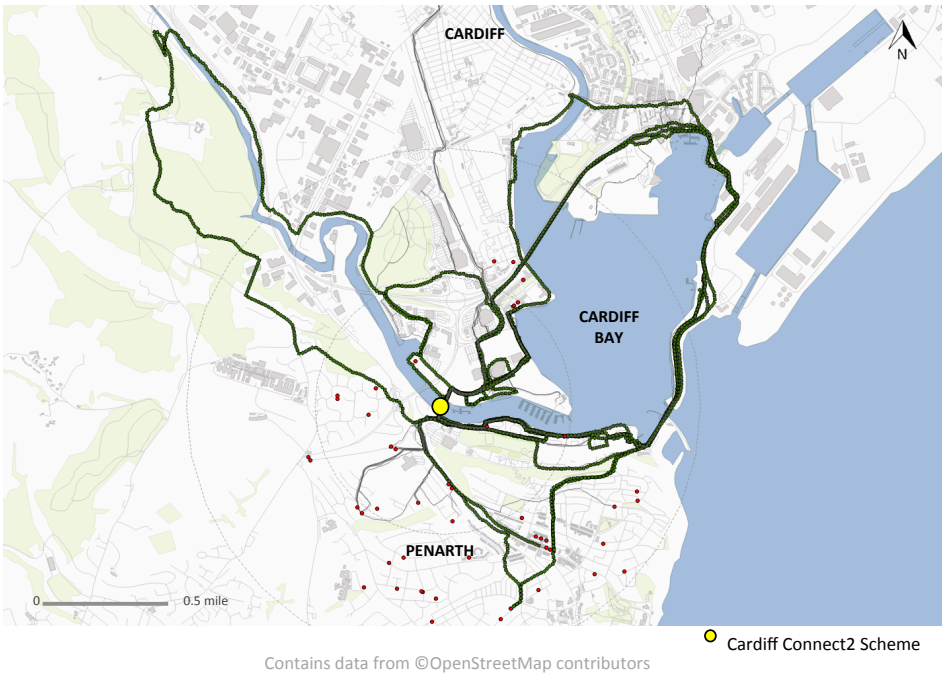


Figure 7.14 - Example of recreational round trips recorded over new Connect2 scheme

Box 7.4

I go for a run twice a week. I usually choose the route Home – Cosmeston – Old railway (5 miles) or Home – Barrage – Pont y Werin. Before the Connec2 scheme was implemented, it was simply not possible to choose route number two, which I actually prefer. (David, 53 years old)

I usually cross the Connect2 scheme when I go for a run. The scheme has just opened up a nice route for jogging very close to home. (Christian, 30 years old)

One of my favourite recreational walks is now around Cardiff Bay. This round walk became only available after the implementation of the Pont y Werin. The new bridge has just transformed the accessibility to the Cardiff Bay that was completely inaccessibly before. (Cindy, 65 years old)

7.3.2 Connect2 scheme users

Nearly one third of the participants (N=15) have crossed the Pont y Werin Bridge at least once during the period of the study (2011 and 2012). Users of the scheme were equally distributed in terms of gender (53.3 % were female) and well distributed across the various age categories. Nearly three quarters of the users were economically active and half had an annual income higher than £40,000 year. Comparisons with sample study (N=50) suggest that users of the scheme (N=15) appeared to be broadly representative of the study group but slightly older and with fewer children.

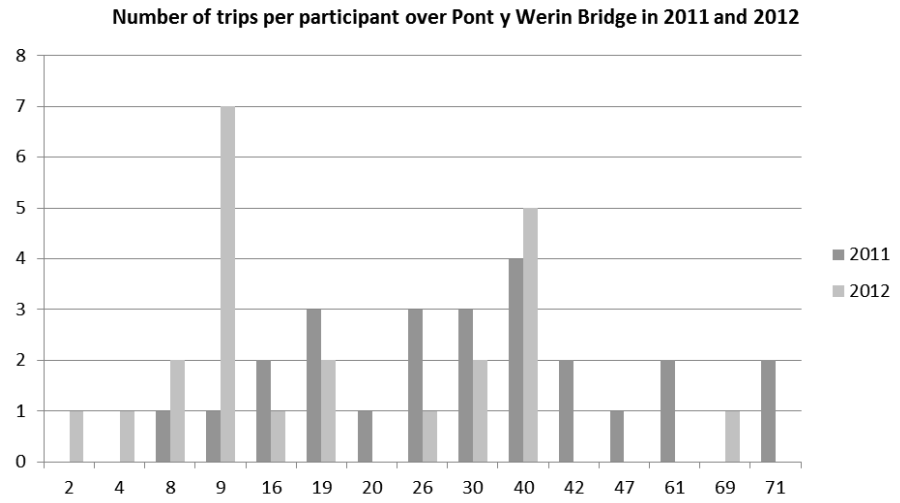


Figure 7.15 – Walking trips recorded over the Connect2 scheme at an individual level (N=15): 2011 and 2012

Twelve participants have crossed the Connect2 scheme in 2011 and ten have done it so in 2012. Three participants have walked over the new infrastructure for the first time in that same year and reasons are highlighted in Box 7.5. Participant 9 and participant 40 are however considered potential outliers, with a standardized residual of 3.4 and 3.9, respectively, as see in Figure 7.15.

Box 7.5

For Robbie (34 years) [participant 9] reason to walk more frequently over the Connect2 scheme in 2012 was indirectly related with the fact that he become unemployed, that had more free time and a had simultaneously desire to be more physical active. As the scheme created a pleasant route for jogging and Robbie lived very close to the scheme (0.5 miles), hence the reason pointed out for using it so frequently in the second year of the survey.

Alfredo, Angelina and David [Participants 2, 4 and 69] have crossed the bridge for the first time in 2012. Their walking trips recorded over the bridge in 2012 were part of a leisure walk (3.5 miles), social trip to a food festival in Cardiff Bay (2.8 miles), and jogging trip (5.3 miles).

Table 7.2 – Number of walking trips recorded over the Connect2 scheme at individual level

Descriptive Statistics	N	Mean	Std. Deviation	Maximum
Walking recreation over C2 in 2011	8	1.75	0.886	3
Utility walking over C2 in 2012	5	2.2	1.304	4
Walking recreation over C2 in 2012	7	2.14	2.193	7
Utility walking over C2 in 2012	5	1.8	1.304	4

A Wilcoxon test indicated that at a participant level there was no significant changes on number of trips recorded over the Connect 2 scheme for recreational (Z = 0.18, p=0.50) or utility (Z = -1.00, p=0.50) purposes during the years 2011 to 2012.

7.3.2.1 Proximity to the infrastructure

The number of trips made by each participant over the scheme and their household location is plotted in Figure 7.16. While three of the participants living closer to the

scheme were responsible for a third of all the walking journeys recorded over the new route, a linear regression could not establish that distance from household to the new infrastructure could statistically predict number of trips recorded over the new scheme (β = -0.07, p = .61). Distance to the scheme accounted only for 0.6% of the explained variability in number of trips over the scheme.

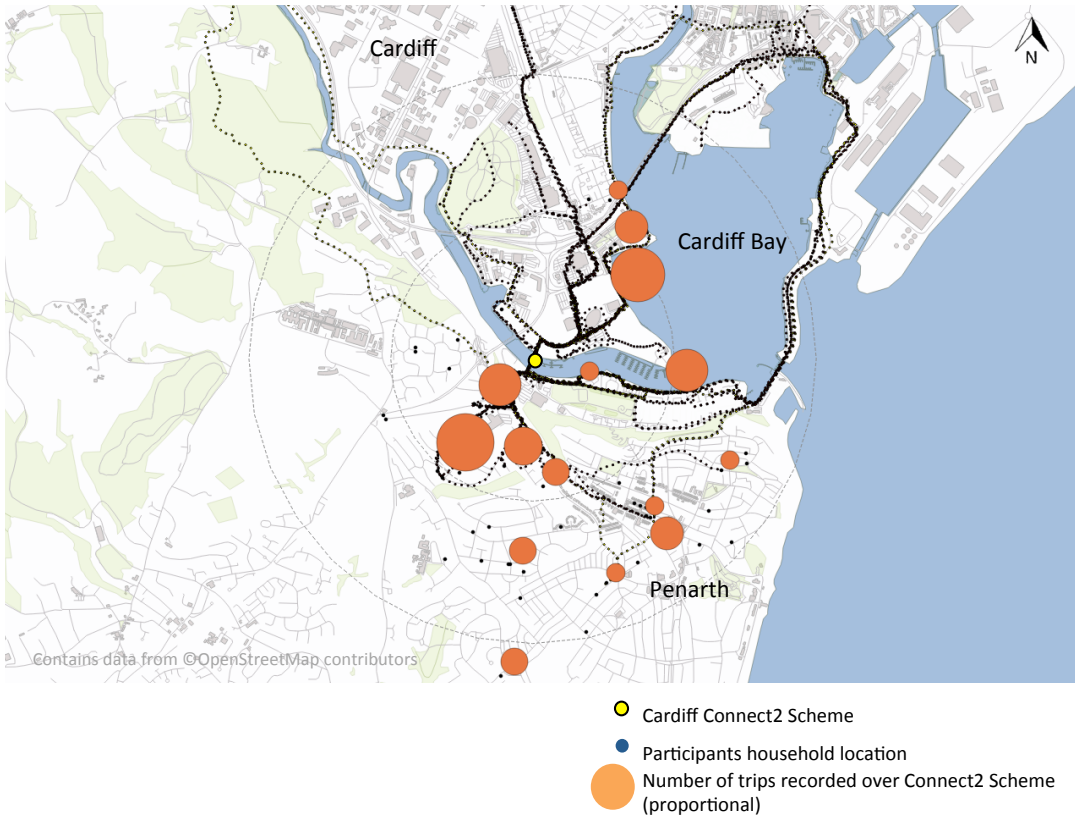


Figure 7.16 - Participant location and individual number of trips recorded over the scheme

7.3.2.2 Participants' views

A great number of participants in the study were positive with regards to the implementation of the Connect2 scheme and new opportunities provided, even if they have not use the new route (Box 7.6).

> *Box 7.6*
>
> *I can see a lot more people walking (and cycling) over the new bridge. It seems that this small link has just opened up the bay. (Katherine, 51 years old)*

The new bridge has opened a new route and it is now possible to run around the bay. I use it more frequently for running and fitness or when walking or skateboarding with my sons to the swimming pool. (Naomi, 40 years old)

I can see now a steadily flow of people using the new bridge. Unfortunately, I never get a chance to go to that part of Penarth. (Karen, 36 years old)

The Pont Y Werin has created a new link to Penarth. I have not used it yet but I am planning to do so. (Lily, 26 years old, lives less than 0.2 miles away from the Connect2 scheme).

Some participants were however more critical about certain aspects of the Connect2 scheme, namely **the location of the scheme**. For some of them, the limited number of facilities and activities in Cardiff Bay Area in close range to new Connect scheme were not enough to attract people to walk over there (Box 5.8).

Box 7.7

I have never crossed the Pont Y Werin Bridge. Actually, I cannot see the purpose of crossing it as there is nothing that attracts me to go to that part of Cardiff Bay, excluding the Raft Centre and International Swimming Pool. I would not feel comfortable going there at night too, as it feels a bit creepy over there. (Jennifer, 35 years old)

I see people occasionally crossing the new bridge. However, I do not believe there is a great point of residents in Penarth to go to the other side [Cardiff Bay Area]. The bridge may have beneficiated more people living in the Bay because it connected them to Penarth but not the other way around. (Celina, 34 years old)

Furthermore, the **poor quality of the feeder routes** to the scheme was frequently pointed out as a significant barrier.

Box 7.8

I have walked over the Pont y Werin 4 or 5 times over the last year with my children for recreation. However, I found the links to the scheme very poor and unsafe. That is one of the reasons that have put me off of going there more often to be honest. (Helen, 39 years old)

I think the access point to the bridge need to be improved. The bridge is OK, but the link to Penarth needs to be upgraded. At the moment the only alternative is to walk along a very busy road – Windsor Road. (Rodrigo, 64 years old)

The links between Penarth and the new bridge are not good. The missing link [zig zag route] would be very important to improve its accessibility from Penarth. (Thomas, 48 years old)

In conclusion, the new Connect2 scheme was well used by participants in this study as 30% of the participants have crossed it between 2011 and 2012 and 4.9% of all walking journeys have used it as part of their route. The scheme was likely to be more popular for recreation (n=29) than everyday travel (n=19). This may be explained by location of the scheme, type of connection provided and different characteristics of utility and everyday travel. No statistically significant changes in usage of the scheme were however detected between survey waves. Most participants were positive about provision of the new route but some were more critical with regards to its location or poor quality of the feeder routes.

7.4 Understanding changes in walking levels over time

This section examines how walking levels have changed during the period of the survey, both in terms of trip frequency and distance, at an aggregate and individual level. The reasons for some of the most significant detected changes are explored and the role of the new Connect2 scheme in promoting any of these changes investigated.

7.4.1 Changes in trip frequency and distance walked: aggregate level

Overall, figures suggest that participants have walked a similar number of times over the week in 2011 (9.4 ± 6.4) as they did in 2012 (9.9 ± 7.8)[45]. The mean difference between years is 0.5 (95% CI, -1.25 to 2.34) and the paired t-test indicated no significant change over the one-year period ($t_{(49)}$ =-0.60, p=0.55).

With regards to **distance** walked over time, figures in Table 7.3 also suggest that difference between years might also be residual: 8.8 (± 8.0) miles in 2011 and 7.8 (± 6.5) miles in 2012. Again, the result of a paired t-test indicated no significant change for the distance walked at a participant level between 2011 and 2012 either ($t_{(45)}$ =0.60, p=0.55).

Table 7.3 – Mean walking trip frequency and distance walked for utility and recreational purposes in 2011 and 2012

	Mean	*95% Confidence Interval for Mean*	*5% trimmed mean*	*Median*	*Std. Deviation*	*Skewenesss*
Total number of walking stages						
in 2011 (P1)	9.44	(7.6, 11.3)	9.06	8	6.42	0.93
in 2012 (P2)	9.98	(7.8, 12.2)	9.50	9	7.84	0.72
Difference in distance walked between years: t2-t1	0.54	(-1.25, 2.34)	0.18	0	6.33	-0.89
Total distance walked						
in 2011 (P1)	8.79	(6.5, 11.1)	8.18	5.95	8.06	1.20
in 2012 (P2)	7.78	(5.9, 9.6)	7.49	6.40	6.45	0.50
Difference in distance walked between years: t2-t1	-1.01	(-2.84, 0.83)	-0.79	-0.80	6.45	-0.44
Distance walked - utility						
in 2011 (P1)	5.25	(3.42, 7.07)	4.38	3.65	6.42	2.34
in 2012 (P2)	5.01	(3.63, 6.39)	4.67	3.65	4.86	0.34
difference in distance walked between years: t2-t1	-0.24	(-1.61, 1.14)	-0.06	-0.50	4.84	-1.65
Distance walked - recreation						
in 2011 (P1)	3.54	(2.16, 4.92)	2.97	1.75	4.85	1.74
in 2012 (P2)	2.77	(1.71, 3.84)	2.36	1.15	3.74	1.59
Difference in distance walked between years: t2-t1	-0.77	(-2.25, 0.72)	-0.53	0.00	5.22	-0.77

At a disaggregate level, figures also suggest that distance travelled for utility or recreation purposes is similar across the period of the study. A paired t-test analysis shown no statistical significant changes from 2011 to 2012 concerning both distance

[45] Data presented are mean ± standard deviation, unless otherwise stated.

walked for **utility purposes** ($t_{(23)}$ =0.50, p=0.62), and **recreational purposes** ($t_{(41)}$ =0.26, p=0.80). Additionally, average trip length of both utility and recreational trips is steady across the period of the study: 1.6 and 0.6/0.7 miles, respectively.

In summary, there were not statistically significant changes detected in walking levels between 2011 and 2012.

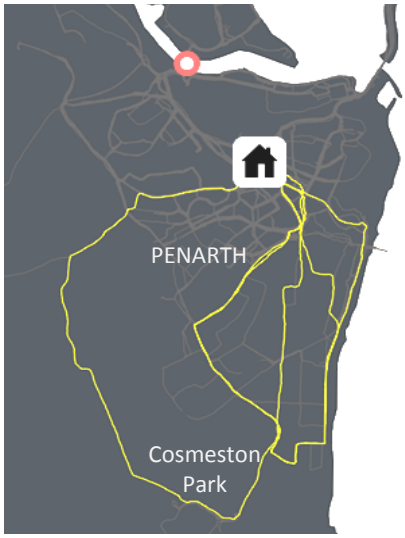
7.4.2 Individual changes in walking behaviour

Although no statistical significant changes in walking levels were detected between 2011 and 2012 at the sample level, small variations between years were detected at an individual level. Twenty participants[46] have **walked further** in 2012 as they did in 2011 (six of these participants have walked at least 5 miles further in the second year of the survey). Reason and motivations for such increase include health awareness, desire to be more physical active and purposively introduction of more walking or running activities into participants' day life routines. From those participants that have increased distance walked over time (more than 5 miles), only one has also crossed the new Connect2 scheme as illustrated in Figure 7.17.

[46] Of the 49 participants that have walked 20 have walked further in 2012 but a larger group of 27 have walked for longer distance in 2011; 2 participants have walked a similar distance between both years of the survey.

Henry, 36 years old - walked 11.7 miles further in 2012
Mainly motivated by a desire to be more physically active, Henry started to run more frequently in 2012. He lives in Penarth Town Centre and despite living relatively close to Cardiff Bay paths (improved by the Connect2 Scheme), he usually goes for a run in Penarth West and Cosmeston Park.

- Increase in walking not related to the new Connetc2 Scheme.



Robbie, 34 years old, have walked 10.7 miles further in 2012 *as he did in the previous year. Robbie became unemployed in 2012; despite job search and taking an online course, he spends most of his days at home. Feeling more sedentary than usual, Robbie wanted to be more physical active. He lives in Cardiff Bay and despite he has not run for a couple of years, he decided to start running again. Naturally, due to its proximity, routes around Cardiff Bay are usually chosen. This includes crossing the Connect2 Scheme quite frequently*

- Increase in walking influenced by the new Connetc2 Scheme.



Olga, 53 years *old, is another example of a participant that walked* ***further 5.6 miles*** *over a period of a week in 2012 as she did in 2011. In this case, health awareness and desire to be more active made her walk more often on a daily basis while commuting to work (Cardiff) or more frequently at lunchtime or at work. In this case, the participant introduces more walking/ physical activity while travelling from place to place.*

- Increase in walking not related to the new Connetc2 Scheme.



Figure 7.17 – Walking patterns of participants that have increased distance walked more expressively in the second year of the survey (contains data from ©OpenStreetMap contributors)

From those 27 participants that have walked less in the second year of the survey, main reasons for a decrease in walking included:

a) Replacement of a commuting walking journey by other mode of transport such as bicycle (Lucas, walked 22.8 miles less), train (David, walked 9.4 miles less) or bus (Katherine, walked 8.3 miles less in 2012);

b) Walk less frequently to work as a result of change from full time to part time job (Sara, walked -9.9 miles less 2012);

c) Walk less frequently for recreation due to perceived poor weather conditions (Juliette, walked 9.2 miles less in 2012);

d) Activity replacement - participant replaced jogging by indoor activities in gym close to workplace (Michel, walked 12.2 miles less in 2012).

7.4.3 Role of the Connect2 scheme in influencing travel behaviour

Based on the results of correlation analysis, it appeared that participants who walked more miles have also crossed the new bridge more often in 2011 (r= 0.78) as well as in 2012 (r=0.65) (see table in Appendix J). However, only 3 participants acknowledged the implementation of the new Connect2 scheme as a main reason to have walked more often or to promote an occasionally modal shift. These 3 participants lived in Penarth Marina and Cardiff Bay, less than 0.3 miles away from the new scheme and their views are described below (Box 7.9).

Box 7.9

I am now walking more frequently for recreation and the availability of the Pont y Werin is likely to have influenced me, as it open up new pleasant routes around the [Cardiff] Bay that were not accessible before. I guess that living very close to the scheme has also played a role. (George, 71 years old)

In 2011, George has crossed the Connect2 scheme 5 times over a period of a week.

I am running more often now and I can say that the implementation of the new Connect2 Bridge played a role. I can now easily go to Penarth Marina and Cardiff Barrage, which are the most pleasant places close to home to go for a run. (Robbie, 34 years old)

Robbie crossed the Connect2 scheme 7 times during the period of the study.

I usually go for a walk in the evenings around Penarth Marina where I live. Now that the new bridge is there, I go more frequently to the other side of the bay. I also walk occasionally to the local supermarket [other side of the bay] instead of driving my car, as I use to do frequently in the past. This is however more related with change in work policy; I am not allowed to use my nurse clothes outside work and therefore need to go home before being able to go shopping. In these occasions, walking ends up being more appealing than going back to the car again. (Katherine, 51 years old)

Katherine crossed the Connect2 scheme twice during the period of the study.

Although there were only three people, who indicated that have driven their cars in order to walk over the new Connect2 Scheme, it should be noted the potential role of the scheme in generating a few new car journeys (Box 7.10).

Box 7.10

Rebecca (58 years old) lives 1.5 miles away from the Connect2 scheme. Rebecca goes occasionally for a walk with her children around Cardiff Bay; however, she usually travels by car when she goes there. She recognizes that would be possible to walk from home to the Cardiff Barrage but that if travelling with children, car travel makes it more convenient and quicker.

Juliette (63 years old) lives 0.5 miles away from the new Connect2 scheme. She goes frequently for a recreational walk with her friends around Cardiff Bay and over the new scheme. However, she usually travels by car to meet her friends at the local car park, as she finds it more practical and comfortable.

Rodrigo (64 years old) lives 0.7 miles away from the new scheme. He rarely crosses the Connect2 scheme, as he perceives car parking availability in

vicinity of the scheme as an issue. He would not consider walking from home all the way towards the new Connect2 Scheme.

In summary, findings suggest that walking levels for both recreational and utility purposes have not statistically changed between 2011 and 2012. There were however small variations detected at an individual level but these were more likely to be related with increasing health awareness and desire to be more physical active. Correlation analysis suggests that participants that have walked more were also more likely to have crossed the new Connect2 scheme. However, only three participants stated that the new scheme was likely to have influenced their walking behaviour. For others, the new scheme may have mainly influenced route displacement in a few occasions, as they were already active walkers prior to the provision of the new scheme.

7.5 Discussion of main findings

This section presents a synthesis of the main findings in this chapter and discusses the extent to which the new Connect2 scheme had influence travel behaviour in terms of the nature of journeys and where and when these take place.

7.5.1 Connect2 scheme: levels of use

Findings shown that nearly one third of participants (N=15) have crossed the new Connect2 scheme during the period of the study and that 4.9% of the trips recorded over similar period of time took place over the Connect2 scheme. Records and observations demonstrated also that the scheme was use at different periods of the day and for different purposes. Overall, this may suggest that the new scheme was relatively well use by local population.

At a year level, results shown that number of trips recorded over the new scheme was somewhat similar in both years of the survey (25 trips in 2011 and 23 trips in 2012) and no statistical significant difference between years could be detected. A similar level of

use by two-year follow up suggests therefore that these findings may not simply reflect a novelty effect.

7.5.2 Connect2 scheme: more popular for recreation than utility purposes

Results presented in section 7.3 suggested that the new Connect2 scheme may have had a greater impact for recreational purposes rather than everyday travel. At a participant level, findings shown that 16% and 14% of the participants have crossed the new Connect2 scheme for recreational purposes in 2011 and 2012; and 10% for utility purposes over similar period of time. This result is aligned to some extent[47] with findings from the wider iConnect study that shown that 27% and 33% of the wider sample had used a Connect2 scheme in 2011 and 2012 for recreational purposes and 11% and 12% for utility purposes over similar period of time (Goodman et al. 2013).

As shown in section 7.1, utility and recreational walking trips have distinctive patterns, as qualities of the environment desired or prioritized by pedestrians seem to differ according to the main activity. **Utility walking** trips were conducted most frequently in built up areas with a good mix of activities and provision of services and facilities while **recreational walking trips** seem to be more sensitive to the quality of the physical environment and quality of the experiences that could be derived from such environments. Based on these findings, it may be argued that the potential of the Connect2 scheme in encouraging utility walking may have been limited by the location of the scheme in the outskirts of Penarth and the reduced number of facilities linked by the new scheme. On the other hand, greater use of the new Connect 2 scheme for recreational walking activities may be explained by the fact that the new scheme

[47] It should be taken into account the limitations of such comparison due to different sample size (n=1849 vs. N=50), number of case study sites (3 sites vs. 1 site) and methodology employed for data collection. In the iConnect study, participants were asked to report on *any* use of the scheme (either utility or recreation and not frequency) while in this study results are based on GPS based travel data.

completed a circular route[48] in a pleasant, high quality and popular destination for leisure activities. **Overall, findings seem to suggest that despite the Connect2 provided local residents with a new and well-used route for recreation, the new scheme may have not provided practical new routes to the particular destinations most residents needed to reach.**

7.5.3 Connect2 scheme: promoting changes in travel behaviour?

Findings suggest that walking levels for both recreational and utility purposes have not statistically changed at an overall level between 2011 and 2012. There were however small variations detected at an individual level but these were more likely to be related with other factors. From those 20 participants that have walked further in 2012, only 3 have actually crossed the Connect2 scheme and the majority pointed out **health awareness, desire to be more physically active or influence from peers** has a main reason to have increased walking levels between years of the survey.

Correlation analysis suggested however that participants that have walked more in 2011 (r= 0.78) as well as in 2012 (r=0.65) were more likely to have crossed the new Connect2 scheme. But once again, only 3 participants claimed that the new scheme was likely to have effectively triggered an increase in walking levels as they found it an attractive, functional or convenient route for either recreational (N=2) or utility (N=1) journeys. For other participants, the new Connect2 scheme was perceived as an important link but not as a reason to increase walking levels. Some participants acknowledged however that the scheme was likely to have triggered route displacement for some of their recreational journeys. A linear regression could not establish that distance from household to the new infrastructure could statistically predict number of trips recorded over the new scheme (β = -0.07, p = .61).

48 Nearly one quarter (22.4%) of walking journeys recorded over the new Connect2 scheme were round trips.

Despite low number of cases (N=3), it was noted that the implementation of the new Connect2 scheme may have generated some car journeys to access Cardiff Bay Area. This association between car travel and recreational walk was however more evident at an overall level, as for **39.4%** of recreational walks in the local area (2 miles buffer), participants did also travelled by car in order to conduct their walking activities. This finding may suggest that there is still some sort of separation between walking for health and pleasure, in the park with others who engaged in a similar activity, and walking on the streets to get to and from a destination.

7.5.4 The complexities of walking behaviour and perceived barriers

Despite walking activity has been dealt as a rather simplified concept in most urban planning and design research (Saelens et al. 2003; Lee & Moudon 2006; Choi 2013), spatial and contextual data collected in the case study site has revealed some its complexities in a real world setting. This included an identification of how **features of the built environment** are differently desired or prioritized according to main activities being conducted or on how journeys, route choice, distance or average speed also vary according to the purpose of the journey. As an example, mixed-use, higher density, well connected and car restricted areas appeared to generate more walking for **everyday travel** while **recreational walking** activities seemed to be more sensitive to the quality of the physical environment (attractiveness, presence of vegetation, open water, scenic views). Additionally, utility walking journeys were shorter (mean 0.5-0.8 miles), usually had a fixed origin destination and were greatly influenced by efficiency in the movement. Recreational trips, on the other hand, were more flexible between moving and stopping, were not always guided by shortest distance (mean 1.6 miles) and favoured round routes.

In general, walking was frequently associated with general feelings of health, wellbeing, independence and engagement with the environment (recreational walking) and

motivated by proximity, convenience or lack of alternative (everyday travel). Traffic congestion, car park cost or limited availability alongside presence of reliable public transport service was also likely to have a positive effect on utility walking. Perceived **barriers** or deterrents to walking in the local area included however the lack of connectivity and legibility of routes for pedestrians, poor quality of infrastructure, narrow width of the pavements, difficulty to find safe and convenient crossing points or the quality and attractiveness of the built environment. Despite the definition of what is an unattractive environment may vary from person to person, it was found that features such as lack of activities or interesting things along the way, proximity to other road users or noisy and smelly environment were associated with places were participants would not be so pleased to walk. Distance, topography and poor weather conditions were other natural barriers frequently cited as a reason not to walk, especially for recreational purposes. Additionally, family and work constraints, along issues of convenience and practicality were also likely to reduce the feasibility of walking for everyday travel.

These findings support therefore that walking is a very complex activity and that thus, the implementation of a safe and pleasant route for walking may not be sufficient to significantly increase walking levels, especially for utility purposes. These findings suggest therefore that a wide range of measures, such as policies that favour mix of uses and activities at walking distance, good provision of public transport and restrictions to car use in town centres would contribute to make walking a more attractive proposition. Furthermore, better infrastructure for pedestrians, such as legible and connected footpaths, well-maintained and wider pavements or safe crossings alongside attractive, comfortable, clean and well-kept streetscapes should also contribute to make walking more friendly.

7.6 Summary

This chapter set out to explore the context of utility and recreational walking in the local area and to understand the extent to which the implementation of the new Connect2 has influenced travel behaviour. Findings revealed that nearly one third of the participants in this study have crossed the new Connect2 scheme over the period of the study and that trips made over the new route accounted for 4.9% of all walking journeys recorded. Results obtained suggest however the new scheme may have been more popular for recreational journeys rather than for everyday travel, as the new scheme may have not provided practical new routes to particular day to day destinations most residents needed to reach. Overall, this suggests that in the context of an environment that is still relatively supportive of car travel, and alongside the complexity of individuals' day to day travel (and nature of walking behaviour), the implementation of a new route for pedestrians may have limited impact in promoting a significant change in travel behaviour for a large number of individuals.

The next Chapter explores in detail the extent to which the new Connect2 scheme did (or did not) influence cycling behaviour amongst the panel of participants.

8 Cycling for Everyday Travel and Recreation: Understanding the Impact of Connect2

'The decision of whether or not to ride a bicycle for a particular purpose; and once the decision is made, the choice of what route to take, are two of the most important behavioural decisions on cycling' (Dill & Gliebe 2008)

8.1 Introduction

This chapter explores the factors influencing cycling for everyday travel and recreation in the local area, the complex process of route choice and the extent to which the implementation of the Connect2 scheme influenced cycling behaviour among cyclists and non-cyclists. This chapter aims to address sub research question 2:

> **How does Connect2 influence cycling behaviour among cyclists and non-cyclists, including the nature of their journeys and route choice decisions?**

The first part of this chapter describes the context of cycling in the local area. For this purpose, the characteristics of group of participants that have cycled are described and patterns of cycling for everyday travel and recreation in the local area identified. Motivations and perceived barriers towards cycling are also explored. The second part of the chapter investigates the extent to which the new Connect2 scheme was likely to have influenced cycling levels among local community, including changes to route choice decisions and why. Following on this, changes in cycling behaviour over time are measured and reasons influencing such changes examined, including a further exploration of the role of the Connetc2 scheme. The chapter concludes a summary of the key findings and discussion of the extent to which the Connect2 scheme has influenced cycling behaviour among the local community. The data presented in this

chapter is based on the analysis of 142 cycling journeys and 755.1 miles of bicycle travel recorded between 2011 and 2012.

8.2 Who was cycling, and who was not

Nearly one third of the participants (N=17) within the study sample reported cycling at least once during the survey period. This section provides a summary of the key socio demographic and spatial data of group of cyclists, non-cyclists and "new starters" (participants that have started to cycle for the first time during the period of the survey).

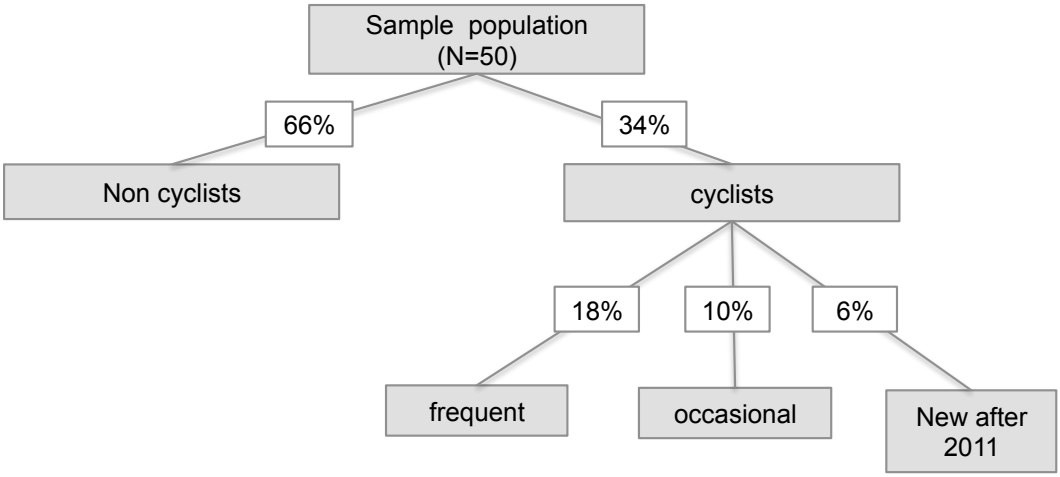


Figure 8.1 – Cyclists, non-cyclists and new starters within the sample study

8.2.1 Cyclists vs. non cyclists

Demographic and socio economic characteristics of cyclists and non-cyclists are summarised in Table 8.1. Overall, the average age of both group of cyclists and non-cyclists was similar (44.5 and 46.3 years old, respectively). The youngest participant to have cycled was 26 years old, and the oldest participant was 71 years old. Male respondents were more likely to have cycled (N=11) than female participants (N=6).

Cyclists and non-cyclists were in general highly educated (82% and 73% of participants in both groups had a degree or equivalent) and economically active (82% and 70% respectively). The group of cyclists was however more likely to have a higher income, as 8 in 10 cycling participants had an annual household income greater than £40,000

compared to 4 in 10 for non-cyclists. Furthermore, adult respondents with young children (62%) were more likely than those without children (24%) to have cycled during the period of the study.

Table 8.1 - Socio demographic characteristics of participants that have cycled during the period of the study

			cyclists N=17		non-cyclists N=33		Local population (CENSUS 2011)
Domain	**Variable**	**level**	*N*	**(%)**	*N*	**(%)**	
Demographic	Sex	female	*6*	35%	*19*	58%	51.3%
		male	*11*	65%	*14*	42%	48.7%
	Age	18-34 years	*4*	24%	*11*	33%	20.1%
		35-49 years	*6*	35%	*7*	21%	20.3%
		50-64 years	*6*	35%	*11*	33%	19.7%
		> 65	*1*	6%	*4*	12%	18.7%
	any child under 16	no	*9*	53%	*28*	85%	66.2%
		yes	*8*	47%	*5*	15%	33.8%
Socio Economic	Education	Degree	*14*	82%	*24*	73%	30.0%
		A-level or GCSE	*6*	35%	*8*	24%	45.6%
		no formal	*0*	0%	*1*	3%	24.6%
	Annual household income	> £40,000	*14*	82%	*14*	42%	-
		< £40,000	*3*	18%	*19*	58%	-
	Housing tenure	home owner	*16*	94%	*30*	91%	71.2%
		renting	*1*	6%	*3*	9%	27.5%
	Employment Status	economically active	*14*	82%	*23*	70%	61.8%
		economically inactive	*3*	18%	*10*	30%	38.2%
Car and Bike access	cars in the household	no cars	*1*	6%	*1*	3%	20.2%
		1 car	*8*	47%	*20*	61%	43.0%
		2 or more cars	*8*	47%	*12*	36%	36.9%
	adult bikes in the household	0	*0*	0%	*14*	42%	
		1 to 2	*12*	71%	*13*	39%	
		more than 3	*5*	29%	*6*	18%	
			N=14		*N=23*		
Spatial location	Distance home - work	less than 3 miles	*3*	21%	*8*	35%	
		3 to 5 miles	*4*	29%	*5*	22%	
		5 to 10 miles	*3*	21%	*6*	26%	
		more than 10 miles	*4*	29%	*4*	17%	
	Distance home - Connect2 Bridge	less than 0.5 miles	*2*	12%	*5*	15%	
		0.5 to 1 mile	*9*	53%	*14*	42%	
		1 to 1,5 mile	*5*	29%	*10*	30%	
		1.5 to 2.5 miles	*1*	6%	*4*	12%	

Car ownership levels were similar between both groups however cyclists were more likely to have access to two or more cars in the household. As anticipated, bicycle

ownership is lower among non-cyclists as 42% of these participants did not have access to a bicycle in the household.

Nearly two thirds of participants in both group of cyclists and non-cyclists lived less than 1 mile away from the new Connect2 scheme: 65% and 57% respectively. However, from those living more than 1 mile away from the new Connect scheme only 12% were cyclists (compared to 28% of non-cyclists).

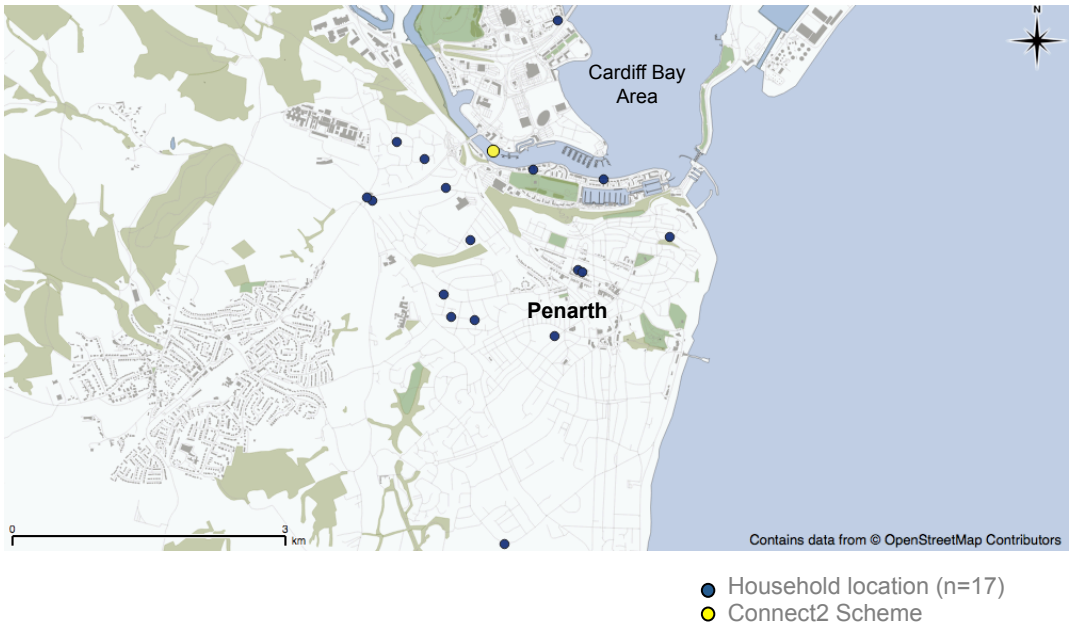


Figure 8.2 - Household location of cycling participants (N=17)

As seen in (Figure 8.2), participants that have cycled were well distributed across the local area. From those in full time work (N=37), 14 participants were cyclists and half of those lived less than 5 miles away from their workplace. Similarly, 56% of non-cyclists worked less than 5 miles away from home.

In summary, socio demographic and spatial indicators suggest that group of cyclists is comparable to the wider sample of participants in this study but biased towards being male, younger, more educated and with higher car ownership levels than the local population.

8.2.2 Subsample of cyclists:

Based on participants' actual travel behaviour and perceptions towards cycling, it was possible to identify two main groups of participants that have cycled: **committed/frequent cyclists** and **recreational cyclists.**

Committed cyclists were participants that frequently cycled to work on a daily basis. They were typically men; aged 30-40's year's old and physically active. These participants were usually confident cyclists that did not mind cycling on busy roads, as they prefer shorter and quicker routes while cycling. Some of them were also active road/ sport cyclists; and while riding a bicycle for sport, they were usually motivated by speed and distance.

Recreational cyclists were participants that cycled almost exclusively for leisure, recreation or fitness. While these participants enjoyed cycling they did not configure cycling as an alternative mode of transport in current quotidian life. Reasons were usually twofold: perceived lack of supportive environment for cycling (associated with lack of infrastructure, cycle lanes or secure parking) or practical issues (most common included journeys distance, convenience of car travel, need to carry children or shopping). These participants felt usually more comfortable cycling on quitter roads or traffic free routes. While cycling for recreation, these participants tended to value the experience of cycling, the environmental quality of the route, the social aspect if cycling with friends but as not as much the speed or journey distance.

The main characteristics of the group of participants that cycled during the period of the study are summarised in Table 8.2; these include their anonymised names, socio demographics and purpose of main activities conducted while on a bicycle (utility, recreation or both).

