Excess capacity in urban transport – how much is there and how could it be used to reduce CO_2 emissions?

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Declaration of work

The candidate confirms that the work submitted is her own, except where work has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

The work in Chapter 3 of the thesis has appeared in publication as follows:

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This paper forms part of Chapter 3 of the thesis, reviewing modelling approaches available for examining CO_2 emissions in transport. This paper was predominantly authored by the candidate with editorial advice provided by co-authors.

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Development of the definition of capacity and theoretical framing in Chapter 2 of the thesis build on the work in this paper. This paper was predominantly authored by the lead author, with editorial advice from the co-authors.

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Abstract

Transport contributes around 25% of greenhouse gas emissions, responsible for climate change. The present work explores the potential to reduce these emissions through enhanced use of excess capacity in the urban transport system. For example, average occupancy in the UK is only 1.4 persons per vehicle for cars, therefore considerable excess capacity exists in these vehicles. Capacity and sustainability have largely been examined in isolation in various academic literatures. Existing research on capacity has focused on engineered specifications of transport infrastructure, rather than examining the potential to make more efficient use of infrastructure. Research on the sharing economy and transport and the potential of increasing vehicle occupancy for fuel savings is emerging, beginning to address some aspects of capacity and sustainability. The present work contributes to and extends these emerging areas of research.

The objective of this research is to explore the potential for enhanced use of current and future excess capacity within an urban transport system in order to reduce CO_2 emissions. This objective addresses the identified knowledge gap and practical challenges of reducing transport emissions. The research draws on theoretical approaches from a range of disciplines, including economics, engineering and sociological perspectives, integrating these through a socio-technical systems approach. The work also draws on the sustainable mobilities perspectives to provide a holistic examination of the urban transport system.

The empirical work focuses on a case study of Greater Manchester (GM), which represents an archetypal large urban area in the UK. A behavioural study incorporates a survey of 500 residents of GM, in order to understand how people use their transport capacity. The survey results are then developed into a series of scenarios: 1 A: Shared Automobility, 1 B: Intelligent Automobility, 2: Public Mobility and 3: Flexi-mobility. These scenarios are then modelled using a traffic network model. Policy recommendations are made throughout this thesis and discussed with stakeholders through interviews to understand the practicality, acceptability and barriers to implementation.

The present work shows that approximately 56% of vehicle capacity is found to be excess in GM, however the survey identified a number of potential areas for making enhanced use of this excess capacity. 53% of participants were found to be willing to car share and participants showed flexibility in their travel behaviour and mode choices.

Transport modelling of the scenarios shows that Scenario 1 A: Shared Automobility has the greatest potential for reducing emissions, with a reduction of 35% in CO_2 emissions in 2035 compared to Business as Usual. However, stakeholders identified practical and political barriers to increased sharing, and suggested that other policy measures, such as re-regulation of transport, have greater potential for influencing the sustainability of urban transport.

This thesis shows that there is a significant amount of transport excess capacity in GM and that enhanced use of this capacity could contribute to reductions in CO_2 emissions. These findings are applicable to areas with similar transport systems to that of GM, particularly in the UK. The framework developed in this thesis could be applied to other urban transport systems to assess the emission reductions potential of making enhanced use of excess capacity in urban transport.

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List of Abbreviations

ASTRA – Assessment of Road Transport Strategies

ATIS – Advanced Traveller Information System

BAU – Business as Usual

CLD – Causal Loop Diagrams

CO_2 – Carbon Dioxide

DECC – Department for Energy and Climate Change

DfT – Department for Transport

DRACULA – Dynamic Route Assignment Combining User Learning and microsimulAtion

EIA – Environment Information Administration

EMIGMA – Atmospheric **Em**issions **I**nventory for **G**reater **Ma**nchester

EPSRC – Engineering and Physical Sciences Research Council

EU – European Union

EU ETS – EU Emissions Trading Scheme

EV – Electric Vehicle

GCAM – Global Change Assessment Model

GDP – Gross Domestic Product

GM – Greater Manchester

GMPT – Greater Manchester Public Transport Model

GMSM – Greater Manchester SATURN Model

GMSPM – Greater Manchester Strategy Planning Model

HEV – Hybrid Electric Vehicle

HGVs – Heavy Goods Vehicles

HOV – High Occupancy Vehicle

IAM – Integrated Assessment Model

IEA – International Energy Agency

ICCT – International Council on Clean Transportation

ICE – Internal Combustion Engine

ICT – Information and Communication Technology

IPPR – Institute for Public Policy Research

ITS – Intelligent Transport Systems

KMO – Kaiser-Meyer-Olkin

LGVs – Light Goods Vehicles

LTP – Local Transport Plan

MaaS – Mobility as a Service

MARS – Metropolitan Activity Relocation Simulator

MATSIM – Multi-Agent Transport Simulator Toolbox

MLP – Multi-Level Perspective

MNL – Multinomial Logit

NEDC – New European Drive Cycle

NTS – National Travel Survey

OGVs – Other Goods Vehicles

OLEV – Office for Low Emission Vehicles

ONS – Office of National Statistics

PHEV – Plug in Hybrid Electric Vehicle

POLES – Prospective Outlook for the Long Term Energy System

PTE – Public Transport Executive

QCS – Quality Contract Scheme

SATURN – Simulation and Assignment of Traffic to Urban Road Networks

SD – System Dynamics

SMMT – Society of Motor Manufacturers and Traders

SNM – Strategic Niche Management

TASM – Transport Appraisal and Strategic Modelling

TfGM – Transport for Greater Manchester

TfL – Transport for London

TPB – Theory of Planned Behaviour

TTW – Tank to Wheel

VED – Vehicle Excise Duty

VKM – Vehicle kilometres

VOCs – Volatile Organic Compounds

WEB TAG – Transport Analysis Guidance (DfT)

WEPS+ - World Energy Projection System Plus

WLTP - Worldwide harmonized Light vehicles Test Procedures

WTT – Well to Tank

WTW – Well to Wheel

Chapter 1- Introduction

The transport system, in its current state, is inherently unsustainable. In particular, emissions of carbon dioxide (CO_2) from transport, and the resulting impact on the global climate system, represent a significant challenge. Management of these environmental issues is even more challenging in cities, where transport systems face strain from a whole range of factors. The work in this thesis aims to explore approaches for improving the sustainability of urban transport systems and this chapter provides the context for the research that follows. The present work seeks to explore mitigation of CO_2 from transport through the objective, research questions and approach outlined in this introduction. An overview and outline of the structure of this thesis is then provided.

1.1 Context

The Stern Review of the economics of climate change describes it as "*the greatest and widest-ranging market failure ever seen*" (Stern, 2007, p.i). Transport contributes a significant proportion of CO_2 emissions responsible for causing climate change (DECC, 2013, International Energy Agency, 2009) and it is essential that these are mitigated in order to avoid dangerous climate change (Intergovernmental Panel on Climate Change, 2007). The UK government has set legally binding emission reduction targets of 80% by 2050 based on 1990 levels, within the 2008 UK Climate Change Act (HM Government, 2008) and transport will need to be virtually decarbonised in order to meet this target. There is now widespread consensus that policy needs to facilitate a more sustainable transport future in order to minimise negative environmental impacts (Eliasson and Proost, 2015).

In urban areas there are additional challenges posed by transport, including air pollution, congestion and noise (Schäfer, 2009). Congestion costs 1% of gross domestic product (GDP) annually within the EU (d'Orey and Ferreira, 2014, European Commission, 2006). In addition, concerns around the health implications of car dependent lifestyles are increasingly raised (Cohen, 2006). Demand for transport continues to grow, the world is on track for two billion cars by 2020 (Sperling and Gordon, 2009). In the UK, transport is the only sector in which carbon emissions have not fallen, largely because improvements in engine efficiency and fuel consumption are offset by increasing demand (Hickman et al., 2012). Despite these issues, the socio-economic importance of transport is irrefutable (Mullen and Marsden, 2015) and there is a need to find sustainable options for providing transport services.

Banister et al (2008) suggest that there are three main reasons to look beyond the extrapolation of existing trends when conceptualising the future of travel. These are 1. Changes in the external environment, such as the growth in ICT; 2. The need to address environmental and sustainability concerns; and 3. Increasing urbanisation of the population (Banister et al., 2008). For these reasons, the present research explores how urban transport capacity is used and how that use might be made more efficient in order to contribute to emission reductions.

Many options for achieving a low carbon transport sector are focused on technological fixes, such as new vehicle technologies and alternative fuels, e.g., electric vehicles (EVs), plug-in hybrid electric vehicles (PHEV) etc. Technology plays an inherent role in policy for sustainability (Hoogma et al., 2002). If, however, interventions can be designed to make more efficient use of the technology and infrastructure we have, as well as best use of future infrastructure and improvements in technology, then there may be potential for emission reductions. This is the rationale for the integrative approach, including the socio-technical systems perspective, which is outlined subsequently.

There is excess capacity in urban transport systems, both spatially and temporally. In the UK, average vehicle occupancy for private cars is 1.6 persons per vehicle, and for buses it is around 9.5 passengers, rising to 19 in London (Department for Transport, 2011a), therefore there is excess capacity within vehicles. In addition, transport flows are concentrated within the morning and afternoon peaks, thus excess capacity arises in the roadspace outside of these times. There is potential for the excess capacity identified in urban areas to be more effectively used which could, in turn, reduce emissions from the transport system, a critical goal for urban transport planners (Banister, 2011). Capacity is defined in the box below:

Capacity is the space within the transport system through which transport demand can be met. This refers to physical space, both within vehicles and the roadspace, which can facilitate mobility. There are also elements of temporal capacity within the transport system, as there are high levels of loading on the system when demand is high during peak hours, and periods of much lower loading of the system.

This definition is limited to looking at the excess capacity in the existing transport system, rather than potential capacity in the future. This is intended to move away from the idea that technological fixes must be applied to the system to deliver sustainability or that building additional capacity will alleviate congestion, evidence on induced congestion disputes this (Goodwin, 1996b, Hidalgo et al., 2013). Rather, the present research aims to highlight the existing excess capacity that arises from the way that the transport system is used and explore options for enhanced use of this excess capacity to reduce CO_2 emissions. This is expanded further through the research questions below and through discussion of the definition of capacity in Section 2.5.

Research on capacity and emission reductions in urban transport have tended to be considered in distinct research areas. The present research seeks to bring together research on capacity and emissions in order to bridge the knowledge gap and explore the role that capacity use could play in future emission reductions, as well as introducing ideas around collaborative consumption and the sharing economy to explore how excess capacity might be used. Chapter 2-Section 2.5, explores how capacity has been conceptualised in the literature and provides additional context for the research questions that follow.

1.2 Research objective

The objective of this research is to explore the potential for enhanced use of current and future excess capacity within an urban transport system to deliver reductions in CO_2 emissions.

1.3 Research questions

The questions identified below are used to explore the objective outlined above through the approach described below:

1. When/where is there excess capacity in the urban transport system?
2. What might be the carbon benefits and penalties of an enhanced use of this excess capacity and any facilitating interventions?
3. How could more effective use of excess capacity be facilitated in order to reduce emissions?
4. How could enhanced use of capacity be incorporated into pathways for sustainable urban transport systems?

Table 2:4, in the literature review, provides an overview of the relevant areas of literature for each research question and direction to the location of the analysis within the thesis.

1.4 Approach

As demonstrated by the questions above, the research is highly interdisciplinary, incorporating elements of travel behaviour research, sustainability transitions and transport modelling. The interdisciplinary nature of the research means that multiple approaches are utilised throughout the thesis. Figure 1:1 shows the interconnected research areas and frameworks used in the thesis. The area at the centre of the diagram represents the examination of different pathways for use of transport capacity, which have been constructed using behavioural analysis, through a survey of residents of Greater Manchester, and transition pathways techniques and are quantified using transport modelling approaches. Each of these research areas are expanded upon in the coming chapters, both within the literature review in Chapter 2- and in the chapters that follow. Figure 1:3 shows the thesis structure but also demonstrates some of the interconnections between the different research areas and is useful for providing additional clarity on the research approach.

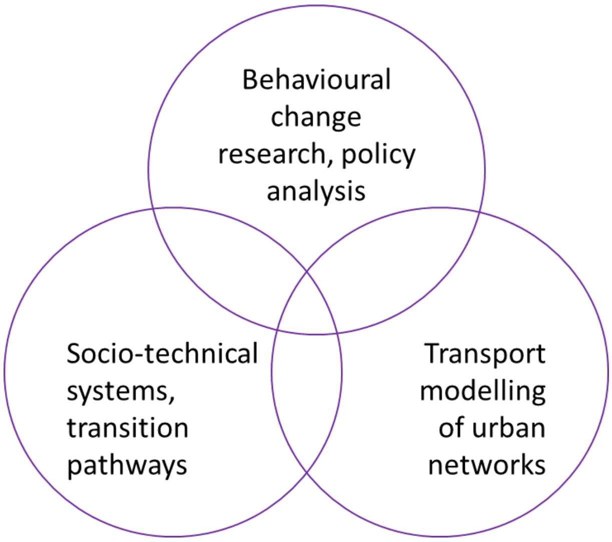

Figure 1:1 - Interconnected research areas

1.4.1 Greater Manchester case study

The research questions are explored through the use of a case study of Greater Manchester (GM) and the framework that is developed in Chapter 3- has been applied to this area. GM is a large metropolitan county in the North West of England, covering 1,276km^2 and around 2.4 million residents, and comprises 10 local authority districts (Transport for Greater Manchester, 2013). Figure 1:2 shows the area included in the GM combined authority. GM has been selected as the case study for this work as it is an archetypal urban area, with a mixture of local roads, ‘A’ roads (primary roads) and motorway links, connected by an orbital motorway. It is possible to see in Figure 1:2 the layout of major road links into the city centre. In addition, the presence of the combined authority, a central authority which brings together the smaller constituent areas into one governance structure, improves the accessibility and availability of data and other resources for the whole area. The framework and survey that are developed in this research have been tested for GM. However, the methods are fully replicable in principle, and could be applied to other areas to develop the same indicators of urban transport capacity use and potential emission reduction potential, given the correct data inputs.

Figure 1:2 - Greater Manchester (source: Google Maps)

1.5 Research scope and limitations

This research sets out to meet the research objectives through the examination of the research questions above. This is predominantly achieved through the case study of GM outlined, however, as suggested below the methodologies developed could be used to examine excess capacity in additional urban transport systems. A definition for the term 'urban' is provided below and Chapter 3- Figure 3:1, shows the scope of the urban transport system considered within this research, demonstrating which aspects are included in the analysis and which are excluded, though some may be included as exogenous factors which influence capacity use.

'Urban' refers to towns and cities and is generally understood as being an area where the population size and/or density exceeds certain thresholds, for example, a population greater than 3000 people would be classified as urban based on the definitions below (DfT, 2011b). Urban also captures behavioural and structural characteristics such as economic functions (Johnston et al., 2000).

The Department for Transport classification of urban areas is as follows:

- *”London boroughs* – [which make up] *the whole of the Greater London Authority*
- *Metropolitan built-up areas – the built-up areas of former metropolitan counties of Greater Manchester, Merseyside, West Midlands, West Yorkshire, Tyne and Wear and Strathclyde (excludes South Yorkshire)*
- *Large urban – self-contained areas over 250,000 population*
- *Medium urban – self-contained urban areas over 25,000 but not over 250,000 population*
- *Small/medium urban – self-contained urban areas over 10,000 but not over 25,000 population*
- *Small urban – self-contained urban areas over 3,000 but not over 10,000 population*
- *Rural – all other areas including urban areas under 3,000 population*” (DfT, 2011b, p.54)

One of the primary data sources for the research in this thesis is a survey of 500 residents of GM, which was designed by the present author and carried out by Accent Market Research. This work underlies the behavioural analysis presented in Chapter 4- and Chapter 5- and provides many of the inputs for the framework which is developed in Chapter 3-. Details of the survey design can be found at the start of Chapter 4-. As with any behavioural research, there is the possibility of bias been introduced to the data collection, and in particular, with the collection of travel data, participant fatigue is a risk. However, steps were taken to minimise the risk of this, as described in Chapter 4- and this should not present a significant limitation to the quality of the research and analysis in this thesis.

Chapter 7- presents the results of the traffic network modelling of scenarios developed in Chapter 6-. There are inherent limitations in creating a model of the real world, however, steps have been taken to minimise these limitations. Chapter 3- provides an extensive review of transport modelling approaches in order to identify the most applicable tools and techniques for addressing the research questions in this thesis. Chapter 7- Section 7.1.4, discusses the limitations of the modelling approaches used, and highlights the validation procedures and techniques that are used to minimise the impact of this on the results.

Policy recommendations are made throughout this thesis, and these are discussed with stakeholders and policy makers though interviews, in order to assess the validity and practicality of the suggested policy measures and identify any barriers to their uptake. The results of these interviews are presented and discussed in Chapter 8-.

1.6 Originality and contribution to knowledge

The research in this thesis provides a novel perspective for examining urban transport capacity and emissions, developing a new, integrated framework for quantifying capacity and CO_2 emissions. While existing research has examined potential fuel savings from increasing occupancy of private cars, the research in this thesis goes beyond that, to explore capacity across the transport system, looking at multiple modes and temporal capacity, to quantify the benefits of enhanced use of capacity across the transport system. The collection and analysis of new data on transport behaviour in GM, which is presented in Chapter 4- and Chapter 5-, and developed into modelling scenarios, represents a significant contribution to the understanding of how individuals perceive transport capacity and how interventions could be designed to make enhanced use of this. In addition, the focus on CO_2 emissions and the role that enhanced use of excess capacity could play in future emission reduction targets provides useful and original research outputs, with the potential to impact on future policy decisions. As such, it is hoped that the outputs will be accessible to a wide audience of transport policy makers, planners and decision makers, and the thesis is communicated in such a way to ensure maximum accessibility to this audience. The discussion of the policy recommendations that have been made in this thesis with experts, the results of which are presented in Chapter 8-, should ensure the applicability, relevance and usefulness of the outputs of this work.

1.7 Thesis overview and structure

This section provides an overview of the thesis and the contents of each of the chapters that follow. Figure 1:3 shows the structure of the thesis, and the interconnections between the work presented in each chapter.

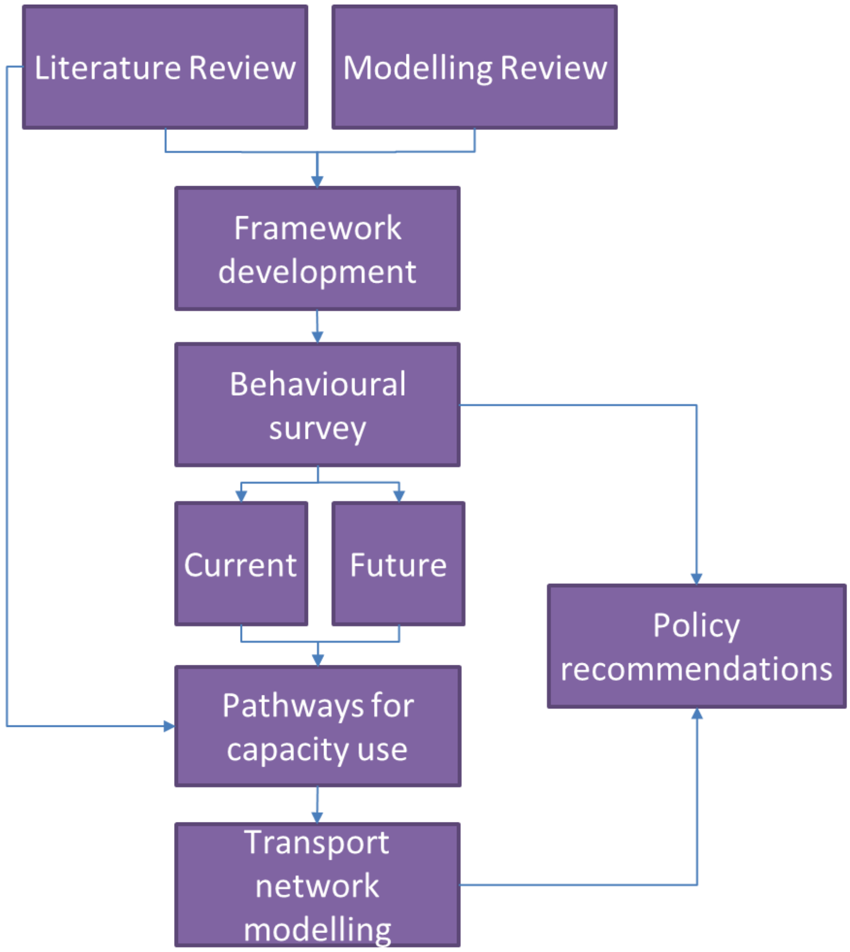

Figure 1:3 - Thesis structure

Chapter 2- contains the review of the academic literature relating to sustainable transport. This includes economic approaches, an overview of technologies available for reducing the environmental impact of transport, insight into the sustainable mobilities paradigm and socio-technical systems literature and an introduction to the analysis of behaviour in relation to sustainability in transport. A policy review is also included in this chapter, in order to give context beyond the academic literature and also to provide the background necessary for exploring potential policy options for facilitating enhanced use of excess capacity in urban transport systems.

Chapter 3- develops the frameworks that are used within this research to analyse and quantify enhanced use of excess capacity. An extensive review of modelling approaches available for examining CO_2 in transport systems is conducted to identify the most appropriate techniques for addressing the research questions as outlined above. Following the identification of the modelling approaches to be used, a framework which integrates the different research areas is developed, to demonstrate how the behavioural data generated through the survey and modelling of different scenarios for capacity use are drawn together.

Chapter 4- analyses the survey results related to current travel behaviour. The chapter begins by providing an introduction to the methodologies available for conducting behavioural research in transport and explains how these are adapted and used for the collection of behavioural data undertaken in the present work. The survey approach is outlined and the results of questions about how people travel presently are presented and discussed. A range of statistical techniques are used in this analysis and are explained in the early parts of the chapter.

Chapter 5- continues the analysis of the survey data, focusing on the questions relating to how participants felt they would travel in the future. Factors such as home working, modal shifting and the key influences on individuals' future travel are examined through propensity modelling and factor analysis and these results are then discussed and their role in the development of future scenarios is proposed.

Chapter 6- takes the findings from the survey results and the underlying trends identified in the literature review and constructs a series of pathways for the future use of urban transport capacity. Dynamics in the pathways include the role of sharing in transport, uptake of intelligent transport systems, the role of policy mechanisms such as devolution of transport powers to local areas and the potential for travel to become more flexible with increases in home working and flexible working hours.

Chapter 7- undertakes traffic network modelling of the pathways developed in Chapter 6- in order to understand their impacts on excess capacity use and emissions within GM. An overview of how TfGM approach network modelling is provided and detail given on how the pathways developed in Chapter 6- are prepared for network modelling. Results are then presented and discussed, focusing on emissions and travel within the network in order to understand how the different scenarios impact on excess capacity and CO_2 emissions within the urban transport network.

Chapter 8- presents the results of the interviews which discuss the policy recommendations made in this thesis with decision makers and stakeholders across the transport sector or those with expertise in environmental or urban policy. The approach and interview design is provided followed by an analysis and discussion of the results.

Finally, Chapter 9- provides the conclusions for this thesis, drawing together the key insights and findings from the chapters that have preceded. In addition, areas for further work are outlined, highlighting areas that could be explored building on the present work in this thesis.

Additional direction for the work contained in this thesis can be found in Section 2.7.1, where Table 2:4 takes each research question and presents the relevant literature reviewed in Chapter 2- and provides direction to the location of related analysis within the thesis.

Chapter 2- Review of the literature related to sustainable urban transport and excess capacity

The following chapter undertakes a critical review of the academic literature related to sustainable transport, in the context of the objective and research questions outlined in the previous chapter. The chapter will begin by outlining the theoretical and disciplinary perspectives that are of relevance to addressing the research questions. These perspectives will then be examined and critiqued in the context of a number of themes relating to sustainable urban transport and the challenge of enhanced use of excess capacity. These themes include, in the order they are presented, sustainability in transport, technology and behaviour change, socio-technical systems perspectives and capacity in urban transport systems. This review is then summarised in Table 2:4 to show which aspects of the literature are used in the thesis to address the specific research questions.

Additional literature is included in other chapters, which relate specifically to their content including behavioural approaches and survey techniques in Chapter 4-, and an overview of approaches for conceptualising the future of transport in Chapter 6-. Chapter 3- provides a review of modelling approaches, which includes extensive literature on approaches to modelling in transport.

Policy recommendations are made throughout the thesis, based on the results. Thus it is necessary to understand the nature of sustainable transport policy at present in order to suggest how mechanisms might be used to leverage excess capacity use for emission reductions. Accordingly, a review of policy related to sustainable urban transport and excess capacity is presented in Section 2.6. The chapter then concludes, highlighting the main trends emerging in the literature and policy which will influence the subsequent sections of the thesis, such as the survey analysis and the construction of scenarios for future enhanced use of urban transport excess capacity.

2.1 Approaches and perspectives in transport research

There are a range of theoretical and disciplinary perspectives that address transport challenges. These include economics, examining transport supply and demand from traditional economic perspectives, sociological research that looks at transport behaviour, socio-technical systems and engineering, which examines the potential for technology to influence the transport system. The following list highlights the areas of these disciplinary perspectives that are relevant to the research questions outlined in the introduction:

Economics

- Traditionally based on rational decision making
- The use of pricing, the relative pricing of modes and the influence on modal choice
- Fiscal mechanisms for influencing choice and demand, such as fuel tax
- The conceptualisation of transport challenges as negative externalities

Sociological perspectives, e.g. sustainable mobilities, automobility

- Provides a framework for exploring the role of behaviour change in delivering sustainable transport
- Often interdisciplinary approaches emerging from a sociological perspective
- Examines the interconnections between activities and behaviours in influencing travel
- Sustainable mobilities paradigm - interactions between technology, pricing, land-use and information (Banister, 2008)
- Explores emerging trends outside transport that are influencing behaviours in the system, such as ICT

Engineering

- Focus on the technological dimensions of transport
- Improving the efficiency of vehicles and introducing new technologies to the transport system
- Introduction of ICT into transport, through Intelligent Transport Systems (ITS) and the impact this has on the use and efficiency of the transport system

Socio-technical systems

- Integrating sociological and technological perspectives to produce a system wide approach
- Socio-technical systems refers to a range of factors, including, but not limited to, "*technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and production systems"* (Geels, 2005, p.1).
- Emerge from studies of science, technology and innovation
- Applied to the transport system in a number of studies to examine differing dimensions, such as spatial, socio-cultural and diffusion of innovation

The disciplinary perspectives outlined here will be examined through a number of themes relating to the research, such as sustainability, the balance of behaviour change vs technology in decarbonising transport, and capacity in urban transport. Additional perspectives are also referenced, such as work that focuses on transport at the urban scale and examines the interactions between transport and land use, but the four areas highlighted above are the main theoretical perspectives that are reviewed and critiqued within this chapter. The review is then synthesised in Table 2:4 which shows the relevant literature for each research question in this thesis.

2.2 Sustainability in transport

Sustainability is a key aspect of the present work, as the thesis examines the potential to reduce emissions of CO_2 from urban transport through enhanced use of excess capacity. However, sustainable and sustainability are contested and culturally loaded terms. The term sustainability has its origins in ecological science, referring to an ecosystem's ability to self-sustain over time (Holden et al., 2014). Docherty and Shaw (2008) critique the term 'sustainability' for its vagueness, however they recognise the value of the term, and suggest that stating the terms of reference for using 'sustainability' is critical. In general, the accepted definition is that of the Brundtland Report (World Commission on Environment and Development, 1987) which refers to meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. There are three pillars to sustainability: economics, society and the environment, known as the three pillars of sustainable development, and none should be pursued at the compromise of the others (Docherty and Shaw, 2008, O'Riordan and Voisey, 1998). In addition, some academics add a fourth pillar of governance, for example, Kennedy et al (2005) discuss sustainable urban transport as resting on four pillars: governance, financing, infrastructure and neighbourhoods. There are also concerns about how activities impact on the present day population, and the sustainability of those activities, such as urban air pollution impacts on health (Santos et al., 2010b). Holden et al (2014) derive four primary dimensions from the Brundtland Report: "*safeguarding long-term ecological sustainability, satisfying basic human needs, and promoting intragenerational and intergenerational equity*" (p.131). They then provide indicators and threshold levels to assess the sustainability of nations, finding that no country is currently on a pathway of sustainable development (Holden et al., 2014). Agyeman (2008) has argued that a focus on environmental targets has overshadowed the other pillars of sustainability, and that 'just sustainabilities' should be the goal, taking into account social dimensions of these challenges.

Within the present work, the pillars of sustainability – economics, society, environment and governance, are recognised to have important and interconnected impacts. However, environmental challenges are the focus of the present research, exploring how CO_2 emissions can be reduced. While reducing emissions of CO_2 is explored in the context of Holden et al's four dimensions of sustainability (2014), environmental targets remain the focus in the present research, although pursuit of improved environmental conditions should not be at the expense of social sustainability, equity and accessibility. The potential to explore additional dimensions of sustainability in low carbon urban transport are identified in Section 9.3 within further work. Within the present work, sustainability and sustainable development are used interchangeably because, as Holden et al suggest, "*the two concepts entail the same dimensions and same policy implications*" (Holden et al., 2014, p.131).

Historically, transport policy has been structured around a 'predict and provide' model, which predicts future transport demand and accordingly builds additional roadspace capacity to meet this demand. This philosophy, however, is predicated on the pursuit of economic growth, and the assumption that growth can continue indefinitely, a goal that is not necessarily compatible with sustainability unless the economy can be decoupled from emissions (Goulden et al., 2014). In addition, the construction of additional roadspace leads to induced demand and congestion effects, which offset any benefits from expansion of roadspace, (Goodwin, 1996a, Hidalgo et al., 2013). The phenomena of induced congestion and rebound effects are explored further in Section 2.2.2.

Perrels (2008) argues that it is difficult to imagine a truly sustainable transport future unless environmental impacts of transport are decoupled from economic growth. The late 1990s saw a move away from predict and provide and towards the inclusion of more holistic mobility goals, e.g., demand management and public transport improvements, in transport planning (ibid). This is reflected in the emergence of the sustainable mobilities paradigm in the academic literature (Banister, 2008), which is discussed further subsequently. Recently, there has been a return to road building as a priority for government transport funding, with the Summer 2015 budget announcing £28bn for road building (HM Treasury, 2015) and the impact of this on future sustainability in transport remains to be seen (transport policy is further discussed in Section 2.6). Conversely, the emergence of the sharing economy, as an alternative to neoliberal economics, could present an opportunity for a different kind of consumption, which could be more sustainable (Martin, 2016). The sharing economy has influenced transport in a number of ways, from carpooling, car sharing and ride sharing, through to the shared ownership models for cars, vans and bicycles (Cohen and Kietzmann, 2014). The implications of the sharing economy for travel behaviour are discussed further in Section 2.3.2, focusing primarily on car sharing. The ideas behind collaborative consumption and the sharing economy are incorporated into the definitions of capacity developed in Section 2.5.

2.2.1 Conceptualising and addressing transport challenges

Transport demand is generally derived economically from income and population, so as GDP and population increase so does demand for transport (Schwanen et al., 2011). This is found across the transport literature as well as for other sectors of the economy, such as energy. Within techno-economic transport modelling approaches, the demand for transport is often driven by the growth in GDP, see for example, the ICCT Roadmap model (Façanha et al., 2012). Alternative approaches explore the ways in which transport demand is derived from behavioural choices, and there are modelling approaches which conceptualise this (see for example Davidson et al., 2007, Stern and Richardson, 2005). Modelling approaches for this are covered in more detail in Chapter 3-. The link between growth and increased demand occurs across sectors beyond transport and this is why many suggest that decoupling of economic growth and demand for energy and transport is needed in order to reduce emissions (Perrels, 2008).

Transport challenges, including CO_2 emissions, have often been discussed, within economics, as negative externalities and quantified in monetary terms (Santos et al., 2010a). This means that pollutants are as a result of a process within the system that is not accounted for economically, there is no cost to the polluter associated with the emissions (O'Riordan and Jordan, 2000). Internalising these costs, by ensuring that the polluter pays for these emissions, is often proposed as a favourable approach to reducing emissions (Schäfer, 2009). Carbon taxes are proposed as one option for encouraging more sustainable transport choices, however, complex issues around the implementation of these and challenges of equity have stalled uses of these measures (Miyoshi and Rietveld, 2015, modelled a hypothetical example of this). The focus on purely economic aspects of travel demand can obscure the impacts of behavioural choices on travel, and alternative approaches are required to integrate these dimensions.

The mobilities perspective, on the other hand, emphasises the importance of interdependencies and interconnections between activities and behaviours. This moves beyond the consideration of transport demand being a product of societal income (Sheller and Urry, 2006), diverging from conventional economic approaches. Mobilities takes a holistic approach to transport by examining the underlying behaviours and transport activity. The objective based system adopts an integrative approach to transport research, planning and policy, reflecting an increased focus on ‘sustainable mobility’ goals (Sheller, 2011). Banister (2008) introduced the concept of the sustainable mobility paradigm, there are four key elements to this sustainable mobility paradigm:

“a) Making the best use of technology…

b) Regulation and pricing means that the external costs of transport should be reflected in the actual costs of travel…

c) Land-use development, including planning and regulations, needs to be integrated…

d) Clearly targeted personal information…” (Banister, 2008, p.78-79)

The sustainable mobilities paradigm moved transport research beyond the traditional ‘predict and provide’ and economic conceptualisations of transport challenges and began to look more objectively at the system as a whole while retaining sustainability at the heart of the perspective. Hickman and Banister argue that, in order to deliver a sustainable mobility system, reducing the need to travel in developed countries and avoiding the business as usual trajectory in developing countries, is essential (Hickman and Banister, 2014). The sustainable mobilities paradigm retains some aspects of the traditional economic framing of transport challenges, recognising that the internalising of negative externalities through pricing and regulation has a key role (Banister, 2008). In addition, Banister emphasises the importance of information in influencing the sustainability of the mobility system. However, the impact of information on travel behaviour is disputed and debated, and while effective information provision can influence travel decisions, mode choices are often habitual (Verplanken et al., 2008), therefore information about transport options may not be frequently sought (Waygood et al., 2012). Even where travel information is acquired by individuals, they cannot always be expected to act rationally based on this information as mode choice can be influenced by “*independence, privacy, social interaction, convenience, time (total, portion), cost (real, perceived), comfort, experience, environmental impact, social impact (e.g. safety, congestion) or health*” (Waygood et al., 2012, p.315). Section 2.3.2 examines approaches to influencing travel behaviour, including provision of information, in more detail, and highlights some of the ways that information campaigns and interventions can be effectively designed in order to leverage change in behaviour. This is also examined in the context of the results in Chapter 4- and Chapter 5-.

It is interesting to examine Banister’s sustainable mobilities paradigm in the context of the definitions of sustainability and sustainable development developed by Holden et al (2014). In their paper, Holden et al argue that sustainability must go beyond the environmental impacts and incorporate the meeting of human needs and inter and intra-generational equity (Holden et al., 2014), and these do not seem to be reflected in the key elements of the sustainable mobilities paradigm identified above. However, as suggested earlier in Section 2.2, the focus of the present work is on the environmental impact of transport, thus the sustainable mobilities paradigm is appropriate in the present work and additional aspects of sustainability are explored further in Chapter 9-.

Banister’s sustainable mobilities perspective provides a useful framing for exploring excess capacity in urban transport systems, and much of the work that follows in this thesis is presented in the context of this theoretical perspective. The sustainable mobilities approach is also coupled with the socio-technical systems perspectives, presented in Section 2.4, to develop the theoretical framing for the present research.

2.2.2 Congestion, induced congestion and rebound effects in transport

Congestion occurs where volume of traffic within an intersection, or along a section of road, or link, reaches such a level that speeds begin to drop (Grant-Muller and Laird, 2006). Congestion is associated with increased emissions, where vehicles are often idling or covering distances at low speeds. Thus reducing congestion and making more efficient use of capacity could help in reducing emissions and the present work considers this within the exploration of urban transport excess capacity. In addition to the impacts of congestion on private car transport, there are additional implications for public transport, with May (2013) suggesting that congestion can undermine public transport service with negative impacts on accessibility. These interconnections between private car traffic and public transport service quality are important for the urban transport system at a whole network level, and the allocation of roadspace to the different modes influences this balance.

There are some questions around the levels of acceptable congestion as expansion of available roadspace tends to lead to induced traffic demand, and hence congestion, which is explored further subsequently in this section. Therefore it would appear that some level of congestion is necessary to suppress increasing demand (Goodwin, 1996a). Gordon and Richardson argue that congestion is, in fact, sustainable, so long as traffic emissions can be reduced through efficiency measures, and that sprawling, non-dense settlements are key to maintaining travel speeds (Gordon and Richardson, 1995). However, despite being written 20 years ago, the suggested improvements in vehicle efficiency have not been realised sufficiently to mitigate the effects of ever increasing demand for travel, and suggest that congestion is not, at present, sustainable. Their perspective also ignores the need for dense urban structures to facilitate transit investments, highlighted earlier, and the important role that public transport will need to have in a sustainable urban environment. Barbour and Deakin (2012) show how legislation has been introduced in California to reduce the environmental impact of transport through limiting urban sprawl, which contradicts the arguments presented by Gordon and Richardson that urban sprawl and resulting congestion are positive for sustainability (Gordon and Richardson, 1995).

Induced congestion occurs when roadspace capacity is created, and additional traffic is created subsequently (Goodwin, 1996a, Hidalgo et al., 2013). It is essential that engineered and policy solutions address the risks of induced congestion and make efforts to mitigate the effects (Naess et al., 2012). Rebound effects examine how reducing the cost of using a service, for example driving through greater efficiency in vehicles, results in an increase in the use of that service, e.g., driving further because it costs less per km (Macmillen, 2013). There are also examples of indirect rebound effects, where rather than driving more, someone may use the money saved as a result of the reduced cost of driving to undertake a different activity, for example, going on holiday (Sorrell and Dimitropoulos, 2008). An additional dimension to rebound effects occurs because newer cars are more comfortable and are driven further, so despite being more efficient than an older vehicle, the emissions benefits are somewhat offset (Brand et al., 2013). The interaction of rebound effects and induced congestion have a profound influence on the impact of transport infrastructure projects, and must be considered in the planning process.

Hymel et al represent induced congestion and rebound effects in transport with the following equations, extended from the model by Small and Van Dender (2007), (Hymel et al., 2010).

$$M = M(V, P_M, C, K1, X_M)$$

$$V = V(M, P_V, P_M, X_V)$$

$$E = E(M, P_F, R_E, X_E)$$

$$C = C(M, K2, X_c)$$

[Equation 2:1]

Where M = vehicle miles travelled (VMT) and is a function of V = vehicle stock, P_M = per-mile cost of driving, C = congestion, $K1$ = accessibility-related road capital stock and X_M = exogenous factors. P_M is equal to P_F = price of fuel, divided by E = fuel efficiency and is endogenous. V is a function of P_V = price of a new vehicle, P_M and X_V = exogenous factors. E is a function of M, P_F, R_E = regulations and X_E = exogenous factors. C is a function of M, $K2$ = urban road capacity, and X_C = exogenous factors (Hymel et al., 2010). This is presented in Chapter 7- as a causal loop diagram, in order understand how the benefits of making enhanced use of excess capacity might be offset by induced demand or rebound effects.

Estimates of rebound effects vary across the literature. “Estimated short-run and long-run rebound effects (based on fuel price elasticities) average about 12% and 30% respectively” (Hymel et al., 2010, p.1223). Sorrell (2007) conducted a meta-analysis and found similar results of direct rebound effects of 10-30% for the impact of improved efficiency on distance travelled. Wang and Chen (2014) suggest that equating rebound effects and fuel price elasticities is flawed, as different income groups exhibit different response to the changes, and these are nonlinear responses (Wang and Chen, 2014).

Research has drawn attention to techniques for locking in the benefits of any investment in transport infrastructure or efficiency measures that may be offset by induced congestion or rebound effects, through approaches such as allocating roadspace to public transport modes (Banister, 2011, Hensher, 1998). This is critical for the present work, which is exploring more effective use of urban transport capacity as defined in Section 2.5, because if capacity use is made more efficient through increased occupancy rates, and traffic is thus reduced, these benefits need to be locked in and not lost to induced demand.

2.2.3 Sustainability in transport – section summary

This section has explored how different disciplinary perspectives examine sustainability in transport, particularly focusing on economic analysis of transport challenges and the sustainable mobilities paradigm. In addition, a critique of the concept of sustainability was provided, and a definition for the present work derived from this. This discussion of sustainability in transport research contributes to the framing of the work that follows in this thesis. The following section looks at technology and behavioural change measures for influencing the sustainability of the transport system.

2.3 Technology, behaviour change or both? A balancing act

The previous section introduced the challenges of achieving sustainability in transport. Both technology and behaviour change offer opportunities for reducing the environmental impact of transport and this section seeks to examine the available options, critique their role and explore the balance and interconnections between technology and behaviour change.

2.3.1 Technology for reducing CO_2 emissions from transport

This section provides background information on the technologies available for reducing the environmental impact of transport and examines their role in the delivery of a sustainable urban transport system. CO_2 emissions from new cars have been falling over recent years, through incremental improvements in efficiency and addition of new technologies. As of 2014, new vehicles in the UK had average tailpipe emissions of 124.6 gCO_2/km (SMMT, 2015). This improvement in vehicle efficiency has been driven by regulations from the European Union, which mandated a target of fleet average emissions for new cars of 130 gCO_2/km by 2015 (European Union, 2015). The technologies used to achieve emissions reductions from vehicles are expanded upon further in this section, as well as their potential to mitigate emissions of CO_2 in the future. However, it should be recognised that these values are based on the New European Drive Cycle (NEDC), and vehicles generally underperform drive cycle emissions in the real world (Ntziachristos et al., 2012). The forthcoming

Worldwide harmonized Light vehicles Test Procedures (WLTP) drive cycle should bring stated tailpipe emissions closer to those that are delivered under real world driving conditions (Tutuianu et al., 2015).

Figure 2:1 shows a schematic overview of technologies that are available for reducing the environmental impact of vehicles, including changes to engine design, propulsion and fuel. Vehicles are central to the figure and there are a number of technological modifications that can be made to vehicles to improve efficiency or change the drive train, in order to reduce emissions. Jackson and Rivera (2013) and the IEA (International Energy Agency, 2009) provide overviews of the technologies available for reducing CO_2 emissions from cars, and these technologies are, in some cases, applicable to other vehicle classes, although the picture may be different for heavy goods vehicles (HGVs).

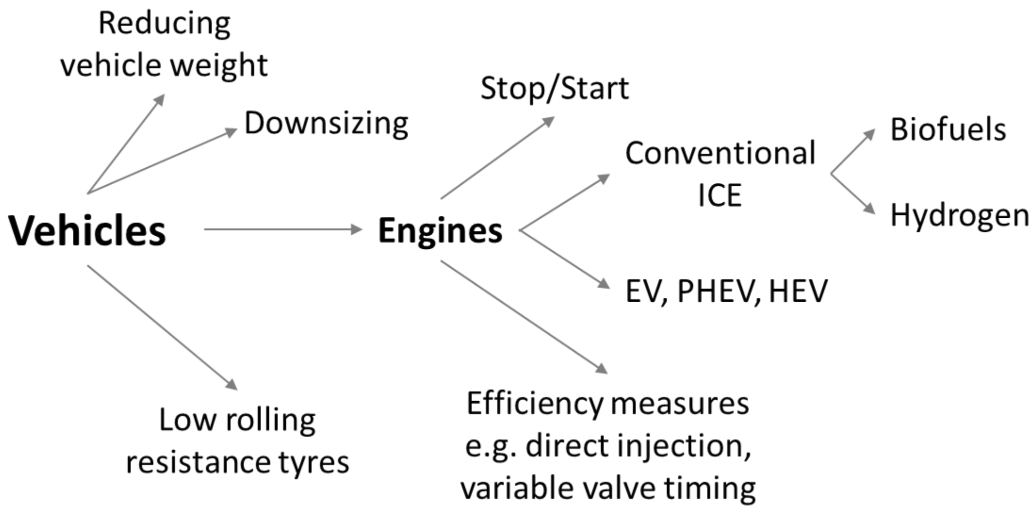

Figure 2:1 - Technologies for reducing CO_2 emissions from vehicles

Bishop (2013) provides estimates of the emission reduction potential of these technologies in transport, demonstrating that some combination of these measures could deliver significant efficiency benefits. However, even with substantial improvements in the emissions from vehicles, understanding behaviour is important, in order to ensure that take-up of new vehicles is properly supported and incentivised for consumers and to regulate manufacture of vehicles. This highlights the need for an integrative, socio-technical approach to reducing emissions from transport and the theoretical basis for this is developed for the present work in Sections 2.4 and 2.5 based on the work reviewed in this section. The way that a vehicle is driven influences its environmental impact and engine efficiency, this is discussed further in Section 2.3.2 under eco-driving.

Intelligent Transport Systems

The integration of ICT into transport systems is often referred to as Intelligent Transport Systems (ITS) and a range of technologies are including under this umbrella term from information services that provide information about the transport system to the users to new technological applications such as automated vehicles, accident prevention technologies (Bunn et al., 2009). ITS combines technologies from sensing and processing and communication technologies to improve transport systems (d'Orey and Ferreira, 2014). In addition, ICT can influence the way that individuals value their time when travelling, for example by incorporating activities or work into time spent travelling on public transport, and this could affect the relative costs of modes as well as influencing travel decision making (Lyons and Urry, 2005).

Black and Geenhuizen (2006) outline two key ways that ICT can influence transport:

- It can influence and change the way in which the system is used, through new infrastructure applications, such as variable sign messaging, improved navigation services and remote working and shopping capabilities
- It can influence the travel choices that individuals make by providing real time transport information as well as information about the alternative travel choices (Black W and van Geenhuizen M, 2006)

Lyons et al, (2011) emphasise the importance of ITS in management of traffic and supporting travellers with increased access to information services, supporting the key points identified by Black and Geenhuizen. Grant-Muller and Usher (2013) refer to ITS as including ICT linking the transport sector with other sectors and facilities and embedded ICT within transport infrastructure. There are, however, challenges with over inflated expectations for the impacts of ICT infrastructure development, across sectors beyond transport, and there is the risk that the promise of ICT based solutions may not be realised (Borup et al., 2006). There are also a range of gaps in the research relating to ICT and transport infrastructure links, with much of the knowledge based on simulations rather than real world experience, suggesting that the anticipated impacts of ICT on the transport sector are somewhat uncertain (Black W and van Geenhuizen M, 2006). d'Orey and Ferreira (2014) suggest that ITS can contribute to the sustainability of the transport system in a number of ways, including making the operation and routing of the vehicle more efficient (eco-driving and eco-routing) and through managing the traffic system to reduce fuel consumption, and this goes beyond the suggestions of Black and Geenhuizen (2006). ICT represents a potential tool for improving the sustainability of the transport system, particularly through ITS, however, alone it will be insufficient, and must be part of wider technological and social changes (Thomopoulos et al., 2015a).

Automation of vehicles refers to the increasing levels of computerised control in vehicles, and is linked into ITS through the development of ICT and facilitating infrastructure. The US National Highway Traffic Safety Administration (NHTSA) refers to five levels of automation, from level 0 where the driver has full control of the vehicle, through increasing levels of automatic control of vehicle functions such as acceleration, braking and steering, up to level 4 which has full self-driving automation (National Highway Traffic Safety Administration, 2013). Vehicle automation is important for sustainability, through the impact that automated vehicles have on emissions, and capacity use, as automated vehicles can travel much closer together, thus more vehicles can travel in the same amount of roadspace. Wadud et al (2016) examine the energy efficiency impacts of vehicle automation, suggesting that increased efficiency through aerodynamic and engine efficiency, plus vehicle right sizing will have positive energy impacts. These could, however, be offset by increased demand, additional demand from groups who cannot presently use cars such as the elderly and children, and additional vehicle km through vehicles driving empty (Wadud et al., 2016). Additional work has been undertaken exploring emerging business models for automated vehicles, for example, examining the potential impacts of shared use, automated vehicles, and this could have a profound impact on the state of the urban transport system (International Transport Forum, 2015). There are interconnections between the work presented in this section on technology and the behaviour change perspectives presented in

Section 2.3.2, particularly when looking at uptake of alternative fuelled or automated vehicles, and the potential to influence travel decisions.

These developments in ITS and vehicle automation present opportunities for making enhanced use of excess capacity through, for example, efficient movement of vehicles through the urban transport network or more intensive use of the roadspace through reduced headway in automated vehicles, thus providing an interesting perspective for the present research. In particular, this is useful in addressing research question 3, on how more effective use of excess capacity in urban transport systems might be facilitated. ITS and automation are also interesting for research question 4, exploring how enhanced use of urban transport excess capacity may fit into scenarios for a future sustainable transport system, as these are emerging technologies that could influence the pathways for low carbon transport. In addition, the sustainability impacts of the uptake of ITS is largely unknown, which represents a gap in knowledge.

2.3.2 Influencing travel behaviour to reduce emissions

This section introduces some of the options available to influence individuals' behaviour in order to make the transport system more sustainable. Predominantly, this section provides examples of behaviour change interventions, but some theoretical understanding of how to influence behaviour is introduced first. Chapter 4- also contains insight into behaviour, looking at the theoretical perspectives underpinning behavioural research in transport. In addition, Section 2.6 provides detail on transport policy, which reflects many of the behaviour change measures and interventions introduced in this section.

Travel behaviour is a multidimensional concept and influencing behaviour has been tackled in the literature in a number of ways (Van Acker et al., 2016). As Marsden et al (2014) suggest, measures for travel behaviour change draw on a range of disciplines including economics, psychology, political theory and philosophy. Shove suggests that many efforts to design policy to influence behaviour have been based around the 'ABC' framework, "*in which 'A' stands for attitude, 'B' for behaviour, and 'C' for choice*" (Shove, 2010, p.1274).

Travel choices have been conceptualised in different ways within the transport literature, from planned decisions (Ajzen, 1985) to habits (Schwanen et al., 2012, Thøgersen and Møller, 2008) and as social practices (Watson, 2012). The mechanisms through which individuals make travel behaviour decisions, or the extent to which they become habitual vary across these perspectives and the techniques that can be used to influence decisions also vary accordingly. For example, in the case of habitual travel behaviour, often behaviour remains constant until some disruption occurs, such as a change in life circumstances, which acts as habit-breaking or forming (Schwanen et al., 2012, Thøgersen and Møller, 2008)

Dargay and Hanly found that life change points influence travel behaviour: "*about 25% of households that either move house or change job change car ownership*" (Dargay and Hanly, 2007, p.946). Scheiner and Holz-Rau (2013) suggest that life events, such as starting a family, have an impact on individuals trip volume and mode choice, and their evidence suggests that these responses are highly gendered. By understanding which groups are most flexible in their travel behaviour, and what life events are leveraging change, policy can be targeted in order to deliver the maximum benefits. This is emphasised throughout the research that follows, particularly where looking at behaviour associated with capacity use and how to influence this through policy interventions in Chapter 4- and Chapter 5-.

Cass and Faulconbridge (2016) examine commuting as a social practice, and suggest that the practice of commuting by car represents a different practice to commuting by bus or bicycle, thus the practice is not the commute itself but is dependent on the mode. This is an interesting perspective, which could suggest that many interventions designed to encourage modal shift are overlooking the distinctive nature of commuting by a specific mode.

Van Acker et al (2016) emphasise that, while mode choice is important, travel behaviour goes far beyond mode choice, incorporating aspects such as frequency of trips, destinations, driving styles, social arrangements, convenience and comfort. This perspective is important for the present work, which examines multiple dimensions of travel behaviour in order to understand capacity use in the urban transport system. Box 2:1 shows the factors which influence travel behaviour according to Zhou (2012). This incorporates a wide range of factors, and provides an extensive list of potential influences on travel behaviour.

Box 2:1 - Factors influencing travel behaviour (Zhou, 2012, p.1015)

Group 1: Physical environment and urban form factors such as population density, land use mixture, topography, availability of infrastructure, and multimodal networks' connectivity

Group 2: **Mode specific factors** such as availability, access, convenience, comfort, privacy, freedom, safety, travel time and cost

Group 3: **Trip-makers' personal attributes** such as occupation, marriage status, gender, age, income, daycare responsibilities, car ownership and possession of a drivers' licenses

Group 4: **Trip characteristics such as time of travel, trip purpose, trip distance, trip origin and destination**

Group 5: **Presence of Travel Demand Management (TDM)** measures such as parking cost or restriction, information campaigns against car usage and transit pass subsidy

Group 6: **Psychological factors** such as habit, attitude, concerns over health and the environment, familiarity with alternation modes to driving and unconscious attachment to car usage

The present work does not examine the full extent of Zhou's factors, rather focuses on those dimensions which are most closely related to capacity, as it is defined in Section 2.5. The most critical factors for the present work are emboldened in Box 2:1. The review and discussion of behaviour change approaches that follows in this section reflects this.

Nudge

'Nudge' refers to a particular approach to influencing behaviour change, which has emerged in recent years, and in the UK the government established The Behavioural Insights Team, also known as 'The Nudge Unit' (The Behavioural Insights Team, 2015). As Thaler and Sunstein (2008) define it, nudge refers to choice architecture that influences people to make choices that will improve their lives, without actually restricting their choices or significantly incentivising improved choices economically. Waygood et al (2012) provide an example of nudge used in Advanced Traveller Information Systems (ATIS) to encourage more sustainable travel choices. By ensuring that sustainable mode choice options are included by default for journeys searched for by individuals, and even potentially framing the gains of a sustainable choice or loss of the less sustainable choice, travel information can be presented in such a way that can 'nudge' individuals to make the more sustainable choice. In addition, some of the behavioural change approaches that are presented subsequently contain aspects of nudge, as they are not restricting choices, merely trying to encourage individuals to make more sustainable choices. However, as suggested earlier, the impact of information on travel choices is not always clear, as individuals do not make entirely rational transport decisions, but rather are influenced by a whole range of factors (Waygood et al., 2012).

Eco-driving

Driving behaviour influences the emissions from the vehicle, eco-driving has been proposed as an option for reducing emissions from transport (Barkenbus, 2010). This involves educating drivers to engage in gentler breaking and acceleration and changing gears at the optimum times in order to reduce fuel consumption (ibid). While this is not a technology in itself, this demonstrates the close interconnections between behaviour and technology when examining decarbonisation options. There are technologies available to encourage eco-driving, and these have been demonstrated to deliver reductions in fuel consumption as high as 16% (van der Voort et al., 2001). Eco-driving is also connected to ITS, as in vehicle technologies are emerging to encourage eco-driving, such as gear shift indicators, and increasing automation in vehicles will facilitate smoother acceleration and deceleration, providing efficiency gains (Wadud et al., 2016). Gear shift indicators have been mandatory on new cars sold in the EU since 2012, and fuel savings associated with these is estimated at around 7% if they are actively used (Committee on Climate Change, 2014) Eco-driving represents an opportunity to make more effective use of present infrastructure while still reducing emissions, which could be coupled with more effective use of urban transport capacity in order to contribute to a sustainable urban transport system.

Smarter Choices

A range of approaches have been proposed for influencing peoples' travel behaviour and allowing them to make 'smarter choices'. Many of these apply

ICT to mobility related decisions, particularly where they are providing improved information or access to services that previously required travel. These smarter choices or soft measure approaches include, but are not limited to:

- Personalised, workplace and school travel plans;
- Car clubs and car sharing;
- Home shopping;
- Travel awareness;
- Public transport information;
- Campaigns for increased walking and cycling; and
- Teleworking and teleconferencing (Cairns et al., 2008)

They have been suggested as lower cost methods of facilitating emission reductions and efficient usage of the transport system, with suggested emission reductions in the region of 4-5% nationally with low intensity application, and up to 15-20% with high intensity application and favourable local conditions (Cairns et al., 2008). However, others have raised concerns about the long-term effectiveness of smarter choices programmes (Richter et al., 2011), and this remains an area for further exploration. Recent research on travel disruptions has identified that travel patterns are highly variable, and responses to disruptions can result in longer term changes to behaviour (Marsden and Docherty, 2013), and, as such, it may be possible to suggest that changes made through smart choices programmes could be long-lasting. Richter et al (2011) also suggest that public transport should be prioritised as the strategy for sustainable mobility because walking and cycling can be prohibitive to certain user groups. However they can play an important role in the transport mix, as demonstrated in European countries such as the Netherlands and Denmark, where cycling represents 27% and 18% of trips respectively (Pucher and Buehler, 2008), therefore they should be part of a sustainable transport future. The Committee on Climate Change include smarter choices as part of the suite of measures used to reduce GHG emissions from transport in the UK. Over the Third Carbon Budget (2018-2022), they are expected to reduce total car vehicle km by 5% compared to the business as usual (BAU) case (Committee on Climate Change, 2014).

These approaches are compatible with the sustainable mobilities paradigm, in exploring factors beyond the cost of travel and emphasising one of the key elements of the paradigm, in clearly targeted personal information. Thus, smarter choices could be important in considering how effective use of urban transport capacity might be achieved. Some of the different smarter choices options are expanded upon subsequently, while some are included in the policy review Section 2.6. Again, it should be recognised that, as Waygood et al (2012) suggest, individuals may not respond rationally to information, but the results of schemes reviewed suggest that smarter choices can deliver benefits for the sustainability of transport, and provide useful potential policy options for facilitating enhanced use of urban transport excess capacity.

Workplace and school travel plans

Both workplace and school travel plans, where they are supported by local authorities, can be effective in changing travel behaviour of participants (Cairns et al., 2004). Workplace travel plans can be implemented by organisations for a range of reasons, including being a requirement as part of planning applications, which creates a powerful policy mechanism that can be used to leverage more sustainable travel behaviour (Roby, 2010). School and workplace travel plans can be tailored to local situations, and can include measures such as encouraging walking, cycling and public transport use, restriction of parking provision and car sharing schemes (Rye, 2002). These interventions, and potential policy tools, could be useful in exploring how enhanced use of excess urban transport capacity might be delivered and will be explored in the ongoing work.

Public transport, walking and cycling information

Clear and accurate public transport information is important for encouraging more sustainable mode choices. For example, Van Exel and Rietveld (2009) demonstrated that in the Netherlands, the discrepancy between perceived travel time by public transport and the actual travel time, meant that people may choose not to use the public transport option. In addition, Table 2:1 shows perceived advantages and disadvantages of buses and private car (Beirão and Sarsfield Cabral, 2007), suggesting that there are areas where there may be discrepancies between perceptions of different modes and the reality. Therefore, potential improvements to public transport information could deliver an improvement in ridership. In addition, Cairns et al (2008) find that travel awareness campaigns, where individuals are made aware of the impact of their travel choices and provided with information about potential alternatives, could help to influence travel behaviour towards more sustainable choices.

Table 2:1 - Perceived advantages and disadvantages of buses and private car (Beirão and Sarsfield Cabral, 2007)

Advantages	**Disadvantages**
Public transport	
Cost Less stress No need to drive Be able to relax Be able to rest or read Travel time on bus lanes Less pollution Talk to other persons on the vehicle	Waste of time Too crowded Lack of comfort Time uncertainty Lack of control Unreliability Long waiting times Need of transfers Traffic Lack of flexibility Long walking time
Private car	
Freedom / independence Ability to go where I want Convenience Rapidity Comfort Flexibility Know what I can expect Safety Having my own private space Listen to music	Cost Difficulty of parking Cost of parking Stress of driving Traffic Waste of time in rush-hour traffic Pollution Accidents Isolation

Telecommuting, teleworking and teleconferencing

Telecommuting applies telecommunications technology to facilitate work at home or at a centralised office space that is not the normal location for work (Nurul Habib et al., 2011). Cairns et al (2008) define teleworking as "*where employers encourage employees to adopt a range of remote working practices, including working at home or in a closer location than their main workplace for some or all of the time*" and teleconferencing as "*where telecommunications are used to facilitate contacts that might otherwise have involved business travel*" (p.595). The following insight spans telecommuting, teleworking and teleconferencing applications.

There are a number of ways that telecommuting can impact on transport and travel behaviour. Lyons (2009) also suggests that additional ways that telecommunications can influence travel include supplementing travel, enriching travel and allowing that time to become productive and through adjusting current journey timings, see also Haddad et al (2009). Asgari et al, suggest that a range of benefits could emerge from increased telecommuting such as "*economic, environmental and social aspects including trip reduction, congestion mitigation, cost savings for office space, increased productivity and a better home-work balance*" (Asgari et al., 2014, p.107). However, the costs and environmental benefits of telecommuting are debated, with some authors suggesting that in the USA telecommuting has resulted in increased km travelled (Zhu and Mason, 2014).

There has been research on the role that telecommuting can play in the achievement of transport goals including sustainability and alleviating congestion. Much of this work has taken place in the USA and has found that there are environmental benefits of encouraging home working and telecommuting, though they are not found to be substantial, see for examples, Zhou (2012) and Pouri and Bhat (2003). Nelson et al (2007) looked at the impact of the ecommute program in the USA, a telecommuting scheme in five US cities, which included 535 employees from 49 companies. The evidence from this study suggested that ecommuting had positive impacts on emissions of NO_x and VOCs and that, while the reductions were small, telecommuting should still be encouraged for travel demand management. However, the impacts of telecommuting on sustainability are complicated, it is not as simple as avoiding journeys through homeworking, there are energy penalties associated with more people working in disparate locations and people may still travel in different ways and at different speeds (Mokhtarian, 1991). Haddad et al (2009) examined the desire and behaviour for whole and part-day homeworking in the UK, suggesting that while part-day homeworking did not avoid the travel altogether, it allowed flexibility to travel outside the peak and thus may have positive impacts on congestion. While the results and impacts of telecommuting and other travel substitution schemes have been varied, the Haddad et al study demonstrates positive benefits in the UK context, thus this perspective is taken forward in the present work.

Car Sharing

Car or ride sharing provides an opportunity to increase vehicle occupancy rates and reduce the excess capacity in the system. While car sharing is often defined as vehicles which are shared and ride sharing refers to sharing the space within vehicles, the term car sharing is more widely recognised by the UK public as the term for sharing space in vehicles (Cairns et al., 2008). Hence, subsequent references to car sharing in this work refers to sharing the space within vehicles and where other works are referenced, ride sharing may refer to the same practice. An additional dimension of car sharing is 'casual carpooling', defined as "*the sharing of a ride with a driver and one or more passengers, where the ridesharing between individuals is not established in advance but coordinated on the spot*" (Kelly, 2007, p.119). Agatz et al (2012) suggest that both sharing the space in vehicles car or ride sharing, and shared ownership of vehicles aim to increase access and reduce absolute car use. Urry argues that car sharing, and the de-privatisation of automobility is one of the six factors that could help to deliver a sustainable transport system (Urry, 2004).

Car sharing is not a new innovation, it was encouraged during WWII to save fuel (Chan and Shaheen, 2012). It has, however, seen a resurgence with new applications of ICT to encourage and facilitate the practice (Thomopoulos et al., 2015b). Factors involved in influencing journey decisions, including the decision to car or ride share are suggested by Furuhata et al (2013) as "*cost, travel time, flexibility (ability to adapt to changes in schedule), convenience (such as the location of the pick-up and drop-off points, the ability to listen to music, or privacy), reliability, and perception of security*" (p.28). There are number of emerging innovations that change how transport users can interact with capacity including peer-to-peer sharing platforms such as 'BlaBla Car' in the UK and 'Carpooling.com' or 'Ride' in the USA (Cohen and Kietzmann, 2014).

