University of Southampton

Faculty of Engineering and Physical Sciences

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Examination of the effects of new transportation technologies and business models on urban structure

by

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Thesis for the degree of Doctor of Philosophy

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<u>Abstract</u>

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We live in a new era in transportation with advancements in technology changing people's lives in multiple ways. The problem researched in this project is the effect that these advancements could cause to land use. The first element here, as in any research, is to identify the research gap and formulate the aim and the objectives of the project. Subsequently, the thesis is separated into three main parts, namely the literature review, the methodology developed to address the research gap and scenario modelling to evaluate predictions of the effects. Following a detailed literature review of relevant topics was conducted and it was found that the land use effects of new technologies have received limited attention, which constitutes a gap in knowledge, for which this thesis aims to provide answers. Following, the principles of the methodology are described and it is also analysed how the application of these principals in the context of this thesis is feasible in order to produce valuable results. For the application of the principles, different key values such as generalised costs, car ownership costs, variables related to road capacity and trip rates were used for calibration and parts of the internal modelling structure of the selected LUTI model are changed. More specifically, a new car ownership model was calibrated and incorporated in the system. The selected case study for this analysis is the West Midlands region (UK) and as a result, test scenarios that incorporate new vehicles technologies and business models in the West Midlands region were designed. Based on the produced results, it is evident that the incorporation of new vehicle technologies and business models in the transportation system can increase total regional population and total regional employment. However, the urban areas with the highest financial power have decreasing trends in terms of population and employment and as a result a spatial redistribution of activities is evident in the test scenarios that incorporate the aforementioned transport innovations. Moreover, the zones that neighbour with the region have decreased population and employment, which indicates that due to increased accessibility from the transportation technologies and business models different form of economic activity is attracted to the region. Finally, the developed methodology and the produced results were validated by utilising a combination of the validation methods of sensitivity analysis and validations by experts.

Keywords: Land Use and Transport Interaction, New Transportation Technologies, Business Models, Modelling, Urban and Regional structure

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List of Accompanying Materials

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This thesis is dedicated to my parents and Giorgos

"All models are wrong, but some are useful"

- ***George Box***

Definitions and Abbreviations

AA..Activity Allocation

AM.......................................Ante Merīdiem (ENG: before midday)

AMoD ....Automated Mobility On-Demand

API ....Application Programming Interface

ASC ....Alternative Specific Constant

AVs ....Autonomous Vehicles

BAU ....Business as Usual

BEV ....Battery Electric vehicles

CA ....Cellular Automata

CAVs ....Connected Autonomous Vehicles

CBD......................................Central Business District

CC ....Combined Costs

C-ITS ....Cooperative Intelligent Transport Systems

CO2......................................Carbon Dioxide

COCO ....Car Ownership Costs

CRP ....Comprehensive Renewal Program

CS ....Car Sharing

DfT.......................................Department for Transport

DSC ....David Simmonds Consultancy Ltd

DTCO ....Difference in Total Cost of Ownership

ED ....Economic – Demographic Model

ERGO ....Ethics and Research Governance Online

EVs.......................................Electric Vehicles

FACTS ....Forecasting Air pollution through Car Traffic Simulation

FC ....Fuel Costs

FREC ....Faculty Research Ethics Committee

GC .... Generalised Cost

GDHI..................................... Gross Disposable Household Income

GDP .... Gross Domestic Product

GEV .... General Extreme value

GIS.. Geographic Information System

GPS....................................... Global Positioning System

HEVs..................................... Hybrid electric vehicles

HOV...................................... High-Occupancy Vehicle

HS2....................................... High Speed (Rail) 2

HSTM .... Highly Strategic Transport Model

i.i.d. .... independent and identically distributed

ICEVs .... Internal Combustion Engine Vehicles

ICT .... Information and Communication Technologies

IDE.. Integrated Development Environment

IIA... Independence from Irrelevant Alternatives

ILUMASS .... Integrated Land-Use Modelling and Transportation System Simulation

ILUTE .... Integrated Land Use, Transportation, Environment

IOT.. Input/Output Table

ITLUP .... Integrated Transport And Land Use Planning

ITS .... Intelligent Transport Systems

IUM .... Integrated Urban Models

JRC.. Joint Research Centre

JT .... Journey Time

K.U. Leuven .... Katholieke Universiteit Leuven (ENG: Catholic University of Leuven)

kg .... kilogram

km .... kilometre

KRW .... (South) Korean Won

L... Litre

LiDAR................................... Light Detection and Ranging

LUS .... Land Use (for MEPLAN)

LUTI .... Land Use and Transport Interaction

MaaS .... Mobility as a Service

MATSIM................................ Multi-Agent Transport Simulation

MC....................................... Mobility Cost

MEPLAN .... Marcial Echenique Plan

MIM..................................... Mobility Investment Model

MIT .... Massachusetts Institute of Technology

ML .... Mixed Logit

MNL..................................... Multinomial Logit model

MNP .... Multinomial Probit model

MTC..................................... Metropolitan Transportation Commission

MUSSA................................. Modelo de Uso Suelo de SAntiago (ENG: Land Use Model of SAntiago)

NB.. Naive Bayes

NFC...................................... Non-Fuel Cost

NL .... Nested Logit

NRTF.................................... National Road Traffic Forecasts

NWM................................... Non-West Midlands (County)

O-D .... Origin-Destination

OLS .... Ordinary Least Squares

OSGB .... Ordnance Survey of Great Britain

PAV...................................... Private Autonomous Vehicles

PCU...................................... Passenger Car Unit

PECAS .... Production, Exchange and Consumption Allocation System

PHEVs .... Plug-In Hybrid Electric Vehicles

PRISM .... Policy Responsive Integrated Strategy Model

PT .... Public Transport

PV.. Private Vehicles (For ICEVs)

R .... Retired (population)

R&D..................................... Research & Development

RELU-TRAN........................... Regional Economy Land Use and Transportation Models

RUBMRIO .... Random utility-based multi-region input–output models

RUT .... Random Utility Theory

SAVs .... Shared Autonomous Vehicles

SCGE.................................... Spatial Computable General Equilibrium

SD.. Space Development

SD-A .... Space Development - Aggregated

SD-D .... Space Development - Disaggregated

SILO .... Simple Integrated Land Use Orchestrator

SM .... Shared Mobility

SMMT .... Society of Motor Manufacturers and Traders

SP .... Stated Preference

SPSS..................................... Statistical Package for the Social Sciences

St .... Student (population)

SUMPs.................................. Sustainable Urban Mobility Plans

TAS .... Transport (for MEPLAN)

TCO .... Total Cost of Ownership

TELUM................................. Transport Economic Land Use Model

TRESIS .... Transportation, land use and Environmental Strategy Impact Simulator

TRG .... Transportation Research Group

UCL...................................... University College London

UK .... United Kingdom

USA .... United States of America

USD......................................United States Dollar

V2I ....Vehicle to Internet

V2R......................................Vehicle to Infrastructure

V2S ....Vehicle to Sensor

V2V......................................Vehicle to Vehicle

V2X ....Vehicle to Everything

VAT ....Value Added Tax

VHT......................................Vehicle Hours Travel

VMT.....................................Vehicles Miles Travelled

VoT ....Value of Time

WiFi ....Wireless Fidelity

WM ....West Midlands

ZINB.....................................Zero-Inflated Negative Binomial

ZOV......................................Zero Occupancy Vehicle

ZT...Zone Type

Chapter 1 Introduction

1.1 Introduction

In this chapter, a comprehensive investigation of new transportation vehicle technologies and business models is conducted, to analyse the need for evaluating their land use impacts. Furthermore, in section 1.3 the identification of the research gap is presented, which is the basis of this research. Subsequently, section 1.4 outlines the aim, and the objectives of the thesis and section 1.5 presents the broader significance of this research while in section 1.6 the overall thesis structure is presented.

1.2 Background

Transportation evolves rapidly and is expected to become more innovative with the existence of new disruptive technologies. These changes are expected to influence how people travel and also affect their daily lives. Some examples of new transportation technologies include vehicle automation and electrification and of new transportation business models include On-Demand Transport, car sharing and Mobility as a Service (MaaS). The level of innovation entailed in the development of these technologies is ground-breaking and significant, that it has been compared to the time that private vehicle ownership began (Hawkins & Nurul Habib, 2019). The accessibility that private vehicle ownership created a century ago resulted in financial opportunities that shaped today's cities and the spatial distribution of activities within them. Hence, it is highly likely that the new transport technologies currently being developed will affect land use of cities and regions during the next century. It remains unclear whether urban sprawl or densification should be expected from the existence of new disruptive technologies (Milakis, Kroesen & van Wee, 2018; Wellik & Kockelman, 2020).

Land use is a term that describes how land is mainly used by humans and different land uses represent the different cultural and economic activities in space. Land use changes can be seen at different spatial scales and have a number of cumulative impacts, for example on air and water quality, climate, human health, and generation of waste (United States Environmental Protection Agency, 2022). As a result, land use planning and organisation is important to create secure and defined development of the cities and regions of tomorrow in order to minimise environmental impacts and contribute towards sustainability.

To examine in depth the change that new innovations in the transport sector will have on land use of cities and regions, it is crucial to identify critical transport innovations, because technology has affected all domains of the transport sector (Gkoumas & Tsakalidis, 2019). First of all, it is essential to mention that the literature on the relationship between land use and transport is mainly focused on passsener trips rather that freight trips, bacause passenger transport is highly depandent on that locations of human activities and vice versa (Van Wee, 2002). As a result, specifying and analysing new disruptive technologies related to mobility of passengers would provide a wider perspective on land use results, comparing to analysing new disruptive technologies related only to mobility of freight.

Another element that is essential is the spatial scale of analysis, that can provide compehensive results in terms of land use and the future of urban cores. Since, different transport modes are used for serving different trip lenghts and different trip purposes (Simons *et al.*, 2014), it is essential to determine the spatial scale of this research based on merits and advantages. Burger, Meijers and van Oort (2014) specifically mention in this respect, that an analysis that focuses on the regional scale of analysis has the advantage of providing analytic results for multiple cities, while also serving as a link between the urban and the national level (Burger, Meijers & van Oort, 2014). This is an important element to consider and incorprate in this research, hence modes that operate to serve trips at a regional scale should be determined.

The Joint Research Centre (JRC) of the European Commission (2019) as well as the UK Department for Transport (2023) specifically mention that the emerging technologies that require further research are connected and autonomous vehicles, electric vehicles and new transport business models related to shared mobility. This is because these technologies significantly affect the transport sector, while also having a substantial impact on the economy, the environment and land use (Joint Research Centre (JRC) of the European Commission, 2019; UK Department for Transport, 2023a). At this point, it is essential to note that a number of additional transport innovations are developed, including hyperloop and high-speed rail (Premsagar & Kenworthy, 2022), drones (Khosravi *et al.*, 2021), and the development of shared schemes with micro-mobility (Reck & Axhausen, 2021). Having stressed though the importance of the examination of modes for passenger trips at a regional scale of analysis for this research, the most critical emerging technologies examined are connected and autonomous vehicles, electric vehicles and new transport business models related to shared mobility.

The current literature on new transportation technologies and mobility business models is extensive. Some examples include analyses on their effect on factors related to transport economics (Steck *et al.*, 2018; Tajaddini & Vu, 2023; Perrine, Kockelman & Huang, 2020), on their impacts on traffic and car ownership (Li *et al.*, 2023; Hensher *et al.*, 2020; Palmer *et al.*, 2018; Mitropoulos, Prevedouros & Kopelias, 2017) and on accessibility (Soteropoulos, Berger & Ciari, 2018; Alemi *et al.*, 2017; Papaioannou *et al.*, 2023). Nevertheless, the changes that may occur from the co-existence of all these new mobility options on land use and sustainability has not been researched to a fully satisfactory extent (Nikitas, 2024). Thus, a main research question is derived: "How will the new transportation technologies and business models affect land use?". The spatial distribution of activities at different scales is affected from the existing transportation systems, and thus the dynamics and relationships between transport demand, service locations, transport networks, spatial allocation of activities and urban and regional economics are of high importance.

Simulations and mathematical modelling are essential tools for the investigation of this research question. Wegener (2006) highlighted that an important research question that concerns planners, modellers and researchers is how traditional urban planning can be linked with other kinds of planning. The use of Land Use and Transportation Interaction (LUTI) modelling is considered an appropriate method for modelling interactions between the two (de la Barra, 1989). Based on UK Department for Transport (2014a) transport models require inputs of land-use, which are exogenous. LUTI models include a land use and a transport module that interact and can generate their own results on the evolution of land use, because they incorporate changes in accessibility from the transportation system and inputs from land-use policies (UK Department for Transport, 2014a).

According to Hawkins and Nurul Habib (2019) LUTI models are an appropriate modelling framework that can be used to model new transport innovations and obtain results regarding the urban development. Consequently, LUTI models could also be used to model other types of technologies and simulate the existence of new transportation business models. The main reason that LUTI models have been deemed appropriate for simulating land use effects is because they have a solid theoretical and mathematical background and have been used for policy evaluation, which specifically focuses on sustainability (Bierlaire *et al.*, 2014; Hawkins & Nurul Habib, 2019). At this stage, it should be mentioned that there are alternative approaches to LUTI modelling, such as spatial computable general equilibrium (SCGE) modelling (Simmonds & Feldman, 2011), that could potentially be utilised for further investigation.