Table 8.2 - Description of subsample of cyclists (N=17)

Participant ID	*Fictious name*		*Age*	*Employment status*	*Children in the household*	*Cycling*
3	Henry	♂	36	work full time	yes	utility
6	Julliete	♀	63	retired	no	recreation
7	Lucas	♂	27	work full time	no	utility & recreation
15	Tim	♂	33	work full time	yes	utility
19	George	♂	71	retired	no	recreation
20	Katerhine	♀	51	work full time	no	recreation
24	William	♂	28	work full time	no	utility
26	Jennifer	♀	31	work full time	no	recreation
31	Chris	♂	55	work full time	no	utility & recreation
32	Jim	♂	40	work full time	yes	utility & recreation
33	Naomi	♀	40	part time	yes	utility & recreation
35	Myles	♂	36	work full time	yes	utility & recreation
46	Rebecca	♀	60	work full time	no	utility
55	Helen	♀	39	part time	yes	recreation
62	Ernesto	♂	55	retired	no	recreation
63	Paul	♂	38	part time	yes	utility & recreation
69	David	♂	53	work full time	yes	utility & recreation

8.2.3 New starters

Three participants have started to cycle for the first time between 2011 and 2012. Two participants were in the age category (18-35) and one in the plus 65. Two participants were female and two of them bought a new bicycle in 2012. One participant did not have a car; one participant was considering selling her car and a third one had two cars available in the household. One was in full time work, other become full time student and the other retired. Their stories are given in the Box 8.1 below.

Box 8.1

***Lucas** [32 years old, single, full time work, no car in the household]*

Lucas lived in a new development in Cardiff Bay Area (north bank of river Ely). He went to the university in Cardiff and has been living since in the local area. He shared his flat with two other friends. As Lucas has always been living close to the city centre while studying and now working, he does not feel a need to have a car to get around. He usually walks or travels by public transport.

Occasionally though, he takes a car lift with some friends. Lucas workplace is just 1.8 miles away from home.

In 2012, influenced by his colleagues at work and motivated by a need to do more exercise, Lucas bought a new bicycle. He initially used his bicycle for recreational rides around Cardiff Bay Area but soon started to use at as a mean of transport to go to work too. He enjoyed the flexibility and freedom of cycling and the fact that commuting that commuting journey was quicker (he walked to work before). Lucas also used his bicycle to explore the countryside, taking frequently his bicycle on the train and then cycling all the way home. Lucas lives 0.7 miles away from the Connect2 Bridge.

***Julia** [63 years old, married, retired, two cars in the household]*

Julia gave up cycling many years ago due to changes in life circumstances and lack of opportunity/time and motivation. In 2011, when asked about the reasons why she did not cycle she stated that:

'Travelling by car became so embedded in my daily life that it seems just impossible that cycling could be a feasible alternative. Moreover, the local area is very hilly, or at least where I live (Llandough) and perhaps more important, I find road environment totally unsafe for cyclists. I feel already smashed by cars and lorries as pedestrians on busy roads and junctions… I cannot even imagine how that will be like to cycle in such conditions. I admire however people that cycle every day. If I was younger, I would definitely like to cycle as they do'.

In 2012, Julia bought a bicycle, influenced by her sister and motivated by a desire to be more physical active and engage in new activities; she started to cycle in that same year. Julia claims however that she did not feel confident to cycle on the main roads. Therefore, she cycled in local parks or traffic free areas and travelled by car to these locations (she got a folding bicycle for this reason). Julia lives 0.4 miles away from the Connect2 Bridge.

***Jennifer** (31 years old, single, works full time, one car)*

Jennifer is a young, active, motivated and environmental aware individual. She uses public transport for a great part her journeys and despite having a car, she rarely uses it. Jennifer had a bicycle on her garden shed for years but she has not cycled for a very long time. In 2012, motivated by her friends that had recently started to cycle and were organizing a bike ride event, she decided to

have a go on cycling. After having her bicycle serviced, Jennifer started to cycle occasionally for recreation around Cardiff Bay, alone or with friends. While she enjoys cycling for leisure, she perceived the local environment as not friendly and inviting for most people to cycle for everyday travel. Therefore, does not configure cycling as an alternative mode of transport in current quotidian life. Jennifer lives 0.8 miles away from the Connect2 Bridge.

The stories of these three participants suggest therefore that **influence of significant others, perceived health benefits and the desire to be more physically active**, and enhanced opportunities in the locality may have been key reasons influencing take up on cycling. Over the next sections of this chapter, it will be examined the extent to which the new Connect2 scheme was also likely to play a role in motivating or supporting an increase in cycling levels among the local community, including these participants.

8.3 Cycling around the local area: patterns and perceived barriers

This section provides the context of cycling in the case study site by identifying the spatial patterns of utility and recreational cycling activities alongside participants' motivations and perceived deterrents towards cycling in the local area.

8.3.1 Cycling for everyday travel

Cycling for everyday travel accounted for nearly three quarters of all the cycling trips recorded during the period of the study (73.0%). **Cycling for everyday travel** (or utility cycling) is here defined as cycling from place to place rather than for recreation, sports or leisure. It usually involves travelling short and medium distances, often in urban environment. The majority of the utility cycling trips recorded took place around Penarth, Cardiff Bay Area and Cardiff City. Only 6 utility cycling trips took place towards west of the case study site, as seen in Figure 8.3.

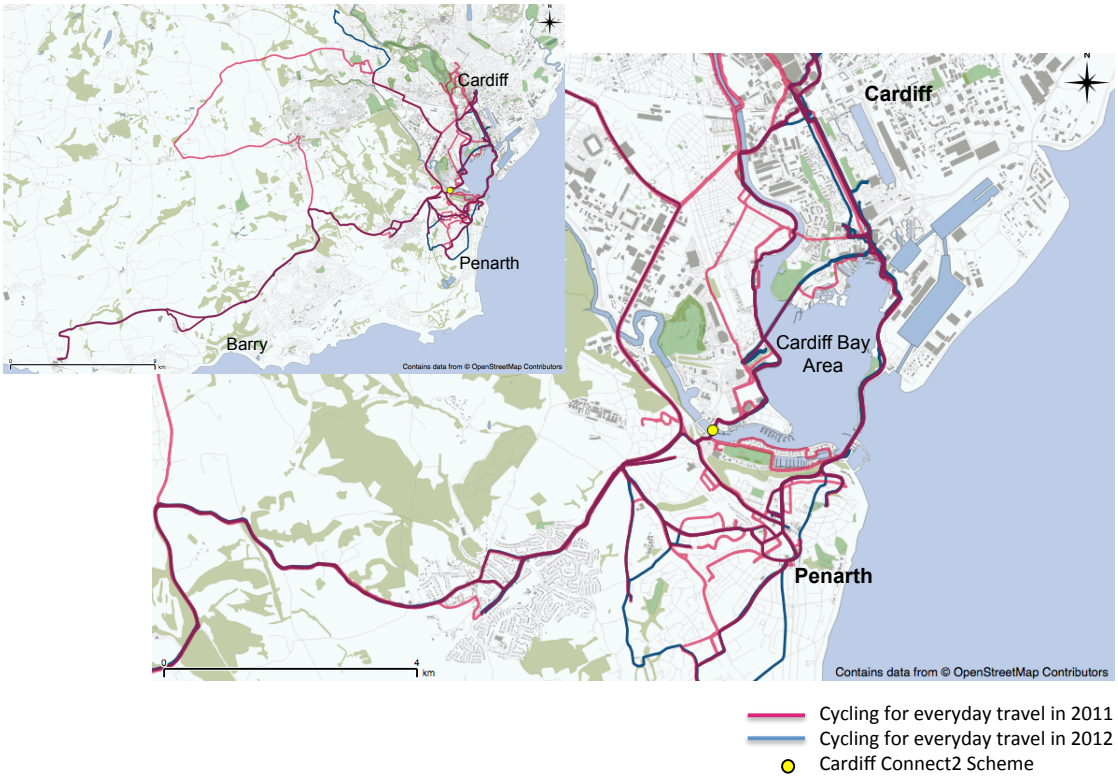


Figure 8.3 –Cycling for everyday travel in the case study site: 2011 (pink) and 2012 (blue)

Travelling to work was, within utility travel, the main reason to ride a bicycle as a mean of transport (90.4%). Participants that cycled to work regularly were usually motivated by health benefits, speed, low cost, limited access to vehicles in the household, influence/ support of peers and provision of facilities at work. Most of these participants were male, physical active and aged 30-40 years old; only one female participant cycled occasionally to work. Commuting trips were in average 4.1 miles long, lasted 23 minutes and had an average speed of 17.7 km/ hour.

It is usually assumed that cyclists tend to choose the shortest route possible while travelling for utility purposes The main reason for this assumption is that cycling relies on human power and by doing this energy output is minimized (Broach et al. 2012; Heinen et al. 2010). However, cyclists' decisions were often more complex and other factors such as perceived directness, safety, topography, quality of ride or scenic context of the route also played a route choice decision, as summarised in Table 8 and illustrated in Figure 8.4.

Table 8.3 – Utility cycling trips deviation from shortest path (miles) (n=103)

Deviation from shortest path *(difference in miles)*	**Number of trips**
0 miles	63
0.2 to 0.49 miles	16
0.5 to 0.99 miles	15
1 to 1.99 miles	8
plus 2 miles	3

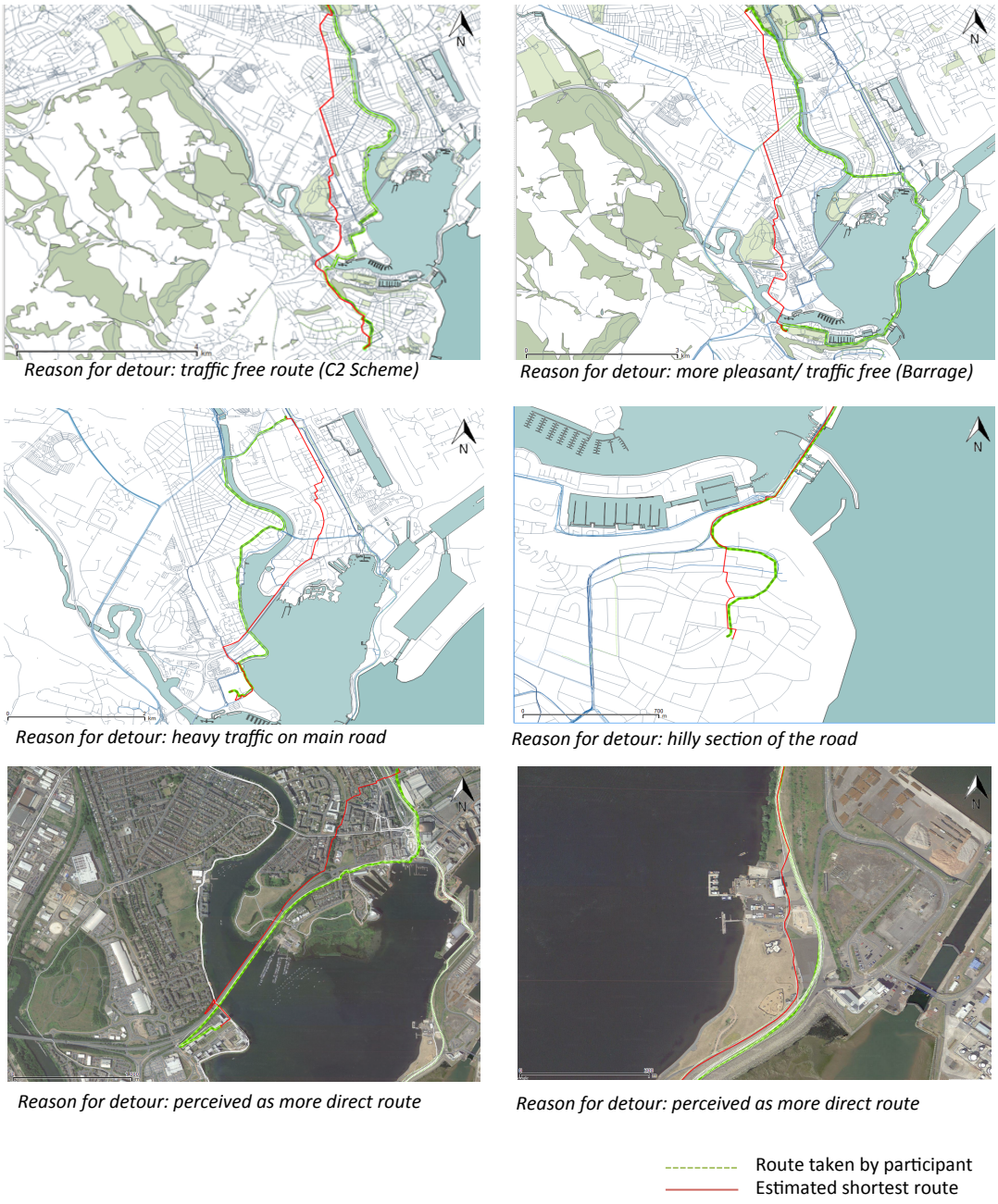


Figure 8.4 - Examples of deviation from shortest route and reasons underlying route choice (basemap: ©OpenStreetMap contributors and @2014 Google)

Nearly one quarter (24.6%) of utility trips recorded deviated at least 0.5 miles from the shortest path. The estimated mean deviation from shortest path was 0.27 miles (95% CI 0.19; 0.36), if two outliers of 10.2 miles were excluded. Main reasons underlying deviation from shortest path included the directness of the route, presence of traffic free paths/ bicycle facilities, volume and speed of traffic on main roads and junctions, slope, route exposition to weather conditions (wind) or scenic and environmental qualities of the route.

8.3.2 Cycling for recreation

Cycling for recreation accounted for a quarter of trips recorded in both wave surveys (n=38). The main purpose of these trips was recreation/leisure, fitness, sport or exercise.

Recreational cycling trips had distinct spatial patterns from utility cycling as the destinations were less fixed, loop patterns were more frequent and the shortest distance did not always direct route choice. Diverse trips patterns were recorded during the period of the study (Figure 8.5). Those included medium-long road cycling trips to Breacon Beacons National Park, Newport or Swansea peninsula; mountain bike trips along off road tracks on Ebbw Forest and along Taff River; short round trips at slow pace around Cardiff Bay; or multimodal journeys involving train travel. In average, recreational cycling trips were 9.3 miles long, had duration of 52 min and an average speed of 15.2 km/h.

Recreational trips varied however in distance covered, average speed, duration and route. **Active road or mountain bike cyclists** were usually motivated by physical activity intensity level, distance, speed and route gradient. Inversely, **casual recreational cyclists** were more likely to cycle over shorter distances and at a lower cadence. For these participants, a greater importance was given to the appeal, pleasure and experience of cycling and the characteristics of the route, such as being

traffic free or its environmental quality. The Cardiff Bay path, linked by the new Connect2 scheme, was a popular destination for leisure cycling due to its traffic free paths and scenic quality.

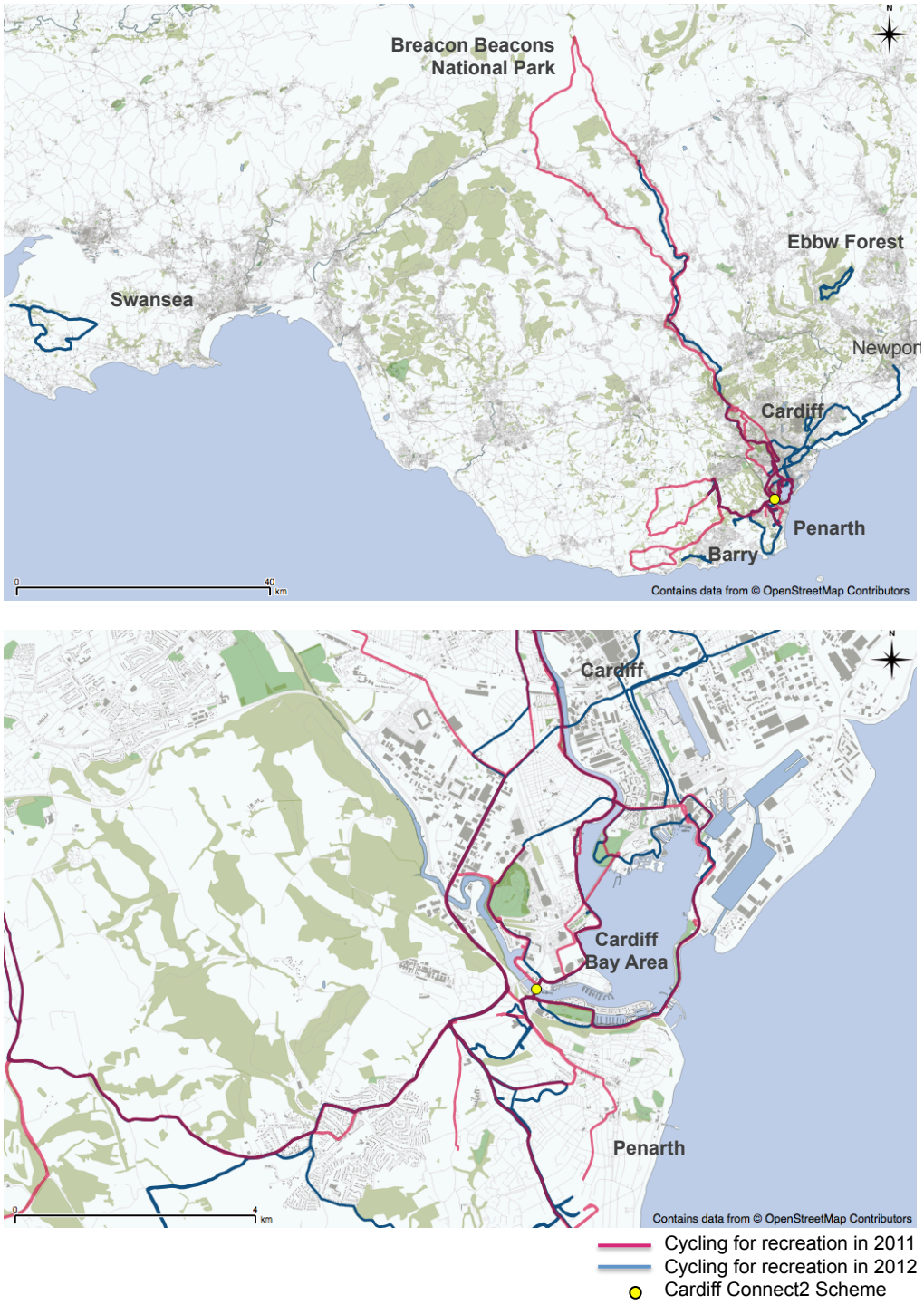


Figure 8.5 – Spatial representation of recreational cycling trips recorded in 2011 and 2012

While some of these recreational trips took place outside the case study area (n=7), for others, despite being in the local area, participants have travelled by car or public transport prior to ride their bicycles. Reason for this was usually related with trip distance (too long to be cycled from home to destination and the way backwards) or perceived safety/lack of confidence. Remarkably, the three new starters have done a trip of this type in 2012.

8.3.3 Perceived barriers for cycling around the local area

This sub section explores the factors influencing cycling levels in the local area based on participants' revealed perceptions.

For most of the participants, **volume and speed of road traffic** was a main barrier to cycling around the local area (Box 8.2).

> *Box 8.2*
>
> *Cycling around Penarth is a very dangerous activity as there is just too much traffic and roads are very narrow. I do not like cyclists to cycle on the pavement but I understand they do not have other alternative.* (Rodrigo, 64 years old, non-cyclist)
>
> *My children love cycling but I do not allow them to cycle on the main road as it just too dangerous.* (Rebecca, 58 years old, non-cyclist)
>
> *You really need to be extremely motivated to cycle around, as there is little alternative but drive. The risky situations I have faced while riding my bicycle around Penarth would have put lot of people just off their bicycles.* (Paul, 38 years old, cyclists)

The lack of dedicated, safe, well-connected and functional **network of routes for cyclists** was also identified as a main deterrent to cycling (Box 8.3).

> *Box 8.3*
>
> *For people to cycle more around the local area, it would be crucial to have dedicated infrastructure for cyclists away from traffic. There are a few paths but*

they look a bit ridiculous sometimes, as they seem to go from anywhere to nowhere. (Douglas, 31 years old, non-cyclist)

I use to cycle on a daily basis for great part of my life while living in the Netherlands but after moving to Penarth a few years ago, I just stopped. There is no dedicated infrastructure for cyclists here, or where it exists is very poor and not connected. I simply do not feel safe or comfortable cycling around here. (Julia, 52 years old, non-cyclist)

Cycle paths in our local area are usually not linked or when they are in place, they are frequently just lanes of paint on the pavement. (Rebecca, 58 years old, non-cyclist)

Availability of secure bicycle parking or facilities at work (such as showers and lockers) were simultaneously perceived as either a barrier (when not available) or facilitator for cycling (Box 8.4).

Box 8.4

There are no storage facilities in my building where I can securely leave my bicycle. As I live on third floor with no lift, it would be very hard for me to carry a bicycle all the way up and down whenever I would like to go for a ride. I would love to have a bicycle but at the moment that looks just too difficult. (Angelina, 30 years old, non cyclist)

One of the reasons that definitely influenced my decision to start to cycle to work was the presence of good shower and locker facilities at my workplace. (William, 31 years old, committed cyclist)

Urban form, land use mix or network layout determine distance between activities and, therefore, are likely to influence cycling levels. Despite its importance, only a few participants have mentioned distance as a key obstacle to cycling around the local area. Local topography, hilliness and weather were acknowledged, however, more frequently as deterrent to cycle. Hilliness was perceived as a major barrier in particular by non cyclists but also frequent cyclists agree that some section of the local road

network would require an extra effort. Poor weather conditions and in particular rain[49], were also likely to impact on participants' decision to cycle.

Attitude, norms and habits were also likely to play a role in influencing cycling levels among sample of participants. A great number of respondents recognized cycling positive contribution to the wider community (as an alternative to car in short journeys as an example) or at an individual level (in terms of its health and fitness benefits). Most cited reasons to cycle were in fact health, fitness, enjoyment, flexibility, convenience, appeal and outdoor experience. Other factors influencing cycling behaviour included affordability, cost and travel time.

Despite the widespread appreciation of the benefits of cycling, other participants claimed that factors such as perceived danger, shortage of time, effort required, journey distance, safety or inconvenience (for picking up children, carry shopping or need to change clothes if sweaty or wet, as an example) discouraged them to ride a bicycle either for utility or recreational trips. Participants' ability, experience and confidence were also likely to influence participant's decision to cycle**.** Remarkably, some other factors, such as effort or convenience, were mentioned as both an advantage and a deterrent.

Overall, it was noted that some of the identified barriers to cycling were perceived differently between the groups of cyclists and non-cyclists. Safety of a trip, effort needed, cost and travel time, were some of the most valued factors for cyclists. Older age groups and women cycled less and were likely to have greater concerns about cycling. However, no relationship could be established between socio-economic factors and cycling levels within the study sample.

[49] The second wave of this study travel survey was conducted between April and July 2012. According to the Met Office, this period was the wettest on record in Wales precipitation series since 1766 (MetOffice, 2013).



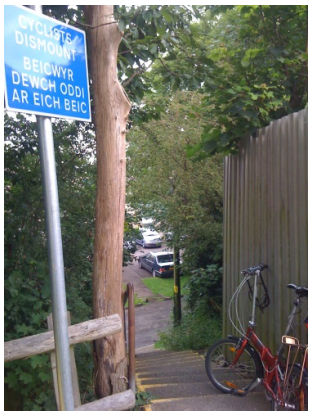
Congested road in Penarth Town Centre.



Cycling on the pavement.



Intersection on Penarth Road leading to Cardiff.



Lack of continuity of routes.



High gradient road section in Penarth.



Cycle lane on high gradien



Lack of cycling parking facilities in Penarth Town Centre and new developments in Cardiff Bay leading to residents leaving their bicycles on flats' balconies

Figure 8.6 –Perceived barriers to cycling in the local area (source: author)

This section has provided a context to actual cyling behaviour in the local area by identifying the different patterns of utility and recreational cycling and investigatting participants motivations and perceived barriers towards cycling, This sets out the context to a better understanding of the impact of the new Connect2 scheme in influencing cycling in the local area.

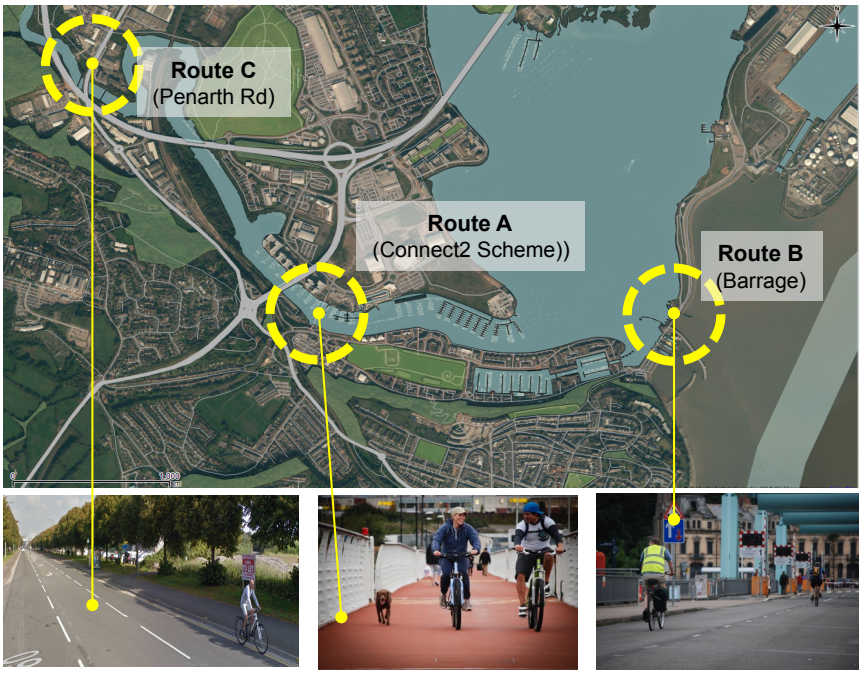
8.4 Connect2 scheme influence on cycling levels and route choice

Nearly one in five of all cycling journeys recorded during the period of the study were made over the new Connect2 scheme (n=25). This section explores the extent to which the Connect2 scheme influenced cycling levels and participants' route choice decisions.

8.4.1 Connect2 scheme influence on cycling for everyday travel

Sixty per cent of all **utility trips** recorded during the period of study took place between Penarth (where majority of participants live) and Cardiff Bay/ Cardiff City (where most of the participants work). The Connect2 scheme provides a dedicated connection over the river Ely and is one of the three routes available that links these two areas (Figure 8.7).

A total of 17 utility cycling trips were recorded over the Connect2 scheme during the period of the study. However, a greater number of trips (n=30) was recorded over alternative route B (Barrage); and shortest route calculations suggest that this was in fact the shortest path for a greater number of journeys conducted between Penarth and Cardiff (n=39). Table 8.4 compares in more detail routes taken by participants, estimated shortest route and average deviation. For 13 out of 17 trips made over the Connect2 scheme, route B provided a shortest journey and estimated average deviation was 0.8 miles.



Route			Cycling trips recorded	Estimated shortest route
A	**Connect2 Scheme**	dedicated bridge for pedestrians and cyclists; Perceived as pleasant but no direct/ quicker route	17	12
B	**Barrage**	traffic free path; Perceived as safe, direct, pleasant, quicker route.	30	39
C	**Penarth Road**	no dedicated infrastructure for cyclist; Perceived as direct and quicker route by confident cyclists	16	12
	Other routes not crossing river Ely	*routes around local area; mostly on residential streets and major road; predominantly no bicycle facilities.*	*42*	

Figure 8.7 – Routes available for cycling between Penarth and Cardiff: (A) Connect2 scheme, (B) Barrage and (C) Penarth Road.

Table 8.4 – Route taken vs. estimated shortest route (trips count and average deviation)

			Trips (count)				**Average deviation** (miles)		
			Estimated shortest route				***Estimated shortest route***		
			Route A	**Route B**	**Route C**		**Route A**	**Route B**	**Route C**
Route taken	**Route A**	*A - Connect 2 Scheme*	**4**	13	-	-	-	0.8	-
	Route B	*B - Barrage*	6	**24**	-	-	0.4	-	-
	Route C	*C - Penarht Road*	2	2	**12**	-	0.1	0.3	-
		not aplicable	-	-	-	**42**	-	-	0

The following section explores with further detail participants' commuting journeys and reasons influencing decision to cycle either over route A (Connect2 scheme), route B

(Barrage) or route C (Penarth Road). Eleven participants have cycled for utility purposes; from those, four used the new Connecct2 scheme on the way to work during the period of the study.

8.4.1.1 Cycling over the Connect 2 scheme (route A)

Henry (35 years old, full time work) and William (29 years old, full time work) are two committed cyclists that live in Penarth and cycle to work in Cardiff on a daily basis. These two participants cycle frequently over the Connect2 scheme. Trip details, including trip frequency, distance, duration and elevation profile are summarised in Figure 8.8.

> For **Henry**, the Connect2 route is a crucial link that provides a direct and safe route to work. Additionally, the fact that the new scheme is open 24 hours a day and well lit at night makes it a favoured choice (the access to the alternative route B – barrage - is conditioned between 10pm – 7 am).
>
> **William** is the participant that lives further away from the Connect2 scheme (2 miles). Yet, he cycles frequently over the Connect2 scheme as he finds it a pleasant and convenient route to commute to Cardiff. Occasionally, William also cycles over route C (Penarth Road), as this is a shorter (0.5 miles) and a quicker (9 minutes) route despite it does not have segregated infrastructure for cyclists.

Elevation profiles in Figure 8.8 suggest that for both participants' routes B and C are likely to be more predominantly flat.

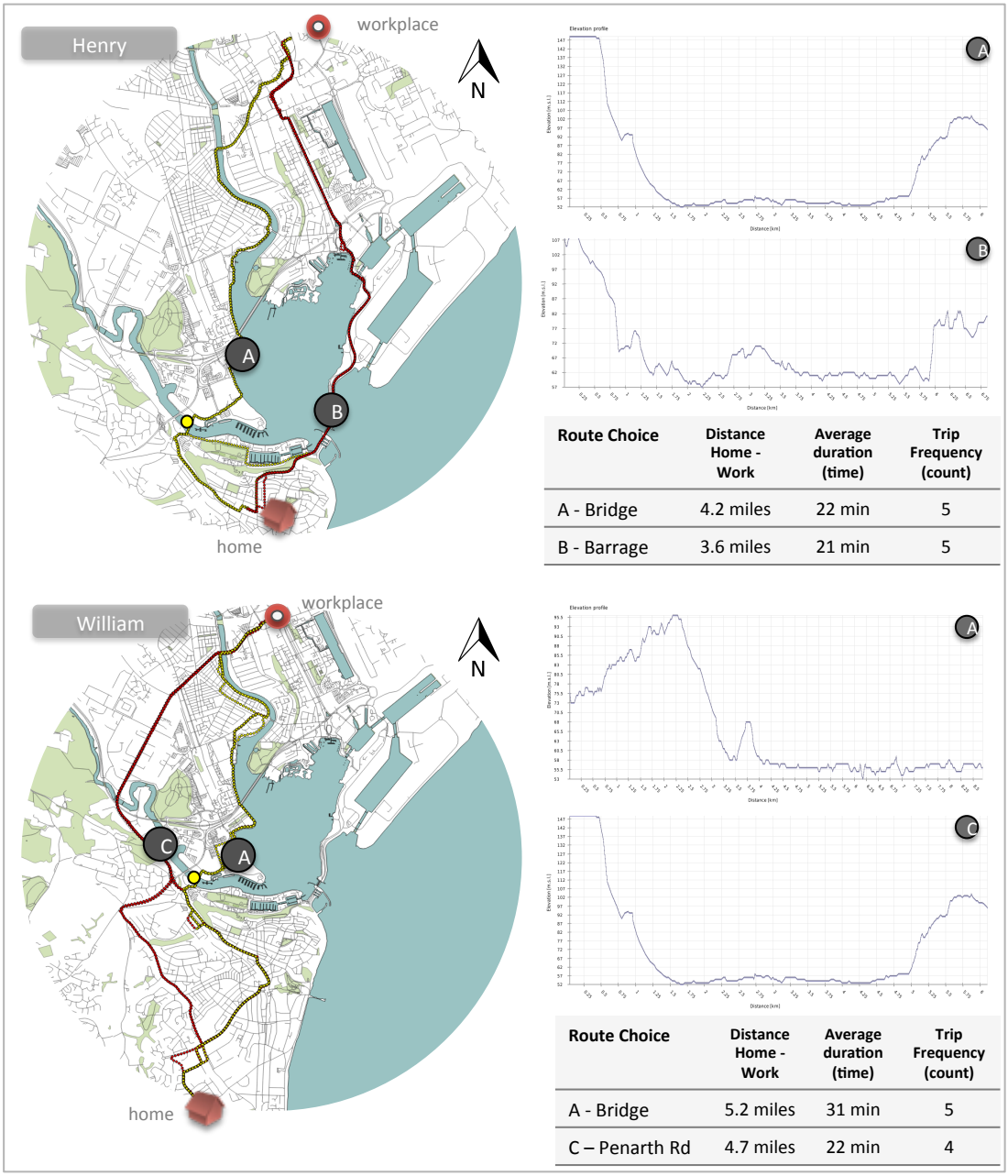
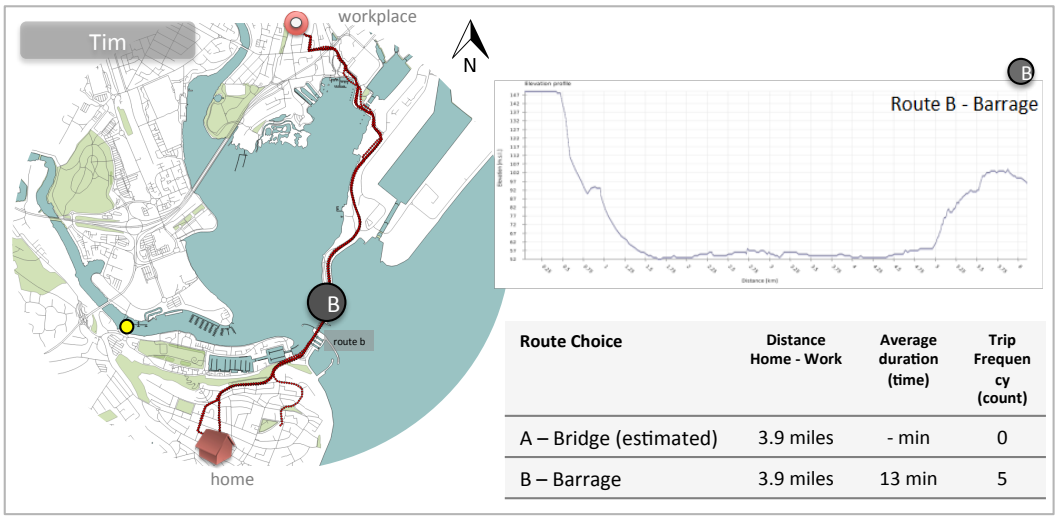


Figure 8.8 – Cycling commuting typical journeys by participant Henry and William (over route A)

8.4.1.2 Cycling over Barrage Route (route B)

Tim (34 years old, male, full time work*)* cycles everyday to work. He lives in Penarth town centre and works in the north side of Cardiff Bay. Distance of cycling to work via Connect2 scheme (A) or Barrage (B) is similar – 3,9 miles. Tim, prefers however to cycle over route B, as it is a pleasant, safer and more direct route (Figure 8.9).



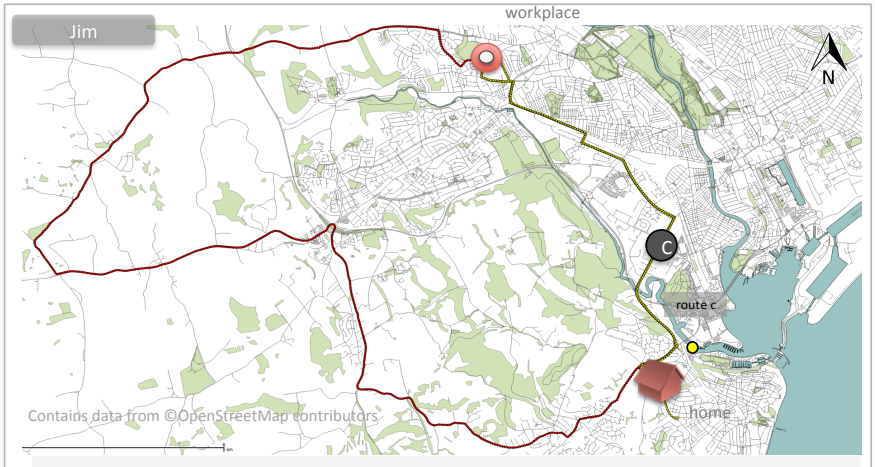
Route Choice	Distance Home - Work	Average duration (time)	Trip Frequency (count)
A – Bridge (estimated)	3.9 miles	- min	0
B – Barrage	3.9 miles	13 min	5

Figure 8.9 – Cycling commuting typical journey by participant Tim (over route B)

> *Cycling through the Pont y Werin route may be quicker; however I do not find it as attractive and safer as the barrage route [route B]. The main access to the Pont y Werin Bridge [route A] is made via Winsor road, and that is just too narrow, busy and dangerous for cycling.*

8.4.1.3 Cycling over Penarth Road (route C)

Jim (39 years old, full time work) is a confident and active cyclist that uses his bicycle either as a method of travel to work or as a mean of sport and recreation. Jim lives in Cogan and works in in northwest of Cardiff. His typical commuting trip is 5.1 miles long and takes him, on average, 22 minutes to travel to work by bicycle (Figure 8.10).



Route Choice	Distance Home - Work	Average duration (time)	Trip Frequency (count)
A – Bridge (estimated)	6.5 miles	- min	0
C – Penarth Road	5.6 miles	22 min	9

Figure 8.10 – Commuting routes for participant Jim (route C)

The new Connect2 Bridge may have created a safer route for a short section of Jim's commuting journey; however, it does not provide the most direct route. Despite living less than 0.5 miles away from Connect2, Jim has never used the route to travel to work. Instead, he cycles along the busy Penarth Road (Route C). Jim explains why he usually choses route C rather than route over the Connect2 scheme:

> *I do not mind cycling on the main road (…) I guess I am just use to do it. Also, when I am cycling to work, I value direct and quick routes. The new Bridge [Connect2] scheme may provide a good link for some users but not for me.*

As shown in Figure 8.10, Jim also frequently takes a longer route while cycling back home. From all cycling journeys recorded, Jim is the participant that has deviated further away from the shortest path - 10.2 miles. This behaviour is explained by the need a need to add exercise to his sedentary work.

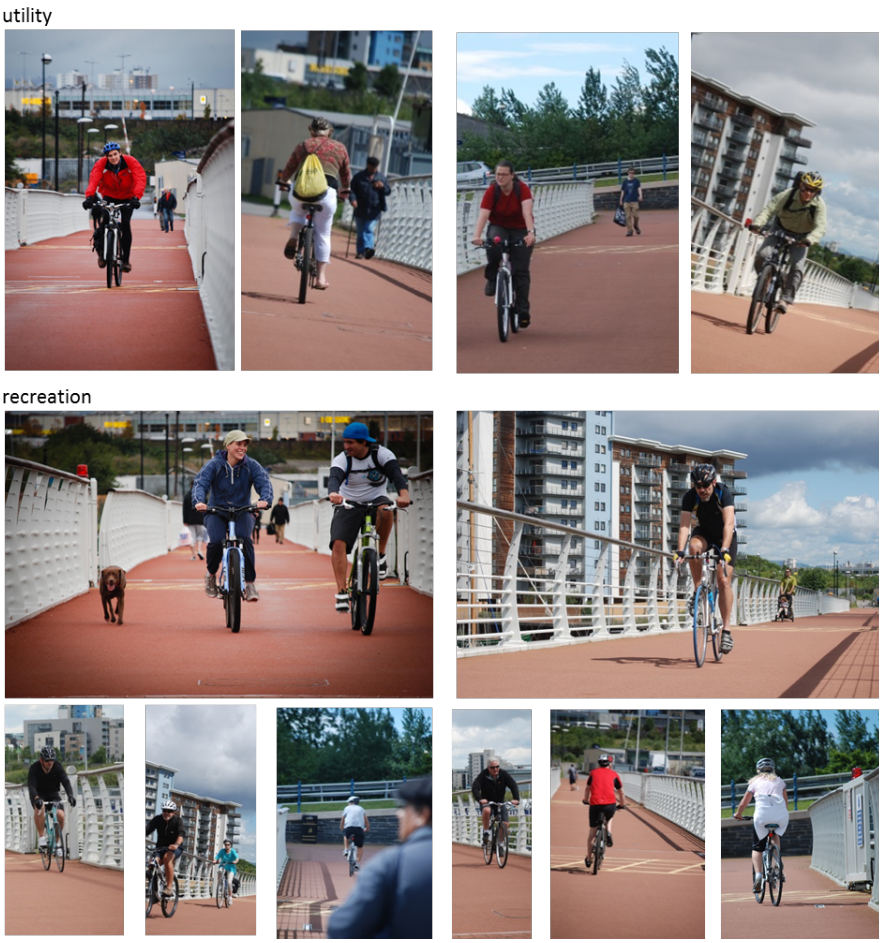


Figure 8.11 - Cycling for utility and recreational purposes over the new Connect2 scheme (source: author)

8.4.2 Cycling for recreation, route choice and the Connect2 scheme

GPS data records demonstrate that 24% (n=9) of all recreational cycling journeys recorded during the period of the study were made over the Connect2 scheme (Route A) and that the route over the new scheme was the most popular for recreational journeys conducted between Penarth and Cardiff. Most of these cycling trips had a loop pattern as seen in figure below.