An AA study in 2010 found that one in five of its members car share at least once a week (The AA, 2010), although this study is not representative and only includes car users. Table 2:2 shows some of the additional results from the survey. It is interesting to note that reduction of CO_2 emissions is a significant attraction for those who car share. The survey also found that 18-24 year olds are the most likely to car share once a week but 25-35 year olds are more likely to give or receive a lift every day (The AA, 2010).

Table 2:2 - The AA car sharing survey results (The AA, 2010)

How often do respondents car share?	• 3% - every day • 7% - most days • 10% - once a week • 7% - once a month
What are the attractions?	• Saving money on fuel and wear and tear (77%) • Reducing CO_2 (71%) • Sharing as and when travel coincides with someone else (70%) • Saving on parking costs (65%)
Reasons that those who don't currently car share might be encouraged to start	• A guarantee of being able to get home (25%) • The opportunity to share with someone they know (21%) • Clear information about other potential sharers (20%) • Reserved parking for car sharers (15%) • A cash incentive (13%)

Minett and Pearce (2011) calculated the impact that increasing casual carpooling in San Francisco could have on fuel use, to explore the potential for the practice to manage transport demand in case of oil price rises. While Minnet and Pearce focused on fuel use and the practice of casual carpooling, the magnitude of the potential fuel conservation identified is high, at 5.3-11 KT oil equivalent per year (Minett and Pearce, 2011).

Jacobson and King (2009) quantify the potential that increasing occupancy of vehicles in the USA, through ride sharing, has for reducing fuel use, including the impact of increased weight of additional passengers on fuel consumption. They find that if every 1 in 100 vehicles carried an additional passenger, 2.5 MT oil equivalent could be saved annually, if every 1 in 10 vehicles had an additional passenger this rises to 24 MT oil equivalent (Jacobson and King, 2009).

Both the Minnet and Pearce study and the Jacobson and King study focus on the potential of car sharing to reduce fuel use. This work looks more closely at CO_2 emissions and projects this into the future, as well as looking at capacity across the urban transport system, not for car mode choice alone. The examination of the wider system around urban transport allows the network impacts to be explored and any potential interconnections and causal effects to be identified and analysed.

Dynamic ride sharing: Agatz et al (2012) explore how dynamic ride-sharing systems could be used to facilitate the practice. They define dynamic ride-sharing as “a system where an automated system made available by a ride-share provider matches up drivers and riders on very short notice or even en-route” (Agatz et al., 2012, p.295). It removes the need for prior organisation that is required with the options described above, which could overcome a barrier to participation. Agatz et al (2011) demonstrated the effectiveness of dynamic ridesharing for a modelled case study of Atlanta, and showed that even with low participation rates that dynamic ride-sharing could be sustained.

The potential of car sharing to influence the sustainability of the urban transport system is explored further within the present thesis, particularly in the context of enhancing excess capacity use through increased vehicle occupancy rates. Section 2.7.1 highlights how car sharing is a key trend for the present research and Table 2:4 demonstrates the connections to the research questions.

2.3.3 Summary of technology and behaviour change approaches

The preceding section provided a review and critique of the technological and behavioural change approaches to reducing the environmental impact of transport systems, demonstrating the interconnections between these two areas. It is clear that behaviour change and technological solutions are both necessary to mitigate climate change, though the balance of these, and the optimal mechanisms are still under debate (Schwanen et al., 2012). Hence the present research examines aspects of behaviour change and technological approaches to sustainable urban transport systems. Section 2.4 provides an overview of a socio-technical systems perspective, theory which integrates the different approaches to sustainability and transport, and applies it to the present work.

2.4 An overview of socio-technical systems

Lyons argues for a coming together of technological approaches and behaviour change measures in order to transition towards sustainable mobility (Lyons, 2011). A socio-technical systems perspective thus provides a useful framework for analysing approaches to deliver sustainable transport. This is coupled with the sustainable mobilities paradigm introduced in Section 2.2 to frame the discussion of urban transport capacity within the present work. This section introduces the theoretical perspectives behind socio-technical systems in order to provide the context for the present research.

Socio-technical systems refers to a range of factors, including, but not limited to, "*technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and production systems*" (Geels, 2005, p.1). Whilst technological developments will be key in reducing emissions, there are important additional considerations and the socio-technical perspective incorporates multiple aspects (Kemp et al., 2011). Actors within socio-technical systems are both influenced by the system – their practices and actions are a result of the conditions of the system – and their actions are simultaneously influencing the system (Geels, 2005). In the context of urban transport, this could be conceptualised as individuals consuming transport services are influencing the system through their mode choices, however their mode choice may also be influenced by that which a specific urban transport system provides.

This socio-technical systems perspective has been applied to the transport sector by a number of researchers. Dennis and Urry outline the interconnected elements of the socio-technical system surrounding car transport; "*We examine the car system as being made up of humans (drivers, passengers, pedestrians), machines, materials, fuel, roads, buildings and cultures. What is key is not the 'car' but its system of connections…*" (Dennis and Urry, 2009, p.63-64). This captures the many dimensions of the system, outlined in Section 2.3 and also reflects the multiple perspectives incorporated into the sustainable mobilities paradigm.

Marletto (2014) examines the socio-technical system of cars in urban areas, developing 'socio-technical maps' in order to present connections between emerging business models and propulsion technologies. Three pathways emerge: ‘AUTO city’; ‘ECO-city’; and ‘ELECTRI-city’, in which different dynamics of new technologies and business models interact in different ways in order to result in a divergent socio-technical futures (Marletto, 2014).

Spickermann et al (2014) examine futures for urban transport, using a socio-technical systems perspective, and consulting with stakeholders, to design different pathways for the future of urban mobility. Their adoption of this perspective allows them to integrate multiple dimensions of the urban mobility system, particularly as they are interested in multimodal models for urban transport, and the behavioural and technological challenges that this brings (Spickermann et al., 2014). Their work reflects the integrative approaches in the present research, and their use of a socio-technical framing reiterates the value of this perspective.

Zijlstra and Avelino (2011) explore the spatial aspects of the socio-technical system in transport, suggesting that factors such as speed, individualism, consumerism, inequality and the design of spaces for automobiles, contribute to the dominance of the car as mode of choice, thus a wide range of socio-technical and socio-spatial changes are required to deliver a sustainable transport system. This reflects the analysis of the literature presented in Section 2.3, which demonstrated that focusing on behaviour change or technology alone will be insufficient to meet the sustainability targets in the transport sector.

This section has provided a brief introduction to socio-technical systems perspectives, and the framing that is used in the present research. Figure 2:2 in the next section adapts Geels’ (2002) conceptualisation of the socio-technical system in urban transport in order to incorporate the idea of excess capacity. More detail on socio-technical systems is provided in Chapter 6- which explores how socio-technical systems perspectives have been used to examine sustainability transitions. Additional critique of the socio-technical systems perspective is provided in the review of sustainability transitions in Chapter 6-. The definitions of capacity that are developed in the subsequent section reflect the socio-technical systems framing within the context of the literature critiqued on sustainable transport in Sections 2.2 and 2.3, particularly the sustainable mobilities paradigm.

2.5 Examining capacity in the context of sustainable transport

This section develops a definition of capacity, and excess capacity, in order to frame how this will be examined in the context of sustainable transport in the present work. This begins with an overview and critique of how capacity has been conceptualised in transport literature and then looks at additional dimensions of transport that are relevant for the examination of capacity in the present work, such as congestion and crowding. Section 2.5.2 then provides the definition of capacity for the present work and Figure 2:2 shows the socio-technical system for capacity as defined for the present research.

The Highway Capacity Manual (TRB, 2010) presents capacity in terms of system performance, and this is discussed as follows;

"System performance can be measured in the following dimensions:

- Quantity of service - *the number of person-miles and person-hours provided by the system;*
- Intensity of congestion - *the amount of congestion experienced by users of the system;*
- Duration of congestion - *the number of hours that congestion persists;*
- Extent of congestion - *the physical length of the congested system;*
- Variability - *the day-to-day variation in congestion; and*
- Accessibility - *the percentage of the populace able to complete a selected trip within a specified time.*"

Technical definitions of capacity, as the one given above, focus on the engineered specifications of the infrastructure and the metrics associated with this such as flow rates of vehicles along a specific link or past a specified point, within a given time. For example, '*In general, the capacity of a facility is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions*' (Minderhoud et al., 1997, p.59).

Mallinckrodt (2010) developed a regional volume/capacity index (VCI) to examine the relationship between roadspace and the levels of traffic at a regional level, rather than for a specific link. This approach goes beyond the traditional examination of capacity at the confined scale of a link, and incorporates more system wide aspects into the analysis. While these approaches are useful for assessing the performance of junctions, roads and even networks, they fail to take into account many of the behavioural aspects of travel that have been highlighted in preceding sections.

Much of the research on excess capacity in transport has focused on freight and has not directly considered the emissions penalty that might be associated with this excess capacity (Abate, 2014, Braekers et al., 2011). Other work has suggested how construction of new roadways and other infrastructure increase capacity and the impacts of this, see for example Bauer et al (2004).

Hensher (1998) suggests that by allocating roadspace to transit systems, therefore reducing roadspace for private cars, the overall impacts of investment in transit can be maximised. There seems to be little value in improving transit to reduce congestion if the released capacity is immediately filled with induced demand, and this relates to the examination of induced congestion that was provided in Section 2.2.2.

In addition to considering capacity within the roadspace, this research will be exploring both temporal capacity and spatial capacity within vehicles, for private cars and public transport modes. In the case of public transport, the concept of capacity will largely refer to the number of seats within a given vehicle and the number of vehicles moving within a system (dell'Olio et al., 2012), which is particularly important where the systems represent a kind of closed network, such as urban light rail or bus rapid transit (BRT) infrastructures. Also important in considering the capacity of these systems will be the location and frequency of services, as these factors will be key in determining ridership rates.

The idea of making more effective use of capacity draws on the ideas of the sharing economy and collaborative consumption (Chase, 2015). The sharing economy was introduced earlier as a potential opportunity for different kind of economic system, less based on individual private consumption, but more on making effective use of resources (Martin, 2016). In addition, an overview of car sharing was provided in Section 2.3.2.

There are examples of the use of excess capacity in other systems to encourage sustainable choices through the sharing. One such example is peer-to-peer travel which allows people to rent their spare rooms, beds and sofas, and reduces the need for additional infrastructure and capacity to meet this demand for accommodation, for example through airbnb.com or couch surfing, (Botsman and Rogers, 2010). Examples of approaches that could reflect the principles of collaborative consumption in transport could include car sharing schemes or innovations such as Zipcar (Zipcar, 2016) which provides hourly vehicle rentals and may reduce the need to own a vehicle (Botsman and Rogers, 2010). Chase (2015) explains how BlaBla Car, a car sharing platform introduced in Section 2.3.2, was founded by Frederic Mazzella, when he found that public transport options could not meet his needs so he wished to make use of the excess capacity in other people's vehicles. BlaBla Car now facilitates more than 2 million people to travel in strangers' cars every month in Europe (ibid.), thus demonstrating the potential power of making enhanced use of excess capacity.

Bridging the divide between public and private transport is important for sustainability goals (Hoogma et al., 2002) and the idea of using capacity more effectively through car sharing, to a certain degree, breaks down the public-private divide in transport, as people share their vehicles. This could be important for sustainability in transport, and in socio-technical systems more broadly.

2.5.1 Capacity, crowding and time

Exploring the impacts of crowding and acceptable and desirable load factors for public transport will be key in exploring what capacity goals are realistic for these services. Wardman and Whelan (2010) suggest a number of factors that are key in the importance of crowding in public transport including, a sense of entitlement to a seat with ticket purchase and behaviours that include arriving early to obtain a seat or making reservations. However value of seating is highly personal, with some passengers choosing to stand (ibid.). There are also links between levels of crowding and value of time with (Li and Hensher, 2011) suggesting that crowded conditions in public transport travel increases values of travel time savings.

Additional considerations for understanding crowding in public transport should take into account the psychological components, as the experience can induce stress and other emotions. It is also important to recognise that crowding is highly subjective, what one passenger considers crowded and stressful, another passenger may not (Mohd Mahudin et al., 2012).

Capacity and time are intrinsically linked in multiple ways, some of which have been presented, through the impacts of congestion on journey times, value of time and the impacts of crowding on the value of travel time. This is key in the present work, which explores the role of modal shifting in making effective use of capacity, and the relative value of travel time between different mode choices can be a key influence on individual mode choice.

Lyons and Urry (2005) present the following hypothesis for changing values of travel time associated with improvements in ICT:

"*The boundaries between travel time and activity time are increasingly blurred. Specifically many people are using travel time itself to undertake activities. The 'cost' to the individual of travel time is reduced as travel time is converted into activity time. In turn, less of the individual's travel time budget is used, enabling more travel or encouraging greater use of modes that may enable en-route activities to be undertaken*." (Lyons and Urry, 2005, p.263)

This perspective is interesting for linkages between time and capacity. If travellers are able to make better use of their travel time by incorporating activity into their journey they may be considered as enhancing their use of time based capacity. In addition, as suggested, the integration of travel and activity time may lead to modal shift, and could help with greater efficiency in the transport system if increases are seen in public transport use.

2.5.2 Defining capacity and the use of excess capacity in urban transport

This section draws together the critique of capacity in the transport literature provided in Section 2.5 so far, and provides the definition of capacity for the present work.

Figure 2:2 below adopts a similar layout to that used by Geels (2002) in order to introduce some of the concepts that may be considered when representing the socio-technical system around urban transport capacity. It highlights the multiple aspects that must be considered when exploring the role of enhanced use of urban transport capacity within transition pathways to sustainable mobility. It also incorporates ICT, which is important for this socio-technical system and the present research.

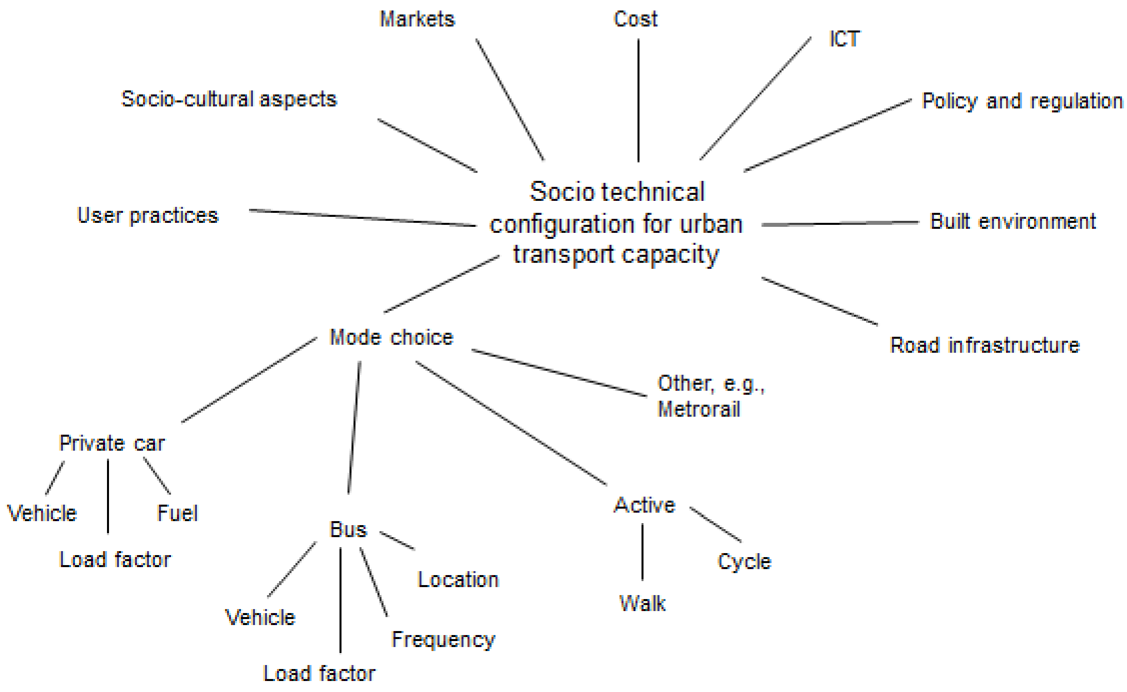

Figure 2:2 - Socio-technical configuration for urban transport capacity

This section has drawn together the elements of capacity in the wider literature that are used to inform the study of enhanced use of excess urban transport in the research in the chapters which follow. The multiple dimensions of capacity in the literature are apparent and these create a rich, although extensive, area from which to draw the definition. Capacity is defined for the present work in the box below. This is the definition which underpins the present research and will be used throughout this thesis. This definition focuses on existing capacity in the transport system, rather than expanding to look at capacity that might be added in the future through infrastructure expansion and construction. The rationale for placing this boundary on the definition is explored below.

Capacity is the space within the transport system through which transport demand can be met. This refers to physical space, both within vehicles and the roadspace, which can facilitate mobility. There are also elements of temporal capacity within the transport system, as there are high levels of loading on the system when demand is high during peak hours, and periods of much lower loading of the system.

The definition of capacity given is based on our current understanding of how transport capacity is used and on infrastructure that already exists. However, this is limited by not considering the potential capacity increases of new infrastructure or other potential shifts that might influence capacity use. For example, if EVs are more widely taken up, these vehicles may be smaller, say two seaters rather than four or five that are the current norm, and this would have a profound impact on available capacity, and hence capacity use. Autonomous vehicles would also influence capacity use, with potentially empty vehicles travelling in the road network. Some of these dimensions are captured in the work that follows as influences on capacity use in the future, through the scenarios constructed in Chapter 6-, such as increased vehicle automation. Others are not directly captured in this definition, or explicitly in the work which follows, however the framework developed in Chapter 3- could be extended to explore future infrastructure investments and their impact on capacity use.

Considering how capacity will be influenced by wider transition to sustainable transport is also important, and will be emphasised throughout this thesis. The role of technology and behaviour change are both central to conceptualising how enhanced use of excess capacity could be achieved and the potential policy mechanisms that might be implemented. This is reflected in the socio-technical systems framing used in the present work. The concept of excess capacity is taken to refer to the space and time, as defined in the box above, that is unused, for example, empty seats in vehicles. It is capacity, as defined above, and the excess capacity that arises in the system that is explored in this thesis, and whether more effective use of this could contribute to CO_2 emission reductions from transport, and so deliver a more sustainable urban transport system.

2.6 Policy for sustainable transport provision

The following section looks at policy measures for sustainable transport. Different types of policy measures are identified and their impact evaluated through examples of their implementation. This draws on policy specific documents and the academic literature about transport policy. Table 2:3 presents an overview of the policy measures available for delivering sustainable transport. "*One can classify the research literature on sustainable transport* *policy into two approaches. The first one is more local and planning-oriented; the other approach is the more traditional economic approach to transport and the environment*" (Eliasson and Proost, 2015, p.93). The first half of the Table 2:3 looks at top down economic and regulatory policies and the second half examines the more locally driven planning type approaches to sustainable transport policy.

Public acceptability of policy measures is critical for their success or failure to bring about changes in transport behaviour or technology uptake. Marsden et al (2014) suggest that acceptability of pricing measures is challenging and an additional barrier to measures is the limiting of individual choice, which is seen as widely unacceptable. The construction and effectiveness of policy measures was included implicitly in Sections 2.2 and 2.3. Understanding the policy options available to influence sustainability of the transport system will be important in conceptualising how enhanced use of urban transport excess capacity might be achieved in the future, and the role it could have in reducing CO_2 emissions. Of particular importance for this research are the land use and information policies, although a broad understanding of the wider policy environment is valuable.

An additional important dimension for excess capacity use in urban transport system is the trend towards increased devolution of powers to city regions and the potential re-regulation of public transport systems as a result (Greater Manchester Combined Authority, 2014, HM Government, 2009). Devolution has been addressed in the academic literature, both in terms of devolved powers to the nations that make up the United Kingdom, and city level devolution, and there are challenges around the level of fiscal and political devolution and powers which remain with central government (Clifford and Morphet, 2015, MacKinnon, 2015). There is potential for city scale devolution to enhance local integrated transport planning (MacKinnon and Vigor, 2008) and new policy mechanisms could offer opportunities for improvement of public transport services and information provision (Raikes et al., 2015, Rowney and Straw, 2014).

Table 2:3 - Transport Policy Measures

Type of policy measure		**Specific policy**	**Real-world example and impacts**
Economic	Taxes	Fuel Tax Vehicle Excise Duty (VED)	In the UK, VED is based on the average gCO_2/km emissions from the vehicle. Chapter 4, Table 4:22 has the different price bandings for emissions, with zero tailpipe emission vehicles paying no VED. This can incentivise uptake of lower emission cars however, findings on the effectiveness of this are mixed (Anable and Shaw, 2007, Brand et al., 2013).
	Subsidy	Plug-in-Car Grant	The UK government incentivised uptake of plug-in-vehicles by offering a £5000 subsidy on the purchase price (Office for Low Emission Vehicles, 2009). This was extended in December 2015, with the expectation that it will support a further 100,000 vehicles (Department for Transport, 2015c).
	Charging	Road User Charging Congestion charging / Low emission zones	A congestion charge was introduced in central London in 2003 with the aim to reduce congestion and improve bus services (Transport for London, 2008). Between 2002 and 2003, there was around a 14% reduction in traffic and around 19.5% reduction in emissions of CO_2 (Beevers and Carslaw, 2005). It has resulted in increased patronage of bus and underground services in London (Transport for London, 2008).

Type of policy measure		Specific policy	Real-world example and impacts
	Cap and Trade	EU Emission Trading Scheme (EU ETS) Personal carbon trading	At present, emissions trading has not been widely used in transport but mechanisms exist for emissions trading as part of the Kyoto Protocol mechanisms (UNFCCC, 1997). Emissions trading policy has the potential to reduce emissions in transport by incentivising action across stakeholders, and may be an important policy approach in the future (Wadud, 2011)
	Incentives	Scrappage scheme	The 2009 UK scrappage scheme offered £2000 for customers to scrap older vehicles for newer, lower emission cars. Over the 10 months of the scheme, 400 000 vehicles were exchanged (SMMT, 2010).
Regulatory	Fuel standards	EU Fuel Quality Directive	The EU Fuel Quality Directive legislates that fuel suppliers should reduce the lifecycle greenhouse gas emissions from fuel supplied by 10% by 2020, 6% through the use of biofuels or other alternative fuels, 2% though carbon capture and storage and electric vehicle use and 2% through trading of emissions (European Commission, 2009)
	Emission standards	EU fleet average CO_2 emission standards	The EU set a legal target for manufactures new car fleet average emissions in 2015 of 130gCO_2/km, which has been met, and the target for 2021 is 95gCO_2/km, a reduction of 40% compared to 2007 (158.7gCO_2/km) (European Union, 2015).

Type of policy measure		Specific policy	Real-world example and impacts
	Bus re-regulation	City deals	City deals have been established by the UK Government to provide devolution of power to the local authority, for example in Greater Manchester, including powers over transport planning and regulation, which can improve co-ordination of services and provision of information, as seen for Transport for London (Greater Manchester Combined Authority, 2014, HM Government, 2009, Raikes et al., 2015)
Land Use Planning	Public Transport	Allocating space to public transport	An example of providing increased roadspace for public transport is the A34, Oxford Road corridor in Greater Manchester, where parts of the road will be bus, taxi and cycle only, and this will improve journey times for public transport and improve the environment for cyclists (Transport for Greater Manchester, 2014)
	Walking and Cycling	London cycle super highway	Investment in cycling infrastructure represents a sustainable transport policy, in London they are constructing a series of 'cycle superhighways' to improve facilities for cyclists (Transport for London, 2016).
		Shared space	Shared space projects remove traditional hard traffic management engineering and slow traffic speeds in order to encourage active travel mode choices (Department for Transport, 2011b, Kaparias et al., 2012).
	Densification	Designing new and existing settlements to minimise travel	In California, legislation has been put in place to reduce carbon emissions through limiting urban sprawl and minimising the need for motor vehicle travel (Barbour and Deakin, 2012)

Type of policy measure		Specific policy	Real-world example and impacts
Information	Vehicle labelling	Compulsory vehicle labelling	Was introduced in 2005 as part of a 1999 EU Directive compulsory vehicle labelling was introduced (European Commission, 1999), and this was rolled out in the UK in 2005, with labels including information about VED banding and fuel cost of driving 12,000 miles, which allows informed decision making about vehicle purchase choice (Gärtner and Automobil-Club eV, 2005).
	Public transport information	Impact of Quality Partnerships on bus travellers and information	Quality Partnerships for buses bring together operators and the local authority to enable collaboration (Butcher, 2011), which can lead to improved information and increased passenger numbers (Cairns et al., 2004). This has also been demonstrated through regulation in London, where there has been continued growth in bus patronage over recent years (Cairns et al., 2004).
	Workplace travel planning	Local authority support	Cairns et al, (2004) suggest that where workplace travel plans are supported by local authorities, travel discounts can be offered for public transport passes and this can result in changes in behaviour.
	School Travel Plans	Local authority school travel campaigns	School travel plans, supported by local authorities, can influence the mode choice and travel patterns of travel to school, in some cases resulting in a decline in car use for school trips (Cairns et al., 2004).

This section has provided an overview of policy mechanisms and techniques for facilitating sustainable transport. This is important for the research that follows in this thesis, particularly where exploring how potential interventions to facilitate enhanced use of excess capacity might be designed. Policy recommendations are made throughout this thesis, and these are discussed with stakeholders through a series of interviews, the results of which can be found in Chapter 8-.

2.7 Chapter summary and key emerging trends

This chapter has reviewed and critiqued the literature relating to sustainable transport, technology and behaviour change and capacity. This final section draws together this analysis, highlighting the key trends that emerge in the literature, which are examined in the context of enhanced use of excess capacity in urban in subsequent chapters. Table 2:4 returns to the research questions which were provided in Chapter 1- Section 1.3, and highlights the areas of the literature review which are relevant to each question and provides direction as to where the further analysis of this is positioned in the thesis.

2.7.1 Key trends emerging for excess capacity use and CO_2 emissions

The following points highlight the key trends emerging from the literature and policy review in this chapter that are relevant for examining excess capacity and CO_2 emissions in urban transport systems.

- **Vehicle technologies for reducing emissions** – Section 2.3.1 examined how vehicle technologies are improving and emissions in terms of gCO_2/km are reducing, see also Figure 2:1. This is key for quantifying CO_2 emissions associated with excess capacity and the role that reducing the emissions associated with excess capacity could play in a sustainable urban transport system. This is examined in the modelling of scenarios for future capacity in Chapter 7-.
- **ITS** – Section 2.3.1 introduced ITS and the role this could play in the sustainability of the transport system. These technologies could have a profound influence on ways transport is used and impact on capacity use, thus this is explored further in the scenario construction found in Chapter 6-.
- **ICT for homeworking and increased flexibility** – this is an area that could influence the amount of travel and the use of temporal capacity and was introduced in Section 2.3.2 on travel behaviour. These aspects are examined in the survey analysis in Chapter 4- and Chapter 5- and

are then integrated into the pathway construction and modelling found in Chapter 6- and Chapter 7-.

- **Modal shifting** to more sustainable mode choices, which are usually high occupancy, public transport modes, represents a behavioural change approach, introduced in Section 2.3.2. The potential for this to influence excess capacity use in urban transport systems is explored through the survey analysis in Chapter 4- and Chapter 5-, and then the pathway construction and modelling found in Chapter 6- and Chapter 7-.
- **Increases in sharing** – the sharing economy was introduced in Section 2.5 and details on car sharing approaches were given in Section 2.3.2. The potential for car sharing to influence excess capacity use is examined through the survey in Chapter 4- and Chapter 5- and then incorporated into scenario design and modelling in Chapter 6- and Chapter 7-.
- **Devolution and re-regulation** represent key policy trends, introduced in Section 2.6 which could influence the urban transport and impact on excess capacity use and sustainability. This is explored in the scenario construction in Chapter 6- and modelled in Chapter 7-.

These trends are incorporated into the analysis in the ongoing chapters and they are returned to in Table 5:14, Table 6:2 and Table 7:1.

2.7.2 Research questions and the literature reviewed

Table 2:4 shows the research questions and highlights the areas of this chapter that are most relevant to these questions, providing cross references to the appropriate sections. Table 2:4 also provides direction to the chapters in the thesis where the research questions are addressed, building on the key trends highlighted in Section 2.7.1.

Table 2:4 - Literature reviewed and the relevant research questions

Research Question	**Literature reviewed**
1. When / where is there excess capacity in the urban transport system?	The socio-technical systems literature, reviewed in Section 2.4 provides a framing that facilitates exploration of multiple perspectives – such as the spatial and temporal dimensions of capacity. Section 2.5 provided a definition of capacity and also examined the concepts of time in relation to capacity. Congestion and induced congestion were examined in Section 2.2.2, which is relevant in quantifying the use of spatial capacity, and potential excess capacity. This is addressed in Chapter 4- and Chapter 5-.
2. What might be the carbon benefits and penalties of an enhanced use of this excess capacity and any facilitating interventions?	Section 2.3 examined technological and behavioural change approaches for sustainable transport. Using the definition in Section 2.5.2, the carbon benefits of enhanced use of excess capacity can be quantified. Modelling approaches for this analysis are introduced in Chapter 3-. This is addressed in Chapter 7-.

3. How could more effective use of excess capacity be facilitated in order to reduce emissions?	Section 2.3.2 examined a range of approaches to influencing travel behaviour that could be adapted to facilitate excess capacity use. This included an overview of car sharing, which is relevant for exploring how more effective use of the excess capacity within vehicles might be facilitated Section 2.6 presented an overview of policy measures and these can be explored for facilitating enhanced use of urban transport excess capacity. This is addressed in Chapters 4, 5, 6, 7 and 8.
4. How could enhanced use of capacity be incorporated into pathways for sustainable urban transport systems?	The socio-technical systems perspective was introduced in Section 2.4 and this is developed in Chapter 6- to examine potential pathways for excess capacity in a sustainable urban transport system. This draws on literature on sustainable mobilities (Section 2.2), technology and behaviour change (Section 2.3) and sustainable transport policy (Section 2.6). This is addressed in Chapter 6-.

This chapter has presented a review and critique of the literature related to sustainable transport in order to provide the context for the present research. An overview of the policy environment has also been given in Section 2.6. Additional literature is also found in other chapters, where this is appropriate, such as the inclusion of literature on behavioural research in transport in Chapter 4- and literature on conceptualising the future in transport research in Chapter 6-. Chapter 3- which follows, presents a review of modelling approaches used to analyse CO_2 emissions from road transport, including literature and methodological critiques, building on the literature and perspectives provided in this chapter and this is used to develop the framework for the present work.

Chapter 3- Framework for modelling urban transport capacity and emission reductions

This chapter develops a framework for analysing the potential emission reductions from enhanced use of urban transport capacity. Building on the literature on sustainable transport reviewed in Chapter 2- the methodological perspectives are developed in order to address the research questions outlined in Chapter 1-. This chapter begins by providing a definition of the urban transport system as it is conceptualised in this work, building on the definition of urban in Section 1.5 and the definition of capacity in Section 2.5.2. A review of modelling approaches follows, which explores different tools available for estimating and forecasting CO_2 emissions from road transport. This enables identification of the most appropriate methods for modelling urban transport capacity and associated CO_2 emissions. A new framework, that is developed from these methods identified, and equations for quantifying excess capacity and emissions are presented in Section 3.3, showing how the modelling approaches and behavioural study will be combined in the subsequent chapters. This is then drawn together and summarised in Section 3.4.

3.1 Defining the urban transport system

In order to analyse the excess capacity that exists within the urban transport system, it is first important to clearly define what is included within the system, factors which are excluded and those which may be represented as exogenous factors in the modelling stages of the work.

The definition of the urban transport system here builds on the understanding in Section 2.4, which introduces the socio-technical systems literature in the context of sustainable transport. This means that both policy, sociological and behaviour change aspects are included alongside technological elements. The structure of Figure 3:1 is adapted from Geels (2002, Figure 1, p.1258), in which he conceptualises the socio-technical system associated with personal transport, including technological, behavioural, regulatory and policy aspects of the system. This structure is used and adapted as the transport system considered in this work incorporates both social and technological aspects of transport, and the work draws on the socio-technical systems perspectives developed by Geels and others (Geels et al., 2011, Geels, 2002, Geels, 2012).

A definition for ‘urban’ was given in Section 1.5, and the focus of this work is on ‘large urban’ or ‘metropolitan’ areas; Greater Manchester (GM), the case study area, fits into the latter. Figure 3:1 shows the aspects that are considered within the urban transport system for the purposes of this work. Aspects considered include both behavioural elements about journey purpose and mode choice and elements regarding infrastructure and emissions associated with the travel as well as policy and implementation. Figure 3:1 adapts some of the underlying principles from Geels (2002) such as the inclusion of both technological, social, regulation factors etc., and the structure of the diagram, but key changes are the inclusion of aspects of travel behaviour such as journey purpose and the exclusion of some of the details around vehicle characteristics. These changes reflect the focus of this work on the journey characteristics in order to identify excess capacity and associated emissions. The additions also incorporate greater agency into the socio-technical systems framing, which has been a criticism of the framework in the literature (see Geels, 2011, Smith et al., 2005) Further discussion of socio-tehcnical systems, and the criticisms of the approach, can be found in Chapter 6-.

Within Figure 3:1 some aspects are in bold, some are italics and others are greyed out. Those in bold are directly incorporated into the analysis in this research, and can be found as part of the framework structure that is developed subsequently and can be seen in Figure 3:4. ICT is in bold but is not considered in the survey data; this is included because of its influence on people’s willingness to car share, ability to work from home and other aspects of transport behaviour which are explored further in Chapter 4- and Chapter 5-. Those aspects that are greyed out are considered part of the urban transport system but are not incorporated into the calculations of excess capacity but may influence how capacity is used, for example, freight traffic may contribute to congestion and influence individual journey decisions. The aspects which are in italics, such as active modes and costs, are considered within the survey data that is analysed in Chapter 4- and Chapter 5- and as part of the urban transport system, but are not incorporated directly into calculations of excess capacity as they are defined in the framework and equations that follow in Section 3.3.

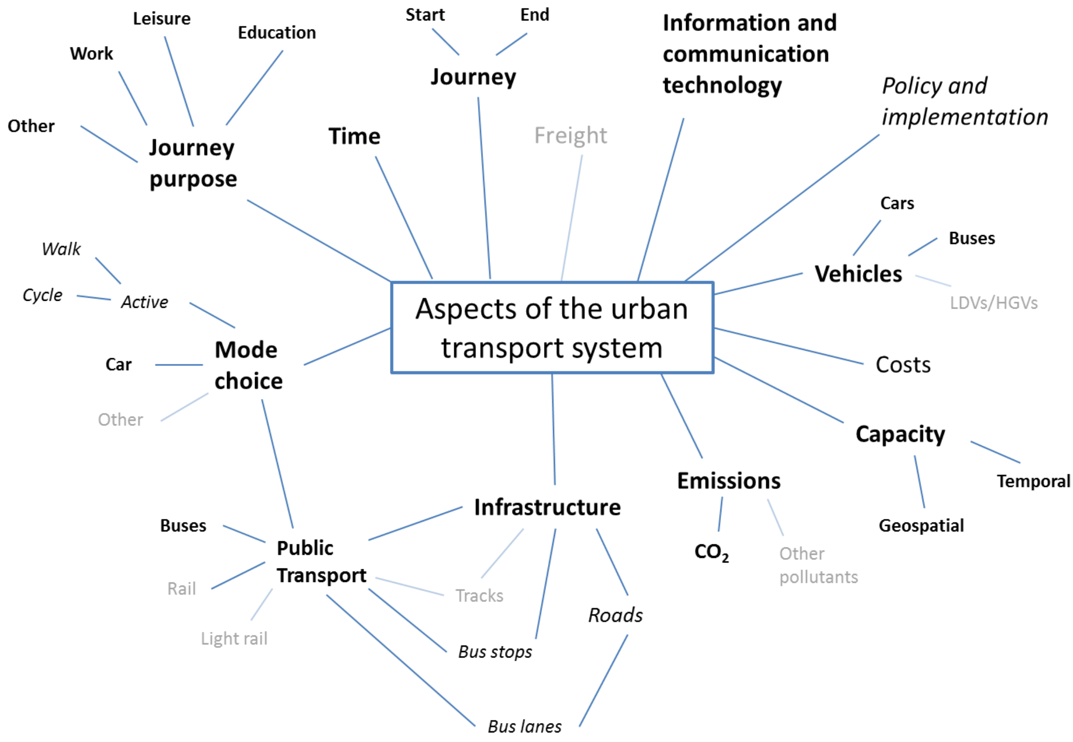

Figure 3:1 - Aspects of the urban transport system (the factors in grey are included as exogenous variables, those in italics are not directly quantified but influence calculations)

3.2 Review of modelling approaches for CO_2 in road transport

The following section presents a review of the modelling approaches available for analysing, estimating and forecasting CO_2 emissions from road transport. Beginning by introducing transport modelling and the approaches that are included in this review, Table 3:1 systematically reviews the models, the elements of the transport system that are captured, the underlying concepts and the emissions calculation. A discussion and critique of the models then follows, with the modelling approaches that will be used in this work being summarised in Section 3.2.6.

Modelling transport is a key element of transport research, exploring a multitude of factors and situations at a range of scales to provide insight and understanding of the challenges in transport (Hensher and Button, 2008). Using computational, mathematical models to understand the dynamics of the transport system allows interactions within these systems to be analysed in order to aid planning and policy decisions (de Dios Ortúzar and Willumsen, 2011). Motivations behind transport modelling are as numerous as the challenges, and include such factors as improving inefficiencies in networks and examining the potential traffic impacts of changes to infrastructure (Gudmundsson, 2011, Brömmelstroet and Bertolini, 2011), exploring socio-economic effects of transport (Wismans et al., 2011), understanding supply and demand for transport (Proost and Van Dender, 2011), as well as modelling air quality and emissions (Brand et al., 2012b, Samaras et al., 2012). The scale of transport modelling is also wide-ranging, from the micro level modelling of a single intersection, or local road network, to the global transport system.

Models have accelerated over recent years in their levels of accuracy for capturing transport dynamics and their ability to replicate real-world situations and interventions. Additional inclusion of Intelligent Transport Systems (ITS) and behavioural aspects create further layers of detail and interest within transport modelling. There are also a diverse range of models beyond traditional transport modelling that can be applied to this kind of system to deliver insight into the spectrum of dynamics within the system. However, with increasing detail the data requirements and computational power required are increasing, so appropriate ease of use must be considered alongside accuracy when considering the most applicable transport modelling approaches and is considered for the research in this thesis in Section 3.2.6.

The following section reviews a range of approaches and techniques for modelling CO_2 emissions from transport. This is targeted at developing a methodology and framework to explore the research questions outlined in Section 1.3. The aims of this section are to:

a. Explore what approaches are available for quantifying CO_2 emissions from transport;
b. Explore options for modelling transport behaviour; and
c. Identify the most appropriate techniques for analysing urban transport capacity and emissions.

Six types of modelling approaches are analysed in the following review:

- Traffic network models: microsimulation;
- Behavioural models;
- Agent based modelling;

- System dynamics (SD) modelling;
- Techno-economic, and;
- Integrated assessment models (IAM)

The models have been classified according to these six types as they provide a broad range of perspectives for modelling the transport system. Figure 3:2 shows the modelling approaches in terms of the spatial and temporal scales which they cover, from the local to the global and the near term future to longer forecasting horizons out to 2100 (Linton et al., 2015).

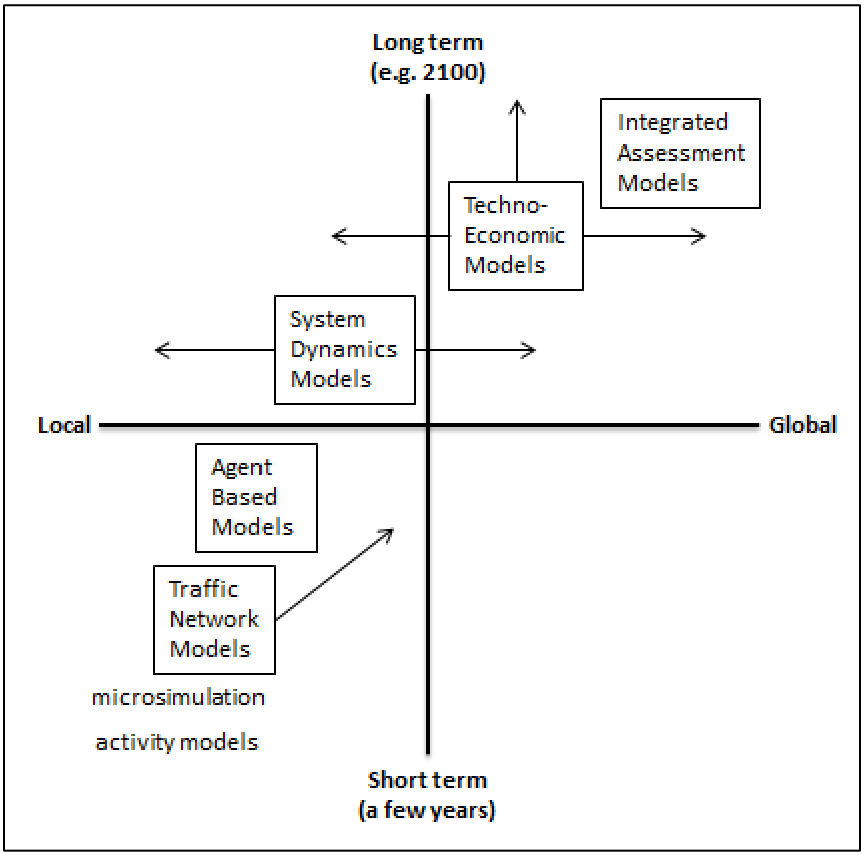

Figure 3:2 - Spatial and temporal scales for the models reviewed (Linton et al., 2015)

Table 3:1 – Systematic review of approaches for modelling emissions from road transport (adapted from Linton et al (2015)). The analysis of these models is developed further below.

Modelling Approach	Example packages/studies	Elements of transport system captured	Underlying concepts	Emissions calculation
1. Traffic Network models - Microsimulation	• DRACULA (Dynamic Route Assignment Combining User Learning and microsimulAtion) • VISSIM	Captures movement of vehicles within a pre-defined traffic network. Aggregate data across the network for emissions, delays, travel time etc.	Microsimulation modelling is built on the principles of the four stage trip model (de Dios Ortúzar and Willumsen, 2011). The four stage model is as follows: 1. Trip generation 2. Trip distribution 3. Mode split 4. Traffic assignment Built on the principles of car following and lane changing rules which determine how the vehicles interact by maintaining gaps between vehicles through algorithms for minimum gap acceptance (Gipps, 1981, Young and Weng, 2005).	**DRACULA** assumes that fuel consumption factors are constant for vehicles that are idling or decelerating and calculates fuel consumption for accelerating vehicles using Equation 3.2. This is then converted into CO_2 under the assumption that fuel burned is converted to CO_2. This does not take into account alternatively fuelled vehicles. **VISSIM**: requires an add-on to module 'enViVer Pro' which imports vehicle data to calculate CO_2 emissions in the study area and outputs a table and graph of this (PTV Group, 2015)

Modelling Approach	Example packages/studies	Elements of transport system captured	Underlying concepts	Emissions calculation
2. Behavioural models	• Stern and Richardson (2005) process-oriented framework	Captures greater detail about individual decision making and travel choices	Activity based models explore the activities that necessitate mobility to understand levels of transport and generate a clearer picture about decision making. Travel is seen as result of activities and behaviour.	Quantifying levels of transport demand that can then result in calculation of emissions of CO_2 through the application of emission factors.
3. Agent Based modelling	• MATSIM (Multi-Agent Transportation Simulator Toolbox)	Captures the dynamics of behaviour in the transport system, as for behavioural models above, captures more detail than just the trips that are made but understands behaviour and motivation	Models behaviour through a series of heterogeneous agents within a 'practice space', the modelled world in which the agents interact (Köhler et al., 2009).	Coupled with an emissions model can deliver unique insight into travel behaviour and road transport emissions MATSIM itself does not calculate emissions from road transport. However, (Hatzopoulou et al., 2011) combined outputs from MATSIM with MOBILE6.2 (US EPA, 2003) to calculate emissions

Modelling Approach	Example packages/studies	Elements of transport system captured	Underlying concepts	Emissions calculation
4. System Dynamics	• ASTRA – Assessment of Road Transport Strategies (Rothengatter et al., 2000) • MARS – Metropolitan Activity Relocation Simulator (Research Centre for Transport Planning and Traffic Engineering, 2009)	Can capture interactions and feedbacks within complex systems such as transport	SD models are built on causal loop diagrams and stock and flow relationships. Entities are identified and connected by directional causal links, which form the loops that are reinforcing or balancing, representing positive or negative feedbacks within the system, see Pfaffenbichler, (2011) for more details.	**ASTRA**: Environment Sub-module calculates gaseous transport emissions **MARS**: 3 separate equations calculate emissions from road transport, the first calculates emissions from specific cars using speed output from MARS, another, total CO_2 for private cars using distance and number of trips from MARS outputs and one which calculates CO_2 emissions from public transport.

Modelling Approach	Example packages/studies	Elements of transport system captured	Underlying concepts	Emissions calculation
5. Techno-economic models	• Roadmap (International Council for Clean Transportation, 2012) • World Energy Projection System Plus (WEPS+) (US Energy Information Administration (EIA), 2011)	Capture large scale dynamics of the transport system through the socio-economic changes that occur, using a top-down modelling approach	Draws on socio-economic characteristics and forecast changes to estimate transport demand and technological forecasts are used to develop emission factors that allow projections of future emissions to be established. Roadmap: runs over 5 year time steps from 2000 to 2050.	**Roadmap**: Tank-to-wheel CO_2 emissions are estimated based on energy consumption, calculated from vehicle km travelled (VKT), which is established using socio-economic indicators, and vehicle efficiency using the following equation: $Energy\ consumption\ (MJ) = vehicle\ efficiency\ \left(\frac{MJ}{KM}\right) * VKT$ [Equation 3:1]

Modelling Approach	Example packages/studies	Elements of transport system captured	Underlying concepts	Emissions calculation
6. Integrated Assessment models	• Global Change Assessment Model (GCAM) (Kim et al., 2012)	Large scale modelling of economy and environment with a sub-module for transport, capturing technological change and environmental impact driven by socio-economic factors	Runs in time steps of 15 years from 2005 to 2095 and achieves regional equilibrium in the regional markets in each time step (Kyle and Kim, 2011)	Demand for transport is calculated in **GCAM** using Equation 3.5. Equation 3.6 calculates the costs of passenger transport modes and Equation 3.7 uses this to calculate mode share. These can then be coupled with emission factors to provide regional and global projections of emissions from transport.

The models that have been included in the systematic review in Table 3:1 represent a spectrum of modelling approaches spanning the spatial and temporal scales that are shown in Figure 3:2. The packages presented are representative of the techniques used in the various approaches reviewed, but are by no means an exhaustive list of the modelling packages available within these approaches. They are merely used to illustrate and provide examples of the various types of modelling approaches. The following section draws together the insight from Table 3:1, provides more detail on the approaches and begins to draw out some of the relative advantages and disadvantages of the different approaches.

The traffic network, behavioural and agent based modelling approaches have been grouped together, because they represent the micro-scale approaches which deal with disaggregate data and capture individuals' or vehicles' movements, choices and behaviours. These are followed by the system dynamic modelling approaches and the macro scale techno-economic and integrated assessment models. Examples of combining modelling approaches are also examined to show the additional insight and information that can be delivered by using multiple approaches. The section is then drawn together and the applications of the modelling approaches to exploring urban transport excess capacity and associated CO_2 emissions are explored.

3.2.1 Traffic network, behavioural and agent based models

Traffic network models cover a range of scales, from macro to micro; here the focus is on microsimulation approaches. This is because microsimulation represents a key subset of network models, and is of relevance to the work that follows in this thesis. Transport demand is generated within microsimulation modelling using an origin destination (O-D) matrix. This represents individual trips within the network and in the traffic assignment part of the four stage model (McNally, 2008). The network that underlies traffic models is constructed from real world networks using 'nodes', 'links' and 'zones' (Willumsen, 2008). Nodes represent junctions and intersections whilst links are roads that connect nodes. The zones are areas between which (or within which) trips are made and from which the O-D matrix is constructed. For example, a trip will be from origin (O) – zone x, to destination (D) – zone y (Atkins-ITS, 2013). Further details on the behavioural rules that govern microsimulation of traffic can be found in the detailed manuals for the models (Liu, 2007, Verkehr, 2011). Table 3:1 summarises the general method for emissions calculation within microsimulation packages. Equation 3.2 shows how fuel consumption is calculated in DRACULA, which is then used to calculate CO_2 emissions through the application of emission factors (Liu, 2005).

Calculation of fuel consumption in **DRACULA**:

$$\boldsymbol{f} = \boldsymbol{c_0} + \boldsymbol{c_1} * \boldsymbol{a} * \boldsymbol{v}$$

[Equation 3.2]

Where:
f = fuel consumption factor;
v = speed of the vehicle;
a = acceleration of the vehicle; and
c_0 and c_1 are constants defined in (Ferreira, 1982).
In VISSIM, an alternative traffic network model, an additional add-on, 'enViVer' is required to calculate emissions (PTV Group, 2015). This package draws on the emission calculations developed in the VERSIT+ model which uses the following equation to calculate traffic emissions for pollutant *j* (TE_j, g/hour):

$$TE_j = \sum_{k,m} \left(E^F_{j,k,l} \times TV_{k,m} \times L_m \right)$$

[Equation 3:3]

"*Where* $E^F_{j,k,l}$ *presents the predicted mean emission factor (g/km) for pollutant j, vehicle class k and speed-time profile l,* $TV_{k,m}$ *presents the traffic volume with respect to vehicle class k (vehicles/hour) for a particular section of road m, where speed-time profile l would apply and* L_m *presents the length of road section m (km)*" (Smit et al., 2006, p17). This is used to calculate the emissions across a network simulation in VISSIM, and accounts for different vehicle classes and the speed-time profile for each vehicle.

By quantifying levels of demand for transport within the traffic system for a specific scenario, the level of emissions can be established and the impacts of policy interventions analysed (Dowling et al., 2002). There are a range of additional behavioural rules within microsimulation that are not presented in column 4 ('Underlying Concepts') of Table 3:1. Details of these can be found in the individual model manuals (Liu, 2007, Verkehr, 2011). Overall, microsimulation provides a useful set of techniques for modelling emissions from road transport, by allowing the impacts of changes in the network to be examined in terms of transport flows and the resulting emissions. This is interesting in the context of the research questions being addressed in this thesis, as the examination of CO_2 emissions within an urban network is central to the research, and the changes that enhanced use of excess capacity could make to the network could be examined through such a microsimulation approach.

One of the aims of behavioural research in transport is to better understand how individuals use transport infrastructure in order to improve decision making and provide a more holistic perspective of activities and transport demand (Davidson et al., 2007, Stern and Richardson, 2005). Behavioural models draw from the disciplines of social psychology and behavioural economics for the underlying principles and frameworks (Schaap and van de Riet, 2012). Stern and Richardson (2005) present a 'process-oriented framework' for understanding travel behaviour. This process-oriented framework looks at travel demand and behaviour in terms of the motives and needs for travel and the constraints that then influence the decision making and resultant behaviour. They also account for external factors such as travel safety which may influence behaviour and longer term factors such as spatial reorganisation, which can influence travel patterns over time. Through this framework, Stern and Richardson (2005) demonstrate how additional factors beyond the need to travel from and origin to a destination can be considered in understanding travel behaviour, including factors such as the motivation for travel, scheduling and any constraints on travel. This is important in considering how capacity is used, in particular when thinking about possibilities for car sharing or flexible travel, as additional behavioural practices or external constraints could restrict changes to behaviour, such as trip chaining for dropping children at school, which is constricted by prescribed timings. The activity based approaches are reflected in the survey design and analysis included in Chapters 4 and 5, as well as being analysed as a distinct modelling approach here.

Activity based models focus on the underlying motivations behind travel decisions, allowing travel patterns to be more clearly understood and to quantify transport demand (Axhausen and Gärling, 1992, McNally and Rindt, 2008). Emission factors can then be applied to the volume of travel that occurs within a network, quantified through the activity based model, to calculate emissions.

Agent based models have been used in activity based approaches and elements of agent based approaches have been incorporated into some traffic network modelling. Agent-based modelling characterises a series of agents within a practice space, the modelled world in which the agents interact, in order to understand behavioural dynamics (Köhler et al., 2009). Agents have behaviours and interact with other agents and their environment, which can then alter their behaviour (Macal and North, 2010). These interactions and changing behaviours provide insight into the dynamics of the system being modelled and the influence on the agents. These approaches have been used in the social and biological sciences (Grimm et al., 2006) and there are examples of their use in transport, including Köhler et al., (2009) and Shafiei et al (2012a). There are also examples of the inclusion of agent-based modelling principles in traffic micro-simulation models. PARAMICS is a traffic network model that captures pedestrian activities and pedestrian traffic interactions, thereby incorporating elements of an agent based modelling approach (Quadstone Paramics, 2013). In addition, qualitative methods and virtual reality approaches outlined by Dougherty et al (2000) are areas that have the potential to increase the degree of agency within traffic network simulation. Using agent based modelling in transport can deliver detailed insight into the interactions in the system and allow a ‘bottom-up’ approach to be taken (Garcia, 2005, Shafiei et al., 2012a). The relative benefits of bottom-up and top-down approaches is discussed further in Section 3.2.5, looking at combining different modelling approaches.

MATSIM captures the dynamics of the transport system with a behavioural oriented approach, characterising agents within a traffic network. The MATSIM programme itself does not calculate road transport emissions, but a study by Hatzopoulou et al.,(2011) coupled MATSIM with the MOBILE6.2 model to estimate the emissions. MOBILE6.2 uses fuel economy outputs to calculate emissions of CO_2 but these are not varied for speed and engine type, as the calculations for other pollutants in MOBILE6.2 are (US EPA, 2003). However a wide range of vehicle types are accounted for within the model and the addition of the CO_2 calculation was new for version 6.2 (ibid.).

A different use of agent based modelling is used in a study by Shafiei et al (2012b). An agent-based modelling approach is applied to explore uptake of Electric Vehicles (EVs), using a Multinomial Logit (MNL) model to characterise purchase decisions and analyse the willingness of agents to consider an EV over a conventional vehicle. The model examined the extent to which exposure to information affects willingness to consider alternatives. The data requirements of this approach lie in the parameters for characterisation of the agents. The model outputs information about the market share of EVs over the scenario period. Shafiei et al (2012b) demonstrate the application of agent-based modelling approaches to the transport sector and their ability to capture behavioural dynamics in the market. While this modelling approach does not output direct emission calculations from road transport, it provides useful insight into the future vehicle fleet and uptake of alternative vehicles. This is useful in understanding future emissions from road transport and the extent to which emission reduction targets might be met by uptake of alternative vehicles. It is also possible to envision an approach in which agent based modelling could be used to explore uptake of innovations to make more effective use of urban transport capacity, for example by examining diffusion of information about car sharing and willingness of agents to engage in car sharing practices. This is beyond the scope of the research in this thesis but could be an interesting direction for further work, highlighted in Chapter 9-.

3.2.2 System Dynamics

Fishwick (2007) describes a dynamic model as one which captures the way a system changes in time. This type of approach has been used across disciplines in the physical and social sciences. SD models are based around causal loop diagrams (CLD) that simulate and analyse relationships and mathematical modelling of stocks and flows (Sternman, 2000). They incorporate both qualitative and quantitative techniques and analysis, making them versatile tools (Pfaffenbichler et al., 2010). Shafiei et al (2012a) describe SD modelling of complex systems as a "*top-down approach that looks at the process of market developments as a whole and facilitates understanding the interactions of many stakeholders…*" (Shafiei et al., 2012a, p.45).

CLD are the main technique used within SD modelling to explore the qualitative relationships between aspects of the system. They work by identifying entities, which are the aspects of the system that can affect other aspects and can be affected by others, and they must represent an unspecified quantity. There are also exogenous factors that are pre-defined constants interacting with the identified entities. These entities are then connected by directional causal links, which form the loops that are reinforcing or balancing, representing positive or negative feedbacks within the system, see Pfaffenbichler (2011) for more details. SD has been applied in transport because the feedback and linkages these models are able to capture are useful for identifying interactions within the transport system. Shepherd (2014) provides a review of the ways that SD modelling has been used to capture the transport system.

The SD model ASTRA has an environment sub-module (ENV) which calculates CO_2 emissions. ENV uses socio-economic factors to characterise the vehicle fleet and transport demand, which are then fed into the emissions calculation to quantify CO_2 and other emissions. Upstream embodied emissions in the fuel production and vehicle production are also accounted for in calculating the total emissions from the activity in the model (Rothengatter et al., 2000).

The calculation of CO_2 emissions in the SD model MARS is undertaken using the equation given below (Pfaffenbichler, 2003).

$$^{\mathrm{CO2}}e_{ij}^{PC}(t) = a_2 \times \left(V_{ij}^{PC}(t)\right)^2 + a_1 \times V_{ij}^{PC}(t) + a_0$$

[Equation 3:3]

Where

$^{\mathrm{CO2}}e_{ij}^{PC}(t)$= specific carbon dioxide emissions of the mode car for a trip from *i* to *j* in year *t* (g/Vh-km);

$V_{ij}^{PC}(t)$ = average speed for a car trip from *i* to *j* in year *t* depending on the applied policy instrument vector output of MARS (km/h); and

a_n = Parameters, source MEET project (Samaras and Ntziachristos, 1998)

This demonstrates how the outputs from the trip model in MARS are used to calculate emissions of CO_2 by applying an emission factor, based on average speed, to the vehicle km outputs (Pfaffenbichler, 2003). The emission factors are drawn from the MEET project (Samaras and Ntziachristos, 1998). These are then aggregated through the MARS model to produce total emissions generated by specific modes of transport within the system being modelled. The use of average speed could lead to discrepancies in the emissions calculations, because different driving styles could result in different emission profiles for the same distance and average speed (Barkenbus, 2010). This was suggested in Chapter 2- Section 2.3, under eco-driving. However, as an indicator of the magnitude of emissions from a given volume of traffic, this still provides useful data outputs.

MARS and ASTRA are selected as examples of SD modelling in transport because they demonstrate how the techniques can be applied at the city and regional scale respectively. SD approaches are effective at capturing complex dynamics at a larger geographical and temporal scale than the behavioural models, which incorporate different factors into the calculation of CO_2 emissions from road transport. It is clear from these two examples of SD approaches that they are versatile tools. For example, the calculations made in ASTRA account for upstream emissions embodied in the vehicle and fuel production, where the MARS model does not. This will lead to variations in the outputs for emissions from road transport, in some cases the inclusion of upstream emissions may be seen as more accurate in accounting for total emissions from transport, however, there may be policy questions that just address the tank-to-wheel emissions, and the inclusion of upstream emissions may distort results in these cases. The selection of the most appropriate tool must be considered with the specific policy or research questions being examined.

3.2.3 Techno-economic models

Techno-economic models include a range of tools that explore the relationships between technology, the economy and the wider impacts of this and can also be combined with socioeconomic data (Anable et al., 2012). These reflect the conventional economic approaches used to examine transport, which were introduced in Section 2.2. E3 models are a subset of this category and capture interactions between energy, economy and the environment. These models tend to be macro-scale models, often only looking at transport as a sub-sector of the wider economy (Schafer, 2012). They deliver insight on sector level emissions and generally provide aggregate outputs. As with many macro-scale models, the details captured in traffic models or behavioural approaches are often overlooked but there are examples of attempts to integrate some of this detail into macro-scale modelling.

The ICCT Roadmap model is an example of a techno-economic model. The model combines socio-economic indicators with vehicle fleets and fuel technology projections to produce estimates of future emissions from road transport. This is provided for tank-to-wheel (TTW) emissions (in-use), well to tank (WTT) emissions (the emissions involved in fuel production) and combined to give well-to-wheel (WTW) emissions (International Council for Clean Transportation, 2012).

Figure 3:3 shows an example of the outputs from the Roadmap model. On the right hand side of the figure is a base case scenario for global WTW CO_{2e} emissions to 2050. The left hand side has been subjected to a policy trajectory by adjusting the uptake of alternative vehicles and the efficiency of those vehicles. Outputs can also be calculated for specific modes or regions. This demonstrates the value that this kind of model can have in understanding macro patterns of emissions, future projections and modal share, as well as providing insight into regional responsibilities, which can be used in international policy making.

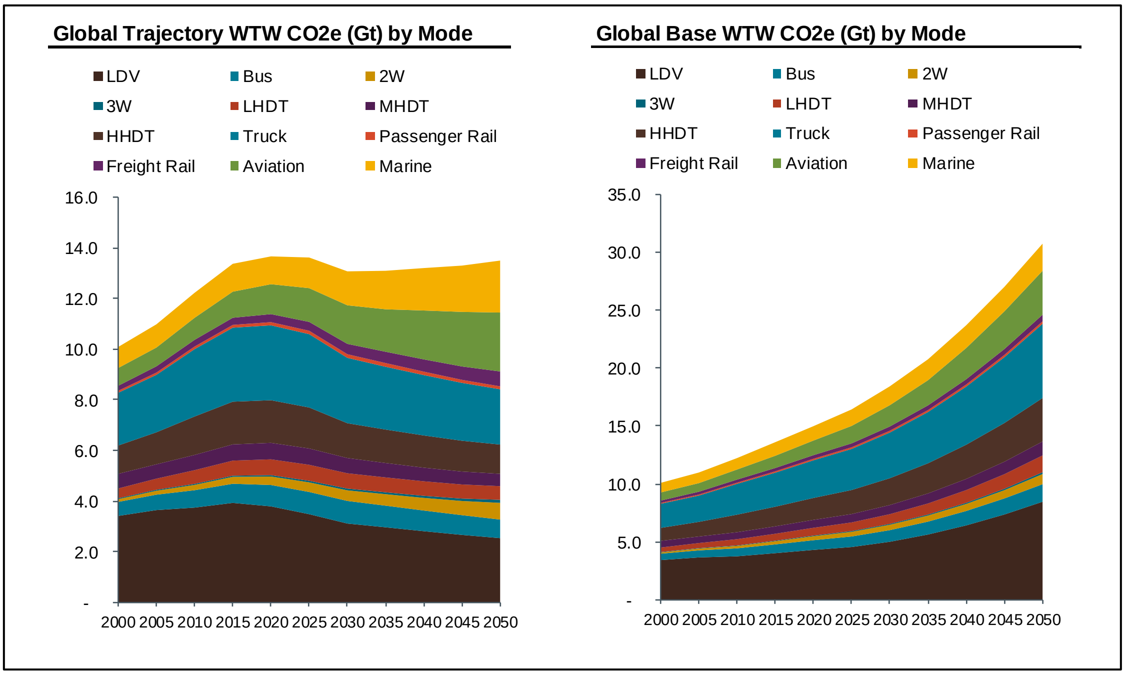

Figure 3:3 - Outputs from Roadmap for global WTW transport CO_{2e} emissions to 2050

IMACLIM-R is a hybrid-dynamic equilibrium model that explores emissions from the transport sector for 2001-2100 (Waisman et al., 2013). This model characterises transport emissions as based on four factors:

- Technological
  - Intensity of fuels
  - Energy intensity of mobility
- Behavioural
  - Modal structure
  - Volume of mobility

The model captures non-energy and non-price drivers of transport dynamics as a bridge between top-down and bottom-up modelling approaches. The model includes specific features for rebound effects, induced traffic, modal breakdowns and impacts of land-use decisions (Waisman et al., 2013).

An example of E3 modelling of transport is the US Energy Information Administration's (EIA) World Energy Projection System Plus (WEPS+) (US Energy Information Administration (EIA), 2011). Within WEPS+, the Transportation Sector Model (ITRAN) captures the transport sector. The model is a macro-scale model which provides aggregate sector emission projections. These outputs are based on socio-economic activity, GDP and population figures in a macroeconomic model, and fuel prices from refinery/electricity models. Outputs from the model include service demand in passenger miles by sub-mode, fuel and region, and service intensity in passenger miles per Btu by sub-mode, fuel and region (US Energy Information Administration (EIA), 2011).