Currently, it is not evident how LUTI models can incorporate these new vehicle technologies and business models and be able to adequately capture land use changes without any adaptation. More specifically, vehicle automation, connectivity and electrification and new transport business models are expected to affect among others travel behaviour, accessibility, transport related costs and public acceptance. Example of such changes from the literature are:

- *Travel behaviour* (Sucu, Dadashzadeh & Ouelhadj, 2022; Nikitas *et al.*, 2017; Soteropoulos, Berger & Ciari, 2018).

An example in this respect, is the change of users' travel behaviour given the introduction of MaaS to current transport systems. According to Ho (2022), the extent to which travel behaviour will change and whether possible travel behaviour changes will contribute towards sustainability, resilience, and transport equity, remain rather underexplored (Ho, 2022). The lack of reliable and empirical data from revealed preference surveys in this respect plays an important role for this uncertainty (Ho, 2022).

- *Accessibility* (Meyer *et al.*, 2017a; Alyamani, Pappelis & Kamargianni, 2024; Zhong *et al.*, 2020).

The effect of vehicle autonomy and MaaS on accessibility has also been a matter of scientific research. In Figure 1.1 for example, the cartographical representations of the results of Nahmias-Biran *et al.* (2020) regarding changes in accessibility from autonomous vehicles in both monetary and time values are presented.

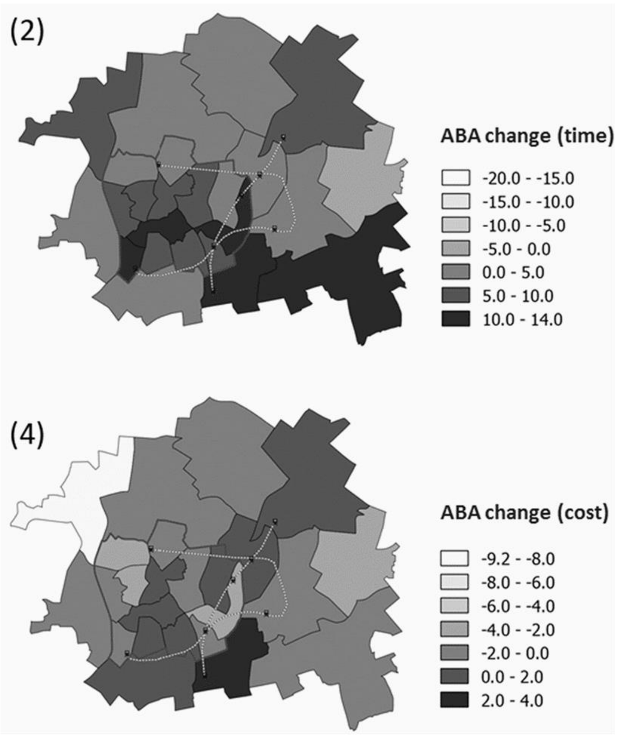


Figure 1.1: Cartographical representation of changes in accessibility from the existence of autonomous vehicles

Source: Adapted from Nahmias-Biran *et al.* (2020)

- *Transport related costs* such as values of time and car ownership costs (Palmer *et al.*, 2018; Kolarova *et al.*, 2018; Hörcher & Graham, 2020; Langbroek, Franklin & Susilo, 2017).

In this respect, the analysis of Wadud and Mattioli (2021) presents in a distinctive way changes of total costs of ownership and use for fully autonomous vehicles in the UK. The distribution of total costs of ownership and use for both conventionally (left) and electric (right) vehicles and mobility options is presented is Figure 1.2.

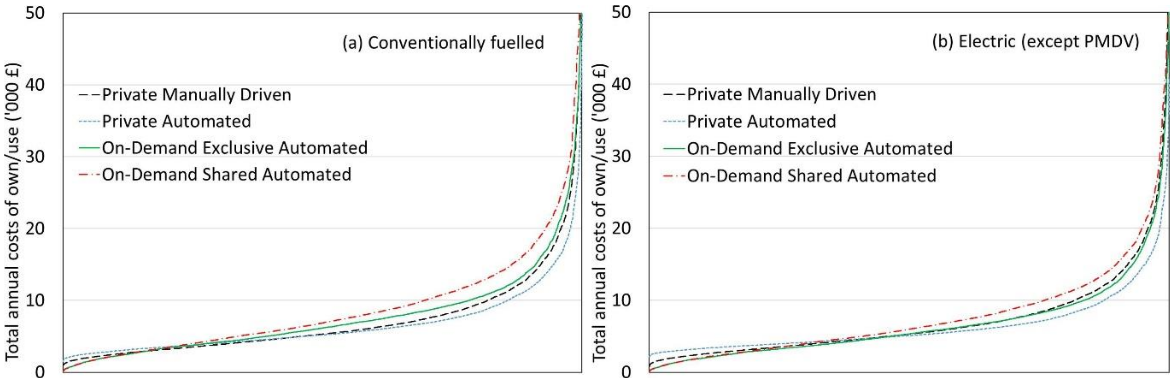


Figure 1.2: Distribution of total costs of ownership and use for both conventionally fuelled (left) and electricity powered (right) mobility options.

Source: Adapted from Wadud and Mattioli (2021)

- *Public acceptance* (Janatabadi & Ermagun, 2022; Mustapha, Ozkan & Turetken, 2024).

Public acceptance of autonomous vehicles can be different depending on the geographical area and can essentially affect the proportions of autonomous vehicles in the fleet. Taniguchi *et al.* (2022) investigated public acceptance of Autonomous Vehicles (AVs) in the UK, Japan, and Germany. The three counties have different results in respect to public acceptance. Based on these results, Japan shows the most promising results of higher levels of acceptance comparing to the UK, which had neutral results, and Germany, which had relatively negative results (Taniguchi *et al.*, 2022).

As it can be inferred, impacts of new vehicle technologies and business modes on different societal aspects related to land use can differ significantly based on the geographical location, the economy, and the possible implementation schemes. Moreover, impacts from these innovations remain a field of intense scientific research. As a result, additional data, adjustments of the current modelling procedures of LUTI models and development of multiple simulation scenarios are necessary to determine land use effects from new transportation vehicle technologies and business models.

1.3 Problem Statement

At this point it is essential to identify the research gap as it can be derived from the literature. Milakis et al. (2017) mention the need to estimate the long-term effect of automation using LUTI models and accessibility metrics (Milakis et al., 2017). The same was also noted in the study of Meyer *et al.* (2017), Soteropoulos et al. (2018) and Emberger & Pfaffenbichler (2020), as an important element of future research. Moreover, Harney (2019) mentions that the co-existence of electrification, automation, and new mobility services, is expected to bring significant changes, thus there is more insight if the innovations are researched together (Harney, 2019). This co-existence of shared mobility and technologies is also suggested as important for further investigation in the paper of Correia *et al.* (2019) and their impact on sustainability is important to be further researched and examined (Santos, 2018). Finally, Luo *et al.* (2019) and Nahmias-Biran *et al.* (2020) investigated the impact of shared and private automation on accessibility (Luo *et al.*, 2019) and land use (Nahmias-Biran *et al.*, 2020) respectively, without though including electrification or MaaS. This research project aims to shed light to these questions and suggestions for future research in the literature, by investigating the co-existence of new vehicle technologies and transport business models simultaneously, within a land use and transport interaction framework, in order to obtain holistic land use effects on multi-level scales of analysis.

Hence, since the current literature does not cover these questions in a holistic way, a new methodology needs to be developed, that could be applicable to different simulation models and provide principles for modelling many different future transportation scenarios to different case studies. Moreover, analysing such results at both regional and urban levels of analysis, is indeed an important element, as it could provide important information for urban dynamics and the future of modern cities and societies. Finally, demonstrating how a new modelling methodology could incorporate new vehicle technologies and business models, can become a significant milestone, for developing more advanced procedures and forecasting reliable results.

1.4 Aim and objectives

The aim of this research project is to investigate how new transportation technologies, such as autonomous vehicles, and new business models, such as MaaS, can affect the spatial pattern of land uses and activities. To achieve this, five objectives have been formulated and are:

1. Identification of the appropriate modelling framework to allow for simulation of new vehicle technologies and transportation business models.
2. Examination of the current transportation innovations.
3. Development of a methodological framework for the incorporation of innovations to the modelling framework.
4. Calibration and Validation of the new methodological framework.
5. Assessment of the impact of new vehicle technologies and business models on land use.

1.5 Significance of this research

Sustainable planning is, indeed, a multidimensional concept and requires the involvement of several scientific disciplines, as the subject has three main pillars, namely social equity, environmental responsibility, and economic efficiency (Rodrigue, Comtois & Slack, 2016).

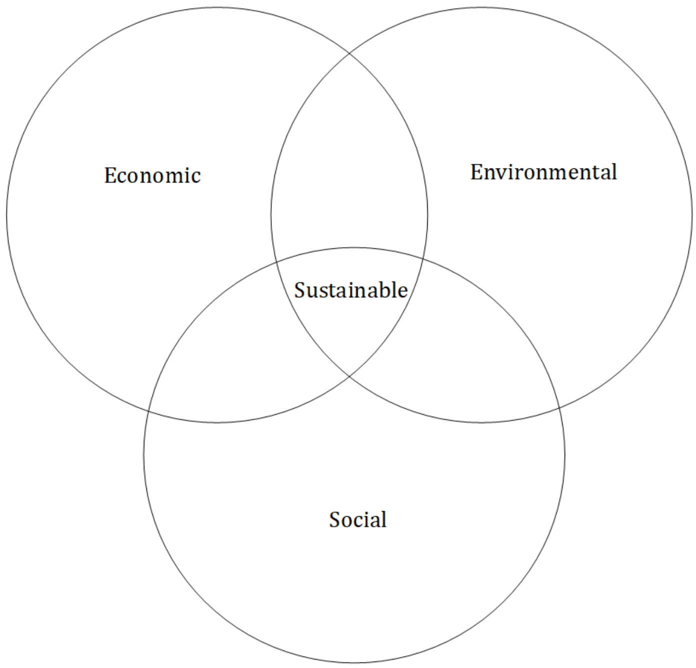


Figure 1.3: The three pillars of sustainability

Source: Adapted from Rodrigue, Comtois & Slack (2016)

Being able to provide reliable results that represent predictions on land use from the existence of new vehicle technologies and transportation business models in future transportation systems, can be an important tool for researchers and decision makers. Moreover, knowing the holistic land use results from such technologies and business models could benefit policy makers and planners and contribute in order to plan towards sustainability.

1.6 Thesis structure

Chapter 2: Land Use and Transport Interaction

This chapter provides analysis on the concept of land use and transport interaction and Land use and Transport Interaction (LUTI) models. A comparison among different LUTI models is conducted, to conclude on a model appropriate for this research.

Chapter 3: Innovations in the transportation sector

In this chapter critical transport innovations for this research are identified. Moreover, it consists of a presentation of the vehicle technologies and business models that are chosen to be modelled. More specifically, the innovations are defined, and some applications are named.

Chapter 4: Key elements affected by new technologies

The chapter aims to draw conclusions on how modelling factors related to transport demand change from the existence of new transport innovations, based on the modelling experience until now in the literature.

Chapter 5: Methodology

In this chapter the principles that are associated with the objectives of the project are described to provide a methodological framework that can be applied to various models in order to simulate new transportation technologies and business models and receive realistic and reliable results.

Chapter 6: Applying the Methodology

In this chapter the completed calibration procedure of the model for the formulation of the future scenarios based on the methodological principles from the previous chapter is discussed in detail.

Chapter 7: Results

Having modelled the scenarios, the effects are appraised on both regional and urban levels of analysis. The analysis of the results is carried out with the help of cartographical representations and graphs in order to draw conclusions.

Chapter 8: Conclusions

From the analysis that has been conducted the main conclusions are analysed and the limitations regarding this research project are outlined. Finally, proposals for future research are discussed and there is also a reference on the published work derived from this project.

In Figure 1.4 the project structure and the links between the chapters are presented.