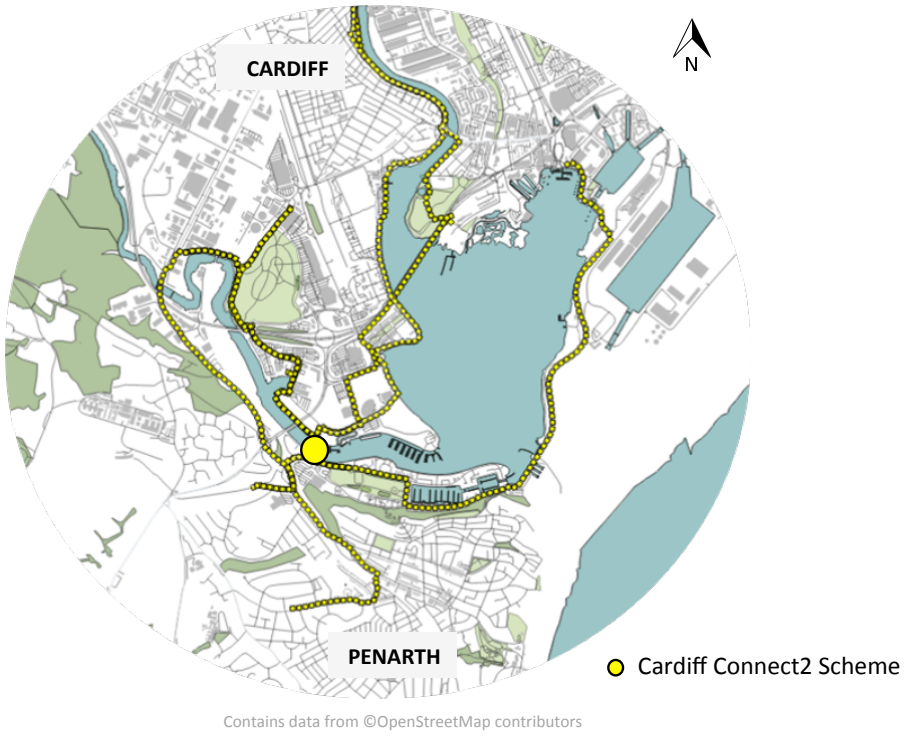


Figure 8.12 – Recreational trips recorded over the new Connect2 scheme: short distance and loop patterns

Figures presented in Table 8.5 suggest however that trips recorded over Route C were in general longer (23.2 miles average) and had a higher average speed (13.9 mph) than those recorded over Connect2 scheme (3.3 miles average distance and 7.8 mph average speed). This may suggest that the Connect 2 scheme was a preferential route for short, low speed, leisure cycling trips but that route C was in fact the route favoured when cycling for long and sporty rides.

Table 8.5 - Number of recreational trips recorded over Connect2 scheme and alternative routes

Route		Characteristics of the route	Total trips	Freq (%)	Average distance (miles)	Average speed (miles/ hour)
A	***Connect2 Scheme***	dedicated brigde for pedestrians and cyclists;	6	16%	3.3	12.6
A+B	***C2 Scheme + Barrage***	using in the same trip both routes A and B	3	8%	10.8	20.9
B	***Barrage***	traffic free path;	2	5%	8.5	10.1
C	***Penarth Road***	A road (2-4 lanes), no dedicated infrastructure for cyclist; direct route to Cardiff	5	14%	23.2	22.5
E	***not applicable***	diverse; most frequently on road	21	57%	7.6	13.9

In conclusion, this section has explored the extent to which the new Connect2 scheme was likely to have influenced cycling for everyday travel or recreational cycling in the case study site. Findings show that the new Connect2 scheme was located alongside the most popular corridor for commuting in the area as 60% of all utility trips recorded took place between Penarth and Cardiff. However, despite participants frequently crossing the new Connect2 scheme, route B was a more popular choice and provided a shortest path for a great number of journeys. For recreational activities, findings suggest that the route over the new scheme is the most popular route; however, it may be favoured for leisurely shorter rides.

8.5 Changes in travel behaviour over time and role of Connect2

This section examines how cycling levels have changed over the period of the study and explores the extent to which the new Connect2 scheme supported any potential increase in cycling for everyday travel or recreation.

8.5.1 Changes in overall cycling levels

Absolute figures suggest that participants have cycled more frequently in 2011 (86 journeys) than in 2012 (55 journeys). At a disaggregate level, figures show that distance travelled for utility cycling was also likely to have dropped during the second

year of study (Table 8.6). Weather conditions during the survey period in 2012 and atypical events of two committed cyclists are likely to have contributed to this drop in cycling levels though.

The result of paired t-test indicated a significant decrease over the two time points for the number of cycling stages for utility purposes ($t_{(16)}$=2.38, p<0.05), but no significant change over the two time points for the number of cycling stage for recreational purposes ($t_{(16)}$=-0.95, p=0.36). A Wilcoxon Signed Rank test demonstrated that there is a statistically significant median difference in distance travelled by bicycle for utility purposes during the period of the study (Z = -2.166, p = 0.03), but that there was no significant change in the length of cycling for recreational purposes over the two time point (Z=- 1.27, p=0.23).

Table 8.6 –Total trip frequency and distance travelled by bicycle in 2011 and 2012

Trip frequency (count) N=17						
		Mean	CI 95%	Median	Maximum	Total
All trips	*2011*	5.1	*(2.3; 7.3)*	2	16	86
	2012	3.2	(1.3; 4.5)	2	9	55
Utility trips	*2011*	4.2	*(2.2; 6.4)*	3	12	71
	2012	1.9	*(.4; 3.4)*	0	9	32
Recreational trips	*2011*	0.9	*(0; 1.6)*	0	5	15
	2012	1.4	*(0.4; 2.3)*	1	5	23

Distance travelled (miles) (N=17)						
		Mean	CI 95%	Median	Maximum	Total
All trips	*2011*	27.4	(3.6; 50.5)	7.1	110	466.2
	2012	16.9	(6.1; 26.8)	6.4	58.8	287.8
Utility trips	*2011*	17.2	*(5.4; 28.9)*	6.5	76.3	292.3
	2012	6.9	*(1.7; 12.1)*	0	26	117.4
Recreational trips	*2011*	10.3	*(0; 23.9)*	0	58.8	173.9
	2012	10.0	*(1.3; 18.8)*	1	104.7	170.4

8.5.2 Connect2 scheme: use over time

Two thirds of the trips recorded over the new scheme in 2011 were utility journeys; however, in 2012, the proportion of recreational and utility travel trips recorded over the scheme is similar (table 8.7).

Table 8.7 –Utility and recreational cycling journeys recorded over the Connect2 scheme in 2011 and 2012

	2011		**2012**	
	Count	*Freq (%)*	*Count*	*Freq (%)*
Utility cycling	11	12.8%	4	7.3%
Recreational cycling	6	7.0%	4	7.3%
Total recorded over Connect2 Scheme2 Scheme	**17**	19.8%	**8**	14.5%
Total Recorded	*86*		*55*	

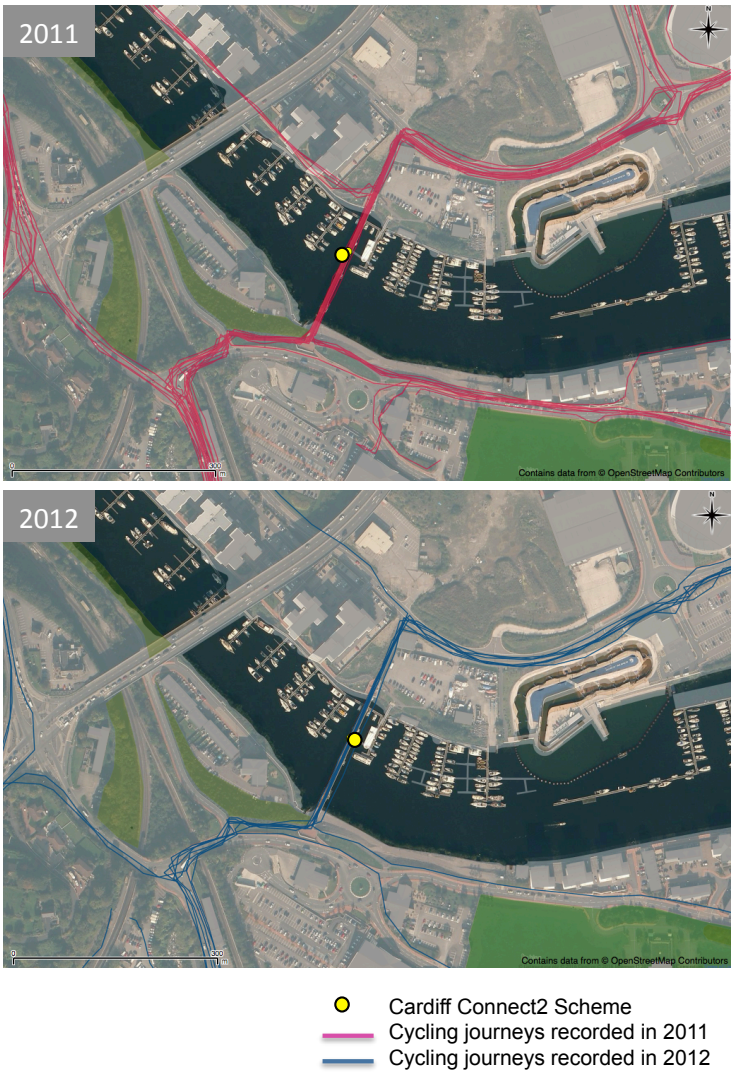


Figure 8.13 - Cycling trips recorded over the new Connect2 Bridge in 2011 and 2012 (basemap: BingMaps © Microsoft Corporation)

At participant level, a Wilcoxon Sign test, indicated that neither number of recreational (Z = 0.32, p=0.45) or utility (Z = -1.84, p=0.63) cycling trips made over the new Connet2 scheme were significantly different between 2011 and 2012.

In summary, total trip frequency and distance cycled for utility purposes decreased in the second year of the survey however no significant changes were detected over time in the number of cycling journeys crossing the new Connect2 scheme, either for utility or recreational purposes.

8.5.3 Factors influencing changes in cycling levels over time

Despite the statistically significant decrease in number of utility cycling trips recorded in the second year of the survey, results at an individual level shown that 6 participants have cycled further in 2012, including 3 new starters (Table 8.8).

In those cases, reasons to have **increased cycling levels** (or to have started to cycle) were usually related to a desire to be more physical active, influence of friends and peers or changes in life circumstances (e.g. having only one car available in household).

Weather conditions, atypical events or changes in life circumstances were however the most likely reasons for an overall decrease in cycling levels on the second year of the survey. Examples included atypical week of work limiting availability for sport cycling, bicycle stolen two weeks before survey period or new job further away from home. Issues with a GPS device from a committed cyclist were also likely to have influenced overall figures.

Table 8.8 – Individual changes in cycling behaviour over time and reasons

Participant	Individual difference in distance travelled by mode between 2011 and 2012 (miles)					Cycling over C2 Scheme		Reasons for change in cycling levels	
Fictitious name	Walk	Bicycle	Car	PT	TOTAL	2011	2012		
Jim	+	**-166**	+	--	---	-	-	**week variability**	*atyical week of busy work. Did not not cycle twice for sport during the week in 2012 as he usually does*
David	+	**-30**	-	**+++**	**+++**	2	0	**week variability**	*active commuter; got his bicycle stolen 2 weeks prior to the survey period in 2012*
Chris	+	**-25**	++	0	++	2	0	**week variability**	*one commuting journey less recorded to work one trip less to work by bicycle (13 miles)*
William	-	**-22**	+	+	+	5	4	**week variability**	*influenced by weather conditions (rain); replaced some commuting journeys by bicycle to publci transport and/or car*
Henry	+	**-14**	++	+	+	5	0	**week variability**	*one day on leave during travel survey period in 2012; difference Is one day less of commuting to work recorded*
Myles	0	**-7**	+	0	+	-	-	**-**	*issues with gps device*
Rebecca	-	**-6**	--	0	--	-	-	**life cirscunstances**	*she is now freelancer so her commute pattern is more variable; she has a folding bicycle that use often on the way back from work in 2011.*
George	-	**-5**	+	+	+	1	0	**attitudes/ awareness**	*attitudes : replacing some outdoor activities by squash (friends influence)*
Naomi	-	**-4**	++	-	+	-	-	**-**	*no significant changes*
Katerhine	+	**-4**	+	++	++	1	0	**-**	*novelty effect of the C2 Scheme*
Garret	+	**-3**	-	+	--	-	-	**-**	*no significant changes*
Amelie	+	**6**	---	++	--	0	2	**attitudes/ awareness**	*desire to be more physical active; influenced by friends; novelty of cyclingand*
Tim	+	**8**	0	0	+	-	-	**car ownership/ life circunstances**	*one car in the household and need to share it with wife that is now back to work following maternity leave; as a result, commutes now more often by bicycle*
Helen	-	**20**	-	+	+	1	-	**attitudes/ awareness**	*she is cycling more for sport/ more pysical active; also cycling now with their children that just got new road bicycles*
Paul	+	**24**	++	-	+++	-	1	**attitudes/ awareness**	*cycling more for sport/ recreation; in part, by replacing running due to health issue*
Julliete	-	**2**	-	0	-	-	-	**attitudes/ awareness**	*got new folding bicycle in 2012; influenced by friends; desire to be more physical active*
Lucas	-	**43**	+	+	+	0	1	**attitudes**	*got new bicycle in 2012; peers influence; replaced commute walk by bicycle*

8.5.3.1 Connect2 scheme and changes in overall travel behaviour

From all participants no one reported that the new Connect2 scheme was responsible for a significant change in travel behaviour between 2011 and 2012, apart from route replacement in some occasions. This quote from Paul illustrates this nicely.

> *I might have changed my route in a few occasions and have crossed the new Pont y Werin Bridge while cycling for recreation in the local area. However, I do not feel that the scheme has made me to cycle more often. I have might use the new bridge as it provides me a better route for some journeys, but I would have done the same journeys anyway (Paul, 38 years old, occasional cyclists).*

Moreover, none of the new starters (3 participants) acknowledged the new scheme as the main reason to have started to cycle during 2012. Instead, for these participants, health awareness, influence from friends and peers or buying a new bicycle have played a more important role.

There was however one exception. Henry (36 years old) states that the implementation of the new Connectt2 scheme was in fact a main trigger to have started to cycle to work (in early 2011, prior to the first wave of the GPS Survey). Henry lives in Penarth and works in Cardiff Central.

> *I never considered to cycle to work before the implementation of the new Connect2 scheme. I had seen some people commuting by bicycle to work in Cardiff but could not configure that as a feasible alternative for me. The route via Penarth Road [route C] was too dangerous and the route via Barrage [route B] did not work for me, as it is only open after 6am and I need to be at work around that time. Therefore, I usually travelled to work by bus. The implementation of the new Connect2 scheme, in 2010, made me however consider whether cycling to work was now possible to me; I decided to have a go and bought a new bicycle. I am now cycling to work on a daily basis and really enjoying it. The Connect2 scheme provides me a direct, safe and 24h accessible route over river Ely and towards my workplace.*

8.5.3.2 Potential limitations of the Connect2 scheme in inducing cycling levels

While a great number of participants agreed that the Connect2 scheme was an important link for cyclists in the local area, it was felt that the **poor quality of feeder routes** and the presence of an **alternative traffic free route** were likely to limit its impact.

Firstly, it was felt that the low quality of the feeder routes[51] influenced perceived connectivity to the scheme itself (Box 8.6).

> *Box 8.6*
>
> *In order for me use the new Connect2 scheme, I need to cycle along Windsor Road, the main access and the busiest road in Penarth. However, I cannot feel safe cycling over there as the road is too narrow and volume and speed of road traffic are just too high… I guess that the main issue of the scheme is definitely the access routes that are not just good at the moment (David, 53 years old).*
>
> *In my view, there is need of safe and shorter routes to link Penarth Town to the new Connect2 scheme and make it more attractive (Damien, 64 years old).*
>
> *I have cycled through the new Connect2 scheme with my children 4 or 5 times in the last year. However, we have not cycled directly from home over there but have instead, travelled by car. The main reason is that there is no traffic free path between our place and the new scheme and the main road access is just too dangerous to cycle with the children (Helen, 39 years old).*

The presence of an alternative traffic route – the Barrage - running parallel to the Connect2 to scheme and providing linkages with Mermaid Quay and Cardiff City Centre was also likely to have influenced participants' use of the new Connect2 scheme (Figure 8.14). Route B (barrage) directness, safety and environmental quality

[51] The main accesses to the Connect2 scheme were either the Windsor Road or the Paget Road. The first one is the main road access to Penarth, a road with high volume of traffic and with no dedicated facilities for cyclists. The second alternative is a narrow road with a high gradient and that usually implies a long detour from desired line/ shortest path.

was valued by many participants, including more experienced cyclists (Box 8.7); and in a greater number of cases this route provided a shortest journey (as seen in section 8.4.1).



Figure 8.14 – The alternative traffic free route over Cardiff Barrage (source: author)

Box 8.7

The new Connect2 scheme may provide a shorter route to work; however, I do not find it as quicker and safer as cycling through the Barrage route. Furthermore, it does not have as many cars as in the other alternatives routes (Tim, 33 years old, committed cyclist).

There is a lot of zigzag and interruptions on the way to Cardiff if you follow the Connect2 scheme route. The route via the barrage is a more direct (David, 56 years old, committed cyclist).

The Barrage is my favourite route to cycle to Cardiff because it is traffic free and very pleasant. A drawback may be that is more exposed to the wind and it is not

lit which is more an issue over the winter (Rebecca, 60 years old, occasional cyclist)

In conclusion, this section shown that trip frequency and distance cycled for utility purposes decreased in the second in year of the survey among the study sample but that no significant changes were detected in the number of cycling journeys using the new Connect2 scheme either for utility or recreational purposes. At an individual level, findings suggested that participants that have cycled more frequently were usually motivated by a desire to be more physical active, influence of friends and peers or changes in life circumstances (e.g. having only one car available in household). The new Connect2 scheme was likely to have promoted route replacement in several occasions; however, only one participant acknowledged the implementation of the new scheme as the main a reason for a modal change.

8.6 Discussion of main findings

This section provides a summary of the key findings and discusses the extent to which the Connect2 scheme has influenced cycling behaviour in terms of the nature of journeys and where and when these take place.

8.6.1 Connect2 scheme: levels of use and nature of journeys

Findings revealed that nearly one fifth of all the cycling journeys recorded during the period study (18.3%) took place over the new Connect2 scheme. Absolute figures shown that higher number cycling trips recorded over the new scheme were part of everyday travel (n=17 vs. n=9) but relative figures suggest that the Connect2 scheme may have been more popular for recreational rather than utility purposes (24.3% vs. 16.2% of cycling journeys recorded, respectively).

For **recreational cycling**, findings suggest that Connect2 scheme was the most popular route for sport or leisure journeys conducted between Penarth, Cardiff and

Cardiff Bay. Trips recorded over the new scheme were however usually shorter and had a lower average speed than recreational trips recorded over other routes (see table 8.5). This may suggest therefore that the provision of the scheme may have been more relevant for occasionally/ inexperienced cyclists rather than sport cyclists. As describe in section 8.2.2, active road or MTB cyclists usually prioritized speed, distance, topography and physical activity levels whereas for casual recreational cyclists, the environmental quality of the route (including segregation from traffic) and the experience of cycling seem to be more relevant.

For **everyday travel,** findings suggested that potential of use of the Connect2 scheme was high as 60% of all utility cycling trips were recorded along the new link provided by the infrastructure (Penarth – Cardiff). Results revealed however that despite participants have frequently crossed the new Connect2 scheme (n=17), parallel route B (Barrage) was a more popular choice (n=30). The fact that the new Connect2 scheme was well lit, open 24 hours a day, less exposed to weather elements (wind) and provided convenient access to some local facilities made it a favoured route for some participants. However, the fact that route was B was traffic free, perceived as more direct, with less interruptions/stops (junctions), had better access routes and superior environmental quality influenced its preference for most cyclists, including experienced cyclists.

8.6.2 Connect2 scheme and changes in travel behaviour

The number of recreational cycling trips was similar over time but the number of utility journeys dropped between 2011 and 2012 ($t_{(16)} = 2.38$, $p<0.05$). The absolute number of journeys recorded over the Connect2 scheme fell as well by the second year of the survey, but at a participant level, no statistical significant change could be detected between 2011 and 2012. Three participants have started to cycle however for the first time during the second wave of the survey: two for recreation purposes and one for

both utility and recreation. Reasons influencing the decision to start to cycle was somewhat similar across participants – influence from peers and perceived health benefits. None of these participants acknowledged, however, that uptake on cycling was influenced by the new Connect2 scheme.

From the group of cyclists (N=17), one participant reported however that the implementation of the new Connect2 scheme was the main trigger to change his travel behaviour. This participant replaced bus travel commuting by cycling to work following the implementation of the scheme in 2011. The new scheme provided a direct and safe route to cycle to work that was not available before and was decisive for this participant to consider cycling as a feasible travel option. Other participants reported that the new scheme may have promoted a route change in a few journeys but that the scheme was unlikely to make them cycle more often or to promote a modal shift. Participants that have increased cycling levels over the period of the study reported that a desire to be more physical active, influence from friends and peers or changes in life circumstances was more likely to have played a role.

Studies at a city level in Netherlands (Goeverden & Godefrooij 2011; Wilmink & Hartman 1987), Denmark (Troelsen et al. 2004), *US Cities* (Buehler & Pucher 2011; Krizek et al. 2008; Dill 2009) or Australia (Pucher, Garrard, et al. 2011) have detected or explained an increase in cycling levels due to cycle infrastructure provision. In the United Kingdom, the Cycling Demonstration Towns programme found that number of adults cycling in a typical week increased by 14% over a period of 3 years following improvements to infrastructure in 6 selected towns (alongside media campaigns, personalised travel planning, cycle repair and cycle training services) (DfT 2009) and the iConnect study reported a 5-12 % increase in cycling levels in three communities where a new route for cyclists was implemented (Goodman et al, 2014).

While findings from this research suggest that the Cardiff Connect2 scheme was well used by local residents one and two years after its implementation (14% and 8% of the

study sample study have crossed the new scheme in 2011 and 2012 respectively), findings did not suggest that cycling levels have increased over time. Findings presented have the advantage of being derived from detailed GPS travel; however, limitations posed by a small sample size, scale of the intervention, its location in the outskirts of town and quality of feeder routes at the time of the survey should be considered in the evaluation of these results.

8.6.3 Complexities of route choice

The analysis of route data has provided an useful insight for understanding factors influencing cyclists travel behaviour in real world setting and to learn more about how much and for what reasons cyclists with different skills and aptitudes deviate from shortest path. In general, it is argued that cyclists choose the shortest route between origin and destination as that minimizes their energy output (Aultman-Hall et al. 1997; Howard & Burns 2001; Broach et al. 2012). Results in this study have shown however that participants deviate from shortest path for at least 25% of trips and that mean deviation from shortest path is in average 0.27 miles. This suggest that cyclist's decisions are often more complex and other factors such perceived directness of the route, fast connectivity, traffic (volume, speed), slope, number of stops, exposure to weather conditions and environmental qualities of the route are likely to play a role. This result supports evidence from studies that suggest that along with trip distance, other factors such as traffic volume, cyclists' experience, ease of cycling, slope, weather conditions, interaction with motor vehicles or the presence of bicycle facilities are also likely to influence cyclists behaviour (Winters & Teschke 2010; Krizek et al. 2007; Broach et al. 2012).

Findings suggested however that some of these features were perceived differently between participants. As an example, non-cyclists often mention distance as an excuse for not cycling but 45% of those who have cycled to work (5 out of 11) lived up to 13

miles away from work. Furthermore, experienced cyclists usually did not prioritize cycling infrastructure as much as casual or non-cyclists (probably because they have developed habits and skills to negotiate the street space with cars and to cycle under such conditions). This is aligned with previous research that has suggested that importance given to continuity of infrastructure might vary according to cyclists skills (Forsyth & Krizek 2010; Heinen et al. 2010; Stinson & Bhat 2005) or that complex interactions between participant characteristics and environmental exposures and perceptions are likely to vary between individuals (Brown et al. 2007; Forsyth & Krizek 2010).

8.6.4 A wider network of connected routes

Participants in this study identified **absence of a well-connected and functional network of cycling routes in the local area** and **perceived safety** as key factors inhibiting cycling, alongside convenience and practical issues. While new routes for cyclists [52] were implemented in the case study over the period of the study (2011-2012); these new routes were limited in length, were not well connected between each other and covered only a few streets of the local road network. Therefore, the infrastructural improvements did not seem enough to change participants' perceptions about the cycling friendliness of the local environment. **This may suggest therefore that provision of a wider, well-connected and functional network of routes for cycling is essential but that a piecemeal approach is likely to have limited impacts in changing individuals' perceptions about conditions for cycling or influencing their behaviour.** This is aligned with Dutch planners' guidelines that suggest that cycling infrastructure must be coherent, direct, attractive, safe and

[52] The Pont y Werin Bridge was implemented in 2010; Arcot Street was regenerated to accommodate a contra flow lane (2011); bike lane painted on Plassey Street (2012) It should be noted that existing cycling network prior to these interventions in Penarth is almost inexistent (see Chapter 4).

comfortable, linking desired activities and minimizing travel times (Goeverden & Godefrooij 2011).

As suggested in participants' discourses, other measures could however contribute to support cycling further. These included measures that reduce traffic speed, improve intersections design or provisions of secure parking - where bicycles could be left without fear of being stolen – and facilities at work, such as showers or lockers, as an example. Findings also suggested that measures that make it harder for people to drive their cars may have a positive impact in promoting cycling (availability/ cost of car parking at workplace and traffic congestion, as an example).

8.7 Summary

This chapter set out to explore how a sample of residents in Cardiff Bay Area perceived and experience cycling as a method of travel and recreation and the extent to which the Connect2 scheme has influenced behaviour in terms of the nature of journeys and where and when these take place. Findings demonstrate that the new Connect2 scheme provided a key route for cyclists in the local area and that it was relatively well used by participants in this study (18.3% of all trips recorded). Results suggested however the new scheme may have provided a new route more popular for recreation then for utility purposes at an overall level; and it could not be found that the new intervention had triggered a modal shift away from motorised transport (except for one participant). These findings suggest therefore that wider improvements to the transport network are required for cycling to be perceived as an attractive and practical proposition for individuals of all ages and skills.

The next chapter explores the potential of walking and cycling in replacing short car trips, carbon emissions impacts of such modal shift in the panel of participants and the role of the new Connect2 scheme in promoting this change.

9 Short Car Trips and the Potential of Walking and Cycling in Contributing to a Lower Carbon Transport System

"Many households are becoming very car dependent, using the car even for very short trips without considering alternatives" (Mackett 2003)

9.1 Introduction

Policies and strategies focused on reducing overall CO_2 emissions have primarily focused on technological improvements such as vehicle efficiency or low carbon fuel systems. It is increasingly acknowledged however that changes in travel behaviour - such as reducing frequency and volume of car travel or replacing car trips by walking, cycling or public transport - should play a more crucial role in low carbon strategies (de Nazelle et al. 2010; DfTT 2011a; Blondel et al. 2011; Ogilvie et al. 2004; Brand et al. 2014; Sloman et al. 2010). Due to engine inefficiency over short trips (cold-start emissions), especially in the winter, short car trips are likely to have higher impact per mile on air pollution and CO_2 emissions than longer journeys (Beckx et al. 2013; Vagane 2007). Corresponding with national trends, nearly half of all monitored car trips in this study were shorter than 3 miles (Chapter 6). Theoretically, therefore, it would be feasible to encourage people to walk or cycle over such distances - it would take around 15-20 min to walk 1 mile and around 30 min to cycle 3 miles.

This chapter explores the potential of walking and cycling in replacing short cart trips, the impact of such modal shift in the panel of participants in this study and the role of the new Connect2 scheme in supporting this change. It aims to address sub-research question 3:

- **What is the potential for replacing short car trips by walking and cycling within a community served by Connect2 and its carbon emissions impacts?**

For this purpose, the first section of this chapter explores the patterns of short car trips in the case study site and reasons influencing such modal choice. Following this, the potential for replacement of short car trips by walking and cycling is assessed based on journey distance, journey context (trip chain) and trip purpose. Section 9.3 examines the CO_2 emissions impacts of short car trips; and in section 9.4, walking and cycling CO_2 emissions mitigation potential is assessed alongside the role of the new Connect2 scheme in supporting this shift. The chapter concludes with a synthesis of the main findings and a discussion of how walking and cycling can contribute to moving towards a lower carbon transport system and to what extent a specific high profile intervention set within the spatial context of Cardiff is effective in supporting such change.

9.2 Short car trips

This section explores the patterns of short car trips in the local area and reasons influencing such modal choice. Following on this, potential for replacement of short car trips by walking and cycling is assessed based on journeys distance, context (trip chain) and purpose.

9.2.1 Definition

While the threshold for the definition of what is a short trip varies to some extent between studies, it is commonly agreed that trips that are up to 5 miles (8 km) can be defined as short (Beckx et al. 2013; Mackett 2003)[53]. However, when considering

[53] Beckx et al. (2013) adopted 8km as the threshold value while investigating the potential of active modes in Flanders. In the UK, the Government's Department of the Environment Transport and the Regions defines short trips to be those under 5 miles/8 km (Mackett 2003).

potential of replacement of these same trips by walking and cycling, some suggest that distance people would be willing to walk or cycle vary with other factors, such as time constraints or skills, as an example. A study in the USA concluded that the limit for how far people think it is acceptable to walk is 2 miles (3.2 km) (Vojnovic 2006). In the Netherlands, (Johan de Hartog et al. 2010) defined a trip distance of 4.7 miles (7.5 km) as the threshold value for a potential substitution by bicycle, arguing that a person shifting from car to bicycle over such distance would meet the minimum recommendation for physical activity (7.5 km at 15 km/hour = 30 min). A recent study on walking and cycling in the UK (Pooley et al. 2011) was more conservative and defined 0.5 miles (800 m) and 1.5 miles (2400 m) as distances people would be willing to walk or to cycle, respectively, based on the assumption that on average this is the distance travelled by each mode of transport over an acceptable uninterrupted travel time of 10-15 min. In the UK, the National Travel Survey (DfT 2012b) reports that the average walking trip is 0.7 miles (1.1km), and the average distance cycled is 2.9 miles (4.7 km). **In this study, short trips are defined as trips less than 3 miles.**

Nearly sixty per cent (58.8%) of all trips recorded during the period of the study (n=2664) were less than 3 miles. As seen in Figure 9.1, walking was the main method of travel for trips less than 1 mile (18.3%). However, cycling trip frequency was constant over different trip lengths, suggesting that distance may not be so significant for cycling as it is for walking. Car travel dominated all journeys longer than 1 mile. 29.9% of all trips recorded were car trips less than 3 miles long.

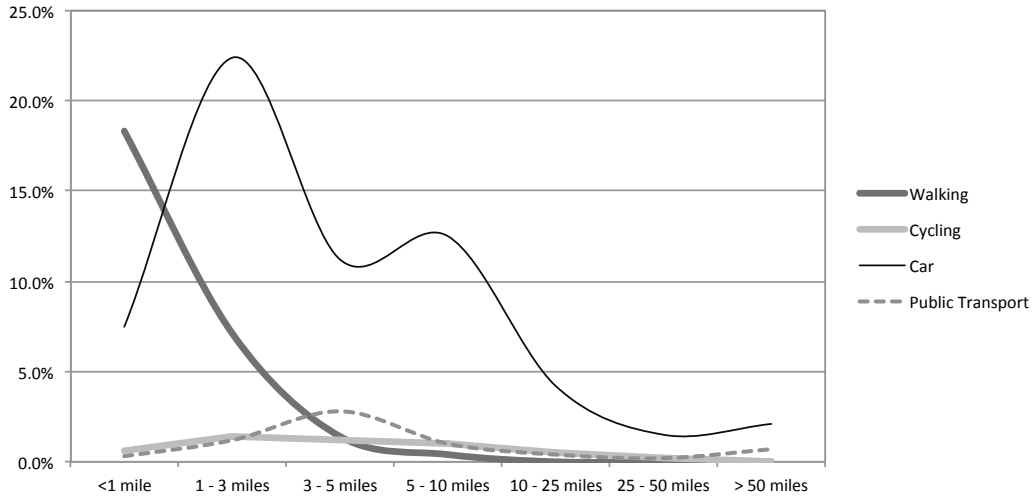


Figure 9.1 – Distribution of trips by mode and trip length (n=2664) (walking and cycling journeys at trip level)

Table 9.1 - Distribution of trips by mode and trip length (n=2664) (walking and cycling journeys at trip level)

	Walking	Cycling	Car	Public Transport	Cumulative % by trip length
<1 mile	18.3%	0.6%	7.5%	0.3%	26.7%
1 - 3 miles	7.1%	1.4%	22.4%	1.2%	58.5%
3 - 5 miles	1.4%	1.2%	11.2%	2.8%	75.4%
5 - 10 miles	0.4%	1.0%	12.5%	1.0%	90.3%
10 - 25 miles	0.0%	0.5%	4.2%	0.4%	95.4%
25 - 50 miles	0.0%	0.2%	1.5%	0.2%	97.2%
> 50 miles	0.0%	0.0%	2.1%	0.7%	100.0%

9.2.2 Short car trips: for what, where and why?

From all car trips recorded during the period of the study, nearly half (48%; n=798) were shorter than 3 miles. The main purpose of these short car trips (46.6%) was travelling to shops or personal business activities. Other popular reasons to use the car over short distances included social purposes (17.4%) or accessing leisure activities (13.9%) (Figure 9.2).

The main destinations of short car trips in the local area are represented in Figure 9.3. Those included local shops in Penarth town centre and local leisure centre and schools on south bank of river Ely; or facilities on Cardiff Bay Retail Park, Cardiff City and Mermaid Quay (north bank of river Ely). Penarth Leisure Centre was the location most frequently visited by short car trips (18 car trips recorded – largest circle in figure 9.3).

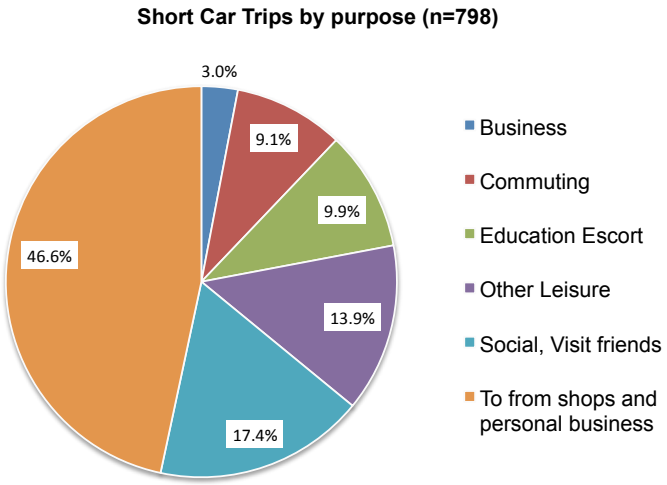


Figure 9.2 - Purpose of short car trips (n=798)

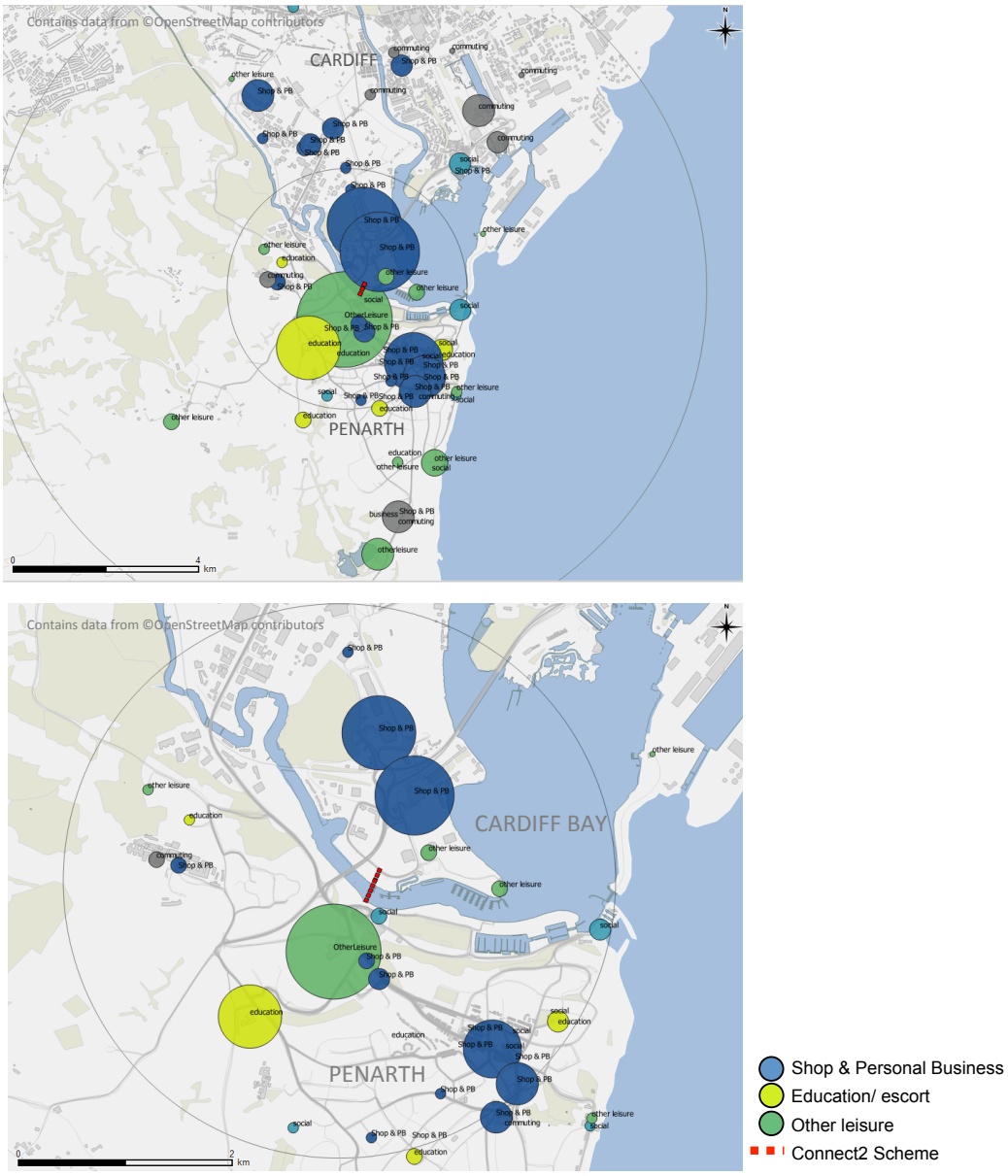


Figure 9.3 – Main destinations in the local area accessed by short car trips (<3 miles)

The main reasons pointed out by the participants to use the car over short distances were usually related with time constraints, convenience, need to carry heavy goods, giving lift to passengers, escorting children (to and from school, day care facilities or leisure activities) or lack of feasible alternatives (Box 9.1).

Box 9.1

I drop my children at school by car every day. The school is not far though and we could potentially walk but as I am on my way to work I found this way more practical and quicker (Helen, 39 years old, two children).

I cannot walk for more than 100 metres due to a long-term illness. Therefore, driving a car is the only way I have to get around and run errands (Austin, 66 years old).

I usually drive my car to go to the local supermarket, as this is more convenient for carrying groceries and shopping. However, I also drive my car even if I just need to buy a newspaper or some milk. I got used to travel around by car; and to be honest, I do not find the local environment very supportive for walking (Jocelyne, 54 years old).

I go frequently for a bike ride with my children at Cosmeston Park or Cardiff Bay Area (less than 2 miles away from home). However, as I do not feel safe to cycle with my children on the main road I usually drive over there (Paul, 38 years old, two children).

Since that I am on a career break and taking care of our children, I end up driving our car all the time. My daily routines include dropping and picking up the children from nursery, school and activities; and .run errands on the limited time left. I found it very hard not to rely on the car, even if just travelling for short journeys; it definitely makes things more manageable and practical. (Jennifer, 35 years old, three children)

For most of the participants, it was clearer the advantages of the car over walking or cycling, as it was faster, enabled them to carry passengers and goods, did not require any physical effort and was comfortable while protecting them from the surrounding environment. Examples of short car trips conducted by two participants in the study are

illustrated below. Jennifer (35 years old, three children) relied on her car to travel around on daily basis, including picking up/dropping their children at school or leisure activities or shopping (80% of trips made by Jennifer (n=60) were less than 3 miles long). Second example shows short car journeys to the local supermarket made by participant Jocelyne, who lives less than 0.6 miles away from the supermarket (if walking) but that usually prefers to drive 1.5 mile.