These models provide aggregate emission projections for the transport system at a large spatial scale. Unlike the micro-scale approaches, individuals or vehicle dynamics are not included but the insight can be useful for national and international policy and decision making. In particular, demonstrating the magnitude and geographical distribution of emissions from transport can proportion responsibility for those emissions and the need for delivery of emission reduction measures, as transport and climate change are issues of a global context.

3.2.4 Integrated Assessment Models

Integrated Assessment Models (IAM) can be used to model the interactions between the economy and the environment across the entire system in order to understand long term changes and processes at the macro-scale. They capture the transport sector as a component of economic activity and some models allow the running of sectoral modules independently. They are similar in scale and scope to techno-economic models, however they are designed to further explore the environmental changes associated with the economy. These models are interesting in the context of the research questions addressed in this thesis because they provide a direct link between transport activity, or other economic sectors, and the environment. The focus on urban transport systems within this thesis means that these models may go beyond the scope of this work, but IAMs could also provide a tool for exploring the wider impact of making enhanced use of excess capacity on CO_2 emissions from transport.

The Global Change Assessment Model (GCAM) is an open licensed IAM (Kim et al., 2012). It is a partial equilibrium model which allows the individual areas of the economy to be modelled independently. It is a large scale model which produces aggregate emission projections. The transport module can deliver insight on future technological pathways and mode shares for the global regions (Kim et al., 2012) which can be useful for international policy making. The following equations are used to calculate emissions from transport in GCAM (Kyle and Kim, 2011):

Demand for passenger transport in region r and time period t, D_{rt}, is calculated using the following:

$$D_{rt} = \sigma_r \left(Y_{r,t}\right)^{\alpha} \left(P_{r,t}\right)^{\beta} \left(N_{r,t}\right)$$

[Equation 3:4]

Where:

σ = base year (2005) calibration parameter;

Y = GDP per capita;

P = total service price aggregated across all modes;

N = population;

α = income elasticity; and

β = price elasticity.

Total cost of any passenger mode (P_i) in region r and time period t is calculated using the following:

$$P_{i,r,t} = \frac{(FP_{i,r,t})\left(I_{i,r,t}\right) + NFP_{i,r,t}}{LF_{i,r,t}} + \frac{W_{r,t}}{S_{i,r,t}}$$

[Equation 3:5]

Where:

FP = fuel price;

I = vehicle fuel intensity;

NFP = vehicle non-fuel price;

LF = load factor;

W = wage rate; and

S = vehicle speed.

Market share of a given mode S_i is calculated as follows:

$$S_{i,r,t} = \frac{(SW_{i,r})(P_{i,r,t})^{\lambda}}{\sum_i^n (SW_{i,r})(P_{i,r,t})^{\lambda}}$$

[Equation 3:6]

Where:

SW = share weight;

P_i = cost of transport service from above;

λ = cost distribution parameter; and

n = number of modes.

These equations are used to calculate emissions from transport in GCAM. As is the case with techno-economic approaches, aggregate outputs concerning emissions from transport are produced from this type of model. Additional changes in technology, load factors and modal share can also be captured, and the impacts on emissions from the transport sector be analysed. These aggregate outputs are useful for policy and decision making and at the national and international levels, however they may not deliver results at the appropriate scale for examining the urban transport system in the context of the research questions in the present work.

3.2.5 Combining modelling approaches

As Shafiei et al (2012a) suggest, '*The real world problems in the transportation system, however, do not match up well with a single modelling approach*' (p.43). Combining multiple modelling techniques and approaches can deliver a new perspective of the transport sector or generate new understanding of the dimensions of the transport system (e.g. Shafiei et al., 2012a, Köhler et al., 2009, Samaras et al., 2012).

Both Köhler et al (2009) and Shafiei et al (2012a) use SD modelling and agent based models to create new approaches for looking at transitions for sustainable transport. Combining these two approaches allowed the exploration of behavioural interactions amongst heterogeneous agents in the agent based modelling study components. The agent based modelling components are then interfaced with a SD tool to explore how these behaviours evolve in a future transition to sustainable mobility. This integration of modelling approaches allows both a bottom up and top down lens to be applied to the problem space. The agent based modelling provides details about individuals and interactors and the SD modelling allows a broader, high level picture to be developed. This demonstrates the value of combining multiple approaches and the additional insight that can be delivered. This is useful in a policy environment, because it analyses multiple dimensions of the problem. This could be useful in exploring excess capacity and emissions because the individual activities that impact on how transport capacity is used can be analysed using one set of techniques and this can be integrated with additional modelling tools to look at the emissions impact and potential transport network effects.

As a further example of combining modelling approaches, Samaras et al (2012) combined a traffic network model with a model of ICT applications in transport to look at the emissions implications arising from the integration of ICT in transport. This combination of multiple tools allowed the exploration of emissions from new ICT enabled transport schemes that was otherwise challenging within the scope of a single modelling approach.

The EU GHG-TransPoRD project combined a series of modelling approaches to look at regional emissions from transport and understand trajectories for emission reductions in the transport sector (Schade and Krail, 2012, Fiorello et al., 2012). The research integrates three regional models including ASTRA, POLES (Prospective Outlook for the Long Term Energy System), TREMOVE and the metropolitan scale MARS model to deliver greater understanding of potential emissions of greenhouse gases at the EU scale towards 2050 (Fiorello et al., 2012). This combining of multiple approaches, including SD modelling, can deliver insight into the complex interconnections of the international transport sector and meet the challenges of long term forecasting of emission reductions.

The use of integrated models within a single research study allows some of the short comings of individual modelling techniques to be overcome. For example, combining focused behavioural studies with broader models such as traffic network models or SD tools allow the understanding of individuals' mobility behaviour to be placed in the wider context. In examining the interactions between urban transport capacity and CO_2 emissions, multiple modelling approaches may be required and this is explored further subsequently.

3.2.6 Review summary and approaches that will be used in the present work

This review of modelling approaches has identified a range of approaches available for modelling CO_2 emissions from road transport. It is clear that the broad spectrum of techniques allows the application of transport models to a wide range of transport challenges. However, there are clear limitations to modelling approaches and in their ability to capture the full dimensions of the transport system. Combining of multiple modelling approaches can help to overcome some of these limitations, where a single model might not be able to address specific challenges, through the use of multiple approaches further insight can be gained and additional questions may be answered. When exploring transport in the context of a socio-technical systems framework, as the present work aims to do, capturing the different levels of analysis and the multiple interconnected interactions, as well as quantifying CO_2 emissions of a range of scenarios, is challenging, and no single existing modelling approach can deliver this.

SD offers an approach to capturing high level dynamics, policy and regulatory changes, but also changes in culture or spatial dynamics. This work will use the

SD platform ‘Vensim’ to characterise the urban transport system and the capacity within this. Several pathways are constructed in Chapter 6- using a socio-technical systems approach, to understand how capacity might be used and the potential role this could play in delivering CO_2 emission reductions and the transition to a sustainable urban transport system. However, due to the constrained nature of the work, these pathways are not quantified using the SD platform, as there is not an existing SD model available for the case study region of GM.

Traffic network models were reviewed in Section 3.2.1 and can be used to explore emission reductions and changes to the traffic network. Emission reductions associated with the scenarios that are developed in Chapter 6- are quantified using the traffic network model SATURN (Simulation and Assignment of Traffic to Urban Road Networks). This is used at the scale of Greater Manchester (GM), which is the main case study in the present work, to understand how the impact of enhanced use of excess capacity will play out at the network level. This also allows potential induced congestion effects to be explored. This work will take the pathways developed in Chapter 6- and examine them in the network model in order to understand and quantify the impacts at the network level of making enhanced use of excess capacity. The modelling takes place in conjunction with Transport for Greater Manchester (TfGM), making use of their network and carbon models to explore the research questions. The findings of this work can be found in Chapter 7- as well as more details about the specific TfGM models and approaches that are used in this work. However, it should be noted that the modelling of the socio-technical scenarios is SATURN is somewhat limited by the nature of the modelling approach. Traffic network models are unable to capture the richness of the socio-technical scenarios developed, and the extent of the policy and behavioural factors that are characterised in Chapter 6-. The modelling results presented in Chapter 7-, from TfGM’s SATURN model, provide an indication of the magnitude of emission reductions associated with each scenario but are limited by the extent to which the inputs to SATURN can be changed. The scenarios are modelled through changes to the trip matrix and emission factors, which cannot capture the full range of socio-technical interactions.

The following section draws on the insight from this review of modelling approaches to develop a framework for modelling the excess capacity in urban transport and the associated emissions. This particularly focuses on how the behavioural data and modelling work are integrated to quantify excess capacity and associated emissions and develops equations for analysing these aspects.

3.3 Framework for quantifying excess capacity in urban transport

Building on the literature and modelling reviews presented previously, this section develops the framework for analysing excess capacity and emissions in urban transport systems. The framework demonstrates how behavioural data, collected through the survey (the analysis of which can be found in Chapter 4- and Chapter 5-) and fleet information are combined to quantify excess capacity and how the scenarios will be developed using different factors which may influence how capacity is used in the future transport system. The survey is described in Chapter 1- Section 1.4 and the design of the survey is outlined in Chapter 4- Section 4.1.3.

As suggested in Chapter 1- particularly in Figure 1:1, this thesis works on the intersection of behavioural research, transport modelling and socio-technical systems literature. The framework developed here reflects the integrative approach, incorporating technical aspects of fleet data and behavioural insight from the survey, to deliver understanding about the socio-technical system of urban transport, and the potential emissions associated with vehicle excess capacity.

3.3.1 Conceptual framework for excess capacity in urban transport

Figure 3:4 shows a flow chart which conceptualises the framework for modelling excess capacity and associated CO_2 emissions. On the left hand side of Figure 3:4 are the data indicators derived from the survey of residents of GM, the findings of which can be found in Chapter 4-. These include information about journey distance, frequency of journey, mode choice and the load factor of the vehicles in which these journeys are made. The selected indicators from the survey data allow an understanding of how transport capacity is being used by the participants at present. On the right hand side of the flow chart, fleet data for the UK vehicle fleet is drawn into the framework, derived from a number of data sources (DfT, 2015, SMMT, 2015, Boulter et al., 2009). This includes, vehicle available space, for cars the number of seats and for public transport this also includes standing room, the fuel type, vehicle size and the associated emission factors. The aggregation layer brings together the data from individual survey participants to understand the aggregate patterns emerging from the data for travel amount, CO_2 emissions and excess capacity. For some of the data, the aggregation layer totals the factors, e.g., for distance travelled, and for others it produces an average value, e.g., for the vehicle load factors and emissions in gCO_2/km. Below the aggregation level, on the left of the flow chart, the distance, mode share and emission factors are drawn together to calculate the CO_2 emissions per person, per week. In the centre of the flow chart, the load factors are coupled with the mode share to calculate mode weighted vehicle fractional excess capacity. This uses Equation 3.9 to calculate this. The emissions associated with excess capacity are then calculated by multiplying the total CO_2 emissions per week by the mode weighted vehicle fractional excess capacity to quantify the volume of emissions associated with excess capacity.

This approach to developing a framework through integrating the different aspects of behaviour, in terms of transport capacity use, and technology, in terms of the vehicles that are being used and their emission factors, reflects the socio-technical theoretical underpinning that was presented in Chapter 2-.

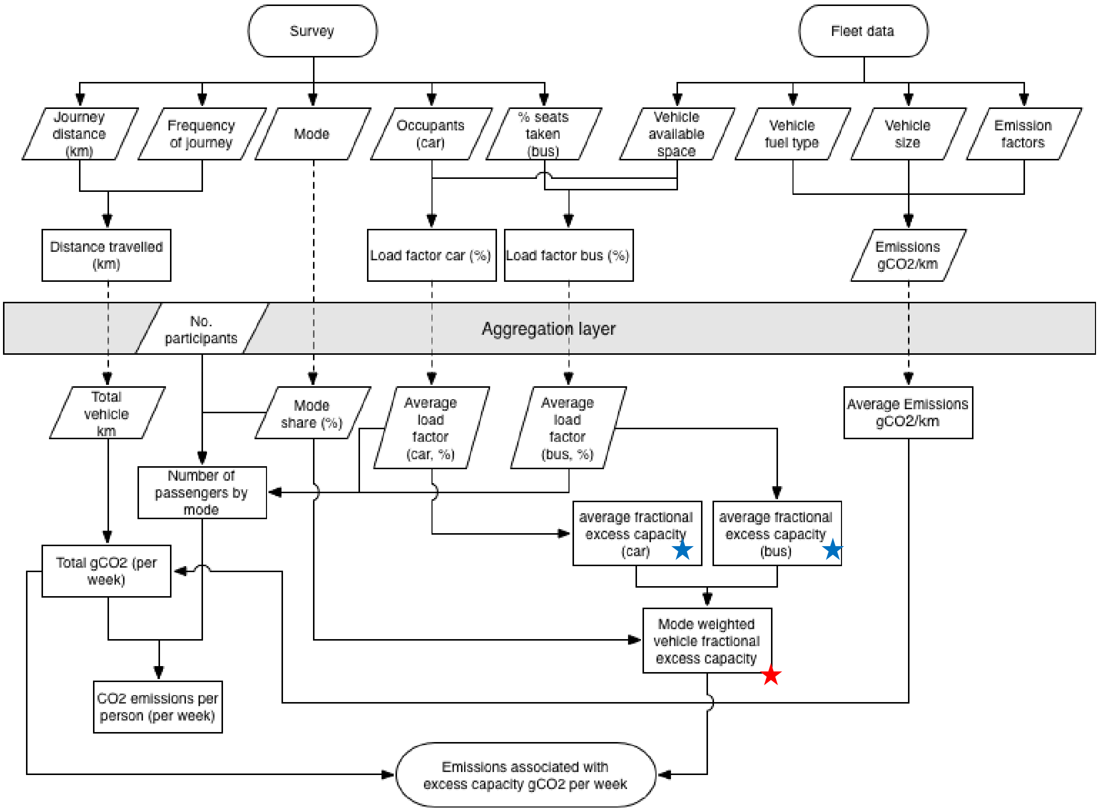

Figure 3:4 – Framework for Quantifying Excess Capacity

3.3.2 Equation for mode weighted fractional vehicle excess capacity

Mode weighted fractional vehicle excess capacity provides a single value for the amount of unused capacity in the urban transport system being modelled. This can be seen in the flow chart in Figure 3:4. The flow chart processes for vehicle fractional excess capacity are designated with blue stars and the mode weighted vehicle fractional excess capacity is designated with a red star.

The term fractional excess capacity is used to refer to the amount of the space within a vehicle which is unused. This is found by taking the load factor for the vehicle and dividing it by the available space, using Equation 3:8.

$$EC = 1 - \frac{LF}{AS}$$

[Equation 3.8]

Where:

EC = fractional excess capacity

LF = load factor

AS = available space

The mode weighted fractional excess capacity takes into account the mode share in the sample, which in this work will be the survey data. To calculate the excess capacity across vehicles within the urban transport system, the mode weighted vehicle fractional excess capacity (EC_{mw}) is calculated using the following equation:

$$EC_{mw} = (EC_c \times MS_c) + \left(\frac{EC_b}{2} \times MS_b\right)$$

[Equation 3:9]

Where:

EC = fractional excess capacity

MS = mode share

c = car

b = bus

mw = mode weighted (vehicles including car and bus)

The fractional excess capacity for bus is divided by 2 because, for buses to maintain a constant level of service and provide peak travel, they must run in the opposite direction to the peak flow, often running with few passengers. The buses running in the direction of peak flow will be much fuller, the value given for the load factor for buses does not take into account the empty running services in the opposite direction, and thus the excess capacity in for buses is divided by 2. More on this can be found in Section 4.2.1.

Figure 3:4 demonstrates how data derived from the survey, which can be found in Chapter 4- and Chapter 5-, will be combined with fleet data in order to quantify the excess capacity in the urban transport system and the emissions associated with this. Future years will be explored through the survey data about how people perceive they may use their transport capacity in the future, predominantly through construction of scenarios using a socio-technical systems approach informed by the literature found in Chapter 6- and then the modelling of these scenarios in Chapter 7-.

The main focus of the research presented in this thesis is internal vehicle capacity, which is quantified using the framework outlined here. Additional dimensions of capacity, including temporal capacity are included in further analysis. Temporal capacity is captured in the survey through questions about the ability and willingness of individuals to adjust their journey departure times. These indicators are then used to develop a scenario that will explore the impact of this on CO_2 emissions in the urban transport system. This can be found in Chapter 6- and Chapter 7-.

3.4 Chapter summary

This chapter has outlined the frameworks and modelling approaches that underpin the research in subsequent chapters. This chapter began by providing a definition for the transport sector considered in this research and demonstrated the theoretical basis for the inclusion and exclusion of certain aspects of the transport system. This was summarised in Figure 3:1.

Section 3.2 presented the review of modelling approaches, which culminated in the selection of the modelling techniques that will be used to quantify excess capacity in the urban transport system and the associated CO_2 emissions. SD has been identified as the most appropriate approach for exploring the role of enhanced use of excess capacity in reducing emissions in future transport systems, and will be used to explore scenarios in Chapter 6-. Traffic network modelling will be used in Chapter 7- to explore the network effects of making enhanced use of excess capacity and any induced congestion effects.

Finally, this chapter developed a framework for the subsequent analysis. Taking the findings from the survey of travel behaviour and capacity use in GM and coupling with fleet data, the excess capacity and emissions will be quantified and scenarios will be developed for the future role of this.

Chapter 4- Current travel behaviour, capacity use and emissions

In order to explore the impact that enhanced use of excess capacity might have on urban transport emissions, first it is important to establish how transport capacity is being used at present. This chapter examines travel behaviour, capacity use and emissions in the current transport system. It focuses on the survey of residents of Greater Manchester (GM), predominantly on the elements of the survey which explore the current transport system and behaviour. The data relating to future travel behaviour is presented in Chapter 5- and developed into scenarios in Chapter 6- while the analysis of current behaviour provides the foundations for the Business as Usual (BAU) scenario and the starting point for the other scenarios. This chapter begins by providing the theoretical underpinning and the methods used in the study design, building on the literature in Chapter 2-. The questionnaire itself is included in Appendix A – Survey Questionnaire. The results from the survey are then presented, discussed and evaluated and some conclusions are drawn.

4.1 Designing the behavioural study

The main focus of this part of the research is answering research questions 1 and 3, looking at where and when there is excess capacity in the urban transport system and what might facilitate more effective use of this excess capacity. The questions in the survey include elements of temporal and spatial capacity, as well as yielding insight about mode choices and potential factors which may influence future travel choices, and this will feed into the construction of scenarios in Chapter 6-. The subsequent section provides some background on the approaches used for collecting both qualitative and quantitative behavioural data about individual’s travel.

4.1.1 Approaches to behavioural research in transport

Behavioural research has been a key element of transport research and Chapter 2- Section 2.3.2, gave some examples of the increasing importance of behavioural research for understanding sustainability transitions for transport and in designing effective policy instruments. In addition, behavioural models were presented as part of the review of transport modelling approaches section in Chapter 3-. Here some insight is provided into the techniques and approaches used to analyse behaviour in transport and how these are used in designing the survey for this behavioural study.

Qualitative, quantitative and mixed methods

Before looking at the different theoretical perspectives used in transport behavioural research, a short section is first presented which examines the differences between and relative advantages of qualitative and quantitative data and approaches. The integrated nature of the research means that multiple techniques are used, and this section provides the context for this.

There are distinctive features of qualitative research methods, drawn from its epistemological position. Examples of these features include, a socially constructed reality and cultural meaning, focus on interactive processes, value-rich studies, thematic analysis, and the researcher is involved and authenticity is key (Neuman, 2003). Qualitative research methods are "*typically depicted as subscribing to an epistemological position that rejects the natural science model, along with its assumptions and its image of the nature of the social world*" (Bryman, 1998, p.139). Qualitative research approaches draw on a wide range of disciplines for philosophical arguments, methodologies and data analysis, including literature, history, sociology, psychology and anthropology (Miller and Salkind, 2002).

Quantitative research methods have contrasting distinctive features to qualitative approaches due to their own epistemological position. "*Quantitative research is seen as implacably wedded to a natural science version (and in particular to a positivist version) of both the character of the social world and how it ought to be studied*" (Bryman, 1998, p.138). Features of a quantitative approach include, exploration of objective facts, production of value free research, statistical analysis with a focus on variable, and the researcher should remain detached (Neuman, 2003). "*In many disciplines, the quantitative paradigm is still the dominant one (although there is some within-discipline variation from one country's social and behavioural science community to another).*" (Fielding and Schreier, 2001, p.1).

The integration of qualitative and quantitative methods in behavioural research is fairly innovative and pioneers have promoted the use of mixed methods approaches. Mason (2006), for example, suggests that "*social experience and lived realities are multidimensional*" (p.10) and that this requires the mixing of multiple methods. The present work seeks to integrate qualitative and quantitative approaches, as the research incorporates perceptions, attitudes and choices about transport and travel with information about distance travelled, time of day and the emissions associated with travel. The research is interdisciplinary, drawing on geography, transport studies, engineering, economics and sociology, to provide a socio-technical perspective on urban transport emissions associated with excess capacity and the interdisciplinarity of the work requires multiple methods to be employed (see Chapter 2- Section 2.1 for an overview of the disciplinary perspectives incorporated into the analysis in the present work). The need to integrate multiple perspective in order to examine the research questions identified in the present work was also identified in Chapter 3- when exploring different modelling approaches. The challenges, and value, of exploring the system around urban transport capacity, lie in the multiple dimensions of the socio-technical system, and this in turn requires the integration of multiple research approaches, theoretical perspectives and techniques.

Theories of travel behaviour

There are a broad range of theories and perspectives on how individuals make choices about their travel behaviour, drawing on a spectrum of disciplines. Some of this was introduced in Chapter 2- Section 2.3.2, when looking at how policy can be designed to influence behaviour drawing from behavioural economics and psychology. This section expands on this and extracts the elements most relevant to the design of the survey presented here.

The Theory of Planned Behaviour (TPB) was developed by Ajzen (1985) to explain how behaviours were a result of intention, subjective norms, attitudes and perceived levels of behavioural control (Ajzen, 1991). This theory has been applied in transport research to explore travel behaviour, for example Hunecke et al (2010), Bamberg et al (2003) and Anable (2005).

Mokhtarian et al (2015) explored how different theories have conceptualised behaviour and present how the TPB has been criticised and then adapted and developed. The Model of Goal-Directed Behaviour and then the Extended Model of Goal Directed behaviour incorporate emotional aspects into the behavioural framework of the TPB (Mokhtarian et al., 2015, Perugini and Conner, 2000). This allows some of the aspects which were not included in Ajzen's TPB to be accounted for and develops further dimensions in understanding the behaviours and choices of individuals.

Exploring the possibilities of making enhanced use of urban transport excess capacity requires an understanding of how transport related decisions are made. For example, the TPB suggests that perceived levels of behavioural control are important in influencing decisions. This could be applied, in the case of making effective use of capacity, to the constraints around working hours, which may make individuals feel a lack of ability to car share or adjust their journey departure times. This, and other dimensions of behaviour change, are explored further in Section 2.3 as well as in subsequent chapters, particularly in the context of how policy measures could be designed to make more effective use of capacity.

There have been criticisms, however, of the TPB's lack of awareness of the ways that travel related behaviour can become habitual and decisions are not necessarily planned and goal oriented in the ways that the TPB and other frameworks suggest (Schwanen et al., 2012, Verplanken et al., 2008). Schwanen et al (2012) present systematic approach for exploring how travel habits can influence behaviour change. This includes examining habit formation and renewal as well as habit breaking, breaking down the barriers between technological and behaviour change approaches and targeting stakeholders beyond the conventional 'users' of the transport system (Schwanen et al., 2012). Verplanken et al (1994) suggest that there is a trade-off between attitude and behaviour in the prediction of behaviour, one of either attitude or habit will have a stronger influence on behaviours. Verplanken et al (2008) suggest that travel behaviour, in particular mode choice, becomes habitual and disruptions to this habitual behaviour can lead to the planned decision making seen in the TPB; this is known as 'habit discontinuity'. By integrating both planned decisions and habitual travel behaviour, habit discontinuity becomes a useful framework for examining both aspects of travel related behaviour and when considering how to design policy interventions to influence behaviour.

While the survey in the present research does not directly collect data on individuals' travel habits, understanding of how travel behaviour can become habitual may be important for exploring interventions to influence behaviour change. The analysis in the present research explores the links between potential key life events, such as moving house or starting a family, and changes to travel behaviour, and this concept has been explored widely in the literature (see for example, Scheiner and Holz-Rau, 2013, Verplanken et al., 2008). Habit discontinuity could be a useful approach for examining changes to travel behaviour and developing policy interventions that could make more effective use of urban transport capacity. Policy options are suggested in Section 4.4 and developed further through the interviews in Chapter 8-.

Subjective / objective data

An additional important dimension of behavioural research in transport is the differences between subjective and objective data, and this can be significant in survey design and structure. This can be key, particularly when looking at how people perceive their travel patterns compared the reality. Curl et al, (2015) define objective and subjective measures as follows for their work on accessibility, "*objective relates to a government indicator or measure designed to reflect the 'real' situation, and subjective is used to understand an individual perception or experience of that reality*" (p.87). Noting that the differences between objective and subjective values for travel behaviour, for example for journey time, can be important for research and for policy making. Curl et al (2015) found there were significant differences between the travel time found in the objective National Travel Survey (NTS) and the more subjective Core Accessibility Indicators, both of which are datasets commissioned by the Department for Transport (DfT).

Van Exel and Rietveld (2009) found differences between objective and subjective measures for their study of travel behaviour in Amsterdam. This was particularly pronounced when examining the differences between perceived and real travel times by public transport for those who rarely used public transport, and this represented a perceived barrier to modal shift. Their findings suggest that improved public transport information is needed to bridge the gap between the perception of journey times and the reality (Van Exel and Rietveld, 2009). This is important when considering capacity use in the present work, as modal shifting to higher occupancy modes represents an opportunity to make more efficient use of the urban transport capacity and improved information is a policy option that could leverage this modal shift.

Subjective versus objective data is also important when examining perceived relative costs of modes which are key in influencing travel decisions, as Verplanken et al suggest "*car use is driven by a perceived balance of costs and benefits, which thus favours the car over alternative modes*" (Verplanken et al., 2008, p.121). This is supported by Hoogma et al (2002) who suggest that the pre-paid nature of many of the costs of car use versus the immediate payments for alternative modes can lead to an underestimation of the real costs of driving when compared to public transport, reinforcing car as the main mode choice. Addressing the gaps between perception and reality in relation to the relative differences in travel time and costs across modes could be useful in incentivising individuals to make more effective use of urban transport capacity and encouraging more sustainable transport decision making. Improving information is a clear policy opportunity to address this, and Chapter 2- presented some options for this through smarter choices and other policy interventions, see Section 2.3. In addition, addressing misconceptions about the relative costs of different modes, thus emphasising the cost of owning and running a car, could be useful in encouraging increased levels of car sharing. Policy options are also developed further in Section 4.4 and Chapter 8-.

4.1.2 Travel diaries

Travel diaries are widely used to collect information about people's travel activity, particularly within longitudinal studies. Travel diaries ask participants to record their journeys for a given time period, generally for a week or less, although some longer studies do exist. Studies tend to be fairly short because the quality of data tends to degrade as the study length increases (Schlich and Axhausen, 2003).

There are challenges associated with travel diaries for data collection, with the key one being participant fatigue. Axhausen et al (2007) suggest that participant fatigue reduces the number of days and number of trips reported by travel diary participants, which detrimentally impacts on the data gathered. In addition, shorter trips are often left out by participants as the length of study increases (Schlich and Axhausen, 2003).

The survey in the present research collected data over the course of a ‘typical week’, i.e., not in the school holidays. The participants were asked at the start of the survey whether this week’s travel represents what they consider to be typical of their normal travel behaviour and, if not, to fill in the survey for a normal week. This focus on a ‘typical week’ is used in the hope that the survey data collected will show the travel patterns of residents of GM without bias being introduced. The focus on a single week’s travel was intended to minimise participant fatigue and protect the integrity of the results. However, some elements of participant fatigue are identifiable in the results, and these are discussed further in Section 4.1.6. Participants were asked to provide data on their travel over the past week, therefore the survey is not a diary in the sense that participants are writing about their travel each day as it happens. This introduces some risk of error in how participants recall their travel behaviour over the last week, but due to the short time period over which participants are asked to recall their travel patterns, this is considered minimal.

4.1.3 Survey design and implementation

In order to ensure that a representative sample of transport users in GM was recruited, Accent MR were employed to conduct the survey through an online panel survey. An online panel survey involves recruiting participants, providing incentives for survey completion. Information about incentives is recognised as commercially sensitive data, so precise information is not available, but panel providers tend to have a system where you bank points for survey completion and these are then used to obtain rewards such as vouchers. The incentives are similar across online panel survey providers but specific details are confidential.

The sample size was 500 participants, plus an additional 50 participants took part in the initial pilot study. This sample size was chosen because it provides a substantial and robust, yet manageable data set. A sample size of 500 participants provides confidence interval greater than 95% with a fractional margin of error of 0.045, thus we can have confidence that the risks that the sample will differ from the population are minimised.

The survey collected both qualitative and quantitative data from the participants to understand people's travel behaviour and how they use the urban transport capacity. This included multiple choice questions and open ended answers in order to understand and explore the research questions around people's current and future travel behaviour.

A pilot study was conducted with Accent to test the survey design which was written by the present researcher. Accent recruited the panel participants and delivered the survey. Before the pilot took place, the construction of the survey and question clarity was tested on colleagues to ensure that the questionnaire design was effective and to test the clarity of questions, while recognising that this was not a representative sample, given their interest in the field and levels of educational attainment. The pilot study took place in August 2014 and 50 residents of GM were recruited to participate. The questionnaire took about 10-15 minutes to complete. The survey was effective in delivering the data required, however, it was found that a number of participants were dropping out in the early stages of the survey due to the remaining length of the survey. In order to try and mitigate this effect, some questions were removed that were deemed to be less critical for the research and the description of what was required from participants was made clearer to ensure that participants were not entering more data than necessary. Questions that were removed included ones about what kind of car access you might have in the future, e.g. shared ownership, company car, intention to learn to drive in the future, and future fuel type and size of vehicle that participants might own. The questions about car ownership were interesting to understand the role of new business models for car access but space and time constraints on the survey meant it was necessary to remove them. The questions regarding future vehicle size and fuel were interesting to understand peoples' perceptions of future vehicle technology, however, projections about the future fleet are available in the literature, and these are sufficient for informing the modelling study that follows, thus these questions were removed. The questions about the factors that might affect your future transport decisions were adjusted to more accurately reflect people's responses, so rather than rating the importance of the factors on a likert scale as in the pilot study, participants in the full version were asked to rank the factors in order of importance, selecting at least 5. Despite the survey been shorter in the full version, some elements of participant fatigue are still identifiable and this is discussed further in section 4.1.6. The full questionnaire used to develop the online panel survey is included in Appendix A – Survey Questionnaire.

4.1.4 Ethics

This work has undergone ethical review in accordance with the University of Leeds ethical review procedure. Despite using personal information about travel behaviour within this research, the data has been anonymised and treated with confidentiality. The data has been stored on a secure server and no identifying features are reported in the write up or any associated publications. Aggregate, anonymised data, with geographically identifiable information removed, will be placed in the University of Leeds data repository, in accordance with the Engineering and Physical Sciences Research Council's (EPSRC) data guidelines. The ethical review approval record can be found in Appendix B – Ethical Approval.

4.1.5 The sample

The section provides some information about the demographics of the sample and then compares some of the information emerging about the survey participants' travel behaviour to some overview data from the NTS. The following tables present some socio-demographic information about the survey sample and the general GM population, data from Office of National Statistics (ONS) Neighbourhood Statistics (Office of National Statistics, 2014b). The survey sample was made up of 48% male participants and 52% female participants.

Table 4:1 shows the distribution of ethnic origin for the survey participants and the population of GM. The sample has similar shares for all the different ethnic groups, suggesting a representative sample has been achieved.

Table 4:1 - Ethnic background of survey participants and GM population (n=501)

Ethnic Origin	Survey sample	GM Population
British	82%	80%
Irish	1%	1%
Any other White background	3%	3%
White and Black Caribbean	1%	1%
White and Black African	1%	0%
White and Asian	1%	1%
Any other Mixed background	1%	0%
Indian	1%	2%
Pakistani	3%	5%
Bangladeshi	1%	1%
Any other Asian background	0%	1%
Caribbean	0%	1%
African	2%	2%
Chinese	1%	1%
Any other ethnic group	0%	2%
Prefer not to answer	1%	n/a

Table 4:2 shows the age distribution of the sample, with the age limits of 18-65 years old. ‘Soft quotas’ were set for age, based on the age profile of the local population to ensure the sample was representative. A target proportion of the survey was defined, e.g. for 30-44 years, 33% would have been a target of 165 participants, and then a minimum level of participants was defined, for 30-44 years this was 120, to ensure that the sample was not dominated by a specific age group. Table 4:2 shows the age distribution achieved in the sample and these are close to those in the GM population. Participants were aged 18-65 years old, the upper age limit being placed at 65 years old as we were asking

people about their future travel behaviour, and it was deemed insensitive to ask those over 65 about how they would be travelling in the future.

Table 4:2 - Age distribution of survey sample and GM population (n=501)

Age Group	**Survey Sample**	**GM Population**
18 to 24 years old	13%	16%
25 to 29 years old	8%	12%
30 to 44 years old	30%	33%
45 to 59 years old	36%	30%
60 to 65 years old	13%	9%

Figure 4:1 to Figure 4:4 show how the data collected in the present survey compares to some selected data from DfT's NTS. Figure 4:1 and Figure 4:2 show the number of trips by main mode and distance for the NTS and the survey data respectively. The data shows a similar distribution, however, there seems to be an under representation of walking journeys. This is not of major detriment to the research as the focus is on capacity within private and public transport, however it is interesting to note and it may be the case that survey participants didn't feel it was necessary to include shorter, walking journeys within their responses. This is a trend that has been identified elsewhere in the literature for travel diary type research (see for example, Schlich and Axhausen, 2003). It should also be noted that the NTS is a national data set, and the survey looks at one local area, therefore it could be expected that there may be some variation in trends emerging from the data.

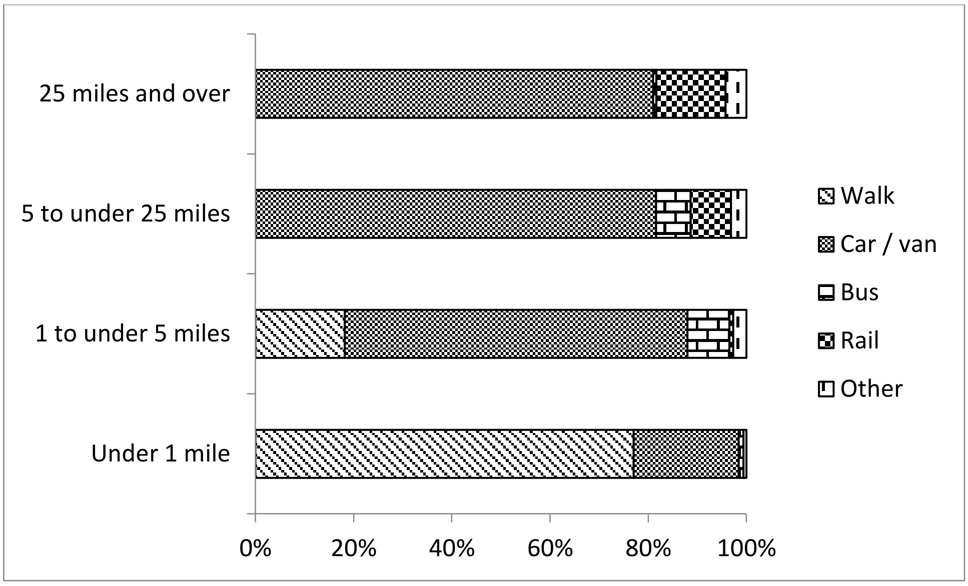

Figure 4:1 - NTS - Percentage of trips by main mode and distance (data taken from DfT, 2015)

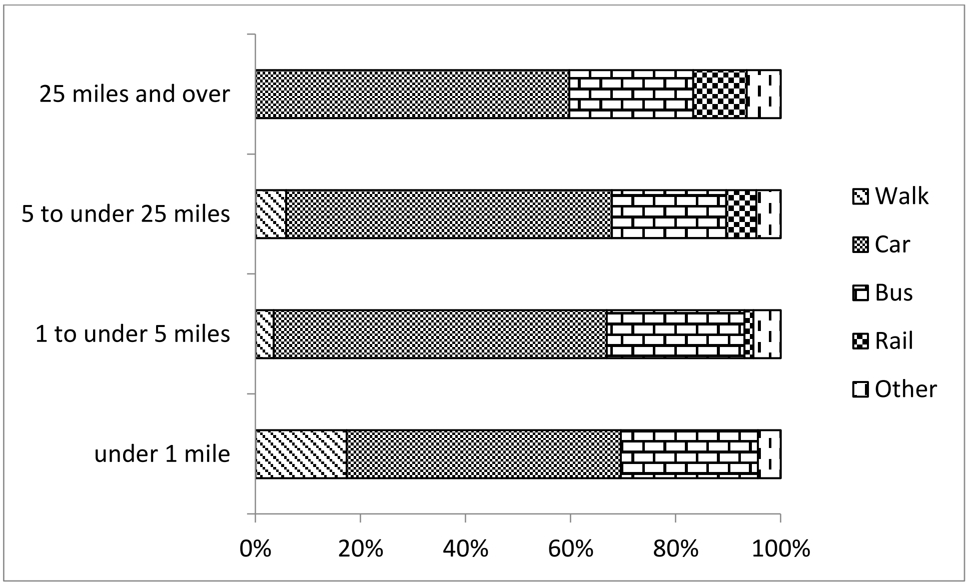

Figure 4:2 - Survey data - Percentage of trips by main mode and distance

Figure 4:3 and Figure 4:4 show mode share by distance travelled for the NTS and survey data respectively, and again there is a similar pattern with an underrepresentation of walking trips. Generally, the similarity of the patterns between the two datasets is reassuring of the representativeness and robustness of the survey data collected.

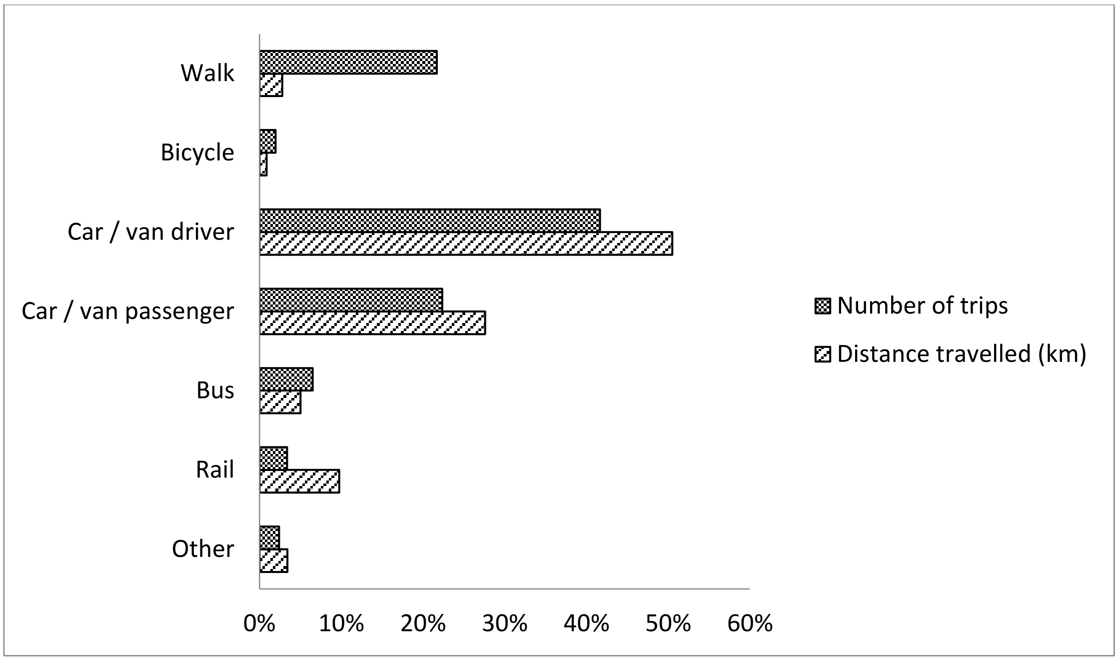

Figure 4:3 - NTS - Mode share - number of trips and distance travelled (data taken from DfT, 2015)

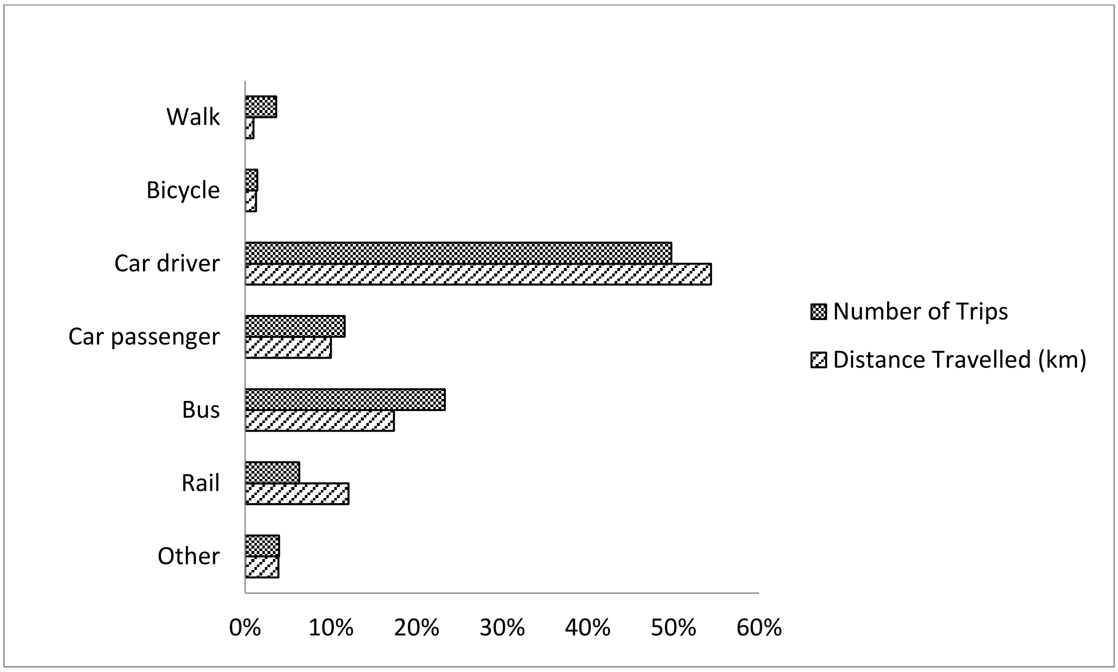

Figure 4:4 - Survey - Mode share - number of trips and distance travelled

4.1.6 Participant fatigue

Figure 4:5 shows the flow rate for road traffic in GM compared to number of journeys reported at different times across the day in the survey data. While this is not an ideal direct comparison, because the survey journeys include journeys on rail, metro and active modes, walking and cycling, the trends are demonstrated. The data suggests that there may have been some elements of participant fatigue emerging as respondents reported the journeys they were making, with a similar shape to the data in the morning peak and overnight but the numbers of journeys being reported later in the day dropping off. For the purposes of the research questions, the responses are still valid, in terms of load factors, mode choices and modal shifting and ability to adjust journey timing, however, there may be lessons for survey design to be taken from this finding.

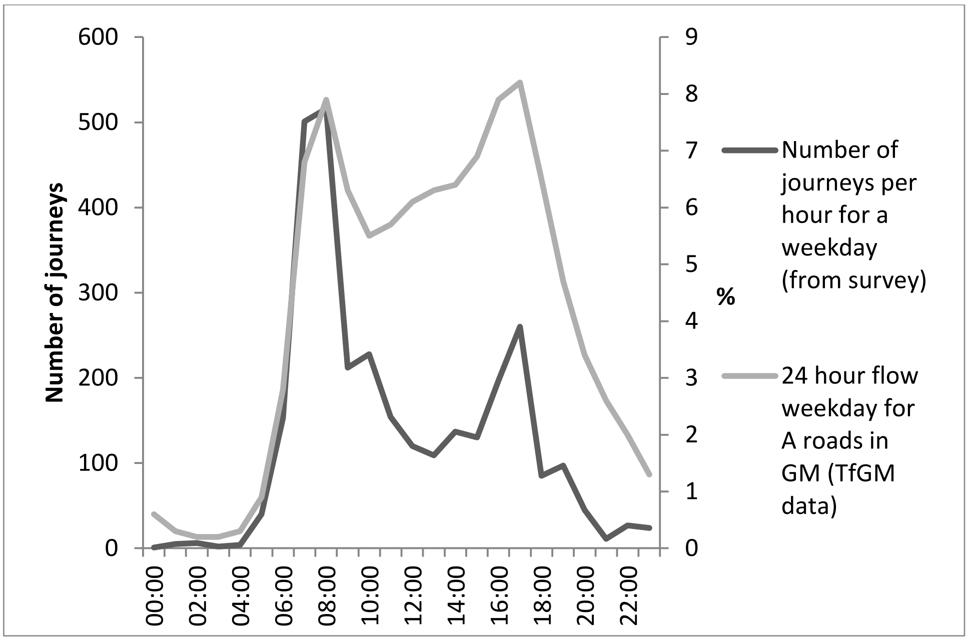

Figure 4:5 Journeys and traffic flow over a 24 hour period

4.1.7 Reflections on the data collection

The survey has delivered useful data on the transport behaviour and capacity use of residents of GM and the sections which follow analyse and present the findings from this data. However, as identified above, the survey design did result in some elements of participant fatigue, and this is evident in Figure 4:5. It was also identified that there is a possible underrepresentation of shorter trips and walking trips in the survey data, which is a common problem in travel diary type studies.

There are identifiable challenges in the survey design which could have resulted in this participant fatigue. The survey collected quite a broad range of information about the participants travel behaviour in order to develop a picture of how transport capacity is being used at present and the potential to make enhanced use of this in the future and the sustainability impacts. However, the lack of focus on specifics of travel behaviour may have resulted in the survey being somewhat confusing for the participants, and the length of the survey may also have been a barrier. These reflections could be taken into account for future work and in any replication of the framework for further case studies.

4.1.8 Approaches to statistical analysis of the survey data

Section 4.2 presents statistical analysis from the survey data. Descriptive statistics from the survey are initially presented along with some indicators of how transport capacity is being used under current travel behaviour using the framework and Equations 3:8 and 3:9 developed in Chapter 3-. This is also presented along with some data from existing sources, particularly the NTS, in order to compare the data gathered in the survey to the published data.

Multinomial logistic regression modelling is undertaken on a number of survey outputs. This seeks to suggest the propensity of sectors of the survey sample, and hence the population, to certain behaviours, such as car sharing or a change in mode choice. The multinomial logistic regression modelling has been undertaken in SPSS drawing in the independent variables through a stepwise procedure. Multinomial logistic regression modelling is selected for examining propensity for a number of variables including willingness to car share and willingness and ability to adjust journey departure times, as this can be used where the dependent variable is categorical, as is found for the present data (George and Mallery, 2012).

The multinomial logistic regression modelling is calculated using the following. For a dependent variable *j*, the probability that the *i'th* case falls into category *j* is given by $Prob_{ij}$ where:

$$Prob_{ij} = \frac{e^{z_{ij}}}{e^{z_{i1}} + e^{z_{i2}} + \cdots e^{z_{ij}} + 1}$$

[Equation 4:1]

z_{ij} is the value of *j'th* unobserved variable for the *i'th* case (Greene, 2003).

It is necessary to calculate the 'by chance' accuracy for the multinomial logistic regression modelling to ensure that the data classification achieved by the model has not occurred by chance alone. This is calculated by summing the squared marginal proportion for the categories and multiplying by 1.25, as a 25% improvement in accuracy is the commonly accepted benchmark for accuracy (Greene, 2003). The output tables include the following data indicators. The Std. Error column shows the standard error for the B coefficients and detects multicolinerality in the modelling. A Std. Error value greater than 2.0 is problematic. The Wald test examines whether the independent variable can be used to distinguish the reference category from the other categories and the sig. column shows the extent to which this is statistically significant, a value of 0.05 or smaller indicates statistical significance (Agresti, 2007). The results of the propensity modelling are presented and discussed following the descriptive statistics for each area of the research. The output tables and chance accuracy calculations for the propensity modelling can be found in Appendix C – Statistical Outputs, with an example provided in Section 4.2.1 for clarity.

4.1.9 Section summary

This section has outlined how the behavioural survey has been designed in order to address the research questions reflecting on behavioural research elsewhere in the transport literature. The statistical approaches used to analyse the data which will be found in the subsequent sections were also introduced. The presentation of the survey results now follows, and some aggregate estimation of the carbon emissions associated with excess capacity are made and presented for the GM case study. The discussion of the results is integrated into this section. A summary and conclusions section, which includes some policy recommendations follows in Section 4.4.

4.2 Current behaviour and capacity

The following section presents the survey results and a discussion of these in the context of the theoretical and academic literature presented previously elsewhere. This begins with looking at vehicle occupancy and mode weighted vehicle fractional excess capacity (EC_{mw}) and goes on to explore home working, departure times and car sharing. The discussion is integrated into each of these areas.

4.2.1 Excess capacity under current travel behaviour

In order to provide context for the use of capacity within the results presented subsequently, capacity use from the NTS is first presented, which can then be compared to the findings from the survey.

Figure 4:6 shows the average occupancy for car/van in England between 2002 and 2014. The average occupancy fluctuates over time, but remains around the average value for this period which is 1.57 persons per vehicle. It is important to also note that occupancy rate varies by location and by journey purpose.

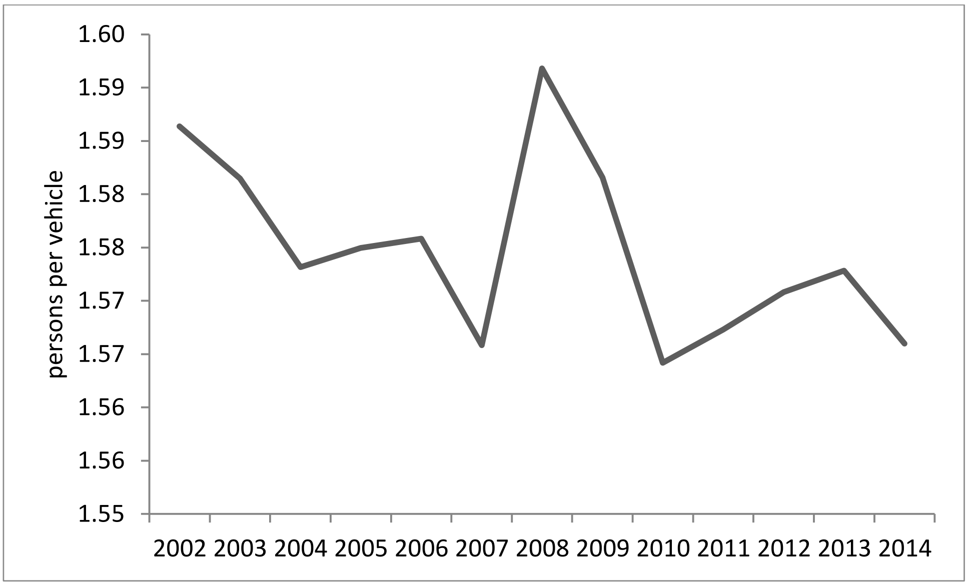

Figure 4:6 - Average occupancy for car/van in England, 2002-2014 (DfT, 2015)

Table 4:3 shows car occupancy for different trip purposes from NTS data. It shows how occupancy rates are lower for modes such as commuting and business and higher for education trips. This can be compared to Table 4:6 which shows occupancy rates by journey purpose for the survey data.

Table 4:3 – Car occupancy by trip purpose

Purpose	**Average car / van occupancy**
Commuting	1.2
Business	1.2
Education	2.0
Shopping	1.7
Personal business	1.4
Leisure	1.7
Holiday / day trip	2.0
Other including just walk	2.0
All purposes	1.6

Fractional Vehicle Capacity: Table 4:4 shows some illustrative examples of fractional excess capacity for a comfort and extreme case. In the comfort case there are four seats available per car (a driver plus 3 passengers) and fifty nine seats available per bus, which represents a typical bus, based on average of single and double decker buses in DfT's bus statistics (Department for Transport, 2016a). In the extreme case, the fifth seat in a normal car is also used (a driver and 4 passengers), although this may not be deemed comfortable by all passengers, hence the two cases are used. For bus, in the extreme case, an additional twenty five standing spaces are available, taking total available space to eighty four; however, again, this may not be the optimal loading for a bus as passengers may become uncomfortable past a certain level of loading. Chapter 2- presented some information on capacity and crowding, see Section 2.3, and thus informs these two cases. The national average values are taken from the NTS, however these numbers are subject to regional variation and vary by journey purpose, this can be seen Table 4:3 from the NTS and in the data derived from the survey in Table 4:6. The data in Table 4:4 for GM is taken from Berry and Westland (2013).

Table 4:4 – Illustrative examples of fractional excess capacity

Vehicle		Occupancy	Comfort		Extreme	
			Available Space	**Fractional Excess Capacity**	**Available Space**	**Fractional Excess Capacity**
Car	National average	1.6	4	0.60	5	0.68
	GM peak	1.2	4	0.70	5	0.76
	GM off peak)	1.4	4	0.66	5	0.89
Bus	Local (national average)	10	59	0.83	84	0.88
	London (average)	19	59	0.68	84	0.77

Table 4:5 shows the variation in occupancy rate across the day for bus and car trips from the survey data. It demonstrates that occupancy for cars is higher in the inter peak and evening off peak period, lower for the PM and AM peaks and at its lowest overnight. This reflects the TfGM data shown in Table 4:4, which shows for cars, occupancy is lower in the peak than the off peak period. For buses, the highest occupancy is seen for the AM and PM peaks and is lower in the evening off peak, inter peak and overnight. The average occupancy for cars found in the survey is 1.39 persons per vehicle and for buses this is around 40 people. For buses this is much higher than the values found in Table 4:4 and this is discussed further subsequently. Table 4:5 also shows the mode split by time of day, as this is required with the occupancy levels in order to calculate mode weighted fractional excess capacity, which is shown in Table 4:9. Throughout the day, car makes up at least 50% of the modal share, although this is lower during the AM and PM peaks, and highest in the inter peak and overnight off peak. Bus modal share varies between 23% and 27%, and is highest during the AM and PM peaks.

Table 4:5 - Occupancy by time of day

Time of day	Car Occupancy	Car mode share	Bus Occupancy	Bus mode share
Off Peak 00:00 - 07:00	1.2	63%	29	23%
AM Peak 07:00 - 10:00	1.4	56%	48	26%
Inter Peak 10:00 - 16:00	1.5	63%	33	24%
PM Peak 16:00 - 19:00	1.3	55%	44	27%
Off Peak 19:00 - 00:00	1.5	59%	22	24%
Average	1.4	62%	40	23%

Table 4:6 shows occupancy by journey purpose from the survey data. This demonstrates that occupancy for cars is lowest for work related travel, at just 1.24 persons per vehicle, and highest for education, at 2.48 persons and this may be associated with carrying multiple children to school for education journeys. This concurs with the data in Table 4:3 which showed that at a national level, car occupancy rate was highest for education trips, and lower for commute and business travel. For buses, the occupancy is higher for work and education trips, and this is probably associated with the fact that many of these journeys take place in the AM and PM peak, when occupancy is higher, as shown in Table 4:5. Table 4:6 also shows the mode split by journey purpose. This is used to calculate the mode weighted fractional excess capacity by journey purpose shown in Table 4:10. This demonstrates that bus has the highest mode share for education trips, otherwise, car dominates the mode share, in excess of 50% for all other journey purposes and as high as 82% for journey purpose ‘other’.

Table 4:6 - Occupancy by journey purpose

Journey Purpose	Car Occupancy	Car mode share	Bus Occupancy	Bus mode share
Work	1.2	59%	40	23%
Shopping	1.8	64%	35	25%
Leisure	1.8	55%	37	28%
Education	2.5	25%	48	49%
Other	1.7	82%	38	12%

Table 4:7 shows the average trip length by journey purpose. This is useful to understand how trip length varies for different journey purposes, with education and shopping trips being shorter than work and leisure trips.

Table 4:7 - Trip length by journey purpose

Journey Purpose	Average trip length (km)
Work	9
Shopping	5
Leisure	13
Education	7
Other	8

Table 4:8 shows the current main mode by age group, showing that younger people are more likely to be a car passenger or bus users, and older age groups are more dominated by the mode car driver. This is interesting in understanding who is making specific mode choices, for example, there are fewer walking and cycling trips among the over 60 group, and fewer car drivers in the 18-24 group, and these dynamics could be used to inform policy interventions.

Table 4:8 - Main mode by age group

Which of the following age groups are you in?	Current Main Mode							Total
	Car, driver	Car, passenger	Bus	Train	Metro	Cycle	Walk	
18 to 24	4	14	24	6	2	0	6	56
25 to 29	12	2	10	7	1	1	1	34
30 to 44	68	9	34	11	4	4	3	133
45 to 59	101	17	30	6	2	2	6	164
60 to 65	38	4	12	7	2	0	0	63
Total	223	46	110	37	11	7	16	450

The following section takes the data for excess capacity found in the survey and uses this to calculate EC_{mw} in order to understand the magnitude of this excess capacity in the current transport system.

Calculating excess capacity

In Section 3.3.2 the equations for calculating fractional excess capacity (EC) and mode weighted fractional vehicle excess capacity (EC_{mw}) were presented and they are shown again below.

$$EC = 1 - \frac{LF}{AS}$$

[Equation 3:7]

Where:

EC = fractional excess capacity
LF = load factor
AS = available space

$$EC_{mw} = (EC_c \times MS_c) + \left(\frac{EC_b}{2} \times MS_b\right)$$

[Equation 3:8]

Where:

EC = fractional excess capacity
MS = mode share
c = car
b = bus
mw = mode weighted (vehicles including car and bus)

Equation 3:8 goes beyond the fractional excess capacity values given in Table 4:4, which are for specific modes, calculated using equation 3:7, and takes into account mode share to calculate EC_{mw} across the vehicles in the system being considered. The following section presents the calculations for EC_{mw} for the data derived from the survey.

Table 4:9 shows EC_{mw} at different times of day, for a comfort case and an extreme case. The comfort and extreme cases are explained above. EC_{mw} is highest in the overnight off peak and lowest in the AM Peak, with other time periods falling in between. However, what the table demonstrates is, that even in the comfort case, at any one time at least 52% of capacity is excess in terms of EC_{mw}, and this is even higher in the extreme case.

Table 4:9 – EC_{mw} by time of day

Time of day	Comfort Case	Extreme Case
Off Peak 00:00 - 07:00	0.61	0.67
AM Peak 07:00 - 10:00	0.52	0.59
Inter Peak 10:00 - 16:00	0.57	0.63
PM Peak 16:00 - 19:00	0.54	0.61
Off Peak 19:00 - 00:00	0.56	0.62
Average	0.56	0.62

Table 4:10 shows EC_{mw} for different journey purposes, demonstrating that the excess capacity is greatest for work related travel and the journey purpose ‘other’, and much lower for education journeys.

Table 4:10 - EC_{mw} by journey purpose

Journey Purpose	Comfort Case	Extreme Case
Work	0.57	0.62
Shopping	0.53	0.61
Leisure	0.49	0.57
Education	0.38	0.48
Other	0.55	0.63

Both the existing literature and the survey data demonstrate that occupancy rates for private cars vary by journey purpose. The highest occupancy found in both the survey data and the NTS is for education trips, with work related travel generally having the lowest. Examination of the variation between occupancy rates for different journey purposes may be interesting for exploring policy options available to make more effective use of EC_{mw}. Potential policy options for making enhanced use of excess capacity are suggested in Section 4.4 and developed further through the interviews with stakeholders in Chapter 8-.

Occupancy rates for education trips are the highest, at 2.48 persons per vehicle for cars and 48 persons per vehicle for buses. Education journeys are constrained by the hours of the institutions and journeys take place within a specific catchment area for primary and secondary education which, in urban areas, is relatively small. Occupancy rates may be higher for this journey purpose due to taking multiple children to school, or car sharing for trips that are not necessarily school related but are classed as education trips, such as travel to university. There could, however, be additional opportunities for car sharing for school trips, due to the constrained journey times and localised nature of trips, trips for education are shorter than work trips, at an average of 7km, see Table 4:7. At present, there remains excess capacity for these trips. EC_{mw} for education trips is just 38% in the comfort case, much lower than for other journey purposes.

School travel plans can be effective at changing behaviour for education related trips (Cairns et al., 2004, Sloman, 2003) and this was introduced in Sections 2.3.2 and 2.6. It may be that interventions to increase occupancy rates for cars making education trips could be rolled out as part of future school travel plans.

It is also important to recognise that for education trips, car makes up a relatively small proportion of the mode share, particularly when compared to other trip purposes, at just 25%, therefore it is necessary to ensure that facilitating further car sharing for education trips is not encouraged at the expense of trips that are currently made by public transport or active travel.

The reported occupancy rates for education trips made by bus are among the highest, and this, again, is probably due to the constrained hours of education meaning that most journeys for this trip purpose are made in the peak hours when occupancy rates are highest.

For work related travel, occupancy rates are much lower, with an average of 1.24 persons per car, although for buses it is not the lowest of all trip purposes, at 40. However, cars make up about 60% of the mode share for work related travel, therefore the associated EC_{mw} is high at 57% in the comfort case. Car sharing could play an important role for increasing occupancy rates for cars on the journey purpose work, and this could be encouraged through workplace travel planning as well as other options such as online car sharing tools. Car sharing is explored further in Section 4.2.4.

It is also interesting to note the changing occupancy patterns across the day. For cars, the highest occupancy rates are seen in the inter-peak (10:00-16:00) and the evening off peak (19:00-00:00) and it is lower during the peaks and overnight off peak, these can be seen in Table 4:5. For buses, the occupancy patterns are different, with the highest occupancy in the AM and PM peaks, and lower occupancy at other times of day. When this is coupled with the mode share across the day which is seen in Table 4:6, the EC_{mw} for the different time periods can be calculated and this can be seen in Table 4:9. The EC_{mw} varies for different time periods, but what it is clearly demonstrated by the results in Table 4:9 is that at any time for the comfort case, at least 50% of capacity is excess, this is lowest in the peak periods, and rises as high as 61% for the overnight off peak. For the extreme case, this rises to 59-61% in the peak periods and as high as 67% in the overnight off peak period. This demonstrates that there is a large amount of excess capacity associated with the way vehicles are used in the current transport system, and subsequent analysis will suggest ways that it might be utilised.

As suggested at the beginning of this chapter Section 4.2.4, it is important to recognise the differences between subjective and objective data (Curl et al., 2015). The data collected about occupancy rates for private cars is reported data, responding to the question

'*If car is the main mode, how many people are in the vehicle? (Drop down list :) 1, 2 , 3, 4, 5, more than 5, N/A*'.

Whereas for buses, the question asked was:

'*If using public transport, on average how crowded is your service? (Drop down list :) <1/4 seats taken; 1/4-1/2; 1/2-3/4; almost all seats taken with space to stand; all seats taken, no space to stand, N/A*'.