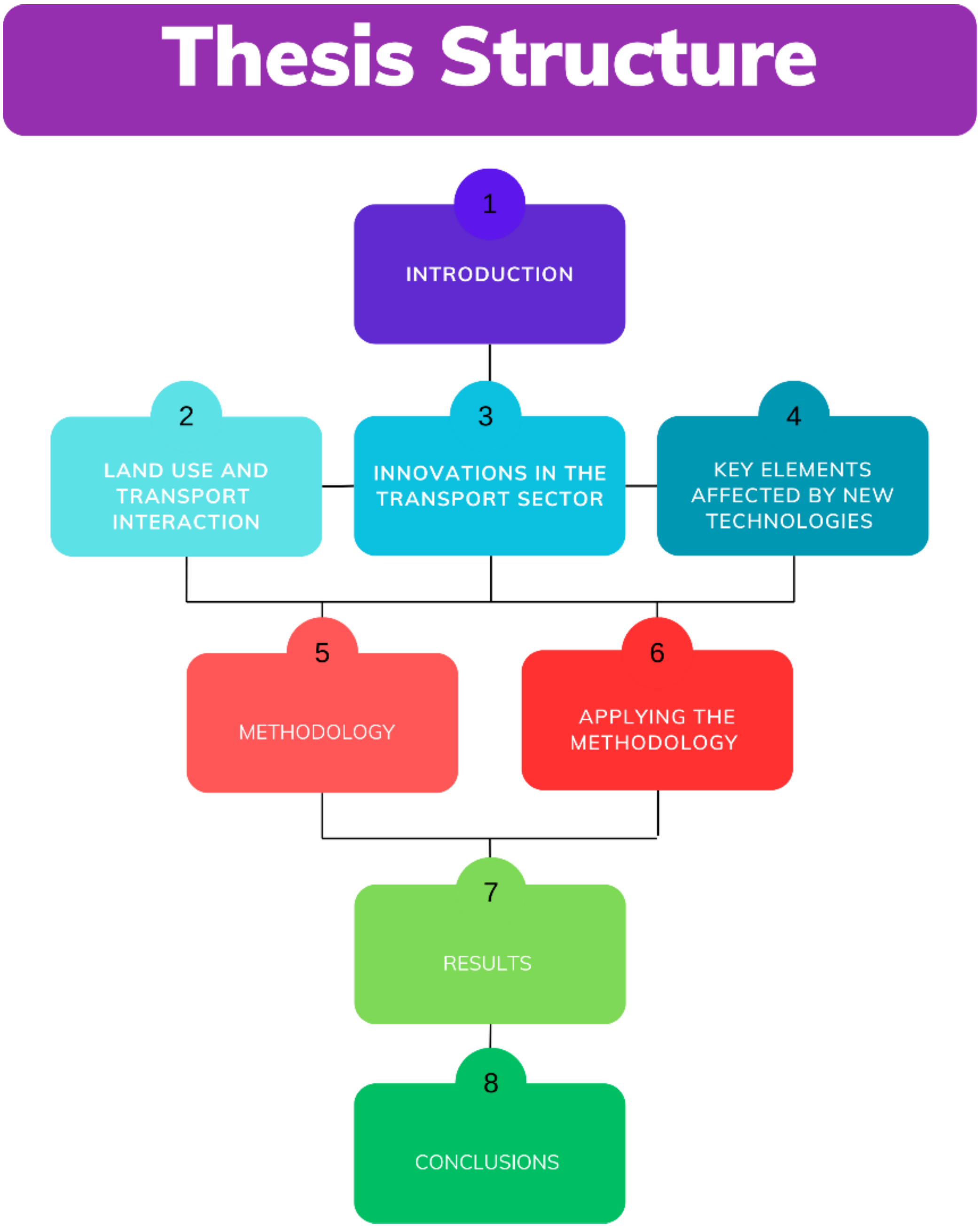


Figure 1.4: Project Structure

Chapter 2 Land Use and Transport Interaction

In this chapter the interaction of land use and transport is examined, through a review of urban and transport systems. Based on this concept, LUTI models were developed to assist with transport planning as well as urban and regional planning. There are three main methodologies on which LUTI models are based and thus their principles are reviewed in this chapter to identify which methodology, or methodologies would be most appropriate for the objectives of this research. A comparison of the methodological characteristics of LUTI models is conducted to the end of the chapter.

2.1 Introduction

Land use and transportation are two aspects that have a relationship of interaction and interdependence. The way that activities are spatially distributed influences the need for travel as well as the infrastructure and transportation services available for these needs. Until the middle of the 19th century urban areas were mostly surrounded by walls. With motorised means of transportation and industrialisation, which played a vital role for labour specialisation (Glaser & Rahman, 2014), cities started to expand (da Silva, 2020). As a result, conurbations and metropolis start to form (da Silva, 2020). The geographical location of cities and also the way they grow appear to have similar patterns in many examples around the world. Many cities have been developed near ports, river crossings or trade routes (Wegener & Fürst, 1999), for example London (UK), New York (US), Rome (Italy), Athens (Greece) and Paris (France). In other words, cities were located and grew where transportation infrastructure was available.

The evolution of transportation systems is generally viewed as economic growth, or as a harbinger of economic growth (Balliet, 2013), as for example happened with the evolution of the American and transcontinental railroads (Thorne, 1918). As a result, the investments on transport have always been a matter of debate. The structure of cities and regions is the main factor that affects activity patterns and as a result, demand for transport. New investments are located in the places with high transport supply, because of the gathering of different activities and land use mix (Giuliano, 2004).

In this section it is important to analyse the theoretical foundations that explain this interaction from land use to transportation and vice versa. Initially, there is an introduction on urban economics and geography and on transportation modelling. Subsequently, this is followed by the conceptual models of the relationship between transport and land use and later by an analysis and comparison of specific computational models, in order to finally find an appropriate model for this project

2.1.1 Theories on urban economics and urban geography

Urban economics have played a major role in terms of understanding how the urban cores develop (Mills, 2000). This field is a branch of macroeconomics that explain and analyse the urban economies, and more specifically spatial structure and the location of firms and households (Kempf-Leonard, 2004).

During the end of the 18th century, Adam Smith first tried to explain the relationship between location and trade. The two elements are interwoven, as trade affects location choice and location affects trade flows. Following, Von Thunen in 1842 extensively analysed the location of agricultural production, with the use of a profit maximisation scheme. With his theory he was able to visualise different agricultural products, as concentric circles. The illustration was based on the comparative cost theory of Ricardo and can be seen in Figure 2.1. The theory of Von Thunen is deemed as the foundation of urban economics (Gorter et al., 2015).

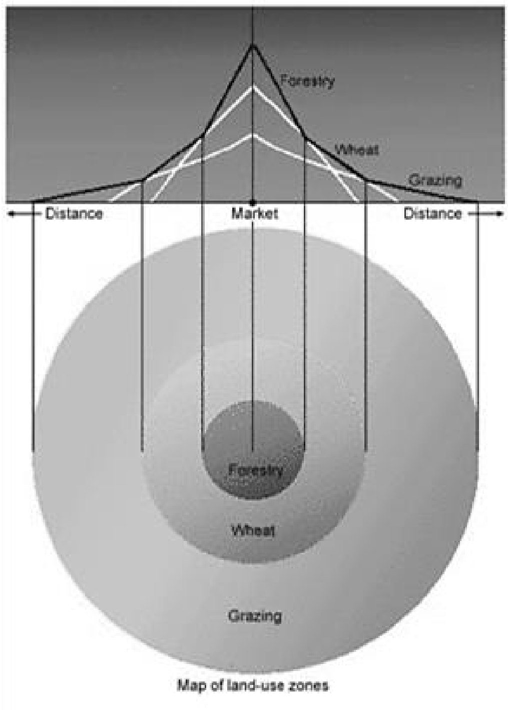


Figure 2.1: Hypothetical Rent Gradients & Land - Use Models

Source: https://bit.ly/2kKnwFP (Troughton, 2016)

Land use modelling has been a major area of scientific interest for decades, because urban systems are dynamic and complex (Bretagnolle, Daudé & Pumain, 2006). Over the decades, many models have been created for this purpose. According to Still (1995) the first steps towards understanding the influence that transport has on land use and as a consequence on the urban structure were conducted by German scientists, such as Weber, Christaller and Losch and they were deeply linked to the correlations between transportation and accessibility (Still, 1995a).

2.1.1.1 Regional models

Weber (1909) developed a theory regarding industrial location that influenced regional science and economic theory. According to this theory, each industrial unit, in order to have a unit output, requires specific amounts of fixed localised inputs. Following, he then studied the optimal location of these industrial units in order to minimise cost from transportation. This analysis included the location – triangle, which consists of an industrial unit or a market and also two supply units and a mathematical model. Extending on this theory, Weber generalised it, by studying labour costs and not just transport costs. Since this theory is concentrated on analysis of price, it has been criticised that it does not consider the determination of prices endogenously (Weber, 1909 cited in: Fujita, 2010).

More specifically, if the test point of the location of a firm has coordinates (x, y) and the input units, which are pre-located, have coordinates (x_i, y_i) and i=1…n, with n being the total number of input units, it is feasible to calculate the Euclidian distance (d) from the firm to the input units with the formula (Puu, 2003):

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2} \qquad (2.1)$$

Assuming that the cost of transport is proportional to the distance, every d_i is multiplied with a weight w_i, which is a constant for the cost of transport from each input per unit of distance and also per unit of output. According to this the total transportation cost is (Puu, 2003) :

$$T = \sum_{i=1}^{n} w_i * d_i = \sum_{i=1}^{n} w_i * \sqrt{(x_i - x)^2 + (y_i - y)^2} \qquad (2.2)$$

Finally, in order to find the coordinates for the minimum cost given (x_i, y_i) and w_i with i=1…n, the T equation is partially differentiated and then equalised to zero (Puu, 2003). Thus:

$$\frac{\partial T}{\partial x} = \sum_{i=1}^{n} w_i * \frac{x - x_i}{d_i} = 0 \qquad (2.3)$$

and

$$\frac{\partial T}{\partial y} = \sum_{i=1}^{n} w_i * \frac{y - y_i}{d_i} = 0 \qquad (2.4)$$

Figure 2.2 is a representation of Weber's theory with n, which is the total number of input units, being equal to three (3).

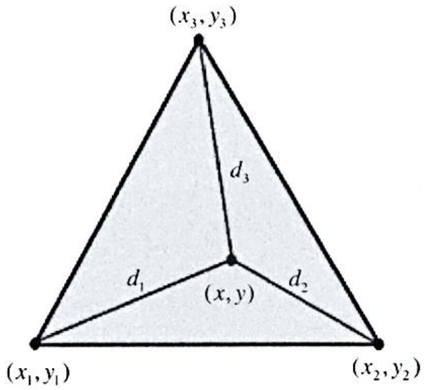


Figure 2.2: Weber's triangle

Source: Puu (2003)

Central place theory, developed by Christaller in 1933 and Lösch in 1954 (Ladias, 2003), considers three fundamental components for the spatial structure, the location of specialised industries, the location of service industries and finally the transport nodes and links. Graphical representations regarding the central place theory are provided in Figure 2.3 and Figure 2.4. The theory seeks to explain the number, size, and location of settlements within a region or urban system, based on the minimum market needed to bring about the selling of a particular good or service, known as the threshold, and also the distances that consumers are prepared to travel to actually access that good or service (Dauphiné, 2017). The basic assumptions behind this theory are:

- The surface of the area is flat without obstacles to the everyday transportation.
- The transportation costs depend on the distance and the services for transport are homogenous within the area.
- The natural resources are equally distributed (Stratigea, 2015).

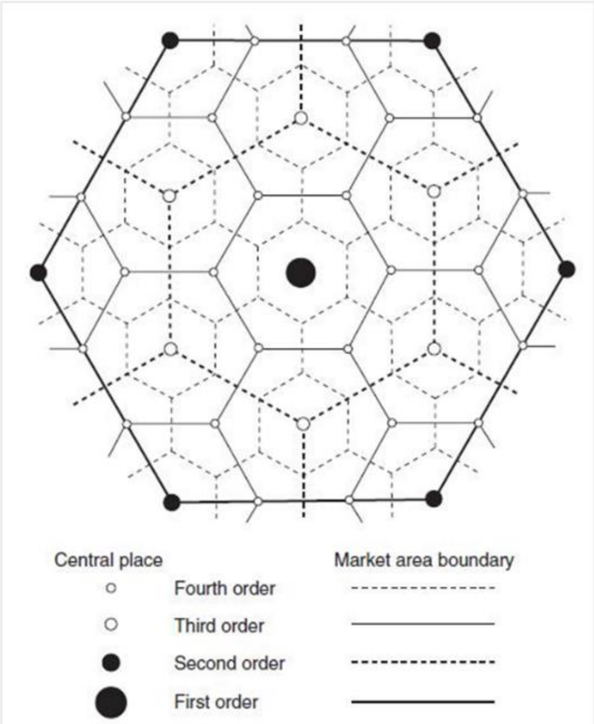


Figure 1 A hierarchical spatial agreement of central places.

Figure 2.3: Hierarchy of central places

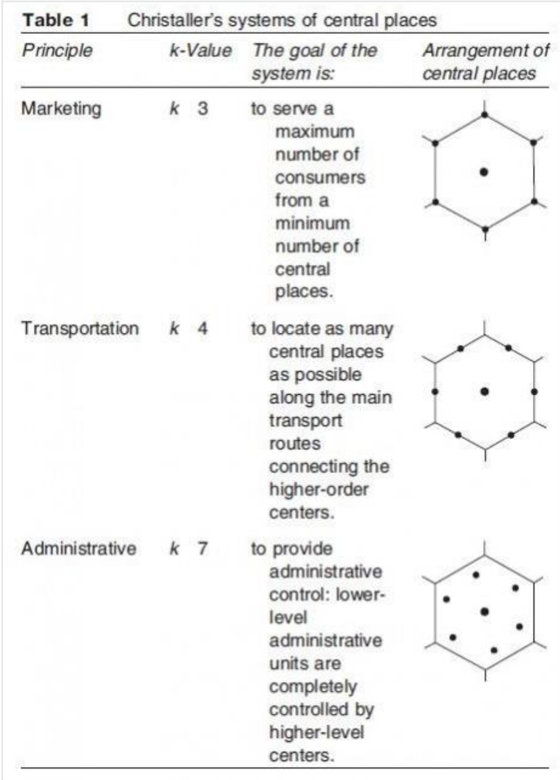


Table 1 Christaller's systems of central places

Principle	*k-Value*	*The goal of the system is:*	*Arrangement of central places*
Marketing	*k* 3	to serve a maximum number of consumers from a minimum number of central places.	
Transportation	*k* 4	to locate as many central places as possible along the main transport routes connecting the higher-order centers.	
Administrative	*k* 7	to provide administrative control: lower-level administrative units are completely controlled by higher-level centers.	

Figure 2.4: Christaller's systems of central places

Source: http://geography.name/classical-central-place-theory/

However, it has been criticised by Still (1995a) that this simplicity in the aforementioned theories differ substantially from the empirical truth. His first point was that in a macroscopic level of analysis the impact that the transportation system has on land use cannot be determined directly, because there are a number of socioeconomic factors that affect location decision making, and this should be taken into account. The impacts that the transportation system has on land use can be seen over long periods of time and during these periods there is a variation of the strength of the interactions. Finally, it is mentioned that a way to examine the influence is by analysing the economic growth, which comes from the investments in the transport system. However, distinguishing the difference between economic activity that is generated to that occurred by the redistribution of activities is not always feasible (Still, 1995a).