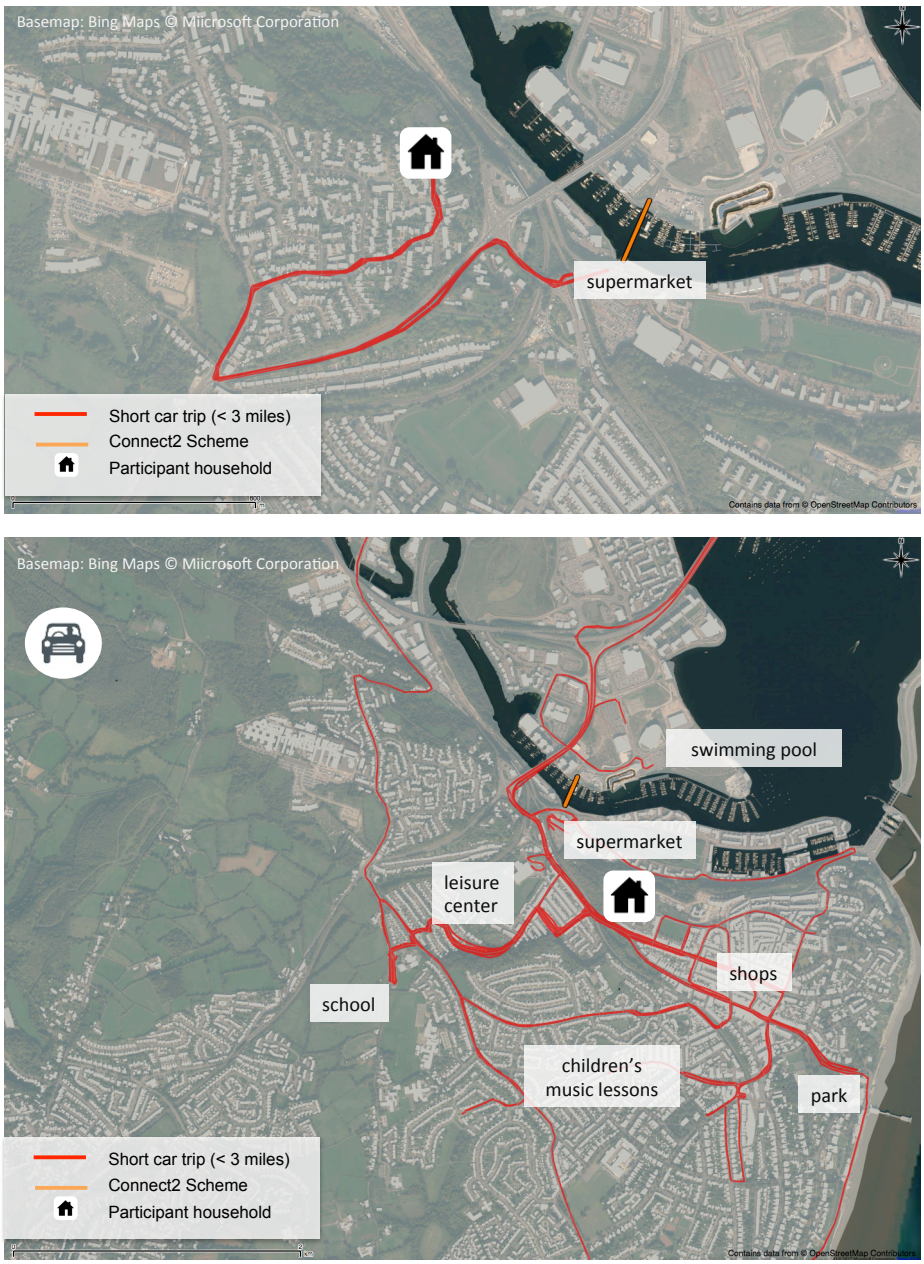


Figure 9.4 – Example of short car trips conducted in the local area while doing school run and running errands (above) or going for shopping at the local supermarket (below)

Table 9.2 summarises the main purpose of driving a car over short distances disaggregated by gender and age groups. Male participants were more likely to drive their car over short distances for shopping or personal business activities (57.1%) while women travelled by car over short distances for a wider mix of reasons. Another difference between genders was also that women were more likely to travel for escort and education over short distances (16.5%) than males (1.9%). Finally, for elderly participants (plus 65), shopping or personal business activities were the main reason to drive over short distances (48.2%).

Table 9.2 - Short car trips by purpose, gender and age (n=798)

	Gender		Age				Total
	male	**female**	**18-35**	**35-49**	**50-64**	**65+**	
Business	3.9%	2.3%	7.1%	1.9%	2.6%	0.0%	3.0%
Commuting	7.8%	10.3%	28.8%	3.0%	5.8%	0.0%	9.1%
Education Escort	1.9%	16.5%	3.5%	18.9%	8.0%	0.0%	9.9%
Other Leisure	14.1%	13.7%	5.9%	13.0%	17.2%	22.6%	13.9%
Social, Visit friends	15.2%	19.2%	18.8%	17.8%	18.2%	10.7%	17.4%
To from shops and personal business	57.1%	38.0%	35.9%	45.6%	48.2%	66.7%	46.6%
Total	100%	100%	100%	100%	100%	100%	100%
Count (n)	361	437	170	270	274	84	**798**

The absolute number of short trips recorded varied to little extent during the period of the study (406 short car trips in 2011and 392 short car trips in 2012).

9.2.3 Potential of replacement of short car trips

Nearly half (48.8 %) of all car trips recorded during the period of the study were shorter than 3 miles[54]. Theoretically, such trips could be replaced by active transport modes; however, further analysis of other trips features, such as trip purpose or context, can provide a better understanding of replacement feasibility. This section estimates the journey transfer potential of short car trips by taking into account presence of the short trip within a tour/ home-based trip chain and its purpose.

[54] The feasibility of replacing short public transport trips by walking and cycling is not considered in this evaluation. Furthermore, the replacement of short car trips by public transport is not also attempted as public transport access is conditioned by many external factors and frequently public transport is not available for most of the short trips conducted.

9.2.3.1 Short car trips: trip chains matter

Understanding the whole setting of the trip is crucial to assess the journey transfer potential as trips are usually connected with other trips and travel mode choice is frequently made based on the whole chain. As an example, if a one-mile car trip is only one element in a longer chain of several longer trips, car may be a more reasonable travel option. Tour or trip chains are defined in this study as a sequence of trips that start and finish at home (see section 5.4 - Data analysis).

Table 9.3 – Short car trips frequency by trip chain distance and number of stages (elements) within the tour

		car trip < 3 miles		**car trip > 3 miles**	
		count	*%*	*count*	*%*
Trip chain total distance	< 8 miles	550	68.9%	989	14.9%
	8 - 20 miles	152	19.0%	291	44.2%
	> 20 miles	96	12.0%	269	40.9%
Number of tour elements	1	0	0.0%	0	0.0%
	2	322	40.4%	296	45.0%
	3	198	24.8%	139	21.1%
	4	118	14.8%	74	11.2%
	5 or more	160	20.1%	149	22.6%

A total of **1010 tours** were recorded during the period of the study involving all the modes of transport. From those, **612 were car-based tours and 68.9% were shorter than 8 miles**. These tours were in average 23.3 miles long and consisted of 3 elements (Table 9.3). Trips that were not part of a home-based tour up to 8 miles (12.8km) were excluded from the analysis, as it would not be reasonable to expect a journey transfer/ modal shift for short trips that were part of longer trips.

9.2.3.2 Short car trips: purpose matters

As described in the previous section, journey distance and the complexity of the trip chain is not the only reason that explains why people decide to drive a car over short distances. Instead, trip purpose also plays an important role in mode of transport

choice. Therefore, in this study, short cart trips where participants escorting to and from a place (n=87) or shopping trips to large retail areas[55] were filtered out (n=54) alongside trips where participant was not main driver (n=83). Short car trips to local shops and personal business were however considered; this was based on the assumption that when individuals do local shopping they usually shop more frequently but in less quantity at each time and therefore carrying lighter goods is more feasible if walking or cycling.

Table 9.4 - Filters applied to assess feasibility of replacing short car trips by walking and cycling

Filters applied	Freq (count)
Short car trips (<3 miles)	798
Short car trips part of tours < 8miles	550
Short car trips as a driver	467
Short car trips (escort trips removed)	383
Short car trips (shopping to large retail areas removed)	329
	20%

Following these criteria mentioned above, results suggest that **20%** of short car trips recorded during the period of the study (n=798) could be classified as 'being replaceable by walking and cycling'.

In conclusion, this section has shown that 59% of journeys recorded during the period of the study (n=2664) were less than 3 miles and that from all the car trips recorded, 48.8% were less than 3 miles (n=798). Main reasons to drive a car over short distances usually included time constraints, convenience, need to carry heavy goods, giving lift to passengers, escorting children or lack of feasible alternatives. Based on applying relatively conservative filter criteria walking or cycling could replace around 20% of short car trips.

[55] It is assumed that participants are usually carrying heavy goods and groceries when travelling to these destinations and therefore, car travel is a more convenient alternative.

9.3 CO_2 emissions from surface transport and short car trips

The section examines the CO_2 emissions impacts of surface transport - derived from travel activity of panel of participants during period of study - and estimates the relative impact of short car trips. This provides the basis for the exploration of the role of walking and cycling in contributing to a lower carbon transport system.

9.3.1 CO_2 emissions impacts from surface transport

Based on individual distance travelled by participants (N=50) and characteristics of the trips made (mode, average speed, fuel type, engine size, age), it is estimated that participants travel activity has generated a total 2.87 tonnes of CO_2 during the period of the study. This represents an average of 28.6 Kg CO_2 *(95% CI 21.1; 37.1)* per participant per week (median 22.2 Kg CO_2)[56] , figures that are in line with the results reported for the iConnect core survey using paper and pen approach (Brand et al. 2013; Brand et al. 2014). Car travel was responsible for the largest share of CO_2 emissions accounting for 89.9% of total CO_2 emissions from surface transport, again comparable with empirical data from iConnect (ibid) and similar studies (Brand & Boardman 2008).

[56] 27.0 Kg CO_2 (95% CI: 17.93; 38.33) in 2011 and 30.24 Kg CO_2 (95% CI: 22.66; 40.20) in 2012.

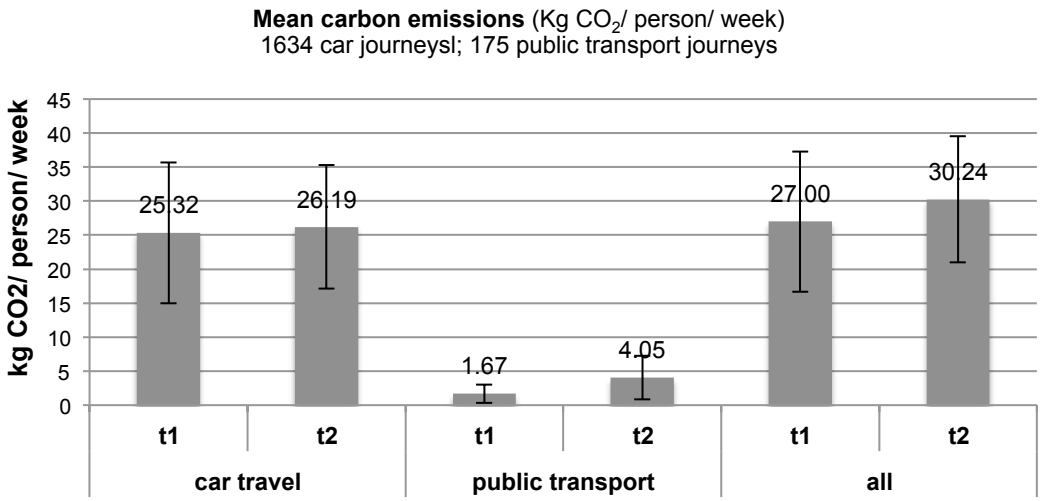


Figure 9.5 – Mean CO_2 Emissions for car travel and public transport ($KgCO_2$) by participant during the period of the study

At trip purpose level, results suggest that trips for shopping and personal business activities (large trip frequency but lowest trip distance) had a lower impact in terms of CO_2 emissions. Trips to work and for social or leisure purposes were, on the other hand, responsible for larger share of CO_2 emissions from surface transport (Table 9.5).

Table 9.5 - Average trip frequency, trip length and CO_2 emissions by trip purpose and year

	2011			2012		
	Trip frequency	*Mean trip distance*	*Mean CO2 emissions*	*Trip frequency*	*Mean trip distance*	*Mean CO2 emissions*
Travel to work and education	27.5%	6.9	4.6	29.0%	9.7	7.2
Business trips	4.9%	20.5	2.5	4.8%	26.7	4.6
Shopping and personal business	35.1%	4.0	3.3	34.4%	4.7	3.7
Social and leisure	32.6%	10.3	6.0	31.9%	10.7	7.1

In both years of the survey, distributions were skewed towards a small minority of participants producing a large share of the total. The top 20% of the sample were responsible for 54.8% of emissions while the bottom 20% for just 2.6%. Emissions from shopping and personal business trips were the most equally distributed and those from business and commuting trips the least equally (Figure 9.6).

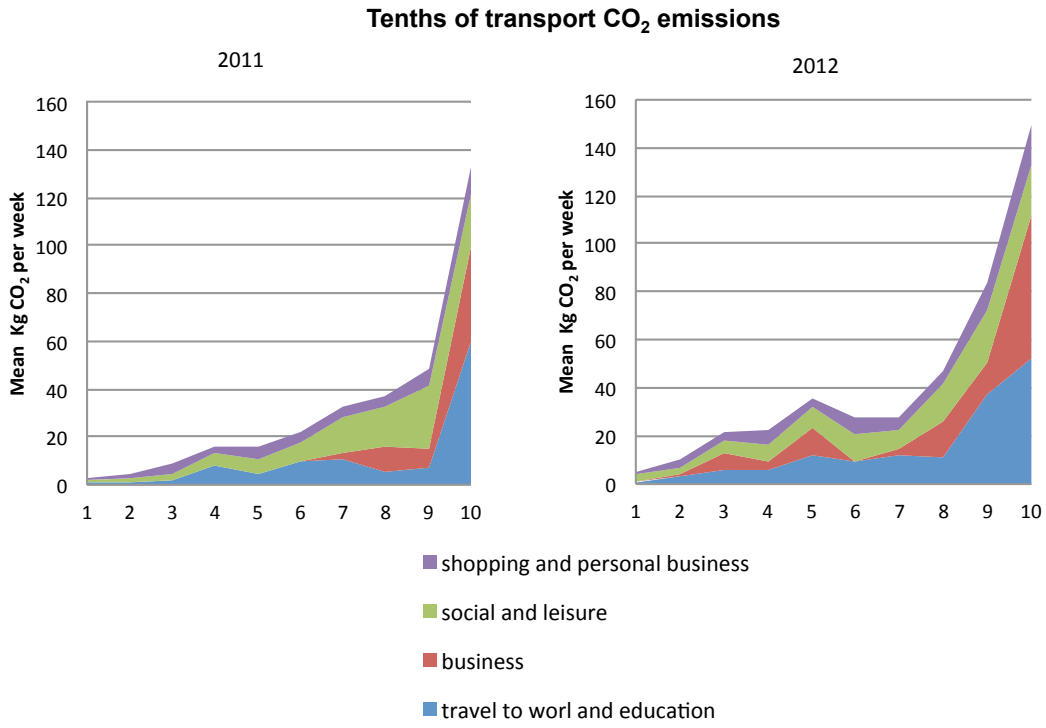


Figure 9.6 - Distribution of CO_2 emissions by travel decile subdivided by journey type. The x-axis divide study sample (N=50) into tenths (deciles) according to their total weekly travel emissions in 2011 and 2012

9.3.1.1 Changes over time

A comparison between the two years of the survey suggests that CO_2 emissions from surface transport increased by 8.9% in 2012 and a Wilcoxon signed-rank test[57] determined that there was a statistically significant median increase in carbon emissions levels (4.77 Kg CO_2) between 2011 (16.9 kg CO_2) and 2012 (21.4 kg CO_2), $z=2.13$, $p<0.05$ (0.33). This change[58] could be partially explained by an increase in distance travelled by public transport of a small group of participants in the second year of the survey (due to change in life circumstances) and year-to-year variability (Figure 9.7).

[57] This test was used, as opposed to the t-test s because the observed distribution of emissions was not normal (but rather skewed as exemplified by the large difference between mean and median values) and therefore violated the condition for the t-test to be used.

[58] Estimated mean CO_2 emissions for car travel were 26.38 Kg of CO_2 (95% CI 15.70, 37.06) in 2011 and 26.72 Kg CO_2 (95% CI 17.51, 35.94) in 2012. For public transport, mean CO_2 emissions levels increased from 1.67 kg of CO_2 (95% CI: 0.53, 3.06) in 2011 to 4.06 Kg of CO_2 (95% CI 1.35, 7.63) in 2012. Distance travelled by public transport increased by 1149 miles in 2012.

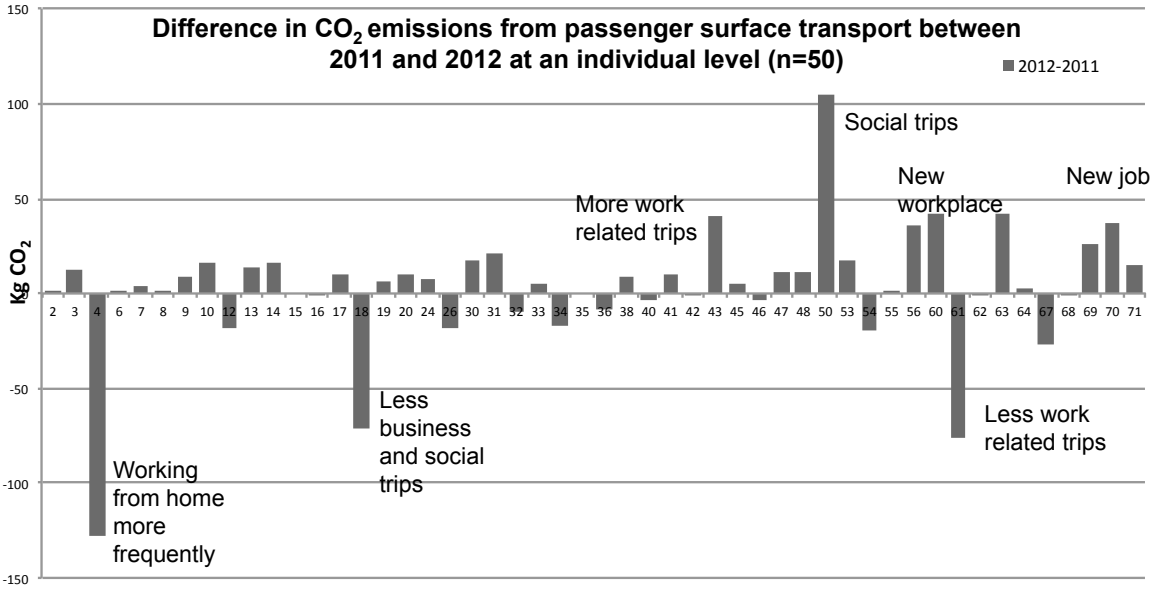
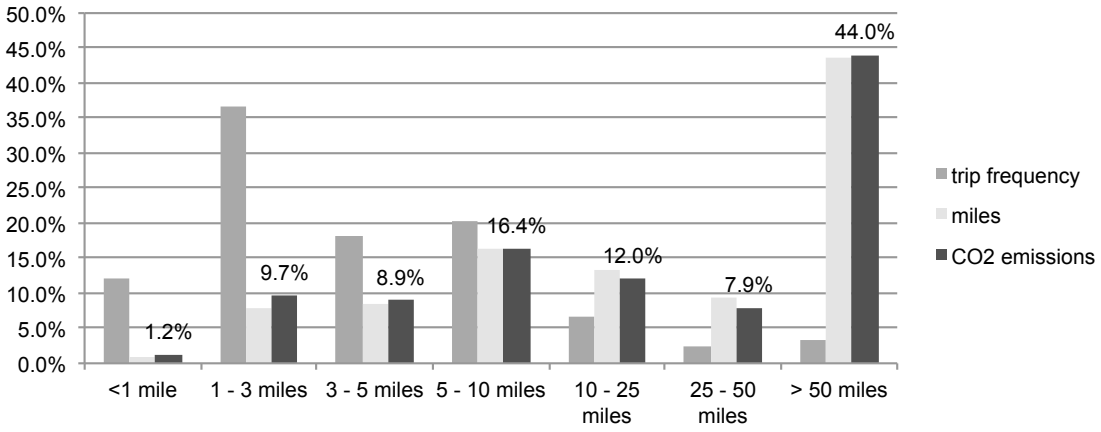


Figure 9.7 – Difference in Individual CO_2 emissions from passenger surface transport between 2011 and 2012.

Qualitative data collected did not suggest however that any of the most relevant changes detected (either drop or increase in CO_2 emissions) could be attributed to a shift away from the car motivated by change in attitudes towards walking or cycling and/ or facilitated by changes to the local transport infrastructure.

9.3.2 CO_2 emissions from short car trips

Figure 9.8 summarises the relative distribution of car trips by distance travelled and CO_2 emissions per trip length. Short car trips (less than 3 miles) were responsible for 10.9% of all CO_2 emissions from car travel. Despite the low frequency of trips longer than 50 miles, they are in fact the greatest responsible for a large share of all CO_2 emissions (44%).



	Trip frequency	Total distance (miles)	CO_2 emissions (hot+cold $KgCO_2$)	Trip freq (%)	Miles (%)	CO_2 emissions (%)
<1 mile	200	131.8	31.2	12.2%	1.0%	1.2%
1 - 3 miles	598	1071.6	248.9	36.6%	7.8%	9.7%
3 - 5 miles	299	1155.4	230.2	18.3%	8.4%	8.9%
5 - 10 miles	332	2239.4	421.4	20.3%	16.3%	16.4%
10 - 25 miles	111	1847.4	309.1	6.8%	13.4%	12.0%
25 - 50 miles	39	1297.3	202.4	2.4%	9.4%	7.9%
> 50 miles	55	6024.4	1132.4	3.4%	43.8%	44.0%
	1634	**13767.3**	**2575.5**			

Figure 9.8 - Relative distribution of trips, distance travelled and CO_2 emissions per trip length (n=1634)

Estimates made suggest that replacement of 20% of short car trips by walking or cycling (see section 9.3.2) had the potential to mitigate overall carbon emissions from surface transport by 4.1% (116.8 $KgCO_2$).

In summary, this section has shown that within the study sample, car travel was responsible for the largest share of carbon emission from personal travel (89%), that short car trips represented 10.9% of total CO_2 emissions and that a 20% modal shift would contribute to the mitigation of 4.1% of total carbon emissions. The following section estimates the extent to which walking and cycling for everyday travel (actual behaviour) and the new Connect2 scheme impacted on carbon emissions from personal travel.

9.4 Role of walking and cycling in contributing to lower carbon transport system

9.4.1 CO_2 emissions mitigated by actual behaviour – walking and cycling for everyday travel

Participants (N=11) in the study have ridden their bicycles for utility purposes in at least 104 occasions and for a total of 409.7 miles. Estimates[59] suggest that if cycling activity recorded during the period of the study (2011 and 2012) was a substitute of car driving or any other form of motorised transport, the total amount of CO_2 emissions from surfaced transport would have been **4.1% higher (+106.76 $KgCO_2$)**. In 2011, cycling for utility contributed to a saving of 89.2 kg of CO_2 savings and in 2012 for 17.2 kg CO_2 savings.

Table 9.6 – CO_2 emissions mitigation levels from actual (and potential) walking and cycling behaviour

CO_2 emissions mitigated from actual travel behaviour ($KgCO_2$)		(%)
Utility walking	20.7	0.8%
Utility cycling	106.8	4.1%
Walking and cycling for everyday travel	127.5	**4.9%**
Walking and cycling journeys for everyday travel made over Connect2 Scheme	12.3	**0.5%**
CO_2 emissions mitigation - potential ($KgCO_2$)		(%)
If 20% of short car trips replaced by walking and cycling	116.8	4.1%
If short car trips running parallel to the Connect2 Scheme replaced by walking or cy	32.9	1.2%

Walking for everyday travel, i.e., walking to the shops, personal business and social activities, or just commuting to work represented the main purpose of 531 of the walking trips recorded (walking stages not considered here). If all utility trips performed by walking during the period of the study (2011 and 2012) were replaced by car travel,

[59] CO_2 emissions were estimated by assuming an average speed of 40 km/h, shortest car route trip distance between original trip start and destination and participants' car details (engine size, fuel type, vehicle age). Estimates also take into account cold and hot emissions.

the total amount of CO_2 emissions from surfaced transport would have been **0.8% higher (+20.86 KgCO_2).** In 2011, walking utility trips (n=279) may have mitigated 11.5 kg of CO_2 among the study panel; and in 2012 (n=250), CO_2 savings from utility walking may have prevented the emission of 9.3 *kg CO_2*.

Overall calculations suggest therefore that walking and cycling for everyday travel contributed to a mitigation of **4.9% of total CO_2** emissions from surface transport.

9.4.2 CO_2 impacts of Connect2 scheme - actual

The Connect2 Bridge provided a route for both utility cycling (n=17) and walking (n=20) for everyday travel journeys. If these trips were a substitute for car driving or other form of motorised transport, journeys recorded over the scheme may have contributed to the mitigation a total of 12.3 Kg CO_2 (0.5% of total CO_2 emissions recorded). This figure can be considered however small.

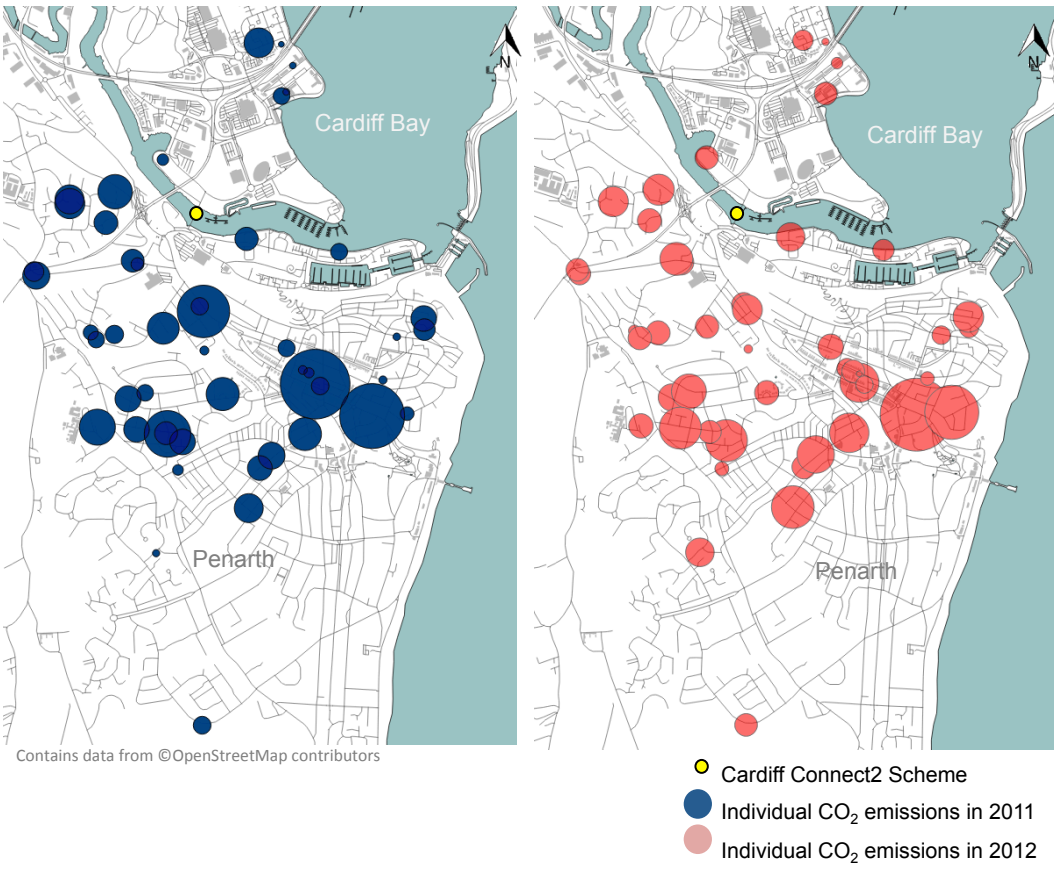


Figure 9.9 – Geocoded carbon emissions profiles from surface transport (N=50)

At a participant level, no significant or consistent variation between proximity to the infrastructure and higher/ lower levels of CO_2 emissions could be attributed (Figure 9.9). An ANOVA test determined that there was no significant difference between the participants living less than 0,5 mile, 0.5 mile – 1mile or more than 1 mile away from the Connect2 scheme (p = .754) and their CO_2 emissions profile.

9.4.3 CO_2 impacts of Connect2 scheme - potential

Potential CO_2 emissions impacts of the Connect2 scheme were estimated based on the following assumptions:

- The new Connect2 Bridge connected Penarth (south bank of river Ely) to Cardiff Bay and Cardiff City (north bank river Ely). The Connect2 scheme provided an optimal route for pedestrians and cyclists if car journeys that started in south bank of river Ely and finished on north bank of river Ely (or vice versa) were replaced by walking and cycling (figure 9.10).
- Short car trips along the Spurt or Penarth Road are within this category (figure 9.10.)
- Trips that were part of a home-based tour up to 8 miles, trips whereas participant was not the driver (n=83) or that involved escorting to and from a place (n=87), and trips to large retail stores were not considered.

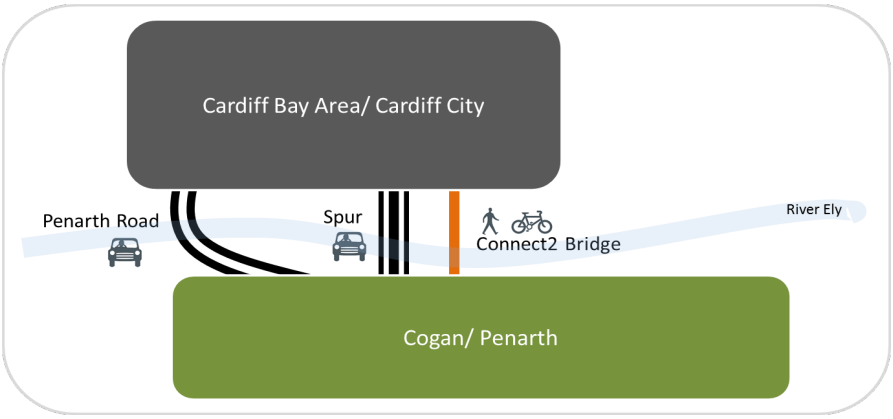


Figure 9.10 - Rational for Connect2 scheme potential as main route for pedestrians and cyclists replacing short car journeys between Penarth and Cardiff

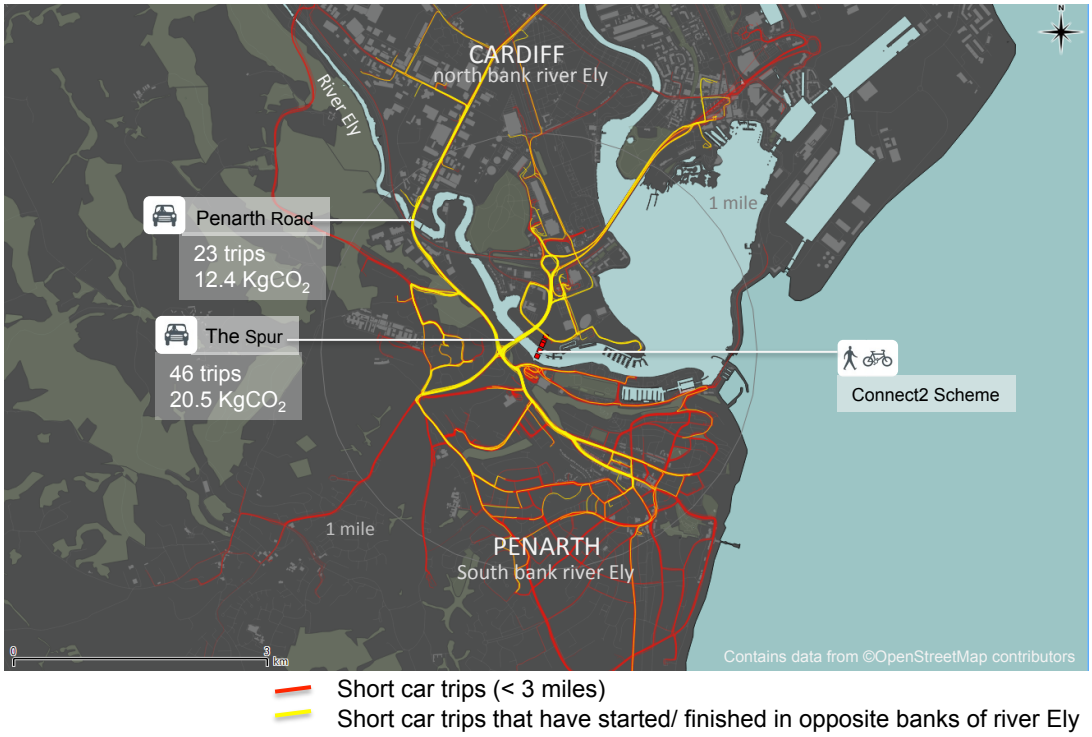


Figure 9.11 - Short car journeys (<3 miles) conducted in the local area colour coded by trip origin and destination

A total of **69** short car trips (out of 329 potentially replaceable by walking and cycling – section 9.2.3) are within assumptions made, as they have crossed the river Ely through the Spur or Penarth Road, were less than 3 miles long and were not part of tours longer than 8 miles. And for these trips, the new Connect2 scheme would have been provided an optimal route. Therefore, it is estimated that within the study sample, the new Connect2 scheme could have supported a further mitigation of 32.9 Kg CO_2 (1.2% from total CO_2 emissions from surface transport).

9.5 Walking and cycling supporting public transport use

GPS records shown that during the period of the study participants have travelled 2547 miles by public transport (182 journeys). This sub section provides a short description of how walking and cycling have also supported public transport use in the local area, and therefore, contributed (indirectly) to reduce need to travel by car. The potential for public transport use in the local area is not examined at this out of the scope of this study.

A total of 239 walking stages were recorded as part of a multimodal journey involving public transport use. More than two thirds of these walking stages (70.7%) took place while commuting to work, usually from Cardiff to Penarth (Figure 9.12). It can be observed in this same figure that the new Connect2 scheme facilitated at least two of these multimodal journeys.

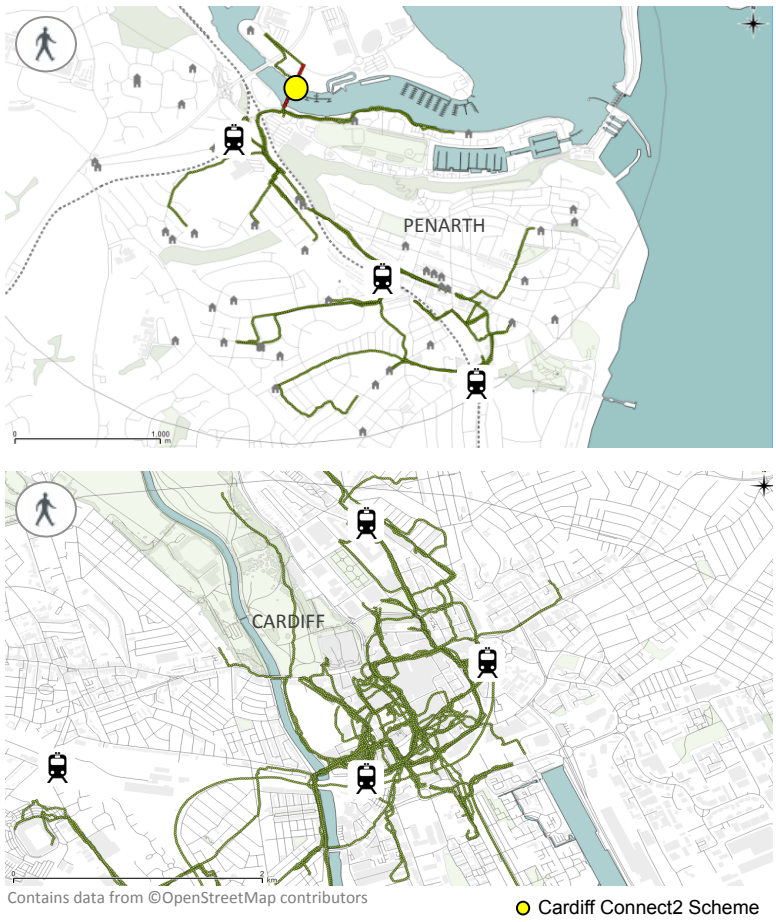


Figure 9.12 – Example of walking journeys made in the local area to access public transport services

Cycling was also a method of travel used by one participant in order to complement his commuting journey to work by public transport. In this case, travelling by bicycle as a leg of the journey had the advantage of increasing the catchment area of the train station far beyond walking range, as exemplified by Paul's commuting pattern (Figure 9.13).



route	Distance	duration
Home – Train station	1.3	5 min
Train journey	16	35 min
Train Station - workplace	2	10 min

Figure 9.13 - Example of a multimodal bicycle and train commuting trip

> Paul's typical commuting journey involves cycling from Penarth to Eastbrook train station (1.3 miles), travelling by train for 35 min, and them cycling from Llantwit Major Train Station to his workplace (2 miles away). Eastbrook train station is not the closest to Paul's home; however, by catching the train at this station, Paul can get a fast train. The alternative (if walking) would involve changing trains in Cogan Train Station and that would add at least 20 minutes to his commuting journey.

According to participants, public transport use was influenced by service provision (including regular frequency[60] and cost,), proximity to bus or train stops or restrictions to car travel/ parking. As an example, participants claimed that they have travelled frequently by train to Cardiff (either for shopping or commuting), as the service was regular, journey duration was short (20 minutes by train compared to up to 45minutes

[60] Thornton et al. (2011) reported that at least every 15 minutes bus services are associated with regular bus travel.

by car during rush hour) and affordable (if compared to car parking rates in Central Cardiff). Older participants travelled more frequently by bus over short journeys and were usually motivated by convenience and cost (holding a free bus pass). Those participants that lived further away from train stations were less likely to have travelled frequently by public transport.

As mentioned above, trip distance between participants home/work and bus/train station was likely to influence individuals to use public transport. In particular for cycling, participants perceived presence of cycling infrastructure as crucial; these included availability of cycle routes between desired destination, parking at train stations or opportunity to carry bicycles on public transport, as an example. The Connect2 scheme has improved access to Cogan train station for residents in Cardiff Bay and on-site observations suggested that train commuters frequently crossed the new scheme, in particular during peak hours. GPS records have also shown that at least two walking journeys were recorded over the new Connect2 scheme in order to access the local train station. No statistical relationship could be however established on how access and egress distance affected public transport, walking and cycling frequency.

9.6 Discussion of main findings

This chapter explored the potential of walking and cycling in replacing short journeys by car among a community served by a Connect2 scheme. The main findings are discussed in this section including estimated replacement potential, CO_2 emissions impacts of promoting such shift and Connect2 scheme contribution.

9.6.1 Understanding short car trips and potential of replacement by walking and cycling

Results shown that 48.8% of all trips recorded during the period of the study were less than 3 miles. This is somewhat above national figures – in the UK, 57% of trips less than 5 miles are made by car (67.1% in this study) (DT 2014b). This can be explained by national statistics under-recording short trips, mainly by walking and off-road cycling (ibid). The main reasons given by participants to drive over short distances were usually related with habits, time constraints, convenience, need to carry goods, need to escort people (frequently children) or lack of alternatives. Overall, most of these reasons were aligned with findings from previous studies too (Mackett 2000; Mackett 2003; Vagane 2007). The potential of replacing short car trips by walking or cycling was assessed using trip distance, trip purpose and trip context (i.e., the presence of the short trip within a tour/ home-based trip chain) as main criteria. Rather than a trip based approach, where all trips are treated equally, a chain trip approach has the potential to provide a more accurate assessment (Davidson et al. 2007; Vagane 2007; Beckx et al. 2013). The spatial detail contained in the original travel data set was crucial to perform this assessment.

Results obtained suggested that 20.3% of short cart trips recorded during the period of the study could be classified as being 'replaceable by walking and cycling. One of the few studies up to date that investigated the potential of active transportation, based on GPS data, suggested that 9.5% of car monitored trips could be replaced by walking and cycling (Beckx et al. 2013). This study was conducted in Belgium, had larger number of vehicle trips (n=20,634 vehicle trips) but a lower number of participants (N=20) and assessment methodology was somewhat different, as an example, trips to large retail shops or trips to local shops were not treated differently (as performed in this study). Other studies reported different figures too. An older study in the UK estimated that 31% of trips could be transferred from car to walking and 78% could be

shifted to some alternative mode (Mackett 2003); this study was based on a data from National Travel Survey but applied a less detailed approach to estimate replacement potential. Another study for the UK Sustainable Travel Demonstration Towns found that only subjective reasons prevented one third of all trips made by car to be made by walking, cycling or public transport (Sloman et al. 2010). Despite figures in these studies are slightly different, they suggest a similar potential and are useful in contributing to a better understanding of the role that walking and cycling can have in everyday travel.

It is acknowledged however that several factors and conditions are required to support this modal shift. First of all, physical environment needs to be supportive and inviting for pedestrians and cyclists of all ages and skills. As described in Chapter 7 and Chapter 8, a wide network of functional, safe and well connected routes for walking and cycling needs to be in place alongside policies that support mix of uses and restrictions to car use. Cultural and individual factors are also likely to play a role as individuals' attitudes and preferences, including perceived convenience and flexibility, value of time and cost or environmental beliefs also influence modal choice and are likely to impact on decision to drive a car over short distances choice (Vagane 2007; Vandenbulcke et al. 2011; Vredin Johansson et al. 2006; Beckx et al. 2013). While shopping trips and escorting passengers are responsible for the largest share of short trips in this study, it is here argued that such activities may not always exclude other means of transport, as frequently perceived. As an example, the use of shopping trolleys, pushchairs, bike panniers, bicycle racks, bicycle children seats, cargo bicycles, bike trailers or electric bicycles could facilitate some of these journeys if walking or cycling for such purposes. As an example, in Copenhagen, Denmark, 25% of families with two or more children have a cargo bike and 50% of all Copenhageners with a cargo bike use it to transport

children (TEA TD 2011). E-bikes[61], on the other hand, can enable people of different ages and skills to comfortably cycle over longer distances, in hilly terrains or when carrying heavy loads.