Because for buses, this is based on the perception of how crowded the service may have been, the reported values may be higher than the actual values for occupancy rates on these buses. In addition, for example, the passenger may have remained on the ground floor of a double decker bus, which seemed crowded, but there may have been seats available upstairs. The values for bus occupancy from the survey were higher than those found in national datasets, see Table 4:4. However, when the values are halved, as there will be largely empty services running in the opposite direction to the full ones at peak times, the numbers come closer together, with the average occupancy being around 20, and the NTS reports average occupancy for London at 19 and national average at 10. The values for GM are likely to be closer to those found in London, as the national average will include many rural services with low patronage, whereas London represents a metropolitan area. Van Exel and Rietveld (2009) found that the perceived and real journey times for public transport journeys were different, with users perceiving that journeys were longer than they really were. They argue for improved public transport information to address the discrepancy between real and perceived journey times (ibid). From the results about public transport occupancy, it is possible to suggest that there is a discrepancy between the perceived levels of crowding on bus trips and the actual levels of crowding, based on the differences between the survey data and NTS data, although this could be due to regional variation. However, if this discrepancy does exist, we could argue as Van Exel and Rietveld did, for improving public transport information in order to address this and encourage modal shift to public transport modes. Another additional tool which could help address misconceptions of the levels of crowding on buses could be the seat level indicators, which have been trialled London buses (Transport for London, 2014), which tell passengers how many seats are available on the upper deck of a double decker bus service. Improving information about the likely levels of crowding on specific services could also be useful for encouraging people to adjust their departure times in order to be able to travel in additional comfort if this is an available option.

This section has analysed the survey data and quantified EC_{mw} for different times of day and journey purpose. Section 4.3 explores the emissions associated with the EC_{mw} and further develops the analysis of the impacts of EC_{mw}. The sections which follow examine behaviour from the survey around home working, shopping, departure time adjustment and car sharing.

4.2.2 Home Working

This section examines the data relating to whether survey participants are able to work from home. The concepts of homeworking and telecommuting were introduced in Chapter 2- Section 2.3.2. This is interesting for transport sustainability because increasing individuals' ability to work from home could have an impact on the levels of transport demand, and improved ICT infrastructure could facilitate this (Asgari et al., 2014). The ONS found that, on average, around 13.9% of workers work from home, and in the North West it is slightly lower at 12.1% (Office of National Statistics, 2014a). The trends indicate that the share of people working from home is increasing over time, from 11% in 1998 to nearly 14% in 2014 (ibid). The following section explores responses to questions around home working from the survey, looking at demographic differences in home working, and making some suggestions of how this could be used in policy to deliver more effective use of capacity and the use of this in the scenarios that follow in Chapter 6-.

Table 4:11 - Ability to work from home

Are you able to work from home?	Number of Participants
Not at all	265 (53%)
Occasionally	110 (22%)
Once a week	15 (3%)
About half the week	21 (4%)
More than half the week	10 (2%)
All the time	80 (16%)

Table 4:11 shows the responses to the question 'Are you able to work from home'. Over half of participants were unable to work from home at all and 22% were able to work from home occasionally. 16% were able to work from home all the time, though they may not always choose to do so. As such, this could

represent an opportunity for suppressing transport demand in the future and policy options are discussed further in Section 4.4.

Table 4:12 and Table 4:13 show the numbers of people working from home compared to income and age respectively. This is interesting when explored in the context of the propensity modelling found in Table 4:14.

Table 4:12 - Ability to work from home against income

Gross household income before tax and other deductions	Are you able to work from home?						Total
	Not at all	Occasionally	Once a week	About half the week	More than half the week	All the time	
Less than £10,000	23	5	1	4	3	15	51
£10,000 - £19,999	60	14	1	3	1	19	98
£20,000 - £29,999	59	22	4	7	1	17	110
£30,000 - £49,999	70	30	5	5	3	15	128
£50,000 - £99,999	17	19	1	2	1	3	43
£100,000 or more	2	3	0	0	0	0	5
Prefer not to answer	34	17	3	0	1	11	66
Total	265	110	15	21	10	80	501

Table 4:13 - Ability to work from home against age

Age	Are you able to work from home?						Total
	Not at all	Occasionally	Once a week	About half the week	More than half the week	All the time	
18 to 24	25	20	2	5	2	9	63
25 to 29	22	9	2	2	0	3	38
30 to 44	80	37	5	3	3	24	152
45 to 59	98	39	5	9	2	28	181
60 to 65	40	5	1	2	3	16	67
Total	265	110	15	21	10	80	501

Table 4:12 and Table 4:13 show the ability to work from home against income level and age respectively. This demonstrates which sectors of the sample have the ability to work from home, for example, it seems that as a share of the survey sample, younger people are more likely to be able to work from home, at least some of the time.

The following presents the results from the multinomial logistic regression modelling of ability to work from home. The methods for this analysis were presented in Section 4.1.8, and it is used here to understand whether certain groups are more or less likely to work from home. The statistical output tables are included here, as an example of the source of the figures, however, for subsequent multinomial logistic regression modelling the output tables can be found in Appendix C – Statistical Outputs.

Table 4:14 - Propensity model - Ability to work from home

Parameter Estimates							
Are you able to work from home?		B	Std. Error	Wald	df	Sig.	Exp(B)
Not at all	Intercept	1.560	.633	6.077	1	.014	
	Age	-.186	.128	2.126	1	.145	.830
	Income	.150	.090	2.786	1	.095	1.162
Occasionally	Intercept	1.201	.699	2.953	1	.086	
	Age	-.474	.143	11.034	1	.001	.622
	Income	.340	.100	11.636	1	.001	1.405
Once a week	Intercept	-1.760	1.327	1.759	1	.185	
	Age	-.332	.258	1.653	1	.199	.718
	Income	.413	.173	5.740	1	.017	1.512
About half the week	Intercept	.664	1.014	.429	1	.512	
	Age	-.393	.217	3.267	1	.071	.675
	Income	-.064	.172	.139	1	.709	.938
More than half the week	Intercept	-1.716	1.574	1.188	1	.276	
	Age	-.140	.319	.192	1	.661	.870
	Income	.093	.224	.173	1	.677	1.097
a. The reference category is: All the time.							

Chance Accuracy:

$1.25*(0.527^2 + 0.227^2 + 0.029^2 + 0.044^2 + 0.02^2 + 0.153^2) = 44\%$

Classification accuracy 53%

The classification accuracy exceeds the chance accuracy, therefore the model can be deemed to be a good fit. The model has a significant relationship with independent variables ‘Age’ and ‘Income’ with p values of p = 0.013 and p = 0.002 respectively, both <0.05. Table 4:14 shows the outputs of the propensity modelling of ability to work from home. The model was able to differentiate between the reference category ‘All the time’ and the categories ‘Occasionally’ and ‘Once a week’ by income, sig = 0.001 and sig = 0.017, both <0.05. This suggests that for a unit increase in income, the likelihood of being able to work from home occasionally increases by 41% (calculated by (1.405-1)*100%, from Table 4:14) and for once a week increases by 51% (calculated by (1.512-1)*100%, from Table 4:14). The model was also able to differentiate between ‘All the time’ and ‘Occasionally’ by age, sig = 0.001, <0.05. This suggests that for a unit increase in age, the likelihood of being able to work from home occasionally decreases by 38% (calculated by (0.622-1)*100%, from Table 4:14).

These results suggest that the likelihood of being able to work from home is statistically significantly associated with levels of income and age of the respondents. The results suggest that as income increases, the likelihood of being able to work from home also increases. The model also suggests that younger people are more likely to be able to work from home occasionally than older respondents. This result is contradictory to those found by Agrasi et al, who found that older people were more likely to engage in telecommuting (Asgari et al., 2014), however, this study took place in North America, therefore the results may not be applicable to a UK context.

The trend of younger people working from home could be the result of a generational difference, younger people may be more inclined to work from home if they have the opportunity, or it could be a result of the kind of jobs that younger people are employed in, or a combination of both. If it is a generational shift, then as these people age then home working could become more widely practiced. It is difficult to suggest which of these the main influencing factor is, and this would make an interesting area for further work in order to design effective policy measures to increase levels of home working. Policy options are discussed further in section 4.4 and Chapter 8- and Chapter 9-.

Future scenarios will examine the role of home working in a future with greater ubiquity of ICT and increased flexibility of working in order to understand the impacts of this on transport demand, capacity and emissions. These future scenarios are developed in Chapter 6- and modelled in Chapter 7-.

4.2.3 Departure Times

This section presents results about participant's willingness and ability to shift their current journey departure times. This is interesting in examining transport excess capacity because if people are able to shift their journeys out of peak hours then congestion could be reduced and more efficient use of the temporal capacity in the system could be delivered. Peak spreading, encouraging journeys to take place in less congested times have been explored in the literature, modelling studies have been undertaken to understand the impacts this would have (Yushimito et al., 2014) and much research has been done looking at variable road pricing or public transport ticketing to encourage these behaviours (Cain et al., 2001). This section analyses the survey data relating to this area.

Table 4:15 shows responses to the question of whether participants are able to adjust their regular departure time at present and how much by. 44% of respondents are not able to adjust their departure time at all at present and Table 4:16 shows some of the reasons why people are unable to adjust their departure times. Most people who are able to adjust their departure times are able to adjust up to an hour either side of their current departure time, though some respondents were able to adjust their departure time further.

Table 4:15 - Ability to adjust journey departure times

Are you able to adjust your regular departure time at present?		Number of Participants
Not at all		220
Earlier	Up to 30min	25
	30 minutes - 1 hour	15
	1 hour - 1h30mins	5
	1h30mins - 2 hours	2
	More than 2 hours	9
Later	Up to 30min	20
	30 minutes - 1 hour	13
	1 hour - 1h30mins	7
	1h30mins - 2 hours	4
	More than 2 hours	9

As Table 4:16 shows, most participants were unable to adjust their departure time due to the constraints of working hours, although other reasons were also given.

Table 4:16 - If unable to adjust departure time, why not?

If you are unable to adjust your departure time at present, why not?	Number of Participants
Working hours	150 (30%)
School hours or other caring responsibilities	34 (7%)
Public transport timing	11 (2%)
Other, please state	25 (5%)

Table 4:17 shows the willingness of participants to adjust their departure times. Many participants suggest that they are willing to adjust their departure times, with most people willing to shift within 30 minutes of their current departure time, but others willing to adjust up to 2 hours earlier or later than their present departure time. This has potential for peak shifting and adjusting the pressure during rush hours.

Table 4:17 - Willingness to adjust journey departure times

Are you willing to adjust your regular departure time at present?		**Number of Participants**
Earlier	Not at all	37
	Up to 30min	133
	30 minutes - 1 hour	57
	1 hour - 1h30mins	11
	1h30mins - 2 hours	14
	More than 2 hours	29
Later	Not at all	60
	Up to 30min	87
	30 minutes - 1 hour	68
	1 hour - 1h30mins	14
	1h30mins - 2 hours	17
	More than 2 hours	35

The results from the responses to these questions suggest that over half of participants are able to adjust their journey departure times from their current departure time, see Table 4:15, with the highest shares being able to adjust their departure time up to 30 minutes earlier or later than their current departure time. For those who were unable to adjust their journey departure time, the most commonly selected reason for this is working hours, with 30% of respondents suggesting this was the main constraint. Flexible working conditions is an important consideration in the future demand on the transport system, and the future scenarios developed in Chapter 6- explore the impact that increased working flexibility could have on transport. In particular, increased flexibility could encourage people to travel outside peak hours and reduce the pressure of peak loading, therefore making more effective use of the transport capacity. Work in Chapter 6- and Chapter 7- will examine the implications of this and any potential CO_2 emissions reductions that could be delivered through this.

Of those who were able to adjust their journey departure time, many were willing to do so, see Table 4:17 and most of these were willing to adjust their departure time up to an hour either earlier or later then they currently departed. This demonstrates significant potential for reducing pressure on the transport system at peak hours, as many people are both able and willing to adjust their journey departure times.

The following discusses the results for the propensity modelling of ability and willingness to adjust departure times and the statistical output tables can be found in Appendix C. For the **ability** to adjust departure times **earlier**, the classification accuracy achieved by the model exceeds the calculated chance accuracy, therefore the model can be deemed to be a good fit. The model has a signification relationship with the variable ‘Age’ with a p value of p = 0.025, <0.05. The model was able to differentiate between the reference category ‘More than 2 hours’ and ‘Up to 30 mins’ by the independent variable ‘Age’, sig = 0.011, <0.05. This suggests that for a unit increase in age, the likelihood of being willing to adjust your departure time by up to 30 minutes earlier decreases by 33% (calculated by (0.669-1)*100%)

For the propensity modelling of **ability** to adjust departure times **later**, the calculated chance accuracy of 28% is exceeded by the classification accuracy, therefore the model can be deemed a good fit. The model has a significant relationship with the independent variables ethnicity and age, p values of p = 0.031 and p = 0.000046 respectively, both <0.05. The model was able to differentiate between the category ‘More than 2 hours’ and the categories, ‘up to 30 mins’ and ’30 minutes – 1 hour’ using the independent variable ‘Age’, sig = 0.00 and sig = 0.012 respectively, both <0.05. This suggests that for a unit increase in age, the ability to adjust the journey time by up to 30 minutes later decreases by 56% and the ability to adjust the departure time by between 30 minutes and an hour decreases by 40% (calculated by (0.443-1)*100% and (0.605-1)*100%).

For the propensity modelling of **willingness** to adjust journey departure times **earlier**, the classification accuracy achieved by the model is 49%, which exceeds the calculated chance accuracy of 38%, therefore the model can be deemed a good fit. The model has a significant relationship with the independent variables age, gender and ethnicity, with p values of p = 0.036 for age, p = 0.062 for gender and p = 0.013 for ethnicity, all <0.05. The model is able to differentiate between the reference category of 'More than 2 hours' and categories 'Not at all' and 'Up to 30 minutes' by gender, sig = 0.020 and sig = 0.043. The model is able to differentiate between the reference category and the category 'Not at all' by age, sig = 0.030, suggesting that for a unit increase in age, the willingness to not adjust the journey time at all decreases by 41% (calculated by (0.595-1)*100%). The model is able to differentiate between the reference and willingness to adjust the journey departure time by 1 hour – 1 hour 30 minutes earlier by ethnicity, sig = 0.037.

For the propensity modelling of **willingness** to adjust journey departure times **later**, the model classification accuracy exceeds the calculated chance accuracy, therefore the model can be deemed a good fit. The model has a significant relationship with the independent variable age with a p value of p = 0.007, <0.05. the model is able to differentiate between the reference category 'More than 2 hours' and the categories 'Not at all', sig = 0.002, 'Up to 30 minutes', sig = 0.025, and '1 hour to 1 hour 30 minutes', sig = 0.047, by the independent variable age. This suggests that for a unit increase in age, the willingness to adjust journey departure time up to 30 minutes later decreases by 35% and the willingness to adjust departure time between 1 hour and 1 hour 30 minutes later decreases by 44% (calculated by (0.649-1)*100% and (0.565-1)*100%).

These results suggest that different relationships are identified for the ability to adjust journey departure times earlier and later and the willingness to do so too. For the ability to adjust the journey departure time earlier, a relationship was identified with age, suggesting that as age increases the ability to adjust journey departure times earlier than the current time decreases. The results suggest a significant relationship with the independent variables age and ethnicity and the ability to adjust departure times later than at present. Particularly noticeable are the results that suggest that younger people are more likely to be able to adjust their journey departure times later. This suggests that perhaps, policy interventions to encourage people to adjust their departure times both earlier and later than present and in order to travel outside peak hours could be targeted at younger people, who appear to have greater ability to adjust, in order to maximise the impact. This reflects the findings in the Section 4.2.2

which showed that younger people were more likely to be able to work from home, and this increased flexibility could be associated with fewer caring commitments before having a family.

When it comes to willingness to adjust journey departure times, the modelling suggests that there is a statistically significant relationship between age, gender and ethnicity and the willingness to adjust departure times earlier. For adjusting departure times later, there is a negative link between age and willingness to adjust departure times later. These results follow those for the ability to adjust departure times, suggesting that younger people are more willing to adjust their departure times both earlier and later than their present departure times, and policy could be targeted at this section of the population to encourage journey departure time adjustment.

This section has explored the ability and willingness of survey participants to adjust their current departure times, and this is developed into policy recommendations in Section 4.4 and used to inform the pathways developed in Chapter 6- and the modelling in Chapter 7-. The following section examines car sharing in the survey data.

4.2.4 Car Sharing

The literature review provided background on car sharing, see Section 2.3.2. Car sharing is used here to refer to what has been called ride or trip sharing elsewhere in the literature, which is the sharing of the spare seats within a vehicle, with a person who has a common, or similar destination. This terminology is chosen because the term car sharing is more commonly understood in the UK, thus was used in the survey.

Table 4:18 shows the responses when participants were asked whether they would be willing to car share. 53% of people were willing to car share in some capacity, with 19% of participants willing to carry other passengers, 20% willing to be passengers in someone else’s car and 14% willing to do both. This demonstrates that a significant proportion of people are open to the idea of car sharing. This could have potential to facilitate more effective use of capacity and this is discussed further in subsequent sections.

Table 4:18 - Willingness to car share

Question	Number of Participants
I would be willing to carry other people in my car	96 (19%)
I would be willing to be a passenger in someone else`s car	98 (20%)
Both of the above	69 (14%)
Not willing to car share	181 (36%)
Don't Know	57 (11%)

Table 4:19 shows what options were selected as factors when participants were asked what would make them willing to car share. The most commonly selected response was sharing with a colleague or friend, and this suggests that trust and safety may be concerns for people in their willingness to car share.

Table 4:19 - Factors that would make you willing to car share

Factor	Number of Participants
Sharing with a colleague or friend	354 (71%)
A car sharing scheme at work	148 (30%)
An online car sharing forum	42 (8%)
Flexible working hours	96 (19%)
Other	81 (16%)

Some other reasons given for being willing or not willing to car share outside of the factors above included:

- trip chaining
- safety
- saving money through car sharing
- preferring other modes including walking, cycling and bus
- lack of flexibility when car sharing
- needing to have the car for work, site visits or field work etc.

These responses are developed in the scenarios in Chapter 6- when exploring scenarios for future urban transport capacity use.

Table 4:20 and Table 4:21 show the willingness to car share compared to current main mode and age respectively. This is particularly interesting in the context of the propensity modelling that follows.

Table 4:20 - Willingness to car share against current main mode

Current Main Mode	Willingness to car share					Total
	Willing to carry passengers in my car	Willing to be a passenger in someone else's car	Both	Not willing to car share	Don't know	
Car (driver)	57	12	38	92	24	223
Car (passenger)	3	13	7	15	8	46
Bus	17	41	11	27	14	110
Train	4	15	3	12	3	37
Metro	2	0	1	5	3	11
Cycle	2	1	2	2	0	7
Walk	3	5	1	5	2	16
Total	88	87	63	158	54	450

Table 4:21 - Willingness to car share against age

Age	Willingness to car share					Total
	Willing to carry passengers in my car	Willing to be a passenger in someone else's car	Both	Not willing to car share	Don't know	
18 to 24	10	18	15	12	8	63
25 to 29	11	9	6	9	3	38
30 to 44	32	31	18	57	14	152
45 to 59	33	30	22	72	24	181
60 to 65	10	10	8	31	8	67
Total	96	98	69	181	57	501

The survey results identify that more than half of participants were willing to car share. While there are still many constraints that prevent 36% of people being willing to car share and leave 11% unsure, the fact that 53% of participants were willing to either carry other passengers in their own car, be a passenger in someone else’s car or both shows a promising opportunity to increase occupancy rates in vehicles and reduce EC_{mw}. Table 4:20 and Table 4:21 show the willingness to car share against current main mode and age respectively. These are useful in identifying the sectors of the survey sample that are most willing to car share, e.g. car drivers and younger people. This can lead to targeted policy development and maximise effectiveness of any policy intervention. Policy recommendations are further developed in Section 4.4.

The following discusses the results from the propensity modelling of willingness to car share. As the classification accuracy exceeds the chance accuracy the model can be deemed a good fit. The model has a significant relationship with independent variables ‘Current Main Mode’ and ‘Age’, with p values of $p = 0.000046$ and $p = 0.002$ respectively, both <0.05. The model was able to differentiate between the category ‘Don’t Know’ and ‘Willing to be a passenger in someone else’s car’, by the independent variable ‘Current Main Mode’, sig = 0.048, < 0.05. The model was also able to differentiate between ‘Don’t Know’ and ‘Both of the above’, by the variable ‘Age’, sig = 0.038, <0.05. This suggests that for a unit increase in age, the likelihood of being willing to both be a passenger in someone else’s car and carry passengers in your own car decreases by 29% (calculated by (0.710 - 1)* 100%).

The multinomial logistic regression modelling undertaken to examine willingness to car share shows that there is a significant relationship with the independent variables age and current main mode and the willingness to car share. Particularly interesting is the relationship between age and the likelihood to be willing to both carry passengers in your own vehicle and willingness to be a passenger in someone else’s car, suggesting that younger people are more likely to be willing to do both types of car sharing. This relationship between car sharing and age is identified elsewhere in the literature, with a study by the AA suggesting that 18-24 year olds are most likely to share once a week and 25-35 year olds are most likely to give or receive a lift every day (The AA, 2010).

Factors identified as preventing people from being willing to car share can be seen in Table 4:19. These are similar to those found elsewhere in the literature (Furuhata et al., 2013, The AA, 2010) and can be interesting for exploring policy interventions. For example, one of the key factors selected as something that would make participants more willing to car share would be sharing with colleagues or friends. This overcomes some of the concerns around security, and identifies that car sharing approaches through workplace travel plans could facilitate the practice amongst colleagues.

This section has explored the survey findings around car sharing and suggested what some of the barriers are to the practice, as well as identifying the groups most willing to car share. This insight is used to explore policy measures, presented in Section 4.4, in the development of pathways for future urban capacity use in Chapter 6- and discussed with stakeholders through the interviews which are presented in Chapter 8-.

4.3 Calculating emissions associated with current capacity use

The following section develops the calculation of the emissions associated with the excess capacity. Estimates of emissions associated with EC_{mw} are made based on the survey results for GM and then scaled up to look at the wider impacts of making enhanced use of EC_{mw} for the rest of England to demonstrate the magnitude of potential emission reductions. The conclusions and policy recommendations follow this section.

4.3.1 Emission Factors

Table 4:22 shows the breakdown of the vehicles in the UK car fleet by the fuel type (petrol / diesel) and the Vehicle Excise Duty (VED) band. Alternatively fuelled vehicles have not been included in this table as they currently represent such a small portion of the UK vehicle fleet at present. This shows that the most common vehicles are petrol cars in band G of the VED, which has an average emission of 158 gCO_2/km.

At present, the average emissions from a car in the UK vehicle fleet is 157 gCO_2/km (SMMT, 2015). This is useful for calculating the emissions associated with EC_{mw} and EC_c and some of the values for this are found below. Table 4:23 shows fuel consumed by different sectors of transport activity in the different areas of GM, which is useful in understanding the share of emissions that are associated with personal and commercial activity. Table 4:24 shows the emissions from different classes of roads within GM. Together, these provide a clear understanding of the origins of transport emissions in the region and will be used to quantify the CO_2 emissions associated with EC_{mw}.

Table 4:22 - Breakdown of component vehicles in UK car fleet (SMMT, 2015)

VED	Average CO_2 (g/km)	Petrol		Diesel	
		Vehicles	% Total Vehicles	Vehicles	% Total Vehicles
A	80	243,844	1.1%	319,924	1.5%
B	106	505,862	2.3%	609,120	2.8%
C	116	828,351	3.8%	1,394,454	6.3%
D	126	1,220,484	5.6%	854,966	3.9%
E	136	2,034,169	9.3%	1,376,707	6.3%
F	146	1,791,769	8.2%	1,032,015	4.7%
G	158	2,212,310	10.1%	1,684,463	7.7%
H	170	1,049,799	4.8%	476,492	2.2%
I	180	857,367	3.9%	359,505	1.6%
J	193	702,443	3.2%	479,081	2.2%
K	213	536,305	2.4%	380,463	1.7%
L	240	270,919	1.2%	276,546	1.3%
M	280	290,731	1.3%	193,964	0.9%
Totals:		12,544,353	57%	9,437,700	43%

Table 4:23 - Fuel consumption from Road Transport in Greater Manchester in 2013 (Department of Energy and Climate Change, 2015)

Area	Personal				Freight			Totals		
	Buses	Diesel Cars	Petrol Cars	Motorcycles	HGV	Diesel LGV	Petrol LGV	Personal	Freight	Total
Bolton	5,053	30,698	42,535	422	17,250	16,436	718	78,709	34,404	113,114
Bury	3,721	26,076	33,129	297	24,092	15,288	633	63,223	40,013	103,236
Manchester	10,555	41,916	58,437	544	18,719	19,813	884	111,452	39,416	150,868
Oldham	3,455	15,373	21,908	200	7,807	8,506	379	40,936	16,692	57,628
Rochdale	3,585	24,283	30,895	278	31,973	14,872	617	59,041	47,461	106,503
Salford	4,620	34,204	43,633	399	35,359	18,943	792	82,855	55,094	137,949
Tameside	2,851	17,309	23,140	236	10,690	9,960	427	43,536	21,077	64,613
Trafford	3,646	23,701	32,467	298	12,026	11,704	515	60,112	24,245	84,358
Wigan	5,063	28,008	38,321	407	24,575	16,244	698	71,799	41,517	113,316
Total GM	42,549	241,568	324,466	3,082	182,492	131,765	5,663	611,665	319,920	931,585

(In Litres of fuel (diesel/petrol) for individual modes, in Tonnes of oil equivalent for Totals)

Table 4:24 - Emissions from Road Transport in Greater Manchester ($kTCO_2$) 2012 (Department of Energy and Climate Change, 2014)

Second Tier Authority	I. Road Transport (A roads)	J. Road Transport (Motorways)	K. Road Transport (Minor roads)	Total Road
Bolton	152.0	117.9	182.1	452.0
Bury	81.4	207.3	117.2	405.9
Manchester	213.6	138.9	253.4	605.9
Oldham	98.0	42.5	89.0	229.6
Rochdale	99.3	248.1	93.5	440.9
Salford	150.5	267.1	124.1	541.8
Stockport	138.1	109.0	159.5	406.6
Tameside	83.0	88.9	88.0	259.8
Trafford	93.9	90.7	151.2	335.8
Wigan	157.7	147.4	148.8	453.9
GM Total				**4,132.2**

Emissions for an average occupancy rate for GM of 1.39 persons (Table 4:5), based on the survey data and an average car emitting 157 gCO_2/km, are equivalent to 113 gCO_2/passenger km. If occupancy could be increased to 4, the comfort case available space, this would decrease to 39 gCO_2/passenger km.

For buses, the average emission from a diesel bus is 496 gCO_2/km travelled in urban conditions (Department for Transport, 2014). Given the national average occupancy of 10 and the London occupancy of 19, the CO_2 emissions per passenger km travelled are 50 gCO_2 and 26 gCO_2 respectively. Given the higher occupancy rates reported in the survey, with an average of 40 passengers, this would fall further still to 12 gCO_2/passenger km. However, given the fact that these numbers are reported, and do not take into account services that may be running empty at one or both ends of the route, therefore it is sensible to halve this occupancy rate, to 20, which gives emissions of 25 gCO_2/passenger km. This number is closer to what is seen for London. In the comfort case, it is suggested that there are, on average, 59 seats available on a double decker bus, though this number should be halved for the same reasons given above. If an average occupancy of 27.5 could be achieved, this would reduce emissions to 18 gCO_2/passenger km.

Total emissions from road transport for Greater Manchester in 2012 were 4132 $kTCO_2$ (Department of Energy and Climate Change, 2014). 2012 is the most recent year for which this data is available. Based on fuel consumed by the component parts of road transport in GM (Department of Energy and Climate Change, 2015) 66% of these emissions are associated with personal transport and 34% with freight transport (see Table 4:23). The focus of this research is on personal road transport, which has associated emissions of 2727 $kTCO_2$ in GM, see Table 4:23 and Table 4:24.

Based on the values in Table 4:9 for average EC_{mw}, we can suggest that in the comfort case 56% of these emissions are associated with excess capacity and in the extreme case 62%. This equates to 1527 $kTCO_2$ in the comfort case and 1691 $kTCO_2$ in the extreme case. Based on the average car emitting 157 gCO_2/km (SMMT, 2015) and travelling around 12,640km a year in the UK (Department for Transport, 2011a), the average car emits 1.9 TCO_2 a year. This means that the emissions associated with EC_{mw} are equivalent to around 800,000 average cars a year for the comfort case, which represents a large volume of emissions.

Bla Bla Car, an online service for advertising and selling spare seats in vehicles, achieve an average occupancy of 2.8 persons per vehicle for journeys registered through their site (Bla Bla Car, 2014). If this could be achieved as an average occupancy, then EC_{mw} falls to 34% and 45% for the comfort and extreme cases respectively. This assumes that the mode share remains at the national average level and bus occupancy is at the level given for London (19) which is likely to be closer to that in urban areas than the local bus value (10) as the local bus value will include many low occupancy rural routes. This is a large reduction in excess capacity from the 56% found in the comfort case for GM and demonstrates that car sharing could deliver a substantial benefit in increasing the efficiency of the transport system. Minett and Pearce (2011) calculated the impact that increasing casual carpooling (defined in Chapter 2-Section 2.3.2) in San Francisco could have on fuel use, to explore the potential for the practice to manage transport demand in case of oil price rises. While the study focused on fuel use and the practice of casual carpooling, the magnitude of the potential fuel conservation identified is high, at 5.3-11 KT oil equivalent per year (ibid.). This supports the findings from the survey that the potential of decreasing excess capacity in transport could have beneficial implications for sustainability.

The survey data showed that 53% of people were willing to car share in some way and 47% were not or were unsure. If we assume that the 53% who are willing to car share could achieve the occupancy of the average Bla Bla Car trip at 2.8 persons, and the remaining 47% have an average occupancy of 1.4 persons per car, then the average car occupancy that would be delivered would be 2.1 persons. Assuming mode share remains the same, this would see EC_{mw} at 45% and 54% in the comfort and extreme cases respectively. This could deliver a reduction in the emissions associated with EC_{mw} in GM of around 300 $kTCO_2$. It should be noted, however, that the occupancy rate of 1.4 persons per car, does not account for the levels of car sharing at present, some of this occupancy rate may be due to people already car sharing, and this could result in some double counting of people willing to car share. The exact levels of car sharing at present are not known but an AA study of its members found that 1 in 5 people were car sharing some of the time (The AA, 2010), more details on this study can be found in Section 2.3.2.

4.3.2 Impact of enhanced use of urban transport excess capacity in England

This section takes the calculations of EC_{mw} and emissions from the previous section and explores what the potential emission reductions might be if this were scaled up. This is based on the assumption that GM represents an archetypal urban area in the UK, with a typical mixture of motorways, A roads and local roads. Also, the match between the survey data collected and the NTS that was suggested in Sections 4.1.5 and 4.2.1 support the assumption that the data collected in the present study should be applicable to other urban areas. Therefore this has been tested for the urban areas designated as 'metropolitan', built up, areas within England (DfT, 2011b), see for Section 1.5 for more details on the different definitions of urban areas. While there are differences between the cities, such as the size, population density and presence of mass transit systems, the metropolitan areas in England all suffer from peak congestion and a dominance of the private car as the main mode choice. Table 4:25 shows the CO_2 emissions from personal transport in the 6 metropolitan areas in England. This excludes London because it is not an archetypal urban area in the UK (Department of Energy and Climate Change, 2014). These areas account for about 11.5m people, just over 20% of the English population based on the 2011 census (Office of National Statistics, 2014b). These are also the areas covered by the 'Urban Transport Group', with the exception of London, who suggest that there are more similarities than differences between these metropolitan areas (Urban Transport Group, 2016).

Table 4:25 shows that the CO_2 emissions associated with the metropolitan areas is 12 $MTCO_2$, which is equivalent to about 12% of total transport CO_2 emissions and 18% of personal transport CO_2 emission in England. The earlier results suggested that in a comfort case, 56% of emissions are associated with excess capacity, which is just over 6.5 $MTCO_2$ for the metropolitan areas. Based on the car sharing analysis above, we can suggest that EC_{mw} could be reduced by around 10%, assuming that the average load factor would increase to 2.1 persons per car and traffic levels would reduce accordingly. This could deliver an emission reduction of 1.2 $MTCO_2$ a year across the metropolitan areas.

Table 4:25 - Transport emissions of English metropolitan areas 2012 (Department of Energy and Climate Change, 2014)

Personal Transport Emissions $kTCO_2$	
Greater Manchester	2,727
Merseyside	1,237
South Yorkshire	1,670
Tyne and Wear	1,105
West Midlands	2,611
West Yorkshire	2,549
Total	**11,899**

Brand et al (2012a) examined a number of scenarios for low carbon transport using the UK Transport Carbon Model. The scenarios included increasing fuel duty (FD1), speed enforcement (SPE1), accelerated electric vehicle take up

(EV1) and a combined scenario (PP1), which were compared to the reference case. The emission reductions delivered by the scenarios over the period 2010 to 2020 were varied, with the highest emission reductions seen in the PP1 scenario at 5% below the reference case, saving 57 $MTCO_2$ over this period (Brand et al., 2012a). The FD1 scenario increases the cost of driving by 7% in 2020, delivering an emission reduction of 5% from car travel, while the SPE1 decreases emissions by 2.3% in 2020 (Brand et al., 2012a).

This provides an example of how the enhanced use of EC_{mw} compares to other emission reductions approaches that have been modelled and explored elsewhere in the literature, and shows how the emission reductions that might be delivered could contribute to emission reduction targets. This discussion is expanded upon in Chapter 7- where scenarios for enhanced use of capacity, and associated emissions, are modelled.

The policy levers that would be required to make more effective use of EC_{mw} would be based around behavioural nudge policies, providing information for car drivers about the potential benefits of increasing occupancy, and this could be coupled with infrastructure measures to lock in the benefits, such as high occupancy vehicle (HOV) lanes. Chapter 2- Section 2.3.2 presented a range of options for influencing travel behaviour, including smarter choices policy approaches. These all represent options for making more effective use of EC_{mw} and Section 4.4 provides more detail on policy options along with drawing conclusions of the work in this chapter.

4.4 Chapter summary and conclusions

The following section draws together and summarises the findings from this chapter and makes some policy recommendations based on the analysis. This chapter has presented the results from the behavioural study undertaken in GM. This chapter has focused on the data relating to current travel behaviour and capacity use and explored the CO_2 emissions that are associated with this. Drawing on the framework presented in Chapter 3- and the literature from Chapter 2- this work has analysed and interpreted the data from the survey and established some of the trends emerging in the data about travel behaviour and capacity use in GM.

4.4.1 Chapter key findings

Some of the key findings from this chapter include:

- The survey results in the present study suggest that a large share of people are willing to car share (53%), with younger people being more willing to car share, and this has the potential to deliver enhanced use of excess capacity in urban transport.
- EC_{mw} in GM is an average of 56% in the comfort case and 62% in the extreme case. In the comfort case, this is associated with around 1527 $kTCO_2$ a year in GM, and when this is scaled up to metropolitan areas in England, EC_{mw} is associated with 6.6 $MTCO_2$. This is a large volume of emissions and making more effective use of EC_{mw} could reduce this.
- Younger people appear to have more flexibility in their travel patterns; they demonstrate the greatest willingness and ability to adjust their departure times, and they are likely to be able to work from home.
- Trips with the journey purpose ‘work’ have the highest EC_{mw} associated with them (57% in the comfort case and 62% in the extreme case), whereas trips with the journey purpose ‘education’ have the lowest (38% in the comfort case and 48% in the extreme case).

These key findings are used in the scenario development in Chapter 6- along with the results presented in Chapter 5- about future travel behaviour.

4.4.2 Policy recommendations

Some policy recommendations are now made, reflecting on the key findings above:

- Car sharing represents a significant opportunity for transport planners to reduce emissions, therefore developing platforms and information campaigns to raise awareness of this could encourage the practice. These could be focussed on targeting younger people as they demonstrate a greater willingness to engage in car sharing. Infrastructure improvements such as HOV lanes can also help to facilitate car sharing.
- In addition to being more willing to car share, younger people demonstrate increased flexibility in travel behaviour. Policy interventions, such as smarter choices campaigns to encourage home working, and

measures to encourage departure time shifting, could be targeted specifically at younger people in order to maximise the benefits.

- As trips related to work travel have the highest excess capacity, workplace travel plans could be used to encourage more efficient use of this capacity. This could be by encouraging modal shifting or providing car sharing platforms for employees. Workplace travel plans can be encouraged through policy measures that require them as part of the planning process. More information on workplace travel plans can be found in Sections 2.3.2 and 2.6.
- In addition to workplace travel plans, school travel plans can help to encourage changes in behaviour for journeys related to education. While education trips had the lowest excess capacity, there could be further potential to reduce EC_{mw}, particularly as education trips are often within constrained areas. Sections 2.3.2 and 2.6 provide more information on school travel plans.

A number of these policy recommendations focus on providing additional information to transport users in order to influence behaviour. It should be recognised that transport decisions are often not made rationally, and information does not always lead to a rational change in behaviour (Waygood et al., 2012). Section 2.3.2 discusses this further.

The subsequent chapter will present and analyse the survey data relating to future travel behaviour and capacity use. This is then developed into the scenarios for how excess capacity might be used to reduce emissions in the future transport system in Chapter 6-. Chapter 8- takes the policy recommendations and discusses them with stakeholders, to understand their applicability and usefulness for achieving transport goals.

Chapter 5- Future travel behaviour and capacity use

This chapter explores outputs from the survey that relate to future travel behaviour. This analysis responds to research questions 3 and 4, looking at how use of excess capacity could be facilitated and how this could be incorporated into pathways for sustainable transport systems. This analysis builds on Chapter 4- which examined the survey data relating to current travel behaviour.

The chapter begins by exploring the questions around future mode choice and propensity modelling is undertaken to understand the likelihood of mode shifting. This is followed by an exploration of survey participants' perceptions of their ability to adjust their journey departure times in the future and propensity modelling of this is also presented. The propensity modelling seeks to ascertain whether there are differences in behaviour, such as willingness to adjust departure times or likelihood of mode shifting, between different demographic groups. More detail on this approach can be found in Section 4.1.8. Then an analysis of the factors that might influence participant's future travel behaviour is presented, including propensity modelling and factor analysis. Factor analysis is used in the present research to explore whether there are groups of survey participants who exhibit similar behaviours, more detail is provided in the subsequent section and the results are presented in Section 5.5. This is followed by conclusions, key findings and policy recommendations in Section 5.6.

5.1 Approaches to statistical analysis the survey data

This section provides an overview of the statistical approaches used to conduct the analysis of the survey data in the present study. The multinomial logistic regression modelling approach was explained in the previous chapter, see Section 4.1.8, thus will not be repeated here. A detailed description of the factor analysis technique used in this chapter is provided.

Factor analysis is undertaken to explore patterns emerging in the data about what might influence future travel behaviour and to try and understand whether there are cohorts of individuals with the sample, and thus the population, whose travel behaviour might be influenced by different sets of factors. This is done through an exploratory factor analysis approach (Bryman and Cramer, 2012) using the statistical software SPSS, as follows.

"*We start with an m by m correlation matrix. The underlying model is*

$$X_i = a_{i1}F_1 + a_{i2}F_2 + a_{ir}F_r + a_iU_i$$

[Equation 5:1]

Where U is a unique factor plus a random error. The factors are standardised and uncorrelated so the variance of variable 1 equals

$$1 = a_{i1}^2 + a_{i2}^2 + a_r^2 + a_i^2 = h_i^2 + a_i^2$$

[Equation 5:2]

Where h_i^2 is the communality of variable i, variance is based on the common factor space." (de Gruijter and Van Der Kamp, 2007, p.127), *X* represents the matrix, *F* are the factors after correlation and *a* are constants. The variances are then replaced by the estimated communalities through the factor analysis (ibid). Factors that emerge with an eigenvalue higher than 1 are accepted (Pallant, 2010). The factors are then rotated, using the varimax procedure to conduct an orthogonal rotation, in order to produce a rotated component matrix, with factors which are unrelated to each other (Bryman and Cramer, 2012).

The Kaiser-Meyer-Olkin (KMO) value is generated by the factor analysis procedure in SPSS and measures the sampling adequacy, a KMO value greater than 0.6 is suggested as the minimum value for a good analysis (Pallant, 2010, Tabachnick and Fidell, 2007). The KMO values for the analysis conducted in this work are presented with the component matrices in Appendix C – Statistical Outputs. In addition, Bartlett's test of sphericity must also be significant for a good analysis (Pallant, 2010).

Tabachnick and Fidell (2007) suggest that correlations must exceed 0.3 (Pallant, 2010), however, in this work, correlations above 0.6 have been accepted, this can be seen in the results in Section 5.5. This sets a higher threshold of association than the minimum requirement, in order to ensure that the correlations are sufficiently robust and to differentiate between cohorts.

The factor analysis is used to explore the data around influences on future behaviour and the results are presented and discussed in Section 5.5. The technique is useful for exploring groups of people with similar behaviours that may emerge from the present survey data and understanding the potential for targetted policy levers for the use of EC_{mw} and other options for sustainable transport. Segmentation based approaches, such as factor analysis, have been used elsewhere in the transport literature to explore groups who exhibit similar travel related behaviour (see for example Anable, 2005, Hunecke et al., 2010). The analysis in the present reasearch contributes to this literature, applying the techniques to the examination of excess capacity use in transport. The results of the factor analysis also inform the development of the socio-techncial scenarios that are presented in Chapter 6-. The most interesting and useful results from the factor analysis are presented and discussed in Section 5.5, with additional statistical outputs in Appendix C – Statistical Outputs.

This section has provided the methodology for the statistical analysis used to generate the results that follow and gives the rationale for the techniques selected in the present research. The results from the survey are now presented analysed and discussed.

5.2 Anticipated future mode choice

This section explores how survey participants responded to questions about their anticipated future mode. Mode choice has a direct influence on how urban transport capacity is used, and by exploring the results of these questions, in the context of the analysis of current mode choices and capacity presented in Section 4.2.1, suggestions can be made about potential future capacity use.

Table 5:1 shows what participants suggest will be their main mode in the future. The car remains dominant however public transport makes up 28% of the mode share, with bus the largest of these. Fewer people selected car passenger than were identified as using this mode presently, this may be because people aspire to be car drivers in the future, however, indications about car sharing in Section 4.2.4 make promising suggestions for future load factors of private vehicles. It is clear that car remains the dominant mode, with 53% choosing car driver and 4% choosing car passenger, a slight decrease from a mode share of 62% in the current survey data (see Section 4.2.1). The next largest mode share is bus, which makes up 17%, a decrease from 23% in the current survey data.

Table 5:1 – Future main mode choice

In the future how do you think you will travel for most of your day-to-day journeys?	Number of Participants
Car (driver)	267 (53%)
Car (passenger)	22 (4%)
Bus	87 (17%)
Train	26 (5%)
Metro	29 (6%)
Cycle	13 (3%)
Walk	39 (8%)
Other	18 (4%)

Table 5:2 shows the share of survey respondents who have the same or different main mode in the future as their current main mode. It shows that over half of respondents perceive that their future mode will be different to their current main mode.

Table 5:2 - Is the future main mode the same as the current main mode

Is future mode the same as current mode?	Frequency
Yes	234 (47%)
No	267 (53%)

53% of respondents chose a different main mode for the future than their current main mode, which suggests there is a large degree of potential movement amongst respondents around which mode they use, and this could be useful in designing policy interventions, such as smarter choices programmes. Box 2:1 showed groups of factors which influence travel behaviour (Zhou, 2012) and it is clear that mode specific factors are a clear influence. Cost, comfort, safety etc. are key to leveraging modal shifting, and these could be targeted in order to influence the 53% of people who may change their main mode in the future, and to ensure that these choices become more sustainable. It is also essential that accurate information is provided to individuals in order to ensure that informed decisions can be made about mode choice and modal shifting, based on reported, rather than perceived, metrics about public transport (Van Exel and Rietveld, 2009). Hoogma et al (2002), argue that accurate information about the relative costs of modes is also important, however, rational responses to transport information cannot be guaranteed (Waygood et al., 2012). While 53% of people changed their main mode in the future, 47% remained the same. Verplanken et al suggest that mode choice is driven by habit, therefore leveraging modal shift requires adjusting the characteristics of these habits (Cairns et al., 2014, Verplanken et al., 1994). However, practice theory emphasises the importance of meaning associated with mode choice and the cultural context is also important (Cairns et al., 2014). Suggestions are made below about how behaviour change might be leveraged and developed in the policy recommendations in Section 5.6, in the context of Sections 2.3.2 and 2.6.

There is an increase in participants choosing walking and cycling for the future main mode, at 8% and 3% respectively, increasing from 4% for walking and 2% for cycling in the current main mode. This shows positive intentions from the survey participants and is a promising indicator for the sustainability of mode choices in the future. This contradicts suggestions by Richter et al (2011) in their review of smarter choices measures, that walking and cycling should not be prioritised in sustainable transport futures ahead of public transport, as the present survey data identifies more people indicating a perceived modal shift to these active modes than to bus. However, perhaps the lower interest in bus and public transport modes suggests that policy needs to address the public perception of these modes. This could be achieved through information campaigns or workplace travel plans, and addressing the discrepancies between real and perceived journey times and costs may help to encourage modal shifting. This has been discussed elsewhere, see Sections 4.1 and 4.4 and is discussed in the interviews with stakeholders, the results of which are presented in Chapter 8-.

As suggested above, there is a noticeable decrease in the number of people who perceive that car passenger would be their main mode in the future, decreasing from 10% observed in the current survey data to just 4% in the future. This could be due to younger people aspiring to future car ownership which has been delayed by the prohibitive costs of owning, running and insuring a car (Goodwin and Van Dender, 2013) and the anticipation of life events that might require a car in the future, discussed further subsequently. Table 5:5 shows the future main mode against age and suggests that younger people perceive car driver as the main mode they will use in the future. The previous chapter demonstrated that a significant proportion of the survey participants were open to the idea of car sharing, however, the decrease in the numbers who choose car passenger as their main mode could have a negative impact on the rates of potential car sharing, especially if we see large numbers of people who are willing to car share as a driver, but less so as a passenger in someone else's car.

The following tables show future main mode choice against a number of independent variables from the survey data. They are interesting in the context of the propensity modelling of future mode choice which follows as they demonstrate which sections of the survey participants are indicating a shift in mode choice. Table 5:3 shows the future main mode choice selected by survey participants against their current main mode. It demonstrates what was shown in Table 5:2 that there is quite a lot of change between current main mode and the future perceived main mode. Particularly apparent are the increases in the numbers of current bus users who shift to car drivers and the larger number of people who select metro as their future main mode than is seen in the current main mode, increasing from 11 persons to 29 in the future. This could be associated with proposed Metrolink expansion in GM (Transport for Greater Manchester, 2016).

Table 5:3 - Future mode choice by current main mode

Current Main Mode	In the future how do you think you will travel for most of your day-to-day journeys?								Total
	Car, driver	Car, pass.	Bus	Train	Metro	Cycle	Walk	Other	
Car, driver	176	6	10	4	10	3	8	6	223
Car, pass.	21	6	6	1	4	0	7	1	46
Bus	37	2	54	8	3	1	1	4	110
Train	13	0	5	12	2	1	2	2	37
Metro	1	0	0	0	8	0	1	1	11
Cycle	0	0	1	0	1	5	0	0	7
Walk	5	0	4	0	0	1	6	0	16
Total	253	14	80	25	28	11	25	14	450

Table 5:4 shows future main mode by household income:

Table 5:4 - Future mode choice by household income

What is your gross household income before tax and other deductions?	In the future how do you think you will travel for most of your day-to-day journeys?								Total
	Car, driver	Car, pass.	Bus	Train	Metro	Cycle	Walk	Other	
Less than £10,000	25	2	14	1	1	2	5	1	51
£10,000 - £19,999	51	5	19	6	3	3	8	3	98
£20,000 - £29,999	51	7	26	6	4	3	10	3	110
£30,000 - £49,999	79	2	16	6	11	3	7	4	128
£50,000 - £99,999	26	2	0	2	5	2	2	4	43
£100,000 or more	3	0	1	0	1	0	0	0	5
Prefer not to answer	32	4	11	5	4	0	7	3	66
Total	267	22	87	26	29	13	39	18	501

Table 5:5 shows future main mode against age group:

Table 5:5 - Future main mode against age group

Which of the following age groups are you in?	In the future how do you think you will travel for most of your day-to-day journeys?								Total
	Car, driver	Car, pass.	Bus	Train	Metro	Cycle	Walk	Other	
18 to 24	40	2	10	3	2	2	3	1	63
25 to 29	20	1	7	5	3	0	1	1	38
30 to 44	78	7	22	9	13	6	15	2	152
45 to 59	101	9	31	4	8	5	14	9	181
60 to 65	28	3	17	5	3	0	6	5	67
Total	267	22	87	26	29	13	39	18	501

Table 5:4 shows the future main mode choice by income group and demonstrates that across income groups at least 50% of respondents are choosing car as the main mode in the future. Lower income groups see more respondents selecting bus as the main mode, and higher income groups have more respondents choosing train and metro for the main mode choice in the future. Buses represent the lower cost public transport mode than rail and metro, and these more expensive public transport modes can be seen as aspirational. Table 5:5 show the future main mode choice against age, and demonstrates that the car is the dominant mode choice across age groups and active travel trips are most common amongst those aged 30 to 59 years old.

Propensity modelling for future main mode choice: The following presents the results for the propensity modelling of future main mode choice. The rationale and methodology for this can be found in Section 4.1.8 and the output tables can be found in Appendix C. Here, it is used to explore whether there are relationships between independent variables, such as current main mode, age and gender, and the selection choice for the perceived future mode choice. The classification accuracy of the model, 58%, exceeds the calculated chance accuracy, 45%, therefore the model can be deemed a good fit. The model has a significant relationship with the independent variables ‘Current Main Mode’, ‘Age’ and ‘Ethnicity’, all having p values <0.05. The model distinguishes between the reference category ‘other’ and modes ‘Car driver’ and ‘Cycle’ through the independent variable ‘Current Main Mode’, sig = 0.00 and sig = 0.042 respectively. The model distinguishes between the reference category and the mode ‘Bus’ using ethnicity sig = 0.028. The model also distinguishes between the reference category and modes ‘Car driver’ and ‘Bus’ using age, sig = 0.0001 and sig = 0.061 respectively. This suggests that for a unit increase in age, the likelihood of selecting car driver decreases by 65% and for bus it decreases by 45%, (calculated by (0.349-1)*100% and (0.563-1)*100%).

This propensity modelling analyses the selection of future mode choice against the independent variables current mode choice, age and ethnicity. An interesting point to note from this analysis is the decreasing likelihood of selecting car driver as the future mode choice with increasing age. This is likely associated with the giving up of the car in old age and the availability in the UK of a free bus pass for travel between 09.30am and 11.00pm for elderly and disabled people since 2008 (Department for Transport, 2015a), meaning that elderly persons are more likely to make this mode choice. Dargay and Hanly also found that there is a significant reduction in car ownership associated with retirement (Dargay and Hanly, 2007).

Evidence suggests that changes in life circumstances can leverage changes in travel behaviour (Verplanken et al., 2008). This could indicate that some of the changes in mode choice in the future are associated with future life choices, e.g. those younger participants who select car as their main mode choice in the future could be anticipating changes in travel associated with starting a family.

Scheiner and Holz-Rau found that entry into employment was associated with increased driving in their study of travel patterns in Germany and this response is gendered: “*men appear to change their mode use from walking cycling or using PT* [public transport] *exclusively towards driving when commencing a job, women seem to change from walking to driving or using PT*” (Scheiner and Holz-Rau, 2013, p.176).

Incentives present one option for encouraging individuals to change modes, and a study in Denmark found that when participants were given a free one-month public transport pass people switched from their cars, although they tended to switch back after the trial period (Thøgersen and Møller, 2008). Perhaps if incentive schemes could be coupled with changes in life circumstances which can leverage changes in travel behaviour as shown by Verplanken et al (2008) then a more lasting shift in travel patterns could be delivered. Potentially, this could be conducted by providing clear and effective information about travel options, or offering public transport incentives, when employees start a new job, or transport information could become an integral part of searching for a new home through an online platform. Policy options for this are discussed further in Section 5.6 and in Chapter 8-.

In terms of understanding the ability of participants to modal shift, it is necessary to consider the availability of alternatives. This is emphasised by Richter et al (2011) who suggest that perceived or actual availability of suitable alternatives to car use may represent a barrier for people mode shifting and to the success of any smarter choices programme which aims to change transport related behaviour. Where this is a perceived barrier, rather than an actual lack of available alternatives, providing accurate information could help to overcome this, although rational changes in transport behaviour may not necessarily be delivered (Waygood et al., 2012).

This section has drawn together insight on anticipated future mode choice from the survey data and demonstrates demographic trends amongst those who may shift modes. Further discussion is provided with the development of policy recommendations based on this analysis in Section 5.6.

5.3 Perceived future travel amount

The following section explores how survey participants perceived their future travel amount, whether they felt they would travel the same amount or more or less than they presently travel. Figure 5:1 shows the change in travel amount given by participants. They were asked by what percentage more or less they thought they would travel in the future, which is shown on the x axis. On the y axis is the present travel amount, in thousands km/year and it is apparent that those who travel the most are least likely to perceive a significant change in the transport amount in the future. The darker the points, the more people identified their change in travel amount here. It appears in Figure 5:1 that many participants are travelling small amounts, but it should be noted that the average annual distance travelled is around 12,000km (Department for Transport, 2011a), and many of the points on the graph are around or below this. This demonstrates that people perceive a range of future travel amounts when asked this question. It should be noted that the total km travelled per year by survey participants is lower than that reported in the literature, and this is because the data collected looks at normal day-to-day travel, therefore may exclude longer, more unusual, journeys which would increase the amount travelled in the year.

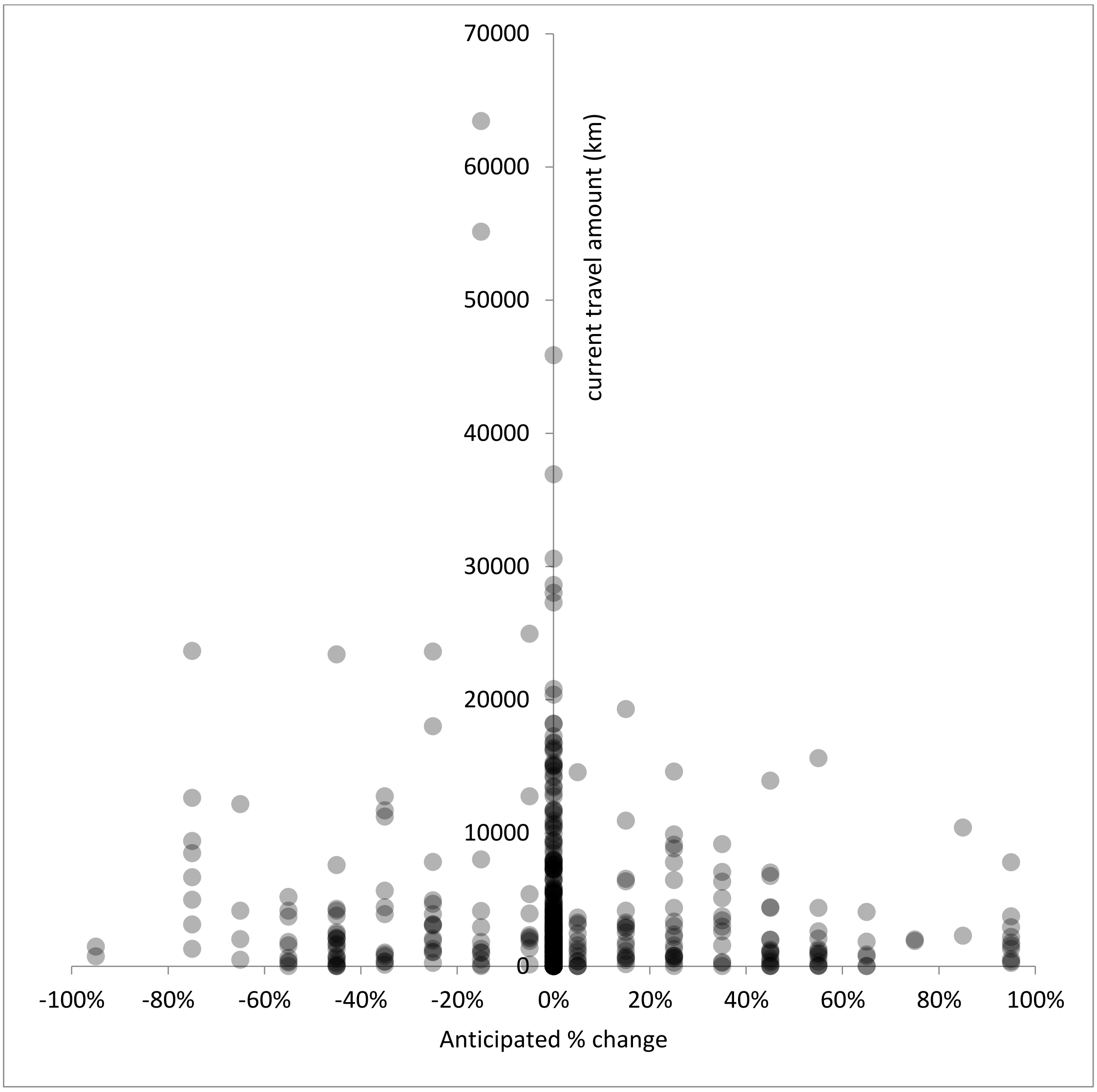

Figure 5:1 - Anticipated change in travel amount in the future

Table 5:6 shows the responses to the question ‘Do you think you will travel more or less in the future?’ by age. It shows that the younger age groups are more likely to select the same or more, whereas older age groups are more likely to select less. This is discussed further in the context of the propensity modelling of future travel amount subsequently.

Table 5:6 - Future travel amount by age

Age	Do you think you will travel more or less in the future?			Total
	Less	The same	More	
18 to 24	3	18	42	63
25 to 29	4	20	14	38
30 to 44	11	111	30	152
45 to 59	43	112	26	181
60 to 65	32	32	3	67
Total	93	293	115	501

Just under 60% of participants felt they would travel the same amount in the future, with 19% saying they would travel less and 23% saying they would travel more. Figure 5:1 demonstrates that those who travel the most seem to feel their travel amount will not change substantially and those who felt their travel would change more or less seem to travel fewer km per year. This may because those travelling larger distances in the year may be making more business and work related trips, which tends to result in higher distances travelled and which may be unlikely to change substantially in the future. This is demonstrated by the significantly higher mileage for company cars than for private vehicles, at over 29,000km compared to 12,000km for private cars, however, recent declines in the number of company cars mean that they now make up just 3% of the car fleet (DfT, 2015). Section 2.3.2 suggested that telecommuting, teleworking and teleconferencing can have a positive impact on travel amounts and journey substitution (Asgari et al., 2014, Lyons, 2009, Nelson et al., 2007). This could help to reduce the large distances being travelled by some participants and potentially target employers to reduce travel amounts of their employees.

The following discusses the results of the propensity modelling for anticipated change in future travel amount, whether participants thought they would travel more, less or the same. The chance accuracy of 53% is less than the classification accuracy achieved by the model, 62%, therefore the model can be deemed a good fit. The model shows a significant relationship with the independent variables ‘Current Main Mode’ and ‘Age’ with p values of $p = 0.031$ and $p = 0.00$ respectively, both <0.05. The model is able to distinguish between the reference category ‘More’ and the category ‘Less’ using the variable ‘Current Main Mode’, sig = 0.015. The model is also able to distinguish between the reference category and the categories ‘Less’ and ‘The Same’ using ‘Age’, sig = 0.00 and sig = 0.00 respectively. This suggests that, for a given increase in age, the chances of selecting ‘Less’ (travel in the future) increases by 341% and the chances of selecting ‘The Same’ (amount of travel in the future) increase by 98% (calculated by (4.409-1)*100% and (1.980-1)*100%.

Table 5:6 shows the anticipated future travel amount by age and demonstrates that younger people more frequently select more travel in the future and older people more frequently select less travel in the future. This is supported by the propensity modelling, which suggested that for a given increase in age, the likelihood of selecting less increases by 341%. It is also interesting to note that the previous section demonstrated that older people are more likely to select bus as the main mode of travel, and the average distance travelled by survey participants by bus is 5km, compared to 10km for car drivers, so this could also be linked to the decline in travel amount with increased age. The propensity modelling also showed that there is a link between current main mode and the anticipation of future travel amount.

It could be suggested that the anticipated increase in travel amount by younger people could be associated with entering work, if people are still in education, and potentially by the impacts of moving house and/or starting a family, which are major life decisions that can increase travel amounts (Verplanken et al., 2008). Chapter 4- highlighted the increased flexibility that younger people have in relation to their travel decisions, and it may be that policy measures to encourage home working could be targeted at younger people in order to suppress some of the perceived increase in future demand for travel. For older persons, the decrease in travel amount may be associated with life changes such as retirement and a decrease in travel. It is anticipated that the UK population will see a doubling of those aged over 65 years old by 2030 (Cracknell, 2010), and while this causes a number of challenges to public services, this could result in a suppression in demand for transport if trends of older people reducing their travel amount are realised.

This section has presented the results from the survey examining perceived future travel amount. This is interesting for exploring policy options to suppress growing demand for transport, and the sustainability impacts of this. Future travel volumes are incorporated into the development and modelling of pathways for capacity use in Chapter 6- and Chapter 7-.

5.4 Perceived future ability to adjust departure times

This section presents the responses from survey participants when they were asked about whether they might be able to adjust their departure times in the future. This relates to the presentation of the results in the previous chapter, Section 4.2.3, which looked at whether participants were willing and able to adjust their departure times at present. Table 5:7 shows the responses, demonstrating whether participants thought they would be able to adjust their departure times earlier or later.

Table 5:7 - Ability to adjust departure times in the future

Do you think you will be able to adjust your regular departure time in the future?		**Number of Participants**
Not at all		162 (32%)
Earlier	Up to 30min	87 (17%)
	30 minutes - 1 hour	46 (9%)
	1 hour - 1h30mins	13 (3%)
	1h30mins - 2 hours	10 (2%)
	More than 2 hours	25 (5%)
Later	Up to 30min	61 (12%)
	30 minutes - 1 hour	55 (11%)
	1 hour - 1h30mins	19 (4%)
	1h30mins - 2 hours	18 (4%)
	More than 2 hours	27 (5%)
Don’t know		155 (31%)

Table 5:7 shows how people perceived adjusting their departure time in the future. One third of participants felt that they wouldn’t be able to adjust their departure time in the future and another third responded ‘Don’t know’. Within

the remaining third, a range of responses arose, as for departure time presently, with more people selecting smaller adjustments of 30 minutes earlier or later than their present departure time but others stretching up to 2 hours either side.

The following discusses the propensity modelling of ability to adjust journey departure time in the future. For the model of ability to adjust departure time earlier, the classification accuracy achieved by the model exceeds the chance accuracy calculated above; therefore the model can be deemed a good fit. The model has a significant relationship with the independent variable gender with a p value of $p = 0.037$, <0.05. The model distinguishes between the reference category ‘More than 2 hours’ and the category ‘Up to 30 minutes’, using the independent variable gender, sig = 0.013.

For ability to adjust journey departure time later, the classification accuracy exceeds the chance accuracy calculated, therefore the model can be deemed a good fit. The model has a significant relationship with the independent variables ‘Current Main Mode’ and ‘Gender’, with p values of $p = 0.016$ and $p = 0.002$ respectively. The model distinguishes between the reference category ‘More than 2 hours’ and the categories ‘Up to 30 minutes’ and ‘1 hour to 1 hour 30 minutes’, using the independent variable gender, sig = 0.026 and sig = 0.003 respectively.