2.1.1.2 Urban models

An important urban model that is examined is the Burgess model, which was developed to investigate how Chicago evolved during 1890. Figure 2.5 shows a modified Burgess model taking into account the presence of a shoreline in Chicago (Rodrigue, Comtois & Slack, 2016). It is based on concentric zone theory, where the main assumption is that the city expands from the city centre to the outskirts, forming this way rings of land development with one centre (Torrens, 2000). The total number of zones that the city is classified in is five, and these are:

1. The central business district (CBD), which is the zone with the most financial activity but also the part of the city with the most developed transportation infrastructure.
2. The zone of transition, which is district with some households and also manufacture.
3. The working-class zone, which includes households of people of the working class.
4. The residential zone, which consists of newly constructed housing for the people of the middle classes.
5. The outer commuter zone, which is the outer ring and generally has better quality of housing for the residents of the upper class (Torrens, 2000).

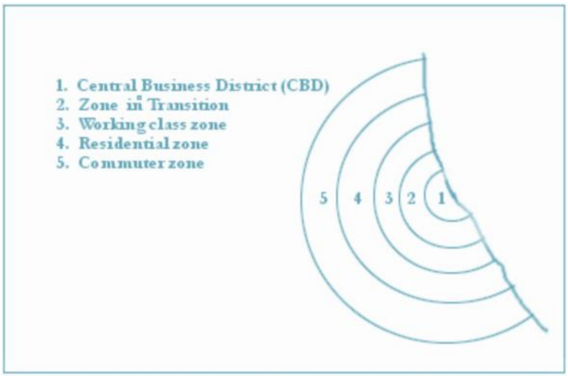


Figure 2.5 The Burgess model

Source: EW Burgess (1925); Carter (1981) cited in Torrens (2000)

Two examples that are suitable for European cities are the Hoyt model developed in 1939 and is presented in Figure 2.6, which is a sector model and also the Harris and Ullman model presented in Figure 2.7 and developed in 1945, which has been characterised as polycentric (Rodrigue et al., 2016). The Hoyt model, unlike the Burgess model, does not consider land uses to evolve in the form of homocentric circles. However, they both have one central business district (CBD). Different geometric shapes are representing different land use sectors. The distinguishing feature in this case is that the existing transport system influences the land use sectors (Rodrigue et al., 2016).

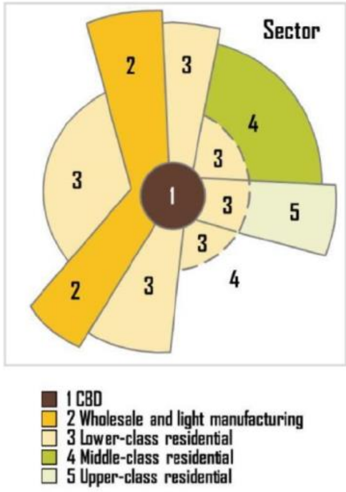


Figure 2.6: Hoyt model

Source: Rodrigue et al. (2016)

On the other hand, the polycentric model of Harris and Ullman is differently structured. In comparison with the Hoyt and the Burgess models, the cities do not expand on the basis of only one centre, but with many different centres distributed in all the urban area (Rodrigue et al., 2016). The geography of the locations of these centres differs depending on:

- Differential accessibility. The location of the activities highly depends on the facilities that are available.
- Land use compatibility. In general activities with the same financial interest are located closely.
- Land use incompatibility. On the other hand, for different socioeconomic reasons many activities are not able to be located close to each other.
- Location suitability. Achieving the optimal rent is not always feasible, thus residential areas may be located in places where people compromise (Rodrigue et al., 2016).

This theory can be graphically seen in Figure 2.7.

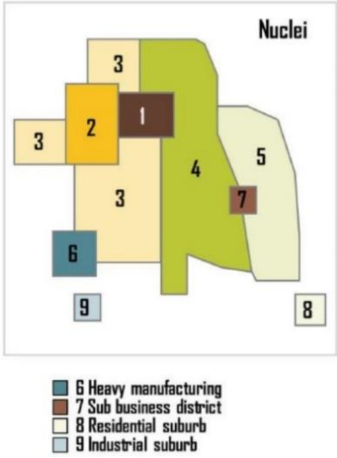


Figure 2.7: The Polycentric Model

Source: Rodrigue et al. (2016)

Despite the fact the that these theories are the basis of urban economics and urban geography, they have been examined in this research because they are important and in relation with this research. More specifically, if the existence of new transportation vehicle technologies and business models affects the urban structure that would lead an urban core or a region transforming from one model to another, this is a crucial element to recognise and analyse.

2.1.2 Transportation models

The four-stage model is the most widely used transport model (Zhong *et al.*, 2022) and is presented in Figure 2.8. The main purpose is to determine travel demand in a transport network (Peterson, 2007; Zhong *et al.*, 2022). There are 4 steps on this model:

1. Trip Generation (Frequency): The aim of this step is to find how many trips happen from (Production) and to (Attraction) a zone.
2. Trip Distribution (Destination): The generated sums from the previous stage are distributed in the zones. The models used are usually the gravity model, the growth factor method or logit models.
3. Modal Split (Mode): The distributed trips are later separated into the different modes that are available. After calculating the utility of each mode, the Multinomial Logit model is used to create the OD matrix for each mode.
4. Assignment (Route): The OD matrix for each mode is assigned in the transport network of the study area, in order to calculate the flows in the links of the networks.

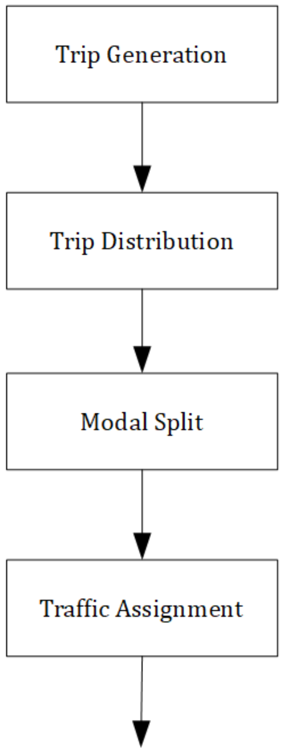


Figure 2.8: The 4-stage model

Source: Adapted from Peterson (2007)

The four-stage model has a number of limitations, including that travel demand from participation to activities is ignored, the trips are treated as independent ignoring temporal, spatial and social interactions and there is emphasis on home-based trips, while also having limitations in terms of policy sensitivity (Jana, 2019; Zhong *et al.*, 2022). These limitations resulted to lack of realism and lack of prediction (Rasouli & Timmermans, 2014).

To surpass these limitations transport modelling evolved and as a result dynamic modelling and activity-based modelling were developed. Dynamic models use data for the existing situation and can forecast their evolution through time, resulting to the expected situation in the future. Activity based models use a different unit of analysis comparing to the 4-stage model, as the trips are not independent. These models analyse the activity schedule of the individual. Thus, in these models, it is essential to examine not just the relationships of the individual trips, but also the trip purpose (Rasouli & Timmermans, 2014). According to Hasnine and Nurul Habib (2021) some important limitations of these models are that they can be very demanding in terms of data and computational requirements, additionally that tour-mode choice may be simplified and that difficulties in predicting and incorporating activity patterns of future scenarios cannot be surpassed (Hasnine & Nurul Habib, 2021).

Finally, other advances in transportation modelling that are under research, including attitudes and beliefs, for example the desire to travel sustainably. For this reason, psychological models are useful to be incorporated into transportation modelling, and this would result to the inclusion of people's perception when travelling, making the modelling procedure more realistic (Rasouli & Timmermans, 2014).

2.2 Land Use and Transport Interaction (LUTI) Models

Cities and regions appear to be very complex in terms of social, economic, political, and environmental characteristics. What is even more important is that these characteristics evolve and change over time (Efthymiou, 2014). Unlike other sciences, with urban planning it is not possible to experiment, which has led to making theoretical and mathematical models in an attempt to represent reality (Jones, 2016). For this reason, Wegener and Fürst (1999) developed the land use and transportation feedback circle, which is shown in Figure 2.9. This graphical representation shows the way factors are affected from each other and in the end, how a holistic land use and transport system functions. Based on this graphical representation and in order to simulate this interaction, Land use and Transportation Interaction (LUTI) models have been created and their fundamental basis is this circle. These models are also known in the literature as Integrated Urban Models (IUM) (Miller, 2018).

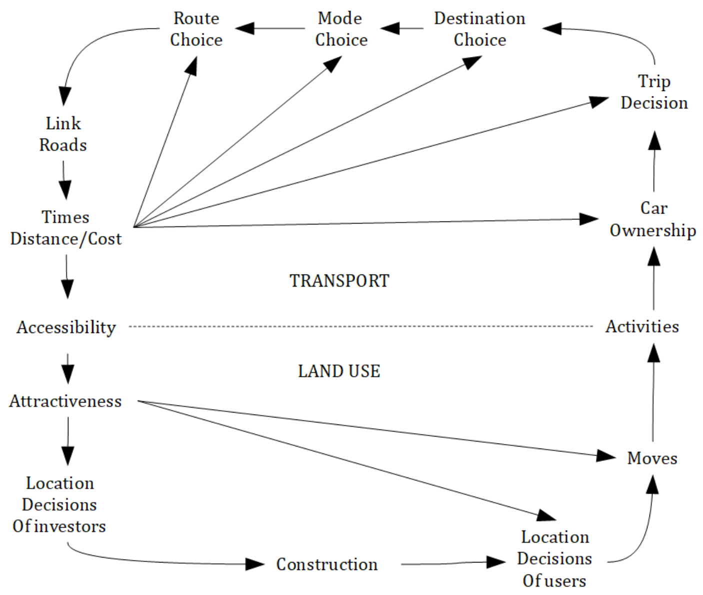


Figure 2.9: Land-Use Transport Feedback Cycle

Source: Adapted from Wegener and Fürst (1999)

Definition: LUTI models stand for Land Use and Transport Interaction- or Integrated as stated in different publications- Models and according to Jones (2016) their key characteristics are *integration*, *comprehension* and finally *operation*. More specifically:

- *Integration*: Identification of relations and from land use to transport and vice versa.
- *Comprehension*: Analysis on spatial process through land use modelling.
- *Operation*: Ability to provide results for evaluation of scenarios and policies (Jones, 2016).

The results, that a LUTI model provides, are for each spatial unit of analysis of the model and are produced based on econometric methods (Jones, 2016). For example, for a LUTI model application developed in Beijing (China), population can be found per zone, which in this case is that spatial unit of analysis (Niu & Li, 2018).

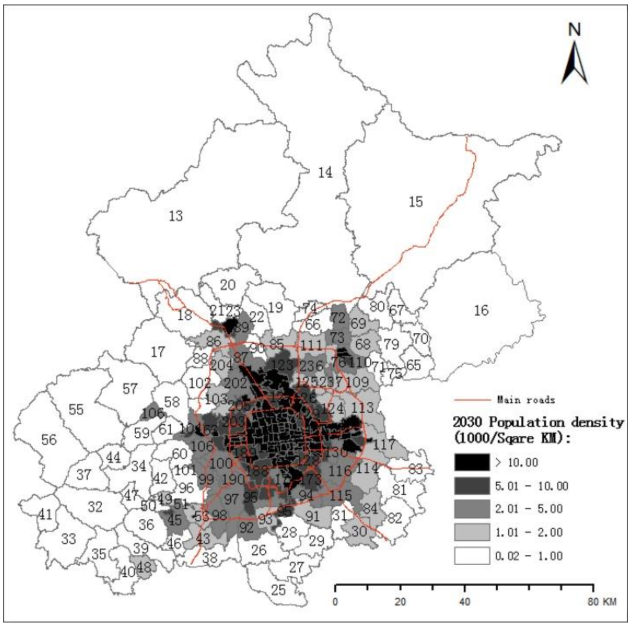


Figure 2.10: Population density derived from the LUTI model of Beijing (China)

Source: Adapted from Niu and Li (2018).

The elements analysed in sections 2.1.1 and 2.1.2 are related to LUTI modelling, as this field has its foundations on the urban, regional and transport models presented, and these models provide a standard reference point to an in-depth understanding of the relationship of transport and land use. Adopting deterministic analytical approaches in this respect, shows how variables related to transport, such as transport costs, can significantly affect the spatial location of activities. Essentially, the use of micro-economic theory on urban economy theories and modes provides the tool for robust frameworks for further qualitative analysis land use and transport (Acheampong & Silva, 2015).

It is essential to mention that LUTI models have a main difference from transport models, which is the fact that any transport model requires inputs of land-use which have been forecast exogenously. On the other hand, LUTI models are able to forecast of land-use and also incorporate land-use policies (UK Department for Transport, 2014a).

LUTI models have major differences in their mathematical structure, content, methodology of modelling but also the amount and the nature of the required data (Efthymiou, 2014). Thus, defining, analysing, and comparing them without referring to their major methodological principles does not provide a holistic view of the frameworks that exist (Zarov, 2016).

2.2.1 Methodology principles of LUTI models

LUTI models have evolved methodologically over time. The three main methodologies that LUTI models have been based on are *Aggregate spatial interaction-based models*, *Utility-maximizing multinomial logit based models* and *Activity based microsimulation models* (Timmermans, 2003; Wegener, 2014; Acheampong & Silva, 2015;Coppola *et al.*, 2013). The principles of these three are analysed in the following sections.