9.6.2 CO_2 emissions impacts from surface transport and short car trips

Results suggest that participants in this study have generated an average of **28.6 Kg CO_2** per participant per week from surface passenger transport during the period of the study. This represents an estimated **1.35 tCO_2** for participant per year. Car travel was responsible for the largest share of CO_2 emissions accounting for **89.9%** of total CO_2 emissions from surface transport.

The figures obtained in this study are below UK government figures that suggest **2.2** tCO_2 per capita road transport (once 30% of emissions from road freight transport on Great Britain are discounted) (DfT 2010b) or **1.6** tCO_2 for participant per year figures obtained in previous studies (Brand et al. 2013). This difference between figures may be partially explained by the different approach employed to record travel data (GPS based travel survey vs. self-reported surveys). However, it should be also noted that in both years of the survey, mean figures were substantially higher than the derived median[62]. This suggests a skewed distribution of emissions, whereas a small proportion of individuals were responsible for most of the emissions. A comparison between years has revealed that CO_2 emissions from surface transport have increased by 8.9% in the second year of the survey. This result is against the secular trend of decrease in CO_2 emissions from surface transport and may be explained by small sample size of this study and influence of outliers. Nevertheless, results supported the

[61] Emissions from e-bikes are found to be in the same range as ordinary bicycles, despite their electricity needs, because they allow for (56%) longer daily commutes and can substitute for cars on 39% of journeys (Blondel et al. 2011).

[62] Mean carbon emissions from all motorised surface passenger travel were 27.0 Kg CO_2 (median 16.9 kg CO_2) per person per week in 2011 and 30.24 Kg CO_2 per week (median 21.4 kg CO_2) in 2012.

evidence for the inequalities in travel and related carbon emissions, as **the top 20% of the sample were responsible for 54.8% of emissions while the bottom 20% for just 2.6%.** This is aligned with previous results from Brand & Boardman (2008).

While car travel accounted for 89.9% of total CO_2 emissions from surface transport, results suggested that short car trips (48.8% of all car trips recorded) were responsible for just 10.9% of all CO_2 emissions from car travel. Following estimated potential replacement figure of 20% of short car trips being replaceable by walking and cycling, findings suggested such modal shift would contribute to a mitigation of **4,1% of total CO_2 emissions** from surface passenger transport. This result supports argument that walking and cycling could play a role in contributing to a lower carbon transport system in urban context.

9.6.3 CO_2 emissions mitigation potential from walking and cycling

Results shown that if **walking and cycling trips recorded for everyday travel** were a substitute of car driving or any other form of motorised transport, the total amount of CO_2 emissions from surfaced transport would have been **4.9% higher.** Cycling contributed to the largest share of savings: **4.1%.** It should be taken into account however that that cycling represented 5% modal share in this study, which is clearly above national average of 1.5%. This figure is somewhat aligned reports that suggest that an increase in cycling share in Britain to levels closer to northern Europe could reduce total emissions by source in UK by around 6% (UK Energy Research Centre 2009). More importantly, this figure support the argument that promoting cycling for everyday travel can play a role also in terms of mitigation of CO_2 emissions mitigation from surface transport.

9.6.4 Impacts of a Connect2 scheme in promoting a modal shift away from car travel and CO_2 emissions mitigation potential

Results shown that if walking and cycling trips conducted over the new Connect2 scheme were a substitute of car travel, the new route may have contributed to the mitigation of **0.5% of CO_2 emissions from surface transport.** A further potential 1.2% of total CO_2 emissions mitigation potential was estimated, if walking or cycling substituted short car trips running parallel to the scheme. Whether the real and projected impact of the new scheme may be considered minimal in terms of CO_2 emissions, it should be considered the limitations posed by the location of the scheme, the scale of the intervention and the poor quality of the feeder routes. Furthermore, it should be noted that the scheme was likely to have a greater higher impact for recreational purposes rather than for utility travel (Chapter 7 and Chapter 8) but that CO_2 emissions from recreational activities are not considered in the estimations provided.

Findings could not suggest however that relevant changes in travel activity, and therefore CO_2 emissions, during the period of the study, could be attributed to a shift away from the car motivated by an increase in walking and cycling and changes to local infrastructure. This is aligned with results from the wider iConnect2 Study that also suggest that extra walking and cycling trips generated by Connect2 did not usually represent a modal shift away from motorised travel (Goodman et al. 2014) or that these effects translated into sizeable CO_2 effects (Brand et al. 2014). Findings did not suggest either that living near the infrastructure or using it predicted changes in CO_2 emissions from motorised travel which is also aligned with results from (Brand et al. 2014). While studies that have measured the effects of improving connectivity for

cyclists (and pedestrians) reported mixing findings with regards to impact on modal share[63] , they have not considered changes in CO_2 emissions levels.

9.7 Summary

This chapter set out to investigate the potential of walking and cycling in replacing short car journeys, the CO_2 emissions impacts of such modal shift and the role of a Connect2 scheme in supporting such change. Findings have shown that nearly half of all car trips recorded were shorter than 3 miles but that at least 20% of these short car trips could be classified as being replaceable by walking and cycling. Promoting such modal shift could potentially mitigate 4.1% of total CO_2 emissions from surface passenger transport recorded among the study sample. Results obtained have also shown that walking and cycling for everyday travel in the case study site has potentially mitigated 4.9% of total CO_2 emissions from surface transport, if walking or cycling journeys recorded would have been replaced by car travel. Overall, these findings highlight the unexploited potential in targeting short car trips that could potentially be replaced by walking and cycling; and that promoting such shift could play a significant contribution towards a lower carbon transport system in urban areas. Findings suggested however that the provision of a key route for pedestrians and cyclists in the local area, implemented through the Connect2 Programme, had a minimal impact in terms of CO_2 emissions mitigation from surface transport.

[63] As an example, following extensive provision of cycle infrastructure in Delft (Netherlands) Wilmink & Hartman (1987) reported a 3% increase in the cycling mode share of all trips after three years with no change in the mode shares for walking or for car. But in Detmold and Rosenheim, households reported a negative modal shift of 5% of all trips (Detmold) and zero modal shift (Rosenheim) after five years (Ogilvie et al. 2004).

10 Synthesis and Conclusions: The potential and challenges of improving infrastructure for walking and cycling and evaluating its impacts

10.1 Introduction

This final chapter draws together the main findings of this thesis that aimed to understand better the links between implementation of physical infrastructure targeted at improving connectivity for walking and cycling at local community level and the influence on personal travel behaviour and associated carbon emissions. This chapter revisits the basis of this thesis and the potential for walking and cycling to replace short journeys in urban areas and the extent to which initiatives targeted at increasing walking and cycling in the UK are effective. Following this, the chapter provides a synthesis of the main findings related to each research question and discusses its implications for policy and practice. Methodological strengths and limitations of this study are examined in the final section, alongside directions for future research.

10.2 Promoting walking and cycling in the UK, the Connect2 Programme and understanding its impacts at detailed spatial and temporal levels

Chapter 2 of this thesis started by outlining evidence on the potential of walking and cycling in enhancing mobility and environment quality in urban areas at the same time as tackling traffic congestion or other harmful impacts of car travel. The chapter then focused on how government and institutions have responded to this need of increasing walking, in particular, cycling levels in the UK. Despite successive policies and initiatives delivered more prominently over the last two decades, current figures on walking and cycling modal share suggest limited success in bringing about a significant increase in walking or cycling at a national level. The dominance of the car in British

society and economy, and a gap between policy rhetoric, and resources required to establish walking and cycling as the main modes of travel in urban areas were identified as a key part of the problem. However, the low levels of walking and cycling also suggested that there is still limited understanding on how some of the initiatives being undertaken are effective in influencing individuals complex everyday travel behaviour. Following on this, the chapter introduced the Connect2 programme, one of the largest and most recent infrastructural projects for promoting walking and cycling in the UK. This project, delivered by the sustainable transport charity Sustrans between 2008 and 2013, aimed to transform everyday travel in 84 local communities by creating new bridges and crossings that would help to overcome barriers for pedestrians and cyclist, such as busy roads, rivers and railways. Sustrans' projections and findings from the iConnect study suggested positive impacts of the programme in improving accessibility for walking and cycling and promoting an increase in physical activity levels. However, at the micro level, it was identified a lack of evidence on how and to what extent the implementation of the Connect2 schemes was likely to influence individuals everyday travel behaviour.

Chapter 3 presented the literature review that was undertaken to understand the complex web of environmental factors influencing walking and cycling behaviour and the extent to which the provision of facilities for pedestrians and cyclists is likely to influence travel behaviour. However, there was little evidence from intervention studies that demonstrated that changes to the built environment through infrastructure provision lead to an effective change in travel behaviour or changes in carbon emissions from personal travel. Some of the limitations of existing evidence are derived from the challenges of measuring walking and cycling behaviour; therefore, the second part of Chapter 3 focused on the limitations of primary sources of travel data in the UK and approaches employed for measuring travel behaviour, including the potential of GPS technology.

Having identified gaps in the literature, the aim of this thesis was specified: to investigate whether and how provision of physical infrastructure for pedestrians and cyclists, namely the Connect2 programme, could effectively influence travel behaviour at the individual level and impact on carbon emissions from personal travel

Chapter 4 discussed the research design and data collection methods adopted for meeting the objectives of this study, defined as the in-depth longitudinal study of a panel of residents living around a Connect2 scheme. By focusing on a single case study location where such intervention has been implemented and using a GPS-based mixed method approach to measure travel behaviour, this study was able to identify at the micro level detail the extent to which the provision of new infrastructure for pedestrians and cyclists influenced individuals travel behaviour in terms of the nature of journeys and where and when these take place.

10.3 Key findings and contributions to the literature

Findings of this study provided detailed evidence on how and to what extent a major walking and cycling intervention, the Connect2 Cardiff project, has influenced everyday travel within a local community. The results provided new insights into the complexities of walking behaviour and contributed to a better understanding of barriers and enablers of cycling for everyday travel or recreation; additionally, some of the results obtained corroborated findings from other studies. Importantly, this study provided detailed methodology and evidence on how projects that provide new infrastructure for pedestrians and cyclists are effective in influencing individual's everyday travel decisions, why and in what circumstances. This section summarises the main findings from the empirical research with a closer look at individual findings related to each of the four research questions postulated and main contributions to the literature.

How and to what extent is local travel behaviour influenced in terms of mode, purpose and spatial-temporal characteristics, among a community

served by a Sustrans 'showcase' Connect2 scheme and what is the overall impact on personal travel related carbon emissions?

The overall key finding of this research is that the new Connect2 scheme provided a well-used route for pedestrians and cyclists in the local area. However, the scheme was likely to have encouraged more engagement in recreational activities rather than in everyday travel. While the scheme was likely to promote displacement of walking and cycling trips and generated some new ones, findings could not establish that the scheme itself was a main reason for a significant change in travel behaviour and carbon emissions from personal travel among the study sample.

Results revealed that nearly one third of the participants crossed the new route during the period of the study (36% in 2011, 26% in 2012) but that more participants have crossed the new bridge for recreational purposes (24% in 2011; 20% in 2012) than as part of everyday travel journeys (18% in 2011 and 12% in 2012). This finding is comparable with results from the wider iConnect study (Goodman et al. 2013; Goodman et al. 2014), as summarised in table 10.1.

Findings did not suggest however that the provision of Connect2 was a key reason for a modal shift away from motorised travel (except for one participant). Most participants that have used the new Connect2 scheme were already frequent walkers or active cyclists and the new starters acknowledged other reasons such as influence of peers or increasing health awareness as the main reason influencing decision to walk or cycle. Connect2 was likely, however, to have influenced some participants to re-route some of their journeys.

Table 10.1 –Connect2 scheme level of use at participant and journey level

Connect2 Scheme - Level of use: participant level				
	This study		*iConnect Study*	
	N=50		*N=1776*	*N=1449*
	T1	**T2**	**T1**	**T2**
Walking for recreation	16%	14%	27%	33%
Cycling for recreation	10%	10%	12%	15%
Recreation	24%	20%		
Walking for transport	6%	6%	11%	12%
Cycling for transport	8%	2%	5%	7%
Utility	18%	12%		
Walking	24%	20%		
Cycling	14%	8%		

Connect2 Scheme - Level of use: journey frequency level *(n=1113*)*		
	T1	**T2**
	count / freq (%)	*count / freq (%)*
Walking for recreation	12.5% *(14)*	16.9% (15)
Cycling for recreation	30.8% (4)	20.8% (5)
Walking for transport	3.1% (11)	2.0% (8)
Cycling for transport	17.8% (13)	12.5% (4)

**n=770 utility walking journeys; n= 201 recreational walking journeys; n=105 utility cycling journeys; n=37 recreational cycling journeys*

Chapter 6 has evaluated participants overall travel behaviour over time and found that changes in life circumstances (such as getting a new job further away from home, starting to work from home, becoming retired, family responsibilities, etc.) were in fact more likely to determine a significant change in travel behaviour over time (modal replacement and increase/decrease in distance travelled). A marginal significant increase was detected in public transport frequency ($t_{bus\ (49)} = 2.28$, $p<0.05$) over the period of the study motivated by some of these factors; but no statistical significant increase in walking or cycling levels could be detected over similar period of time.

Chapter 9 investigated the potential of walking and cycling in replacing short car journeys at the case study site, the CO_2 emissions impacts of such modal shift and the role of a Connect2 scheme in supporting such change. Findings demonstrated that nearly half of the car trips recorded during the period of the study were shorter than 3 miles and that at least 20% could be classified as being replaceable by walking and

cycling. While estimates suggest that walking and cycling for everyday travel mitigated 4.9% of total carbon emissions from study participants' travel, the role of the new Connect2 scheme in supporting these journeys was residual (0.5% CO_2 emissions from total surface transport).

Overall, the findings of this study confirm that in the context of an environment that is still supportive of car travel the provision of a key route for pedestrians and cyclists (at the time of research) may be insufficient to drive a significant change in travel behaviour. This is particularly pertinent given that the selected participants for this study were those who indicated at least moderate intention to walk and cycle more and suggests the picture may be more negative across the wider population who stipulated no intention to increase their level of walking and cycling. This may suggest that wider infrastructural improvements that make transport networks safe, accessible and functional are crucial but that also changes to land use, restraints to car travel and parking availability, and social/individual marketing campaigns are required, as an integrated package, to give individuals the confidence, convenience and practicality required to adopt walking or cycling as a feasible mode of transport in urban areas.

The following sub sections describe with further detail how the findings in the study answered each of the formulated sub-research questions.

10.3.1 How does a Connect2 scheme influence walking behaviour in terms of the nature of journeys and where these take place?

Findings demonstrated that 5% of all walking journeys recorded during the period of the study (n=971) took place over the new Connect2 scheme. Records and observations indicated that the new scheme was used at different periods of the day and for different purposes and a similar level of use after 12 months suggest that these

findings may not simply reflect a novelty effect[64]. Results suggested however that share of recreational walking journeys recorded over the new Connect2 scheme (12.5% in 2011 and 16.9% in 2012) was higher than those recorded for utility purpose (3.1% in 2011; 2.2% in 2012). This results at trip level (and derived from actual travel behaviour measured using GPS technology) supplement and corroborate findings from the wider iConnect study, that found that more respondents have walked for recreation purposes over the new Connect2 Schemes rather than for utility purposes (Goodman et al. 2013).

Despite walking has been dealt as a rather simplified concept in most urban planning and design research (Saelens et al. 2003; Lee & Moudon 2006; Choi 2013), the collection of individual GPS data in a real world setting has provided an opportunity to investigate in more detail how different attributes of the environment are prioritized according to main activities being conducted and how new infrastructure is likely to influence some of the journeys. In this study, **utility walking** journeys were usually short (0.5-0.7 miles average), followed most direct routes between origin and destination, were conducted in built up areas with a good mix and density of services and were frequently associated to public transport use (nearly one quarter of the cases). **Recreational walking journeys,** on the other hand, were usually longer (1.6 miles average), did not follow shortest path between origin and destination, took usually place in areas with higher environmental quality and had frequently a loop pattern. The location of the new Connect2 scheme in the outskirts of town alongside the fact that it has improved access to a reduced number of services and facilities in close range may, therefore, explain its limited impact on utility purposes. On the other hand, as the new Connect2 scheme completed a very popular and pleasant circular route around Cardiff Bay- a sought after destination for leisure activities in the local

[64] A total of 25 and 23 trips were recorded over the Connect2 scheme in 2011 and 2012, respectively, and no statistical significant difference could be detected between years.

area - may offer an explanation for a greater success of the scheme in attracting recreational activities. It should be noted that walking journeys recorded over the new infrastructure were usually longer than trips recorded over other routes[66]. Additionally, results have also suggested that recreational walks were frequently associated with car travel (39.4% of all recreational walking journeys) and that the use of the Connect2 scheme may have triggered a few trips by car by participants living further away from the new intervention, as first observed by Goodman et al (2012).

A small group of participants (N=3) acknowledged that the presence of the new Connect2 scheme may have influenced them to walk more frequently over the period of the study (two for recreation and one for utility purposes) but others suggested that the impact of the scheme was more likely to be on route displacement of some journeys. For those participants that have change their travel behaviour towards more walking during the period of the study, health awareness, influence from peer**s** or desire to be more active were more frequently a key motivation. More generally, participants felt that lack of time, practicality, effort, comfort, perceived safety and convenience of car travel were constraints to walk more frequently in the case study site.

In conclusion, findings suggested that despite the Connect2 Scheme provided local residents with a new and well-used route for recreation, the new intervention may not have provided most residents with practical new routes to the particular destinations they needed to reach. While literature suggests that density of links and connections in a network significantly supports walking levels (Forsyth & Krizek 2010); in this study,

[66] Recreational trips over the Connect2 scheme were in average 2.8 miles long (1.6 miles in the study at an overall level) and utility trips were 1.8 miles long (0.7 miles in the study, respectively).

findings did not suggest that provision of a safe and pleasant route for walking may have been sufficient to increase walking levels, especially for utility purposes.

10.3.2 How does Connect2 influence cycling behaviour among cyclists and non-cyclists, including the nature of their journeys and route choice decisions?

Findings demonstrated that nearly one fifth of all the cycling journeys recorded during the period study (18.3%) took place over the new Connect2 scheme. Absolute figures indicated that a higher number of journeys recorded over the new scheme were part of everyday travel (17 utility trips compared to 9 recreational journeys) but relative figures suggest that the Connect2 scheme may have been more relevant for recreational (24.3%) rather than utility purposes (16.2%).

Spatial analysis suggested the significance of the Connect2 scheme in the local area as nearly two thirds of all **utility cycling trips** (n=65) were recorded between Penarth and Cardiff (where new scheme is located) and 26% of those have crossed the new Connect2 scheme. Reasons given by participants to use the new route included the fact that it provided a convenient access to Cardiff or local facilities, it was well lit at night, open 24 hours a day or less exposed to weather elements (wind). Route analysis suggested however that participants were also likely to cycling along two parallel routes to the Connect2 Scheme. These routes were usually perceived as more direct and therefore providing a faster journey (Penarth Road route – 24.6%); or as safer, pleasant and with superior environmental quality (Barrage Route – 46.2%). For **recreational cycling**, findings suggested that the route provided by the Connect2 scheme was the most popular choice for shorter, low speed, leisure cycling rides in the local area but that sport cyclists were more likely to have cycled over alternative routes too, for longer distances and at faster cadence. This may suggest therefore that the provision of the scheme may have been more relevant for occasionally/ inexperienced cyclists.

While it is usually assumed that cyclists tend to choose the shortest route possible while travelling for utility purposes (Broach et al. 2012; Heinen et al. 2010), shortest route path analysis suggested that cyclist's decisions were often more complex and other factors such directness of the route, segregation from car traffic, perceived safety, number of intersections, convenience or environmental quality were likely to influence route choice decision. Participants have deviated from the shortest path for nearly one quarter of the utility journeys recorded (mean deviation 0.27 mile (95% CI 0.19; 0.36). This figure is aligned with a recent study from Dalton et al (2014) that found that active commuting trips are in average 27% further that modelled routes based on shortest distance.

Although results obtained suggested that the new Connect2 scheme was well used and may have influenced route displacement of some journeys, findings did not suggest that the new scheme was a main reason for an increase in cycling levels over time. During the period of the study, three participants started to cycle for the first time but attributed uptake on cycling due to influence from peers, perceived health benefits or lack of alternative. Likewise, other participants that have increased cycling levels over the period of the study attributed change in travel behaviour to health awareness, desire to be physically active, influence of friends and colleagues at work or changes in life circumstances. Only one participant stated that decision to start to cycle to work (and modal shift away from public transport) was directly influenced by the implementation of the new scheme. While several studies at city level have detected or explained an increase in cycling levels due to cycle infrastructure provision (Troelsen 2004, Buehler & Pucher 2011, Dill & Gliebe 2008, Pucher et al 2011, DfT 2009), results in this study are therefore less conclusive. The scale of the intervention in the case study site should be however considered when interpreting these results. Additionally, participants reported that the poor quality of the feeder routes, the location of the scheme in the outskirts of town, or the presence of a parallel high quality and traffic

free path (the barrage) were likely to influence its impact. More broadly, traffic volume and speed, perceived safety and lack of supportive infrastructure for cyclists were usually perceived as main constrain for cycling in the local area (alongside issues of convenience, practicality, skills or socio-cultural aspects).

Overall, findings seem to suggest that provision of a wider network of safe, direct, functional and good quality routes (complemented with other measures) may be required to promote a higher uptake on cycling but that a piecemeal approach is likely to have limited impacts in providing the required transformation in the local environment necessary for it to become supportive and inviting for cycling of all ages and skills; and therefore support a significant change in overall travel behaviour.

10.3.3 What is the potential for replacing short car trips by walking and cycling within a community served by Connect2 and what are the CO_2 emissions impacts of such shift?

Aligned with national trends (DfT, 2014a), findings in this study demonstrated that car travel is the most popular mode of travel, accounting for 80% of all distance travelled and 89.9% of total CO_2 emissions from surface transport among the study population. Nearly half of these car trips were however shorter than 3 miles (n=798) and accounted for 10.9% of all CO_2 emissions from car travel. The main reasons given by participants to drive over short distances were usually related with habits, time constraints, convenience, need to carry goods or escorting people (frequently children), lack of alternatives and absence of restrictions to car use; these reasons were, overall, aligned with results from previous studies (Mackett 2000; Mackett 2003; Vagane 2007).

Using a trip chain based approach, findings suggested that at least 20% of the short car trips recorded in this study could be classified as being replaceable by walking and cycling (n=329) and that such modal shift could contribute to the mitigation of 4.1% of total CO_2 emissions from surface transport. Estimates have also demonstrated that walking and cycling for everyday travel during the period of the study (actual behaviour)

contributed to the mitigation of 4.9% of total CO_2 emissions from surface transport, if walking or cycling journeys recorded would have been replaced by car travel. Overall, these findings highlight the potential of walking and cycling as an alternative to short car trips in urban context and its potential in contributing towards a lower carbon transport system in urban areas. While other studies have reported different figures for potential of replacement of short car trips (Mackett 2003, Sloman et al 2010, Beckx et al 2013), results present in this study have the advantage of being derived from travel data collected using a mix method approach involving use of GPS technology.

Findings suggested that the provision of the Connect2 scheme may have had, however, a minimal impact in terms of carbon emissions mitigation. If utility walking and cycling journeys conducted over the Connect2 scheme were replaced by car travel, carbon emissions from surface transport would have increased just by 0.5%. Nevertheless, estimates suggested that the new scheme provided a main route for 69 out of 329 short cart trips potentially replaceable by walking and cycling in the local area and that such modal shift could have contributed to a further saving of 1.2% of total CO_2 emissions. In a study with a larger sample of participants but using self-reported travel data, Brand et al. (2014) also suggested that the provision of Connect2 schemes in three case study sites did not translate into *detectable* changes in CO_2 emissions from motorised travel for those participants who used or lived near the Connect2 schemes.

Overall, these findings suggest that there is an unexploited potential in targeting short car trips that could potentially be replaced by walking and cycling. This contributes to the literature on the implications of a modal shift from motorised transport to walking and cycling, based frequently on the generation of scenarios and models (Woodcock et al. 2007, Lovellace et al. 2011). Promoting this shift could have a wider range of benefits and this study has provided evidence of potential gains in terms of carbon emissions mitigation in urban areas. It is however acknowledge that promoting this

modal shift is a complex process and that provision of an important route for pedestrians and cyclists in a local community alone is likely to have a limited impact.

10.3.4 To what extent is the GPS based mixed method approach a feasible, reliable and valid method to collect travel behaviour data at the micro level?

The novel combination of GPS loggers, travel diaries and interviews employed in this study for data collection provided a detailed data set with spatial, temporal and contextual attributes. The level of detail present in this data set of 2664 geo referenced trips, 2939 stages and 1010 tours was crucial to answer the research questions formulated in this study and a similar level of detail could not have be obtained using traditional survey methods.

The use of personal GPS devices provided detailed information on participants' travel behaviour including journeys distance, duration, speed and importantly route taken; this was crucial to assess, as an example, levels of use and nature of journeys conducted over the new Connect2 scheme. Results suggested however that due to equipment failures or participants misuse of the devices, GPS loggers did not capture all trips made by participants' (although the same was also true for the travel diaries). Nevertheless, 92% of the trips recorded in the travel diaries could be matched to GPS records. The adoption of **travel diaries** was useful in providing an opportunity to triangulate data and corroborate GPS data. Moreover, contextual notes recorded on the travel diaries provided valuable information for interpreting atypical events or travel patterns (atypical route choice due to weather conditions or a missing record of a journey due to device battery loss, as an example). Despite a strand of research currently focused on the singularly use of GPS technology in studies of travel behaviour (Gong et al. 2012; Shen & Stopher 2014a) findings in this study suggest the advantages of a combined GPS-diary approach in providing a more comprehensive

data set. This is also supports recommendations of the NTS GPS Feasibility Report (Andersen et al. 2009).

Finally, the **contextual data** collected through interviews and meetings with participants was essential to unveil reasons underlying detected travel behaviour patterns, changes over time[67] or significance of the new Connect2 scheme in influencing participants travel behaviour. The micro level detail gathered using this GPS mixed method approach would be less useful without the context and meaning provided by the qualitative data.

The successful development and deployment of this survey methodology at a real world case study site over two waves of data collection and its acceptance by a diverse group of individuals (N=50) shows the **feasibility and reliability of the chosen approach**. Furthermore, triangulation of data collected by the GPS devices with activity patterns described in the travel diary, and external validation of key findings with secondary data support the **validity** of the results obtained. While privacy concerns in GPS based surveys are sometimes raised in literature, in this study that was not found to be an issue. The comprehensive explanation of the survey methodology provided to participants (including option given to participants to alternative turn off the device or ask the researcher to delete certain trips/sojourns participants did not want to be disclosed) may have contributed to this outcome. Additionally, results seem to suggest that participants' familiarity with recording procedures may be an advantage, as recording performance improved in the second year of the survey.

[67] Most relevant changes detected in travel behaviour over time were related to changes in life circumstances (such as new job further away from home, working from home, become retired or child care responsibilities) or year-to-year variability events (bicycle stolen prior to survey, atypical busy week of business trips, annual visit to see relatives). A less detailed study may not have been able to pick up some of these reasons as determinants for changes in travel behaviour over time, as an example.

10.4 Reflections on the implications for policy and practice

Based on the main findings of this study, this section proposes a set of recommendations to provide policy makers and planners with better information on how walking and cycling can be more effectively promoted. In general, it is here argued that for walking and cycling to be a feasible, attractive and safe alternative mode of transport in urban areas, alongside the provision of schemes that improve connectivity for pedestrians and cyclists, such as the ones delivered by the Connect2 programme, a varied set of measures that prioritize provision of a wider network of high quality infrastructure (alongside changes to land use, restrictions to car travel and social marketing campaigns) are needed to facilitate short journeys by walking and cycling and give individuals the confidence, convenience and practicality required to adopt walking or cycling as a feasible mode of transport.

10.4.1 Wider structural changes: provision of good quality infrastructure for pedestrians and cyclists

Findings have shown that the Connect2 scheme has provided an important link in the local area for pedestrians and cyclists but that the poor quality of the feeder routes and its lack of continuity (perceived and physical) were key factors influencing its use. In particular for cycling, the absence of continuous routes linking desired destinations in the local area and perceived lack of safety (related with volume and speed of road traffic and lack of segregated infrastructure) contributed to the perception of the local environment as not being either supportive or inviting for cyclists of different ages and skills. Route choice analysis has also shown that cyclists usually preferred direct, quicker and shorter routes while cycling for everyday travel (75% of the journeys) but that routes' environmental quality, level of segregation from general motor traffic and number of stops were features likely to make cyclists detour (25% of trips deviated from shortest path based on such premises). Most relevant infrastructural factors found to influence walking for everyday travel were perceived continuity of routes (influenced

by lack of safe or convenient crossings points), narrow width of footpaths (and derived proximity to traffic) or attractiveness of the environment. Overall, these findings suggest the importance of connectivity, accessibility, safety, quality and attractiveness as principles and strategic dimensions for cycling (and walking) infrastructure provision.

10.4.1.1 Recommendation

First, **the provision of a wider cycle network of paths** that provide a safe, convenient and quicker access to all the desired destinations is required. For this to happen, the suggestion is that facilities are created along every main road or where needed and using infrastructure typologies adapted to traffic volume and speed. Routes should also be **direct, accessible** and long detours and interruptions should be minimized. The quality of the routes, type of pavement and space available are also important features that increase route attractiveness and comfort. Intersections and crossing design should also receive especial attention, as this was often perceived as critical points of the infrastructure or as a reason to detour in some occasions[68]. Secondly, it is recommended that a variety of **trip end facilities** are provided to support cycling. As an example, results have demonstrated that lack of secure outdoor bicycle parking (either at home, work on on-street) or shower facilities (at work) were likely to influence individual's decision whether to own or to ride a bicycle for particular destinations (see section 8.3.3). These facilities could include bicycle storage facilities at interchanges and stations, mandatory bicycle storage in any new development, or shower and lock facilities at workplaces. Some of these measures will also have a positive impact in increasing integration of active travel with public transport (see section 9.5).

[68] As an example, results shown that cyclists' preference for route B (Barrage) instead of route A (Connect2 scheme) was usually related with perceived directness, environmental quality, traffic interaction and number of interruptions of one route compared to the other.

The principles mentioned for cycling infrastructure could also be applied for walking infrastructure to some extent. A greater focus should be however placed on improving paths legibility and connectivity (signposting, maps), crossings safety, pavements quality and maintenance alongside streetscape aesthetics and attractiveness.

Finally, it is also suggested that a comprehensive appraisal is performed in the local areas where interventions are to be placed and that schemes prioritization follows a consistent approach. Provision must be coherent and routes must be planned as network/ whole route-basis instead of isolated stretches and disconnected interventions. The fact that Local Authorities rely frequently on Section 106 [69] agreements to provide new cycling infrastructure is in many cases a reason for this disconnected and inconsistent delivery approach. However, as findings in this study suggested, a piecemeal approach to implementation is unlikely to promote a significant change in travel behaviour (at least in the short-term).

10.4.2 Restrictions to car use and a supportive environment for active travel (land use, distance, and mixed activities)

Creating a city that is friendly for walking and cycling is however not simply about providing dedicated infrastructure. In order for walking and cycling to be perceived as a feasible alternative mode of transport for everyone, the urban environment should be also supportive and inviting for these alternatives modes of transport.

Aligned with national trends, findings have shown that car travel was the dominant form of transport in the case study site. However, nearly half of all these trips were shorter than 3 miles and at least 20% could be classified as 'being replaceable' by walking and cycling (see section 9.2.3). Travelling by car was usually perceived as convenient,

[69] Section 106 (S106) of the Town and Country Planning Act 1990 allows a local planning authority (LPA) to enter into a legally-binding agreement or planning obligation with a landowner in association with the granting of planning permission. The obligation is termed a 'Section 106 Agreement.

comfortable and practical; however, participants acknowledged that traffic congestion and car parking cost or availability was frequently a motivation to walk to the local shops, to cycle to work or to replace commuting car journeys by public transport. Utility walking journeys were usually short (0.5-0.7miles average) and conducted in areas with a greater mix of uses and activities (see section 7.2.1). Additionally, findings suggested that limited availability of facilities at close range of the new Connect2 scheme and speed/volume of motorised traffic along main access to the new scheme may have restricted its impact and attractiveness.

10.4.2.1 Recommendation

Imposing restrictions to car use in urban context or changing urban street hierarchy in order to give highest priority to active travel and public transport seem therefore a key strategy. Policies and measures that can slow down traffic in urban areas, restrict its access to certain areas and reallocate/ release road space would be, therefore, crucial. Road traffic dominance makes it challenging to design spaces for people and slower active forms of transport. However, such changes on space, volume and speed could provide new opportunities for active modes and public transport use and enhance the liveability of streets and public space. Additionally, town planning and urban design strategies could also contribute to make the use of the car less attractive.

At a local/city level, land use and planning policies that restrict **dispersal of urban activities,** support **increased densities** and **mix of activities** should also have a positive impact on making walking and cycling a more feasible travel option. By influencing distribution of services and facilities in a way that they can be accessed locally should have an impact on trip distance (example: define thresholds for availability of activities at walking and cycling distance). The integration of transport planning with land use policies should also contribute to build sustainable mobility into the patterns of urban form.

10.4.3 'Soft measures' to complement infrastructure measures

For three participants in the study, the implementation of the new Connect2 scheme was a main reason to have walked or cycled more frequently. For other participants, however, perceived benefits of walking and cycling (health, cost), influence from friends and peers or limited access to vehicles in the household were the main reason triggering an increase in walking or cycling for utility or recreational purposes during the period of the study.

10.4.3.1 Recommendation

It is therefore recommended that alongside physical measures, a range of 'softer measures' including social / individual marketing measures, promotional campaigns (on health risks associated with lack of physical activity, as an example) and targeted activities (workplace, city centre shopping/leisure areas, etc.) are also employed in order to promote cycling and walking more effectively. As an example, bike to work schemes, health check-ups, bicycle maintenance workshops or advertising campaigns on solutions that can overcome some of the perceived limitations of cycling (e-bikes, child seats, waterproof equipment; cargo accessories) could be beneficial.

10.4.4 Co-ordinated, multi-faceted approach to walking and cycling

Overall, these recommendations suggest that a co-ordinated multi-faceted approach is key and that for structural changes to take place there might be need for a change on how walking and cycling are both funded and promoted by the UK Government.

The role of Sustrans initiatives is recognized as making a contribution to support more walking and cycling. However, even if only schemes like Connect2 (or NCN) are implemented and conditions on highways are not improved as a whole, this limited effort may prove to be rather ineffective. This aspect is more critical for cycling infrastructure, which usually requires reallocation of space from motorised travel. In many cases, it seems however that cycling infrastructure is only implemented at

locations where car space does not need to be challenged. This is could be for instance the example of a new cycle lane implemented during the period of the study in Plassey St (a secondary road with higher gradient and low volume of traffic) rather than on Windsor Road (a main road, with higher volume of traffic but linking more desired destinations), as illustrated in Figure 10.1.

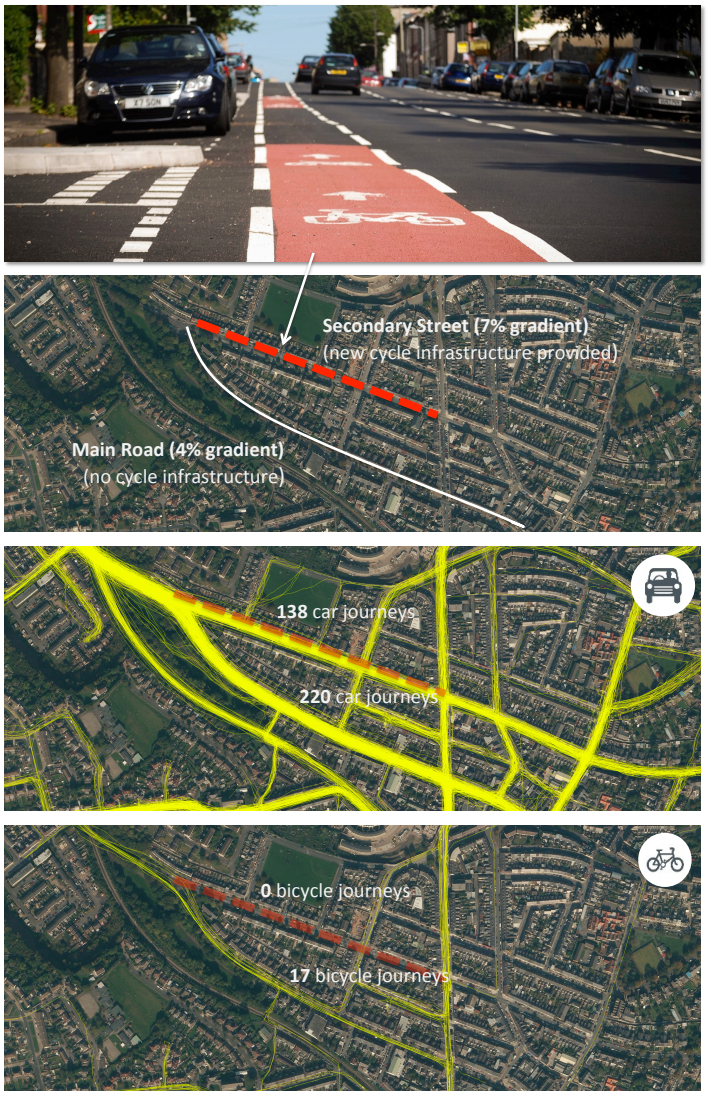


Figure 10.1 – Location of a new cycle lane and road and cycling traffic recorded in close range (basemap: BingMaps © Microsoft Corporation).

In fact, some participants perceived the redesign of the local main roads and intersections to safely accommodate cycling as a higher priority for the local area and questioned whether under a limited budget the Connect2 intervention was a key priority. This may suggest therefore that a comprehensive appraisal of key infrastructure projects in local areas should be performed and that scheme provision

should not be restricted to where they are unlikely to cause confrontation with motorists. It is acknowledged that this requires a clear commitment and that reducing motor vehicle capacity remains a politically unpopular decision.

10.4.5 Encourage walking and cycling and use of Connect2 scheme in the local area

Some practical measures that could increase use of Connect2 scheme for short practical journeys in the local area could include the following:

1. Conclusion of the feeder routes linking Penarth, Cogan and Llandough to the main core Connect2 scheme (it should be noted that the zig zag route linking Penarth Town Centre to Penarth Marina and Pont y Werin Bridge was completed in May 2013). Moreover, improvement of pedestrian and cyclists crossing on the A4055 intersection would facilitate access of residents in Cogan and Llandough to the Connect2 scheme and Cardiff Bay;
2. The redesign of main roads in the local area to provide a wider network of high quality, continuous and safe routes for cyclists; and improve signing along main routes, (including distance and time towards main locations as an example) to improve its legibility, public awareness and perceived connectivity to the new Connect2 scheme;
3. Restrict car parking in Penarth Town Centre and offer incentives to costumers to walk or cycle to the local shops or retail area nearby new Connect2 scheme. Provide load-carrying options for shopping and marketing campaigns on alternatives to carry goods (e-bikes, cargo bicycles, trolleys, trailer hire schemes, etc.);

4. Provision of good quality and safe cycling parking facilities in main local destinations (town centre, train stations) and all new developments in Cardiff Bay Area;
5. Promote walking and cycling to school initiatives (example bus walk, bike to school) school) and loan of pushchairs, child bike seats or bike trailers for parents living in the local area.

In conclusion, these findings support evidence that a fully integrated package of strategies and measures/ wider co-ordinated and a multi-faceted approach that combines high quality physical infrastructure provision, restrictions on car use, social marketing and supportive land use planning and transport policies are key for an effective promotion of walking and cycling as an alternative mode of transport. As articulated by Pucher et al. (2010: 122) '*the impact of any particular measure is enhanced by the synergies with complementary measures in the same package'*.

10.5 Strengths and limitations of the research

This section evaluates the strengths and limitations of the research methods applied in this study. The benefits of a longitudinal panel design, in-depth focus and the use of a GPS based mixed method approach to record travel behaviour data are discussed alongside some of the limitations related to sample size, data processing or case study context.

10.5.1 Strengths:

The main strengths of this study include the longitudinal panel design, in-depth focus and the use of a GPS based mixed method approach to record travel behaviour data. The **longitudinal panel approach** provided the ability to evaluate over a longer period of time participants response to the provision of infrastructure in the local area, measure changes in travel behaviour over time and explore their causal relationships.

The panel design meant that data was collected from same individuals over time and that results obtained were therefore more precise than if from a cross sectional design. The **in-depth approach** provided an opportunity to investigate, at the micro level, the factors influencing participants' complex everyday travel behaviour decisions and within this context, understand better their response to the infrastructural changes in the local area. This approach has been rarely performed in studies evaluating the impact of cycling infrastructure, as an example.