The propensity modelling of ability to adjust departure times identified a relationship between gender and the perceived ability to adjust departure times both earlier and later in the future. Table 5:8 shows the responses to the question ‘Do you think you will be able to adjust your regular departure time in the future?’ split by gender, and identifies that more men than women feel they will be able to adjust their departure times in the future, with 42% of men responding yes and just 32% of women. The survey data also suggests that men are more likely to perceive that they will be able to adjust their journey departure times by a greater amount in the future. The effect of gender on the ability of respondents to adjust their departure time could be associated with additional caring responsibility and trip chaining for women participants. This finding could have interesting implications for the effectiveness of any policy interventions designed to encourage adjustment of journey departure times in order to alleviate peak hour congestion.

Table 5:8 - Ability to adjust departure time in the future by gender

Gender	Do you think you will be able to adjust your regular departure time in the future?			Total
	Yes	No	Don't know	
Male	101	79	59	239
Female	83	83	96	262
Total	184	162	155	501

While many participants were not willing or unsure about adjusting their departure time, if 37% of people were able to adjust their journey departure times either earlier and later, and this resulted in fewer journeys taking place during peak hours, this could deliver benefits for congestion reduction and travel demand management. The implications of journey departure time adjustment will be explored further in the scenarios modelled in subsequent chapters.

This section has examined perceived ability to adjust departure times in the future, and demonstrates some interesting results about this ability, particularly about the gendered nature of the responses. This analysis is used to develop scenarios for future capacity use in Chapter 6- and which are then modelled in Chapter 7-. These are also discussed in the interviews which are presented in Chapter 8-.

5.5 Influences on future travel behaviour

The survey collected data about factors which will influence participant's future travel behaviour in 5 and 15 years' time. Participants were asked to rank the factors, in order of importance, as an influence on their future travel behaviour, they had to rank up to 5 factors though could rank all 12 if they so wished. This section presents the results from these survey questions.

Table 5:9 shows the factors and the frequency with which they were ranked 1, so were the most important factor. 'Family commitments' was frequently ranked as the highest influencing factor in both 5 and 15 years' time.

Table 5:9 - Factor ranked most highly by participants

Factor	Frequency for 5 years	Frequency for 15 years
Family commitments	80	78
Location	69	56
Increased cost of driving	64	69
Reduced cost of public transport	62	55
Distance required to travel	50	51
Congestion	41	35
Mobility / disability	40	69
Ability to work and or shop from home	32	28
Crowding of public transport services	29	23
Flexibility of scheduling	18	17
Environmental concerns	12	16
Other	4	4

Table 5:10 shows the average rank for each of the factors for 5 and 15 years' time, and the fourth column shows the change in rank between these. Those highlighted in blue increased in importance, those in green decreased. Based on average rank, the most important influencing factor in 5 years' time is reduced cost of public transport, followed by increased cost of driving. In 15 years' time, the most influential aspects are increased cost of driving, followed by family commitments.

Table 5:10 - Average rank for factors in 5 and 15 years

Factor	**5 years**	**15 years**	**Change**	**Statistically significant Y/N (95% confidence)**
Increased cost of driving	3.54	3.38	-0.16	N
Reduced cost of public transport	3.49	3.56	0.07	N
Congestion	4.07	4.18	0.11	Y (0.036)
Crowding of public transport services	4.36	4.09	-0.27	N
Environmental concerns	5.31	5.07	-0.24	N
Ability to work and or shop from home	4.55	4.16	-0.39	N
Distance required to travel	3.66	3.47	-0.19	Y (0.009)
Flexibility of scheduling	4.53	4.4	-0.13	Y (0.018)
Family commitments	3.67	3.46	-0.21	Y (0.014)
Mobility / disability	4.51	3.53	-0.98	N
Location	3.66	5.92	2.26	Y (0.006)
Other	6.24	5.7	-0.54	N

The influence which increased its average ranking the most between the 5 and 15 year time periods was 'Mobility/disability', demonstrating an increasing importance of this influence. 'Location' decreased its average ranking noticeably between the 5 and 15 year time periods, suggesting the importance of its influence is declining as people think about the future, this could be associated with the rising importance of other factors such as 'Mobility/Disability'.

'Environmental concerns' as an influence on future travel behaviour was seldom ranked number one and had a low average rank, although this increased slightly between the 5 and 15 years' time. Verplanken et al (2008) suggested that environmental concerns did not have as much influence on travel choices as other factors, such as moving house, so perhaps this is why people do not perceive this as influencing their future travel behaviour, even if they have environmental concerns.

However, as demonstrated by the fifth column of Table 5:10, the results for the difference between average rank for mobility/disability and environmental concerns were not found to be statistically significant. This was tested in SPSS using a Wilcoxon Signed Ranks Test, a nonparametric test used to assess differences between samples which are not expected to be normally distributed. The results which showed statistically significant results for the differences between average rank in 5 and 15 years' time included congestion, distance required to travel, flexibility of scheduling, family commitments and location. This is particularly interesting as some of these influences, such as distance, location and family commitments are influences that change over long time periods, therefore it is interesting to note that the average rank of these factors changed over time.

The following discusses the results of the multinomial logistic regression modelling undertaken on the highest ranked factors for 5 and 15 years' time. For the influences on travel behaviour in 5 years' time, a significant model was generated however, the model was unable to differentiate between the reference case and other factors by the independent variables. The classification accuracy, 22%, exceeds the chance accuracy, calculated at 14%, therefore the model can be deemed a good fit. The model identifies a significant relationship with the independent variables 'Current Main Mode', 'Age' and 'Gender' with p values of $p = 0.009$, $p = 0.00$ and $p = 0.00$ respectively. However, the model was not able to distinguish between the reference category 'Other' and the other factors modelled, using the independent variables.

For the model of the highest ranked factors in 15 years' time, the classification accuracy exceeds the chance accuracy calculated, therefore the model can be deemed a good fit. The model identifies a significant relationship with the independent variables 'Current Main Mode', 'Age' and 'Gender' with p values <0.05 for each. The model is able to distinguish between the reference category 'Other' and all other categories apart from Location, using the independent variable 'Current Main Mode', all with a significance <0.05. The model is also able to distinguish between the reference category and the categories 'Flexibility of scheduling' and 'Mobility', using 'Age', sig = 0.047 and sig = 0.001.

This suggests that for a unit increase in age, the chance of selecting ‘Flexibility of Scheduling’ as the highest ranked item increases by 215% and the chance of selecting ‘Mobility’ increases by 478% (calculated by (3.154-1)*100% and (5.78-1)*100%).

These results suggest that mobility / disability is an influence of growing importance as the participants grow older. This supports findings by Heinen and Chatterjee (2015) which suggested that mobility difficulties have a profound influence on the travel behaviour of older persons. The following section, which explores influences on future travel behaviour through factor analysis, further expands on the role of independent variables, such as age, gender, and mode choice, on influences and the discussion is further developed in this context.

5.5.1 Factor analysis of influences on future travel behaviour

Factor analysis has been undertaken on the influences on future travel behaviour for 5 and 15 years time in order to analyse whether groups of people exhibiting similar influences emerge in the data. The rationale and approach for this techinque was outlined at the start of Section 5.1. Richter et al (2011) suggest that in order for smarter choices programmes to be effective, it is important to understand how different factors influence different groups; the following analysis delivers some insight into this. This also builds on the findings in the preceding sections about influences on future travel behaviours.

The factor analysis for the whole survey sample found a statistically significant result for both sets and a KMO accuracy of 0.914 and 0.885 for 5 and 15 years respectively. Table 5:11 and Table 5:12 show the rotated component matrices for the factor anaysis. The components represent the groups who selected similar influences on their future travel behaviour. The influences highlighted in yellow are the most significant.

Table 5:11 - Rotated Component Matrix for 5 year factors (those highlighted in yellow are the most significant)

	Component	
	1	2
Increased costs of driving	.453	.381
Reduced cost of public transport	.708	-.038
Congestion	.493	.261
Crowding of public transport services	.778	.006
Environmental concerns	.702	.315
Ability to work or shop from home	.638	.257
Distance required to travel	.153	.610
Flexibility of scheduling	.610	.244
Family commitments (parents, children etc.)	.482	.433
Mobility / Disability	.619	.369
Location	.114	.705
Other (please specify)	.096	.531

In the 5 year case, two components are identified. In component 1, the most important influencing factors are reduced cost of public transport, crowding of public transport services, environmental concerns, ability to work or shop from home, flexibility of scheduling and mobility/disability. For component 2, the most important factors are distance required to travel and location.

Table 5:12 - Rotated Component Matrix for 15 year factors (those highlighted in yellow are the most significant)

	Component	
	1	2
Increased costs of driving	.476	.237
Reduced cost of public transport	.696	-.094
Congestion	.578	.259
Crowding of public transport services	.749	-.034
Environmental concerns	.641	.377
Ability to work or shop from home	.430	.457
Distance required to travel	-.002	.666
Flexibility of scheduling	.478	.412
Family commitments (parents, children etc.)	.531	.391
Mobility / Disability	.602	.317
Location	.073	.635
Other (please specify)	.198	.387

In the 15 year case, two components are also identified. In component 1, the most important influencing factors are reduced cost of public transport, crowding of public transport services, environmental concerns and mobility/disability. For component 2, the most important factors are the same as in the 5 year case, which are distance required to travel and location.

From Table 5:11 and Table 5:12, it is possible to suggest that the influences that are significant in component 1 relate specifically to public transport users, and perhaps wider concerns about lifestyle and other external factors such as the environment. These influences could be related to discrepancies between actual and perceived costs and experiences with public transport (Beirão and Sarsfield Cabral, 2007, Van Exel and Rietveld, 2009), suggested earlier in Section 2.3.2, and this could identify a useful area for policy interventions to address.

For component 2 it is possible to suggest that those who fall into this component are concerned about longer term factors, as distance and location which tend to change with major life decisions such as moving house or job, which have been identified as a key influence on travel behaviour (Scheiner and Holz-Rau, 2013, Schwanen et al., 2012).

It is possible to explore the factor analysis within groups such as gender, age and mode choice, in order to look at the extent to which these independent variables affect the components that emerge from the factor analysis. The results for this can be found in Appendix C – Statistical Outputs, and interesting insights from these are discussed here.

For the factor analysis by age group, the outputs of which can be found in Appendix C – Statistical Outputs, no clear trends emerged about changes across age groups and time periods. However, there are a few interesting points to highlight. For the age group 18-24 years old, in the time period 15 years' time, the influences of environmental concerns and those related to public transport emerge together, which suggests that those who are concerned about the environment in this age group may make more sustainable mode choices as a result. In addition, across age groups and time periods, some of the influences repeatedly emerged in the same components, and these are discussed further below.

Gender: When the factor analysis is run for gender, the analysis for 5 years' time was unable to generate a significant model, however, for 15 years' time we can identify differences between the factors that emerge for males and females. Three components emerge for each gender. There are some similarities between the two genders, with cost of public transport appearing for component 1 for females and 2 for males, however there are some clear differences. For females the main influences for component 2 are environmental concerns and flexibility of scheduling, influences which are not significant for any of the components for males. In addition, the main influences for component 1 for males are increased cost of driving and congestion, which are not significant in any of the components for females. It suggests that the influences which related to driving are more important for males, and the wider concerns, such as environment and flexibility, seem to be more important for females. Scheiner and Holz-Rau (2013) found that responses to life events such as starting a family were highly gendered, and this could explain some of the differences in the influences on future travel behaviour between males and females that are apparent in the survey data. Table 5:13 supports this, showing that within the survey participants, females were more likely to rank ‘Family commitments’ as the most important influence on their future travel behaviour and this was even more pronounced in the 15 year time period.

Table 5:13 - Participants selecting 'Family commitments' as the highest influence on future travel behaviour by gender

	Female	Male
5 years’ time	49	31
15 years’ time	53	25

It is interesting to note that Heinen and Chatterjee (2015) found that females have more modal variability, and this could explain why the factors relating to car mode choice (cost of driving and congestion) emerge for males but not for females, as they use a greater variety of modes.

Mode Choice: The factor analysis conducted by mode choice for 5 and 15 years’ time can be found in Appendix C – Statistical Outputs and was conducted for car driver, passenger and bus. Particularly interesting to note is that in the 5 year time frame, for the mode choice car driver, cost of driving and congestion do not emerge as significant in any of the components. This may suggest some level of modal lock in, that the costs of driving are not influences on future travel behaviour, however, congestion does emerge for component 1 in the 15 year time frame. It is also interesting to note that the cost of public transport is an influence for car drivers in component 1 in both 5 and 15 years' time, suggesting that changes to public transport costs may have a greater influence on future travel behaviour of car drivers than changes to the cost of driving. This emphasises the importance of accurate public transport information and the need to address misconceptions and perceptions of public transport that may arise (Beirão and Sarsfield Cabral, 2007, Van Exel and Rietveld, 2009)

For car passengers, in the 5 year time period, component 1 shows that there are influences related to both car travel and public transport, suggesting some level of flexibility in modal choice, and this could identify a cohort who may be able to adjust their modal choice. For bus users, the cost of driving and congestion are factors which emerge for component 3 in 5 years' time and in two separate components for 15 years' time. This suggests, unlike for car drivers, that there is less modal lock in, and that the factors may influence future travel behaviour. This is interesting for policy decisions and considerations of how it might be possible to lock in public transport mode choices could be important for the sustainability of the transport system.

5.5.2 Summary of influences on future travel behaviour

There are some influences that often emerge together within the factor analysis including:

- Distance and location;
- Cost of driving and congestion; and
- Cost of public transport and crowding of public transport.

This suggests that some cohorts of the survey participants are influenced most strongly by the longer term factors, such as moving residential or workplace location, which have been suggested elsewhere as having an important influence on travel behaviour (Dargay and Hanly, 2007, Scheiner and Holz-Rau, 2013). It seems that other groups are more profoundly influenced by factors relating to their mode choice, as the second and third groups that emerge together relate to car and public transport mode choices respectively. This could be interesting for developing policy interventions that focus on these aspects and addressing discrepancies between perceptions of public transport and the relative costs of modes that have been highlighted in the literature (Beirão and Sarsfield Cabral, 2007, Van Exel and Rietveld, 2009). It is also important to note the gendered nature of the influences on future travel behaviour, with ‘Family commitments’ being of greater importance to female participants, and this may be considered in potential policy interventions. These insights about influencing future travel behaviour will also be useful in developing the scenarios in Chapter 6- that will be used to analyse the emissions benefit of making enhanced use of excess urban transport capacity in Chapter 7-.

5.6 Chapter summary and conclusions

This section draws together the insights from this chapter and provides policy suggestions and conclusions.

5.6.1 Future travel behaviour and capacity

While this chapter has not quantified excess capacity and emissions directly, the analysis of future travel behaviour that has been presented informs the scenarios for future transport systems and capacity use, which are developed in Chapter 6-. By exploring people’s future travel amounts and departure times, the scenarios can explore how temporal capacity might be used in a future urban transport system and the impacts this might have on the sustainability of the system and reducing emissions. Looking at the factors that participants perceive as influencing their future travel behaviour allows policy interventions that can facilitate enhanced use of capacity to be informed by behavioural data and insights. The summary section below explains how this will be taken forward into scenario development and quantification of excess capacity and emissions in the subsequent chapters.

5.6.2 Chapter key findings

Some of the key findings about future travel behaviour in this chapter include:

- There is significant potential for modal shifting, with 53% of survey participants identifying a different main mode in the future to their current main mode. Older people are more likely to shift to public transport modes, particularly bus, and younger people aspire to be car drivers.

- This chapter reinforces the finding in Chapter 4- that younger people have greater flexibility in the transport choices, as they are more likely to be able to adjust their future journey departure times. Women are less likely to be able to adjust their departure times in the future, and this could be associated with trip chaining and caring responsibilities.
- Younger people were more likely to suggest that they would travel more in the future, which could be associated with life change points such as entering employment from education and starting a family. Older people, on the other hand, were likely to travel less in the future, associated with retirement and a shift to public transport modes, which is interesting in the context of the UK's aging population.
- In terms of influences on future travel behaviour, the responses are gendered, with males identifying influences specific to a car mode choice more, and females identifying 'Family commitments' and 'Environmental concerns' more heavily. 'Mobility / Disability' increased in importance across participants between the 5 and 15 year time frames, suggesting that it becomes a more important influence further in to the future.

Table 5:14 shows the key trends in the literature and policy that were highlighted in Section 2.7.1 as important for transport capacity and CO_2 emissions and the survey indicators that relate specifically to these from this chapter and Chapter 4-. There are not survey indicators for all of the key trends because some of these relate to high level, system changes, rather than those at the scale of individual travel behaviour.

Table 5:14 - Key trends and survey indicators

Trends in the literature / policy	**Survey indicators**
Vehicle technologies for reducing emissions (Section 2.3)	n/a
Intelligent Transport Systems (Section 2.3.1)	n/a
ICT for homeworking and increased flexibility (Section 2.3.2)	Section 4.2.2, ability to work from home, factor analysis
Modal shifting (Section 2.3.2)	Table 5:2 and factor analysis
Increases in sharing (Sections 2.5 and 2.3.2)	Section 4.2.4, willingness to car share
Devolution and re-regulation (Section 2.6)	n/a

These key findings, and the highlights in Table 5:14, are incorporated into the pathways design in Chapter 6-, which are then modelled in Chapter 7-.

5.6.3 Policy recommendations

The following policy recommendations are presented in the context of the key findings above:

- The analysis presented in this chapter suggests that travel behaviour is influence by key life change points, echoing work elsewhere in the literature. Policy interventions could be targeted at these life change points, such as moving house or starting a new job and could be coupled with incentives for modal shift. For example, employers could offer a free or subsidised public transport ticket for new employees, to couple the incentive with a change in life circumstances.
- Younger people demonstrate increased flexibility in their travel behaviour, therefore policy interventions to encourage, for example, peak spreading, could be specifically targeted at younger people to maximise the impact.
- This chapter, Chapter 4- and the wider literature suggest that there may be gaps between perceptions and reality in relation to costs and experiences of different mode choices. Policy could be designed to

address these perception - reality gaps, through accurate information, in order to encourage modal shifting.

5.6.4 Chapter summary

This chapter explored the data collected through the survey relating to future travel behaviour. This data relates to future mode choice, travel amount, journey departure times and the influences on future travel behaviour. Data was analysed through multinomial logistic regression modelling, factor analysis and the presentation of descriptive statistical outputs. The analysis delivers insight for research questions 3 and 4, looking at how capacity use might be facilitated and the role this will play in the transition to a sustainable transport system. Through delivering greater understanding of people's perceptions of their future travel behaviour, scenarios for sustainable transport can be informed. The discussion places the results in context, develops the analysis further and provides coherence and clarity to the outputs of the survey and statistical testing. The insights emerging will inform the construction of the scenarios in Chapter 6- in particular, the factors that emerge across the data relating to influences on future travel behaviour. The scenarios are then modelled in Chapter 7-. The policy recommendations from this chapter, and the wider thesis, are discussed with stakeholders, and the results of these can be found in Chapter 8-.

Chapter 6- Pathways for future urban transport capacity use

This chapter takes the findings from the survey in Chapter 4- and Chapter 5- as well as wider trends and context from the literature review in Chapter 2- and conceptualises the role that excess capacity may have in future transport systems. The chapter begins by providing some background on how future scenarios have been constructed for transport elsewhere in the literature using different theoretical perspectives. This is then summarised and the aspects that will be used in the construction of pathways for capacity use in the present work are outlined. The pathways are then presented and discussed. The work in this chapter focuses on research question 4, on the ways that the enhanced use of excess capacity could be incorporated into pathways for sustainable urban transport systems, though it will also inform the analysis in Chapter 7- that looks at the carbon benefits of making use of this capacity (research question 3). The policy dynamics that are referred to and developed in this chapter also feed into the discussions of policy recommendations in the interviews that are presented in Chapter 8-.

6.1 Approaches to scenario and pathway construction in transport

Future scenarios have been used in transport research and strategic transport planning by a range of stakeholders, in order to both explore options for the future, assess policy needs and inform decision making (Annema and Jong, 2011). The following section presents some of the theoretical background for construction of scenarios. Table 6:1 presents an overview of the approaches used to explore futures in transport, covering socio-technical transitions, visioning, and forecasting and backcasting approaches. The application of these to the research questions in the present work is discussed subsequently in Section 6.1.1. It should be noted that the terms pathway and scenario are used synonymously in the present research, following Dijk et al (2013).

Table 6:1 - Approaches to exploring transport futures

	Key aspects of the theoretical approach
Socio-technical transitions	A transition is a "*radical systemic innovation*" (Nykvist and Whitmarsh, 2008, p.1373) This perspective emerges from studying systems as made up of co-evolutionary processes (Geels, 2012). Two example approaches: • **Multi-level perspective (MLP)**: conceptualises the system as made up of the landscape, the socio-technical regime, and the niche, where innovation takes place. Each level of the MLP influences the others, see Figure 6:1. This has been applied in transport (Geels, 2002, Geels, 2012, Köhler et al., 2009, Sheller, 2011, Spickermann et al., 2014). The MLP has been criticised for a lack of agency (Geels, 2011, Smith et al., 2005). In addition, the concept of regime resistance was introduced, whereby incumbent actors use power to maintain the status quo of the current socio-technical regime (Geels, 2014) • **Co-evolutionary framework**: looks at the causal interactions in systems between 'Institutions', 'User practices', Business strategies', 'Technologies' and 'Ecosystems', see Figure 6:2. This has not been directly applied in transport, but it has been used to examine sustainability transitions in the energy sector (see, Foxon, 2011, Foxon, 2013)
Visioning	**Visioning**, utopian thinking or foresight methodologies construct futures based on a social constructivist perspective (Fuller and Loogma, 2009, Tight et al., 2011). A vision generally refers to an ideal future that is not necessarily based on something that already exists (van der Helm, 2009) This has been applied to examining futures in transport (see, Tight et al., 2011, Timms et al., 2014)
Forecasting and backcasting	**Forecasting** is based on exploring possible futures, starting from the present day situation. Applied in transport to look at pathways for emission reductions (see, Givoni, 2013, Hickman et al., 2013)

	Backcasting works backwards from the ideal future, say a level of emissions reduction, and constructs a future, or futures, based on meeting this target. Backcasting has been used in transport to look at emission reductions (see, Bristow et al., 2008). Backcasting has been criticised for a lack of attention on how these end goals might be achieved (Nilsson et al., 2011, Olsson et al., 2015).

Figure 6:1 shows the MLP, from Geels (2002) which is referred to and explained in Table 6:1.

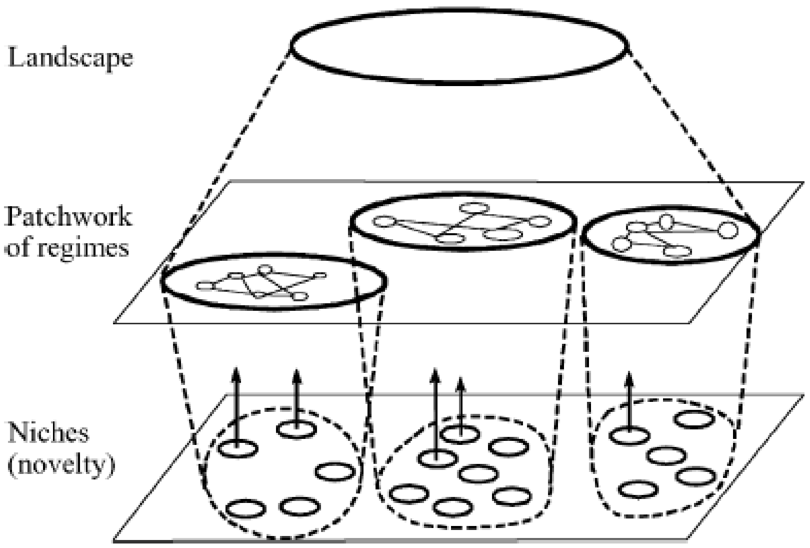

Figure 6:1 - Multiple levels as a nested hierarchy (Geels, 2002)

Figure 6:2 shows the co-evolutionary framework, from Foxon (2011) which is referred to Table 6:1. This framework will be applied in the present work, as explained in Section 6.1.1, which follows.

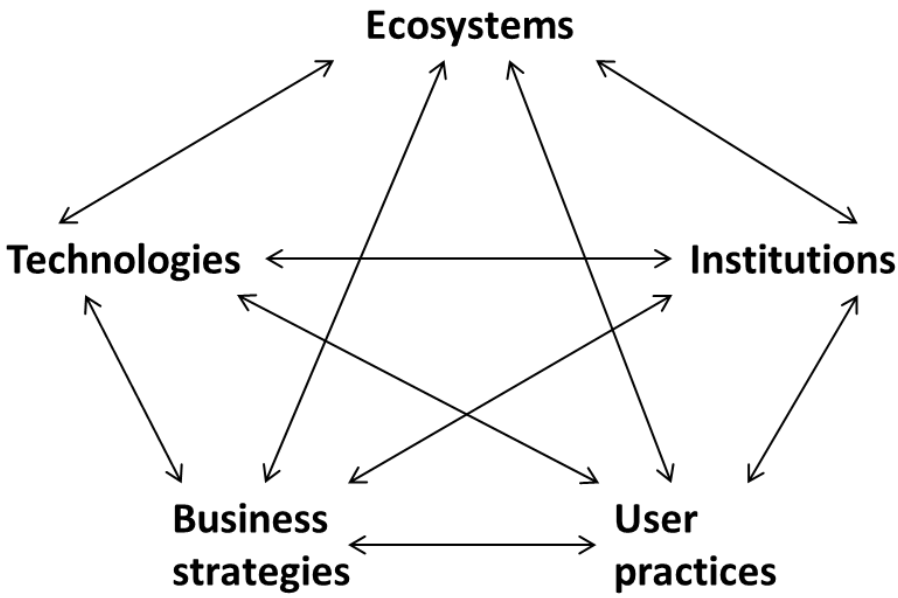

Figure 6:2 - Co-evolutionary framework (after Norgaard, 1994) (Foxon, 2011)

These figures and Table 6:1 provide an overview of theoretical perspectives that have, or could, be applied to exploring transport futures, and offer potential approaches for conceptualising pathways for future enhanced use of excess capacity. Section 6.1.1 outlines how these are applied for the research questions in the present work.

6.1.1 Scenario construction in the present work

Table 6:1 introduced some approaches available for conceptualising the future of transport including socio-technical transitions, visioning and forecasting and backcasting. This section synthesises the overview in Table 6:1 and explains the aspects of the different theoretical approaches used for scenario construction in the present work.

The pathways developed in the present work incorporate aspects of forecasting, in so far as they begin from the present situation. They extrapolate present trends and examine what impacts certain dynamics would have on the sustainability of the urban transport system. The scenarios do not work backwards from an emission reduction target, which would represent a backcasting approach. This follows Perrels' (2008) perspective that it is important to understand the dynamics of the present system before beginning to construct futures. In addition, the use of forecasting recognises the criticism that backcasting approaches can often overlook the policy and societal requirements necessary to achieve targets (Nilsson et al., 2011, Olsson et al., 2015). Policy dynamics are central to the scenarios constructed in the present work, as evidenced throughout Section 6.2.

The visioning approach is not explicitly used in these scenarios, however, as Harvey suggests, in thinking about urban futures, aspects of utopian thinking are often present (Harvey, 2002). There are elements of creative thinking in the construction of scenarios and exploring the dynamics of an urban transport system, which are part of the visioning approach to conceptualising the future.

Socio-technical systems provide much of the theoretical underpinning for this research and socio-technical transitions provide an interesting way of conceptualising future transition pathways. The scenarios that follow are presented using the co-evolutionary framework, looking at the interactions between ecosystems, institutions, user practices, business strategies and technologies to conceptualise how different scenarios for future transport capacity use might emerge. While transition pathways have, conventionally, been used to explore the development of technologies, there are examples of other types of socio-technical transition studies, such as spatial and socio-cultural transitions (Sheller, 2011, Zijlstra and Avelino, 2011). In the present work the socio-technical transitions perspective will be used to explore innovation in technology, behaviour and policy and regulatory environments for a transition to a sustainable transport future. The incorporation of behaviour, in particular reflecting on the analysis of the survey data in Chapter 4 and Chapter 5, helps to address one of the key criticisms of socio-technical transitions, namely the lack of agency in the approaches (Geels, 2011, Smith et al., 2005).

Using the theoretical approaches to pathway construction outlined above, four scenarios are constructed which can be seen in the sections that follow. The narrative of these scenarios is drawn from:

- Survey data in the present research, the results of which are presented in Chapters 4 and 5;
- Key emerging policy trends; and
- The wider academic literature.

These sources are drawn together by the present author, using knowledge and understanding of the transport sector and the policy context. Work in this thesis has been supported by TfGM, hence ongoing conversations with them as a stakeholder organisation has provided additional insight and critique of the pathways. The policy interviews presented in Chapter 8- also provide a critical reflection on some of the dynamics captured in the pathways developed in the subsequent sections. Section 6.2.6 compares the pathways developed in the present work to other socio-technical analyses in the literature, reflecting on their similarities and differences.

This explains how the different possible approaches for examining urban transport futures are drawn together in the subsequent section to develop pathways for enhanced use of urban transport capacity.

6.2 Scenario development for enhanced use of excess capacity in urban transport systems

This section presents the scenarios that have been developed to explore potential urban transport futures and the role of capacity in achieving emission reductions within this system. These scenarios have been developed based on the findings about future travel behaviour in Chapter 5- and using the theoretical frameworks outlined above. Four scenarios are presented, plus a business as usual (BAU) pathway, these are:

- **Scenario 1 A – Shared Automobility** – the car remains the dominant mode choice but enhanced use of capacity is achieved through increased occupancy rates and increasing sharing of vehicles, facilitated by ICT.
- **Scenario 1 B – Intelligent Automobility** – the car again remains the dominant mode, but increased ubiquity of ICT allows more efficient use of transport capacity through innovation such as platooning and autonomous vehicles.
- **Scenario 2 – Public Mobility** – in this scenario public transport mode share increases, through improvements to services and designated infrastructure, which lead to changes in user practices.

- **Scenario 3 – Flexi-mobility** – ubiquitous ICT and changes in user and business practices facilitate increased home working and flexible scheduling allowing people to travel outside peak hours or substitute travel for work or shopping with home based activities.

The time scale on these scenarios is to 2035, which will be modelled using traffic network modelling in Chapter 7-. Due to the time horizon of these pathways, it is assumed that incremental efficiency improvements will be the dominant change in vehicle technology, with some level of market penetration of electric vehicles (EVs), hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs). This assumption takes into account the literature reviewed in Section 2.2.3. The time horizon of 2035 also recognises that these scenarios are not looking over periods of decades that are often deemed necessary for a full system innovation, however, the dynamics of the socio-technical transition that could result in system innovation are conceptualised and discussed. ICT is a key factor in all the scenarios, and this reflects the literature introduced in Section 2.3.1 around intelligent transport systems (ITS) and the influence of increased ubiquity of ICT on transport related behaviour and decisions, as suggested in Section 2.3.2.

Each of the scenarios is now discussed in turn, and they are presented using the co-evolutionary framework introduced in Section 6.1. While this work does not strictly adhere to the theory around the MLP and niche innovations, it is possible to identify possible niches within the pathways that are constructed and these will be highlighted for each pathway. Following the discussion of the scenarios within the co-evolutionary framework, the scenario's causal links are presented using Causal-Loop Diagrams (CLD) drawn using the System Dynamics (SD) software Vensim, for each pathway. These CLDs show the positive (+) and negative (-) causal relationships and feedbacks between the different aspects of the co-evolutionary framework.

6.2.1 Business as Usual

The BAU scenario provides the base case, against which the other scenarios can be compared. Annema and Jong describe BAU scenarios as a scenario which "aims to inform the policy maker of what might happen in the future if the already existing policies continue to be pursued" (Annema and Jong, 2011, p.341). In addition to looking at existing policies, the BAU scenario presented here explores how other factors, such as business strategies and user practices, would influence the future, given extrapolation of existing trends. Figure 6:3 presents the BAU case for the present work structured in the co-evolutionary framework.

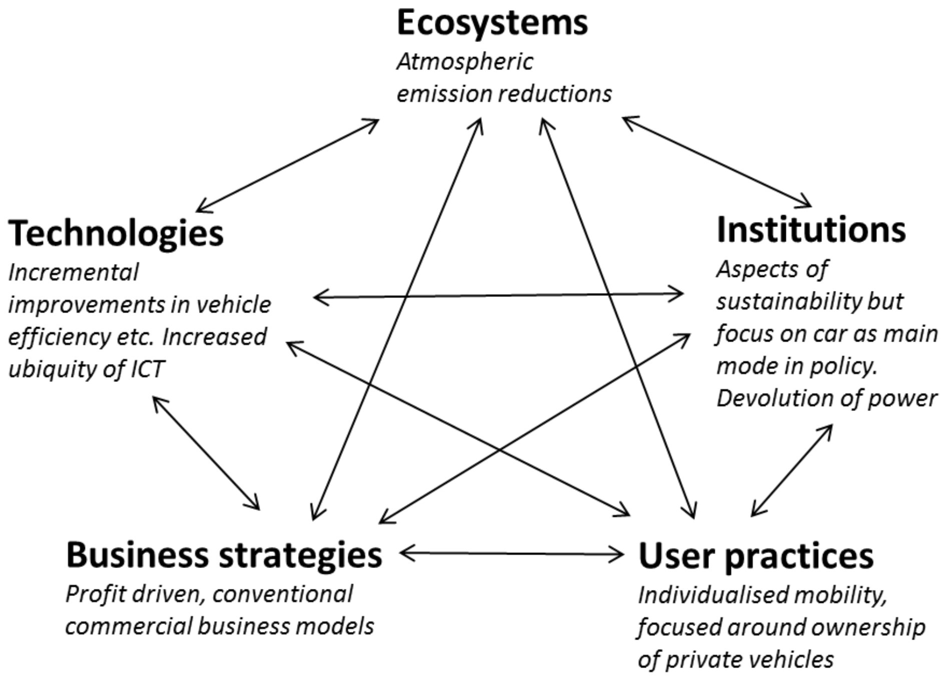

Figure 6:3 - Business as Usual

The main driving forces within each of the aspect of the co-evolutionary framework for the BAU case are highlighted in Figure 6:3. In terms of ecosystems, main driver in all the scenarios is the target of reducing atmospheric emissions, and, while there may be other ecosystem factors in the transport futures, this is the main focus of the research here. In terms of technologies, incremental improvements in vehicle technologies will be driven by the EU emission regulations, introduced in Table 2:1, (European Union, 2015). Increased ubiquity of ICT may also influence user behaviour in relation to transport, the relationships between these factors is explored further subsequently. In terms of institutions, policy is generally driven by central government agendas, but there is an agenda of devolution of powers to local authorities, particularly around transport (see for example, Greater Manchester Combined Authority, 2014, HM Government, 2009). The policy environment around devolution was introduced in the Policy Review section of the Literature

Review, Section 2.6. Sustainability goals are included in policy making, such as the meeting of nationally and internationally set emission reduction targets, but policy is still driven by a road building agenda, thus car remains the dominant mode choice (see, HM Treasury, 2015). Profit driven, commercial strategies remain the dominant model for businesses, including public transport operators, although devolution presents opportunities for re-regulation of bus networks (Raikes et al., 2015), thus different agendas can be set. Individualised mobility remains the dominant user practice, embedding the private car as the main mode choice and occupancy rates remain low.

Figure 6:4 presents some of the causal relationships between factors presented around the co-evolutionary framework, some of which have been implicitly mentioned earlier in this section and will be expanded upon below.

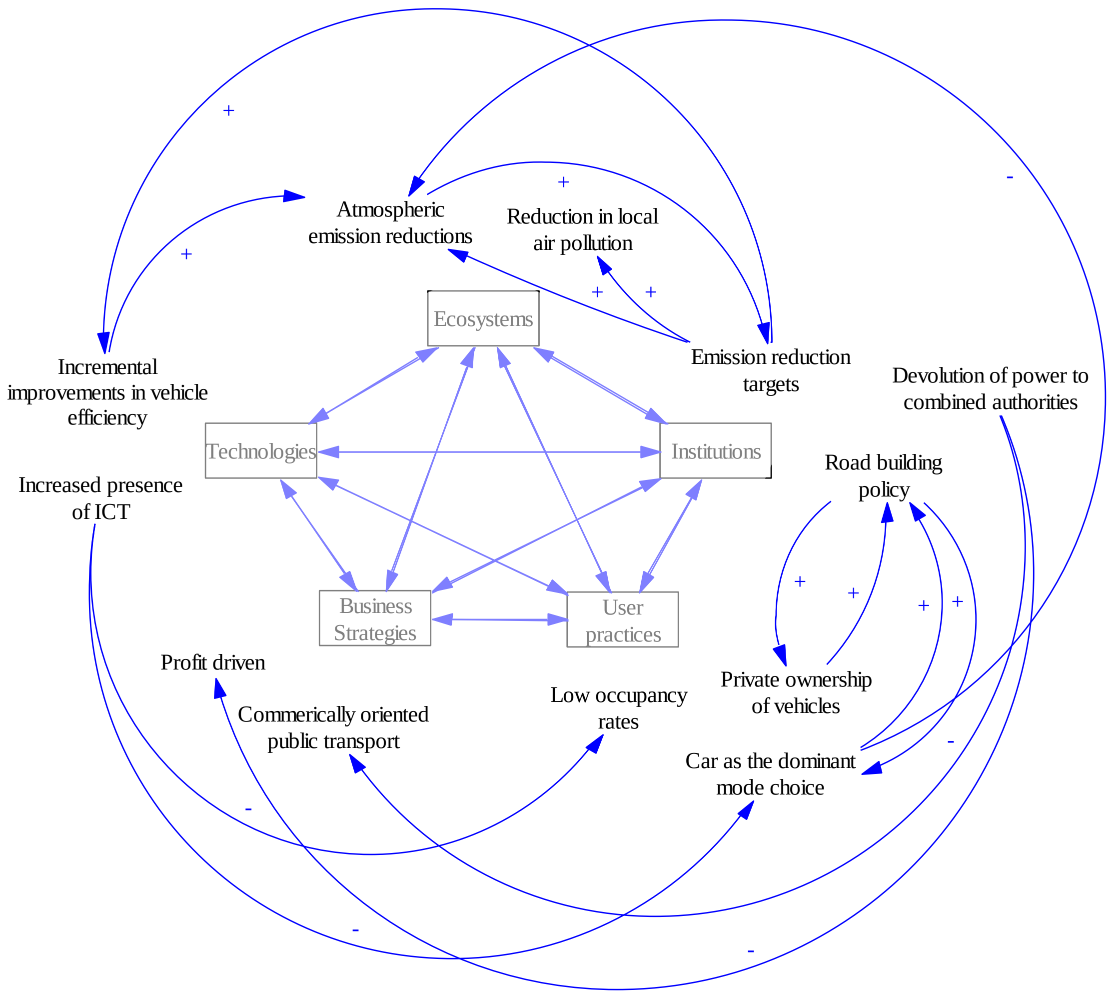

Figure 6:4 – CLD for the BAU scenario

Some of the particularly interesting causal relationships are around atmospheric emission reductions, with emission reduction targets and incremental improvements in vehicles having a positive impact on emission reductions. However, continued dominance of the private car as the main mode choice will arguably negatively impact on any emission reduction targets. Both the dominance of car as the main mode choice and continued private vehicle ownership have a positive feedback relationship with a policy framework that prioritises a road building agenda, as the UK government currently does. Increased availability of ICT could, however, influence user practices, perhaps increasing occupancy rates and allowing improved public transport information, which could challenge the car as the dominant mode choice. Devolution of powers over transport to combined authorities provides the option of bus franchising, as has been delivered in London, where bus operators are required to tender for routes, rather than being driven solely by running the most profitable routes. This consequentially changes the business model and can dramatically improve services, thus the institutional aspect of devolution has a negative impact on commercially oriented business strategies.

This continued reinforcement of the car as the main mode choice entrenches a path dependency into the socio-technical system (Smith and Raven, 2012) and encourages lock-in of the system of automobility. Some of the dynamics and niches introduced in the alternative scenarios represent potential ‘path-breaking’ innovations for a sustainability transition (Smith and Raven, 2012). It is possible to identify aspects of regime resistance in the BAU case, such as the continued dominance of low occupancy, private cars, with individuals and institutions resistance to changes to the socio-technical regime through sustainability innovations (Geels, 2014). As Foxon (2011) suggests, actors within the system benefit from the path-dependent nature of the system and this reinforces lock-in and regime resistance.

The concept of automobility was introduced in Chapter 2-, and this BAU pathway demonstrates many of the features of automobility that are associated with its path-dependency, such as the institutional reinforcement of the dominance of the car (Sheller and Urry, 2000, Walks, 2014). This compliments the conceptualisation of path-dependency within the transition pathways literature and the co-evolutionary framework. Some of the path-breaking innovations that are introduced in the different scenarios that follow are intended to breakdown some of these reinforcing effects and facilitate a transition away from the unsustainable system of automobility that is currently dominant. This is particularly noticeable in the first two scenarios which are built around transformations of the system of automobility. In addition, Macmillen highlights the complexities and non-linear interactions within Urry's system of automobility (Macmillen, 2013, Urry, 2004). The use of the CLDs to illustrate the dynamics in the pathways that follow are useful to demonstrate the non-linear nature of these interactions, as well as the path-dependency of the system.

Figure 6:4 demonstrates some of the interconnections between different aspects in the BAU scenario. It is by no means exhaustive of all of the dynamics at play, but illustrates some of the relationships and highlights the path-dependencies and lock-in within the current urban transport system. This BAU scenario can be compared to the other scenarios that follow to understand how they might change in the future, given a different agenda and dynamics.

6.2.2 Scenario 1 A - Shared Automobility

The first two scenarios are constructed around the assumption that the car will remain the dominant mode choice into the future, but other dynamics may influence how they are used and hence the environmental impact of those vehicles. This reflects the emergence of factors relating to car travel in the factor analysis presented in Chapter 5- which suggested that many participants perceived a continued use, or new uptake, of the car as the main mode choice in the future. These automobility scenarios recognise the path-dependency of the current transport system, and look at how this automobility system could be used differently in order to become more sustainable. The first of these, 'Shared Automobility', examines how an increase in sharing, both in transport and more broadly within the dynamics of the sharing economy, might influence the future urban transport system, and thus how capacity is used. The concepts of sharing and the role this could play in making more effective use of capacity was introduced in Section 2.3.2 of the Literature Review. Figure 6:5 shows the construction of the Shared Automobility scenario in the co-evolutionary framework.

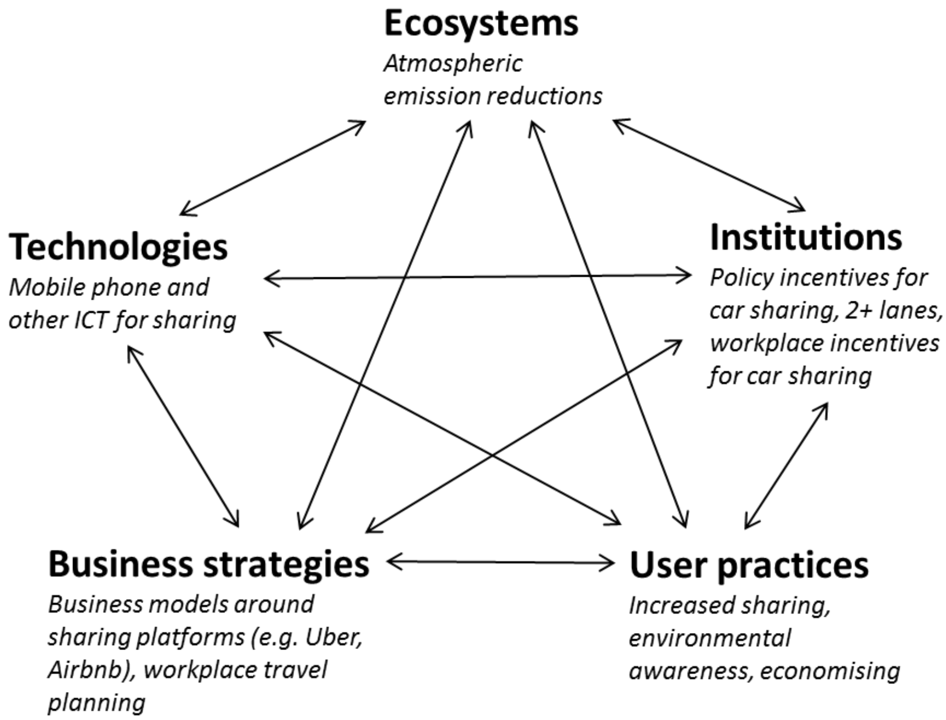

Figure 6:5 - Scenario 1 A – Shared Automobility

In this scenario, the main aspect around ecosystems is the goal of atmospheric emission reductions, as it is for all of the scenarios developed here. In terms of institutions, policy incentives for shared mobility are emerging, encouraging higher occupancy rates and installing infrastructure to support this, such as high occupancy vehicle (HOV) lanes. Technologies, particularly ever increasing ubiquity of ICT, facilitate more effective use of capacity through car sharing and dynamic platforms for demand responsive car sharing emerge. Business strategies facilitate continued growth of sharing economy platforms, like those that can be identified presently, such as Airbnb and Uber, and these encourage more effective use of capacity through shared automobility. (For more on the specifics of these sharing economy platforms, see Section 2.3.2 of the Literature Review.) User practices respond to these external factors and increased use of sharing platforms for transport is adopted. Figure 6:6 shows a CLD for the Shared Automobility scenario and the interconnections and feedbacks that it shows are discussed below.

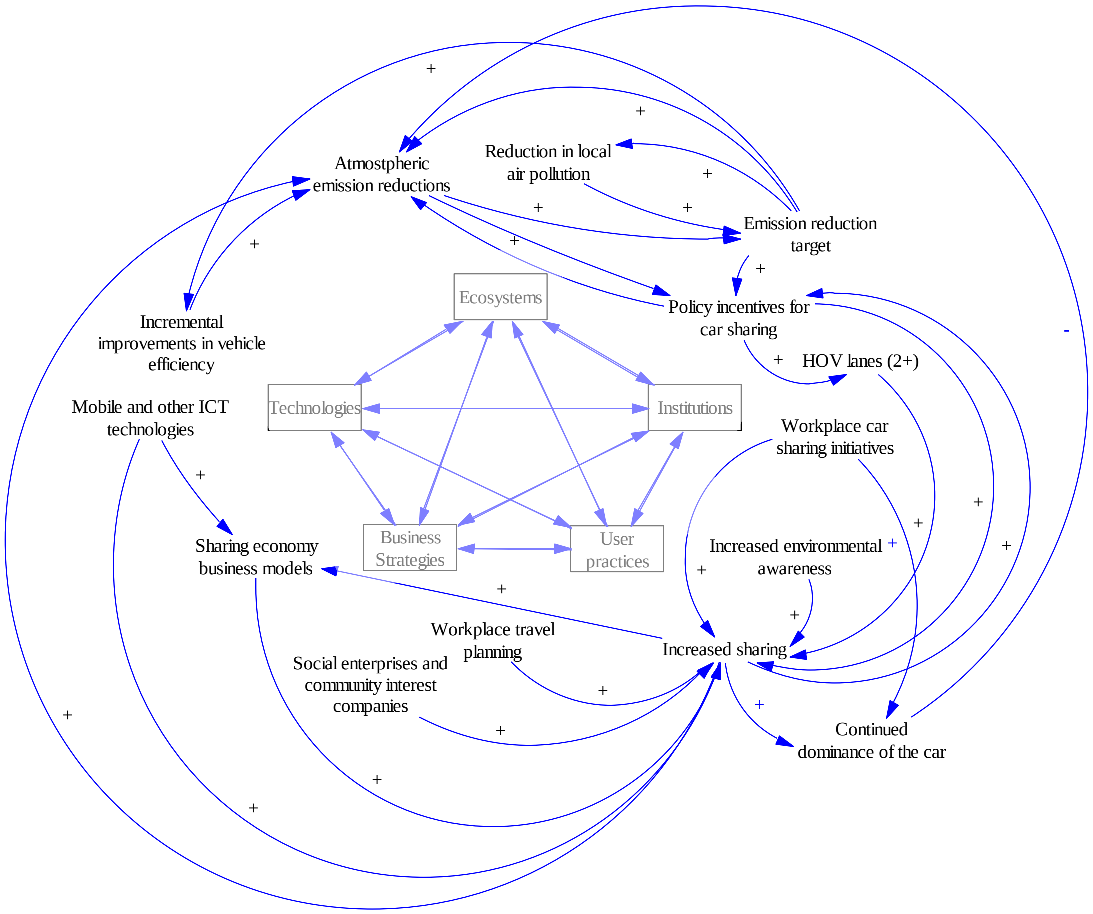

Figure 6:6 - CLD for Shared Automobility

The CLD above demonstrates the relationships between different aspects of the system in the pathway for Shared Automobility. The main driver of change in this scenario is the increase in sharing as a user practice, which has a positive effect on atmospheric emission reductions, and this is facilitated by a range of other system aspects. Increases in the use of transport sharing platforms, particularly for car sharing, will have an internal positive feedback; as more people join and advertise available trips for people to car share, the more availability is in the system, therefore more people can join, and this could have a snowball type effect. Increases in ICT and mobile technologies facilitate improved communication between transport users and can be used by individuals and businesses to facilitate sharing practices. Increased sharing has a positive feedback relationship with policy incentives for sharing and investment in infrastructure to encourage the practice, for example, the more people who are using a HOV lane, the more impetus on policy makers to install such infrastructure, and the presence of such infrastructure will encourage more people to increase their vehicle occupancy through sharing. Therefore, while the car remains the dominant mode choice in this pathway, the vehicles are being used in a more sustainable way, thus there is a positive impact on vehicular emissions. It is, however, important to recognise that rebound effects and induced congestion could mitigate some of these benefits and this is discussed further in Chapter 7-. There is also an additional potential dynamic, not captured in the diagram that could have a rebound type effect. If the increase in sharing reduces the cost of driving, by compensating drivers for carrying additional passengers, then the relative cost of public transport increases, potentially increasing the appeal of car as a mode choice and possibly leading to increases in car vehicle km.

The role of sharing has been examined within a socio-technical framework elsewhere in the literature. Martin (2016) identifies six niche framings relating to the sharing economy, three which reinforce and empower the niche and three which resist and critique it. These include: "*the sharing economy is: (1) an economic opportunity; (2) a more sustainable form of consumption; and (3) a pathway to a decentralised, equitable and sustainable economy… (4) creating unregulated marketplaces; (5) reinforcing the neoliberal paradigm; and (6) an incoherent field of innovation*" (Martin, 2016, p.153). It is possible to identify a number of these framings within the sharing economy innovations for transport, many have criticised car sharing platforms, for example, which remain devoid of formal regulation, which leads to safety concerns among some. However others may argue that it creates a more democratic and sustainable form of transport, and the dominance and influence of such divergent framings remains to be seen.

6.2.3 Scenario 1 B - Intelligent Automobility

This scenario explores how a future might look if car remains the dominant mode choice and ICT has a profound influence on the transport system, and hence on how cars are used. This is reflected in the development of ITS, which was introduced in Section 2.3.2 of the literature review. As for the Shared Automobility scenario, Intelligent Automobility recognises the path-dependency of the current system of automobility and examines potential socio-technical innovation that could impact on the sustainability of this system. Figure 6:5

shows the co-evolutionary framework diagram for this scenario and this is discussed further below.

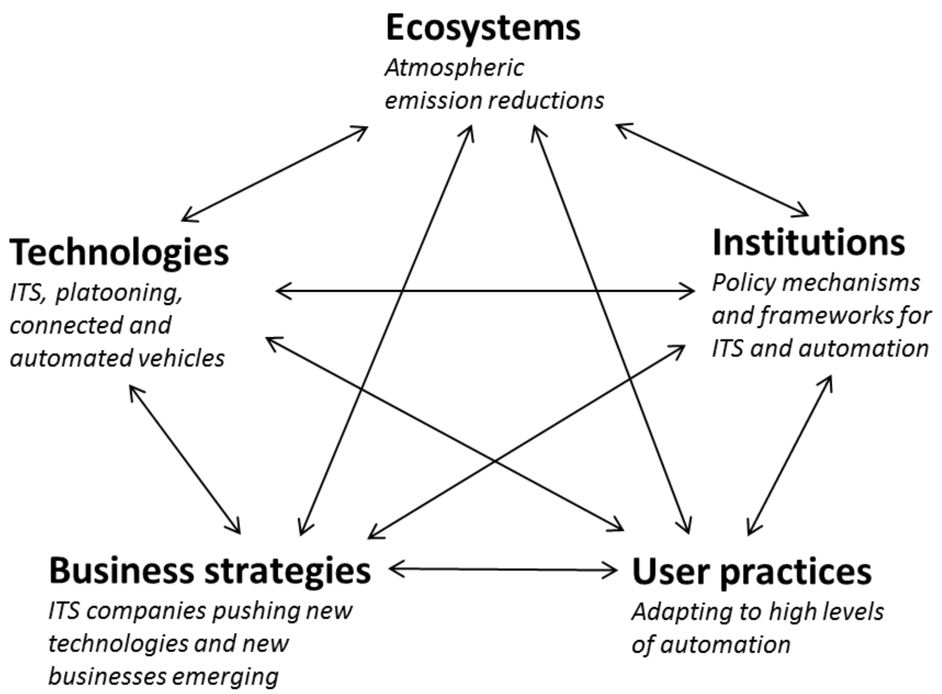

Figure 6:7 - Scenario 1 B – Intelligent Automobility

In terms of ecosystems, reduction of atmospheric emissions remains the dominant goal. Technologies for automation of vehicles develops, along the lines described in Chapter 2- and Wadud et al (2016), increasing levels of automation is apparent in the vehicle fleet and infrastructure facilitating platooning on arterial routes is developed. Policy mechanisms support these developments, including construction of infrastructure and regulation around the safety of automated vehicles. User practices are forced to adapt to high levels of automation as the technologies are more frequently deployed in vehicles. Business strategies see ICT companies developing autonomous vehicles, with tech companies like Google and Apple developing these technologies, ahead of auto-manufacturers (Bolton, 2015), which will influence the future automobile sector. Figure 6:8 develops the CLD for this pathway and demonstrates the interconnections between factors.

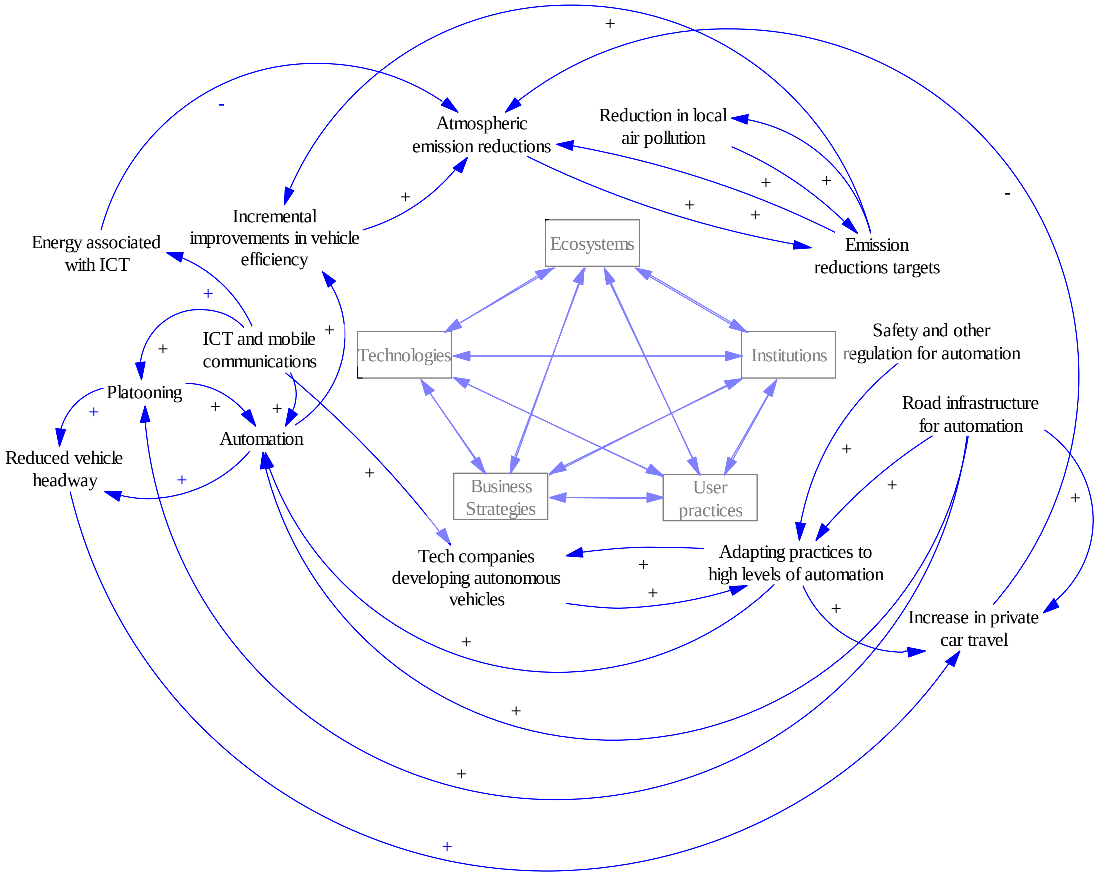

Figure 6:8 - CLD for Intelligent Automobility

This scenario is largely driven by developments in technology, as seen by the ICT, platooning and automation technological developments on the left of the CLD. The business strategies of large tech companies are driving this development, and this is facilitated by ongoing improvements in ICT. Policy measures to support the increasing automation include the implementation of safety and other regulations and support for infrastructure to enable roadways to facilitate automation. One example of policy encouraging the development of such technology is the UK government support for demonstrations of autonomous vehicles in pilot cities (Transport Systems Catapult, 2014). This can be identified as technology emerging within the protected space of the niche (Geels and Kemp, 2011); the demonstration project for autonomous vehicles is testing the technology without exposure to market forces and could stimulate the innovation towards a point where it can influence the wider socio-technical regime. Policy support has a positive impact on both the technology's development and on adapting user practices for higher levels of automation in transport. Automation improves the vehicle efficiency in use, as driving style is smoothed, which may have a positive impact on atmospheric emissions. However, the overall emissions impact of automated and autonomous vehicles is as yet unknown, increased demand for travel through autonomous vehicles may offset any efficiency benefits (Wadud et al., 2016). This is demonstrated in Figure 6:8 by the negative impacts on atmospheric emission reductions through increased private car travel, which is facilitated by technologies for reduced headway and adapting user practices to high levels of automation. Policy interventions to encourage development and uptake of autonomous vehicles tends not to be driven by sustainability goals, hence there is no connection on the causal loop diagram between emission reduction and the policy mechanisms for intelligent automobility. In the USA, policy to encourage autonomous vehicles has been implemented to improve road safety, with President Obama investing $4bn(US) in the industry (Snavely and Bomey, 2016).

6.2.4 Scenario 2 – Public Mobility

This scenario moves beyond automobility and the dominance of the car as the main mode and explores a scenario based around increasing public transport and a mode shift to these modes. Urban transport capacity would be used differently under a scenario of high mode share of public transport, as buses and other public transport modes are higher occupancy vehicles, and roadspace infrastructure investments would be targeted in alternative ways. This scenario which focuses on public transport reflects the emergence of the factors related to public transport in the survey data in Chapter 5- which suggested that cost and crowding of public transport would influence future behaviour, and the pathway explores changes to these factors. Figure 6:9 shows the co-evolutionary framework for Scenario 2 – Public Mobility and this is discussed further below.

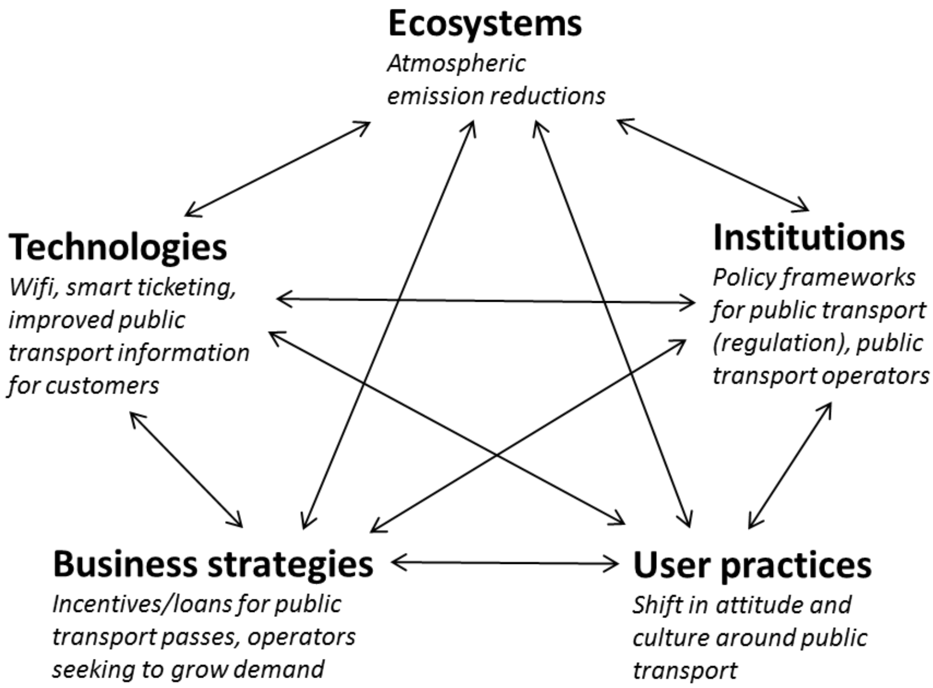

Figure 6:9 - Scenario 2 – Public Mobility

As for the other scenarios, the main ecosystems goal is reduction of atmospheric emissions. In terms of technologies, improvements in ICT allow on-board Wi-Fi and smart ticketing which positively impact passenger experience and improvements to public transport information, including real-time information and increased accessibility. Business strategies will seek to capitalise on these technological improvements and may be driven by policy interventions, possibly through re-regulation of public transport networks, discussed further below. Policy measures will also include the prioritisation of public transport and the reallocation of roadspace for these modes. The improvements mentioned facilitate a shift in attitudes and culture around public transport, and user practices adjust accordingly, leading to a mode shift away from private cars and towards public transport. Figure 6:10 shows the CLD for this scenario and illustrates the interconnections, which are expanded upon below.