2.2.1.1 Aggregate spatial interaction-based models

Spatial interaction is relevant to models that follow procedure similar with the physical relationship of gravity. Applications in field like human geography, made mostly popular by Wilson (1967), considered that the observed pattern of travel between two places is increasing as the activity in the origin but also destination zones increases, while at the same time travelling cost decreases. A significant amount of location choice models is an extension of the gravity model (Fotheringham & O'Kelly, 1989 cited in: Waddell, 2002).

<u>Gravity Models</u>

More specifically, Flow F_{ij} from zone i to zone j comes from equation (2.5). Flows in spatial interaction models can have multiple meanings. If for example the analysis is based on transport F_{ij} represents the number of trips made, but if the analysis is based on activity location, then F_{ij} represents the amount of activities generated in zone i but located in zone j (de la Barra, 1989).

$$F_{ij} = g * \frac{M_i * M_j * f(c_{ij})}{\sum M_i * M_j * f(c_{ij})} \qquad (2.5)$$

Where:

g : Constant of transformation of activity to flows

M_i: Number of activities in zone i

M_j: Number of activities in zone j

$f(c_{ij})$: Cost Function of travelling from point i to j (includes distance, cost, time etc) (de la Barra, 1989).

<u>Entropy Maximisation</u>

Wilson (1970) introduced the entropy maximisation approach in order to make spatial interaction models more theoretical. Gravity models are criticised because they are based on many simplistic and heuristic assumptions such as the assumptions of location symmetry, uniform behaviour and fixed coefficients, which are surpassed in the entropy maximisation models (Capoani, 2023; de la Barra, 1989). In this approach in an origin destination T_{ij} matrix, which represents the number of people travelling from zone i to zone j, there are many possible distributions of flows in order to have the same number of Origins $O_i$and Destinations D_j and in the end the same number of flows T.

More analytically:

$$\sum_j T_{ij} = O_i \qquad (2.6)$$

$$\sum_i T_{ij} = D_j \qquad (2.7)$$

$$\sum_i \sum_j T_{ij} = T \qquad (2.8)$$

Source: de la Barra (1989)

Multiplying also T with c_{ij}, which is the cost of the trip from zone i to zone j, gives the total transport cost C.

$$\sum_i \sum_j T_{ij} c_{ij} = C \qquad (2.9)$$

Source: de la Barra (1989)

The total number of assignments W is defined by equation (2.10).

$$W = \frac{T!}{\prod_{ij} T_{ij}} \tag{2.10}$$

Source: de la Barra (1989)

In order to find the maximum number of W based on the constraints presented in Equations (2.6), (2.7) and (2.9) the Lagrange method is used to maximise L:

$$L = \ln W + \sum_{i}^{1} \tau_i (O_i - \sum_j T_{ij}) + \sum_{j}^{2} \tau_j (D_i - \sum_i T_{ij}) + \beta (C - \sum_i \sum_j T_{ij} c_{ij}) \tag{2.11}$$

Source: de la Barra (1989)

Where:

τ_i: the Lagrangian multiplier associated with equation (2.6)

τ_j: the Lagrangian multiplier associated with equation (2.7)

β: Constant related to Equation (2.8)

In order to maximise L: the following condition needs to be fulfilled.

$$\frac{\delta L}{\delta T_{ij}} = 0 \tag{2.12}$$

Finally using the approximation of Stirling

$$\frac{\delta L}{\delta T_{ij}} = -lnT_{ij} - \tau_i - \tau_j - \beta c_{ij} = 0 \rightarrow T_{ij} = e^{-\tau_i - \tau_j - \beta c_{ij}} \tag{2.13}$$

After Subtracting and the final equation from the equations (2.6) and (2.7) solving in respect to $e^{-\tau_i}$ and also $e^{-\tau_j}$:

$$e^{-\tau_i} = \frac{O_i}{\sum_j e^{-\tau_j - \beta c_{ij}}} \tag{2.14}$$

$$e^{-\tau_j} = \frac{D_j}{\sum_i e^{-\tau_i - \beta c_{ij}}} \qquad (2.15)$$

If $A_i = \frac{e^{-\tau_i}}{O_i}$ and $B_j = \frac{e^{-\tau_j}}{D_j}$ then:

$$T_{ij} = O_i * D_j * e^{-\beta c_{ij}} * A_i * B_j \qquad (2.16)$$

and also:

$$A_i = \frac{1}{\sum_i (D_j * e^{-\beta c_{ij}} * B_j)} \qquad (2.17)$$

and

$$B_j = \frac{1}{\sum_j (O_i * e^{-\beta c_{ij}} * A_i)} \qquad (2.18)$$

The last three equations are the most generic form of entropy maximising spatial interaction models and refer to doubly constrained models. Based on data availability these can differ from doubly constrained to origin constrained, destination constrained or unconstrained.

- *Origin constrained*: In this case only origins are known, but not destinations. Thus, the final equation regarding T_{ij} is presented in (2.19):

$$T_{ij} = O_i * W_j * e^{-\beta c_{ij}} * A_j \qquad (2.19)$$

Where:

$$A_i = \frac{1}{\sum_j (W_j * e^{-\beta c_{ij}})} \qquad (2.20)$$

(de la Barra, 1989)

- *Destination constrained*: In this case only destinations are known, but not origins. Thus, the final equation regarding T_{ij} is presented in (2.21):

$$T_{ij} = W_i * D_j * e^{-\beta c_{ij}} * B_j \qquad (2.21)$$

Where:

$$A_i = \frac{1}{\sum_i (W_i * e^{-\beta c_{ij}})} \qquad (2.22)$$

(de la Barra, 1989)

- Unconstrained: In this case no information is provided for origins and destinations. Thus, the final equation regarding T_{ij} is presented in (2.23):

$$T_{ij} = W_i * W_j * e^{-\beta c_{ij}} \qquad (2.23)$$

(de la Barra, 1989)

The aforementioned methodology can be applied to both transportation and urban and regional modelling. In transportation it would represent a model of flows and in regional modelling it can also be applied as a model of activity location. The most popular entropy based spatial interaction model is the Lowry model (de la Barra, 1989).

<u>The Lowry model</u>

The Land Use and Transportation model of Lowry (1964) is a gravity model and gave the foundations for the current LUTI models, for example, for ITLUP, which used a Lowry-type model that incorporated entropy-maximisation (Gross, 1982). In the following analysis the Lowry model will be mentioned, thus it is essential to analyse the main procedure of its operation. Subsequently, Lowry type models were studied by Fleisher (1965) and also Goldner, (1971) for applications in the US, whereas at the same time Echenique (1983), Mackett (1983), Putman (1983) and Wegener (1982) developed such models for different case studies (Efthymiou, 2014).

The Lowry model was created within 1962-1963 and later was published in 1964 by RAND Corporation. The study area that it was first developed for was Pittsburgh under the Pittsburgh Comprehensive Renewal Program (CRP), which also consisted of other models as well, in order to generate different alternatives and assist in deciding the most appropriate planning options. The structure of the Lowry model can be seen in Figure 2.11 (Goldner, 1971).

According to Boyce and Williams (2015) the Lowry model is formulated on the basis of two employment sectors, which are retail (or service) and basic. Retail employment includes not just retail trade, but also services such as schools and local government. Basic employment is exogenously allocated to the spatial units of analysis. Residential location is dependent on the total employment location, based on the gravity model. Following, a second gravity model is used to relocate retail employment, based on population and total employment (Boyce & Williams, 2015). Subsequently, the generation of households is a result of the repetitive procedure of reversing the journey to employment into the work to residence trip, in order to use workplaces for residential stock, leading essentially to an “instant metropolis”. The two major constraints in this procedure are that there is a threshold in service employment and also capacity constraint in households (Goldner, 1971; Boyce & Williams, 2015). Some generalisations of the Lowry model include:

- Disaggregation of the population sector.
- Incorporation of quasi-dynamic procedures, to analyse results over time.
- Consideration of the supply side, that mainly affect the allocation of stock.
- Use of more sophisticated representations to the gravity model (Boyce & Williams, 2015).

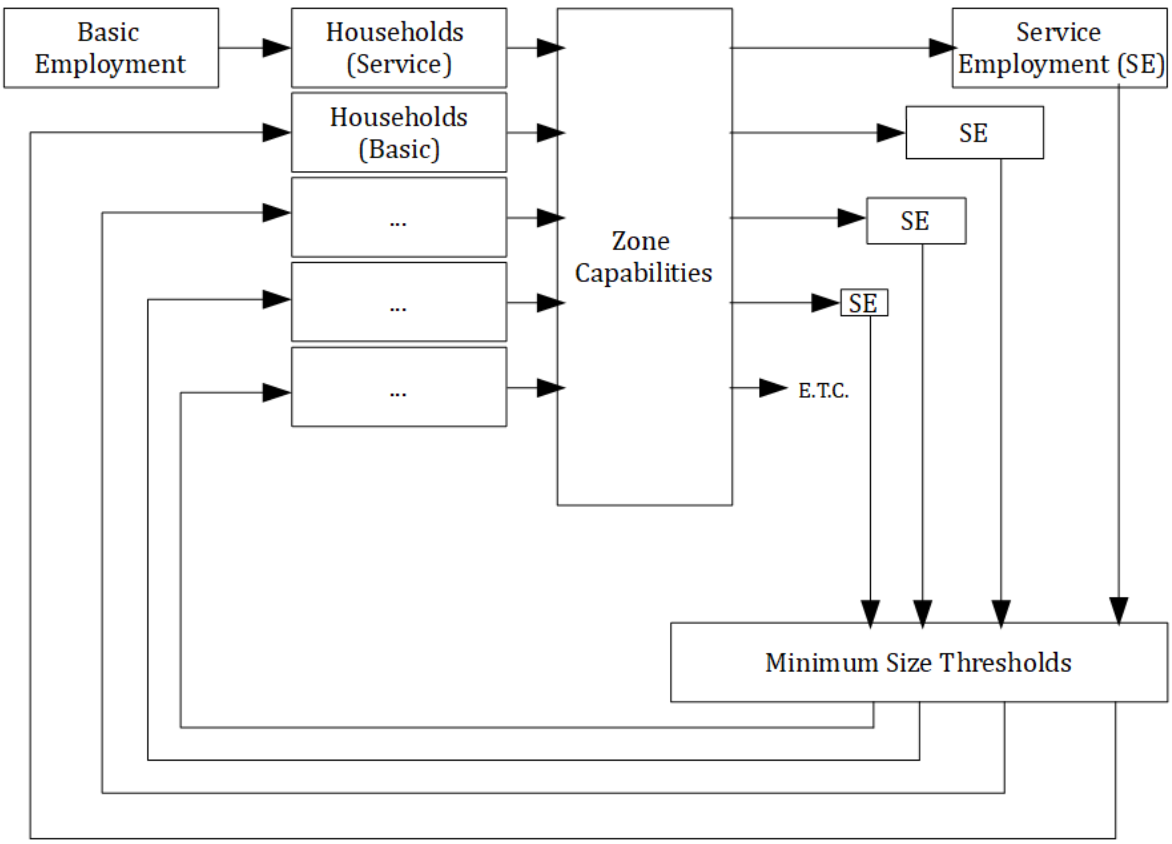


Figure 2.11: The structure of the Lowry model

Source: Adapted from Goldner (1971)

Spatial Input/ Output models

Wegener (2014) mentions that within this category of LUTI models, there are some models that include a multiregional and multi-industry input/output model and that these are the most prominent (Wegener, 2014). The big advantage of such a framework is that it creates links between the production of one industry in a spatial system and the consumption from another industry in the same spatial system. The usual way to represent such relationships are through an input/output table (IOT) and it can become clear that the input/output analysis is based on disaggregation of industry sectors and regional units, which provides the ability to develop a multi-industry regional and interregional models (Oosterhaven & Hewings, 2014). The conceptual framework of an IOT is shown in Table 2.1.

Table 2.1: Input/Output Table Conceptual Structure

		1	**2**	**3**		
		Industry 1	Industry j	Industry N	Final Demand q	Totals
1	Industry 1	…	…	…	…	x_1
2	Industry i	…	z_{ij}	…	y_{iq}	x_i
3	Industry N	…	…	…	…	x_N
	Imports p	…	x_{pj}	…	y_{pq}	
	Totals	x_1	x_j	x_N		

Source: Adapted from Oosterhaven & Hewings (2014)

Where:

z_{ij}: The deliveries from industry i to industry j

x_{pj}: The final number of imports p to industry j

y_{iq}: The final number of deliveries from industry i to demand q

y_{pq}: final inputs type p consumed by demand q

x_i: Input or output of an industry

(Oosterhaven & Hewings, 2014)

The simplest input output model was developed by Leontief & Strout (1963) and since then there have been more input output models based on this. They are relatively popular as they provide an analytical framework of industry-to-industry relationships and can be used for estimating flows (Oosterhaven & Hewings, 2014).

2.2.1.2 Utility-Maximizing Multinomial Logit Based Models

In this theory, behaviour is more integrated as the concept of utility is included. The principles of this methodology are based on Discrete Choice modelling. Discrete Choice modelling has been used for a number of applications and models, not only LUTI models and thus the analysis that follows is extensive including different cases of discrete choice models and their mathematical formulations.

Discrete Choice modelling is based on the fact that decision makers can choose among alternatives. A decision maker is not necessarily an individual, but can also be a household, a firm or any other unit that can make decisions. All the alternatives make the choice set. The three main characteristics that alternatives should have been:

- Only one alternative can be chosen by the decision maker.
- The choice set has to be exhaustive, which means that all the alternatives must be within the choice set.
- There is a set and finite number of alternatives in the choice set (Train, 2003).