The **methodology** developed in this study to record travel behaviour represented also an important methodological advance due to the mixed method approach involving different survey tools and level of detail of collected data. The GPS technology provided accurate information on participants travel behaviour at a stage level and that was crucial, as an example, to examine the nature of the journeys conducted over the new Connect2 scheme. A similar level of detail could not be obtained using traditional approaches that rely on retrospective measures of travel activity, simple counts of users, or route information based on respondents recall. On the other hand, the travel diary acted as an important validation tool of the data collected by the GPS loggers; and the collection of qualitative data provided a comprehensive explanation for measured travel behaviour and attitudes towards walking and cycling. The employment of this methodology for data collection in a case study site and its acceptance by a diverse group of individuals supported the feasibility of the approach and the quality of data collected and its comparison to other sources of data proved its validity and reliability.

The detailed data obtained provided an opportunity to examine substantive questions related to the evaluations of complex infrastructural interventions and spatial aspects of travel behaviour that are not so frequently studied. These included identification of diversity of walking patterns, analysis of cyclists' route choice, assessment of walking and cycling potential based on a chain trip approach or identification of nature of trips

conducted over new infrastructure for pedestrians and cyclists. Also important, detail contained in this dataset (including precise journey distance, average speed and travel mode) enabled to examine with greater level of accuracy the effects on CO_2 emissions from motorised travel by journey purpose and transport mode. This was also a clear advantage compared to estimations based on self-report data, which are frequently limited by underreporting short trips (Bohte & Maat 2009), round off travel times (Dill & Gliebe 2008) or overestimate trip distance and trip duration (Andersen, Abeywardana, Wolf & Lee 2009). The approach develop in this study has the potential to be used by other researchers attempting to design and execute evaluations of complex infrastructural interventions in diverse circumstances.

Another potential strength of this study was the independent measurement of walking and cycling for both utility and recreational purposes. A vast majority of the studies usually focuses in one behaviour at a time (either walking or cycling), one behaviour for one specific purpose (cycle commuting), or one behavioural outcome (e.g. total physical activity). This limitation has been recognized by several authors (Adams et al. 2013; Heinen et al. 2010; Forsyth and Krizek 2010). This distinction is important as examples in this study demonstrated that different attributes of the built environment are associated with different activities (example: walking for recreation or walking for utility purposes) and findings suggested that impacts of the new scheme were different for walking and cycling (and also recreation and utility journeys).

Finally, the heterogeneous sample of participants in the study, including both groups of cyclists, non-cyclists and new starters, was an additional advantage. Usually in cycling studies there is often a bias towards regular cyclists (Pucher et al. 2010b; Dill & Gliebe 2008).

10.5.2 Limitations

This study was originally designed as a **before and after study** as measuring behaviour before and after an intervention is recognized as one of the most robust approaches for establishing causality between environmental factors and travel behaviour (Krizek, Handy, et al. 2009). However, one of the challenges of conducting a natural experiment is that treatment assignment is exogenous and they are determined by nature or other factors out of the control of the experimenters (Ogilvie et al. 2012). The case study site originally selected to conduct this research was the Connect2 Kenilworth, where a new route for pedestrians and cyclists linking Kenilworth town to Warwick University was to be implemented during 2011. The effects of the 2008/09 recessions caused however delays and cancelations for a significant number of the Connect2 schemes, including the one chosen. Therefore, by the end of 2010, it was crucial to choose a new study site in order to conduct this study. The selection of the Connect2 Cardiff as an alternative had the advantage of being one of the flagship schemes of the Connect2 programme and therefore where greater impacts on travel behaviour were expected. However, as the main core of the Connect2 scheme (the Pont y Werin) was already implemented before first phase of data collection, this implied that this study design needed to be adapted. A **longitudinal post intervention panel study** had the advantage of enabling the evaluation of respondents' response to the new scheme over a longer period of time and to validate consistency of results obtained over time. It is recognized however that measuring travel behaviour one and two years after an intervention is a limited time window to capture significant changes in travel behaviour and for habit formation. It may be argued therefore that having more repeated measurements over a larger period of time would have been an advantage; however, that was not possible due to resources commitments (funding available, PhD study timeframe, participant's availability).

The **case study approach** defined in this study provided an opportunity for an in-depth investigation of whether the new Cardiff Connect2 scheme influenced local residents travel behaviour. A limitation of focusing the research at one specific case study is however that findings may not be replicated to other Connect2 sites. As an example, results in this study are influenced by local context and the fact that a crucial feeder route to the scheme (the zig zag route, see page 86) was not completed during the period of the study.

The small **study sample size** (N=50) is other potential limitation of this study; this determined sample lack of representativeness and impossibility of generalizing results to the local population. Additionally, small sample size was likely to have influenced assessment of changes in travel behaviour over time. Results suggested that changes in travel behaviour of a small group of participants (skewed distribution) had a disproportionate impact on overall measurements of travel behaviour. The size of the study sample was determined by the availability and performance of devices for data collection, fieldwork workload, recruitment response rate and attrition between waves (N=19). While attrition is a common issue in panel studies (Deng et al. 2013; Stopher & Stecher 2006), the approach followed – oversampling in first survey wave - rather than replacing participants lost may be seen as a limitation too.

The aim of using intention towards walking and cycling as a criteria in the sample **recruitment strategy** was to increase the probability of including in the sample participants that were likely to walk or cycle in the near future ('near market')[70]. Such approach may have however introduced some bias in the panel study, as participants that revealed no intention to walk or cycle were excluded. Field observations conducted in the case study site also suggested that other types of users of the new Connect2 scheme were not captured in the study sample. Those include groups of teenagers and

[70] From those 17 participants that have cycled during the period of the study, 3 have started to cycle for the first time during the second year of the survey.

visitors to Cardiff Bay Area seen regularly crossing the new Connect scheme. This suggests therefore that Connect2 users' catchment area and age were likely to be far beyond the limit defined in this study (3 miles buffer, participants' minimum age 18 years old).

Despite the greater advantages of using a GPS based mixed method approach for travel data collection, it should be also noted some of its limitations. Firstly, a comparison of GPS and travel diary data records has shown that a considerable proportion of travel diary trips were not matched with GPS data (8%). This could be partially explained by participants forgetting to carry the devices, turning them on or charging or some other technical issues[71]. Secondly, some participants reported to have not deliberately used the GPS device on some journeys, as they found its use inconvenient or uncomfortable during certain occasions (example: going out at night). This potential burden might have been more evident in this study as participants were asked to carry the GPS device and an actigraph in a belt around their waist. This may suggest therefore that alternatives to worn the GPS device should be evaluated, such as wearing the device outside of clothing or in a handbag, as an example. For unknown reasons, three GPS devices were faulty during the period of the study and did not record any data[72]. Thirdly, filling in the travel diaries was perceived as a burden for a great number of participants. This may suggest that alternatives such a simplified memory jogger or web based travel diary should be considered in similar surveys.

Data cleaning and processing was the most challenging stage of this study. After a long period of testing and contact with experts in the field, the researcher decided to

[71] Most common technical issues detected with GPS data were derived from signal scattering, signal loss or failure to record a section of a journey and lack of battery. Cold start issues (i.e. time that GPS device takes to reach satellite signal when is turned on) may explain incompleteness of some journeys.

[72] Equipment failures have also been reported in other studies. As an example, a study by NatCen found that 5 out of 60 devices were faulty and two devices developed faults whilst they were with respondents (DfT et al. 2009).

develop own methodology for trip identification, and trip purpose and mode coding. This approach involved a combination of software packages and manual checks. The level of accuracy on trip identification may be higher for this reason, but the drawback was that this was an extremely time consuming process. **Coding travel data** represented also a challenge due to the great level of detail gathered. Nearly 80 different expressions have been use by the participants to describe the purpose of their trips around the local area. While this approach enabled to capture a greater level of detail on journeys recorded, giving a limited number of trip purpose categories for participants to use instead of leaving it as an open question may have facilitated trip purpose classification.

Finally, it is acknowledged that procedures developed for shortest route analysis and feasibility of replacing short car trips by walking and cycling could be improved. The estimations of shortest route choice did not take into account gradient of road network and a multiplier was not assigned to roads with cycling infrastructure provision, higher environmental quality or less number of intersections; adding this attributes to the model would have enhanced calculations performed (see Yiannakoulias et al. 2012). Moreover, it is recognized that collection of more information on travel behaviour (example: if heavy goods were carried during journeys made) could enhance the evaluation of feasibility of replacing short car trips by walking and cycling. Finally, despite the positive impact of public transport use, its potential as an alternative to short car trips was not estimated, as this was outside the study scope.

10.6 Future research

The research design and approach developed for travel data collection has proven to be promising in exploring the inherent complexities of travel behaviour and impact of infrastructure provision for pedestrians and cyclists in everyday travel. The experience

gained from this study suggests however that future research is likely to benefit from the following.

10.6.1 Measure travel behaviour before, during and after intervention, over longer periods of time and in more communities in the UK

The longitudinal panel approach to travel data collection adopted in this study enabled to understand with a greater level of detail the dynamics of changes in travel behaviour at the individual level and validate results consistency with regards to the usage of the new Connect2 scheme over time. However, a classic **before and after research design** is likely to be a better approach to establish causality (Krizek, Handy, et al. 2009) and would enable to obtain more reliable evidence of the effects of the provision of infrastructure in promoting changes in travel behaviour. Additionally, studies that conduct **repeated observations of the same variables over long periods of time** are likely to provide an advantage, as it takes time for travel behaviour habits to be established and resistance to change to be challenged. Conducting similar surveys in representative sample of communities' recipient of new infrastructure for walking and cycling and communities without such provision will also enable to establish comparisons and evaluate the role of provision of infrastructure in influencing walking and cycling levels. This could also include the study of the impact of different types of cycling infrastructure, as an example. As evidence available in this field is geographically limited, it will be an advantage if more studies in this field are conducted in UK communities and urban areas.

10.6.2 Extend the set of outcome measures that could be explored

While it is acknowledged that an increase in walking and cycling for everyday travel could have cross-sectorial benefits, number of studies assessing its various benefits is limited. Therefore, it is suggested that set of outcome measures to be explored in similar evaluation studies could be extended. This could include, as an example, air

quality emissions (and exposure impact to cyclists), public health benefits (by using accelerometer data that records levels of physical activity) or impacts on urban environment (street life, liveability of public spaces, increase in local shopping, etc.). Collection of GPS travel data provides also an opportunity to evaluate how other elements of the built environment are likely to influence walking and cycling behaviour, namely the quality of the streetscape, presence of green areas along the routes, number of intersections, gradient or traffic volume, as an example. While these relationships were not objectively considered in this study, the geocoded travel data set would enable to explore with a greater level of detail some of these dimensions and their interaction with walking and cycling behaviour. Finally, findings in this study suggested that alongside GPS travel data, collection of qualitative data would enable to explore further the relationships between environmental attributes, individual, social and cultural factors and different behaviours. This data could be collected in a more systematic way using questionnaires, interviews or retrospective biographical data and would enhance understanding of how infrastructure and a complex web of factors at different levels influence walking and cycling behaviour.

10.6.3 Representative sample and wider age group

Travel activity recorded in this study was collected from participants aged 24 to 71 years old; however, observations conducted at the case study site suggested that the new Connect2 scheme was frequently use by groups of teenagers (10-17 years old). Therefore, it is considered beneficial it future studies include younger participants, as there seems to be a great potential for active travel among this group and it would be important to understand how similar interventions are likely to influence their travel behaviour. Furthermore, use of representative panel studies would have the advantage of allowing findings to be generalised, at least at local level. Finally, triangulation of data collected with other sources of data (NTS, UK Census, automatic counters) could contribute to a further validation of the assessments performed.

10.6.4 Technology improvement and exploring other sources of data

The use of GPS technology data has proven to be successful in recording travel data with a greater level of accuracy; however, issues related with data loss due to signal disruption or participants' misuse were likely to influence their overall performance. As technology improves devices are becoming smaller and more efficient and signal reception is likely to improve. Therefore, using more updated devices that could be more easily carried and worn inside clothing or a bag (without disruption of its signal) or have longer battery capacity would be an advantage.

Alternatively, it is believed the use of smartphones as a measurement instrument may represent an opportunity to conduct GPS based travel surveys with fewer burdens for participants and lower cost for researchers. First of all carrying a smartphone, charging it or turning on/off is an embed routine for a great number of people already. Secondly, smartphones provide the possibility to have a purpose built application that could enable the user to validate their travel data in real time. Thirdly, travel data collected may be automatically uploaded to general server, reducing costs and burden associated with delivery and collection of devices. As an example, the application for smartphone Moves (moves-app.com), released in 2013, enables self-tracking, trip mode detection and data editing by the user. The researcher has tested this application on a daily basis over a period of 4 months during 2014 (Figure 10.2). Despite its potential, main drawback at the present is that smartphone battery running out very quickly and lack of accuracy on some routes. Nevertheless, this platform sounds promising for future travel surveys.

Another potential alternative, to conduct further analysis on cyclists or joggers behaviour, is to use travel datasets that are becoming available online, such as the data collected using STRAVA devices (labs.strava.com) (Figure 10.2). A limitation of this data set is however the likelihood of a bias towards recreational activities and the fact that individuals personal data is not available.

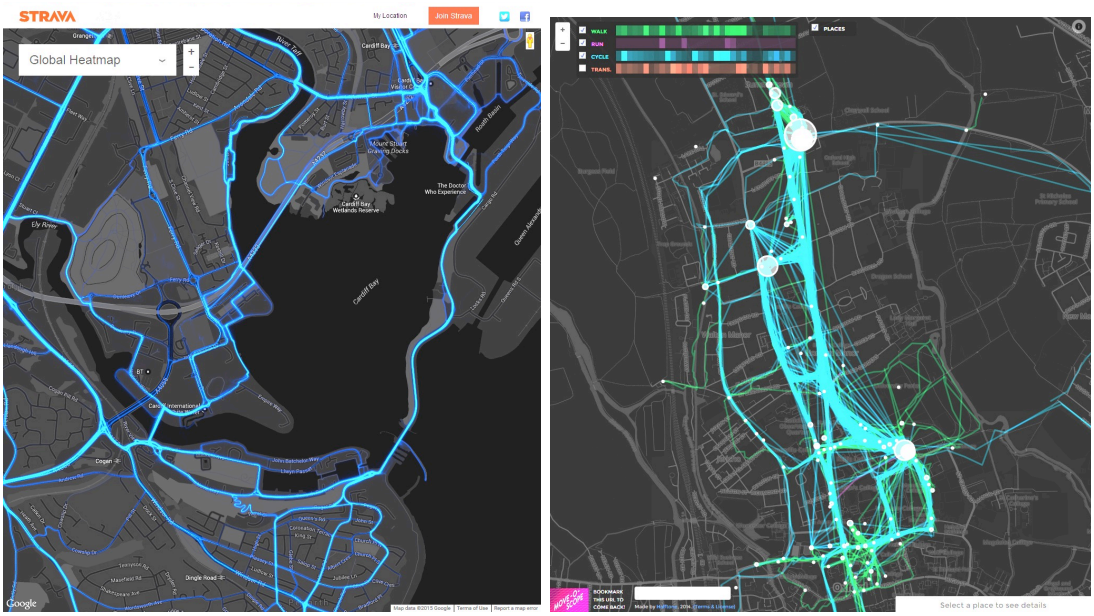


Figure 10.2 – Example of Strava data available in Cardiff Region (labs.strava.com) (left); example of data collected using an application for smartphones (moves-app.com) (right).

10.6.5 Improve data processing techniques

At the present, trip mode and purpose identification from GPS raw data is still a complex process and further automation would be required, especially if working with large data sets. Alongside the development of algorithms to process GPS data, other approaches being tested or use to overcome this issue include the introduction of more instruments/devices to record travel behaviour. Those include, as an example, use of passive cameras (see Shen & Stopher 2014b) or use of web applications to validate collected data (Harder et al. 2010; Bohte & Maat 2009). A potential limitation of the latter could be its use among respondents with very few computer skills, old computers, and limited access to the Internet and/or complex travel behaviour. Nevertheless, it is believed that as hardware, software, and processing techniques continue to progress, some of these issues would improve in the future. Additionally, a revised system of trip classification could be considered in the future in order capture and better represent the emerging complexities of travel behaviour identified and the diversity of factors influencing different activities.

10.7 Concluding remarks

Walking and cycling can play an important role as an alternative, efficient and healthy mode of travel in urban areas as a great number of the journeys are short (as demonstrated in this study) and traffic congestion and other harmful impacts of car travel are becoming more evident. Successive governments and organizations in the UK have recognized the need to increase walking and cycling and have delivered a range of policies and initiatives aimed at promoting more sustainable modes of travel. However, walking and in particular cycling levels remain stubbornly low relative to Northern European neighbours, and there is still limited understanding on how some of these interventions are being effective in influencing individuals complex everyday travel behaviour.

This thesis has provided, as far as the author is aware, **the first in-depth longitudinal study using GPS technology to evaluate the impact of interventions that improve connectivity for pedestrians and cyclists**, namely a scheme delivered by the Sustrans Connect2 Programme. This study aimed to contribute therefore to the current literature and policy debate in the UK on whether interventions aimed at increasing walking and cycling are being effective in influencing individuals travel behaviour and impacting on carbon emissions from personal travel. Findings suggested that the provision of a good quality traffic free bridge and feeder routes for pedestrians and cyclists in the case study site were well use by participants in the study at one and two years follow up but that the intervention was likely to have a greater impact for recreational rather than for everyday travel. Moreover, findings suggested that the new scheme was unlikely to promote a significant change in patterns of everyday mobility for the majority of the participants and while the new routes attracted walkers and cyclists, there was no evidence that this success translate into sizeable decrease in CO_2 emissions from motorised travel. On the other hand, however, findings have

demonstrated the unexploited potential in targeting short car trips that could potentially be replaced by walking and cycling.

While initiatives such as the Connect2 Programme and the wider portfolio of work of Sustrans, should be praised, findings suggest that more systematic changes to the transport system are required. These should include provision of a wider network of direct, convenient, functional, attractive, safe and good quality routes but also more restrictive policies in urban centres (reduction of speed and volume of traffic and car park availability, as an example), reallocation of road space to sustainable modes, changes to mix land uses, improved access to destinations and public spaces and social marketing campaigns. While single fix solutions are attractive, findings suggest that a piecemeal approach is likely to have limited impacts in giving individuals the convenience and practicality required to adopt walking or cycling as a feasible mode of transport for everyday travel.

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Zacharias, J., 2005. Non-motorized transportation in four Shanghai districts. *International Planning Studies*, 10, pp.323–340.

APPENDIX A – List of organizations promoting walking and cycling in the UK

	Aim	Source:
Sustrans	British charity that aims to promote sustainable transport by working on projects that encourage people to walk, cycle and use public transport. Flagship project is the National Cycle Network that has created over 14,000 miles of signed routes through the UK.	http://www.sustrans.org.uk/
CTC	The Cyclists Touring Club is a charitable membership organization supporting cyclists and promoting bicycle use. CTC works at national and local level to lobby for cyclists "needs and wants", provide services to members and organizes groups for local activism and those interested in recreational cycling.	http://www.ctc.org.uk/
Cycling England	Independent, expert body funded by DfT and that aimed to promote cycling in England. It was founded in 2005 to replace the National Cycling Strategy Board. Main projects: Cycling Cities, Cycling Towns. ; Bikeability and National Cycle Journey Planner. Ceased as public body in April 2011.	
Living Streets	A registered charity that advocates for the rights and interest of pedestrians and aims to ' *create safe, attractive and enjoyable streets, where people want to walk'*.	http://www.livingstreets.org.uk/
Campaign for Better transport	Advocacy group that promotes better bus and rail services and for supportive policies and for less expenditure on road building.	http://www.bettertransport.org.uk/
Cycling Embassy of Great Britain	Volunteer run organization that intends to act as a conduit for best practice.	
The slower speed initiative	Increase understanding of the importance of speed control as an instrument of transport policy and to secure lower and better enforced speed limits. Highlight the impacts of speed through sound research and effective advocacy.	http://www.slower-speeds.org.uk/ourwork
Cycle Training UK (CTUK)	Not for profit workers co-operative providing cycling training	http://www.cycletraining.co.uk/
The Bicycle Association	National body representing the bicycle industry	http://www.ba-gb.com/
London Cycling Campaign	Independent membership charity lobbying for better conditions for cycling in London. 11,000 members	http://lcc.org.uk/
Movement for Liveable London's Streets Talks	Promotes discussion on how a fairer, healthier, greener and more pleasant future for London can be achieved by changing the way we move around the city.	http://movementforliveablelondon.com/
Cities fit for Cycling	A media led manifesto/ campaign targeted at public authorities to embrace specific cycling-safety measure for cycling.	http://www.thetimes.co.uk/tto/public/cyclesafety/

APPENDIX B – Recruitment Materials

Advance Letter

Address:

SCHOOL OF GEOGRAPHY AND THE ENVIRONMENT

UNIVERSITY OF OXFORD

17th February, 2011

Dear

Connecting Communities: The case of Connect2 Cardiff, Pont y Werin.

During April or May 2010 you or someone in your household completed and returned an an iConnect questionnaire which sought to gauge your views of the local area and how you you generally move around your local neighbourhood. This was part of a national research research study to assess the Connect2 scheme in your area - the new walking and cycling cycling bridge over the River Ely, Pont y Werin. On the questionnaire you indicated that you you would be willing to take part in further research.

As part of our Doctoral studies at the University of Oxford we are conducting follow-up research which involves gathering opinions about the scheme and assessing how it might have affected household activities. **We would like to invite you to take part whether or not or not you use the Connect2 scheme. As compensation for your time we would provide the opportunity to receive up to £40 in high street vouchers.** The information sheet enclosed provides further details about the study. We will be visiting the area to conduct our research between the 14th March and the 11th April. If you are interested in taking part **please complete and return the attached postcard in the pre-paid self-addressed envelope as soon as you are able.** If you wish to find out more before you decide whether or not to take part, please contact Lucy Mahoney or Andre Neves on **01865285167** or email at **lucy.mahoney@ouce.ox.ac.uk** or **andre.neves@ouce.ox.ac.uk.**

This research has met University Ethics approval but if you have any concerns you may write to the IDREC Officer; Dr. Chris Ballinger, Social Sciences Division, Hayes House, 75 George Street, Oxford, OX1 2BQ or email: **ethics@socsci.ox.ac.uk** reference:
SSD/CUREC1A/11-014 or SSD/CUREC1A/11-029

Thank you for considering this invitation.

Yours sincerely,

Lucy Mahoney and Andre Neves
PhD Students and Researchers of the iConnect study at University of Oxford

EPSRC Engineering and Physical Sciences Research Council

connect

Participant Information Sheet



WILL MY PARTICIPATION BE CONFIDENTIAL?

The information you provide will be held and used in accordance with the Data Protection Act 1998. All information that is collected about you during the course of the research will be kept strictly confidential and stored securely at the University of Oxford or another secure data storage facility.
You will be identified by an ID number and any recordings or transcripts related to you will have your name and address removed so that you cannot be recognised from it. We may quote parts of your interview in our research reports and publications to illustrate the findings of our research, but these quotations will not be attributable to you personally.

WHAT HAPPENS IF SOMETHING GOES WRONG?

If you have any questions about any aspect of this study, in the first instance you should contact either **Lucy Mahoney** (about Module 1) or
Andre Neves (about Module 2). They are the Doctorate candidates conducting this part of the iConnect study.

WHERE CAN I GET MORE INFORMATION?

about the iConnect study *www.i-connect.ac.uk*
about Connect2 *www.sustransconnect2.org.uk/*

CONTACTS




Lucy Mahoney lucy.mahoney@ouce.ox.ac.uk
Andre Neves andre.neves@ouce.ox.ac.uk

University of Oxford
Transport Studies Unit
South Parks Road, Oxford, OX1 3QY, UK

EPSRC Engineering and Physical Sciences Research Council

Information about this study



We would like to **invite you** to take part in a study titled Connecting Communities: ***The Case of Connect2 Cardiff*** that is being conducted by researchers at the **University of Oxford.** This **information sheet** explains what the research is about and what it involves should you wish to take part.



WHAT THE RESEARCH IS ABOUT?

You may be aware that there is a national programme called Connect2 that is currently underway which involves constructing new links for walking and cycling at 79 sites around the UK. One of the Connect2 projects is being implemented in your local area and is known locally as Connect2 Cardiff, the Ely River Connection.
A study to measure and evaluate the travel, physical activity and carbon impacts of the Connect2 programme is also taking place.

The study is called iConnect and is being funded by the Engineering and Physical Sciences Research Council (EPSRC).

The Connect2 Cardiff project has been selected for in-depth research as part of the wider iConnect study to understand the impact of this particular programme on the local community in this particular geographical location.

WHY HAVE I BEEN CHOSEN?

A postal questionnaire survey of residents in Penarth and surrounding area was conducted in Spring 2010 by the iConnect study team. You kindly completed and returned this survey and indicated on the form that you would be interested in taking part in future studies on this subject.

The next phase of the study is to understand more about the travel and physical activity patterns in and around the **Connect2 Cardiff** project site as part of **two Doctorate studies** being conducted by ***Lucy Mahoney*** and ***Andre Neves*** of the School of Geography and the Environment, University of Oxford (contact details below).

We are asking whether you would be interested in taking part in this next phase. ***Below we explain what this will involve.***



WHAT WILL HAPPEN IF I CHOOSE TO TAKE PART?

There are two methods by which we wish to understand more about travel and activity patterns in and around the Connect2 **Connect2 Cardiff, the Ely River Connection** project site what we are calling

module A *and/or* ***module B***

Ideally, we would like you to take part in both modules. However, if you choose to participate in the study, you may choose to take part in only one module.

WHAT ARE THE BENEFITS AND RISKS IN MY TAKING PART?

As well as assisting Lucy and Andre in their Doctorate studies, the information collected during this study will provide a better understanding of the links between transport, health and the environment. We hope this will help to improve policy making in your local area.

There are no risks involved in taking part. We are only asking you to take part in an interview and/or activity monitoring.



WHAT HAPPENS IF I CHANGE MY MIND?

You are free to withdraw from the study at any time and without giving a reason. If you do decide to withdraw, or if you are no longer able to take part in the study, we will use the data collected up to the time of your withdrawal.

To compensate you for your time gift vouchers up to a value of £10 gift will be given per household interview (module a) and a £10 gift voucher per participant wearing a GPS + actigraph for a period of 7 days (module b)

i.e. a total of 20 £ is offered for taking part in both modules.

a MODULE

For this module we would like to conduct an interview with you and people at your household about the local Connect2 Kenilworth project site.

The interview will take place at a time and place that is convenient for you and other household members and will last approximately one hour. During the interview you will be asked a series of open-ended questions about the Connect2 project and your travel and activities in and around the local area. You will not be asked questions of a sensitive or personal nature.



b MODULE

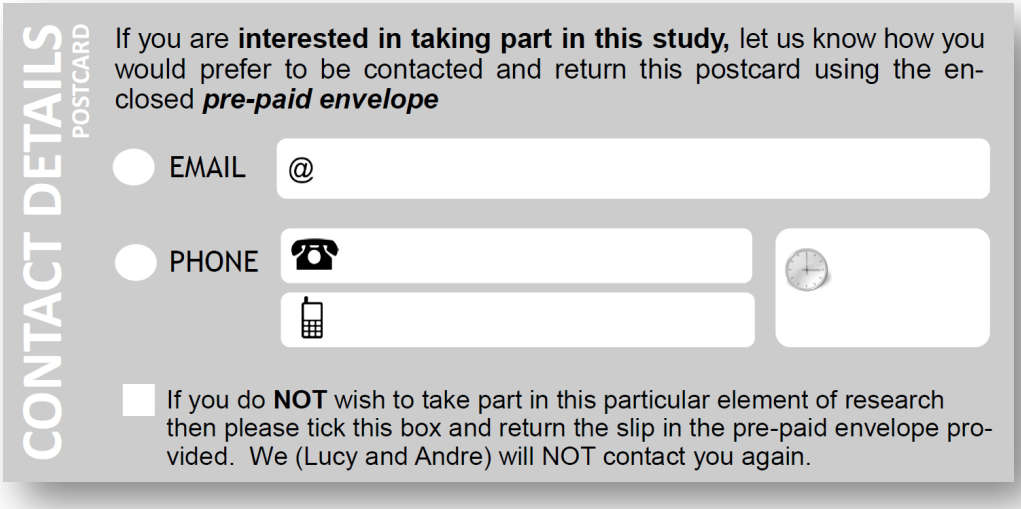
For this module we would like to ask you to wear a GPS and an actigraph monitor over a period of 7 days so that we can measure your travel behaviour and physical activity during this period.

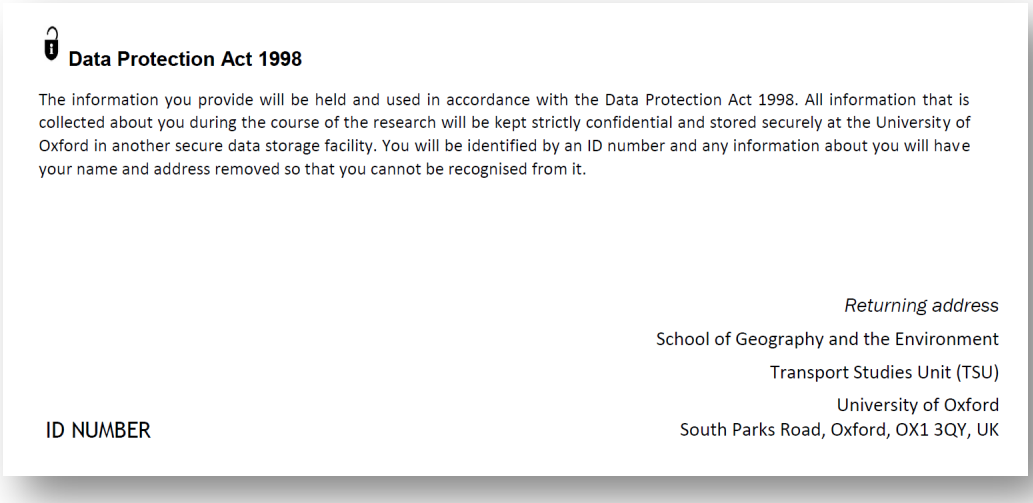
Both the devices are unobtrusive (about the size of a match box) and are simple to use. Full instructions will be provided.

At the end of the activity, we would like to have your feedback and ask you a couple of anonymous questions to complete our data set (~5min).



Contact details return postcard





Response rate

		2011						2012	
		First Wave		Second Wave		**Total**			
		n	%	n	%	n	%	n	%
Invitations sent		100		295		**395**		**69**	
Total replies received		38	38%	112	38%			61	88%
	positive	22	22%	69	23%	91	23%	53	77%
	negaitve	16	16%	43	15%	59	15%	8	12%
Successful contacts/ meetings booked		**71**						**52**	

APPENDIX C – Research ethics approval

SOCIAL SCIENCES & HUMANITIES
INTER-DIVISIONAL RESEARCH ETHICS COMMITTEE

Hayes House, 75 George Street, Oxford. OX1 2BQ
Tel: +44(0)1865 614871 Fax: +44(0)1865 614855
ethics@socsci.ox.ac.uk www.socsci.ox.ac.uk

Co-ordinator of the IDREC
Social Sciences Divisional Office



Wednesday, 9 March 2011

Andre Neves
School of Geography and the Environment

Dear Andre,

Application for research ethics approval

Ref No.: SSD/CUREC1A/11-029

Title: Evaluating change in travel and carbon following implementation of interventions to promote walking and cycling: the case of Connect2 Cardiff

The above application has been considered on behalf of the Social Sciences and Humanities Inter-divisional Research Ethics Committee (IDREC) in accordance with the procedures laid down by the University for ethical approval of all research involving human participants.

I am pleased to inform you that, on the basis of the information provided to the IDREC, the proposed research has been judged as meeting appropriate ethical standards, and accordingly approval has been granted.

Should there be any subsequent changes to the project, which raise ethical issues not covered in the original application, you should submit details to the IDREC for consideration.

Yours sincerely,



Dr Chris. Ballinger

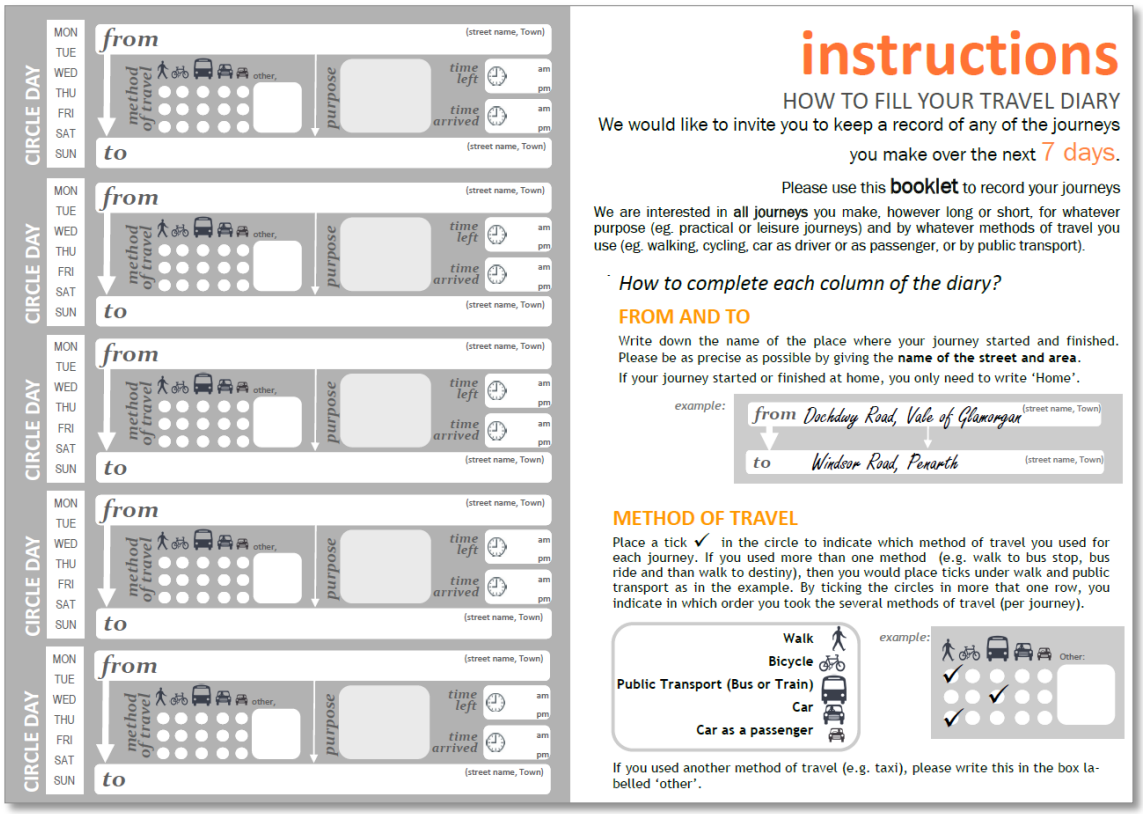
cc: Dr Christian Brand, SoGE
Dr Tim Jones, SoGE
Ruth Saxton, SoGE

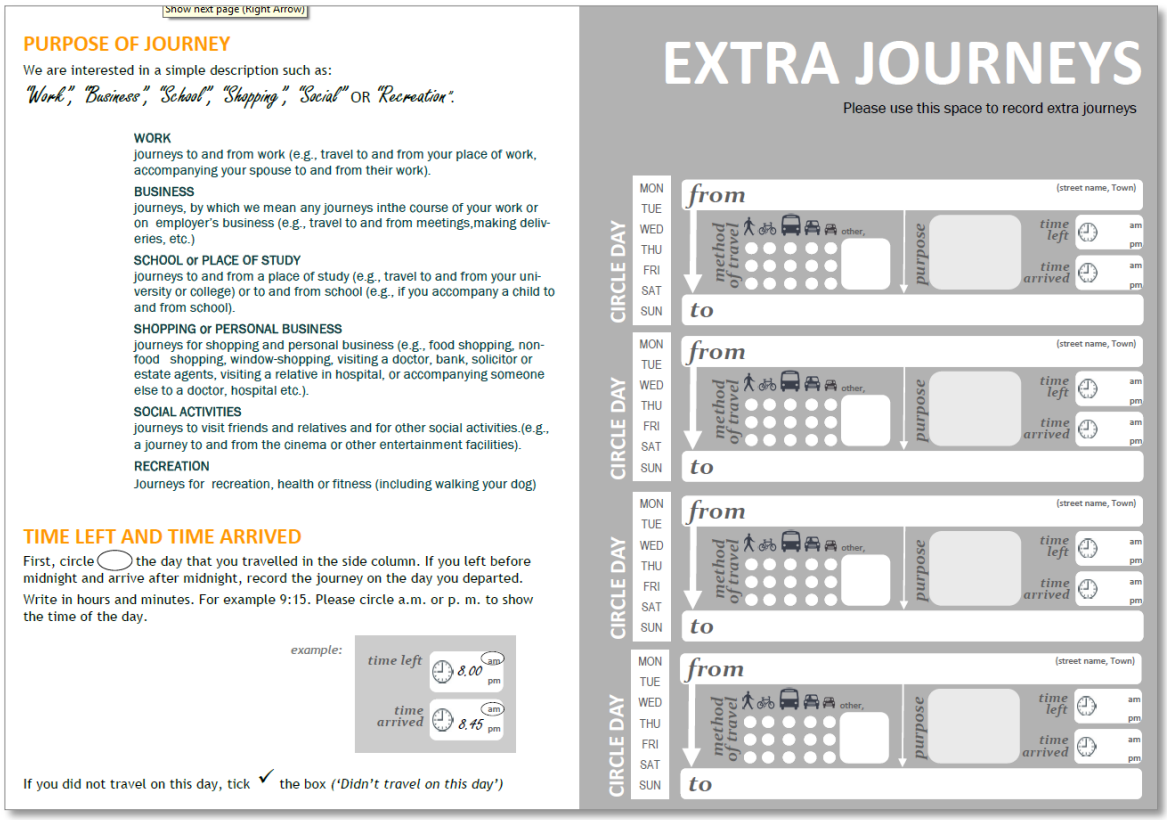
CAJB/EB

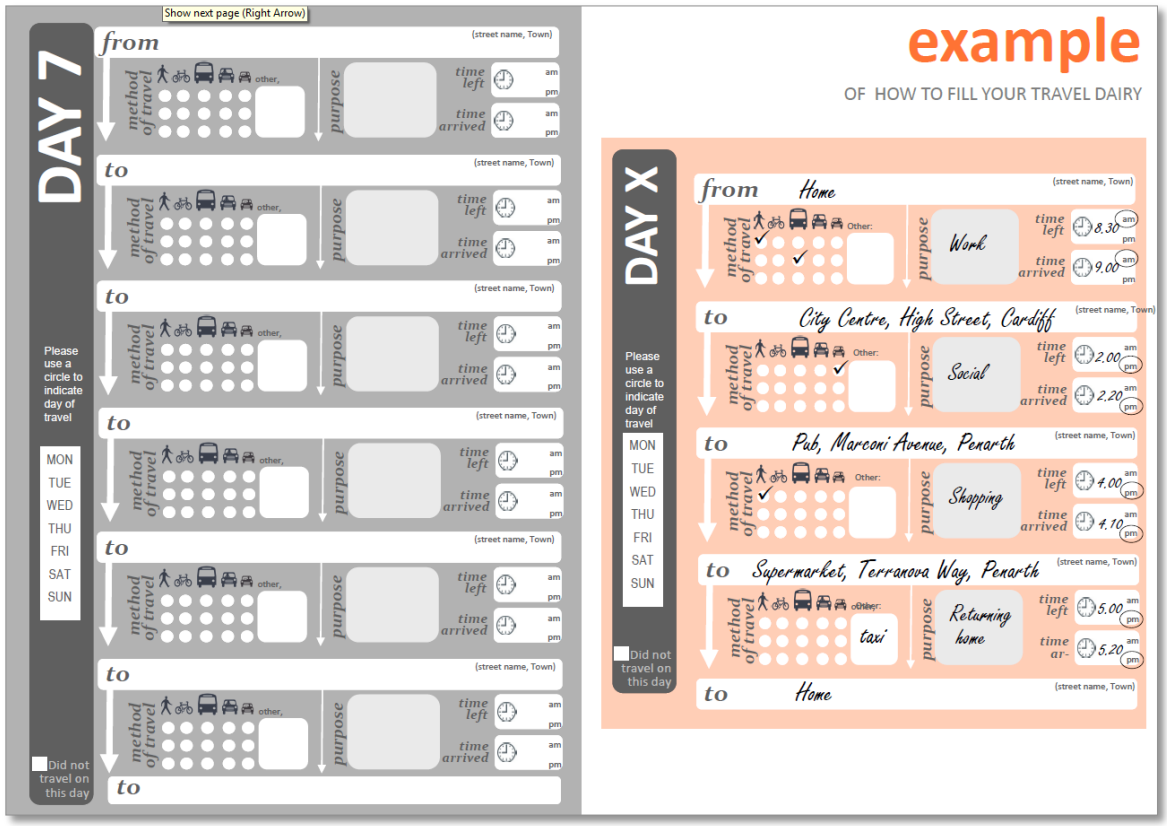
APPENDIX D – Survey Instruments: travel diary