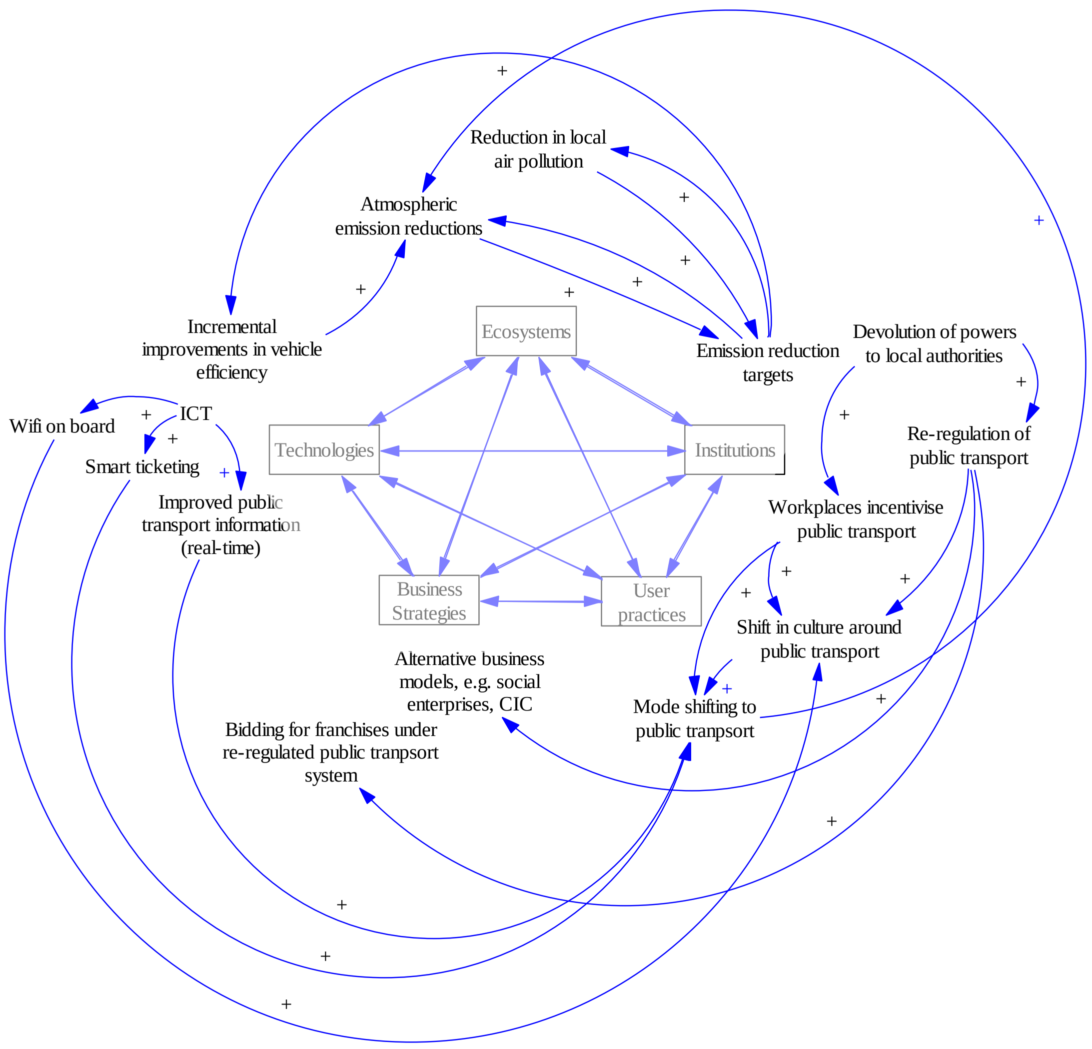

Figure 6:10 - CLD for Public Mobility

The main drivers in this scenario are the prioritisation of public transport at the policy level and the concurrent developments in technology, which facilitate a shift in culture and attitudes around public transport. This could catalyse a modal shift away from the private car and towards public transport modes, which will have positive impacts on levels of atmospheric emissions. As suggested in the BAU scenario, there is an increasing trend in UK policy for devolution of powers to local authorities and this comes with opportunities for re-regulation of public transport. In this scenario, it is assumed that this is a driving force and results in a number of causal interactions. Under a regulated system for public transport, operators are pushed to look beyond profit driven tactics for service delivery and meet tender criteria, which can instil different values and encourage a more customer driven service model. In addition, the way that invitations to tender are structured can encourage smaller operators and alternative business models such as social enterprises to engage in the market. This in turn improves customer experience and encourages modal shifting. The central regulating authority can also improve provision of public transport information, addressing some of the gaps between perception and reality about costs and services of different transport modes. In addition, depending on the authority structure, they may have the powers to invest in infrastructure, such as bus lanes, in order to improve services.

It is possible to suggest that the re-regulation of the bus market in an urban area would represent a sustainability innovation, and a demonstration of the impact of this innovation can be seen within the protected niche environment of Transport for London (TfL). As suggested above, and demonstrated in the CLD in Figure 6:10, the re-regulation of public transport, bought about through devolution of powers to local authorities, could have positive impacts across the transport system. TfL was established under the Greater London Act (Greater London Assembley, 1999) and has powers of control over the public transport network, including regulation of the buses. Over recent years, there has been substantial growth in the numbers of trips made by bus in London, rising from 2.5 million trips a day in 2005/6 to 3.0 million in 2013/14, while numbers of car trips have remained around the same demonstrating a decline in mode share for the car (Transport for London, 2015b). Continued improvement of services in London through the regulated market has leveraged modal shift. Under the regulated system, bus operators compete for tenders to provide services within London (Transport for London, 2015a). Other policy mechanisms exist for this structure to be adopted in other areas, such as the Quality Contract Scheme (QCS) (Butcher, 2011), and devolution city deals (HM Government, 2009), but at present, the regulated bus market in London is unique within the UK. Where regulation has been attempted elsewhere in the UK under the QCS, for example in the North East Combined Authority, is has been met with opposition from regime actors, such as bus operators (Rowney and Straw, 2014). City deals, however, are suggested as an improved mechanism for re-regulation, and this is the approach been used in GM and other areas of the UK (Raikes et al., 2015). Kivimaa (2014) suggests that ‘government-affiliated intermediary organisations’ can be instrumental in fostering socio-technical innovation, and TfL could represent such an organisation, which is providing an alternative policy environment. TfL are working as local actors within the niche of the regulated system Greater London, to provide a protected environment for the bus network, and hence, to a certain degree, protect the public transport system from the market forces at work elsewhere. Smith and Raven (2012) suggest that as well as local actors within the niche, global actors are working to encourage diffusion of the innovation beyond the niche. In terms of public transport regulation, a number of global actors can be identified as pushing for further regulation outside of London. This includes the transport authorities in metropolitan areas, formerly known as Passenger Transport Executives (PTEs), the Urban Transport Group, which provides support to the former PTEs, research institutions and think tanks such as the Institute for Public Policy Research (IPPR) (Raikes et al., 2015, Rowney and Straw, 2014) and increasingly central government policy through the Bus Services Bill (Prime Minister's Office, 2015). The role of regulation and protection of bus networks from wider market forces is echoed by Harman et al (2012), and it is possible to suggest that the trends identified above indicate dynamics which may facilitate this in the UK.

6.2.5 Scenario 3 - Flexi-mobility

The following scenario, ‘Flexi-mobility’, looks at how trends for increasing flexibility in working, shopping and other scheduling patterns, bought about by ever improving ICT infrastructure, might influence travel patterns, capacity use and atmospheric emission reductions. This pathway draws on survey analysis from Chapter 4- which suggested that many people are able to work from home, a trend that is reflected in national statistics (Office of National Statistics, 2014a), and people are both willing and able to adjust their departure times, indicating flexibility in travel patterns. Figure 6:11 shows the co-evolutionary framework for the Flexi-mobility scenario and is discussed further below.

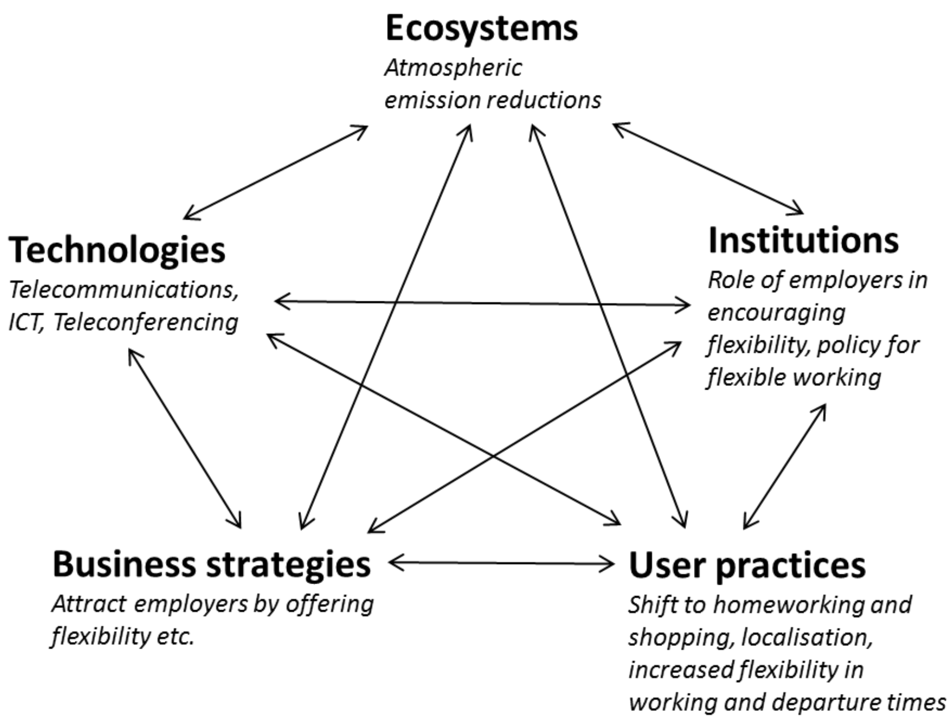

Figure 6:11 - Scenario 3 – Flexi-mobility

In this scenario, increased presence of ICT is facilitating changes in user practices, namely, homeworking and online shopping become more prevalent, which in turn reduces the amount of travel in the system and reduces atmospheric emissions. Increased flexibility in working hours and scheduling, bought about by business strategies that offer this to their employees and policy mechanisms to encourage this, allow people to travel outside of peak hours, which results in a more effective use of the roadspace capacity. Some of the interconnections that occur in the dynamics of this scenario are highlighted in the CLD in Figure 6:12 and expanded upon below.

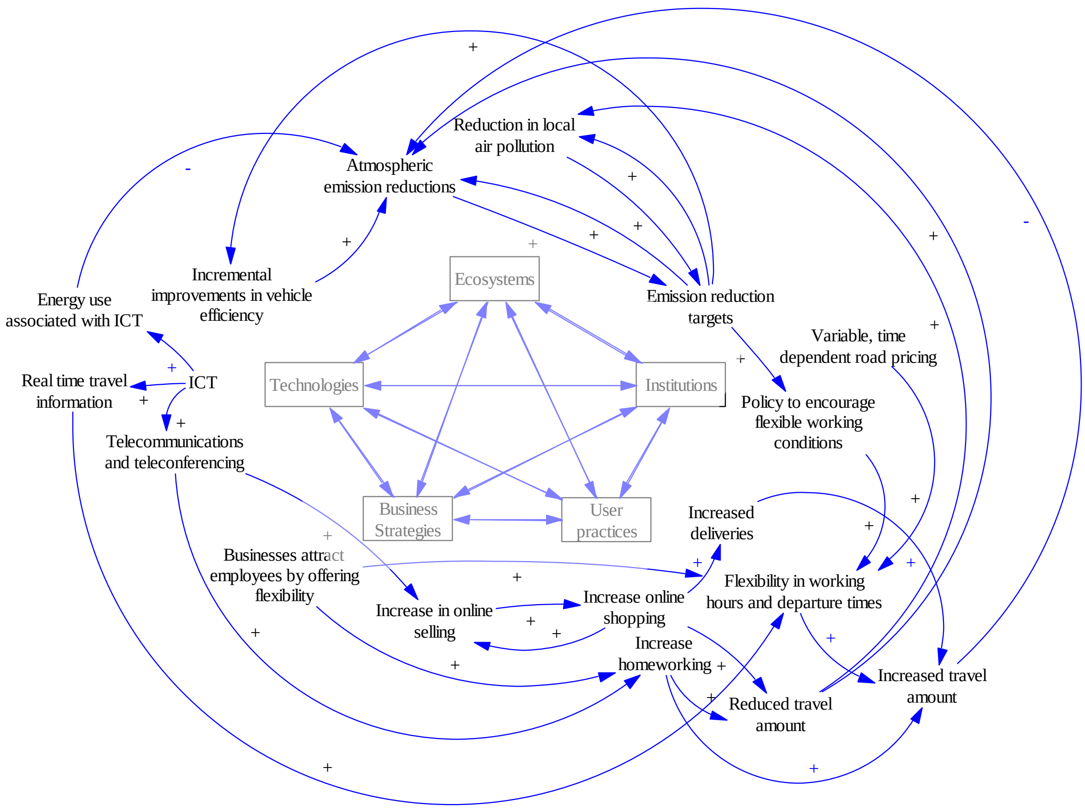

Figure 6:12 - CLD for Flexi-mobility

The CLD above shows how improvements to ICT infrastructure can facilitate changes in user practices and business strategies that could influence flexibility and consequently travel patterns. Telecommunication infrastructure, homeworking and teleconferencing could reduce travel amounts, and policy mechanisms could support these practices. If travel amounts can decrease as a result of this then atmospheric emissions could be reduced. However, the impact of telecommuting on travel amounts is unclear, with some studies showing an increase in travel amounts (Zhu and Mason, 2014). Therefore both reduced and increased travel amounts are shown as user practices resulting from increased flexibility in working, which could have positive or negative impacts on atmospheric emission reductions respectively. Real-time travel information, coupled with flexible working policies, could enable individuals to travel outside peak hours, thus reducing congestion and having positive impacts on emissions. This could also be enabled through a policy framework which includes road pricing, with flexible rates at different times of day, e.g. off peak travel is cheaper than peak hours, incentivising individuals to adjust their journey departure times. The survey data presented in Chapter 4- and Chapter

5- suggests that many people are willing to explore options around adjusting their journey departure times, and this could allow much more effective use of roadspace capacity to be delivered. The induced congestion and rebound effects of such adjustments must also be taken into account and are explored further in Chapter 7-.

6.2.6 Comparison of pathways

This section draws together the different pathways that have been outlined in this chapter and looks at the similarities and differences between the pathways, what factors and dynamics might drive such a pathway and how urban transport excess capacity might be used within each scenario.

As the present thesis is focused on reducing the CO_2 emissions from transport through making enhanced use of excess capacity in urban transport, all scenarios are driven by the goal of reducing atmospheric emissions from transport, which remains constant in Figure 6:3 through Figure 6:12. The scenarios, to a greater or lesser degree, all have implications for the sustainability of the urban transport system, the chapter that follows will model these in an attempt to quantify the impacts.

Table 6:2 shows how the trends from the literature and policy reviewed in Chapter 2- are related to the survey indicators, and builds on Table 5:14, to show the relationship to the pathways developed in this chapter. The cross references in Table 6:2 identify where additional information on the literature, policy or survey indicators can be found elsewhere in this thesis.

Table 6:2 - Ongoing trends from literature and survey indicators, and their inclusion in the pathways

Trends in the literature / policy	Survey indicators	Pathway
Vehicle technologies for reducing emissions (Section 2.3)	n/a	All scenarios
Intelligent Transport Systems (Section 2.3.1)	n/a	Scenario 1B – Intelligent Automobility
ICT for homeworking and increased flexibility (Section 2.3.2)	Section 4.2.2, ability to work from home, factor analysis in Section 5.5	Scenario 3 – Flexi-mobility
Modal shifting (Section 2.3.2)	Table 5:2 and factor analysis in Section 5.5	Scenario 2 – Public Mobility
Increases in sharing (Sections 2.5 and 2.3.2)	Section 4.2.4, willingness to car share	Scenario 1A – Shared Automobility
Devolution and re-regulation (Section 2.6)	n/a	Scenario 2 – Public Mobility

One of the key aspects of altering the trajectory of transport, away from the BAU case, where continued car dominance remains central to urban transport, is a path-breaking innovation. In the first two scenarios, the car remains dominant, but innovations change the way that the car is used in order for it to become more sustainable, however, the type of innovation is different in each case. For Shared Automobility, the innovation comes from user practices, with sharing increasing and technological and policy mechanisms supporting this, and through increased occupancy of vehicles, reductions in environmental emissions from transport are delivered. For Intelligent Automobility, technology is the main driver of change, with advances in automation of vehicles, although user practices must adapt to these changes and policy frameworks are necessary to support and invest in infrastructure for automated and autonomous vehicles. In the Flexi-mobility pathway, both technology and user practices drive the main changes, improved ICT facilitates individuals to have more flexibility in their user practices, thus are more able to work and shop from home. Changes in the policy environment and business strategies also allow more flexibility to travel outside peak hours. The Public Mobility pathway is the only scenario in which the main driver of path-breaking changes is policy led, with re-regulation of public transport through devolution of powers leads to substantial improvements in services, changes in attitudes around public transport and subsequent modal shift away from the car towards public transport modes.

As well as having different factors driving the change in each of the pathways, the way that urban transport capacity is used varies between the different pathways. For example, in the Shared Automobility pathway, the internal vehicle capacity is being used more effectively, as user practices change to increase vehicle occupancy, facilitated by ICT. In the Public Mobility scenario, the modal shift towards public transport means that people are travelling in vehicles with higher capacity and occupancy rates of these vehicles is increasing, thus the mode weighted vehicle excess capacity is reducing. In the Intelligent Automobility scenario, it is the use of the roadspace capacity that is changing, with automated vehicles able to travel closer together, which brings efficiency benefits, but may have a negative impact on the volume of traffic. However, intelligent infrastructure is likely to have a positive impact on congestion, which will result in potentially a more effective use of capacity. The Flexi-mobility pathway focuses mainly on temporal capacity, allowing people to travel outside the peak hours will make more effective use of temporal capacity in urban transport systems. In addition, replacing physical travel with the ability to work and shop from home allows people to make more effective use of their time. These different aspects of capacity will be captured in the modelling study in Chapter 7- where delays, congestion and emissions can all be quantified and examined for the different scenarios presented.

Table 6:3 shows a number of niche and regime innovations form socio-technical studies of sustainable transport for comparison to the pathways developed for excess capacity in the present work.

Table 6:3 - Socio-technical scenarios for sustainable mobility

Scenarios for enhanced use of excess capacity in urban transport	Geels' six niche innovations for greener transport (Geels, 2012)	Kohler et al's alternative regimes for sustainable mobility (Köhler et al., 2009)
1.A Shared Automobility 1.B Intelligent Automobility 2. Public Mobility 3. Flexi-mobility	1. Intermodal travel 2. Cultural and socio-spatial innovations 3. Demand management 4. Public transport innovations 5. ICT, ITS, Teleworking 6. Green propulsion technology	1. Novel fuel technology 2. Change in the use and ownership of vehicles 3. Low mobility demand through changes in lifestyles

There are clear commonalities and differences between the futures presented for the transport system in Table 6:3. Across the studies, technological and social changes are required for sustainability. However, through the focus on capacity, the scenarios developed in the present work look primarily at the use of the transport system, reflecting the definition of capacity developed in Section 2.5.2. Improvement in vehicle technologies are assumed across all four scenarios in the present work, rather than focussing on this as a niche innovation or alternative regimes in itself, as the other studies have done (Geels, 2012, Köhler et al., 2009).

It should be noted that this thesis does not advocate one of these pathways over the others, they are illustrations and conceptualisations of different possible futures for sustainable urban transport. While some of the dynamics illustrated in the scenarios and CLD diagrams are already underway, e.g., devolution of powers to city regions, the full implications for urban transport systems will be felt in the future, as the changes become more embedded in the systems. They provide a framework for the modelling study in the next chapter and scenarios for understanding how capacity could be used in the future and the potential benefits of making use of urban transport excess capacity. The pathways are also not mutually exclusive, a combination of the co-evolutionary relationships that are identified in the four pathways could emerge in parallel and the development dynamics along one pathway should not rule-out the others. It should also be recognised, that in exploring the future of any complex system, a level of uncertainty arises. As Foxon suggests, "*evolutionary analyses highlight the uncertain, path-dependent and cumulative nature of systems change*" (Foxon, 2011, p.2265) and this has been demonstrated through the presentation of scenarios in the co-evolutionary framework and the exploration of causal links and feedbacks within the pathways.

6.3 Chapter summary

This chapter began by presenting different ways of exploring urban transport futures that have been used elsewhere in the literature and identifying the most relevant techniques for the pathways for future use of urban transport excess capacity. Following this, four scenarios were developed:

1. A) Shared Automobility

1. B) Intelligent Automobility

2. Public Mobility

3. Flexi-mobility.

These scenarios were developed using a combination of the theoretical frameworks presented at the start of the chapter. They use forecasting techniques, as they begin from the system as it exists at present and examine possible future trends that may emerge. Aspects of socio-technical systems analysis are also included in the presentation of the scenarios, the co-evolutionary framework is used to highlight interconnections between different aspects of the system. CLD for each of the scenarios present some of the dynamics, in terms of policy, user practices, institutions, business strategies and technologies that are driving changes in the system, and the potential impacts on CO_2 emissions that these could have.

These scenarios are developed in Chapter 7- into modelling scenarios for traffic network modelling in the case study area of GM. The qualitative narratives that have been presented in this chapter are coupled with quantitative indicators to illustrate and understand the potential impact that these scenarios will have on urban transport capacity use and associated CO_2 emissions. The policy recommendations that have emerged in this chapter, and the preceding results chapters, are developed into a series of policy measures that are discussed with policy and decision makers through interviews, the results of which are presented in Chapter 8-.

Chapter 7- Traffic network modelling of enhanced use of urban transport excess capacity

This chapter presents the results of network modelling of the scenarios developed in Chapter 6-, which were based on the survey results in Chapter 4- and Chapter 5-. This predominantly addresses research question 2; on the carbon benefits and penalties of making enhanced use of excess capacity in the urban transport system, although additional impacts are explored, such as the impacts on congestion and delays.

This chapter begins by providing background information about the modelling approaches used. An explanation of how the scenarios developed in Chapter 6- are incorporated into the SATURN (Simulation and Assignment of Traffic to Urban Road Networks) model runs is provided in Section 7.2. The results from the network modelling will then be presented, analysed and discussed in Section 7.3. Section 7.4 takes the results from the network modelling and explores the potential magnitude of direct rebound effects that could offset any emission reductions. Some conclusions and policy recommendations are then given in Section 7.5.

7.1 Transport for Greater Manchester modelling approach

This section presents an overview of the modelling approaches used by Transport for Greater Manchester (TfGM) to undertake network modelling and emissions estimation. The modelling results that are presented in this chapter are used to explore the emissions reduction potential of enhanced use of capacity using the scenarios developed in the preceding chapters. Section 7.2 will demonstrate how indicators were developed for the scenarios to be implemented in the modelling tools described. TfGM use SATURN (Atkins-ITS, 2013, Van Vliet, 1982) to model the traffic network in Greater Manchester (GM) and outputs from this are used in the Atmospheric **Em**issions **I**nventory for **G**reater **Ma**nchester (EMIGMA) model (Hull et al., 2013) to estimate associated emissions. More detail on each of these approaches is given in turn.

7.1.1 Traffic network modelling in SATURN

SATURN is a macro level traffic network model package. The principles of traffic network modelling were introduced in Chapter 3- as part of the review of modelling approaches. Traffic network modelling is based on the four stage trip model approach as follows: 1, Trip generation; 2, Trip distribution; 3, Mode split and; 4, Traffic assignment (de Dios Ortúzar and Willumsen, 2011). Additional rules will govern the movement of the simulated traffic within the network, such as algorithms for car following, lane changing and gap acceptance parameters (Gipps, 1981, Young and Weng, 2005). A short overview of the SATURN package will be provided here to give additional context on the specifics of the SATURN approach, and further details about the model can be found in the model manual (Atkins-ITS, 2013).

There are two main inputs to the SATURN model, the trip matrix and the network visualised in Figure 7:1. It is through changes to these inputs that the scenarios developed in the present research will be modelled, and this is demonstrated in Section 7.2. Additional modelling of scenarios can be conducted by applying factors to the outputs, such as changes to the emission factors to reflect improved vehicle efficiency. Emission factors for the modelling of the scenarios for enhanced use of excess capacity are explored further in the context of EMIGMA in the next section, and in Section 7.2.

The Greater Manchester SATURN Model (GMSM) was developed in 2006 along with the Greater Manchester Strategy Planning Model (GMSPM) and the Greater Manchester Public Transport Model (GMPT) (Morris et al., 2013). The highway network in the model was developed when the model was created in 2006 and has been added to annually as the road network in the real world has been developed, changed and expanded. In addition, proposed network developments, which are already in the pipeline, are incorporated into future year model runs, including in the reference (do-minimum) case. The model includes 993 zones, 864 within GM and 129 zones in the buffer area outside the county (Morris et al., 2013). It should be noted that the terms reference case, do-minimum and business as usual (BAU) are used interchangeably to refer to the baseline scenario, against which the other scenarios are compared.

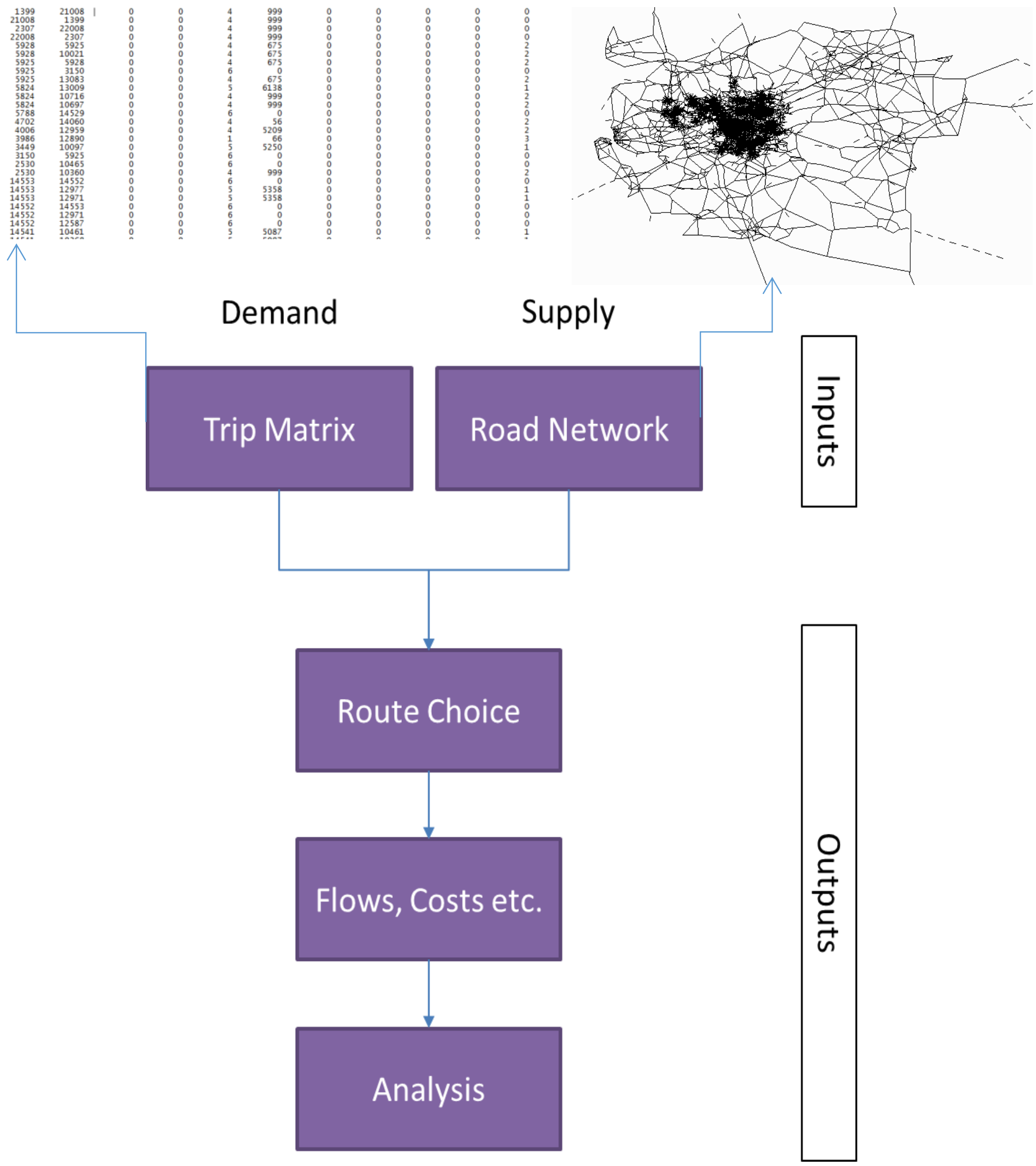

Figure 7:1 - General structure of assignment model (reproduced from (Atkins-ITS, 2013)) with an example trip matrix and network shown above

The trip matrices for the GMSM are developed in a number of stages. First, ‘prior’ matrices are built, using data collected through roadside interviews and observed data within GM (Morris et al., 2013). Matrices are built for 5 different ‘user classes’, which includes: commuting cars; employers’ business cars; other cars; light goods vehicles (LGV); and other goods vehicles (OGV) (ibid.). Note that the public transport matrices are developed in the CUBE platform (Citilabs, 2016), which is used to model public transport for the GMPT, and these are then used in GMSM to model the network. These prior matrices are then subjected to matrix estimation, using additional count data and factoring to provide up–to-date matrices for the current model year and future scenarios (Morris et al., 2013). More details on how the trip matrices are validated can be found in Section 7.1.3. In order to model the scenarios developed in Chapter 6-, changes can be made to the trip matrix to reflect, for example, increasing occupancy rates through sharing (Scenario 1 A – Shared Automobility) or departure time shifting to travel outside peak hours (Scenario 3 – Public Mobility). Table 7:2 shows how indicators for the traffic network modelling are developed for each scenario, highlighting where trips have been made to the matrices, network or factors applied to outputs, in order to simulate the scenarios.

7.1.2 Atmospheric Emissions Inventory for Greater Manchester (EMIGMA)

EMIGMA accounts for emissions of pollutants from multiple sources, including non-transport sources, within GM, drawing on the National Atmospheric Emissions Inventory (Hull et al., 2013, Department for Environment Food and Rural Affairs, 2015). The model is built in a Microsoft Access database and draws in SATURN outputs in order to model emissions. Estimates of emissions are based on traffic speed and flow data from GMSM, using this approach, the emissions will be calculated for the scenarios for enhanced use of urban transport excess capacity. EMIGMA provides estimates of seven pollutants: VOCs, CO, CO_2 as C[3], NO_x, SO_2, NO_2 and PM_{10} (Hull et al., 2013).

Separate calculations of emissions are made for:

- "*Major Roads – representing the warm running emissions from vehicles traveling on major roads represented in the SATURN model*
- *Minor Roads – representing warm running emissions from vehicles travelling on local roads that are not represented in the SATURN model*
- *Cold Starts – representing extra emissions caused by cold-running engines at the start of each journey*
- *Hot Soaks (evaporative emissions) – representing extra emissions emanating from a hot engine after switching off at the end of each journey*" (Hull et al., 2013, p.6)

The cold starts and hot soaks emissions are not relevant for the calculation of CO_2 emissions, which are the main focus of the present research. Hot Soaks is related to the emission of VOCs and Benzene, whilst Cold Starts affect emissions of VOCs, CO, NO_x and PM_{10} (Hull et al., 2013). The factors used to calculate CO_2 emissions in the model runs for the present work are presented in Section 7.2.1, with Figure 7:2 showing the speed emission curves for CO_2 for petrol and diesel cars in each of the modelled time periods (2013, 2020 and 2035).

7.1.3 Validation of the TfGM models

The models used for traffic network modelling by TfGM are subject to regular validation protocols to ensure accuracy. Approaches to validation include, checking trip matrices against count data for highway modes and public transport, checking the accuracy of the coded network, comparing the model assignments to real world flows and public transport passenger movements (Smith et al., 2014).

The TfGM models are all validated in accordance with Transport Analysis Guidance (WEB TAG) from the Department for Transport (DfT), which requires certain conditions to be met. For highways modelling, WEB TAG requires that there should be less than 5% difference between modelled flows and count data, modelled times along routes should be within 15% of surveyed times for 85% of routes, and there are criteria for junctions which are dependent on the traffic flow rate through the junction (Transport Appraisal and Strategic Modelling (TASM) Division, 2014a). For public transport, WEB TAG validation requires that the difference between assigned and counted flows should be less than 15% in 95% of cases (Transport Appraisal and Strategic Modelling (TASM) Division, 2014b).

These validation procedures ensure that the modelling conducted is robust and that the data outputs and results can be relied upon to have achieved the standards outlined by DfT in WEB TAG.

7.1.4 Limitations of the modelling approaches used

There are a number of limitations, in both the modelling approaches used and the assumptions underlying the scenarios, which should be recognised here. Chapter 3- explored modelling approaches available for examining transport CO_2 emissions and through this identified high level limitations on modelling approaches in general. For example, traffic networking models cannot capture the behavioural aspects that are added in an activity based modelling approach, however, network models are very useful for exploring the impacts of, for example, changes to mode share or network developments (see also, Linton et al., 2015). Section 7.1.3 explained how the TfGM transport modelling approaches are validated, using DfT WEB TAG procedures. This rigorous procedure ensures the modelling outputs are valid and robust, limiting the risk of unreliable results.

Beyond the relative advantages and disadvantages of the different modelling approaches, there are fundamental limitations in creating a model of reality and errors are inherent (de Dios Ortúzar and Willumsen, 2011). In addition, exploring the future is rife with uncertainty, as predicting behaviour of individuals in the future is challenging. De Dios Ortuzar and Willumsen (2011) suggest that including complementary approaches can limit the uncertainty in exploring future transport systems. The scenarios that are modelled in the present work draw on both survey data and wider trends in the literature and begin from the established current state of the transport system. Using these multiple complementary sources will limit the uncertainty in the modelling results and enhance the robustness of the analysis. The construction of the scenarios was presented in Chapter 6- and Table 7:1 shows the links between the scenarios, trends in the literature and the survey results.

As discussed in Section 3.2.6, there are limitations to the extent to which a modelling tool, such as SATURN, can capture the full dynamics of the socio-technical system being examined in the present work. The interactions and interconnections illustrated and characterised in Chapter 6- are not fully captured as there are constrains on the inputs to the SATURN model. Table 7:2 shows how indicators for each scenario are developed for SATURN and demonstrates these constraints. For example, for the Flexi-mobility scenario, 5% of trips are moved outside of the peak hours to simulate peak spreading. However for this scenario in Chapter 6, feedbacks between flexible working, variable road pricing, improved ICT and online retails where characterised amongst others, and SATURN does not offer the mechanisms to explore these further. Due to the constrained nature of the present work, the existing GM

SATURN model has been used, as a suitable alternative was not available. Despite these limitations, the modelling results presented subsequently can offer interesting insight into the potential CO_2 associated with excess capacity and indications of the impact of some of the mechanisms developed in the scenarios.

7.2 Modelling of scenarios for enhanced use of urban transport excess capacity

This section explains how the scenarios presented in Chapter 6- are developed for modelling in the traffic network modelling. Using the methods outlined in Section 7.1, the scenarios described in the previous chapter have been modelled in order to understand their impact on CO_2 emissions, travel volumes and other traffic network level effects. The narrative of each scenario is not repeated here, but can be found in Section 6.2. The results of the modelling of the scenarios are presented subsequently.

Table 7:1 shows how the scenarios that were developed in Chapter 6- draw on trends which emerged in the Literature Review in Chapter 2- and indicators from the survey results in Chapter 4- and Chapter 5-. Model indicators are applied to these trends which run throughout this thesis and the model inputs that are developed for each scenario are explained in more detail in Table 7:2.

The trends that are highlighted in Table 7:1 were drawn from the literature in Chapter 2-, and are identified as key factors that influence the future use of excess capacity in urban transport. Some of these, such as homeworking, modal shift and sharing, are explored further within the survey data and the specific references to this are provided in Table 7:1. Other factors, such as technological changes and devolution and re-regulation of public transport systems, are changes taking place at the wider urban transport system level; hence they have not been explored through the survey but are incorporated into the development of the scenarios in Chapter 6-. Table 7:1 shows which trends are relevant to each scenario building on Table 5:14 and Table 6:2.

Table 7:1 - Trends running through the literature, survey indicators and scenario development with relevant modelling indicators

Trends in the literature / policy	**Survey indicators**	**Pathway**	**Model Indicator**
Vehicle technologies for reducing emissions (Section 2.3)	n/a	All scenarios	Improving emission factors (see Figure 7:2)
Intelligent Transport Systems (Section 2.3.1)	n/a	Scenario 1B – Intelligent Automobility	Improved efficiency on motorways, see Table 7:2 for details
ICT for homeworking and increased flexibility (Section 2.3.2)	Section 4.2.2, ability to work from home, factor analysis in Section 5.5	Scenario 3 – Flexi-mobility	Shift in journey departure times out of the peak hours
Modal shifting (Section 2.3.2)	Table 5:2 and factor analysis in Section 5.5	Scenario 2 – Public Mobility	Modal shift to public transport modes
Increases in sharing (Sections 2.5 and 2.3.2)	Section 4.2.4, willingness to car share	Scenario 1A – Shared Automobility	Increase load factors
Devolution and re-regulation (Section 2.6)	n/a	Scenario 2 – Public Mobility	Modal shift to public transport

Table 7:2 shows the modelling indicators that have been developed by the present author in order to simulate the four scenarios for future transport capacity use. The model inputs that have been adjusted are shown in bold, which for all scenarios, apart from 1 B – Intelligent Automobility, have been through changes to the trip matrix. The changes that have been made to the network are included in the reference case and remain the same in the other modelled scenarios. These are based on infrastructure developments that are already in the pipeline in GM.

Table 7:2 - Modelling indicators for each scenario for enhanced use of urban transport excess capacity

Scenario		**Model inputs**	**Limitations and assumptions**
Reference case			
1.A	*Shared Automobility*	This is modelled through a global change to the **car trip matrix**: based on an average load factor of 1.4 persons in 2015 and 2.1 in 2035, that is a per annum increase of 2.5%. This equates to a 32% reduction in car vehicle km (vkm) between 2015 and 2035, 1.6% reduction per annum. These values related to those described in Section 4.3, around the potential of car sharing to increase vehicle occupancy.	The approach used is unable to capture the full dynamics and feedbacks for Shared Automobility captured in Figure 6:6, including the changes in practices or installation of 2+ lanes. An additional, or alternative approach to exploring this could be through the use of an agent based modelling approach to capture the spreading of car sharing as a practice. Agent based approaches were explored in Section 3.2.1 and in further work in Section 9.3.5.
1.B	*Intelligent Automobility*	Based on having a 'connected vehicle' lane on each motorway link, headway reduces in those lanes; aerodynamics (platooning) delivers energy efficiency of 20%; eco-driving (smoothing of braking and acceleration) delivers energy efficiency of 10%; therefore 30% energy efficiency improvement for one lane on motorway links, an average of 10% across motorways (values taken from Wadud et al (2016)). These changes are made	The full dynamics on an automated transport future and complex and highly uncertain. The impact of fully autonomous cars could increase vkm where vehicles are driving empty or potentially make more effective use of capacity through shared ownership as the ITF study suggests (International Transport Forum, 2015). These uncertainties are not captured here, the modelled results merely demonstrate the potential of a subset of ITS technologies to reduce CO_2 emissions and

		through adjustment of the **emission factors** for motorway travel	make more effective use of capacity.
2	*Public Mobility*	Smart ticketing impacts on bus boarding times and travel time, as well as improving passenger experience, and is facilitated through re-regulation of the bus system. This represents a catalyst for modal shift. 13% growth in public transport trips within GM (based on modal shift in survey and TfL impact of oyster introduction) – adjustment to **bus trip matrix**, with the car matrix adjusted accordingly.	This scenario is limited to looking at how smart ticketing and changes in attitudes, which leverage a modal shift to bus, might reduce CO_2 emissions. This is limited to looking at bus, as the focus has been on road transport, but it would be interesting to explore additional interactions with other public transport modes. In addition, improved bus infrastructure, additional bus lanes and improved service frequency would be an interesting extension to the analysis, which has not been captured. At present the definition of capacity in the work has related to existing infrastructure, but this could offer an interesting opportunity for further work.
3	*Flexi-mobility*	Peak spreading, as a result of willingness to adjust journey departure times – reduce peak hour **trip matrices** by 5% to reflect adjustment of journey departure times to outside peak hours. This was taken from survey indicators in Section 5.4.	This scenario is driven by behavioural and cultural shift which lead to more flexible travel and working patterns. The application of the 5% reduction in peak trips represents a crude method to examine the emission reductions potential, but is that which is available in the model used. An alternative tool, such

			as a system dynamics (SD) model, might offer the opportunity to examine different mechanisms for peak spreading and CO_2 emissions.

Scenario 1 B – Intelligent Automobility, is modelled through changes to the emission factors for motorway travel, in order to simulate the impact of autonomous vehicles on efficiency. However, there are aspects of vehicle automation and intelligent transport that are not captured by the modelling of this scenario, these are outlined here. Increases in autonomous vehicles would influence how the roadspace is used because headway between vehicles could be reduced to as low as 1m, therefore many more vehicles could travel in the same roadspace on roads which had the appropriate infrastructure (DFT, 2011a). However, to model this increase in traffic on the motorway links in the traffic network in GM, the junctions which feed traffic into the motorways are likely to break down, as they would be unable to cope with the increased traffic loading on the motorways. In addition, it is difficult to predict at what speed the technology and infrastructure will be rolled out on the network, therefore, at this stage, the modelling has solely examined the potential impact of increased efficiency of greater automation on CO_2 emissions, see Table 7:2 for more details. This scenario has also only been modelled for the 2035 time period, as it is unlikely that significant market penetration of automated vehicles will have been achieved by 2020, although increasing levels of automation are being seen in vehicles. This is demonstrated by the scales of automation that the US DOT suggest (National Highway Traffic Safety Administration, 2013), which can be found in Section 2.3.1. More on the diffusion of ITS can be found in the scenario narrative for Intelligent Automobility (1B) in Chapter 6- and in the Literature Review, Chapter 2-.

This section has presented the development of modelling indicators for the scenarios which examine enhanced use of excess capacity in urban transport and CO_2 emissions. The following section provides more detail on how emissions are calculated in the modelling results.

7.2.1 Emission factors used in the network modelling of urban transport excess capacity

In order to quantify the emissions associated with the volume of transport within the traffic network model, for the different scenarios and time periods, emission factors are applied to the flows through the network, based on vehicle type and speed. Figure 7:2 shows the average speed emission curves for petrol and diesel cars, for 2013, 2020 and 2035.

The improvements in emissions due to new vehicle technologies is apparent for both petrol and diesel cars, with emissions improving between 2013 and 2035, although the pace of improvements is greater between 2013 and 2020 than 2020 and 2035. This is due to the uncertainty in predicting what progress will be made on emission reduction targets after the currently mandated reduction targets from the EU of fleet average emissions of 95 gCO_2/km by 2021 (European Union, 2015).

For buses, the changes in emissions of CO_2 are more gradual, they are not mandated by an EU policy, and the fleet turnover of bus vehicles is slow due to their long service lives. Therefore, due to the slower improvements in emission factors used for quantifying CO_2 emissions from bus travel, it is difficult to see the changes between the time frames on a graph like that in Figure 7:2. However, there have been UK policy measures in place to support the diffusion of low carbon buses, such as the Green Bus Fund and the Clean Bus Technology Fund (Department for Transport, 2013a, Department for Transport, 2016b), which have resulted in the roll out of hybrid, and even battery electric buses. Whilst these measures will impact on the emissions factors from bus vehicles in the future, it is difficult to assess the magnitude of this impact at present.

This section has explained how indicators have been developed for the modelling of the scenarios presented in Chapter 6-. The following section presents and discusses the results of the model runs.

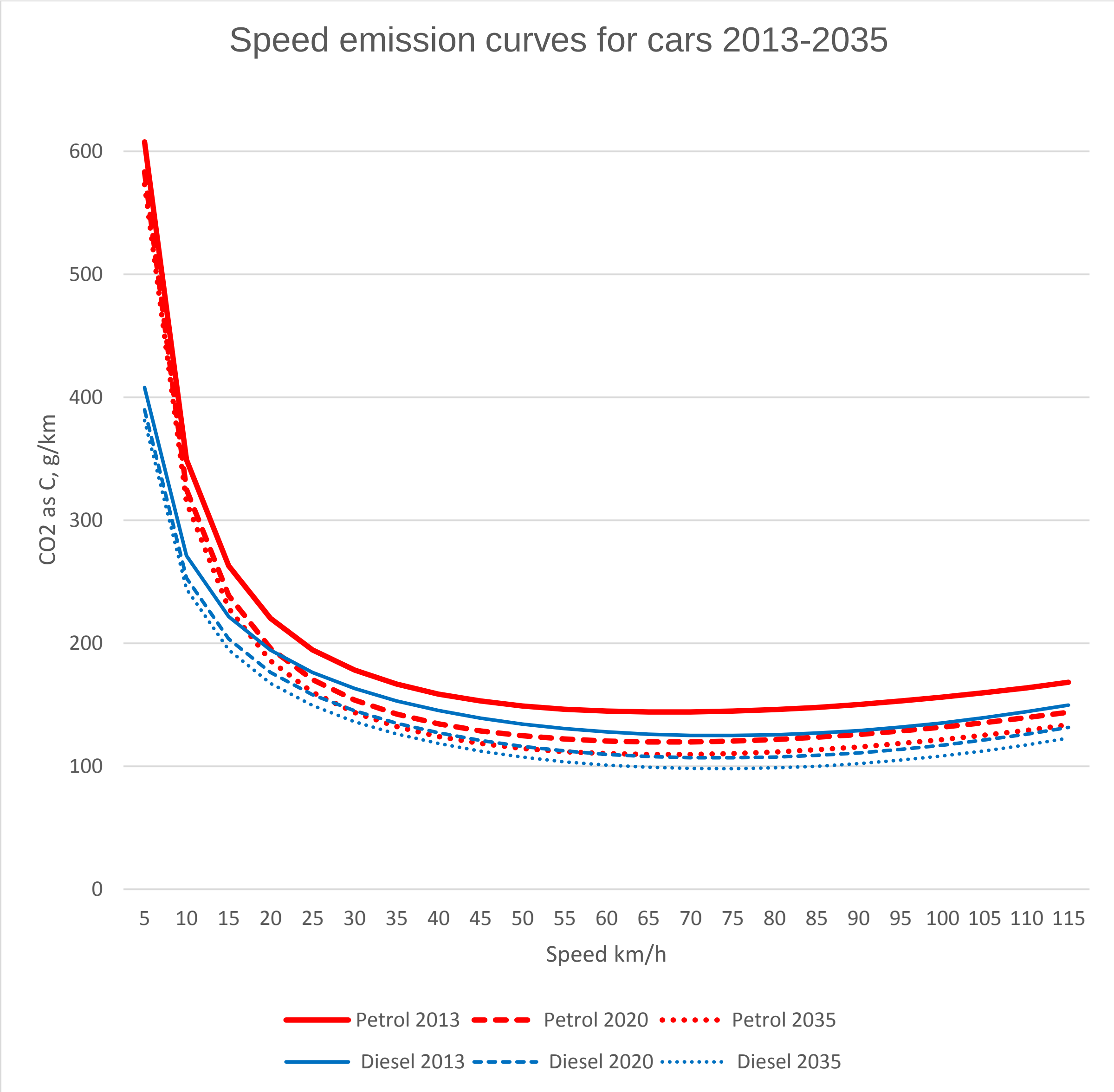

Figure 7:2 - Speed emission curves for petrol and diesel cars (data taken from EMIGMA (Hull et al., 2013))

7.3 Results and discussion of the traffic network modelling of scenarios for enhanced use of urban transport excess capacity

The following section presents the results from the traffic network modelling of the four scenarios developed in Chapter 6- using the approach outlined in the preceding sections. High level results about the emissions and vkm travelled in each scenario are presented first, these are then explored in more detail, looking at mode share and congestion subsequently. These results are discussed in the context of the research questions, addressing the impacts of making enhanced use of excess capacity and chapter conclusions and policy recommendations are presented in Section 7.5.

7.3.1 Modelled carbon emissions and vehicle kilometres

Table 7:3 and Table 7:4 show the high level results, presenting the annual vkm travelled by car and bus in GM and the annual CO_2 emissions associated with that travel respectively.

Table 7:3 – Modelled annual vehicle km for passenger transport (car and bus) (millions km)

Year	Reference	1A - Shared Automobility	1B - Intelligent Automobility	2 – Public Mobility	3 – Flexi-mobility
2013	12,721				
2020	14,018	12,482		13,888	14,054
2035	15,711	10,323	15,711	15,607	15,787

Table 7:4 – Modelled annual CO_2 for passenger transport (car and bus) ($kTCO_2$)

Year	Reference	1A - Shared Automobility	1B - Intelligent Automobility	2 – Public Mobility	3 – Flexi-mobility
2013	2,125				
2020	2,034	1,805		2,014	2,034
2035	2,155	1,395	2,091	2,139	2,158

In the reference case we see increases in vkm travelled between 2013 and 2035, with demand for passenger road transport increasing by around 24%. As the emissions efficiency of this transport improves, there is a reduction in the total emissions of CO_2 between 2013 and 2020. However, as demand continues to increase across the modelled time periods, total emissions then rise again in 2035, although the CO_2 intensity of travel is falling due to improvements in vehicle technologies. This offsetting of improvements in vehicle efficiency, through ever increasing demand for travel, has been a recurring challenge in decarbonising transport (Hickman et al., 2012).

While the value of GM's road transport CO_2 emissions in 1990 is not directly available in the literature, it is notable that CO_2 emissions from road transport in the UK have not changed much between 1990 and 2012. Emissions initially increased from 110.3 $MTCO_2$ in 1990, associated with increasing demand, to a peak of 122.7 $MTCO_2$ in 2008 and then fell after this associated with economic recession, to 108.7 $MTCO_2$ in 2012, resulting in a decrease of 1.5% between 1990 and 2012, however, there may have been some increase post-recession with increased economic activity (Department for Transport, 2015b). The GM Local Transport Plan (LTP) for 2011/12 – 2015/16 shows that the region currently has emissions of 15.8 MT CO_2 per annum, and this needs to be reduced to under 10 MT CO_2 by 2020 and 4 MT CO_2 by 2050 (Transport for Greater Manchester, 2011). The results of the emission reductions achieved, under the scenarios modelled, are compared to these emission reduction targets, in order to understand the potential impact they could have and the role these measures could have in delivering a more sustainable transport system.

Under Scenario 1A – Shared Automobility, a reduction in emissions is evident, which is realised through the reduction in vkm travelled due to increased occupancy of vehicles bought about through car sharing. Demand has been reduced in the system by factoring the car trip matrix to reduce demand by 1.6% per annum, and this results in a 19% decrease in vkm travelled by passenger modes in 2035. It should be noted that, while Table 7:2 indicated a 32% decrease in car travel between 2013 and 2035, when forecasted increase in demand is included in the model runs, this translates to a 19% reduction in passenger transport vkm by 2035, compared to 2013. As a result of this reduction in vkm travelled, the CO_2 emissions are reduced by 15% in 2020 and 35% in 2035, compared to 2020 and 2035 respectively in the reference case. This represents a substantial reduction in CO_2 emissions which could contribute to emission reduction targets, saving nearly 0.8 $MTCO_2$ compared to the reference case. As identified above, GM emissions of CO_2 need to be under 10 MT CO_2 in 2020 and under 4 MT CO_2 by 2050. Therefore, the increases in occupancy rates in the Shared Automobility scenario could offer a valuable policy option for reducing emissions of CO_2 from car travel, with the results suggesting that emissions could be 0.8 MT CO_2 lower in 2035, compared to the reference case.

Under Scenario 1B – Intelligent Automobility, the vehicle km travelled remains the same as in the reference case, as adjustments are only made to the emission factors, no changes are made in the trip matrix. This delivers a 3% reduction in emissions in 2035, when compared to the 2035 reference case. This relatively small reduction is likely due to the fact that the emission factors are only applied to motorway travel, which represents about 40% of vehicle km within GM in 2035. It should be recognised, however, that any large scale uptake of autonomous vehicles, facilitated by ITS infrastructure, could lead to an increase in vehicle km travelled, as there will be additional roadspace available through reduced headways, and autonomous vehicles offer opportunities for those who cannot currently drive to utilised the private car mode choice (Wadud et al., 2016). Therefore, there could be potentially unforeseen impacts on the network of this scenario, through increased traffic, potential bottlenecks and even increases in emissions dependent on the propulsion technologies used and this should be considered in the analysis of the role of ITS in future urban transport systems.

In Scenario 2 – Public Mobility, the emissions and vkm travelled in the modelled period are only slightly lower than for the reference case. Under this scenario, there is a 13% growth in public transport trips, however, due to the dominance of the private car, this only leads to slight reductions in the CO_2 and vkm produced, less than 1% for CO_2 in 2035 compared to the reference case in 2035. In addition, when mode share is explored in the following section, only a small change is seen here. Despite growing public transport trips significantly, the current baseline of car dominance means that the impact is small over the time period modelled.

Under Scenario 3 – Flexi-mobility, emissions and vkm travelled are much the same as in the reference case. For this scenario, the trip matrices were adjusted to simulate people being motivated to adjust their journey departure times, therefore, 5% of trips were moved out of the peak hours. However, this does not result in an actual reduction in the amount of travel so the CO_2 and vkm are similar to that in the reference case. Vkm actually increases slightly under this scenario (0.5%), due to the increase in people travelling off peak, however, emissions do not increase in proportion to this. This is likely due to the fact that these additional km are being travelled in the off peak period and, thus, are not affected by as much congestion. These results suggest that the CO_2 benefits of making enhanced use of temporal capacity are small, however, the economic benefits of reduced congestion could be an additional benefit of the changes made under Scenario 3 – Flexi-mobility.

The results in the present work are interesting in the context of Banister's sustainable mobility paradigm, which takes a holistic approach to transport sustainability (Banister, 2008). The scenarios developed in Chapter 6- take an integrative, socio-technical approach to exploring sustainability in transport, reflecting the principles of the sustainable mobility paradigm. However, they go beyond the socio-technical approaches, in an attempt to quantify the potential emission reductions that could be delivered through the policy and technical changes described, as shown in the results in this chapter.

When these results are compared to those of Brand et al (2012a), the emission reductions are comparable to their modelled scenarios. In their combined policy scenario, they delivered emission reductions in 2020 of 8% in life cycle CO_2 (ibid.). For all the scenarios modelled in the present work, emission reductions were lower than this, apart from Scenario 1A – Shared Automobility, which saw reductions of 15% in CO_2 emissions in 2020. However, Brand et al (2012a) are accounting for life cycle CO_2 emissions, whereas the results in present work are just accounting for direct emissions. Consequently, their results will account for the upstream CO_2 and thus reductions will be lower.

Many of the measures explored in the scenarios modelled in the present work fall into the category of smarter choices, which were explained and discussed in Section 2.3.2. Cairns et al (2008) suggest that smarter choices could deliver emission reductions of 4-5% nationally with low intensity application, or up to 15-20% reductions with high intensity application and locally favourable conditions. These results are comparable to those in the modelling results in the present work, with lower emissions for Scenarios 2 and 3, which incorporate smarter choices measures around homeworking and modal shifting. Greater emission reductions are achieved with increased load factors, associated with car sharing in Scenario 1A, which saw a 15% reduction in CO_2 emissions in 2020. This is comparable to the high intensity application of smarter choices shown by Cairns et al (2008).

Jacobson and King (2009) explored the potential fuel savings that could be achieved by increasing car occupancy rates through sharing in the USA. They found that if there was an additional passenger in every one in ten vehicles, there would be a reduction in fuel consumed of 5.4% (Jacobson and King, 2009). In the present work, occupancy is increased by 32% by 2035, and emission reductions delivered are approximately 15%, which is not due to increased occupancy alone. This suggests that the results are comparable to those found by Jacobson and King (2009).

This section has shown the aggregate annual emissions and vkm travelled under the four modelled scenarios and compared these results to the reference case in order to understand the high level impacts of the different pathways for urban transport capacity use. The results in the present work have also been placed in the context of studies in the wider literature. Sections 7.3.2 and 7.3.3 examine mode share, speeds, congestion and delays under these modelled scenarios.

7.3.2 Modelled speed and congestion

The following section presents and discusses indicators of congestion and network effects from the modelled scenarios. This begins by examining the flow of vehicles in the network at different times of day in each scenario, and then goes on to explore the network speeds found in the modelled scenario results.

Table 7:5 and Table 7:6 show the numbers of vehicles travelling in the network annually in different time periods, AM peak, PM peak and Off Peak, for Car and Bus respectively. The AM peak period represents 0700-1000, the PM peak period is 1600-1900 and the Off Peak includes 0000-0700, 1000-1600 and 1900-2359 (Morris, 2015).

In most of the modelled scenarios and time periods, the change from the reference period is fairly small, but under Scenario 1 A – Shared Automobility, there are noticeable changes in the flow of vehicles for both bus and car. For shared automobility, the number of cars travelling across the day falls by around 10% in 2020 and around 33% in 2035, suggesting that the policy measures and dynamics described in Scenario 1 A have a significant impact on reducing car traffic. The number of buses travelling increases in this scenario, by 1.5% and 0.7% in the peaks and off peak respectively in 2020 and by around 4% and 2% in the peak and off peak respectively in 2035. Scenario 1 A sees the largest increase in the numbers of buses travelling of all scenarios and time periods and is the only scenario where there is an increase in buses travelling between 2020 and 2035.

Table 7:5 - Vehicles travelling in different daily time periods – Car (thousands of vehicles per year)

Year	Reference	1A - Shared Automobility	1B - Intelligent Automobility	2 – Public Mobility	3 – Flexi-mobility
2013	AM: 8,410 OP: 6,519 PM: 9,163				
2020	AM: 9,069 OP: 7,164 PM: 9,856	AM: 8,150 OP: 6,369 PM: 8,851		AM: 8,946 OP: 7,080 PM: 9,747	AM: 8,694 OP: 7,164 PM: 9,438
2035	AM: 9,593 OP: 7,962 PM: 10,547	AM: 6,411 OP: 5,154 PM: 7,039	AM: 9,593 OP: 7,962 PM: 10,547	AM: 9,513 OP: 7,886 PM: 10,483	AM: 9,249 OP: 7,962 PM: 10,166

Table 7:6 - Vehicles travelling in different daily time periods – Bus (thousands of vehicles per year)

Year	Reference	1A - Shared Automobility	1B - Intelligent Automobility	2 – Public Mobility	3 – Flexi-mobility
2013	AM: 133 OP: 137 PM: 125				
2020	AM: 133 OP: 137 PM: 125	AM: 135 OP: 138 PM: 127		AM: 133 OP: 138 PM: 126	AM: 134 OP: 137 PM: 126
2035	AM: 130 OP: 136 PM: 123	AM: 136 OP: 139 PM: 128	AM: 130 OP: 136 PM: 123	AM: 131 OP: 137 PM: 124	AM: 132 OP: 136 PM: 125

It should be noted that across the modelled scenarios, with the exception of 1B, the numbers of cars travelling in the network decrease and the numbers of buses increase, compared to the reference case. This suggests that the policy mechanisms and dynamics that are influencing the transport system within each of these scenarios should have positive implications for sustainability, by shifting travel from low occupancy private car to higher occupancy public transport modes. 1B – Intelligent Automobility, does not demonstrate these changes because no adjustments are made to the trip matrix, therefore the mode share and km travelled are the same as in the reference case.

Table 7:7 shows the average network speed under the different modelled scenarios and years for AM peak, PM peak and Off Peak, in km/h. As for the changes in vehicle numbers, the largest difference from the reference case is found in Scenario 1A, Shared Automobility. In 2020, the AM peak speed is 1 km/h higher and for 2035 it is 1 km/h higher in the AM and off peak, and 2 km/h higher in the PM peak. This provides an indication that congestion is lower under Scenario 1A, as the speeds achieved in the network are higher, supporting the argument that Shared Automobility represents a more sustainable transport system. Scenario 1B has the same speeds as in the reference case, as changes have not been made to the trip matrix.

Table 7:7 - Average network speed (km/h)

Year	Reference	1A - Shared Automobility	1B - Intelligent Automobility	2 – Public Mobility	3 – Flexi-mobility
2013	AM: 29 OP: 39 PM: 32				
2020	AM: 29 OP: 39 PM: 32	AM: 30 OP: 39 PM: 32		AM: 29 OP: 39 PM: 32	AM: 29 OP: 39 PM: 32
2035	AM: 29 OP: 38 PM: 31	AM: 30 OP: 39 PM: 33	AM: 29 OP: 38 PM: 31	AM: 29 OP: 38 PM: 31	AM: 29 OP: 38 PM: 31

It is also possible to compare the speeds achieved under the modelled scenarios to the free flow speed on the link, which represents the maximum speed that could be expected on that stretch of road. In the reference case, the modelled speeds are 11% lower than free flow in 2013, 13% lower in 2020 and 12% lower in 2035, demonstrating that congestion looks set to worsen in the future. Speeds are 12% lower than the free flow for 2020 and 2035 for

Scenarios 2 (Public Mobility) and 3 (Flexi-mobility), which are similar or an improvement on the reference case. Under Scenario 1 A – Shared Automobility, the modelled speeds are 11% lower than the free flow speed in 2020 and 2035, which improves on the reference case in both time periods. However, as above, Scenario 1 B – Intelligent Automobility, has the same differences between modelled speeds and free flow speeds as the reference case. This suggests that the mechanisms and dynamics that underlie the changes that have been made in modelling Scenario 1 A have potential positive impacts for congestion and speeds in the network. In addition, across all scenarios, there is no worsening of congestion compared to the reference case, which suggests that the policy mechanisms and dynamics in the pathways have a neutral or positive benefits for congestion within the transport system, and this could have positive environmental impacts.

7.3.3 Mode share in the modelled scenarios

The modelling results for the scenarios outlined show that mode share for passenger transport, in terms of vehicle km travelled, remains fairly constant across the modelled periods and scenarios. Car travel makes up 98% of the annual vkm related to passenger transport, across the scenarios and time periods, with around 51% of these being petrol cars and 47% diesel. Motorcycles makes up 0.6% of passenger transport vehicle km in all scenarios and time periods. The low share of vehicle km represented by motorcycle is the reason for excluding this from the vehicle km shown in Table 7:8.

Buses make up a small proportion of the total vkm travelled in all scenarios and time periods, varying between the maximum of 1.3% in the shared automobility scenario and 0.8% in all the other scenarios in the time period 2035. The trend in the base case is for a declining mode share for buses, from 1% in 2013 to 0.9% in 2020 and 0.8% in 2035, therefore, the 1.3% mode share for bus achieved in the Shared Automobility scenario in 2035 represents a significant increase in the share of km for buses, even if it is a small proportion of vkm as a whole.

Table 7:8 shows the average percentage of traffic flows on links in GM made up by car and bus vehicles for the different modelled scenarios and time periods.

Table 7:8 - Mode share of total traffic % Car / % Bus

Year	Reference	1A - Shared Automobility	1B - Intelligent Automobility	2 – Public Mobility	3 – Flexi-mobility
2013	75% / 8%				
2020	74% / 8%	72% / 8%		74% / 8%	74% / 8%
2035	73% / 7%	65% / 9%	73% / 7%	73% / 7%	73% / 7%

As for other results, Scenarios 1B (Intelligent Automobility), 2 (Public Mobility) and 3 (Flexi-mobility) do not differ greatly from the reference case, although it should be noted that under these scenarios the relative mode shares of bus and car do not shift in a less sustainable direction of increased car and reduced bus. However, under the Shared Automobility scenario (1A), there is a reduction in the percentage of traffic made up by car, of 2% and 8% in 2020 and 2035 respectively, and for bus there is an increase of 2% in traffic share in 2035, compared to the reference case in the same time period. This demonstrates the impact that Shared Automobility scenario has on the relative mode share of bus and car in the modelled scenarios. This also emphasises the potential positive policy implications of the measures suggested in, and underling dynamics of, the Shared Automobility scenario.