The theoretical framework that discrete choice models derive from is the Random Utility Theory (RUT). Each alternative j is associated with a utility U_{jq} for every decision maker q. Since the modeler does not know all the elements that are considered by the decision maker q for the choice, the utility U_{jq} can be separated into two parts:

1. The element V_{jq} , which is the measurable part of the utility function that consists of all the attributes x considered by the modeller
2. The element ε_{jq} , which represents the random residual of the utility and reflects the tastes and idiosyncrasies of the decision maker.

The final equation regarding utility is presented in (2.24):

$$U_{jq} = V_{jq} + \varepsilon_{jq} \tag{2.24}$$

The most commonly used function of V_{jq} is presented in (2.25):

$$V_{jq} = \sum_{k} \theta_{kj} * X_{jkq} \tag{2.25}$$

Where:

θ_{kj}: constants for all individuals that may vary across alternatives k

X_{jkq}: measured attributes for each alternative j for each individual q across alternatives k

The decision maker q chooses the alternative that maximises its utility if only:

$$U_{jq} \geq U_{iq} \tag{2.26}$$

That is:

$$V_{jq} - V_{iq} \geq \varepsilon_{iq} - \varepsilon_{jq} \tag{2.27}$$

As the modeller has to assume the value of the element $\varepsilon_{iq} - \varepsilon_{iq}$, the probability that a decision maker q will choose the alternative j is presented in equation (2.28):

$$P_{jq} = Prob\{\ \varepsilon_{iq} \leq \varepsilon_{jq} + (\ V_{jq} - V_{iq}\ )\} \tag{2.28}$$

(de Dios Ortúzar & Willumsen, 2011)

Models that follow such structure are called multinomial choice models, with the most influential being the Multinomial Logit model (MNL)- usually called logit model - and Multinomial Probit model (MNP) – usually also called just probit models. MNL models have also been extended to nested logit models (Maddala & Schmidt, 1984; Alvarez & Nagler, 1998;Powers & Xie, 1999 cited in: Dow et al., 2004). An analysis of MNL models and nested logit models is conducted in the following sections.

2.2.1.2.1 Multinomial Logit Model

The Logit model is based on the assumption that the utility functions have error terms, which are independent and also follow identically a Gumbel distribution. Initially, the logit model was developed as a binary model, with the decision maker having to choose only between two alternatives. The model was later extended, giving the decision maker the option to choose among many alternatives. This generalisation is referred a multinomial logit model (Bierlaire, 1998).

The probability Pj that the decision maker q will choose the alternative j is presented in equation (2.29):

$$Pj = \frac{e^{Vjq}}{\sum_k e^{Vkq}} \tag{2.29}$$

Where:

V_{jq}: which is the measurable part of the utility function for the alternative j

V_{kq}: which is the measurable part of the utility function for each alternative k in the choice set

Here it is important to mention that the multinomial logit model is based on the Independent from Irrelevant Alternatives (IIA) property, for which it is stated that the probability ratio of two alternatives j is independent from the choice set (Bierlaire, 1998). Finally, in the MNL a fundamental assumption regarding the stochastic errors ε_{iq} is that the distribution they follow is a type I extreme value distribution (Gumbel, Fréchet, Weibull) (Dow et al., 2004).

2.2.1.2.2 Consumer surplus and Logit Models

According to Train (2003) different interventions require analysis on consumer surplus that has occurred from the policies applied. A new alternative in multinomial logit (MNL) models can represent a new intervention or a new policy. The consumer surplus that is associated with the alternatives in a choice set can be expressed in a closed form and it is feasible to be calculated. An individual has a consumer surplus, which is the utility that is received from the choice and in RUT the decision maker chooses the alternative from the choice set that has the highest utility. Therefore, the utility can be expressed as presented in equation (2.30):

$$CS_q = \frac{1}{a_q} max_j(U_{jq}) \tag{2.30}$$

Where:

CS_q: The consumer surplus of a decision maker q

a_q: The marginal utility of income of a decision maker q

U_{jq}: The utility a decision maker q has for an alternative j

Since it not feasible for the modeler to observe the term U_{jq}, the term V_{jq}, which is the measurable part of the utility, should be used, as the modeller knows its distribution. The expected surplus is therefore presented in equation (2.31):

$$E(CS_q) = \frac{1}{a_q} E[max_j(V_{jq} + \varepsilon_{jq})] \quad (2.31)$$

Where:

$E(CS_q)$: The expected consumer surplus of a decision maker n

ε_{jq}: The error term of the utility function

(Train, 2003)

According to Williams (1977) and Small and Rosen (1981) if each ε_{jq} is independent and identically distributed (i.i.d.) extreme value and the utility is a linear function and term a_q is a constant and thus the previous expression can change as presented in equation (2.32), which is called a *logsum* function:

$$E(CS_q) = \frac{1}{a_q} \ln \left(\sum_{j=1}^{j} e^{V_{jq}}\right) + C \quad (2.32)$$

Where:

C: The unknown value which is the level of the utility which is not feasible to be measured.

(Williams, 1977; Small and Rosen, 1981 cited in: Train, 2003)

The expected difference of two logsum functions between an intervention alternative (j=1) and the base scenario j=0 is presented in equation (2.33):

$$\Delta E(CS_q) = \frac{1}{a_q} \left[\ln \left(\sum_{j=1}^{j^1} e^{V_{jq}{}^1} \right) - \ln \left(\sum_{j=1}^{j^0} e^{V_{jq}{}^0} \right) \right] \quad (2.33)$$

According to de Jong *et al.* (2007) logsums have multiple advantages including:

- The consideration of a degree of heterogeneity in the population.
- The have solid mathematical and theoretical backgrounds.
- Depending on the case, they can easily be estimated.
- They can incorporate many factors that affect choices, including quality, travel time, transport costs as well as household characteristics.

On the other hand, to estimate consumer surplus, marginal utility of income must be known. In case the marginal utility of income is not constant with respect to income, a much more sophisticated and complex approach or even an indirect approach would be required. (de Jong *et al.*, 2007).

2.2.1.2.3 Nested Logit Model

However, many times the individual does not have to choose from only one alternative from a set of alternatives, But the choices, the individual makes, create a decision chain (de la Barra, 1989). In other words, the set of alternatives represent combinations of the underlying dimensions of choices. Modelling this case is not as obvious as in the MNL case. Here there is a specific case of the logit model called the nested logit model (Wittink, 2011). Nested logit models are designed to capture correlations among alternatives. In this model the choice set is portioned into several nests. Each alternative has a utility function that consist of two parts. The first part is associated with the alternative and the second with the nest. For an alternative j in a nest C_k the utility function is presented is equation (2.34):

$$U_{jq} = V_{jq} + \varepsilon_{jq} + V_{Ckq} + \varepsilon_{Ckq} \tag{2.34}$$

The elements ε_{jq} and ε_{Ckq} are the error terms, which are independent.

A graphical example of this case can be seen in Figure 2.12. The alternatives in the nests are correlated but the alternatives in different nests, for example 2 and 9, have a correlation equal to 0. The nested logit model is derived from the General Extreme value (GEV) model (Wittink, 2011). A more descriptive representation of the NL model is provided in Figure 2.13 with the distinctive classification of limps, branches, and alternatives as mentioned in the analysis of Hensher and Greene (2002).

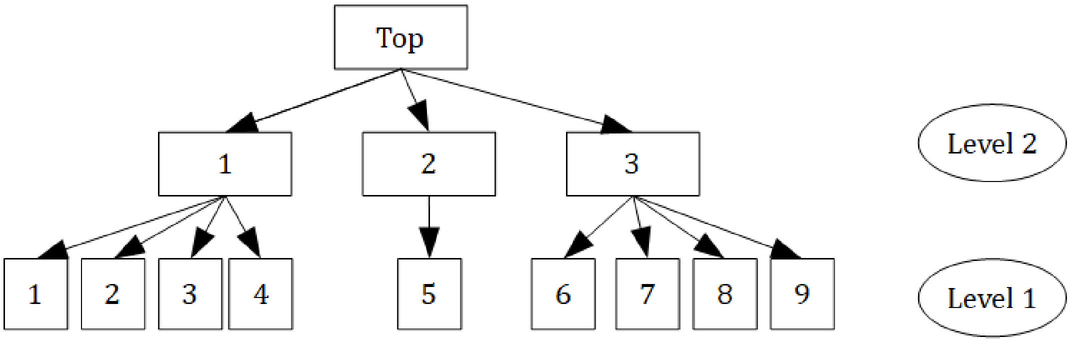


Figure 2.12: Nested Logit (NL) Model Structure

Source: Adapted from Wittink (2011)

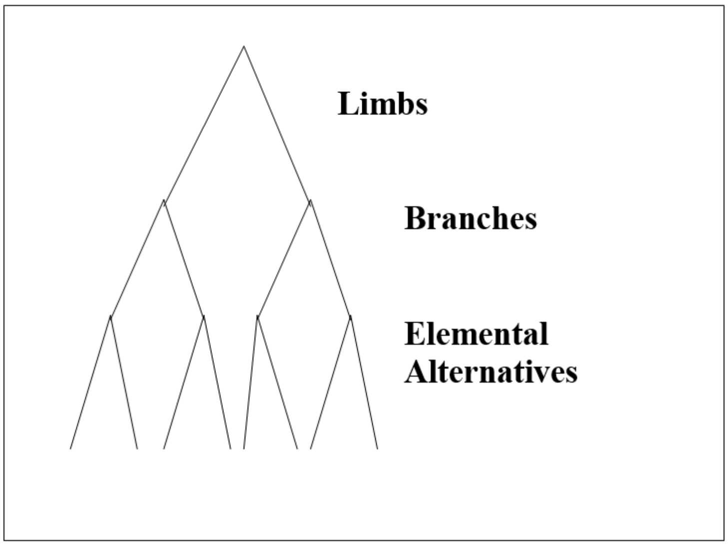


Figure 2.13: Limps, Branches and Alternatives of an (NL) Model Structure

Source: Adapted from Hensher and Greene (2002)

Each nest has a pseudo-utility (also called composite utility, inclusive value or expected maximum utility). The function of the pseudo utility is shown in equation (2.35):

$$V_{Ckq}{}' = V_{Ckq} + \frac{1}{\sigma_k} \ln \left(\sum_{j \in C_k} e^{\sigma_k V_{iq}} \right) \qquad (2.35)$$

The probability model is presented in equation (2.36) :

$$P_{C(jq)} = P_{C(Ckq)} * P_{Ck(iq)} \quad (2.36)$$

Where:

$$P_{C(Ckq)} = \frac{e^{\mu V_{Ckq}{}'}}{\sum_{l=1}^{n} e^{\mu V_{Clq}{}'}} \quad (2.37)$$

And

$$P_{Ck(iq)} = \frac{e^{\sigma_k V_{iq}}}{\sum_{j \in C_k} e^{\sigma_k V_{iq}}} \quad (2.38)$$

The parameters μ and σ_k represent the correlation among alternatives on the nest C_k. the ratio of these parameters is essential to be defined, and as it is not possible to identify them separately, a very common technique is to set one of them equal to 1. If $\frac{\mu}{\sigma_k} = 1$ for the nests, then the nested logit model is the same as the multinomial logit model (Bierlaire, 1998).

2.2.1.3 Activity-Based, Microsimulation Models

LUTI models have been advanced, in order to include behavioural realism, as activity-based modelling in the transport system is incorporated. In activity – based modelling the unit of analysis is the individual (Torrens, 2000) and the travel demand is based on how land uses change (Bowman et al., 1996).

Activity based models have a key difference from the other models as they are tour based. Tour is defined as a series of trips that start and end at work or home. The advantage of modelling tours and not just trips is that the consistency between the inbound and outbound is maintained, because for example the mode that was chosen for work is the same one going back home (Castiglione et al., 2016). There are multiple ways that activity-based models have been developed. Their general structure can be seen in Figure 2.14.

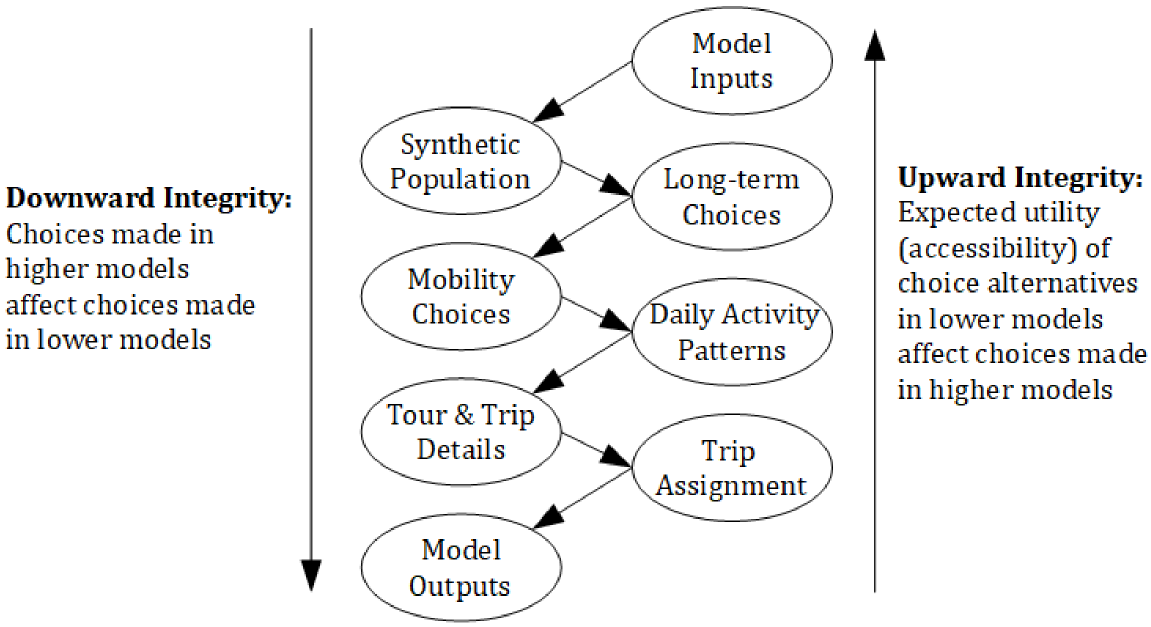


Figure 2.14: Flow chart of the basic structure of an activity-based model

Source: Castiglione et al. (2016)

Individuals in order to travel need choose where to travel, how many stops they will make within their tours, which model to use and so on. The decisions made in the early-stage influence like a chain the decisions made afterwards. This is Figure 2.14 is presented as Downward integrity. On the other hand, the lower-level models feed with information the upper-level, usually in the form of accessibility. This represented in Figure 2.14 as the Upward Integrity. Those two elements actually are the basis of an activity-based model and as mentioned before the main reason that the methodology has been formed in this is to maintain high level of internal consistency, among space, mode dimensions, time and recognising their interdependence (Castiglione et al., 2016).