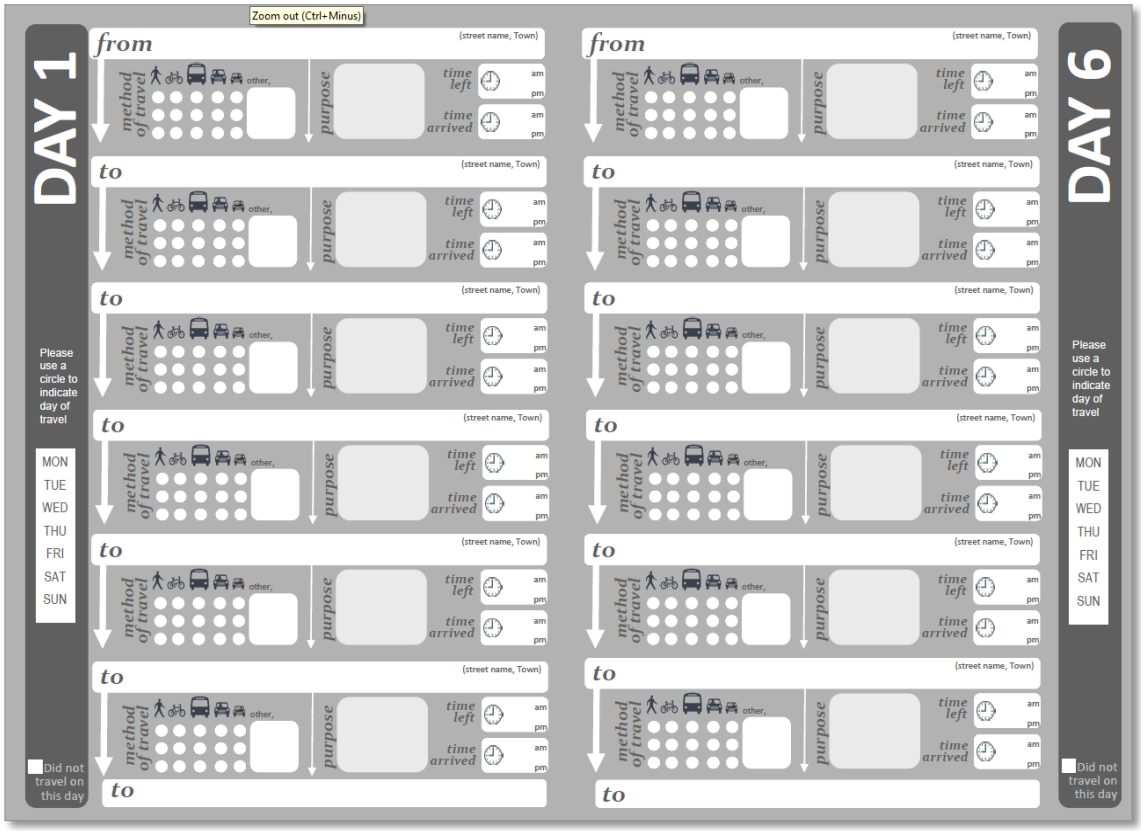
Travel Diary – final

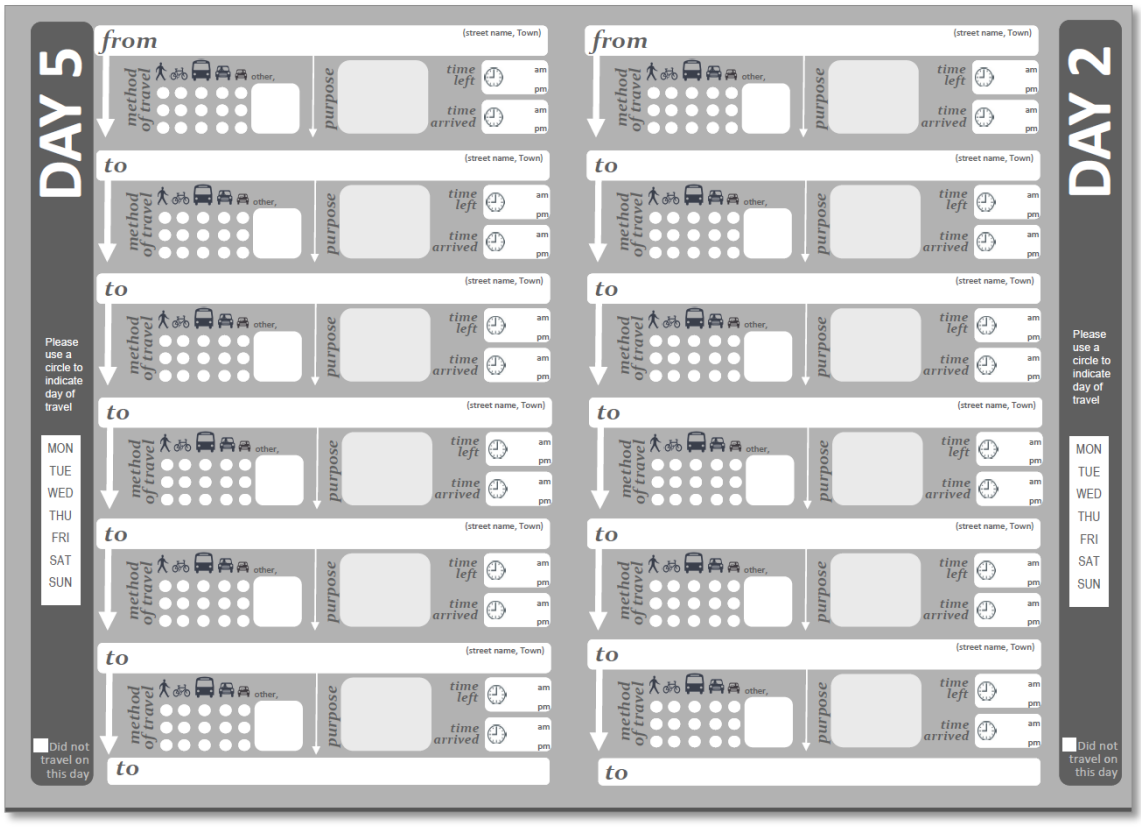


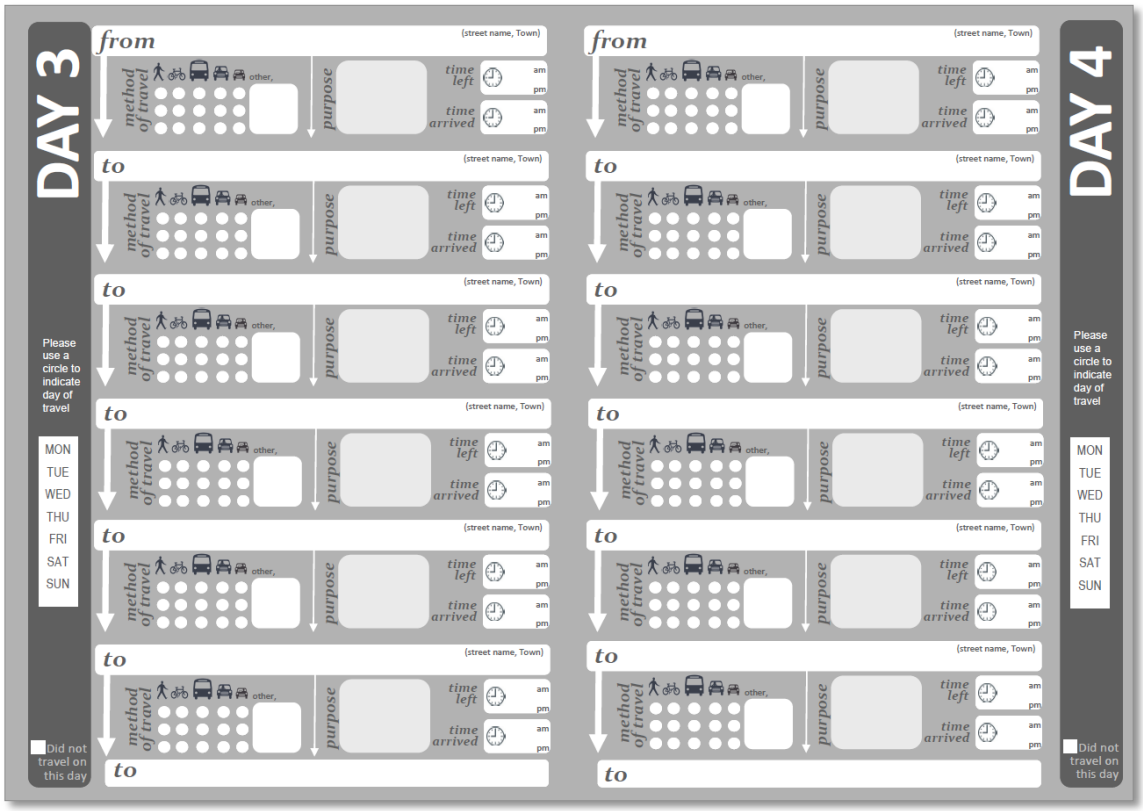



Show next page (Right Arrow)
PURPOSE OF JOURNEY
We are interested in a simple description such as:
"Work", "Business", "School", "Shopping", "Social" OR "Recreation".
WORK
journeys to and from work (e.g., travel to and from your place of work, accompanying your spouse to and from their work).
BUSINESS
journeys, by which we mean any journeys inthe course of your work or on employer's business (e.g., travel to and from meetings,making deliveries, etc.)
SCHOOL or PLACE OF STUDY
journeys to and from a place of study (e.g., travel to and from your university or college) or to and from school (e.g., if you accompany a child to and from school).
SHOPPING or PERSONAL BUSINESS
journeys for shopping and personal business (e.g., food shopping, non-food shopping, window-shopping, visiting a doctor, bank, solicitor or estate agents, visiting a relative in hospital, or accompanying someone else to a doctor, hospital etc.).
SOCIAL ACTIVITIES
journeys to visit friends and relatives and for other social activities.(e.g., a journey to and from the cinema or other entertainment facilities).
RECREATION
Journeys for recreation, health or fitness (including walking your dog)
TIME LEFT AND TIME ARRIVED
First, circle the day that you travelled in the side column. If you left before midnight and arrive after midnight, record the journey on the day you departed.
Write in hours and minutes. For example 9:15. Please circle a.m. or p. m. to show the time of the day.
example:
time left 8.00 am pm
time arrived 8.45 am pm
If you did not travel on this day, tick ✓ the box ('Didn't travel on this day')
EXTRA JOURNEYS
Please use this space to record extra journeys
CIRCLE DAY
MON TUE WED THU FRI SAT SUN
from (street name, Town)
method of travel other,
purpose
time left am pm
time arrived am pm
to


Show next page (Right Arrow)
DAY 7
Please use a circle to indicate day of travel
MON TUE WED THU FRI SAT SUN
Did not travel on this day
from (street name, Town)
method of travel other,
purpose
time left am pm
time arrived am pm
to
example
OF HOW TO FILL YOUR TRAVEL DAIRY
DAY X
Please use a circle to indicate day of travel
MON TUE WED THU FRI SAT SUN
Did not travel on this day
from Home (street name, Town)
Other:
Work
time left 8.30 am pm
time arrived 9.00 am pm
to City Centre, High Street, Cardiff (street name, Town)
Social
time left 2.00 pm
time arrived 2.20 pm
to Pub, Marconi Avenue, Penarth (street name, Town)
Shopping
time left 4.00 pm
time arrived 4.10 pm
to Supermarket, Terranova Way, Penarth (street name, Town)
taxi
Returning home
time left 5.00 pm
time ar- 5.20 pm
to Home (street name, Town)


Zoom out (Ctrl+Minus)
DAY 1
DAY 6
from
to
(street name, Town)
method of travel
other,
purpose
time left
time arrived
am
pm
Please use a circle to indicate day of travel
MON
TUE
WED
THU
FRI
SAT
SUN
Did not travel on this day


DAY 5
DAY 2
from
to
(street name, Town)
method of travel
other,
purpose
time left
time arrived
am
pm
Please use a circle to indicate day of travel
MON
TUE
WED
THU
FRI
SAT
SUN
Did not travel on this day

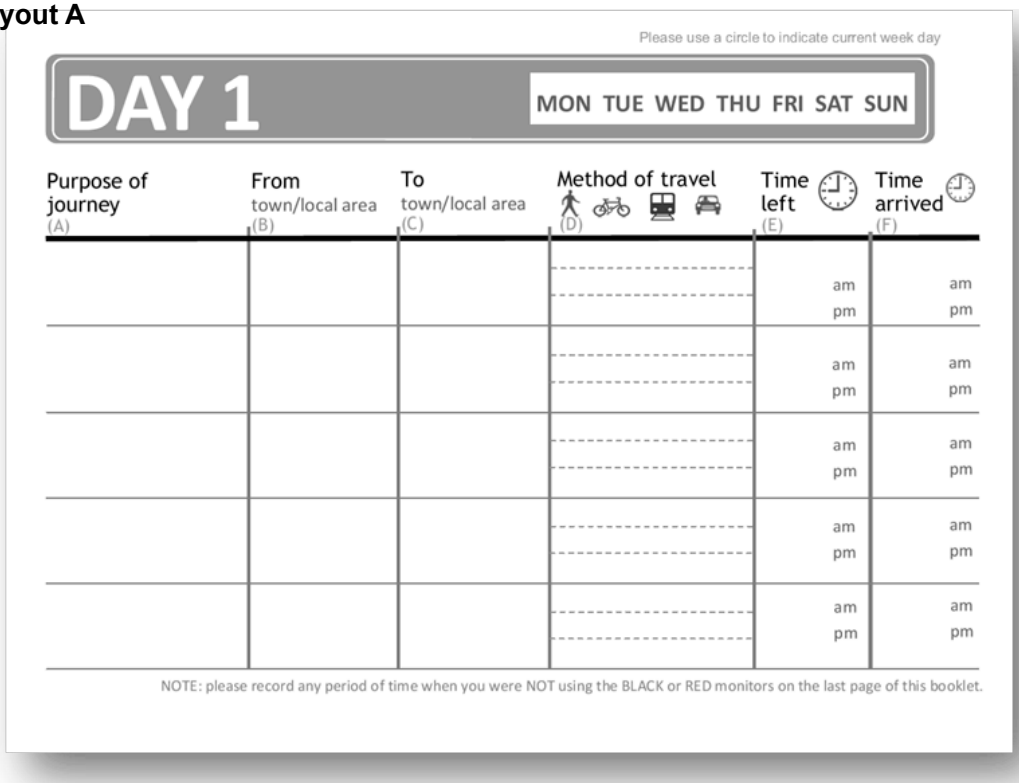


notes

PLEASE WRITE IN ANY OTHER NOTES OR COMMENTS ABOUT THE JOURNEYS YOU HAVE MADE

Other travel diaries layouts designed for this study

Layout A



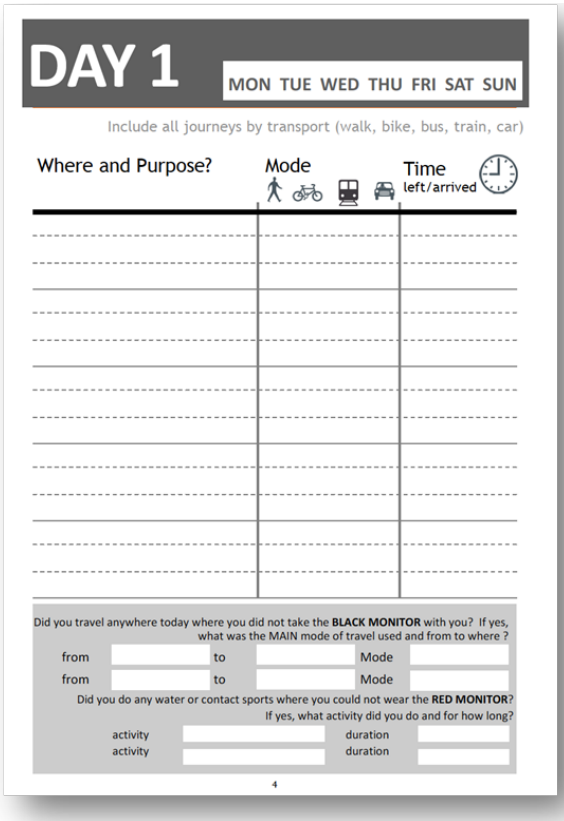
Please use a circle to indicate current week day

DAY 1 — MON TUE WED THU FRI SAT SUN

Purpose of journey (A)	From town/local area (B)	To town/local area (C)	Method of travel (D)	Time left (E)	Time arrived (F)
				am pm	am pm
				am pm	am pm
				am pm	am pm
				am pm	am pm
				am pm	am pm

NOTE: please record any period of time when you were NOT using the BLACK or RED monitors on the last page of this booklet.

Layout B



DAY 1 — MON TUE WED THU FRI SAT SUN

Include all journeys by transport (walk, bike, bus, train, car)

Where and Purpose?	Mode	Time left/arrived

Did you travel anywhere today where you did not take the **BLACK MONITOR** with you? If yes, what was the MAIN mode of travel used and from to where ?

from ____ to ____ Mode ____

from ____ to ____ Mode ____

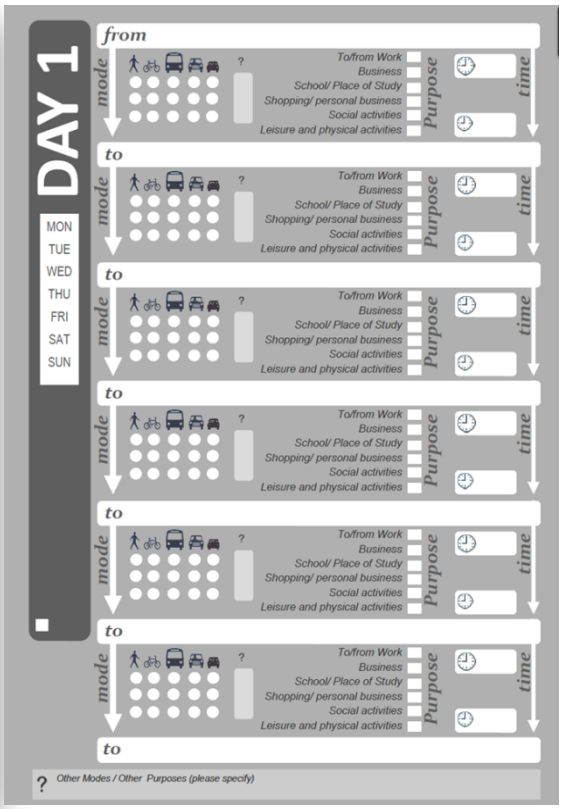
Did you do any water or contact sports where you could not wear the **RED MONITOR**? If yes, what activity did you do and for how long?

activity ____ duration ____

activity ____ duration ____

4

Layout C



DAY 1

MON TUE WED THU FRI SAT SUN

from

mode ? To/from Work / Business / School/ Place of Study / Shopping/ personal business / Social activities / Leisure and physical activities — Purpose — time

to

mode ? To/from Work / Business / School/ Place of Study / Shopping/ personal business / Social activities / Leisure and physical activities — Purpose — time

to

mode ? To/from Work / Business / School/ Place of Study / Shopping/ personal business / Social activities / Leisure and physical activities — Purpose — time

to

mode ? To/from Work / Business / School/ Place of Study / Shopping/ personal business / Social activities / Leisure and physical activities — Purpose — time

to

mode ? To/from Work / Business / School/ Place of Study / Shopping/ personal business / Social activities / Leisure and physical activities — Purpose — time

to

mode ? To/from Work / Business / School/ Place of Study / Shopping/ personal business / Social activities / Leisure and physical activities — Purpose — time

to

? Other Modes / Other Purposes (please specify)

APPENDIX E – Survey instruments: instructions for GPS devices use

Connecting Communities: The Case of Connect2 Cardiff

INSTRUCTIONS

HOW TO USE THE ACTIVITY MONITORS

EQUIPMENT



a b

There are two pieces of equipment that we are asking you to wear:

a. **BLACK DEVICE** (GPS device) that tracks travel and is able to calculate travel distance and duration.

b. **RED DEVICE** (Actigraph) that measures physical activity and energy expended

How to charge the devices?

Black device:

Recharge the GPS device EVERY EVENING once you are home for the night so that is fully charged for the following day.

You recharge the device like a mobile phone.

If the battery symbol on the front of the monitor turns red this means the battery power is low.



1

1.Attach the cable charger to the USB port on the right hand side of the device, as shown in the picture 1.

2.Plug the other end of the charger into the electric socket. Don't forget switching the socket on!



2

3.When the charger is plugged in, the battery symbol on the front of the black monitor will turn green to demonstrate that is charging. Once the battery is fully charged the battery symbol will turn off.



3

Red device:

The red monitor does not need to be recharged.

How to switch the devices on?

Black device - switch button from OFF to LOG (picture 4).

Red device - it is always ON. The battery lasts for approximately 20 days.



4

How do I know if the devices are working?

Black device

If the device is working, the orange light should be ON and flashing (picture 5).



5

As a result of the partnership with the iConnect project, participants in this study were asked to wear an Actigraph alongside a GPS device. This device was the GT3X Tri-Axis Actigraph Monitor and was wear around participant waist for successful data recording. Data collected by this device was not used in this study.

How and when do I carry the GPS device?

The monitors can be worn either underneath or on top of your clothing.

The red device should be worn on the belt on the right hip.

The black device should also be worn on the belt.



It is important that the belt is fastened tightly so that it fits snugly to the body. If it is loose the measurements will be inaccurate.

Wear the two monitors ALL DAY, EVERYDAY for the next 7 Days.



Wear the device whenever you are static sitting or travelling, regardless of the method of transported used ie. car, bus, train, bicycle, foot.

When not to use the devices?

Neither monitor is waterproof so they must NOT get wet. Please take them off when showering, bathing, rowing, or swimming and put them back on afterwards.

Please also remove monitors during contact sports and put them back on afterwards.



FAQ
FREQUENTLY ASKED QUESTIONS

I don't use much technology, what if I can't work the monitor properly?

The GPS monitors are simple to use and do not require any specialist knowledge. If you have any query, we will be happy to help you. You can also call the number below.

Will the GPS monitor harm me in any way?

No, the GPS monitor cannot harm you, The rechargeable battery is securely housed in the device shell. The monitor does not emit radiation, electrical current, vibration or heat.

What if I lose or damage the monitor?

The monitor is an expensive piece of equipment. We would appreciate your help in keeping it safe at all times. However, in case something happens please contact us as soon as possible.

I am already completing a diary, why do you need me to carry a GPS device as well?

The GPS monitor will provide us with additional information on routes taken and duration of travel, as well as accurate distance and time data.

Are you doing this so you can keep track of where I go?

The GPS monitor doesn't transmit your position back to a central computer but simply stores the data in its memory until the device is returned. It does not store any of your personal details.

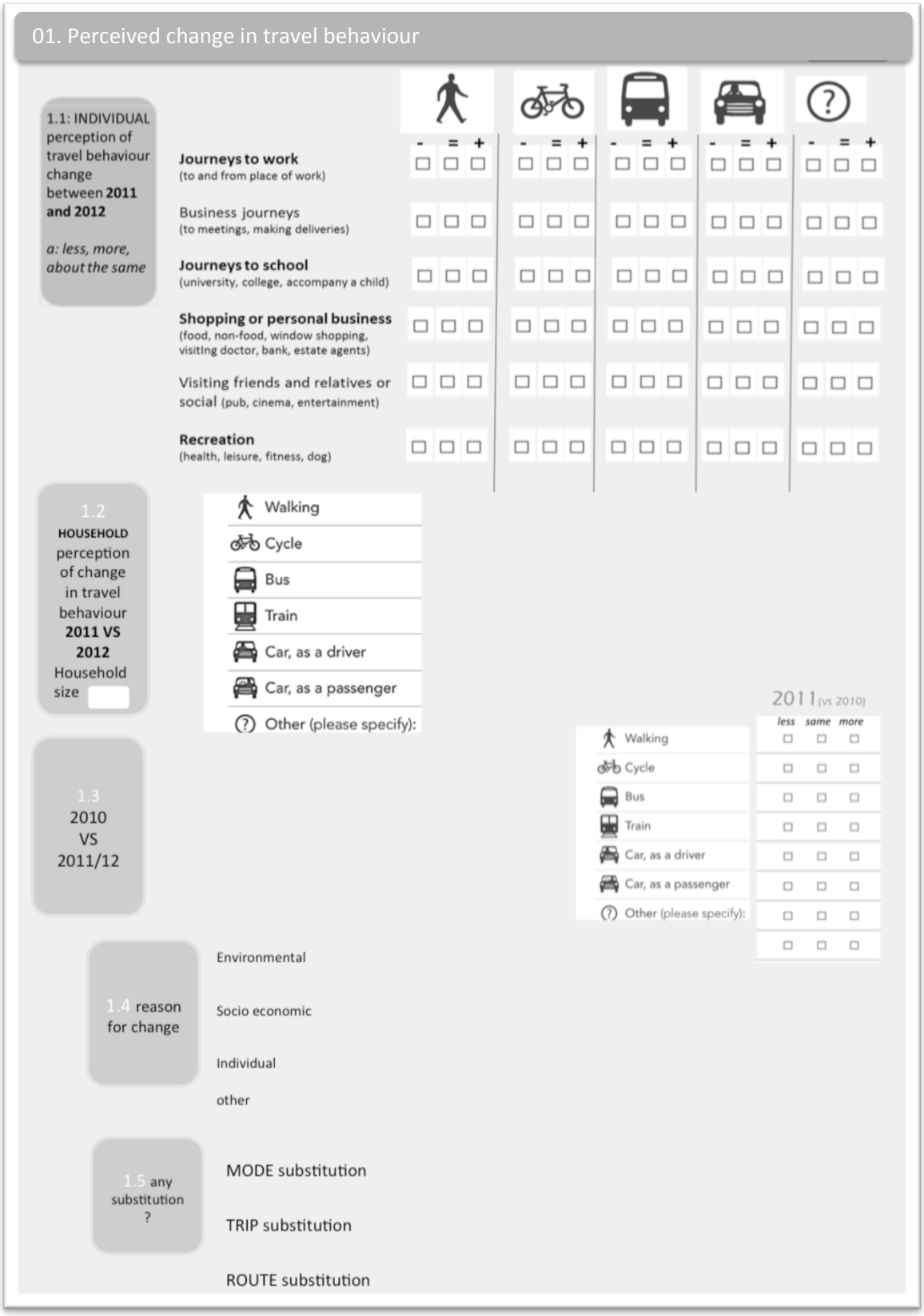
I don't travel much; will I need to use a GPS monitor?

It is important that we include everyone's experiences of travel however much or little they do. Carrying a GPS monitor on the journeys you do make will help to ensure the information we collect is representative of the different types of journeys undertaken.

If you wish to turn off the device at any point for the purpose of protecting your privacy then please do so. However, we would be grateful if you could remember to turn the device back when you are comfortable to do so.

If you have any other questions or are having problems with your devices, please contact Andre Neves on andre.neves@ouce.ox.ac.uk or 07964782411

APPENDIX F – Questionnaire to guide exit interview



02. Walking and cycling behaviour

2.1 your general W & C behaviour: do you usually walk or cycle?

		WALK 	CYCLE 
If YES	How Many/times week/ month?		
	For which purpose?		**Type of cyclist?:** *_Starting to cycle again _Occasional cyclists _Experienced, occasional cyclist _Experience, regular cyclist*
	For how long/ how far? (time/distance)		
	Reasons/ motivations?		
	SPATIALLY – where does it take place		
If NO	Why not? Reasons/motivations?		
	Would be feasible/ possible for you to do any journeys using this transport mode? Which type of journeys/ purpose/distance/ duration?		
What would be important to get more people to W or C?			
Constraints of W & C in Penarth			

03. New Connect2 walking and cycling infrastructure

To what extent the C2 has altered patterns of behaviour, Do you walk or cycle now more frequent due to the new bridge?

IF YES,

For what PURPOSE?

3.3How many times (daily, 2-5 time week, weekly, fortnight, month, yearly)?

(Advantages, disadvantages, problems found?)

What other modes of transport you could have used to complete the journey you did when using the new bridge?

04. Socio-demographics/ feedback on survey methodology infrastructure

	Not a prob.	neutral	difficult
Charging the devices	☐	☐	☐
Using the GPS device	☐	☐	☐
Using the actigraph	☐	☐	☐
Filling in the travel diary	☐	☐	☐

General Problems

forgot to carry
inconvenient to carry
battery ran out
problem charging
other

Gender: M F **Age**

Employment full time, part time, student, retired, unemployed,

Education **degree, higher, GCE level, GCESE Grades, other**

Total household income:

up to 10,000 20,000 30,000 40,0000 more than 50,000 don't know

Car **make**…… **Model**……**Fuel** *petrol diesel*

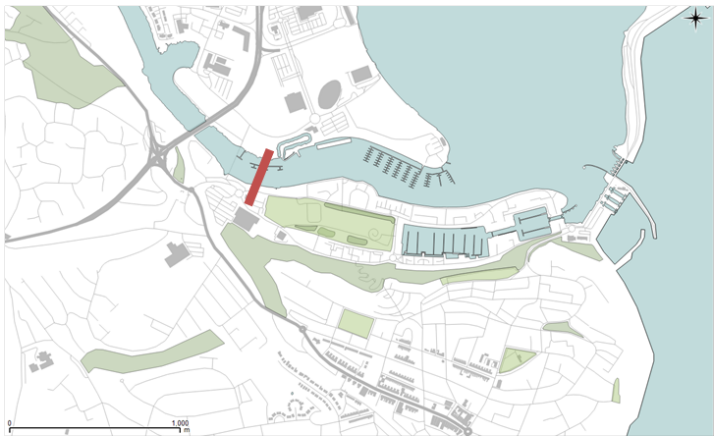
Engine size…… **Age**

Bicycles

APPENDIX G – Infrastructure provision in the case study site

Timeline - infrastructure provision in the case study site

2010



2011

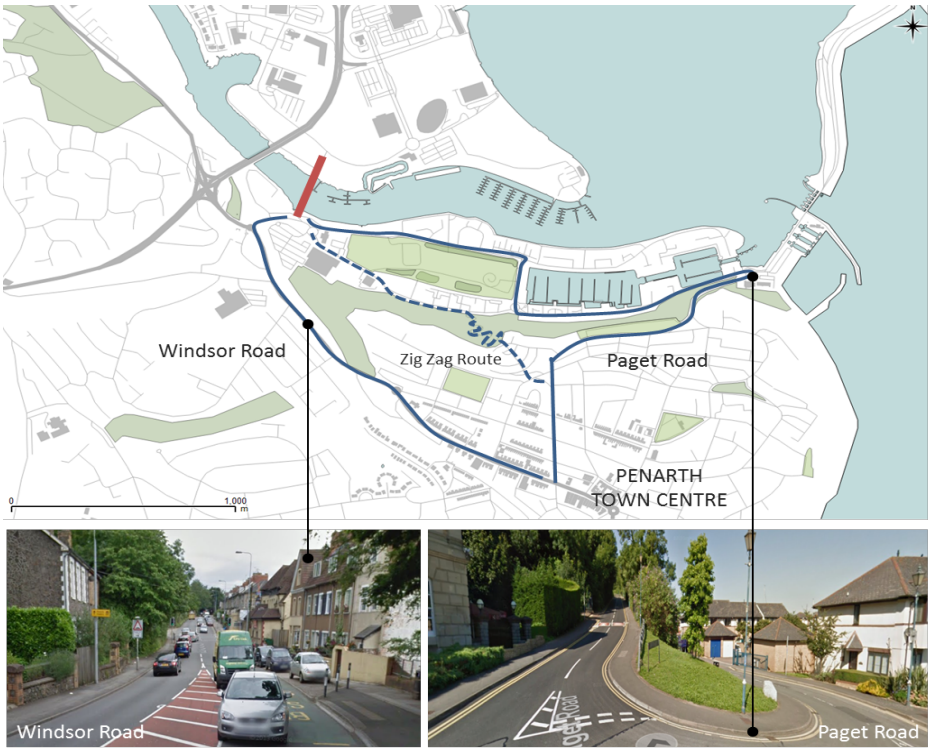


2012



Segregated cycle/footpath (bridge)
On road cycle lane
Repaving existing off road path

Feeder routes to Connect2 Scheme (south) prior to the implementation of "Zig Zag route"



Existing routes over river Ely linking Penarth to Cardiff prior to the implementation of the new Connect2 Scheme

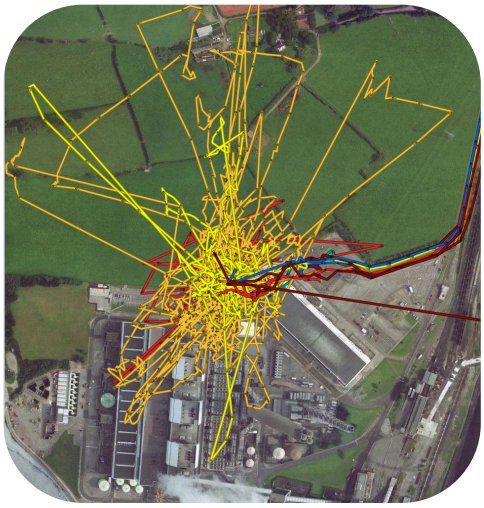


APPENDIX H – GPS data cleaning

Examples of GPS data cleaning – before and after

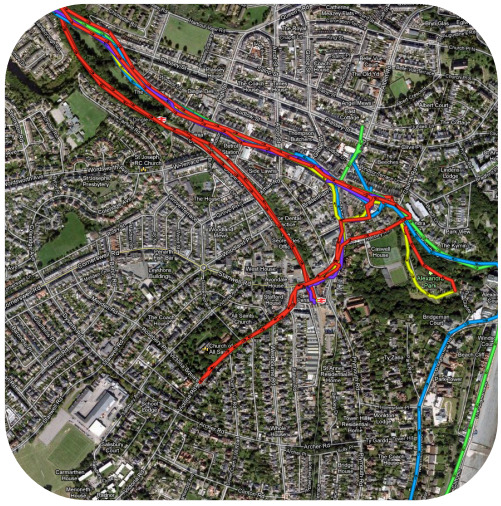










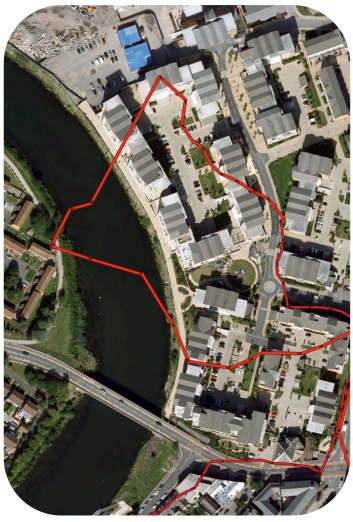


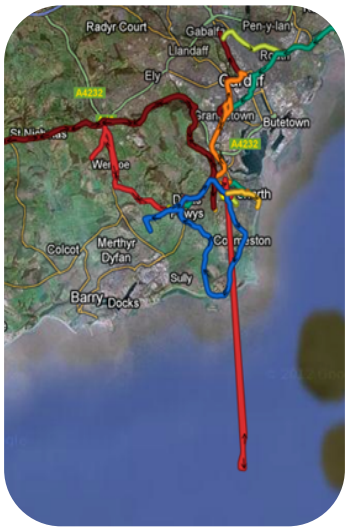
Examples of GPS data map matching – before and after

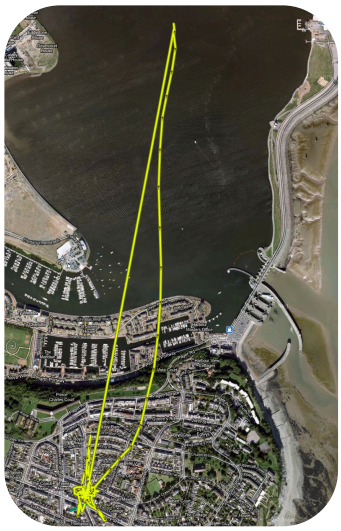


Examples of GPS data errors

Example of GPS records influenced by signal loss



Example of GPS trips influenced by cold start signal issue




APPENDIX I – Data coding

Data set – attributes description

Field name	Attribute description
PARTICIPANT	Participant ID number
ID	Stage ID
StartLat/ Start Long	Decimal degress DDD/DDDD
Start Time	Date Time YYYY-MM-DD HH:MM:SS
EndLat/ End Long	Decimal degress DDD/DDDD
End Time	Date Time YYYY-MM-DD HH:MM:SS
TRIP TYPE	T, S, MS, RT (trip, stage, multimodal stage or round trip)
TRIP MODE_ALL	Bicycle, boat, bus, car, car passenger, motorbike, taxi, train, tube
TRIP MODE_4	BICYCLE WALK CAR CAR PASSENGER PT (public transport)
TRIP PURPOSE	A - commuting B - business C - education escort D- shopping or personal business E – Social or visiting friends and family F - Recreation G - Other leisure
DISTANCE (KM)	km
DISTANCE(MILES)	miles
Average Speed	Km/h
Duration	HH:MM
WEEKDAY	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday
TD START	TEXT: trip start location coded by participant in travel diary
TD FINISH	TEXT: trip end location coded by participant in travel diary
TD_MODE	TEXT: trip mode coded by participant in travel diary
TD_PURPOSE	TEXT: trip purpose coded by participant in travel diary
TD_start time	TEXT: trip start time coded by participant in travel diary
TD_end time	TEXT: trip end time coded by participant in travel diary
TD_NOTES	TEXT: contextual notes provided by the participant on the travel diary
MY_NOTES	TEXT ; Notes on editing performed or any other particular feature
Route_C2 Scheme	1 if over route; 0 if over another route
Route_barrage	1 if over route; 0 if over another route
Route_Penarth Road	1 if over route; 0 if over another route
Route_Spur	1 if over route; 0 if over another route