7.3.4 Wider impacts of the scenarios

In Section 4.3.2, estimates of mode weighted excess capacity were applied to metropolitan areas in England to quantify the magnitude of associated CO_2 emissions. In calculating this, assumptions are made about the similarities between urban areas in order to suggest the potential size of the emissions associated with excess capacity and the emission reductions that could be delivered through making more effective use of this excess capacity. The former metropolitan counties are included in this analysis and Greater London is excluded, in accordance with DfT definition of ‘metropolitan built up areas’ (DfT, 2011b). Table 4:25 shows the metropolitan areas in England and their CO_2 emissions from personal transport in 2012. In estimating the potential impact of enhanced use of excess capacity, it is not suggested that these are exact projections of emission reductions, more an indication of the direction and magnitude of the possible impacts of delivering enhanced use of urban transport capacity. The following section makes suggestions of the potential impact of scaling up some of the measures and dynamics in the modelled scenarios for GM, which have been discussed in the preceding sections.

Table 7:9 shows the projected percentage change, from 2010 levels, in traffic km for large urban areas up to 2035. It demonstrates a projected growth in car km of 32.2% and a reduction in bus km travelled (PSV) of 3.2% by 2035, taken from the DfT road traffic forecasts (Department for Transport, 2013b). The term ‘large urban area’ is used here in accordance with the definition of urban that was given in Section 1.5.

Table 7:9 - Percentage change in traffic km in large urban areas from 2010 levels (Department for Transport, 2013b)

Vehicle Type	2015	2020	2025	2030	2035
Car	2.8%	11.4%	20.5%	26.6%	32.2%
LGV	6.3%	21.4%	37.1%	52.2%	65.8%
Rigid	-5.1%	-2.0%	0.2%	3.6%	5.8%
Artic	-3.6%	1.0%	5.6%	10.5%	15.8%
PSV	4.2%	4.2%	1.6%	-0.8%	-3.2%
All Traffic	2.9%	12.1%	21.7%	28.8%	35.2%

In the reference case model runs for GM, the increase in car vkm between 2013 and 2035 is around 24%. While this is a shorter time horizon than 2010 to 2035, it still demonstrates a lower level of growth in car vkm in the model results than those shown in Table 7:9. When the data for the North West region is examined, the growth in car vkm between 2010 and 2035 is found to be 29% (Department for Transport, 2013b), which is closer to the value found in the GM model runs, suggesting the difference may be down to regional variation. It is interesting to note here that Scenario 1 A – Shared Automobility, projected a 32% decrease in car travel by 2035 as a result of increased vehicle occupancy rates bought about by growth in car sharing, reducing car travel by 1.6% per annum, see Table 7:2. In the modelling, taking into account growing demand, this translates to a reduction in vkm of 35% compared to the 2035 reference case. This suggests that potential increases in car sharing, as calculated in the present work under Scenario 1 A – Shared Automobility, could help to offset projected growth in car km between now and 2035, which is critical, as improvements in vehicle technology are often undermined by increasing demand (Hickman et al., 2012). If the policy measures and dynamics suggested in the Shared Automobility (1A) Scenario could be realised and implemented at the scale of all the metropolitan areas in England, which account for about 12% of national CO_2 emissions, then the impact could be substantial. This could contribute to emission reduction targets for transport. The other modelled scenarios had a smaller impact on vkm travelled and CO_2 emissions but if they were scaled up to cover metropolitan areas in England, then the sum impact of these benefits could contribute further to emission reduction efforts. It is also interesting to note the reduction in passenger vehicle traffic (PSV in Table 7:9) by 2035. Some of the measures modelled, particularly in Scenario 2, could help to stem this decline in public transport use and offset some of the projected growth in car traffic. In addition, the combining of a number of these policy measures could have a greater impact on the resulting emissions and vkm travelled, for example, by coupling together policy initiatives to encourage car sharing and modal shifting to public transport.

This section has made some suggestions of the potential impact of scaling up the scenarios developed and modelled in the present research to metropolitan areas in England. However, it is beyond the scope of the present work to analyse the wider implications of these scenarios for future transport emissions at this scale. The framework and scenarios developed could be applied to other areas, and even urban areas in other countries. This represents an interesting area for further work, which is discussed in more detail in Chapter 9-.

7.4 Induced congestion and rebound effects

Induced congestion and rebound effects have been discussed elsewhere in previous chapters of this thesis see Section 2.2.1. Induced congestion occurs where traffic is alleviated through additional capacity creation and additional traffic moves in to use this additional capacity (Goodwin, 1996a, Hidalgo et al., 2013). Direct rebound effects occur when the cost of a service reduces, and there is an increase in the use of that service as a result, e.g., driving further because it costs less per km (Macmillen, 2013). Indirect rebound effects can also occur, where the cost savings made through the reduced cost of a service are then spent on a different activity, which may offset the benefits, for example, going on holiday (Sorrell and Dimitropoulos, 2008).

This section explores the potential rebound effects, that could occur in association with the scenarios modelled in this chapter, in order to suggest the risk of improvements in emissions being offset through induced demand. This is critical in assessing the potential of enhanced use of excess capacity to contribute to emission reductions, as there seems little value in increasing load factors to reduce traffic if this is then offset by induced demand.

7.4.1 Rebound effects

As suggested above, rebound effects occur as the cost of service reduces and demand for that service then increases. In the scenarios modelled, transport costs reduce through two mechanisms. First, the increased efficiency of vehicles in the future, brought about through more stringent emissions standards and incremental improvements, mean that the cost per km of driving will decrease. The projected improvement in emissions performance of the vehicles can be seen in Figure 7:2. Second, as congestion is alleviated through some of the mechanisms modelled, the time cost associated with travel will also decrease. Sorrel (2007) collated research on rebound effects and Table 7:10 shows the estimates for long run direct rebound effects for personal automotive transport.

For Scenario 1 A, Shared Automobility, which is the only scenario to deliver a significant reduction in emissions and vkm, it is possible to estimate what impact a 10% and a 30% rebound effect would have on the results. 10% and 30% are selected because the average value of studies reviewed by Sorrell (2007) is found to be in between these values. It should be noted that the studies reviewed by Sorrell are in the USA, however, the illustration of the impact of the rebound effects is still valid. As this is a long-run rebound effect, the values for Scenario 1 A in 2035 are evaluated.

In Scenario 1A, the vkm travelled in 2035 is 19% lower than in the reference case and the CO_2 emissions are 35% lower, see Table 7:3 and Table 7:4. If a 10% rebound effect was seen on vkm, the vkm results would increase from 10,323km in the model outputs to 10,861km. Given a 30% rebound effect this would increase further to 11,939 km. This clearly offsets some of the benefits of the policy measures that are being modelled in Scenario 1A, however, it is clear that the results are still an improvement on the reference case and help to deliver a positive impact of travel demand, and the environmental impact.

Table 7:10 Estimated long run direct rebound effects for personal automotive transport (Sorrell, 2007)

Study	**Detail**	**Long-run rebound effect**
Johansson and Schipper (1997)	Data taken for 12 OECD countries, over the time period 1973-1992, uses International Energy Agency (IEA) data for fuel prices	30%
Haughton and Sakar (1996) Small and van Dender (2005) / Small and van Dender (2007)	Looks at the USA over the period 1970 to 1991 Examines US states between 1966 and 2001	22%
Goldberg (1998)	Uses a discrete choice model to assess impact of Corporate Average Fuel Economy (CAFE) standards in USA, using customer expenditure data for 1984-1990	50%
Puller and Greening (1999)	Takes Energy Information Administration (EIA) data over 15 years to produce an econometric estimation of rebound effect in the USA	87%
Greene et al (1999)	Looks at household responses to gasoline price changes in the USA over a 9 year period	23%
Average of 17 studies reviewed by Sorrell (2007)		Between 10% and 30%

7.4.2 Induced congestion

Section 2.2.2 presented equations for induced congestion from Hymel et al (2010), using a model developed by Small and van Dender (2007), which are repeated below:

$$M = M(V, P_M, C, K1, X_M)$$

$$V = V(M, P_V, P_M, X_V)$$

$$E = E(M, P_F, R_E, X_E)$$

$$C = C(M, K2, X_c)$$

[Equation 2.1]

Where M = vehicle miles travelled (VMT) and is a function of V = vehicle stock, P_M = per-mile cost of driving, C = congestion, $K1$ = accessibility-related road capital stock and X_M = exogenous factors. P_M is equal to P_F = price of fuel, divided by E = fuel efficiency and is endogenous. V is a function of P_V = price of a new vehicle, P_M and X_V = exogenous factors. E is a function of M, P_F, R_E = regulations and X_E = exogenous factors. C is a function of M, $K2$ = urban road capacity, and X_C = exogenous factors (Hymel et al., 2010). These equations are presented as a causal loop diagram (CLD) in Figure 7:3.

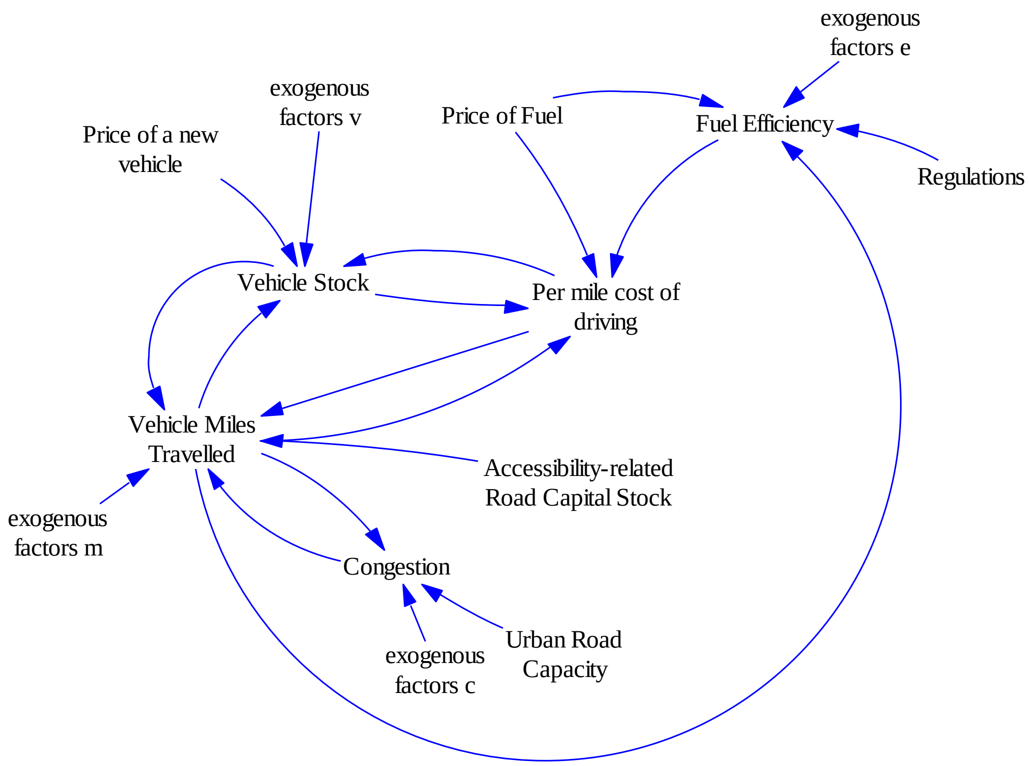

Figure 7:3 - CLD for induced congestion (based on Small and Van Dender (2007) and Hymel et al (2010))

Figure 7:3 demonstrates the complexity and interconnected nature of induced congestion effects. In the present work, the full range of variables needed to calculate the induced congestion effects for the scenarios modelled are unavailable. Therefore, a value of 5.7% is taken from Goodwin (1996a) in order to estimate the impacts of induced congestion on the results of the modelled scenario results. Given a 5.7% rebound effect, the modelled vkm in Scenario 1A would increase from 10,323 km to 10,630 km. This is a smaller increase than that seen for the rebound effects in the previous section, however, it should be noted that these effects are not mutually exclusive, they have some common aspects, therefore may act together to offset the reductions in vkm delivered through the policy measures modelled. In fact, the impact of the cost of driving can be seen in Figure 7:3 and reductions in the cost cause rebound effects. This section has demonstrated that the impacts of induced congestion and rebound effects will likely offset some of the benefits of making enhanced use of excess capacity, however, the reductions in vkm against the reference case, of Scenario 1A, still delivers valuable benefits.

7.5 Chapter summary and conclusions

This chapter has developed the pathways presented in Chapter 6- into scenarios for network modelling. These scenarios have then been modelled in TfGM's SATURN and EMIGMA models, the results of which have been analysed and discussed in this chapter. This final section draws together the key findings, providing conclusions in the context of the research questions, and makes policy recommendations based on these conclusions.

7.5.1 Chapter key findings

Some of the key findings from this chapter include:

- Across all four modelled scenarios, no significant increase in vkm travelled and CO_2 emissions are found and congestion does not worsen, when compared to the reference case. This suggests that the dynamics and policy measures that underline the scenarios either achieve the same situation found in the reference case or improve the situation. However, as suggested in Section 7.2, the full dynamics of ITS are not captured in Scenario 1 B – Intelligent Automobility, therefore the could be unforeseen impacts such as increases in vkm with the roll out of automated vehicles.
- Within the modelled Scenario 1 B – Intelligent Automobility, trip matrices were not adjusted. All other scenarios show a reduction in the numbers of cars travelling in the network and increases in the numbers of buses, compared to the reference case, over the modelled time periods (see Table 7:5 and Table 7:6). This suggests a positive trend, as a result of the policy mechanisms and dynamics in the scenarios, towards an improved share of public transport. However, despite these improvements, due to the continued dominance of private car, the impact on vkm and emissions remains small. This is also demonstrated by the 13% increase in public transport trips in 2035 under Scenario 2 – Public Mobility, which results in a reduction in CO_2 emissions of less than 1% compared to the reference case in 2035.
- Scenario 1 A – Shared Automobility demonstrates the most significant changes to vkm (see Table 7:3) and CO_2 emissions (see Table 7:4) when compared to the reference case, and has the most positive impact

on the mode share of bus and car (see Table 7:8). This suggests that the dynamics and policy measures that underlie the narrative of this scenario have the greatest impact on the sustainability of the urban transport system. The use enhanced use of excess capacity under this scenario, through increased vehicle occupancy, is also significant. In addition, Shared Automobility offers substantial potential to offset much of the forecast growth in demand, which DfT estimates at a 32% increase for car vkm in urban areas in 2035 (Department for Transport, 2013b).

It should, however, be recognised that these results are subject to the limitations of the modelling approach and the assumptions made in modelling the scenarios. Table 7:2 has a column which shows some of the limitations and assumptions behind the modelling. The results suggest that Shared Automobility offers the greatest potential CO_2 emission reductions, however this may be largely down to the assumptions made in characterising the scenario.

It is also important to note that these pathways are not mutually exclusive and it is highly likely that policy mechanisms from each of them will be visible in the transport system but perhaps not one of these distinct pathways will emerge. Hence a mixture of the costs and benefits associated with these scenarios could be seen in the future transport system. The interviews in the chapter which follows capture some of the interconnections between the policy mechanisms in the different scenarios.

7.5.2 Policy recommendations

Some policy suggestions are now made, based on the results presented in this chapter and the conclusions drawn in the findings above.

- The results suggest that Shared Automobility (Scenario 1A) demonstrates the biggest potential impact on emissions, with a 34% reduction in vkm and a 35% reduction CO_2 emissions in 2035, compared to the 2035 reference case. While this result may be somewhat contingent on the modelling assumptions used to characterise the scenario, the volume of CO_2 emission reductions indicate the magnitude of unused capacity and the potential for these sharing interventions to contribute to a more sustainable transport system. This offers a significant opportunity for policy makers to implement interventions to encourage sharing to increase vehicle occupancy, and could yield valuable emission reductions, have a positive impact on congestion and help to offset future growth in demand as projected by DfT (Department for Transport, 2013b). Potential policy mechanisms to encourage these changes in behaviour could include, information campaigns and smarter choices approaches, support for the technologies which facilitate car sharing and even economic measures such as variable road pricing depending on the occupancy rates of a vehicle (see Yang and Huang (1999) for examples of pricing for HOV lanes etc.).

- Whilst the other modelled scenarios do not demonstrate the magnitude of impact on emissions and vkm travelled that are seen for Shared Automobility, the policy measures that underlie the dynamics of these scenarios could be coupled with other approaches and integrated into a system wide approach for sustainable urban transport. As these scenarios are not mutually exclusive, policy measures from different scenarios could be combined or pursued in parallel.

This chapter has assessed the potential for enhanced use of excess capacity to reduce emissions from transport in GM, using the four scenarios that have been developed in the present work. The scenarios have been shown to have varied impacts on CO_2 and vkm in the network, however, they have generally demonstrated a neutral or positive impact on the sustainability of the urban transport system analysed. Chapter 8-, which follows, takes the policy recommendations that have been made in this chapter and throughout the thesis, and examines them through interviews with policy and decision makers. Chapter 9- connects these conclusions and findings with those of the other chapters in this thesis to provide the final conclusions and sets out possible areas for further work.

Chapter 8- Practitioner opinions of policy recommendations for enhanced use of excess capacity in urban transport

Throughout this thesis recommendations have been made about how the findings of the research could be used in policy making to deliver enhanced use of transport capacity and deliver CO_2 emission reductions. These policy recommendations have been discussed through interviews with practitioners in the transport sector to understand their potential, and results of these interviews are presented and discussed in this chapter. First, an overview of the policy recommendations that have been made in earlier chapters is presented. This is followed with the interview design and approach and then an analysis and discussion of the outputs is provided. This chapter addresses research question 3: "*How could more effective use of excess capacity be facilitated in order to reduce emissions*?".

8.1 Policy recommendations emerging from the research

Chapter 4- explored current travel behaviour and capacity use, from data collected through the survey of 500 residents of Greater Manchester (GM). The main policy recommendations emerging from this chapter were as follows:

- Car sharing represents a significant opportunity for transport planners to reduce emissions;
- Work related trips, including business travel and commute trips, have the highest levels of excess capacity associated with them. Therefore workplace travel planning could represent an opportunity to introduce mechanisms that reduce the excess capacity associated with this; and
- Younger people (those aged under 35 years old) show greater flexibility in their travel behaviour than older people, including willingness to car share and adjust journey departure times, so policy mechanisms could be targeted at this demographic.

Further details on the policy recommendations made in Chapter 4- can be found in Section 4.4.2.

Chapter 5- looked at survey data related to future travel behaviour in order to understand how people perceived they might travel in the future and how that may influence urban transport excess capacity and CO_2 emissions. The main policy recommendations from this chapter were:

- Travel behaviour is influenced by key life points and this could be used to maximised the impact of policy interventions;
- Younger people were again identified to be more flexible then older people in their travel behaviour and policy recommendations could be targeted as such, potentially locking in the benefits of more sustainable behaviours; and
- There is a gap between the perception and reality of travel costs, and this could be addressed through policy interventions in order to influence travel behaviour.

More detail on the policy recommendations emerging from the research in Chapter 5- can be found in Section 5.6.3.

Chapter 7- presented the results of the traffic network modelling of scenarios that were developed in Chapter 6- using the survey data and key trends in transport policy. The main policy recommendation from this chapter was that shared transport offers an opportunity for delivering reductions in car travel and resulting CO_2 emissions, in line with other research (Cairns et al., 2008, Jacobson and King, 2009, Minett and Pearce, 2011). This could be through soft measures, such as information campaigns or workplace travel planning, or supported with hard infrastructure measures, such as HOV lanes. However, rebound effects must be considered and attempts to lock in the benefits of any interventions are important. Re-regulation of public transport, through devolution of powers to local authorities, emerged as a key trend in the literature reviewed in Chapter 2-, and was explored as a key mechanism for increasing the mode share of public transport in Chapter 6-. This area of policy is explored further in the interviews presented here.

The policy recommendations that have been made throughout the present work are drawn together into five key areas to be examined through the interviews. These are:

1. Younger people demonstrate increased flexibility, ability to work from home, willingness to adjust their departure times and willingness to car share. Marketing to encourage behaviour change in these areas could be specifically targeted at this demographic in order to maximise impact.
2. Coupling interventions to influence travel behaviour, with changes in life circumstances could maximise the changes in behaviour and lock in those changes, as demonstrated in the literature (Verplanken et al., 2008). This could involve offering new employees free public transport passes for the first month in order to encourage public transport mode choices as new habits are being formed. Public transport options could be made more prominent on online house searching platforms.
3. Re-regulation of public transport and devolution of powers to local authorities offer opportunities to improve information provision about transport options and address the gaps between reality and perceptions of different transport modes.
4. Workplace and school travel planning offer opportunities to address gaps between perceptions and reality relating to relative costs and service between modes, and offer opportunities to facilitate car sharing, as sharing with colleagues helps to overcome safety concerns. These are most effective where they are supported by local authorities.
5. Casual carpooling has been a successful way of encouraging car sharing in some cities in the USA. This involves people offering rides in their vehicles from a public transport station or other location, without any pre-arrangement, in order to take advantage of 2+ lanes or save costs. This can be supported through technology and could be trialled in the UK, where appropriate 2+ lanes exist.

Section 8.2, which follows explains how these policy measures are explored through interviews with experts and practitioners in the urban transport sector.

8.2 Interview design and approach

The interviews that have been conducted and are analysed in this chapter address research question 3, and have the following additional aims:

- To understand the feasibility and acceptability of the suggested policy recommendations;

- To identify potential barriers to uptake and effectiveness of these policy recommendations.

In order to explore the areas outline above, 11 interviews were conducted with a range of stakeholders, Table 8:1 shows the participants, date of interview and whether it was conducted face to face or over Skype.

Table 8:1 - Interview details

ID	Role	Date	Interview type
A	Director of an organisation that represents transport consumers	04/07/2016	Face to face
B	Transport officer from a large organisation	08/07/2016	Face to face
C	Policy officer, transport NGO	08/07/2016	Skype
D	Representative of a new mobility business	14/07/2016	Face to Face
E	Representative of an international transport NGO	15/07/2016	Skype
F	Representative of a local authority	27/06/2016	Face to face
G	Policy officer, transport NGO	13/07/2016	Skype
H	Non-academic policy researcher	18/07/2016	Face to face
I	Academic researcher in environmental policy	27/07/2016	Face to face
J	Representative of a large transport authority	05/08/2016	Face to face
K	Non-academic policy researcher	08/08/2016	Face to face

Participants were recruited from the author's network of contacts across the industry, and while this sample might not be wholly representative of all views in the sector, it provides a broad range of perspectives and a rich dataset for analysing the questions and aims outlined above. Section 8.3.1 provides an overview of the participants' policy priorities which were asked at the beginning of the interviews using the following structure:

On a scale of 1 to 5, 1 being unimportant, 5 being very important, rate the importance of the following transport policy areas:

- Environmental impact

- Accessibility
- Social inclusion
- CO_2 emissions
- Congestion alleviation
- Air quality
- Public health
- Economic growth

Prior to the interviews, participants were provided with information about the policy recommendations from the present work, which have been synthesised into five key areas as shown in Section 8.1. The interviews took a semi-structured approach, collecting both qualitative and quantitative data, using the following structure:

For each policy measure:

- On a scale of 1-5, how practicable do you think this policy measure is (1 being very impracticable and 5 being highly practicable)?
- On a scale of 1-5, how politically acceptable do you think this policy measure is?
- On a scale of 1-5, how useful do you think this policy measure would be in achieving transport goals?
- On a scale of 1-5, how applicable do you think this policy measure would be in your local context? (if applicable)
- Can you identify any potential barriers to the implementation of this policy measure?
- Do you have additional thoughts, or reactions to this suggested policy measure?

Subsequent to the interviews taking place, the recordings were transcribed and the quantitative data transferred to a spreadsheet for analysis, the results of which are presented in Section 8.3. The quantitative responses collected during the interviews are indicative of the opinions of the participants, and provide an illustration of the practicality, acceptability and usefulness of the policy measures.

The interview transcripts have been analysed using the NVivo software (QSR International, 2014). The interviews have been coded using a grounded theory approach (Strauss and Corbin, 1997), which allows themes to emerge from the interview responses. This approach has been taken to reflect the way that the policy recommendations have emerged from the analysis in the present work, and also to allow full expression of thoughts and opinions of interviewees. This also provides a contrast to the constrained responses of the quantitative questions and reflects the mixed methods approaches adopted throughout this thesis, see Section 4.1.

The interview design has been subject to ethical review in accordance with the University of Leeds ethical review policy and the ethical approval record can be found in Appendix D – Example interview transcription.

8.3 Interview results

The following section presents the results of the interviews, first providing the policy priorities of participants and then taking each policy measure in turn. The quantitative results are presented first, to show how the interviewees rated the policy measure in terms of practicality, political acceptability and usefulness. Four interviewees were asked about the local applicability of the policy measures, as this was relevant to their specific role and professional remit. The barriers are then discussed and highlights of the qualitative data from the discussions are presented. It should be noted that where quotes are provided, these are verbatim from the interview transcripts. These are drawn together and summarised in Sections 8.3.7 and 8.4.

8.3.1 Policy priorities of interview participants

Prior to the main body of the interview questions, participants were asked to rank a series of policy areas in order of importance. This section presents the results of these questions in order to give context for the results which follow.

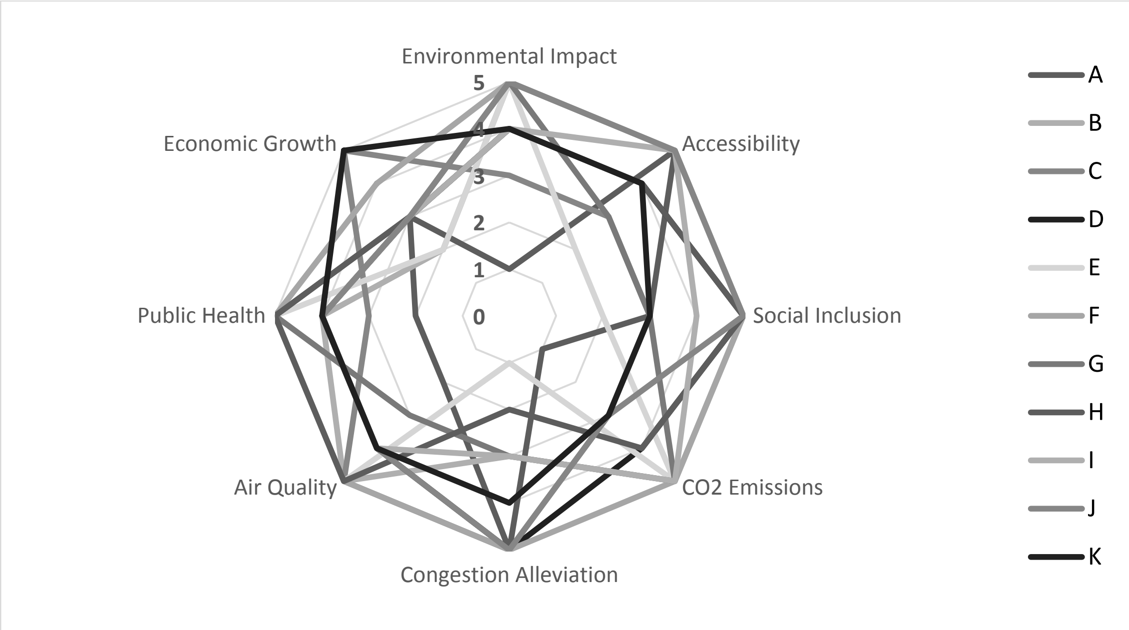

Figure 8:1 - Policy priorities of interview participants (A-K)

The interview participants demonstrated a wide range of key policy priorities, and Figure 8:1 shows these on a radar plot, with each line representing an individual interviewee and each spine showing a different policy area. The broad set of priorities shown by interview participants demonstrates the spectrum of stakeholders interviewed for the present research and the breadth of opinions and expertise that are incorporated into the following analysis.

8.3.2 Younger people's travel flexibility

This section explores responses to the policy suggestion that younger people demonstrate greater flexibility than older persons in terms of their willingness and ability to adjust departure times and car share, and that interventions could be targeted as such to maximise their impact.

This policy measure scored highly on practicality and political acceptability, averaging 4.4 and 4.6 respectively. However, scores for usefulness were lower, with an average score of 3.3. Figure 8:2 shows the scores given by the interview participants for these areas on a radar plot. For local applicability, this measure achieved an average score of 4.

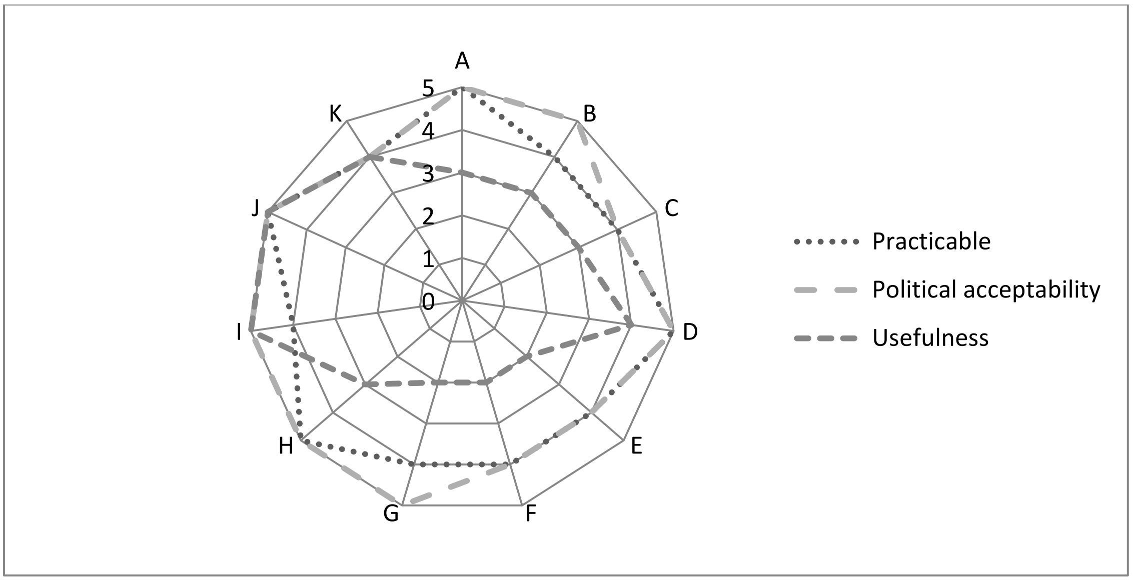

Figure 8:2 - Participant responses for policy measures on younger people's flexibility

Stakeholders interviewed reflected the findings of the survey that younger people have greater flexibility in their travel behaviour through examples including:

"it is much easier for people to be flexible when they're younger because they don't have the same level of demands on them and particularly demands on their time…" [E]

While it was generally accepted by participants that younger people have greater flexibility in their travel behaviour due to fewer commitments, concerns were raised by half of interviewees around the acceptability of flexible and home working arrangements. Examples include:

"whilst more flexible working has become the norm, we're proving remarkably resistant as a society to sort of disperse working at home culture, we thought we might be in 20 years ago." [A]

"the other constraint is workplace attitudes really, it's employer attitudes, which are still in many cases remarkably antiquated with regard to working arrangements, starting times and things like that, attitudes to homeworking. Some employers are very enlightened, many are not…" [E]

In addition, it was raised that it may be easier for some younger people to adjust their travel behaviour than others, depending on their working patterns and other commitments:

“so if they are students I could see it being a lot easier than if they were… if they are working shifts or in, sort of fixed hours or… if they have childcare commitments…” [G]

These points could represent a barrier to the effectiveness of targeting younger people’s travel, in order to influence travel time, mode choice and to encourage homeworking. These responses could also be somewhat gendered, as Chapter 5- showed that family commitments were of greater importance to female survey participants.

However, as several interviewees suggested, even adjusting the behaviour of a small share of individuals could impact on congestion and emissions from transport:

“*You know if you can get people to work flexibly one day a week that would probably reduce a lot of challenges.*” [F]

One participant raised the point that targeting younger people to influence behaviour has the advantages of engaging with people who may not have fully formed travel habits yet:

“*aiming it at younger people yet again who perhaps don’t yet have a car or a driving licence and who are more willing to think of transport in terms of a commodity, rather than having all the emotional attachments to a car…*” [C]

This links to the following point around policy interventions and life change points, which are aimed at disrupting travel habits, however, as suggested above, engaging with younger people could help to influence travel behaviour prior to set habits being formed.

8.3.3 Combining policy interventions with life change points

This section explores the recommendation made in the present work that policy interventions could be coupled with life change points in order to maximise behaviour change and lock in those changes.

Figure 8:3 shows the participant scores for practicality, political acceptability and usefulness for combining policy interventions with life change points. This policy measure scored highly in terms of political acceptability, with an average of 4.5. For usefulness, this measures scored 3.9 on average, but scored lower on practicality, with an average of 3.6, as it was seen to be more challenging to target and deliver. This measure scored an average of 4 for local applicability.

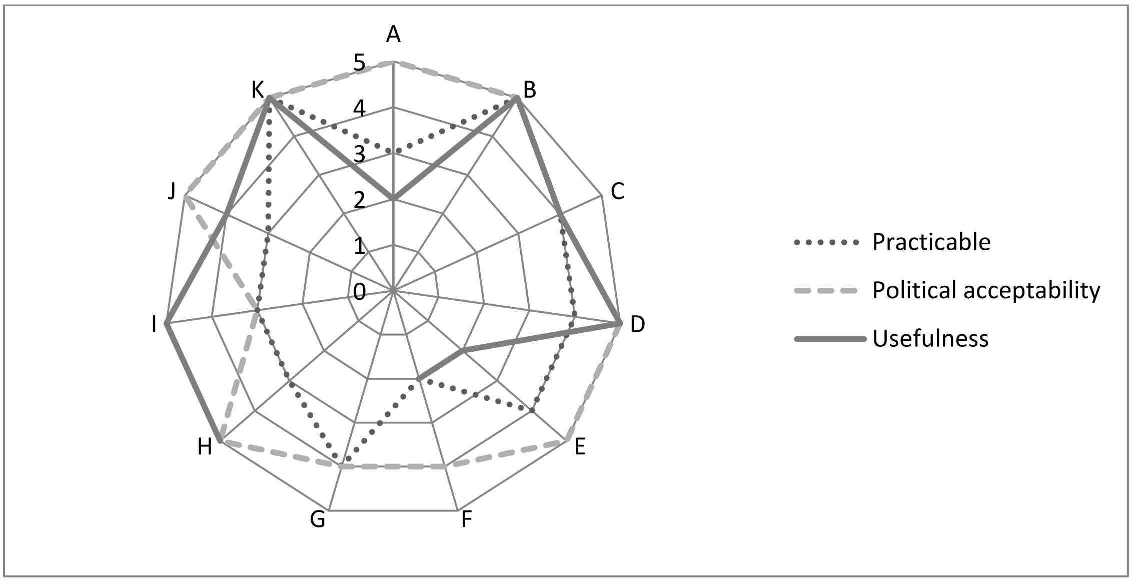

Figure 8:3 - Participant responses for combining interventions with life change points

This policy measure elicited a range of responses from the interview participants. Several respondents were concerned about the embedded nature of peoples travel habits, the challenges of engaging with people at the right time, and the fact that life change points are often already stressful times:

"getting the information to people at the right time it's quite hard…" [A]

"at key times, the changes in life, are the most stressful times…" [I]

"I think it's probably slightly more difficult than you think, and I suspect people in the midst of those sorts of events, the last thing they think about is you know, how I'm going to get to work, because actually a lot of people will be driving anyway." [A]

While these examples raise some concerns and potential barriers for influencing travel behaviour at life change points, other participants provided examples of where this has already been achieved through the planning process or working with housing developers

"New developments are often encouraged to give away free passes, it's part of a Section 106 agreement." [D]

"we know transition points in life like moving house/ new jobs offer chance to form new habits. Plus already examples working in practice, for example residential metrocard in West Yorkshire for new housing developments…" [K]

There are clearly logistical challenges in targeting people's travel behaviour at life change points, however, as the interviews suggest, there are benefits to working at these transition points that can help to maximise the behaviour change achieved and adjust travel habits. This reflects evidence in the wider academic literature that points of change in life circumstances can be effective times at which to influence travel behaviours (Verplanken et al., 2008).

8.3.4 Re-regulation of public transport and devolution of powers

This section looks at how interviewees responded to the policy recommendation that public transport could be re-regulated with devolved powers to local authorities, and the potential that this has for improving capacity use and sustainability in urban transport systems.

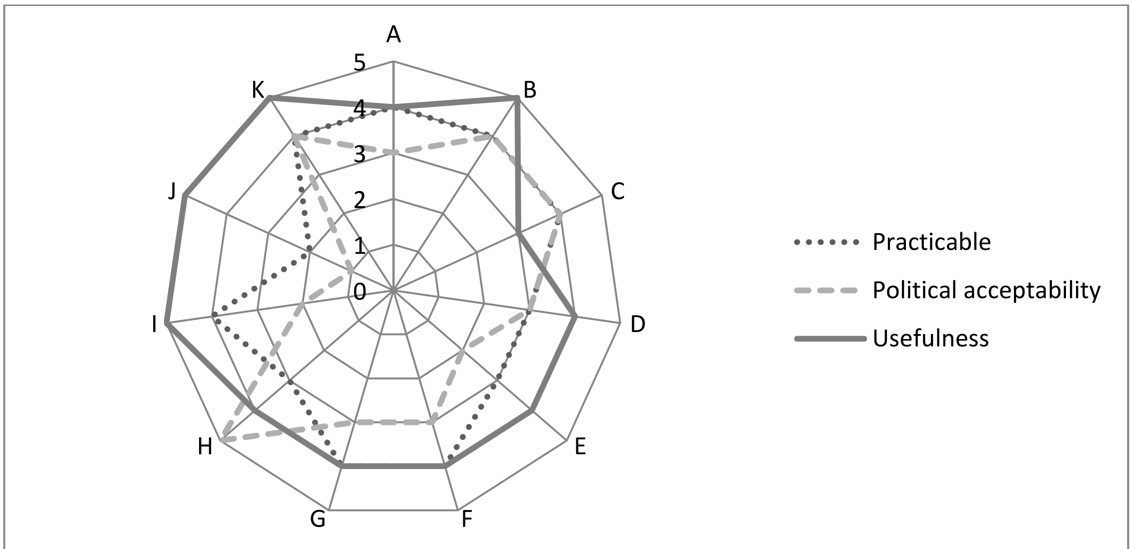

Figure 8:4 - Participant responses for re-regulation of public transport

Re-regulation of public transport and devolution of transport powers was generally seen as practically and politically challenging, scoring an average of 3.5 and 3.1 for these respectively. However, it was clearly identified as useful, scoring an average of 4.3 by participants, and locally applicable, with an average of 4.5. The scores for this measure can be seen in Figure 8:4.

A range of concerns were raised by participants about the regulation of transport networks and devolution of powers to local authorities, particularly around the barriers and the difficulties around challenging private companies in order to regulate or franchise public transport:

"there are obstacles, they're probably not party politically but broader obstacles in the sense that there are obviously interests at play that are apparent…" [H]

"the kind of incumbency of the private companies that provide bus services and they will be reluctant to either potentially lose income or control…" [G]

"private operators will resist efforts to regulate as seen in Tyne and Wear's QCS [Quality Contract Scheme] *proposal."* [K]

However, interviewees provided examples of the ways that current trends are moving towards devolution of powers and that new legislation could make the management of local transport networks easier, through the Bus Services Bill (Prime Minister's Office, 2015):

"Obviously, devolution's is happening. Manchester, for example, is a good example where devolution is definitely happening but we're not necessarily seeing more powers being created, we're just the shifting of the existing power…" [I]

"Well it's just about to become more practical, if the Buses Bill goes through." [A]

Despite the concerns outlined above and the lower scores for practicality and political acceptability, many of the interview participants suggested that they thought that regulation of transport and increased local powers could have a significant impact on the transport system:

"Regulation could have the biggest impact on shifting behaviour through improvement of service quality." [B]

"we need much more local management of transport…" [E]

"Regulation and having a coherent and single transport network is probably the biggest thing that we could do." [H]

"Definitely more devolution is the way to go with more powers for locally accountable transport authorities to plan public transport in the interests of people rather than profit. The City Deal and Buses Bill show we are moving the that direction." [K]

While re-regulation of transport and devolution are challenging, and have been shown to score low on practicality and political acceptability, it is apparent that participants perceived that it could have a significant positive impact on local transport and on capacity use and sustainability in urban transport systems. This reflects the evidence used in the construction of Scenario 2 – Public Mobility, in Section 3.2.5, which suggests that the impact of regulation of public transport in London has been effective in delivering quality of service and high modal share for public transport (Transport for London, 2015b, Transport for London, 2015a). Whilst challenges remain, the general policy trend in the UK is for greater devolution of powers to local transport authorities and for increasing control over their public transport systems (HM Government, 2009, Raikes et al., 2015).

8.3.5 Workplace and school travel planning

This section explores policy recommendations around workplace and school travel planning. The potential this has to address the gaps between perceptions and reality relating to public transport, and hence encourage these more sustainable mode choices, is examined.

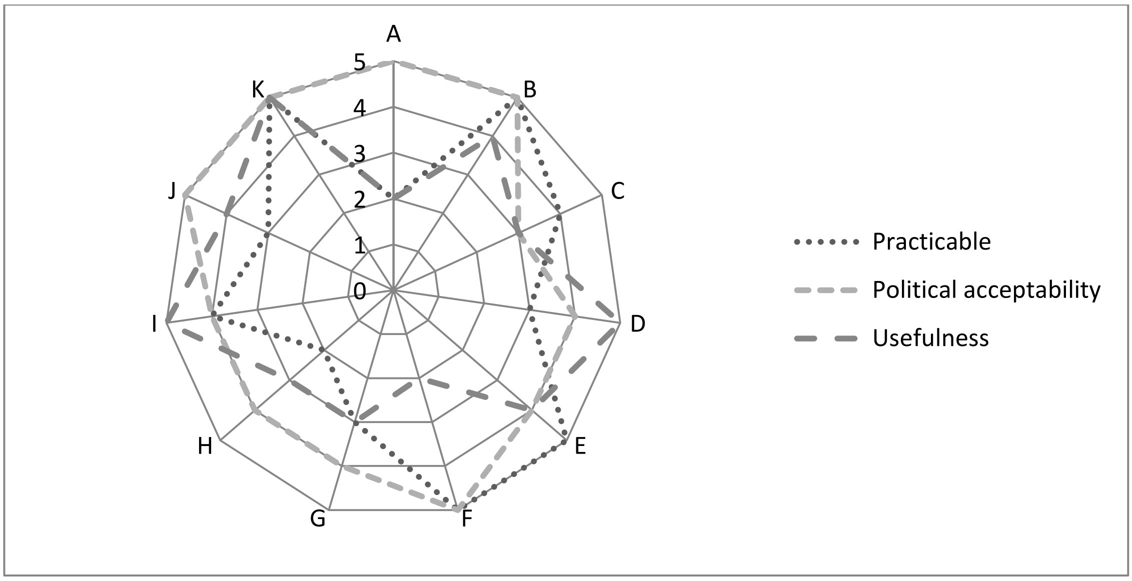

Figure 8:5 - Participant responses for workplace and school travel planning

Scores given by participants for workplace and school travel planning can be seen in Figure 8:5. This measure saw an average score of 3.7 for practicality, 4.4 for political acceptability and 3.6 for usefulness. In terms of local applicability, this measure saw an average score of 5, suggesting that those participants with a local responsibility saw this as a highly relevant measure for their areas.

A range of responses emerged with interviewees around the value and effectiveness of workplace and school travel planning. A key point raised for both workplace and school travel planning was:

"you've got to have really clear leadership in a school or a workplace for this to work…" [F]

In terms of school travel planning, a number of barriers were raised by interview participants, including the lack of resource in schools for addressing travel issues, and the fact that school related travel is often part of a longer trip chain, thus difficult to influence:

"I think the main barriers are often that schools and teachers are just immensely busy." [E]

"people by and large take the car not because they want to drive the kids to school, it's because they need the car for the next stage of their journey." [A]

In terms of workplace travel planning, participants suggested that there are a number of ways in which workplace travel planning is undertaken, through the planning process and at other times, and for reasons including corporate social responsibility:

"There's a lot of work that goes into travel planning at the early stage of the planning process…" [J]

"new employers if they're in the business of asking for planning permission, they get a travel plan as part of their planning permission…" [F]

"bigger companies probably have sort of corporate and social responsibilities where they do actually think a bit more about you know the impact…" [A]

A concern raised by interview participants was that often travel plans are undertaken as part of a planning application, however, the results are often not monitored so it is difficult to know the level of sustained change as a result:

"they never actually go back and measure the impact that it's actually had and the impact of workplace and travel planning…" [J]

However, if interventions are being made in the establishment of new workplaces, or movement of employment locations, then it is possible that they could be occurring at life change points, explored above. This could maximise any shifts in behaviour leveraged through workplace travel planning.

A range of views have been expressed about school and workplace travel planning. Generally, despite the barriers and concerns raised, it is clear that these type of approaches can have value for influencing travel behaviour, and if coupled with some of the measures mentioned earlier in coupling interventions with life change points, such as working with housing developers, there is potential for these to be effective in improving transport capacity use and sustainability. Evidence from the literature supports the finding that travel planning offers potential for improving the sustainability of the transport system, with Cairns et al showing that in local conditions smarter choices, of which travel planning is one part, can deliver emission reductions of up to 20% (2008).

8.3.6 Car sharing and 'casual carpooling'

This section looks at the potential of car sharing and casual carpooling, to improve the capacity use within an urban transport system. Measures that could be used to encourage these practices include 2+ or high occupancy vehicle (HOV) lanes, or support for technological interventions, such as mobile app development.

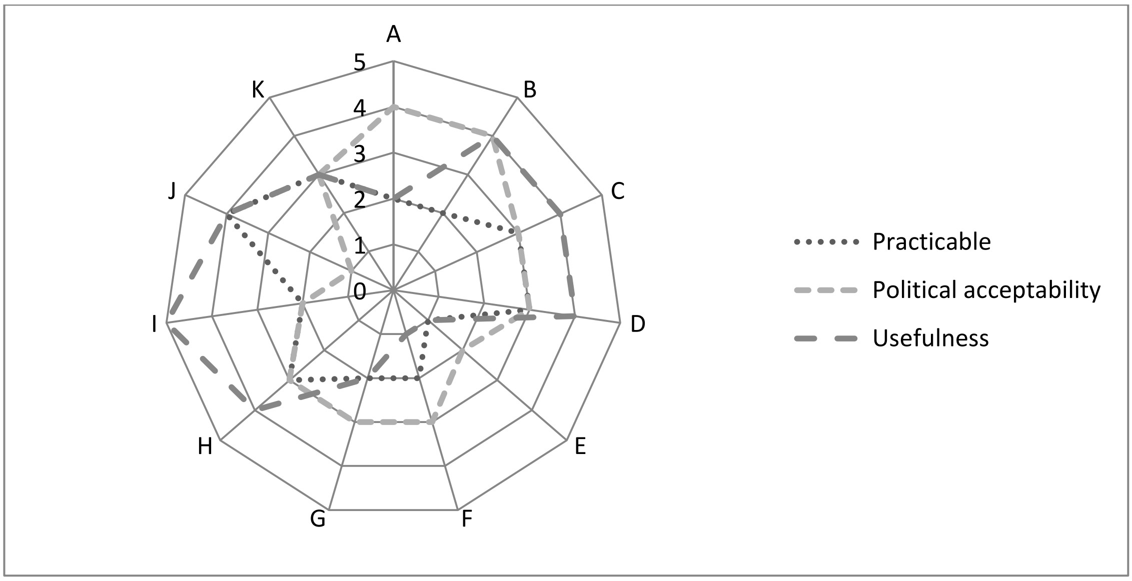

Figure 8:6 - Participant responses for car sharing and casual carpooling

This measure scored the lowest for political acceptability and practicality, with an average of 2.5 and 2.8 respectively. Usefulness was seen as slightly higher, with an average score of 3.1. These scores can be seen in Figure 8:6. In terms of local applicability, this measure scored an average of 4.5.

This policy area raised many concerns for interview participants, however, there were examples of positive responses and potential for this to influence the transport system. The changing dynamics of this area, with regards to the sharing economy was raised:

“That point is particularly applicable to previous generations, about willingness to share, but in the Uber, Airbnb generation, this is a whole new context.” [I]

This is interesting as the sharing of transport is emerging as part of the wider changes around sharing resources across the economy. Some interview participants suggested that the addition of other policy measures, such as congestion charging, could have a positive impact on the viability of car sharing as a policy, while others gave examples of sectors where car sharing is already being used:

“it has to come alongside with the other things that you mentioned, so congestion charging…” [H]

“anecdotally you see a lot of builders and trades in London, you know, travel ... car sharing so you see a car full of lads all heading off to a construction site really early in the morning. And that, again I think that is because public transport isn’t so widely available at that time.” [G]

In terms of casual car sharing, which takes away the formal arrangements associated with car sharing, one interviewee suggested that at an organisational level, the value of removing commitments associated with car sharing could encourage participation:

“Benefits of taking away the commitment associated with car sharing…” [B]

A range of concerns and barriers to car sharing were raised by interview participants, and these reflect those shown in the survey data, see Section 4.4 and in the literature more widely (Furuhata et al., 2013, The AA, 2010) (see Section 2.3.2 for more):

“being in a car is very, very, personal space and it’s… I don't know if necessarily safety, than just the kind of feeling in control, that you’re having to talk to somebody, you’re forced to talk to…” [A]

“Safety will remain the biggest concern…” and *“patchy nature of 2+ lanes…”* [B]

“the personal safety of jumping in a car with someone else, I think there is probably gender issues with that, so I would imagine that there might be safety concerns…” [G]

“concerns about safety, the concerns about reliability, you know concerns about cost, actual or hidden. Concerns about insurance, all that kind of stuff.” [F]

An additional dimension of the safety concerns around car sharing is any political engagement with this as a policy measure and worries that if there is an incident they would be associated with this:

“the politician might say I don’t want to put my name here because if there’s one incident… I am going to be directly associated, so it’s quite a downside risk…” [H]

It remains to be seen to what extent trends around the sharing economy, coupled with new technological applications, will be able to overcome these barriers to car sharing, particularly concerns around safety. Infrastructure, such as further investment in 2+ lanes, and additional policy measures, such as congestion charging, may also be required to capitalise on the opportunities around car sharing.

8.3.7 Comparison of measures and reflections

The following section compares the responses to the different policy measures emerging from this research. Table 8:2 shows the average scores for each of the policy measures on the basis of their practicality, political acceptability, usefulness and local applicability, however, as noted earlier, these values are merely indicative due to the small nature of the sample size interviewed. It should also be noted that only four interviewees were asked about local applicability of the policy recommendations.

Table 8:2 - Average scores for the policy measures

	Targeting younger people's flexibility	Coupling interventions and life change points	Re-regulation of public transport	Workplace and school travel planning	Car sharing and casual carpooling
Practicality	4.4	3.6	3.5	3.7	2.5
Political acceptability	4.6	4.5	3.1	4.4	2.8
Usefulness	3.3	3.9	4.3	3.6	3.1
Local applicability	4.0	4.0	4.5	5.0	4.5

It is interesting to note that regulation of public transport was generally considered to be challenging in terms of its practicality and political acceptability, however, it was seen to be the most useful in terms of achieving transport goals. Other measures were considered to be easier in terms of their practicality and political acceptability but the benefits for transport goals were less.

The policy measures presented in the present work are not mutually exclusive, and in fact are often complimentary in terms of leveraging behaviour change. This was highlighted by one interviewee as follows:

"these are all relatively low cost measures. They're not big capital schemes. So should we be using some of that money to facilitate some of these options? …they're not mutually exclusive. You could do all of them." [F]

This point is interesting given the present funding structure for transport tin the UK, which focuses heavily on large capital projects, rather than revenue schemes (Abrantes and Ellerton, 2015). The policy recommendations in the present work are all revenue type schemes, which may require an adjustment in the structure of transport funding in order to be implemented.

Taken together, these policy measures could help to achieve a more sustainable transport system through more effective use of transport capacity and leveraging travel behaviour change.

8.4 Chapter summary and conclusions

This chapter has drawn together the policy recommendations made throughout this thesis and presented the results of stakeholder interviews to discuss these policy measures. The interviews included both qualitative and quantitative data about the five policy areas identified in the present research. The data suggests that the policy measures are, in many cases, politically acceptable, practical and could be useful in achieving transport goals, although challenges remain. In particular, barriers to these policy measures include habitual travel behaviour, which makes leveraging behaviour change difficult, and in the case of car sharing, many concerns around safety remain, as identified in the survey data in Chapter 4-. Re-regulation of transport through devolution of powers was generally perceived as the most useful policy measure for improving urban transport, though political and practical challenges remain.

This chapter has provided a rich resource and reflections on the policy measures developed throughout the present work, and the insight will be incorporated into the conclusions in Chapter 9- which follows.

Chapter 9- Conclusions

This chapter draws together the research presented in this thesis and provide overarching conclusions. Conclusions have been made at the end of each chapter within this thesis, this chapter aims to bring these together and provide some additional insights, as well as demonstrating the connections of this work to the wider academic literature. The research questions and objectives, originally presented in Sections 1.2 and 1.3 are reiterated, in order to assess the conclusions against these. The potential impact of the present research for influencing policy is suggested in Section 9.2. Areas for further work are outlined in Section 9.3, which demonstrate the potential avenues of research that have been opened up through the integration of the study of capacity into sustainability in transport.

Research objective: The objective of this research is to explore the potential for enhanced use of current and future excess capacity within an urban transport system to deliver reductions in CO_2 emissions.

Each of the research questions is now taken in turn, the evidence from this thesis provided and conclusions are drawn based on this evidence. These are connected to the wider literature and the contribution to knowledge emphasised.

1. **When/where is there excess capacity in the urban transport system?**

In order to examine capacity in the transport system, and the potential for future emission reductions, it was first important to establish the current state of excess capacity in the transport system. Chapter 4- presented and analysis of survey data of 500 residents of Greater Manchester (GM). This was used to understand how people's travel behaviour influenced the excess capacity arising in the system, both in terms of temporal and spatial capacity.

The survey data demonstrated that vehicle occupancy varied by time of day and journey purpose. For cars, occupancy was an average of 1.4 persons per vehicle, with the lowest occupancy associate with work trips, at 1.2, and highest occupancy for education trips, at 2.5. For buses, average occupancy was 40 persons, with lower occupancy overnight, and the highest occupancies associated education trips, at 48. Based on the mode weighted vehicle fractional excess capacity (EC_{mw}), as defined by Equation 3:8, around 56% of capacity in GM is excess under a comfort case and 62% in the extreme case. This demonstrates that a large volume of the potential space in vehicles remains unused, and this is associated with CO_2 emissions, as suggested subsequently.

In terms of temporal capacity, the concentration of traffic into peaks in the morning and afternoon delivers inefficient use of the capacity in the transport system. In addition, the occupancy rates for private cars are lower during peak hours, according to the survey data, at 1.4 and 1.3 in the AM and PM peaks respectively, compared to 1.5 in the inter peak and after 7pm.

Thus the present research shows that there are high levels of excess in both internal vehicle and temporal capacity. By quantifying this, new understanding has been generated about the magnitude of excess capacity in GM, and potentially across other comparable urban areas. The potential for this excess capacity to be used to reduce emissions of CO_2, and interventions that might facilitate this are discussed further below.

2. **What might be the carbon benefits and penalties of an enhanced use of this excess capacity and any facilitating interventions?**

Chapter 4- took the calculated EC_{mw} for the current transport system and applied this to the emissions of CO_2 associated with personal transport in GM to assess the potential emissions associated with EC_{mw}. In the comfort case EC_{mw} is 56%, the emissions associated with this for GM are 1527 $kTCO_2$ a year, based on 2012 road transport emissions, which is equivalent to around 800,000 average cars per year. If this value of 56% excess capacity is applied to the six major metropolitan areas in England, excluding London, this is associated with 6.5$MTCO_2$ a year, based on 2012 road transport emissions. By increasing occupancy rates of private vehicles to an average of 2.1, where the 53% of those willing to car share have an average occupancy of 2.8 and the remaining 47% have an occupancy of 1.4, the EC_{mw} can be reduced to 45% in the comfort case (see Section 4.3.1). This could deliver emission reductions in urban transport, and when applied to the six metropolitan areas in England, this could be associated with a reduction of 1.2 $MTCO_2$ a year. This demonstrates the magnitude of emissions associated with excess capacity in vehicles, across modes. These results are comparable to others in the literature (Jacobson and King, 2009, Minett and Pearce, 2011), however the present work goes beyond these studies to explore capacity in the transport system as a whole, rather than looking only at reducing car fuel use.

Four scenarios were developed in Chapter 6- for enhanced use of transport capacity, using survey data and wider trends in transport policy and literature. These scenarios were then modelled in the GM traffic network model and emission models, the results suggested that for Scenario 1 A, Shared Automobility, vehicle km (vkm) travelled and emissions of CO_2 reduced by 19% and 35% respectively in 2035 compared to the reference case. While for the other scenarios reductions in emissions and vkm were smaller than for Scenario 1 A, in all cases the situation was improved, suggesting that the measures and dynamics developed in the scenarios have a positive impact on CO_2 emissions. Scenario 1 B, Intelligent Automobility, was unable to capture the full dynamics of ITS on capacity use, therefore, there could be unforeseen penalties in terms of CO_2 emissions associated with increasing automation of vehicles, as discussed in Section 2.3. It is also clear, from the results presented in Section 7.3.4, that the impact of making enhanced use of excess capacity in urban transport could contribute to offsetting ever growing demand for car based transport (Department for Transport, 2013b), which is critical to ensuring the transport sustainability (Hickman et al., 2012).

3. **How could more effective use of excess capacity be facilitated in order to reduce emissions?**

A range of strategies have been explored in the present work for making more effective use of excess capacity in urban transport. Chapter 4- and Chapter 5- examined the survey participants' travel behaviour, in order to understand how they use their transport capacity and where there could be opportunities to influence that capacity use. The analysis in these chapters suggested that many people, especially younger participants were flexible in their travel behaviour, showing willingness to adjust journey timings and potentially car share, activities which could improve the capacity use in the transport system. It was also found that there was a significant potential for modal shift amongst survey participants, as many suggested that they perceived they would use a different main mode in the future than they presently used. These generally reflect smarter choices type approaches, which were introduced in Section 2.3.2, and have been shown to have potential to reduce emissions up to 4-5% nationally with low intensity application, and 15-20% locally with high intensity application (Cairns et al., 2008). The use of smarter choices to specifically explore excess capacity in transport opens up a new dimension to the applications of smarter choices measures. It should be noted that there may be gaps between intentions and actions, and the full extent of flexibility suggested by participants may not be realised (Waygood et al., 2012).

The policy suggestions made were discussed with practitioners in the transport sector through a series of interviews, the results of which can be found in Chapter 8-. These interviews suggested that the policies to influence travel behaviour were generally practical and politically acceptable and could be useful in achieving transport goals including improving the sustainability of urban transport systems. Measures such as workplace and school travel planning and targeting policy interventions at life change points, such as a change in employment, could be effective in leveraging behaviour change and delivering more effective use of urban transport capacity, although the longer term impacts are contested. Re-regulation of transport through devolution of powers to local authorities was identified as the most useful policy measure for influencing urban transport by interviewees in Chapter 8-. However, the interviews showed that significant barriers remain, which must be overcome, for this potential to be realised, see Section 8.3.

4. **How could enhanced use of capacity be incorporated into pathways for sustainable urban transport systems?**

Chapter 6- took the findings from Chapter 4- and Chapter 5- along with the trends and dynamics in the literature review in Chapter 2- to develop a set of scenarios for the future of urban transport capacity use. The four scenarios were as follows:

- Scenario 1 A – Shared Automobility: this scenario looked at the continued dominance of car as the main mode, but innovation around sharing improved the capacity use in the transport system;

- Scenario 1 B – Intelligent Automobility: the car remains the dominant mode in this scenario but increases in intelligent transport systems (ITS) deliver changes in the way capacity in the transport system is used;
- Scenario 2 – Public Mobility: in this scenario, improved public transport delivers modal shift to higher occupancy, public transport modes; and
- Scenario 3 – Flexi-mobility: this scenario examined a future where increases in home working and flexible working structures led to reduced demand for travel and allowed people to choose to travel outside the peaks, thus making more effective use of temporal capacity.

These scenarios developed a socio-technical pathway narrative, and these were also incorporated into the modelling presented in Chapter 7-. It has been identified that a transition around innovations for urban transport capacity use could take a number of shapes. Transitions for sustainability can either "*contribute to regime optimization"* or *"contribute to regime shifts"* (Hoogma et al., 2002, p.36). It is possible to suggest that making more enhanced use of excess capacity could optimise how a transport regime or facilitate a regime shift. The innovations explored in the scenarios developed in the present work contribute to the wider analysis of transport as a socio-technical system across the literature (Sheller, 2011, Zijlstra and Avelino, 2011) and applies Foxon's co-evolutionary framework to a new area (Foxon, 2011). The quantifying of the potential impacts of these scenarios in Chapter 7-, through the transport modelling, contributes to an emerging area of work, as conventionally, socio-technical scenarios are not subject to such an approach (Holtz et al., 2015, McDowall and Geels, 2016).

9.1 Contribution to knowledge

The work presented in this thesis offers contribution to knowledge in several areas and extends the academic literature, as outlined here. This work has bought together the literature on transport capacity and sustainability, areas not commonly examined together, to understand how excess capacity in the urban transport system might be more effectively used. Through developing a novel framework to quantify excess capacity, the research has shown that, for the case study area of GM, more than 50% of capacity is excess. A comparable volume of excess capacity can be expected to exist in similar urban areas. Hence, a question which had previously remained unexamined in the academic literature has been addressed through this work.

The development of a series of socio-technical pathways for enhanced use of excess capacity contributes to and extends the socio-technical literature in transport. The use of the co-evolutionary framework to develop the pathways for the transport system represents a novel application of Foxon's approach (Foxon, 2011). In addition, the quantification of the scenarios through the modelling study contributes to the emerging literature which attempts to quantify socio-technical scenarios (Holtz et al., 2015, McDowall and Geels, 2016). However, as the work also highlights, there are significant limitations in the ability of conventional transport modelling approaches and existing tools in capturing the full details, interconnections and interactions of a complex socio-technical system.

The work has shown that making more effective use of urban transport capacity could contribute to CO_2 emission reductions, a valuable finding that could deliver more sustainable transport in cities. This novel approach to exploring urban transport capacity has addressed the knowledge gap in the research around the size of excess capacity in the urban transport system and the potential that enhanced use of this capacity could have for reducing CO_2 emissions. The bringing together of excess capacity and transport sustainability, areas that were previously considered in isolation, opens new areas of work, as well as addressing the knowledge gap in the academic literature. The present work has also developed a series of policy recommendations for making enhanced use of urban transport capacity in order to reduce emissions of CO_2. This represents an original contribution to sustainability in urban transport and has the potential to impact policy, as outlined in Section 9.2. There are a number of further directions that this work could be taken in and these are explored in Section 9.3.

9.2 Potential policy impact of the present work

Policy recommendations have been made throughout this thesis, based on the present research. The dynamics of potential policies were examined in the pathways constructed in Chapter 6- and the potential CO_2 emission reductions quantified in Chapter 7-. Chapter 8- presented the results of interviews with stakeholders about the policy recommendations made throughout this thesis.

Taken together, the findings of the present research, and the insight developed through the interviews, suggest that making more effective use of capacity could contribute to achieving transport goals. Policy makers could develop the recommendations made throughout this thesis, and synthesised in Chapter 8-, in order to make enhanced use of excess capacity and reduce emissions of CO_2. The measures suggested in the present work would also have additional co-benefits, such as reduction of congestion and air pollution, which are significant challenges for transport policy makers in urban areas. It is hoped that the findings in the present work will be accessible and useful for decision makers in the transport sector, and help to deliver improved sustainability in urban transport systems.