2.2.1.4 Selection of analysed models

Gravity models incorporate the concept of cost minimisation, so they have some consistency with the concept of maximisation of utility (Cochrane, 1975), however a behavioural basis of spatial interactions is not provided in their theoretical frameworks Comparing the utility maximisation MNL models to the maximum entropy part of the spatial interaction models it is clear that their starting point is different. In the maximum entropy approach, the choices that are made are considered to be completely random and later the constraint of costs is included to become more rational (de la Barra, 1989). On the other hand, in the MNL and NL methods the utility is a more detailed way of including behaviour as it consists of more elements than just costs and it is more representative of the rational decisions of the individuals. Thus, Gravity models or Entropy maximisation models, cannot be used in order to achieve the aim of the project.

Spatial Input/Output models have been created to illustrate spatial linkages with relationships of fixed trade between producers and consumers. They have been often criticised in the literature as non-realistic, because the links of trade should be a function of transportation costs and financial variables that change over time, rather than fixed values. To surpass this limitation Random utility-based multi-region input–output models (RUBMRIO) models have been created, with one example being TRANUS. The structure of RUBMRIO models follows a procedure that uses the trade links of input output models, but also a utility function (for example travel costs) is attributed to each link. Thus, RUBMRIO models allow for trades to respond actively to changes in transportation through this utility function and estimation of coefficients, which are dynamic (Yu, 2018). As a result, even though spatial input/output models would be typically excluded from this project, due to lack of realism, RUBMRIO models cannot be excluded.

Activity Based models according to Delhoum *et al.* (2020) have been developed to provide high level of detail for phenomena, which are non-linear and as a result they provide a realistic representation of transportation demand changes (Delhoum *et al.*, 2020).

In conclusion, using *utility-based models (MNL, NL or RUBMRIO models)* or *activity-based models* have been deemed as appropriate in this research as they involve behavioural realism, which is essential when analysing new technologies and business models, as the response of people to them will not be the same to classic transportation modes and plans. Jones (2016) identified nine LUTI models that belong in these methodologies after correlating the models that are analysed in the methodological classifications of Timmermans (2003) and Wegener (2014). These nine models are *MEPLAN, TRANUS, MUSSA, URBANSIM, DELTA, PECAS, ILUTE, ILUMASS* and *RAMBLAS* (Jones, 2016). Moreover, two models that belong in these categories are METRONAMICA (Amalan *et al.*, 2023) and *METROSIM* (Solignac, 2018). Finally, Hawkins and Nurul Habib (2019) identified the aforementioned models as well as two other LUTI models appropriate for modelling automation, which are RELU-TRAN and SILO (Hawkins & Nurul Habib, 2019). As a result, their comparison is essential to identify a suitable model for this project.

2.2.2 Review on LUTI models

At this stage it is essential to present the main characteristics of the selected LUTI models against their competitors, to support a comparison of these LUTI models in order to finally find one or more appropriate models for this research. These characteristics are:

- Theoretical framework.
- Model complexity.
- Data requirements.
- Unit and geographic area of analysis.

For this analysis, the latest literature available regarding these four elements has been used.

The term theoretical framework of a LUTI model refers to which of the three main methodologies, presented in section 2.2.1, a model is based on and the summary table in this respect in presented in Table 2.2.

Table 2.2: Theoretical framework of the selected LUTI models

LUTI Model	Theoretical Framework
MEPLAN	Utility Based Model
TRANUS	Utility Based Model
MUSSA	Utility Based Model
METROSIM	Utility Based Model
URBANSIM	Micro-Simulation Model
DELTA	Utility Based Model
PECAS	Micro-Simulation Model
ILUMASS	Micro-Simulation Model
ILUTE	Micro-Simulation Model
RAMBLAS	Micro-Simulation Model
SILO	Micro-Simulation Model
RELU-TRAN	Utility Based Model
METRONAMICA	Utility Based Model

Source: Data adapted from Amalan *et al.* (2023), Wellik & Kockelman (2020), Moeckel (2017), Anas (2020), Hunt, Kriger & Miller (2005) and de la Barra *et al.* (2024)

Model Complexity is a different element from the theoretical framework of a LUTI model and it can refer to many different components and characteristics of a LUTI model. Saujot *et al.* (2016) specifically mentions that model complexity is related to the theoretical structure (mathematical background, number of equations and loops and data), implementation design (spatial meshing and number of modelled phenomena) as well as other elements such as time spent, and level of expertise required (Saujot *et al.*, 2016). Since the mathematical background, the data required and the spatial meshing are examined elsewhere in this section, the analysis at this stage is focused on the number of different models that each LUTI model includes and the phenomena they can simulate. Moreover, the rest of the elements (time and level of expertise required), are not explicitly covered in the literature and cannot be quantified, thus it is not feasible to include this information for all models against their competitors.

Table 2.3: Model Complexity of the selected LUTI models

LUTI Model / Reference	**Models**	**Phenomena**
MEPLAN / (Qisheng Pan & Soheil Sharifi-Asl, 2022)	1. LUS (Land Use) 2. FRED (Interface) 3. TAS (Transport)	<u>LUS (Land Use)</u> Consumption and production of land use sectors in different transport zones <u>FRED (Interface)</u> Conversion of trade to transport flows <u>TAS (Transport)</u> Modal split, assignment, and accessibility measures
TRANUS / (de la Barra *et al.*, 2024; Pupier, 2013)	1. Land use model 2. Transport model	<u>Land use model</u> Location and interaction of real estate activity as well as real estate supply <u>Transport model</u> Transport demand and transportation operational supply
MUSSA – CUBE LAND/ (Bentley Systems, 2024; Martínez, 2007)	1. Demand model 2. Supply model 3. Equilibrium model (rent model)	<u>Demand model</u> Behaviour of household and firms <u>Supply model</u> Real estate developers' behaviour <u>Equilibrium model (rent model)</u> Rent values

LUTI Model / Reference	**Models**	**Phenomena**
METROSIM / (Pfaffenbichler, 2003; Parsons & Quade, 1998)	1. Basic & Non-Basic Employment 2. Housing Real Estate 3. Commercial Real Estate 4. Vacant Space 5. Households And Travel	Basic & Non-Basic Employment Land Use, Floor Space Occupied, Salaries Rent/ square foot, Employees Only for non-Basic Employment: Price index for products, Number of serviced customers Housing Real Estate Vacant commercial space, occupied commercial space, Rent/ square foot, Market Value/ square foot Rate of Demolishing & Constructing / year Commercial Real Estate Vacant housing units, Occupied housing units, Rent/ unit, Market Value/ unit Rate of Demolishing & Constructing / year Vacant Space Total Amount of Vacant land, Total Market Value Households And Travel Locational Distribution of housing, Distribution of trips
URBANSIM / (Liu, Miller & Habib, 2023; Nicolai, 2013; Waddell, 2002)	1. Demographic Transition Model and Economic Transition Model 2. Household Mobility Model and Economic Mobility Model 3. Household Location Choice Model and Employment Location Choice Model 4. Real Estate Development Model 5. Land Price 6. Accessibility model	Demographic Transition Model and Economic Transition Model In these two models the supply is generated, and the data have no location, as this procedure follows on the location models. Household Mobility Model and Economic Mobility Model The market-clearing in URBANSIM is solved by the first come first served approach, which in this case means that if two agents select the same location this is solved by choosing one of them randomly. Household Location Choice Model & Employment Location Choice Model

LUTI Model / Reference	Models	Phenomena
		Those two models have attributes and characteristics for both households and employment. For households for example housing per grid cell may be included and for employment real estate characteristics or neighbourhood characteristics are included. Next the evaluation procedure follows based on the desirability using a multinomial logit model, in order to choose the location, which is most desired by each agent. Real Estate Development Model For each Geographical Unit of Analysis, it is proposed to have some specific type of developments, or no development at all. This model simulates the choices regarding development (new development, no development or redevelopment) using a multinomial logit model, including variables like site location, accessibility, or characteristics of zones. Land Price Model The hedonic regression of property value per unit of surface is used for modelling real estate prices. Accessibility model This is the link between transportation and land use which uses the output data coming from the external transportation model and aims to maintain the accessibility.
DELTA/ (David Simmonds Consultancy Ltd, 2017; Simmonds, 2019a, 2019b)	1. Transition model 2. Car ownership model 3. Location model 4. Employment status model 5. Migration model 6. Investment model 7. Production trade model	***For the urban level of analysis*** Transition model Determination of the amount of moving as well as new households. Car ownership model Prediction of household that own 0,1 or +2 cars, based on type, zone and income. Location model

LUTI Model / Reference	Models	Phenomena
		Location and also relocation of employment and households Employment status model Update of the employment status and also home to work trips, based on the results of the location model ***For the regional level of analysis*** Migration model Relocation of households in different areas in a region Investment model Allocation of the investments in the places of the regions Production trade model Estimation of production of all the employment sectors in all areas of a region
PECAS / (Jones, 2016)	1. AA (Activity Allocation) 2. SD (Space Development) 3. TR (transport model) 4. ED (Economic – demographic model).	AA (Activity Allocation) In this component the activities, which include both households and employment, are allocated in the zones. SD (Space Development) This model can be both aggregated SD-A and disaggregated SD-D. In SD-A the allocation happens by using an MNL model and the disaggregated SD-D uses parcels in each zone and an NL model is used for the choice of development in the parcel. TR (transport model) TR is used for the prediction of transport costs and travel time. ED (Economic – demographic model) This model is used for the forecast of households and employment in the next time step.

LUTI Model / Reference	**Models**	**Phenomena**
ILUMASS / (Spiekermann & Wegener, 2018)	A. **Land Use** with six components: 1. Population 2. Firms 3. Residential mobility 4. Firm location 5. Residential buildings 6. Non-residential Buildings **B. Transport** **C. Environment**	A. Land Use with six components: 1. Population: The model has been created to simulate demographic change of different agents, as well as changes in employment. 2. Firms This model has a similar structure with the population model, but focuses on changes in firms (when is a firm founded, growth or decline) 3. Residential mobility: The model simulates the changes in decisions for residential location. Factors that affect these decisions are attractiveness of location, rent given the income level and quality. 4. Firm location: The factors that affect firm location choice are price, quality, image, size, and accessibility. Every firm checks ten alternative possible locations that will provide significant benefits, based on these characteristics. 5. Residential buildings: This part of the IRPUD model simulates different developments and investments in residential buildings (upgrades, demolishes and new buildings) 6. Non-residential Buildings The final part of the land use component investigates the demand for floor space per spatial unit of analysis.

LUTI Model / Reference	Models	Phenomena
		B. Transport The transport model that is used in ILUMASS has its methodological roots on activity-based modelling. Origins and Destination matrices are being made for every hour of the day and the process is dynamic. C. Environment The outputs of the transport models are used to find emissions, air pollution and traffic noise.
ILUTE / (Salvini & Miller, 2005)	1. Auto Transaction sub-model 2. Housing Market sub-model 3. Activity Generation sub-model	1. Auto Transaction sub-model This model determines whether a household will keep its existing car ownership level or not. 2. Housing Market sub-model This model aims to process all of the active households in the market. These include both those looking to purchase and to rent. 3. Activity Generation sub-model The model ensures that temporal needs of the main model, which vary substantially, could be properly accommodated.
RAMBLAS / (Veldhuisen, Timmermans & Kapoen, 2000)	1. Allocate Module 2. Planning Module 3. Relocate Module 4. Interact Module 5. Present and Prep Modules	1. Allocate Module This module creates synthetic population and redistributes spatially the households to available stock by spatial unit of analysis. 2. Planning Module This module incorporates existing plans for construction and urban development. 3. Relocate Module The module handles this task of relocation, based a logit model for the decision of households and a Monte Carlo analysis for matching demand and housing availability.

LUTI Model / Reference	Models	Phenomena
		4. Interact Module The model simulates agendas of activities, which is important for identifying transport among the spatial units of analysis. 5. Present and Prep Modules These models have been developed to visualise traffic flows in the network
SILO/ (Technical University Munich, 2018)	1. Synthetic Population 2. Demography 3. Household Relocation 4. Real Estate Development 5. Employment 6. Travel Demand Model	1. Synthetic Population The module creates synthetic population and lists of persons, households, jobs, and dwellings. 2. Demography This module considers and incorporates in the modelling procedure all events related to relocation but are not spatial in nature, for example, death, marriage, the birth of a child and others. 3. Household Relocation This household relocation module simulates the search of a household for a new dwelling and is also used for households' migration in and out of the case study area. 4. Real Estate Development This real-estate module handles the current demand and supply of housing. 5. Employment This model updates employment based static exogenous forecasts. 6. Travel Demand Model SILO is not fully integrated, as a travel demand model is not required but recommended. For example, in the case study of Munich, the SILO is integrated with MATSIM.