Participant	ID	StartLat	StartLon	StartTime	EndLat	EndLon	EndTime	TRIP TYPE	TRIP MODE	MAIN TRIP PURPOSE	DISTANCE (meters)	DISTANCE_ miles	AVERAGE SPEED	td_start	td_finish	td_mode	td_PURPOSE	DETAILED_T	td_time_le	td_time_ar	MYNOTES	td_comment	Route_C2 Bridge	Route_Barrage	Route_Spur	Route_Penarth Road
26	2601	51.44207764	-3.186934948	2012-07-06 11:10:10 +0000	51.4393425	-3.172961	2012-07-06 11:23:59 +0000	T	WALK	TOFROMSHOPS	1214.793	0.8	5.3	home	penarth town cent	walk	shopping	SHOPOTHER	12:00:00	12:15:00			0	0	0	0
26	2602	51.43925476	-3.173222065	2012-07-06 11:25:04 +0000	51.44221878	-3.1879261	2012-07-06 11:56:33 +0000	T	WALK	TOFROMSHOPS	1269.927	0.8	2.4	penarth town centre	home	walk	rtn home	RHF SHOPS	12:45:00	13:00:00			0	0	0	0
26	2603	51.44267273	-3.188553095	2012-07-07 10:46:36 +0000	51.44551849	-3.1679349	2012-07-07 11:14:48 +0000	T	WALK	SOCIAL	2181.545	1.4	4.6	home	penarth barrage	walk	social activ	SOCIAL	12:00:00	12:30:00			0	0	0	0
26	2604	51.44603729	-3.167200089	2012-07-07 12:02:23 +0000	51.46291733	-3.1649411	2012-07-07 12:12:38 +0000	T	BOAT	SOCIAL	1924.109	1.2	11.3	penarth barrage	mermaid quay	boat	social activ	SOCIAL	13:00:00	13:15:00			0	0	0	0
26	2605	51.46482468	-3.164804936	2012-07-07 18:11:14 +0000	51.47170639	-3.184221	2012-07-07 18:32:54 +0000	T	WALK	SOCIAL	1802.313	1.1	5	mermaid quay	vegetarian food st	walk	social activ	EATOTHER	18:30:00	19:00:00			0	0	0	0
26	2606	51.4720726	-3.184649944	2012-07-07 20:09:34 +0000	51.48197174	-3.2021141	2012-07-07 20:32:59 +0000	T	WALK	SOCIAL	2068.12	1.3	5.3	vegetarian food stu	chapter arts centre	walk	social activ	PSA	21:00:00	21:30:00			0	0	0	0
26	2607	51.48199081	-3.202027082	2012-07-07 21:47:50 +0000	51.44239426	-3.188345	2012-07-07 21:59:25 +0000	T	R PASSENG	HOME	5349.06	3.3	27.7	chapter arts centre	home	car passen	rtn home	RHF PSA	22:30:00	22:45:00			0	0	0	1
26	2608	51.44221878	-3.187979937	2012-07-08 10:55:57 +0000	51.44922256	-3.1805761	2012-07-08 11:01:27 +0000	T	BICYCLE	RECREATION	1305.98	0.8	14.2	home	cardiff internation	bicycle	recreation	SPLACE	11:50:00	12:00:00			1	0	0	0
26	2609	51.44927979	-3.180603027	2012-07-08 11:04:35 +0000	51.44906998	-3.1811609	2012-07-08 11:58:17 +0000	RT	WALK	RECREATION	7783.875	4.8	8.7	cardiff internationa	cardiff internation	walk	run	SRUN	12:00:00	13:00:00			1	1	0	0
26	2610	51.44924927	-3.180572987	2012-07-08 12:00:33 +0000	51.44234848	-3.188108	2012-07-08 12:08:37 +0000	T	BICYCLE	HOME	1265.265	0.8	9.4	cardiff internationl	home	bicycle	rtn home	RHF SPORT	13:05:00	13:15:00			1	0	0	0
26	2611	51.44240189	-3.188088894	2012-07-08 16:56:30 +0000	51.44624329	-3.188899	2012-07-08 17:02:30 +0000	S	BICYCLE	SOCIAL	542.7062	0.3	5.4	home	DINGLE TRAIN STAT	bicycle + PT	social	SOCIAL	17:55:00	12:40:00			0	0	0	0
26	2612	51.44624329	-3.18889904	2012-07-08 17:02:30 +0000	51.39707565	-3.285033	2012-07-08 17:20:36 +0000	MS	TRAIN	SOCIAL	9173.741	5.7	30.4	DINGLE TRAIN STAC	BARRY TRAIN STATI	bike + PT +	rtn home	SOCIAL	20:30:00	17:55:00			0	0	0	0
26	2613	51.39707565	-3.285032988	2012-07-08 17:20:36 +0000	51.39408112	-3.3159189	2012-07-08 17:43:31 +0000	T	BICYCLE	RECREATION	2912.403	1.8	7.6	BARRY TRAIN STATIC	PORTHKERRY PORTH								0	0	0	0
26	2614	51.39408112	-3.315918922	2012-07-08 17:43:31 +0000	51.39392471	-3.3169	2012-07-08 19:15:46 +0000	T	WALK	RECREATION	1702.923	1.1	1.1	PORTHKERRY PORTH	PORTHKERRY PORTH								0	0	0	0
26	2615	51.39413834	-3.315372944	2012-07-08 19:26:41 +0000	51.39688873	-3.284693	2012-07-08 19:58:56 +0000	T	BICYCLE	RECREATION	4856.214	3	9	PORTHKERRY PORTH	BARRY TRAIN STATION								0	0	0	0
26	2616	51.39696503	-3.284575939	2012-07-08 19:59:06 +0000	51.44631958	-3.189142	2012-07-08 20:15:25 +0000	MS	TRAIN	RECREATION	9170.135	5.7	33.7	BARRY TRAIN STATIC	DINGLE TRAIN STATION								0	0	0	0
26	2617	51.44631958	-3.189141989	2012-07-08 20:15:25 +0000	51.44229889	-3.1881721	2012-07-08 20:19:18 +0000	S	BICYCLE	RECREATION	653.8077	0.4	10.1	DINGLE STATION	HOME								0	0	0	0
26	2618	51.44229126	-3.188141108	2012-07-09 07:10:43 +0000	51.44638443	-3.1891	2012-07-09 07:17:48 +0000	S	WALK	TOFROMWORK	630.3973	0.4	5.3	home	cogan train station	walk	work	COM HW	08:05:00	08:45:00			0	0	0	0
26	2619	51.44638443	-3.189100027	2012-07-09 07:17:48 +0000	51.48920059	-3.179621	2012-07-09 07:41:28 +0000	MS	TRAIN	TOFROMWORK	6685.943	4.2	17	cogan train station	cathays train stati	train	work	COM HW					0	0	0	0
26	2620	51.48920059	-3.179620981	2012-07-09 07:41:28 +0000	51.48801422	-3.1809511	2012-07-09 07:45:33 +0000	S	WALK	TOFROMWORK	314.0055	0.2	4.6	cathays train statio	cathays park office	walk	work	COM HW					0	0	0	0
26	2621	51.48772812	-3.180388928	2012-07-09 08:39:36 +0000	51.65756989	-3.01613	2012-07-09 09:29:29 +0000	T	TRAIN	CWORK	32738.55	20.3	39.4	cathays park office	Cumbran	train	work	CWORK	09:45:00	10:30:00		" I went on various site visits with work. You will have a beter idea from the GPS but in order we went to Pontre Lana, Canal south of Cumbra,	0	0	0	0
26	2622	51.65756989	-3.016129971	2012-07-09 09:29:29 +0000	51.60584259	-3.0918651	2012-07-09 14:50:31 +0000	T	R PASSENG	CWORK	52035.53	32.3	9.7	Cumbran	various site visits	car passen	work	CWORK	10:30:00	15:50:00			0	0	0	0
26	2623	51.60565948	-3.091320992	2012-07-09 15:06:56 +0000	51.44615936	-3.18892	2012-07-09 15:49:10 +0000	MS	TRAIN	TOFROMWORK	28866.1	17.9	41	various site visits ri	cogan train statio	train	rtn home	RHF WORK	15:50:00	16:50:00			0	0	0	0
26	2624	51.44615936	-3.188920021	2012-07-09 15:49:10 +0000	51.445961	-3.1858561	2012-07-09 15:58:00 +0000	S	WALK	TOFROMSHOPS	358.5128	0.2	2.4	cogan train station	tesco penarth mar	walk	shopping	SHOPFOOD					0	0	0	0
26	2625	51.445961	-3.185856104	2012-07-09 15:58:00 +0000	51.44234467	-3.188185	2012-07-09 16:13:35 +0000	T	WALK	TOFROMWORK	833.4545	0.5	3.2	tesco penarth marir	home	walk	rtn home	RHF WORK	17:05:00	17:15:00			0	0	0	0
26	2626	51.44265747	-3.188674927	2012-07-10 07:11:29 +0000	51.44630051	-3.1889949	2012-07-10 07:16:08 +0000	S	WALK	TOFROMWORK	589.3511	0.4	7.6	home	cogan train statio	walk	work	COM HW	08:05:00	09:00:00			0	0	0	0
26	2627	51.44621277	-3.188870907	2012-07-10 07:16:28 +0000	51.56810761	-3.290164	2012-07-10 07:51:46 +0000	MS	TRAIN	TOFROMWORK	19239.54	12	32.7	cogan train station	treforest train stat	train	work	COM HW			edited 15%, missing track, edited based on short route and previious trips		0	0	0	0
26	2628	51.56810761	-3.290163994	2012-07-10 07:51:46 +0000	51.5692749	-3.287787	2012-07-10 07:56:46 +0000	S	WALK	TOFROMWORK	400.6647	0.2	4.8	treforest train statio	QED Centre, Trefor	walk	work	COM HW					0	0	0	0
26	2629	51.56918335	-3.287719965	2012-07-10 16:41:03 +0000	51.56812286	-3.29006	2012-07-10 16:45:03 +0000	S	WALK	TOFROMWORK	374.8092	0.2	5.6	QED Centre, Trefore	treforest train stat	walk	rtn home +s	RHF WORK	17:40:00	18:05:00			0	0	0	0
26	2630	51.56812286	-3.290060043	2012-07-10 16:45:03 +0000	51.48890305	-3.1787381	2012-07-10 17:01:53 +0000	MS	TRAIN	TOFROMWORK	12788.75	7.9	45.6	treforest train statio	cathays train stati	train	social	SOCIAL					0	0	0	0
26	2631	51.48890305	-3.178738117	2012-07-10 17:01:53 +0000	51.48357391	-3.1752341	2012-07-10 17:10:28 +0000	T	WALK	SOCIAL	679.2303	0.4	4.7	cathays train statio	Bellinis, Park Place	walk	social	SOCIAL					0	0	0	0
26	2632	51.48243713	-3.17414999	2012-07-10 18:37:02 +0000	51.47521973	-3.179446	2012-07-10 19:06:40 +0000	S	WALK	TOFROMWORK	1338.748	0.8	2.7	Bellinis, Park Place	cardiff train statio	walk	rtn home	RHF WORK	19:30:00	20:25:00			0	0	0	0
26	2633	51.47521973	-3.179445982	2012-07-10 19:06:40 +0000	51.44005585	-3.1801381	2012-07-10 19:15:30 +0000	MS	BUS	TOFROMWORK	5277.792	3.3	35.8	cardiff train station	dingle train statio	train	rtn home	RHF WORK					0	0	0	0
26	2634	51.44005585	-3.180138111	2012-07-10 19:15:30 +0000	51.44197083	-3.1877649	2012-07-10 19:24:15 +0000	S	WALK	TOFROMWORK	755.6223	0.5	5.2	dingle train station	HOME	walk	rtn home	RHF WORK					0	0	0	0
26	2635	51.44645309	-3.188949108	2012-07-11 07:14:10 +0000	51.56803894	-3.2901361	2012-07-11 07:52:20 +0000	MS	TRAIN	TOFROMWORK	19298.28	12	30.3	cogan train station	treforest starte tra	train	work	COM HW					0	0	0	0
26	2636	51.56803894	-3.290136099	2012-07-11 07:52:20 +0000	51.5694046	-3.287997	2012-07-11 07:58:05 +0000	S	WALK	TOFROMWORK	459.5138	0.3	4.8	treforest starte trair	QED Centre, Trefor	walk	work	COM HW					0	0	0	0
26	2637	51.56796265	-3.285501957	2012-07-11 11:13:27 +0000	51.56673813	-3.282485	2012-07-11 11:17:22 +0000	T	WALK	PB	300.7761	0.2	4.6	QED Centre, Trefore	post office, main a	walk	personal bi	PB	12:10:00	12:20:00			0	0	0	0
26	2638	51.56642151	-3.283248901	2012-07-11 11:25:14 +0000	51.56952667	-3.287622	2012-07-11 11:32:52 +0000	T	WALK	PB	484.5126	0.3	3.8	post office, main av	QED Centre	walk	personal bi	PB	12:25:00	12:35:00			0	0	0	0
26	2639	51.56803131	-3.289984942	2012-07-11 15:16:37 +0000	51.44632339	-3.189173	2012-07-11 15:51:29 +0000	MS	TRAIN	TOFROMWORK	19298.58	12	33.2	treforest train statio	cogan train statior	train	rtn home	RHF WORK					0	0	0	0
26	2640	51.44632339	-3.189172983	2012-07-11 15:51:29 +0000	51.44239426	-3.1883199	2012-07-11 15:57:54 +0000	S	WALK	TOFROMWORK	549.679	0.3	5.1	cogan train station	HOME	walk	rtn home	RHF WORK					0	0	0	0
26	2641	51.44229126	-3.188126087	2012-07-11 16:53:21 +0000	51.4420166	-3.18718	2012-07-11 18:01:09 +0000	RT	WALK	RECREATION	7272.956	4.5	6.4	HOME	home	walk	recreation	SRUN	17:50:00	19:00:00			0	0	0	0
26	2642	51.44462204	-3.186975956	2012-07-12 07:10:34 +0000	51.4464798	-3.1889789	2012-07-12 07:13:59 +0000	S	WALK	TOFROMWORK	298.4367	0.2	5.2	home	cogan train staion	walk	work	COM HW	08:05:00	08:30:00			0	0	0	0
26	2643	51.44641495	-3.189013958	2012-07-12 07:20:59 +0000	51.48889542	-3.1788709	2012-07-12 07:35:44 +0000	MS	TRAIN	TOFROMWORK	6645.061	4.1	27	cogan train staion	cathays train stati	train		COM HW					0	0	0	0
26	2644	51.48889542	-3.178870916	2012-07-12 07:35:44 +0000	51.48806	-3.1811571	2012-07-12 07:40:09 +0000	S	WALK	TOFROMWORK	368.4637	0.2	5	cathays train statio	cathays park office	walk		COM HW					0	0	0	0
26	2645	51.48913956	-3.179155111	2012-07-12 14:02:07 +0000	51.44630051	-3.188966	2012-07-12 14:17:25 +0000	MS	TRAIN	TOFROMWORK	6562.192	4.1	25.7	cathays train statio	cogan train staion	train		RHF WORK					0	0	0	0
26	2646	51.44630051	-3.188966036	2012-07-12 14:17:25 +0000	51.4425087	-3.188379	2012-07-12 14:23:45 +0000	S	WALK	TOFROMWORK	529.3823	0.3	5	cogan train staion	HOME	walk		RHF WORK					0	0	0	0

Travel Diaries Contextual Notes - examples

Days with no travel	*I stayed at home all day;* *I did not not travel on day 4 and day 7;* *On day 4, I end up working from home so have no travelled on this day.*
Factors influencing behaviour	*I was likely to have walked more during this week as weather was particularly good.* *I did not walk as much I usually do as weather conditions were poorly during this week.* *My son was ill during this week and needed to stay at home; therefore, I didn't do the school run on a daily basis as I usually do and spend more time at home.* *I had some bulky items to take to work, so drove my car, instead of travelling by train, as I usually do.* *This was my first journey on bike since I have been knocked down of my bike.* *I drove my child to school on this day as she missed the school bus.* *Weather was lovely on Sunday. We walked along beach and cliffs and stopped for an hour for a picnic lunch.* *Atypical journey to a funeral and church service.* *Unusual work week as I worked from the Bristol office on Wednesday and Friday.* *I travelled by train to work on this day instead of cycling as it was raining so much.* *Unusual three days of car travel as my wife was in the hospital.* *Pouring rain all day – didn't go for a walk as usually do.* *I usually commute to work by train but on this day decide to take the car as it was raining so much.*
Explaining route choice	*I did school run on Friday via longer route as I needed to drop off some items at a friends house.* *I cycled over the new Connect2 route as it was very windy along the Barrage route.* *I was driving to go to the supermarket but as there was a huge traffic queue and turned around and returned home.* *Walk around the block to soothe the baby!* *I went for a walk Cardiff Bay but stopped several times along the way for bird watching.* *I walked to met my wife who was travelling by car. I then drove back home instead of taking the bus.* *I crossed the new bridge twice while running around Cardiff Bay.* *While cycling on the way home, I stopped in a bus stop to get shelter from heavy rain.* *Purpose of the atypical travel pattern was recreation - checking best spot/ beach to go surfing;* *Long trip by motorbike – purpose, to recharge battery of motorbike.* *On my returning journey from work I stopped to return a part for my car (at X) and pick up a parcel (at Y).* *I was looking for spaces available to park my car.*
Device Issues	*I took the device on the commuting journey to work but forgot to turn it on.* *On day 3 GPS device battery ran out.* *I had the GPS device in wrong setting on the first journey of the day. I set it up correctly around 10.30am.* *Day 1 – sorry - left monitors at work* *I might have forgotten to turn GPS device on on day 7.* *Friday, I forgot GPS device for journey 3 and 4.* *On my went to the supermarket on Terra Nova Way, I forgot to take the GPS device.* *GPS device does not seem to be charging correctly after full night on charge is still showing a red light.* *I took the device on the commuting journey to work but forgot to turn it on.* *Forgot to switch device for first 30 min on trip from London to Cardiff by car* *Forgot to use GPS device on the morning of day 4.*

Trip purpose classification - examples

Participants were asked to record purpose of each trip made during survey period in the travel diary provided. Participants were instructed that the study was interested in understanding if the trips made were for work, business, school or place of study, shopping or personal business, social activities or recreation. Participants were told however that they could describe as much as possible the purpose of the trip made. This approach has generated a wide range of expressions. Some examples below:

Take wife to work
Going to allotment
out of office meeting
pick up grand daughter
just for pleasure
Walk Monty (dog walking)
Going for a recording session
band practice
Pick up son from school
Visit family
Take children to brass lesson
Church service
Collect money for sick friend
Drop colleague at home
Drop friend at home
Collect son from nursery
Cycle ride to … (route description)
DVD hire
band rehearsal
Pick up grand children
Take family to church
Go mountain cycling
Wedding service practice
Watch football match
Take children swimming
Library drop off via Sully road (route detail)
Circular walk
Going for music lesson
leisure - taking out granddaughter
Place of study (learning welsh)
Recreation - car ride
Social - baby music class
Walk to a food festival
Take kids to yoga class
To watch classic cars parade
To collect friend - car sharing to work
Cycle ride to meet other cyclists
Take children swimming
Take children to choir
Take children to see film
Going to supermarket to buy newspaper
Fuel (petrol station)
Garage (car service)
Errands
Window shopping
Visit client

APPENDIX J – Tables: overall travel behaviour and statistical tests

Table – Overall Travel behaviour
Total trip frequency and distance travelled by participant between 2011 – 2012

	Year	Total (count/ miles)		Freq (%) by trip distance	Mean		CI 95%	Median	Annual estimates participant / year	NTS 2010
	2011	1340			27	±	3	25	1260	970
			0-5miles	77.1%						
			5 - 25 miles	19.5%						
Number of trips			> 25 miles	3.4%						
	2012	1324			26	±	2.5	27	1245	
			0-5miles	73.7%						
			5 - 25 miles	20.5%						
			> 25 miles	5.7%						
	2011	8213.2			164	±	48	117.1	7720.4	6276
			<25 miles	50.8%						
Distance Travelled			>25 miles	49.2%						
	2012	9547.7			191	±	58.7		8974.8	
			<25 miles	45.0%						
			>25 miles	55.0%						

Table – Overall Travel Behaviour
Mean trip frequency and distance travelled by purpose (2011 and 2012)

Mean trip frequency by purpose per week (N=50)						
	2011			*2012*		
	Mean	CI 95%	Median	Mean	CI 95%	Median
Commuting	7.1	(7.1; 9.5)	8.0	7.4	(5.6; 9.5)	6.0
Business	1.4	(1.4; 2.0)	0.0	1.3	(0.7; 2.0)	0.0
Education	1.7	(1.7; 3.6)	0.0	2.0	(0.7; 3.6)	0.0
Shopping and personal bu	8.8	(8.8; 11.2)	8.0	9.4	(7.8; 11.2)	9.0
Social and visit friends anc	4.7	(4.7; 7.3)	4.0	5.9	(4.4; 7.3)	5.0
Recreation	2.4	(2.4; 2.7)	2.0	2.0	(1.4; 2.7)	1.0
Other leisure	2.6	(2.6;2.6)	2.0	2.0	(1.3; 2,6)	1.0

Mean trip distance by purpose per week (miles) (n=50)						
	2011			*2012*		
	Mean	CI 95%	Median	Mean	CI 95%	Median
Commuting	50.5	(27.1; 81.4)	17.8	51.0	(29.9; 82.7)	18.7
Business	18.1	(3.2; 42.3)	0.0	33.6	(7.6; 78.2)	0.0
Education	2.8	(1.3; 4.4)	0.0	8.0	(2.4; 15.8)	0.0
Shopping and personal bu	26.6	(19.0; 35.5)	17.2	32.2	(20.9; 47.6)	17.6
Social and visit friends anc	31.6	(19.7; 46.3)	10.2	40.7	(25.2; 59.1)	16.1
Recreation	6.9	(3.4; 12.4)	1.9	6.0	(3.2; 9.4)	1.7
Other leisure	28.1	(13.7; 43.6)	3.2	21.2	(11.5; 32.6)	1.6

Table – Motorized travel behaviour
Trip frequency by car and public transport by participant between 2011 – 2012

Car

	2011					2012				
	N	Mean	Median	Std. deviation	95% CI	N	Mean	Median	Std. deviation	95% CI
Commuting	*28*	15.4	6.15	32.21	12.49	*29*	12.87	6.5	18.01	6.85
Business	*10*	14.64	2.46	25.01	17.89	*13*	15.58	1.95	24.65	14.90
Education	*14*	0.95	0.71	0.99	0.57	*11*	5.76	3.48	6.7	4.50
Shopping and Personal Business	*45*	4.71	3.29	4.91	1.48	*41*	6.73	3.76	8.21	2.59
Social	*33*	7.44	4.89	9.82	3.48	*40*	6.43	3.47	7.24	2.32
Other Leisure	*32*	6.81	2.95	10.32	3.72	*23*	5.96	2.71	6.52	2.82

Public Transport

	2011					2012				
	N	Mean	Median	Std. deviation	95% CI	N	Mean	Median	Std. deviation	95% CI
Commuting and Education	11	4.50	1.75	7.51	5.05	15	7.07	2.65	14.32	7.93
Business	3	6.82	0.65	11.26	27.97	6	3.77	2.23	4.73	4.96
Shopping and Personal Business	7	0.98	1.23	0.46	0.43	6	1.64	1.29	1.22	1.28
Social and Leisure	6	1.12	0.89	0.98	1.03	10	6.43	1.87	11.46	8.20

Table – Statistical Test
Changes in trip frequency over time by mode (walk, bicycle, car, public transport)

Paired Sample Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	*Trip frequency by bicycle (t1)*	1.64	50	3.62	0.51
	Trip frequency by bicycle (t2)	0.98	50	2.25	0.32
Pair 2	*Trip frequency by car (t1)*	16.26	50	10.98	1.55
	Trip frequency by car (t2)	16.42	50	11.1	1.57
Pair 3	*Public transport trip frequency (t1)*	**1.22**	50	1.9	0.27
	Public transport trip frequency (t2)	**2.28**	50	3.33	0.47
Pair 4	*Walking trip frequency (t1)*	7.68	50	5.91	0.84
	Walking trip frequency (t2)	6.8	50	5.21	0.74

Results of the paired t-test comparing 2011 and 2012 in terms of the frequencies of each travel mode revealed a marginally significant decrease in the number of travels the participants made by public transportation ($t_{bus\ (49)}$=-2.28, $p<0.05$). However, the number of trips by other modes of travel did not significantly defer from T1 to T2 ($t_{bike\ (49)}$=1.54, p=0.13; $t_{walk\ (49)}$=-0.10, p=0.17; $t_{car\ (49)}$=-0.10, p=0.92). Regarding the length of trip, the results of Wilcoxon Signed Rank test showed a marginally significant increase for travel by public transportation between T1 and T2 (Z_{bus} =2.03, $p<0.05$). Thus, while the numbers of trips by public transportation have reduced, the lengths of travels have increased from 2011 to 2012.

Table – Statistical Test
Changes in distance travelled over time by motorized transport (car and public transport) and by purpose

Time point comparison for public transport trip (2011 vs 2012)	Z	Sig. (2-tailed)	Sig. (1-tailed)
public transporttrip distance for commuting in 2012 - public transport trip distance for commuting in 2011	-1.24	.21	.12
Public Transport trip distance for business in 2012 – public transport trip distance for business in 2011	-.85	.40	.23
Public Transport trip distance for education in 2012 – public transport trip distance for education in 2011	.73	.47	.31
Public Transport trip distance for shopping and personal business in 2012 – public transport trip distance for shopping and personal business in 2011	-.84	.40	.23
Public Transport trip distance for social purposes in 2012 – public transport trip distance for social purposes in 2011	-1.51	.13	.07
Public Transport trip distance for other leisure in 2012 – public transport trip distance for other leisure in 2011	-1.48	.14	.09

Note: Because the numbers of observations for travel for education purposes were only two, and not enough for Wilcoxon test, it was merged with travel to work.

Table ***. Z scores for Wilcoxon test and the p values for distances travelled by car

Time point comparison for car (2011 vs. 2012)	Z	Asymp. Sig. (2-tailed)	Exact Sig. (1-tailed)
Distance for commuting in 2011 - distance for commuting in 2012	.19	.85	.43
Distance for business in 2011 - distance for business in 2012	-1.34	.18	.10
Distance for education in 2011 - distance for education in 2012	-.83	.41	.21
Distance for shopping and personal business in 2011 - distance for shopping and personal business in 2012	.24	.81	.41
Distance for social in 2011 - distance for social in 2012	-.63	.53	.27
Distance for other leisure in 2011 - distance for other leisure in 2012	.19	.58	.29

Two series of Wilcoxon tests were performed to compare t1 and t2 on distance travelled by car and public transport. The results obtained indicated that none of the travel modes had made significantly longer or shorter distances from 2011 to 2012.

Table – Walking behaviour
Trip frequency and average trip length

	2011			2012		
	trip frequency		distance	trip frequency		distance
	count (n=472)	*freq by total (%) (n=472)*	average trip length (miles)	*count (n=499)*	*freq by total (%) (n=499)*	average trip length (miles)
Recreation	112	23.7%	1.6	89	17.8%	1.6
Utility	360	76.3%	0.7	410	82.2%	0.6
Business	*25*	*5.3%*	0.9	*18*	*3.6%*	1.1
Commuting	*108*	*22.9%*	0.9	*150*	*30.1%*	0.6
Education or escort	*25*	*5.3%*	0.5	*20*	*4.0%*	0.6
Other leisure	*3*	*0.6%*	1.3	*8*	*1.6%*	0.8
Social and visit friends or family	*74*	*15.7%*	0.8	*77*	*15.4%*	0.8
To/ from shops and personal business	*128*	27.1%	0.6	*145*	*29.1%*	0.5
Total	**472**			**499**		

Table – Walking
Correlation analysis of distance walked and number of times participants have crossed the new Connect2 Scheme

Walking

		Stage frequency (t1)	Stage frequency (t2)	Distance (t1)	Distance (t2)
Stage frequency (t1)	**Pearson Correlation**	1			
	Sig. (2-tailed)				
	N	50			
Stage frequency (t2)	*Pearson Correlation*	.62**	1		
	Sig. (2-tailed)	0			
	N	50	50		
Distance (t1)	*Pearson Correlation*	**.78****	.51**	1	
	Sig. (2-tailed)	0	0		
	N	50	50	50	
Distance (t2)	*Pearson Correlation*	.48**	.65**	.65**	1
	Sig. (2-tailed)	0.001	0	0	
	N	46	46	46	46

*** Correlation is significant at the 0.01 level (2-tailed)*

Based on the results of the correlation analysis, it appeared that participants who walked more miles have also crossed the new bridge more often in 2011 (r= 0.78) as well as in 2012 (r=0.65).

Table – Walking behaviour
Recreational and utility walking over the new Connect2 Scheme

Ranks

		N	Mean Rank	Sum of Ranks
Recreational walk stages over Connect2 Scheme (t1) - Recreational walk stages over Connect2 Scheme (t2)	Negative Ranks	5 (a)	5.4	27
	Positive Ranks	6 (b)	6.5	39
	Ties	39 (c)		
	Total	50		
Utility walk stages over Connect2 Scheme (t1) - Recreational walk stages over Connect2 Scheme (t2)	Negative Ranks	2 (d)	2.5	5
	Positive Ranks	3 (e)	3.33	10
	Ties	45 (f)		
	Total	50		

a) Recreational walk stages over Connect2 Scheme (t1) < Recreational walk
b) Recreational walk stages over Connect2 Scheme (t1) > Recreational walk
c) Rcreational walk stages over Connect2 Scheme (t1) = Recreational walk
d) Utility walk stages over Connect2 Scheme (t1) < Utility walk stages over
e) Utility walk stages over Connect2 Scheme (t1) > Utility walk stages over
f) Utility walk stages over Connect2 Scheme (t1) = Utility walk stages over

Test Statistics

	z	Asymp. Sig. (2-tailed)	Exact Sig. (1-tailed)
Recreational walk stages over Connect2 Scheme (t1) - Recreational walk stages over Connect2 Scheme (t2)	-0.55	0.58	0.31
Utility walk stages over Connect2 Scheme (t1) - Recreational walk stages over Connect2 Scheme (t2)	-0.71	0.48	0.37

a. Wilcoxon Signed Rank Test
b. Based on negative ranks

To find out if the number of walking over the new bridge was altered over the two time points, the number of trip over the bridge for both recreational and utility purposes were recorded. The results of the analysis on walking through the bridge, using Wilcoxon test, indicated that in fact the number of the trips neither for recreational ($Z = -0.55$, $p=0.58$) nor for the utility ($Z = -0.77$, $p=0.48$) purposes were altered during the years 2011 to 2012.
Adding up the overall number of walking and cycling over the bridge indicated that for utility purposes there was a marginally significant increase from 2011 to 2012 in the number of trips ($Z_{utility} = 1.98$, $p<0.05$). No significant results were found for the recreational purposes ($Z_{recreational} = 0.30$, $p=0.41$).

Table – Cycling behaviour
Distance cycled for recreational and utility purposes over time

Ranks

		N	Mean Rank	Sum of Ranks
Distance cycled for recreation (t2) - Distance cycled for recreation (t1)	Negative Ranks	2 (a)	7.5	15
	Positive Ranks	8 (b)	5	40
	Ties	40 ©		
	Total	50		
Distance cycled for utility (t2) - Distance cycled for utility (t1)	Negative Ranks	11 (d)	7.91	87
	Positive Ranks	3 (e)	6	18
	Ties	36 (f)		
	Total	50		
Stage frequency cycled for recreation (t2) - Stage cycled for recreation (t1)	Negative Ranks	3 (g)	6	18
	Positive Ranks	7 (h)	5.29	37
	Ties	40 (i)		
	Total	50		
Stage frequency cycled for utility (t2) - Stage frequency cycled for utility (t1)	Negative Ranks	11 (j)	6.73	74
	Positive Ranks	2 (k)	8.5	17
	Ties	37 (l)		
	Total	50		

a) Distance cycled for recreation (t2) < distance cycled
b) Distance cycled for recreation in 2012 (t2) > distance
c) Distance cycled for recreation (t2) = distance cycled
d) Distance cycled for utility in (t2) < distance cycled for
e) Distance cycled for utility in (t2) > distance cycled for
f) Distance cycled for utility in (t2) = distance cycled for
g) Stage frequency cycled for recreation (t2) < stage
h) Stage frequency cycled for recreation (t2) > stage
i) Stage frequency cycled for recreation (t2) = stage
j) Stage frequency cycled for utility (t2) < stage
k) Stage frequency cycled for utility (t2) > stage
l) Stage frequency cycled for utility (t2) = stage

	Z	Asymp. Sig. (2-tailed)	Exact Sig. (1-tailed)
Distance cycled for recreation (t2) - Distance cycled for recreation (t1)	-1.274 (b)	0.203	0.116
Distance cycled for utility (t2) - Distance cycled for utility (t1)	2.166 (c)	0.03	0.015
Stage frequency cycled for recreation (t2) - Stage cycled for recreation (t1)	-.973 (b)	0.33	0.192
Stage frequency cycled for utility (t2) - Stage frequency cycled for utility (t1)	2.005(c)	0.045	0.022

Table – Cycling behaviour

Trip frequency of recreational and utility walking over the new Connect2 Scheme

Ranks

		N	Mean Rank	Sum of Ranks
Recreational cycling stages over Connect2 Scheme (t1) - Recreational cycling stages over Connect2 Scheme (t2)	Negative Ranks	3 (a)	4	12
	Positive Ranks	3 (b)	3	9
	Ties	44 (c)		
	Total	50		
Utility cycling stages over Connect2 Scheme (t1) - Utility cycling stages over Connect2 Scheme (t2)	Negative Ranks	0 (d)	0	0
	Positive Ranks	4 (e)	2.5	10
	Ties	46 (f)		
	Total	50		

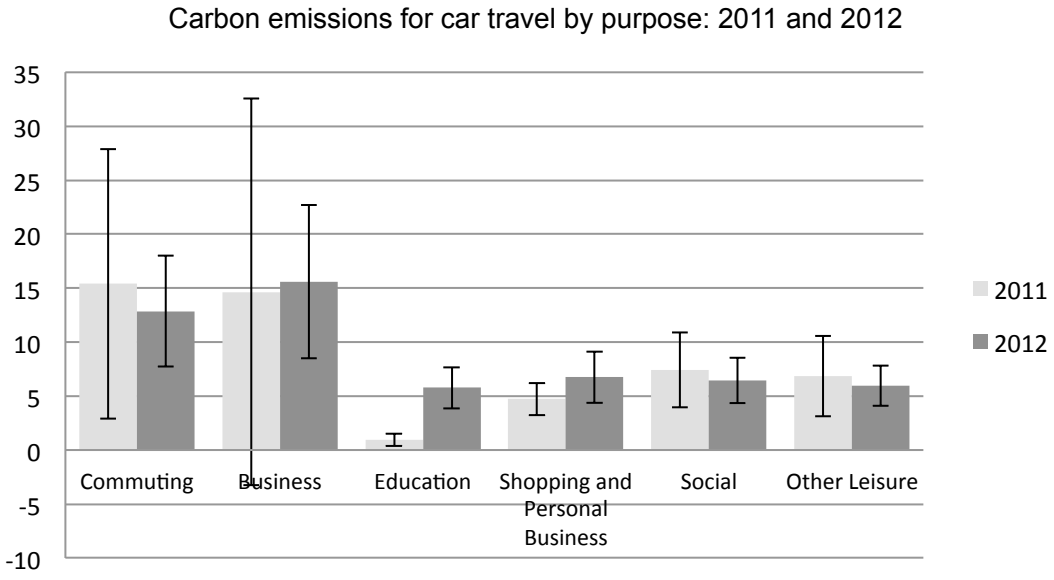
a) Recreational cycling stages over Connect2 Scheme
b) Recreational cycling stages over Connect2 Scheme
c) Recreational cycling stages over Connect2 Scheme
d) Utility cycling stages over Connect2 Scheme (t1) <
e) Utility cycling stages over Connect2 Scheme (t1) >
f) Utility cycling stages over Connect2 Scheme (t1) =

	Z	Asymp. Sig. (2-tailed)	Exact Sig. (1-tailed)
Recreational cycling stages over Connect2 Scheme (t1) - Recreational cycling stages over Connect2 Scheme (t2)	0.322 (b)	0.748	0.453
Utility cycling stages over Connect2 Scheme (t1) - Utility cycling stages over Connect2 Scheme (t2)	-1.841 (c)	0.066	0.063

The results of the Wilcoxon test indicated that the number of trips recorded over the Connect2 Bridge were not altered during the years 2011 and 2012 for both recreational (Z = 0.32, p=0.45) and utility (Z = -1.84, p=0.63) journeys.

Table – Carbon Emissions by purpose and mode

Emissions from surface transport (kg CO2)	wave	Mean	95% Confidence Interval for Mean lower	upper	Median	Standard Deviation	Min	Max	Sum
Car travel	*T1*	26.38	15.70	37.06	15.56	36.77	0.44	185.80	1266.20
	T2	26.72	17.51	35.94	20.76	32.09	0.91	201.94	1309.38
Public transport	*T1*	4.18	1.01	7.35	1.51	6.78	0.48	25.68	83.56
	T2	7.24	1.67	12.81	2.66	14.37	0.17	66.98	202.77
Total	*T1*	27.00	16.67	37.32	16.91	36.31	0.00	185.80	1349.76
	T2	30.24	20.97	39.51	21.43	32.62	1.31	201.94	1512.15



APPENDIX K – Changes in travel behaviour over time at an individual level

Participant		Individual difference in distance travelled by mode between 2011 and 2012 (miles)					Changes in life circumstances (LC)/ perceived reasons for change		Crossing Connect2 Scheme	
ID	fictitious name	Walk	Bicycle	Car	PT	TOTAL			2011	2012
2	*Alfredo*	1.1	0.0	8.3	-4.2	**5**	**-**	*No significant changes*		
3	*Henry*	**11.7**	-14.0	57.1	8.2	**63**	**attitudes/ awareness**	*Desire to be more physical active/ Health awareness*	●	●
4	*Angelina*	-0.3	0.0	-506.5	0.0	**-507**	**life circumstances**	*Working from home*		
6	*Julliete*	-9.2	**2.3***	-3.7	0.0	**-11**		*Weather conditions; new bicycle; peers influence*		●
7	*Lucas*	-22.8	**43.3***	3.2	**27.0**	**51**		*New bicycle in 2012; peers influence; replaced walk commute by bicycle*		●
8	*Sara*	-9.9	0.0	0.0	-4.4	**-10**	**week variability**	*Week variability: less days of work in 2012(walk to work)*		
9	*Robbie*	**10.9**	0.0	83.4	0.0	**94**	**life circumstances**	*Life circumstances: unemployed in 2012; more physical active (health and time)*		
10	*Lili*	0.0	0.0	74.3	-16.9	**59**	**life circumstances**	*Life circumstances and car ownership: new workplace*		
12	*Katherine*	-8.3	0.0	-117.1	15.4	**-110**	**life circumstances**	*Life circumstance and natural variability: workplace reallocated and leisure trip in 2011*		
13	*Jennifer*	0.0	0.0	55.4	0.0	**53**	**family responsabilities**	*Family responsibilities: 3 kids at different schools - school run*		
14	*Tesse*	2.3	0.0	56.7	3.8	**63**	**life cirscunstances**	*Life circumstances: back to work after maternity leave*		
15	*Tim*	0.9	**7.7**	0.0	0.0	**14**	**attitudes/ car ownership**	*Car ownership: 1 car in the household, need to share it with wife that is now back to work following maternity leave; more commuting by bicycle*	●	
16	*Michel*	-12.2	0.0	0.2	-5.2	**-17**	**attitudes/ awareness**	*Attitudes: replaced outdoor running by gym activities in 2012*		
17	*Alexandra*	-1.3	0.0	49.1	-22.6	**25**	**family responsabilities**	*Family responsibilities: mummy to be gets a new car*		
18	*Christian*	0.0	0.0	-418.6	0.0	**-435**	**family responsabilities**	*Family responsibilities: new born son reduces travelling for band practice and music gigs; and week variability: less business trips*		
19	*George*	-3.1	-4.6	23.5	10.6	**26**	**attitudes/ awareness**	*Attitudes: replacing some outdoor activities by squash + week variability*	●	
20	*Katerhine*	1.9	-3.6	21.5	**59.9**	**80**	**week variability**	*Variability: long leisure trip recorded in 2012*	●	
24	*William*	-1.2	-21.5	19.6	**22.9**	**20**	**week variability**	*Influenced weather conditions; replacing cycling commuting by PT and car*	●	●
26	*Amelie*	1.2	6.4	-200.7	**80.2**	**-113**	**life circumstances**	*Give up job and become a full time student*		●
30	*David*	-9.4	0.0	132.5	9.2	**132**	**week variability**	*Replaced some walking journeys to work by public transport - need to carry work related load.*		
31	*Chris*	**9.6**	-24.6	137.2	0.0	**122**	**week variability**	*Leisure car drive (100 miles) recorded in 2012.*	●	●
32	*Jim*	**12.1**	-165.7	35.5	-86.9	**-205**	**week variability**	*Walking more for recreation while on holiday at caravan park and going to allotment;*	●	●
33	*Naomi*	-1.5	-4.3	50.8	-1.2	**44**	**-**	*one trip less to work by bicycle (13 miles)*	●	●

- *Participant crossed Connect2 Scheme in given year*

34	*Karen*	1.0	0.0	-99.7	0.0	**-99**	**week variability**	*Atypical week of work. Did not have time to engage in his weekly sport rides*		
35	*Myles*	.	-7.1	26.1	0.0	**15**	**-**	*No significant changes*	●	
36	*Jocelyne*	0.0	0.0	-44.7	0.0	**-45**	**-**	*Atypical week. Less commuting to work by car. In addition, a social 50 miles trip recorded in 2011.*		
38	*Austin*	0.6	0.0	50.8	0.0	**51**	**-**	*No significant changes*		
40	*Cindy*	-6.4	0.0	-67.0	15.8	**-58**	**week variability**	*No significant changes*		
41	*Damien*	.	0.0	55.3	0.0	**53**	**-**	*No significant changes*		
42	*Emma*	-2.9	0.0	.	7.5	**-8**	**-**	*One leisure car trip of 30 miles in 2011.*		
43	*Lizzie*	1.1	0.0	562.7	-7.3	**557**	**week variability**	*No significant changes*		
45	*Thomas*	-0.9	0.0	10.4	0.0	**10**	**-**	*No significant changes*		
46	*Rebecca*	-3.0	-6.1	-56.7	0.0	**-66**	**-**	*Work from home + business journeys; varies by week in 2012: 10 business trips, Plymouth and reading. in 2011: only one business trip to Milton Keynes*	●	
47	*Sam*	-3.0	0.0	46.6	2.4	**46**	**-**	*No significant changes*		
48	*Celina*	-6.6	0.0	56.2	**36.2**	**86**	**life circumstances**	*No significant changes*		
50	*Therese*	-3.9	0.0	381.6	0.0	**378**	**week variability**	*No significant changes*		
53	*Rodrigo*	3.3	0.0	-118.8	**192.5**	**77**	**life circumstances**	*From maternity leave to back to work: commutes either by train or by car to work.*		
54	*Laurence*	.	0.0	-128.6	-8.0	**-140**		*less business trips; starting to work less days a week (retiring in year after)*		
55	*Helen*	-7.2	**19.5**	-4.2	0.7	**9**	**attitudes/ awareness**	*for sport/ more pysical active*	●	●
56	*Teddy*	.	0.0	148.4	0.0	**148**				
60	*Ernesto*	-5.1	0.0	305.5	**23.0**	**323**	**week variability**	*increase travel for business. Plus in previous year was a few days of work during travel week. Does not have a workplace. Distance travelled varies per week*		
61	*Julia*	-1.3	0.0	-418.6	0.0	**-420**	**week variability**	*in 2012: business trip to north wales; in 2012, commuting trips only*		
62	*Garret*	1.9	-2.7	-25.6	0.0	**-26**	**-**	*no significant changes*	●	
63	*Paul*	3.3	**24.0**	262.9	-10.6	**280**	**week variability**	*social trip to worcester (90 milesx2) + leisure/ sport surf (60 miles X2); weahter better for surf in 2012Idoing more cyling*	●	●
64	*John*	-0.6	0.0	28.9	-8.8	**20**	**-**	*no significant changes*		
67	*Martha*	-1.7	0.0	-12.1	-285.4	**-299**	**week variability**	*had business meeting in London in 2011: 145 miles in each direction*		
68	*Olga*	5.4	0.0	4.0	**30.0**	**39**	**-**	*no significant changes*		
69	*David*	5.8	-29.5	-1.1	**303.8**	**279**	**week variability**	*add 300 miles business trip during survey week in 2012: business trip/ meeting in london*	●	
70	*Douglas*	-1.1	0.0	-151.9	**748.0**	**595**	**life circumstances**	*change to new job in Swindon in 2012. 75 miles by train for each journey (150 mile per day). in 2011, was working in Cardiff and was commuting by car.*		
71	*Rebecca*	1.7	0.0	71.0	13.7	**86**	**-**	*no significant changes*		