9.3 Areas for further work

This section provides some areas for potential further work, reflecting on the work in the present thesis and the conclusions presented above. The areas covered in this section include, examining additional dimensions of capacity in urban transport, the potential to conduct additional case studies using the framework developed in this thesis, examining capacity through a mobility as a service (MaaS) perspective, exploring further dimensions of sustainability and applying an agent based modelling approach to exploring transport capacity and car sharing. These are now expanded in turn.

9.3.1 Additional dimensions of capacity in transport

In the USA, vehicles are unused 90% of the time (Jorge and Correia, 2013), therefore there is much excess capacity in the current ownership models of private vehicles. This would represent an interesting further dimension of exploring excess capacity in urban transport, and the sustainability impacts of the manufacture and consumption of large numbers of vehicles which are only used for a small proportion of the time. This could include examining emerging business models for shared vehicles, e.g. city car club, car2go (Firnkorn and Müller, 2011, Jorge and Correia, 2013) and the role that these could play in reducing the environmental impact of transport and the embedded carbon in private ownership of vehicles.

9.3.2 Additional case studies using the framework developed in the present work

The framework that has been developed for the present work, see Chapter 3-, is not location specific to the case study for which it has been tested. Further work could include additional case studies of excess capacity in urban transport systems and the potential CO_2 emission reductions that could be delivered through more effective use of capacity. The present work has focussed on GM and expanded the analysis to examine the six metropolitan areas in England, however, this could be further expanded to look at additional areas, and modelling the transport systems of cities for international case studies. Due to the focus on road transport in the present work, additional modes may need to be included for other city case studies, such as light rail, bus rapid transit and potentially water based transport. This would represent an interesting expansion of the present work and further develop the potential impact of the work to improve the sustainability of urban transport systems.

9.3.3 Mobility as a Service and transport capacity

MaaS is an emerging model for examining urban transport systems, and while there is no cohesive definition for MaaS, it tends to refer to providing multi-modal transport systems, within an integrated business model. Sochor et al (2015) suggest that MaaS models have the potential to facilitate use of shared resources and improve sustainability of urban transport, aims which are at the heart of examining excess capacity in urban transport systems. Thus, this framework of analysis could be applied to further studies of excess capacity in urban transport, looking at the potential of an integrated, multi-modal business model, to facilitate enhanced use of excess capacity and potential CO_2 emissions reductions.

9.3.4 Exploring additional dimensions of sustainability

In Section 2.2, the definition and contention around sustainability was explored, and it was emphasised that sustainability encapsulates more than just the reduction of environmental impacts (Holden et al., 2014). The focus of the present work has been on reduction of CO_2 emissions, therefore an important area for further work would be to examine the additional dimensions of sustainability. This would involve exploring the impact of making enhanced use of excess capacity on meeting societal needs (Holden et al., 2014), and a particularly interesting and important dimension would be to explore the impact of this on accessibility and social mobility. At present, transport poverty and accessibility challenges affect the poorest in society (Lucas and Pangbourne, 2012), and the extent to which making enhanced use of excess capacity helps to overcome these challenges, or exacerbates them, would be important to establish. In addition, in exploring international case studies and the extent to which the framework could be applied to a developing country city offers another area for further work.

A further dimension of sustainability in transport, and a potential extension of the present work, would be to explore the impact of alternative fuels on the CO_2 emissions of the urban transport system, and the influence that has on the emission reductions delivered through enhanced use of excess capacity. The work in this thesis has assumed that the emissions performance of vehicles improves in the future, using factors within TfGM's SATURN model, but the future fuel mix, and the role of low carbon propulsion technologies is unclear, and this would have a profound influence on the CO_2 emission reductions achieved in the results.

9.3.5 Agent based modelling of making enhanced use of excess capacity in urban transport

Chapter 3- presented a review of modelling approaches for examining CO_2 emissions from road transport. This included agent based models, which have been used in transport to explore a number of sustainability dimensions, including the diffusion of information and the influence this has on uptake of electric vehicles (EVs) (Köhler et al., 2009, Shafiei et al., 2012b). Agent based models could be applied to examining enhanced use of excess capacity in urban transport by exploring how the diffusion of information through social, or other networks, influences decision making, particularly in relation to car sharing and mode choice. This would represent an interesting alternative approach to examining urban transport capacity and practices around sharing, and would be useful for informing policy design for encouraging car sharing and enhanced use of excess capacity in urban transport.

9.3.6 Summary of potential areas for further work

This section has presented a number of potential directions for further research on excess capacity in urban transport systems and the associated CO_2 emissions. These vary in scale, from examining additional dimensions of excess capacity or perspectives of sustainability, through to applying a different kind of modelling approach to the questions of how to make enhanced use of excess capacity. These illustrate how the work presented in this thesis exists not in isolation, but as part of a wider area of research on sustainability in urban transport, and the work presents an approach to examining the questions of delivering a sustainable urban transport future. These areas for further work are also not mutually exclusive, they could be explored together, which would yield additional interesting insights and valuable perspectives.

While the present work has taken an interdisciplinary approach, utilising multiple methods and frameworks, this section demonstrates that additional disciplinary perspectives and techniques are available for examining the research questions in this work, and further work utilising these could yield additional insight.

9.4 Concluding remarks

The research in this thesis aimed to explore opportunities for making enhanced use of excess capacity in urban transport systems in order to reduce CO_2 emissions. Sustainability of urban transport systems is critical, as at present they face unprecedented challenges, from environmental damage to accessibility and social inclusion. Climate change, however, is one of the greatest challenge facing humankind, therefore reduction of CO_2 emissions must be among the highest policy priorities for leaders and decision makers. It is hoped that the analysis in the present work will contribute, in some small way, to making transport more sustainable and improving cities through more effective use of capacity.

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Appendix A – Survey Questionnaire

Thank you very much for agreeing to complete this on-line survey which is being conducted by Accent. The research is being conducted under the terms of the MRS code of conduct and is completely confidential. If you would like to **confirm** Accent's credentials please call the MRS free on 0500 396999. The questionnaire will take about 15 minutes. Any answer you give will be treated in confidence in accordance with the Code of Conduct of the Market Research Society.

This study is part of a research project at the University of Leeds exploring how people in Manchester use the transport system and how emissions of CO_2 from fossil fuels used in transport can be reduced in the future. This survey will ask you to think about how you might travel in the future. You can withdraw from this study at any point while filling out of the questionnaire. After completion, in order to protect your personal information, your name will no longer be linked with your responses. If you have any questions please contact Clare Linton (the researcher) at pmcli@leeds.ac.uk, or Olivier Boelman (the project manager at Accent) at Olivier.Boelman@accent-mr.com. Thanks for your participation.

Q1.In which of the following districts do you live?

Bolton

Bury

City of Manchester

Oldham

Rochdale

Salford

Stockport

Tameside

Trafford

Wigan

Other (THANK AND CLOSE)

Q2.Please give your gender

Male

Female

Prefer not to answer

Q3.Which of the following age groups are you in?
17 or younger

18-24

25-34

35-44

45-54

55-65

66 or over

Prefer not to answer but confirm my age is 18 – 65

Prefer not to answer

IF Q3=1 OR Q3=7 OR Q3= 8, THANK AND CLOSE

Q4.First, please provide some information about **how you travel now**. How many journeys did you have in the last 7 days?

……

IF Q4=0 GO TO Q7

Q5. Please fill in information about your journeys in the last 7 days. If the last 7 days do not reflect what you would consider a normal week, please enter details for a normal week. The first two rows highlighted are provided as an example of the detail required. If you make a journey daily or only at weekends, for example, you need only enter this once and select the option for ‘daily’ or ‘weekends’ in the how often do you make this journey. Please enter both parts of a return journey separately.

(insert table 4x10)

Row 1

Start (Postcode or area)

Destination (Postcode or area)

Distance (miles)

How often do you make this journey?

Time

Reason for this journey

Mode

If car is the main mode, how many people are in the vehicle? (only if car is selected)

If using public transport, on average how crowded is your service? (only if bus or train selected)

Additional comments on level of crowding, any extremes in crowding etc.

Row 2

BN2 3LE

BN1 5AN

2

Weekdays

07.30

Work

metro

5

almost all seats taken with space to stand

(blank)

Row 3

Oldham

Manchester city centre

8

Occasional

19.00

Leisure

bus

3

¼-1/2

One day the bus was completely full due to a cancelled service

Row 4 *(All left blank for respondent to fill in + add drop down lists)*

(Blank)

(Blank)

(Blank)

(Drop down list :) Daily; Weekdays; Weekends; Several Days; Once a Week; Occasional

(Blank)

(Drop down list :) Work; Leisure; Education; Shopping; Other (please state)

(Drop down list :) Car driver; car passenger; motorcycle; bus; train; metro; walk; cycle; other (please state)

(Drop down list :) 1, 2 , 3, 4, 5, more than 5, N/A

(Drop down list :) <1/4 seats taken; ¼-1/2 ; ½-3/4; almost all seats taken with space to stand; all seats taken, no space to stand, N/A

(Blank)

Q6.Would you be willing to car share?

Yes, I would be willing to carry other people in my car

Yes, I would be willing to be a passenger in someone else's car

No

Don't Know

Q7.What would make you willing to car share?

Sharing with a colleague or friend

A car sharing scheme through work

An online car sharing forum

Flexible working hours to allow varying start and finish times

Other, please state

Q8.Are you able to work from home?

Not at all

Occasionally

Once a week

About half the week

More than half the week

All the time

The following questions are about your ability to adjust departure times of journeys.

Q9.Are you **able** to adjust your regular departure time at present?

Yes

No

Q10. **ASK IF Q9=1** By how much?

(Drop down list of):

Up to 30min earlier

30 minutes-1 hour earlier

1 hour-1h30mins earlier

1h30mins-2 hours earlier

More than 2 hours earlier

Up to 30 minutes later

30 minutes-1 hour later

1hour-1h30mins later

1h30mins-2 hours later

More than 2 hours later

Q11. **ASK IF Q9=2** Why not? (Please choose the ***main*** *r*eason)

(Drop down list of):

Working hours

School hours or other caring responsibilities

Public transport timing

Other, please state

Q12. **ASK IF Q9=1** If you are **able** to adjust your departure time at present, how much would you be **willing** to adjust your departure timing?

(Drop down list of):

Not at all

Up to 30min earlier

30 minutes-1 hour earlier

1 hour-1h30mins earlier

1h30mins-2 hours earlier

More than 2 hours earlier

Up to 30 minutes later

30 minutes-1 hour later

1hour-1h30mins later

1h30mins-2 hours later

More than 2 hours later

Q13. Do you think you will be **able** to adjust your regular departure time in the **future**?

Yes

No

Don’t know

Q14. **ASK IF Q13=1** By how much?

(Drop down list of):

Up to 30min earlier

30 minutes-1 hour earlier

1 hour-1h30mins earlier

1h30mins-2 hours earlier

More than 2 hours earlier

Up to 30 minutes later

30 minutes-1 hour later

1hour-1h30mins later

1h30mins-2 hours later

More than 2 hours later

Q15. **ASK IF Q13=2** Why not? (Please choose the ***main r***eason)

(Drop down list of):

Working hours

School hours or other caring responsibilities

Public transport timing

Other, please state

Q16. **ASK IF Q13=1** If you are **able** to adjust your departure time in the **future**, how much would you be **willing** to adjust your departure timing?

(Drop down list of):

Not at all

Up to 30min earlier

30 minutes-1 hour earlier

1 hour-1h30mins earlier

1h30mins-2 hours earlier

More than 2 hours earlier

Up to 30 minutes later

30 minutes-1 hour later

1hour-1h30mins later

1h30mins-2 hours later

More than 2 hours later

Your future travel – The following section asks you to consider how you might travel in the future, in 2020 and 2030.

Q17. In the future how do you think you will travel for **most** of your day-to-day journeys?

Car (driver)

Car (passenger)

Bus

Train

Metro

Cycle

Walk

Other, please specify

Q18. Do you think you will travel more or less in the future?

Less

The same

More

Q19. **ASK IF Q18= 1 OR Q18=3** How much more (**IF Q18=3)** / less **(IF Q18= 1)**?

(Drop down list of:)

(**IF Q18=3)**

Up to 10% more

11%-20% more

21%-30% more

31%-40% more

41%-50% more

51%-60% more

61%-70% more

71%-80% more

81%-90% more

91%-100% more

(IF Q18= 1)

Up to 10% less

11%-20% less

21%-30% less

31%-40% less

41%-50% less

51%-60% less

61%-70% less

71%-80% less

81%-90% less

91%-100% less

Please rank these factors in terms of their importance to your future travel, with 1 being of most importance:

Q20. *DP- PLEASE ROTATE*

In 5 years time?	**Rank**
Increased costs of driving	
Reduced cost of public transport	
Congestion	
Crowding of public transport services	
Environmental concerns	
Ability to work or shop from home	
Distance required to travel	
Flexibility of scheduling	
Family commitments (parents, children etc.)	
Mobility / Disability	
Location	
Other, please state	

Q21. *DP- PLEASE ROTATE*

In 15 years time?	**Rank**
Increased costs of driving	
Reduced cost of public transport	
Congestion	
Crowding of public transport services	
Environmental concerns	
Ability to work or shop from home	
Distance required to travel	
Flexibility of scheduling	
Family commitments (parents, children etc.)	

Mobility / Disability	
Location	
Other, please state	

Q22. Please provide any further comments on your future travel

---

Q23. Any additional comments on this survey

Finally, would you please answer some questions about yourself? The personal information you provide during this survey will be kept confidential by Accent and the researcher at the University of Leeds and will not be disclosed to third parties.

Q24. Which of the following ethnic groups most accurately describes your ethnic background?

A: WHITE
British
Irish
Any other White background
B: MIXED
White and Black Caribbean
White and Black African
White and Asian
Any other Mixed background
C: ASIAN OR ASIAN BRITISH
Indian
Pakistani
Bangladeshi
Any other Asian background
D: BLACK OR BLACK BRITISH
Caribbean
African
Any other Black background
E: CHINESE OR OTHER ETHNIC GROUP
Chinese
Any other ethnic group
Prefer not to answer

Q25. What is your gross household income before tax and other deductions?
Less than £10,000

£10,000 - £19,999

£20,000 - £29,999

£30,000 - £49,999

£50,000 - £99,999

£100,000 or more

Prefer not to answer

Thanks for your participation.

Appendix B – Ethical Approval

Performance, Governance and Operations
Research & Innovation Service
Charles Thackrah Building
101 Clarendon Road
Leeds LS2 9LJ Tel: 0113 343 4873
Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee
University of Leeds

27 January 2017
Dear Clare

Title of study:	**AREA 13-110**
Ethics reference:	**Modelling the emission reductions potential of enhanced use of urban transport capacity – pathways to 2050**

I am pleased to inform you that the above research application has been reviewed by the ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee and following receipt of your response to the Committee's initial comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	*Version*	*Date*
AREA 13-110 Ethics Forms + Survey - CLinton (3).pdf	1	02/04/14
AREA 13-110 Response to Research Ethics Committee Recommendations.docx	1	30/04/14
AREA 13-110 RE 2740 Travel behaviour Manchester.msg	1	30/04/14

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely
Jennifer Blaikie
Senior Research Ethics Administrator, Research & Innovation Service
On behalf of Dr Andrew Evans, Chair, AREA Faculty Research Ethics Committee
CC: Student's supervisor(s)

Appendix C – Statistical Outputs

The following appendix contains the statistical output tables for the analysis in this thesis.

Multinomial logistic regression modelling

This section presents the output tables for the multinomial logistic regression modelling which can be found in Chapters 4 and 5.

Table A - Propensity model - ability to adjust journey departure time (earlier)

Parameter Estimates

Ability to adjust journey departure time (earlier)		B	Std. Error	Wald	df	Sig.	Exp(B)
Not stated	Intercept	.140	2.869	.002	1	.961	
	Age	-1.025	.880	1.358	1	.244	.359
Up to 30min	Intercept	2.690	.723	13.845	1	.000	
	Age	-.403	.159	6.451	1	.011	.669
30 minutes - 1 hour	Intercept	1.022	.793	1.662	1	.197	
	Age	-.118	.171	.473	1	.492	.889
1 hour - 1h30mins	Intercept	-.217	1.042	.043	1	.835	
	Age	-.086	.225	.145	1	.703	.918
1h30mins - 2 hours	Intercept	-2.451	1.692	2.099	1	.147	
	Age	.195	.348	.314	1	.575	1.216

a. The reference category is: More than 2 hours.

Chance accuracy = 37%; Classification accuracy = 43%

Table B - Propensity model - ability to adjust journey departure time (later)

Parameter Estimates

Ability to adjust journey departure time (later)		B	Std. Error	Wald	df	Sig.	Exp(B)
Not stated	Intercept	.992	1.542	.414	1	.520	
	Ethnicity	-.207	.206	1.015	1	.314	.813
	Age	-.424	.313	1.830	1	.176	.655
Up to 30min	Intercept	4.503	.957	22.153	1	.000	
	Ethnicity	-.100	.065	2.400	1	.121	.905
	Age	-.815	.193	17.775	1	.000	.443
30 minutes - 1 hour	Intercept	2.550	.997	6.541	1	.011	
	Ethnicity	.043	.057	.571	1	.450	1.044
	Age	-.502	.200	6.327	1	.012	.605
1 hour - 1h30mins	Intercept	1.654	1.118	2.190	1	.139	
	Ethnicity	.028	.065	.187	1	.666	1.028
	Age	-.424	.225	3.553	1	.059	.655
1h30mins - 2 hours	Intercept	-.526	1.477	.127	1	.722	
	Ethnicity	-.054	.103	.273	1	.601	.948
	Age	-.032	.287	.013	1	.910	.968

a. The reference category is: More than 2 hours.

Chance accuracy = 28%; Classification accuracy = 38%

Table C - Propensity model - willingness to adjust journey departure time (earlier)

Parameter Estimates

Willingness to adjust journey departure time (earlier)		B	Std. Error	Wald	df	Sig.	Exp(B)
Not at all	Intercept	.497	1.463	.116	1	.734	
	Age	-.519	.238	4.735	1	.030	.595
	Gender	1.330	.573	5.394	1	.020	3.780
	Ethnicity	-.015	.114	.017	1	.897	.985
Up to 30min	Intercept	1.673	1.236	1.833	1	.176	
	Age	-.357	.203	3.098	1	.078	.700
	Gender	.947	.468	4.094	1	.043	2.579
	Ethnicity	.049	.096	.260	1	.610	1.050
30 minutes - 1 hour	Intercept	-.780	1.418	.303	1	.582	
	Age	.018	.229	.006	1	.936	1.019
	Gender	.742	.515	2.074	1	.150	2.101
	Ethnicity	.154	.097	2.503	1	.114	1.166
1 hour - 1h30mins	Intercept	-.042	2.084	.000	1	.984	
	Age	-.233	.337	.478	1	.489	.792
	Gender	-.357	.839	.181	1	.671	.700
	Ethnicity	.225	.108	4.357	1	.037	1.253
1h30mins - 2 hours	Intercept	-1.148	2.038	.317	1	.573	
	Age	-.032	.330	.010	1	.922	.968
	Gender	.104	.758	.019	1	.891	1.109
	Ethnicity	.162	.113	2.038	1	.153	1.176

a. The reference category is: More than 2 hours.

Chance accuracy = 38%; Classification accuracy = 49%

Table D - Propensity model - willingness to adjust journey departure time (later)

Parameter Estimates

Willingness to adjust journey departure time (later)		B	Std. Error	Wald	df	Sig.	Exp(B)
Not at all	Intercept	3.211	.945	11.534	1	.001	
	Age	-.627	.206	9.290	1	.002	.534
Up to 30min	Intercept	2.904	.912	10.142	1	.001	
	Age	-.433	.193	5.002	1	.025	.649
30 minutes - 1 hour	Intercept	1.375	.971	2.005	1	.157	
	Age	-.147	.203	.527	1	.468	.863
1 hour - 1h30mins	Intercept	1.527	1.257	1.475	1	.225	
	Age	-.571	.287	3.956	1	.047	.565
1h30mins - 2 hours	Intercept	.403	1.297	.097	1	.756	
	Age	-.248	.279	.790	1	.374	.781

a. The reference category is: More than 2 hours.

Chance accuracy = 28%; Classification accuracy = 36%

Table E - Propensity model - Willingness to car share

Parameter Estimates

Willingness to car share		B	Std. Error	Wald	df	Sig.	Exp(B)
Willing to carry passengers in my car	Intercept	1.558	.807	3.726	1	.054	
	Current Main Mode	-.187	.125	2.244	1	.134	.829
	Age	-.156	.155	1.006	1	.316	.856
Willing to be a passenger in someone else's car	Intercept	.638	.784	.663	1	.415	
	Current Main Mode	.217	.110	3.918	1	.048	1.242
	Age	-.173	.152	1.297	1	.255	.841
Both of the above	Intercept	2.160	.856	6.364	1	.012	
	Current Main Mode	-.270	.142	3.582	1	.058	.764
	Age	-.343	.166	4.293	1	.038	.710
Not willing to car share	Intercept	.559	.755	.548	1	.459	
	Current Main Mode	-.080	.108	.551	1	.458	.923
	Age	.153	.145	1.118	1	.290	1.165

a. The reference category is: Don't know.

Chance accuracy = 30%; Classification accuracy = 37%

Table F - Propensity model - future main mode

Parameter Estimates

Q19. In the future how do you think you will travel for most of your day-to-day journeys?		B	Std. Error	Wald	df	Sig.	Exp(B)
Car (driver)	Intercept	9.468	1.839	26.505	1	.000	
	Current Main Mode	-.726	.208	12.235	1	.000	.484
	Age	-1.054	.319	10.920	1	.001	.349
	Ethnicity	-.101	.064	2.472	1	.116	.904
Car (passenger)	Intercept	3.610	2.406	2.251	1	.134	
	Current Main Mode	-.475	.320	2.207	1	.137	.622
	Age	-.488	.422	1.342	1	.247	.614
	Ethnicity	-.106	.108	.955	1	.328	.900
Bus	Intercept	4.685	1.870	6.279	1	.012	
	Current Main Mode	.128	.201	.406	1	.524	1.137
	Age	-.610	.325	3.523	1	.061	.543
	Ethnicity	-.173	.078	4.844	1	.028	.841
Train	Intercept	3.551	2.041	3.028	1	.082	
	Current Main Mode	.155	.225	.476	1	.490	1.168
	Age	-.694	.356	3.806	1	.051	.500
	Ethnicity	-.060	.079	.564	1	.453	.942
Metro	Intercept	3.025	2.026	2.231	1	.135	
	Current Main Mode	.108	.226	.227	1	.634	1.114
	Age	-.587	.352	2.787	1	.095	.556
	Ethnicity	.029	.070	.169	1	.681	1.029
Cycle	Intercept	.848	2.545	.111	1	.739	
	Current Main Mode	.508	.249	4.153	1	.042	1.661
	Age	-.402	.423	.904	1	.342	.669
	Ethnicity	-.519	.564	.846	1	.358	.595
Walk	Intercept	1.495	2.115	.499	1	.480	
	Current Main Mode	.262	.221	1.406	1	.236	1.300
	Age	-.272	.366	.554	1	.457	.761
	Ethnicity	-.130	.101	1.679	1	.195	.878

a. The reference category is: Other,

Chance Accuracy = 45%; Classification Accuracy = 58%

Table G - Propensity model of future travel amount

Parameter Estimates

Q23. Do you think you will travel more or less in the future?		B	Std. Error	Wald	df	Sig.	Exp(B)
Less	Intercept	-6.117	.937	42.589	1	.000	
	Current Main Mode	-.301	.123	5.962	1	.015	.740
	Age	1.484	.187	62.909	1	.000	4.409
The same	Intercept	-1.641	.518	10.021	1	.002	
	Current Main Mode	-.066	.078	.708	1	.400	.936
	Age	.683	.110	38.318	1	.000	1.980

a. The reference category is: More.

Chance accuracy = 53%; Classification accuracy = 62%

Table H - Propensity model of ability to adjust departure time in the future (earlier)

Parameter Estimates

Ability to adjust journey departure time in the future (earlier)		B	Std. Error	Wald	df	Sig.	Exp(B)
Not stated	Intercept	-38.714	.837	2141.104	1	.000	
	Gender	18.899	.000	.	1	.	161311262.124
Up to 30min	Intercept	-.693	.747	.861	1	.354	
	Gender	1.386	.555	6.233	1	.013	4.000
30 minutes - 1 hour	Intercept	-.706	.803	.772	1	.379	
	Gender	.993	.594	2.797	1	.094	2.700
1 hour - 1h30mins	Intercept	-2.071	1.077	3.697	1	.055	
	Gender	1.127	.752	2.247	1	.134	3.086
1h30mins - 2 hours	Intercept	-1.281	1.261	1.033	1	.310	
	Gender	.182	.960	.036	1	.849	1.200

a. The reference category is: More than 2 hours.

Chance accuracy = 39%; Classification accuracy = 46%

Table I - Propensity model of ability to adjust departure time in the future (later)

Parameter Estimates

Ability to adjust journey departure time in the future (later)		B	Std. Error	Wald	df	Sig.	Exp(B)
Not stated	Intercept	-45.457	2.196	428.665	1	.000	
	Current Main Mode	1.146	.425	7.259	1	.007	3.146
	Gender	20.389	.000	.	1	.	715511647.144
Up to 30min	Intercept	-1.093	.895	1.490	1	.222	
	Current Main Mode	.106	.165	.413	1	.520	1.112
	Gender	1.279	.576	4.927	1	.026	3.592
30 minutes - 1 hour	Intercept	-.550	.891	.381	1	.537	
	Current Main Mode	.009	.169	.003	1	.960	1.009
	Gender	1.007	.581	3.003	1	.083	2.738
1 hour - 1h30mins	Intercept	-4.021	1.318	9.304	1	.002	
	Current Main Mode	.200	.211	.893	1	.345	1.221
	Gender	2.230	.742	9.032	1	.003	9.302
1h30mins - 2 hours	Intercept	-.271	1.157	.055	1	.815	
	Current Main Mode	-.219	.254	.746	1	.388	.803
	Gender	.225	.775	.085	1	.771	1.253

a. The reference category is: More than 2 hours.

Chance accuracy = 31%; Classification accuracy = 38%

Table J - Propensity model of highest ranked 15 year factor

Parameter Estimates

Highest ranked 15 year factor		B	Std. Error	Wald	df	Sig.	Exp(B)
Increased cost of driving	Intercept	-14.040	2.874	23.866	1	.000	
	Current Main Mode	13.194	.141	8725.195	1	.000	537148.689
	Age	.674	.534	1.590	1	.207	1.961
	Gender	.086	1.049	.007	1	.935	1.090
Reduced cost of public transport	Intercept	-17.162	2.941	34.045	1	.000	
	Current Main Mode	13.583	.125	11838.923	1	.000	792441.186
	Age	.984	.542	3.299	1	.069	2.676
	Gender	.503	1.066	.223	1	.637	1.654
Congestion	Intercept	-13.814	2.971	21.617	1	.000	
	Current Main Mode	12.859	.223	3337.522	1	.000	384216.365
	Age	.803	.549	2.142	1	.143	2.233
	Gender	-.496	1.077	.212	1	.645	.609
Crowding of public transport	Intercept	-18.467	3.108	35.309	1	.000	
	Current Main Mode	13.740	.147	8777.741	1	.000	927268.377

	Age	.950	.560	2.877	1	.090	2.587
	Gender	.639	1.122	.324	1	.569	1.894
Environmental concerns	Intercept	-17.727	3.192	30.839	1	.000	
	Current Main Mode	13.557	.181	5592.904	1	.000	772407.762
	Age	.953	.575	2.742	1	.098	2.593
	Gender	.277	1.147	.058	1	.809	1.319
Ability to work or shop from home	Intercept	-14.272	3.014	22.426	1	.000	
	Current Main Mode	13.140	.206	4071.892	1	.000	508937.911
	Age	.426	.553	.593	1	.441	1.531
	Gender	.305	1.101	.077	1	.782	1.357
Distance required to travel	Intercept	-15.010	2.916	26.494	1	.000	
	Current Main Mode	13.514	.127	11318.897	1	.000	740066.181
	Age	.825	.541	2.327	1	.127	2.281
	Gender	-.385	1.067	.130	1	.718	.680
Flexibility of scheduling	Intercept	-18.068	3.202	31.848	1	.000	
	Current Main Mode	13.368	.202	4364.551	1	.000	639356.893
	Age	1.149	.579	3.931	1	.047	3.154
	Gender	.284	1.131	.063	1	.802	1.328
Family commitments	Intercept	-14.858	2.875	26.702	1	.000	
	Current Main Mode	13.276	.132	10086.441	1	.000	582824.742
	Age	.512	.532	.924	1	.337	1.668
	Gender	.969	1.052	.849	1	.357	2.637
Mobility/Disability	Intercept	-20.873	2.996	48.554	1	.000	
	Current Main Mode	13.506	.126	11405.094	1	.000	733995.546
	Age	1.754	.551	10.156	1	.001	5.780
	Gender	.850	1.059	.644	1	.422	2.340
Location	Intercept	-15.038	2.906	26.785	1	.000	
	Current Main Mode	13.598	.000	.	1	.	804230.952
	Age	.911	.541	2.832	1	.092	2.486
	Gender	-.752	1.071	.492	1	.483	.472

a. The reference category is: Other.

Chance accuracy = 14%; Classification accuracy = 27%

Factor analysis

This section contains the results from the factor analysis conducted on influences on future travel behaviour. The tests were conducted in SPSS and split by the independent variables ‘age’, ‘gender’ and ‘current main mode’, to understand the impacts of this on the participants’ perceived influences on their future travel behaviour. The analysis was also run for the entire sample, and the results of this are found in Chapter 5, section 5.5.1. The results presented in this appendix are also discussed in Section 5.5.1.

The output tables show the rotated component matrices for each test, with the significant factors in each component highlighted for clarity. Test statistics are provided at the end of each set of matrices. For more on the approach used in the factor analysis, see Section 5.1.1.

Table K - Rotated Component Matrix for Age = 18-24 years old, 5 years’ time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q25r1. Increased costs of driving	.176	.742	.000
Q25r2. Reduced cost of public transport	.288	.386	.612
Q25r3. Congestion	.311	.725	-.054
Q25r4. Crowding of public transport services	.770	.014	.427
Q25r5. Environmental concerns	.717	.355	-.035
Q25r6. Ability to work or shop from home	.450	.597	.101
Q25r7. Distance required to travel	.143	.600	.143
Q25r8. Flexibility of scheduling	.674	.335	.171
Q25r9. Family commitments (parents, children etc.)	.719	.167	-.042
Q25r10. Mobility / Disability	.636	.502	.246
Q25r11. Location	.113	.575	.372
Q25r12. Other (please specify)	.010	-.014	.876

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 5 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 18 to 24 are used in the analysis phase.

Table L - Rotated Component Matrix for Age = 25-29 years old, 5 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q25r1. Increased costs of driving	.537	.409	-.078
Q25r2. Reduced cost of public transport	.130	.707	.389
Q25r3. Congestion	.603	.237	.425
Q25r4. Crowding of public transport services	.760	.109	.352
Q25r5. Environmental concerns	.490	.574	.346
Q25r6. Ability to work or shop from home	.613	.164	.065
Q25r7. Distance required to travel	.097	.400	.660
Q25r8. Flexibility of scheduling	.702	-.231	.176
Q25r9. Family commitments (parents, children etc.)	.701	.219	-.018
Q25r10. Mobility / Disability	.802	.263	.140
Q25r11. Location	.137	-.032	.855
Q25r12. Other (please specify)	.129	.858	-.009

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 5 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 25 to 29 are used in the analysis phase.

Table M - Rotated Component Matrix for Age = 30-44 years old, 5 years' time

Rotated Component Matrix [a, b]

	Component	
	1	2
Q25r1. Increased costs of driving	.309	.597
Q25r2. Reduced cost of public transport	.747	-.046
Q25r3. Congestion	.368	.268
Q25r4. Crowding of public transport services	.738	.003
Q25r5. Environmental concerns	.714	.308
Q25r6. Ability to work or shop from home	.599	.255
Q25r7. Distance required to travel	.395	.333
Q25r8. Flexibility of scheduling	.618	.210
Q25r9. Family commitments (parents, children etc.)	.318	.599
Q25r10. Mobility / Disability	.630	.319
Q25r11. Location	.117	.597
Q25r12. Other (please specify)	-.064	.758

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization . [a, b]

a. Rotation converged in 3 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 30 to 44 are used in the analysis phase.

Table N - Rotated Component Matrix for Age = 45-59 years old, 5 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q25r1. Increased costs of driving	.535	.196	.182
Q25r2. Reduced cost of public transport	.711	-.066	.017
Q25r3. Congestion	.609	-.024	.128
Q25r4. Crowding of public transport services	.789	.107	-.047
Q25r5. Environmental concerns	.698	.207	.279
Q25r6. Ability to work or shop from home	.676	.308	.023
Q25r7. Distance required to travel	.116	.825	-.122
Q25r8. Flexibility of scheduling	.552	.317	.136
Q25r9. Family commitments (parents, children etc.)	.555	.327	.293
Q25r10. Mobility / Disability	.539	.259	.490
Q25r11. Location	.115	.719	.280
Q25r12. Other (please specify)	.072	.014	.890

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization .[a, b]

a. Rotation converged in 4 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 45 to 59 are used in the analysis phase.

Table O - Rotated Component Matrix for Age = 60-65 years old, 5 years' time

Rotated Component Matrix [a, b]

	Component			
	1	2	3	4
Q25r1. Increased costs of driving	-.012	.827	.168	.140
Q25r2. Reduced cost of public transport	.339	.085	-.272	.639
Q25r3. Congestion	-.009	.180	.733	.136
Q25r4. Crowding of public transport services	.111	.049	.323	.746
Q25r5. Environmental concerns	.518	.444	.321	.114
Q25r6. Ability to work or shop from home	.535	.436	.169	.198
Q25r7. Distance required to travel	.489	.121	.038	-.563
Q25r8. Flexibility of scheduling	.434	.343	.267	.365
Q25r9. Family commitments (parents, children etc.)	.675	.189	.045	-.043
Q25r10. Mobility / Disability	.735	-.088	.028	.145
Q25r11. Location	.216	-.094	.799	-.074
Q25r12. Other (please specify)	.234	.650	-.226	-.220

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 5 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 60 to 65 are used in the analysis phase.

Table P - Test statistics for factor analysis by age, 5 year factors

Test	KMO value	Sig. (Bartlett's test of sphericity)
18 – 24	0.859	<0.05
25 – 29	0.759	<0.05
30 – 44	0.856	<0.05
45 – 59	0.889	<0.05
60 – 65	0.736	<0.05

Table Q - Rotated Component Matrix for Age = 18-24 years old, 15 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q26r1. Increased costs of driving	.651	.200	.142
Q26r2. Reduced cost of public transport	.000	.754	.028
Q26r3. Congestion	.477	.381	.501
Q26r4. Crowding of public transport services	.222	.795	.220
Q26r5. Environmental concerns	.256	.693	.113
Q26r6. Ability to work or shop from home	.556	.337	.105
Q26r7. Distance required to travel	.136	-.100	.860
Q26r8. Flexibility of scheduling	.533	.263	.423
Q26r9. Family commitments (parents, children etc.)	.079	.316	.573
Q26r10. Mobility / Disability	.475	.652	.113
Q26r11. Location	.581	.287	.191
Q26r12. Other (please specify)	.870	-.108	.024

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 4 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 18 to 24 are used in the analysis phase.

Table R - Rotated Component Matrix for Age = 25-29 years old, 15 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q26r1. Increased costs of driving	.288	.685	.217
Q26r2. Reduced cost of public transport	.652	.019	.117
Q26r3. Congestion	.366	.291	.439
Q26r4. Crowding of public transport services	.617	.568	-.063
Q26r5. Environmental concerns	.774	.223	.424
Q26r6. Ability to work or shop from home	.655	.231	.376
Q26r7. Distance required to travel	-.033	.188	.827
Q26r8. Flexibility of scheduling	.473	-.416	.412
Q26r9. Family commitments (parents, children etc.)	.703	-.013	-.029
Q26r10. Mobility / Disability	.776	.463	.120
Q26r11. Location	.150	.073	.614
Q26r12. Other (please specify)	-.006	.753	.231

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 6 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 25 to 29 are used in the analysis phase.

Table S - Rotated Component Matrix for Age = 30-44 years old, 15 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q26r1. Increased costs of driving	-.175	.786	.184
Q26r2. Reduced cost of public transport	.559	.076	.210
Q26r3. Congestion	.602	.256	.164
Q26r4. Crowding of public transport services	.802	.001	-.086
Q26r5. Environmental concerns	.482	.311	.413
Q26r6. Ability to work or shop from home	.228	.665	.006
Q26r7. Distance required to travel	.413	.003	.343
Q26r8. Flexibility of scheduling	.457	.424	.133
Q26r9. Family commitments (parents, children etc.)	.458	.584	.006
Q26r10. Mobility / Disability	.508	.211	.522
Q26r11. Location	.061	.028	.690
Q26r12. Other (please specify)	.086	.090	.756

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 6 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 30 to 44 are used in the analysis phase.

Table T - Rotated Component Matrix for Age = 45-59 years old, 15 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q26r1. Increased costs of driving	.552	.314	-.066
Q26r2. Reduced cost of public transport	.707	.006	.115
Q26r3. Congestion	.632	.216	.070
Q26r4. Crowding of public transport services	.761	.090	.085
Q26r5. Environmental concerns	.557	.462	.250
Q26r6. Ability to work or shop from home	.408	.450	.314
Q26r7. Distance required to travel	.062	.147	.581
Q26r8. Flexibility of scheduling	.327	.597	.229
Q26r9. Family commitments (parents, children etc.)	.390	.612	.255
Q26r10. Mobility / Disability	.294	.495	.249
Q26r11. Location	.060	.028	.842
Q26r12. Other (please specify)	-.100	.802	-.122

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 4 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 45 to 59 are used in the analysis phase.

Table U - Rotated Component Matrix for Age = 60-65 years old, 15 years' time

Rotated Component Matrix [a, b]

	Component			
	1	2	3	4
Q26r1. Increased costs of driving	.765	.069	.063	.133
Q26r2. Reduced cost of public transport	.263	-.047	.753	-.009
Q26r3. Congestion	.582	-.142	.473	-.237
Q26r4. Crowding of public transport services	-.020	.173	.710	.049
Q26r5. Environmental concerns	.770	.210	.104	-.113
Q26r6. Ability to work or shop from home	.106	.753	.060	.072
Q26r7. Distance required to travel	.326	.204	-.495	-.440
Q26r8. Flexibility of scheduling	.275	.418	.400	-.114
Q26r9. Family commitments (parents, children etc.)	.339	.670	.182	.222
Q26r10. Mobility / Disability	.607	.254	-.021	.345
Q26r11. Location	-.034	.731	-.142	-.236
Q26r12. Other (please specify)	.118	-.009	-.023	.883

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 9 iterations.

b. Only cases for which age. Which of the following age groups are you in? = 60 to 65 are used in the analysis phase.

Table V - Test statistics for factor analysis by age, 15 year factors

Test	KMO value	Sig. (Bartlett's test of sphericity)
18 – 24	0.826	<0.05
25 – 29	0.718	<0.05
30 – 44	0.822	<0.05
45 – 59	0.857	<0.05
60 – 65	0.669	<0.05

Table W - Rotated Component Matrix for Mode = Car driver, 5 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q25r1. Increased costs of driving	.282	.104	.539
Q25r2. Reduced cost of public transport	.739	-.053	.184
Q25r3. Congestion	.517	.348	-.082
Q25r4. Crowding of public transport services	.823	.106	.049
Q25r5. Environmental concerns	.665	.187	.284
Q25r6. Ability to work or shop from home	.670	.167	.211
Q25r7. Distance required to travel	.066	.730	.178
Q25r8. Flexibility of scheduling	.655	.100	.091
Q25r9. Family commitments (parents, children etc.)	.508	.304	.084
Q25r10. Mobility / Disability	.556	.188	.396
Q25r11. Location	.205	.789	.025
Q25r12. Other (please specify)	.030	.050	.858

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 4 iterations.

b. Only cases for which Current Main Mode = Car (driver) are used in the analysis phase.

Table X - Rotated Component Matrix for Mode = Car passenger, 5 years' time

Rotated Component Matrix [a, b]

	Component			
	1	2	3	4
Q25r1. Increased costs of driving	.062	.881	-.062	.065
Q25r2. Reduced cost of public transport	.593	.400	-.047	-.321
Q25r3. Congestion	.604	-.007	-.079	.267
Q25r4. Crowding of public transport services	.765	.175	-.061	-.240
Q25r5. Environmental concerns	.676	.416	.095	.062
Q25r6. Ability to work or shop from home	.377	.772	.081	.194
Q25r7. Distance required to travel	.058	.165	-.032	.877
Q25r8. Flexibility of scheduling	.651	.067	.385	.307
Q25r9. Family commitments (parents, children etc.)	.307	.194	.672	.045
Q25r10. Mobility / Disability	.500	.525	.232	.109
Q25r11. Location	.035	.449	.499	-.259
Q25r12. Other (please specify)	-.226	-.188	.714	-.003

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 7 iterations.

b. Only cases for which Current Main Mode = Car (passenger) are used in the analysis phase.

Table Y - Rotated Component Matrix for Mode = Bus, 5 years' time

Rotated Component Matrix [a, b]

	Component			
	1	2	3	4
Q25r1. Increased costs of driving	.436	-.004	.666	.108
Q25r2. Reduced cost of public transport	.165	-.057	.210	.817
Q25r3. Congestion	-.044	.216	.788	.023
Q25r4. Crowding of public transport services	.088	.769	-.022	.120
Q25r5. Environmental concerns	.637	.170	.369	.021
Q25r6. Ability to work or shop from home	.673	.074	.054	.111
Q25r7. Distance required to travel	.676	.132	-.176	.243
Q25r8. Flexibility of scheduling	.508	.587	.134	.009
Q25r9. Family commitments (parents, children etc.)	.654	.263	.276	-.007
Q25r10. Mobility / Disability	.184	.691	.271	.080
Q25r11. Location	.171	.366	.299	.299
Q25r12. Other (please specify)	.050	.310	-.109	.763

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 6 iterations.

b. Only cases for which Current Main Mode = Bus are used in the analysis phase.

Table Z - Test statistics for factor analysis by mode, 5 year factors

Test	**KMO value**	**Sig. (Bartlett's test of sphericity)**
Car driver	0.888	<0.05
Car passenger	0.744	<0.05
Bus	0.813	<0.05

Table AA - Rotated Component Matrix for Mode = Car driver, 15 years' time

Rotated Component Matrix [a, b]

	Component	
	1	2
Q26r1. Increased costs of driving	.524	.037
Q26r2. Reduced cost of public transport	.698	.012
Q26r3. Congestion	.636	.197
Q26r4. Crowding of public transport services	.733	-.049
Q26r5. Environmental concerns	.672	.246
Q26r6. Ability to work or shop from home	.492	.413
Q26r7. Distance required to travel	-.050	.750
Q26r8. Flexibility of scheduling	.590	.295
Q26r9. Family commitments (parents, children etc.)	.566	.307
Q26r10. Mobility / Disability	.481	.366
Q26r11. Location	.098	.688
Q26r12. Other (please specify)	.226	.323

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 3 iterations.

b. Only cases for which Current Main Mode = Car (driver) are used in the analysis phase.

Table BB - Rotated Component Matrix for Mode = Car passenger, 15 years' time

Rotated Component Matrix [a, b]

	Component			
	1	2	3	4
Q26r1. Increased costs of driving	.226	.151	.114	.833
Q26r2. Reduced cost of public transport	.643	.039	-.541	.036
Q26r3. Congestion	.227	.345	.456	-.079
Q26r4. Crowding of public transport services	.739	-.061	.173	-.002
Q26r5. Environmental concerns	.559	.492	.192	.079
Q26r6. Ability to work or shop from home	.178	.785	.055	.303
Q26r7. Distance required to travel	.105	-.121	.757	.214
Q26r8. Flexibility of scheduling	-.001	.542	.566	-.219
Q26r9. Family commitments (parents, children etc.)	.010	.725	-.088	-.141
Q26r10. Mobility / Disability	.780	.311	.031	.030
Q26r11. Location	.494	.337	.064	-.663
Q26r12. Other (please specify)	.527	-.031	.443	.340

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 9 iterations.

b. Only cases for which Current Main Mode = Car (passenger) are used in the analysis phase.

Table CC - Rotated Component Matrix for Mode = Bus, 15 years' time

Rotated Component Matrix [a, b]

	Component			
	1	2	3	4
Q26r1. Increased costs of driving	.138	.089	-.063	.800
Q26r2. Reduced cost of public transport	.164	.639	-.023	.109
Q26r3. Congestion	-.152	.655	.045	.431
Q26r4. Crowding of public transport services	.097	.609	.491	.017
Q26r5. Environmental concerns	.503	.108	.225	.425
Q26r6. Ability to work or shop from home	.623	.183	.033	.111
Q26r7. Distance required to travel	.237	.612	-.277	-.276
Q26r8. Flexibility of scheduling	.228	.365	.359	.161
Q26r9. Family commitments (parents, children etc.)	.712	.216	.127	.210
Q26r10. Mobility / Disability	.247	.023	.625	.367
Q26r11. Location	.702	-.058	-.044	-.098
Q26r12. Other (please specify)	-.116	-.119	.730	-.316

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 8 iterations.

b. Only cases for which Current Main Mode = Bus are used in the analysis phase.

Table DD - Test statistics for factor analysis by mode, 15 year factors

Test	KMO value	Sig. (Bartlett's test of sphericity)
Car driver	0.861	<0.05
Car passenger	0.687	<0.05
Bus	0.710	<0.05

Table EE - Rotated Component Matrix for Gender = Male, 15 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q26r1. Increased costs of driving	.688	.060	.057
Q26r2. Reduced cost of public transport	.223	.694	.078
Q26r3. Congestion	.766	.141	-.016
Q26r4. Crowding of public transport services	.507	.526	-.024
Q26r5. Environmental concerns	.542	.420	.300
Q26r6. Ability to work or shop from home	.517	.264	.258
Q26r7. Distance required to travel	.472	-.195	.360
Q26r8. Flexibility of scheduling	.434	.331	.414
Q26r9. Family commitments (parents, children etc.)	.498	.283	.462
Q26r10. Mobility / Disability	.319	.459	.491
Q26r11. Location	-.055	.682	.068
Q26r12. Other (please specify)	-.040	.024	.859

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 4 iterations.

b. Only cases for which Gender. Please give your gender = Male are used in the analysis phase.

KMO value is 0.883 and significance is <0.05

Table FF - Rotated Component Matrix for Gender = Female, 15 years' time

Rotated Component Matrix [a, b]

	Component		
	1	2	3
Q26r1. Increased costs of driving	.285	.497	-.054
Q26r2. Reduced cost of public transport	.640	.152	-.094
Q26r3. Congestion	.481	.337	.269
Q26r4. Crowding of public transport services	.773	.081	.047
Q26r5. Environmental concerns	.493	.505	.214
Q26r6. Ability to work or shop from home	.077	.733	.118
Q26r7. Distance required to travel	.138	-.042	.823
Q26r8. Flexibility of scheduling	.178	.547	.241
Q26r9. Family commitments (parents, children etc.)	.137	.730	.018
Q26r10. Mobility / Disability	.662	.297	.127
Q26r11. Location	-.001	.370	.653
Q26r12. Other (please specify)	.410	.047	.276

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. [a, b]

a. Rotation converged in 5 iterations.

b. Only cases for which gender. Please give your gender = Female are used in the analysis phase.

KMO value is 0.850 and the significance is <0.05

Appendix D – Example interview transcription

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UNIVERSITY OF LEEDS

**ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee
University of Leeds**

27 January 2017
Dear Clare

Title of study:	**Modelling the CO2 emissions reduction potential of enhanced utilisation of urban transport capacity: pathways to 2030**
Ethics reference:	**LTTRAN-067**
Grant reference:	**EP/G036608/1**

I am pleased to inform you that the above application for light touch ethical review has been reviewed by a School Ethics Representative of the ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee and I can confirm a favourable ethical opinion on the basis of the application form as of the date of this letter. The following documentation was considered:

Document	Version	Date
LTTRAN-067 Clare_LightTouchEthicsFormsigned.doc	1	06/06/16
LTTRAN-067 Invitation letter.docx	2	15/06/16
LTTRAN-067 Participant information sheet.docx	2	15/06/16
LTTRAN-067 Consent form.docx	2	15/06/16

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.
Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie
Senior Research Ethics Administrator, Research & Innovation Service
On behalf of Dr Andrew Evans, Chair, AREA Faculty Research Ethics Committee

<u>Key:</u>

I: **Interviewer**
R: Respondent

I: **And then if I can get you to fill in what you think are policy priority areas for transport, this is just so I can sort of understand what you think is important and compare that to it, if that makes sense.**

R: Okay. They are all important.

I: **You can say that. They are definitely all important.**

So basically I'll just talk through each of the policy measures in turn and ask you about how practical you think it is, how politically acceptable you think it is and how useful you think it is, and then any barriers you can think of and any other thoughts you have on them, if that's alright?

R: Yes, cool.

I: **On the five areas which are on there, but I'll talk through those.**

So the first one is around younger people increased flexibility around their travel behaviour, so the survey shows that younger people are more willing to adjust their journey departure time and engage in things like car sharing, so you can market behaviour change intervention specifically at that demographic in order to maximise your impact of your policy measures, and so you could advertise car sharing for the routes that university students are using, or say, like they've done on TfL now, the bus is busiest between 8 and 8.30, maybe you could travel before or after that time, we've started doing that on some of the tube stations now.

Targeting young people who have got less restraints to try and maximise that impact.

On a scale of 1-5 how practical do you think that is?

R: As sort of as advertising campaigns?

I: **Yes and targeting those younger people to maximise the impact of your intervention?**

R: In terms of the practical, the advertising is quite easy to do and display, is the effectiveness part of the same question or is that the next question?

I: **I've got usefulness as the next question and there's the one after that.**

R: It's easy technically to advertise and to try and change behaviour and the way we target advertising that to young people is doable and it's done across what those other things are, so very. Do you want a scale on that?

I: Yes of 1-5.

R: 5. We could do it. Yes, five.

I: How politically is that toward do you think this policy measure?

R: 5 again. Very, very easy, it's done across all the policy areas.

I: How useful do you think this policy measure could be in achieving transport goals?

R: That's where it possibly falls down because it's quite soft. It's advertising and as I say everyone advertises something for young people, there's lots of billboards everywhere and what's going to make them pay attention to this one in particular when perhaps behaviour changes are not as easy to determine and so perhaps I would say a 3.

I: Okay, cool.

You mentioned sort of the advertising going on and its soft measures, do you think there are any other barriers around it?

R: Well, it's all the other things that are preventing them from taking those options anywhere, whether it's financial soft spots. Just sort of changing behaviour in general and establishing a pattern is quite difficult. I understand that you said it's shown that young people are more flexible but they are still not totally flexible, they still are set in their ways, apart from that they like to use their car, a lot of young people especially if they have got a car, they are not going to jump on the bus. It's kind of a status thing. I never had a car, it was my dad's car but it was still useful. They compare what is useful as well as the transport available.

Journey times, all the classic things, it doesn't do anything about those, it just makes them more aware of public transport as another option, but it doesn't do anything about the fundamental barriers, it just, I suppose, leaves them out.

I: Anything else on that one?

R: Nothing else.

I: The next one is around coupling interventions on travel behaviour with a change in life circumstances. There's quite a lot of evidence in the literature to suggest that if you make changes you've got life change points, like moving house or changing jobs, that you can actually embed those changes in travel behaviour more effectively, so you're forming new habits when you are changing other things in your life as well.

So some ideas around things you could do to maximise that would be offering your employees free public transport passes for the first month to try and start that behaviour off when they are starting in that new job. Or another one could be increasing the prominence of public transport information on house searching platforms, so when you're looking at Right Move it gives the nearest train station. What if you put in your work location and it says this is your average time of commute by X mode, or you could maybe even car share with your neighbours because there might be someone else going in the same direction.

So this one is around trying to couple those interventions at life change points to try and maximise the impact of any behaviour change measures. On a scale of 1-5 how practical do you think that would be?

R: I think that's less practical than the first one. Not impractical, but more challenging, so the Right Move one is relatively easy I suppose in terms of actually doing it, you pay Right Move some money to advertise that on the site.

In terms of actually working with employers, hiring people to do that, more difficult. In fact I'd say that's probably not very doable at all across the whole, I mean if you speak to even the council or other organisations who deal with employers, they can't then have a direct relationship with all those big companies, maybe a few. The way you would be able to do is with the beer companies which do have a certain number of people who they do come into contact with and work with them. Perhaps with workplace packing, that could be a little bit of a backstop; this is what we're trying to get out of this, but if it doesn't work then we're going to try something a little bit more radical.

Perhaps that might work as a bit of an incentive, shall we say, and it's preferable to get our message out there, and would you could do with new developments, new sort of business partners or new people moving into the area is to make that practical, but the planning applications, they do have to have transport plans with them, so perhaps you could speak to them. Someone knows the planning legislation better than myself, so it's about how you could make that requirement to them because there are likely implications perhaps around some things.

So those are the powers that you have to try and help them in place and force them to be in place. I don't think employers are going to do it voluntarily without some sort of either carrot or stick to ask them to do so. Or perhaps they have the social conscious prick, perhaps some of them will want to do something that is good for the environment and tick whatever box and that will be that strategy. So the first question is it practical, I'd say 3 for practicality.

I: How politically acceptable do you think this is?

R: It strikes me as not having any particular obstacles to it. I'm having 5 there.

I: And how useful do you think it could be?

R: 5, I think it would be very easy.

I: **You've mentioned quite a few barriers already, have you got any other thoughts, and there's also another one on work-based planning in a bit, so some of those cross over to that as well.**

R: I think I mentioned the ones that came to me off the top of my head.

I: **Anything else on that one?**

R: No, I think just to say it is a good idea, it is just a question of actually the practical element of trying to put it in place and what you can do legally and how you can actually have a bit of boom with it.

I: **The next one is around the power of having more regulation and devolution for local transport authorities and the opportunities that gives you to improve information provision.**

So there's quite a lot of evidence that there's big gaps between people's perception of service on different transport modes and the costs, so people perceive that getting in their cars is a cheaper option because day to day it's still cheaper. But actually in the long term it's more expensive.

So if you can bring all that information into one place and improve that information provision, what potential that could have for individual behaviour to be really effective, and also it has opportunities for that provision of travellers, so you could, if you've got a regulated authority and you've got your single power pass for the whole region, you could potentially engage employers more effectively around things like having public transport passes for a month or so?

R: I was wondering about that point, I don't think, so what's stopping them from advertising the cheaper journey at the moment? Is that because they are a private company and getting their own passengers?

I: **Yes, I think it's probably lack of clarity on fare information as well and that district picture of everything, you haven't got that central hub of pooling information together and providing information from one place as well, I think.**

R: And that is just about regulation as it applies to information rather than the other benefits of regulation?

I: **The other benefits are sort of part of the package, so the policy is around regulation and that also, so for both.**

How practical do you think this is?

R: Regulation is not going to be as easy as say the advertising options, because obviously whatever they do is going to be, and there is going to be a cost, it will involve putting the genie wrapping of the lamp and that's how it evolves doesn't it. But no-one has done this before, as far as I'm aware? Have they done it in any other country, they certainly haven't done it here in London?

I: **No.**

R: As you know, we've never really deregulated. So, yes deregulation is going to be tough, so I'm going to give that, I'm being optimistic but I'd say 3. It's definitely doable, it's just going to be much more expensive and much more onerous than the other option. It's all relative I suppose.

I: **How politically acceptable do you think it is?**

R: I think again all these things will be very acceptable politically and nothing is likely either; the privatisation will bring up these things, so that's a 5.

I: **And how useful do you think it would be in achieving transport goals?**

R: I'd say about 4.

I: **You mentioned it was challenging?**

R: Yes, so with the information I would need, I would say regulation itself would be about 5 again. Regulation and having a coherent and single transport network is probably the biggest thing that we could do, including one of these things and obviously that one, you have my views on that one. There's a lot of things at play in London, but remember Kiley's went down by a third, but it's just having the tools in order to co-ordinate all the various interventions which regulation offers you, so like congestion charging, and all those things really require a regulated transport network. So yes, 5.

I: **Any barriers?**

R: Yes, dependent on the buses bill, what barriers they put in place and the competition market is messy in this area, unhelpful and have you seen their blog they wrote? Basically saying the market has been perfectly fine despite the fact that a couple of years ago they were the ones who said that there's no head to head competition, that's not the market, there's no competition.

So yes, there are obstacles, there are probably not party politically but broader obstacles in the sense that there are obviously interests at play that are apparent. There will be lots of obstacles. It's doable and it's worth doing, it's just not going to be easy.

I: **Anything else on that one?**

R: No. I mean it's definitely the core option I would say that one, everyone sort of sets their own bit and then there's something that enables everything else we've talked about, because we are that direct control over the transport network and you can't really justify many of the other interventions, you can't really get stuck into everything else, which would probably make this the top priority.

Even when you get to the final two, which we've got, there almost, it is secondary to the tertiary business, it is the primary one that is important.

I: They are a bit of an able buyer?

R: You can really make change and you can do the other things anyway, but they are not as effective and are not as co-ordinated without that, and of course you've got the financial, the income you can get from there maybe you could do something and you can choose from those.

I: So the next one is around workplace and full travelling planning and the opportunities that has to address some of these gaps between perception and reality in customer service. And also perhaps to incorporate car sharing, so the most common insight is concern around car sharing safety and getting into a car with strangers.
If you've got that structure within a workplace, then potentially you can overcome those safety issues like car sharing with colleagues.

And the essential steps are where they are supported by local authorities. So that's that area of policy measure.

So on a scale of 1-5 how practical is that?

R: Practical, I'd say about 2 unfortunately. The reason being that schools are largely, not entirely, but largely outside of local authority rule, even though they are still funded. Local authorities in some cases, they don't really like to be told what to do, the local authority is certainly not, so how they co-ordinate that across, the change is going to be competitive, nonetheless, and it's very fragmented, and also schools, teachers, nobody has any time to sort it out.

That's why for schools as a workplace, as we've discussed before, it's where do you begin if the employers are already there? Very difficult to find the opportunities in the transport at that time to build those relationships. They don't have a mass screening and building a relationship with many of the businesses is too complicated really to do that.

The one perhaps where you could that is at the planning application stage. But again, in some places, in a place like you're likely to impose too many conditions on any planning application and I think that would scare off investors. They don't like to see that. They want to be as dismissive as possible in order to get as much investment and as much building going.

So unfortunately, I agree that it would probably be quite difficult to get through.

I: How politically acceptable do you think it is?

R: It strikes me as 4. There's nothing that means it would have an ideological opposition to it. If you can make it work, that's the first thing. If you make it work, then it will have problems.

I: **How useful do you think it could be in terms of the transport role?**

R: It will only be journey effective; most journeys are not actually taken by people in work because most people aren't in work, so it only includes those people. I think there's quite a small subset of people that we're talking about in this case, who would actually be willing to, first of all, it only targets it for a small number of people, I suppose it streams the other ones as well but it might not have a big impact. So it could be it's not worth doing, but if you could solve all those practical barriers and somehow have a register of all the employers and somehow persuade them to do such a scheme, then yes it would be good, but that's maybe not practical unfortunately. I'd say 3.

I: **You've already mentioned quite a lot about it, is there anything else on that one?**

R: No, I think that's all that springs to mind.

I: **The last one is around car sharing and there's this idea around casual car pooling which has been used in the US quite a bit, where you are sort of picking up people on route rather than having a fixed plan. So it's sort of like more formal hitchhiking and they tend to pick them up from either like a public transport stop or like a big supermarket car park, somewhere public and central. And they tend to do it over there to make use of, well to split the cost control, so it's quite successful in San Francisco where you are going over the bridges to get into the city.**

This one is around whether that could be something that could be tried in the UK? It could be used to take advantage of two plus lanes, where they already exist, I know there's some in Leeds, I'm not sure if there's some in Manchester or not, but there's a few going into the city, and also some are saying you could use it to share the cost of congestion charge, even if you're going into outer London and you're going into the congestion charging zone, you could make use of it there.

And you could see a model where rather than say booking their trip on an app, but registering themselves on the app, so somebody knows where you are it adds that little bit of safety element to it around concerns around security. So there are options there to help you support it as well.

R: Who implements this policy I suppose? Do you leave it to the market to kind of strengthen services, should it be encouraged by the transport authority like it is under a contract for someone to deal with it across the area?

I: **I think in my mind it was something that your local authority could support and promote and potentially, formally facilitate it. I think it is something that could be facilitated by local authority and potentially combined authorities if it was at a regional scale, and would be quite an effective scale at which to do that?**

R: The previous suggestion was that local authority would offer credibility for such a scheme and the response by the [Authority], then they might have been formally assured.

The main problem with this is that I'd very welcome the suggestions, in the likes of hitchhiking there are obviously security fears that people have, and also it's not, people are not inclined to do something that's a little bit too casual in that sense.

I: This one came out of the idea of couch surfing. And where the whole sort of idea for my PHD and the capacity came from because people quite willing to share their home space with people they don't know, and I find that really.

R: Numbers of?

I: A huge number, it's like 7 million couch surfers.

R: That many.

I: That was a couple of years ago actually, so it's probably more than that now. It's incredible. They put more beds on the planet in 7 years than Intercontinental, the biggest hotel chain in the world, did in 6 years, and that's without any building or any planning.

R: It's brilliant, I like stuff like that. I guess I already have an idea, but if you can tap into the market, obviously the couch surfers; people actually sleep on a stranger's couch and without any advertising people actually take it up?

I: Yes.

R: It's something I would do. I mean it's a bit of a while, but have you done it?

I: I haven't done it.

R: I've met loads of people who have done it, it sounds fantastic. So people, I don't know, it's not saying that it's actually a similar kind of thing, a little bit of really out there, but could you imagine phoning somebody and saying I'll just jump in the car and we'll have a random meet up at a bus stop. I'm not quite saying it's bad or good, just that there are people who won't do it and it's about who would take up production and under what circumstances.

So it has to come alongside with the other things that you mentioned, so congestion charging, which would make it, with all those changes coming in at once and if we became quite a simple straight town and that information was provided to drivers, have you thought about this, splitting the car and then you could drive in this lane which is empty for drivers like you. If you combined this with lots of other things and give them the primary local public authority as well, and it was secure etc. then it could be really effective.

I think that's a good idea, but that's dependent on deregulation etc. You need a big bang and then you do the stuff around the edge.

I do like it and it is doable, it's sort of politically practical isn't it? Can you achieve it? Sure. I don't know, it takes me back to the question about who does it, can the transport authority do it if that is the question? I think if you want to one in five transport authorities, stuff like we've talked about, I think it's a bit out of their comfort zone in the sense that it has the local council and not a transport authority one. I sense that if they can move forward with it, it's something like TSTM might be a bit, it's not got the infrastructure, it's a bit out there.

Although I know these interesting things, even the car hire, that has been suggested to come in behind other things. So implementing a car share scheme might be a bit difficult for a transport authority to do. The market might provide something different, and it may require a certain scale to work.

I: Can I ask how politically acceptable you think it is?

R: I guess again it's a question about who does it and if it's the market that does it, then there's no question of it. It's not done by any politician.
I think the rift its obviously around security, whether they're realising, the politician might say I don't want to put my name here because if there's one incident where it happens and I am going to be directly associated, so it's quite a downside risk in my point. So I'd say 3.

I: And how useful do you think it would be?

R: In terms of it's very low cost, I suppose, which is fine. The less spend, it depends what the market is doing, but if the transport authority is doing it, I think it's a four.

I: Anything else on that one?

R: I hope this is okay.

I: This is all good, this is really useful.

R: Is that everything?

I: Yes. Thank you. Thanks so much for your time as well.