LUTI Model / Reference	**Models**	**Phenomena**
RELU-TRAN/ (Anas, 2020)	1. RELU 2. TRAN	1. <u>RELU</u> The model simulates regional economy and land use. 2. <u>TRAN</u> The model simulates travel for commuting and non-commuting purposes by many different modes.
METRONAMICA/ (RIKS, 2011)	1. Land Use 2. Spatial indicators 3. Regional interaction 4. Transport attraction	1. <u>Land Use</u> This model distributes spatially land use demand. 2. <u>Spatial indicators</u> The spatial indicators model estimates in a dynamic way selected spatial indicators, to understand in-depth the evolution of urban areas and the impacts for surrounding factors. 3. <u>Regional interaction</u> This model uses attractiveness to divide the total employment and population, over the regions. 4. <u>Transport attraction</u> The transport model simulates transport flows and is based on a classical four step approach.

Data and Computational requirements of the selected LUTI models are essential to be presented, as LUTI models require extensive data (Amalan *et al.*, 2023) and there are differences between the amount and the nature of the data needed among the LUTI models.

Table 2.4: Data and Computational requirements of the selected LUTI models

LUTI Model / Reference	**Data and Computational requirements**
MEPLAN / (Qisheng Pan & Soheil Sharifi-Asl, 2022)	Zones, population, employment, economic sectors, floorspace, land, transport modes, values of time, transport related costs, trip purposes, road network, link-types, public transport system data.
TRANUS / (de la Barra *et al.*, 2024)	Definition of zones, economic sectors, employment, population, land, floorspace, road network, link-types, modes, values of time, operators, transport related costs and data regarding the transport system.
MUSSA – CUBE LAND / (Bentley Systems, 2024)	Accessibility and attractiveness of each zone, household income and size, area and floor space per land use, policies and restrictions, employment industries and seize, real estate prices.
METROSIM / (Pfaffenbichler, 2003)	Employment, Population, details on the road network and public transport and floor space.
URBANSIM / (Waddell, 2002 cited in: Amalan *et al.*, 2023)	Employment, population for each market segment, income data, household and business establishment units, vacant household units, land value, mobility pattern and travel characteristics
DELTA / (Unpublished DSC documentation, 2016a; David Simmonds Consultancy Ltd, 2019; Simmonds, 2019a)	Detailed land use data, land use plans, development costs, regional control totals, household census data, travel survey and business establishments.
PECAS / (Amalan *et al.*, 2023)	Income, Residential and employment location choice, land allocation, floorspace, and activity--based transport related data (using surveys)
ILUMASS / (Spiekermann & Wegener, 2018)	Housing, Households, Population, number of privately owned vehicles, details on the road network and public transport, floor space and employment data.
ILUTE / (Salvini & Miller, 2005)	Census and residential data, household activity scheduling behavior, data, energy consumption, car ownership, retail and business unit location, real estate data, travel surveys for both passenger and freight and residential mobility
RAMBLAS / (Veldhuisen, Timmermans & Kapoen, 2000 cited in: Amalan *et al.*, 2023)	Employment, Population, Road network, activity data, time-budget survey, and a continuing mobility survey for validation.

LUTI Model / Reference	Data and Computational requirements
SILO / (Technical University Munich, 2018)	Zonal population and employment and data on local land use.
RELU-TRAN / (Costa *et al.*, 2016)	Population, Employment, floor space, details on land and labour markets, housing prices, land rents, wages, and prices of industry commodities, prices of consumption goods and services, travel mode choices, transport-related energy consumption/CO2 emissions, details on road network.
METRONAMICA / (Navarro Cerrillo *et al.*, 2020)	Population and employment data, Economic sectors, data on the road Network and data on trip distribution (car and public transport).

Finally, two elements that are presented are the spatial unit of analysis in each model and the geographical scale that each model can provide simulations. First of all, it is essential to mention that the unit of analysis of most of the selected LUTI models (MEPLAN , TRANUS , PECAS (Qisheng Pan & Soheil Sharifi-Asl, 2022), MUSSA – CUBE LAND (Bentley Systems, 2024), URBANSIM (Fan *et al.*, 2024), DELTA (Sarri *et al.*, 2020), ILUTE , RELU-TRAN (Engelberg *et al.*, 2020), RAMBLAS (Veldhuisen, Timmermans & Kapoen, 2000) and METROSIM (Anas & Arnott, 1994)) are zones, except for METRONAMICA (RIKS, 2011) and ILUMASS (Engelberg *et al.*, 2020) which use Cellular Automata (CA).

The geographical level of analysis is an important element for modelling procedures related to transport and land use. Lopane *et al.* (2023) mention that one of the main advantages of LUTI models is that they can be used for small-scale areas of analysis, namely urban areas, and large-scale areas of analysis, namely for regional and national levels. In general, based on the characteristics of the model, including resolution and type of the spatial unit of analysis, different LUTI models are used for different geographical areas of analysis (Lopane *et al.*, 2023). Table 2.5 includes a presentation of the geographical area of analysis of each LUTI model examined in this research.

Table 2.5: Unit and geographic area of analysis of the selected LUTI models

LUTI Model / Reference	**Geographical area of analysis**
MEPLAN / (Hunt, Kriger & Miller, 2005)	multi-level
TRANUS / (de la Barra *et al.*, 2024)	multi-level
MUSSA – CUBE LAND / (Jones, 2016)	small-level
METROSIM / (Scottish-Executive, n.d.)	multi-level
URBANSIM/ (Jones, 2016)	small-level
DELTA / (Jones, 2016)	multi-level
PECAS / (Jones, 2016)	multi-level
ILUMASS /(Acheampong & Silva, 2015)	multi-level
ILUTE / (Ravulaparthy & Goulias, 2011)	small-level
RAMBLAS / (Veldhuisen, Timmermans & Kapoen, 2000)	multi-level
SILO / (Wellik & Kockelman, 2020)	multi-level
RELU-TRAN / (Anas, 2014)	multi-level
METRONAMICA / (RIKS, 2011)	multi-level

At this point it is essential to mention that some of the references of this analysis are relatively old, for example (Veldhuisen, Timmermans & Kapoen, 2000). However, the sources used in this research as the latest that could be found for each model.

2.2.3 Comparing LUTI models

In order to incorporate the technologies and business models in a LUTI framework and examine their possible effects on urban structure, it is inevitable that one LUTI framework should be chosen. Comparing the LUTI models in respect to their modelling advantages and disadvantages is the key to identify one framework that would be appropriate for the purposes of this project. At this point is essential to mention that the modelling advantages and disadvantages presented and examined in this section explicitly, are found from the existing literature, refer to the incorporation of new transportation vehicle technologies and business models, and are based on the theory and the current applications of the literature. As it can be inferred, modelling advantages for one application, can potentially be disadvantages for a different application. Hence, this analysis is focused and specified for the purposes of this research.

Dynamic modelling

One important advantage that the chosen model should have, is that it should be dynamic or, as also found in literature, quasi-dynamic. The definition of dynamic LUTI models provided by Simmonds, Waddell and Wegener (2013) is: "Dynamic models consider the different speeds of processes of urban change and concentrate on their outcomes over time and the path dependence this implies" (Simmonds, Waddell & Wegener, 2013). The main advantage that dynamic models have is that they consider time, by iterating in discrete time periods. This provides results that show land use and transport impacts over time, and it is more realistic as the behaviour of the different economic actors in an area can change over time based on the new conditions (Bates & Oosterhaven, 1999). It is expected that mode and scheme choices, that are not globally available yet, will not have a direct effect on land use and urban structure. As Rantasila (2015) states, business models like MaaS do not need new infrastructure, however it is expected that they will reduce the use of private cars, later congestion and finally create vacant spaces in places that were initially parking areas (Rantasila, 2015). This will obviously happen over time, so dynamic models are appropriate for this study.

According to Bates & Oosterhaven (1999) MEPLAN, TRANUS, URBANSIM and DELTA are dynamic, while MUSSA - CUBE LAND also simulates time dependent decisions (Lopes, Loureiro & Van Wee, 2019) and has been used for forecasting effects for long time periods (Bentley Systems, 2024). Moreover, PECAS used discrete fixed time steps for the analysis (Hunt et al., 2003) thus is dynamic and METROSIM can be both dynamic and static depending on each case (Bates & Oosterhaven, 1999; Parsons & Quade, 1998). According to Renner et al. (2014) ILUTE and ILUMASS have the ability to forecast changes over time (Renner et al, 2014). SILO is able to provide forecasts until 2040 (Moeckel, 2017), thus it is dynamic, however there are concerns in case the modeller needs to extent the modelling period. Time is also a dimension considered in RAMBLAS (Veldhuisen et al., 2000), which makes the model dynamic. Finally, according to Anas & Liu (2007) RELU-TRAN is also dynamic (Anas & Liu, 2007) and METRONAMICA has this ability as well, has been used to forecast and simulate activity distribution for a 50-year period in Southampton (Nugraha *et al.*, 2022).

Modelling Time periods

On the examination of time as a critical parameter for comparing LUTI models and identifying an appropriate model for this research, it is also important to consider modelling periods of LUTI models. In general, it is essential to note that current simulations, which include new vehicle technologies and business models, have a pattern regarding modelling time periods. Typically, they consider either short-term (namely 3-5 years) effects on variables such as travel time or long-term (more than 10 years) effects for forecasting and evaluating land use impacts (Rahman & Thill, 2023). This is expected and it is rational, as technology in this respect is radically evolving. Forecasting and simulating land use effects from new vehicle technologies for a 30-year or 50-year period would not provide reliable results, mostly because there will be technological advancements currently not adequately known and hence not involved in a simulation. Typically, models that include Cellular Automata, like METRONAMICA and ILUMASS, are used to simulate longer time periods that surpass 30 years (Wagner & Wegener, 2007; Nugraha *et al.*, 2022). Hence, since modelling time periods for new vehicle technologies and business models are smaller, it would be appropriate to use models that include zones and not prefer models with Cellular Automata as they are used for different simulations and purposes. Of course, this does not make models with Cellular Automata completely unsuitable, however a fit-for-purpose model would be more appropriate.

Geographical Level of analysis

Moreover, modelling flexibility is important, and the proposed model should not confine the modeller in many modelling aspects. As Duarte and Beirão (2011) state, flexibility in planning is necessary, as the urban systems of today are very complex and change rapidly (Duarte & Beirão, 2011). One important aspect regarding modelling flexibility is the geographical scale of analysis. It is clear that one part of the analysis has to be conducted in an urban level, however new transport choices may bring expansion and exogenous trips from other urban cores in a regional level. Hence, using a model with the ability of analysis at a multi-level scale provides opportunities for further discussion on the results. As shown in Table 2.5, MUSSA – CUBE LAND, URBANSIM and ILUTE cannot provide this level of flexibility.

Integration of Land use and Transport

Introducing new components to transport requires mathematical alteration of the internal structure of either the land use or the transport modules. If a model is not fully integrated then the change that needs to happen, will only need to be implemented in one of the two modules and not in the whole structure of the model (UK Department for Transport, 2014a). This procedure is obviously more sufficient and faster and thus of high importance for this research study. As a result, a non-fully integrated model, will be more appropriate for this research.

According to Hunt and Abraham (2003), MEPLAN and TRANUS do not consist of separate transport sub-models, whereas DELTA and PECAS can be integrated with separate transport models (Hunt & Abraham., 2003; Jones, 2016), which for DELTA is generally different depending on the application (Davidsimmonds.com, 2019). Moreover, models that consist of a separate transport sub-model are MUSSA – CUBE LAND (Bentley Systems, 2024; Martínez, 2001) and URBANSIM (Efthymiou, 2014). METROSIM and RELU-TRAN are highly integrated transport and land use models (Timmermans, 2003; Anas, 2014). ILUTE, ILUMASS and METRONAMICA are all fully-integrated (Nugraha *et al.*, 2022; RIKS, 2011; Renner, Nicolai & Nagel, 2014) and the same also applies to RAMBLAS (Veldhuisen et al. , 2000). Finally, SILO has been non-fully integrated, as there is evidence that it has interacted with different transport models (Wellik & Kockelman, 2020; Nagel, 2016; Moeckel, 2017).

Intermodality

An important advantage of a LUTI model is to allow for modelling multimodal trips, as it can provide more realistic transport results (D'Acierno, Gallo & Montella, 2011). The analysis of Rifki (2024) specifically mentions that for the simulation of new transport business models, like MaaS and On Demand Transport with autonomous vehicles, the selected LUTI model was selected, specifically because it allows for simulating intermodality (Rifki, 2024). Thus, a LUTI model that allows for this type of modelling, can definitely be of benefit to this research.

From the analysed models, TRANUS and MEPLAN can simulate multimodal trips with use of transfer matrices (Qisheng Pan & Soheil Sharifi-Asl, 2022; de la Barra *et al.*, 2024), which define possible combinations of transport modes within a trip and the costs of transferring from one mode to the other. Moreover, non-fully integrated models can be integrated with transport models that allow for intermodality, such as URBANSIM and SILO that they can be integrated with MATSIM (Llorca *et al.*, 2022; Zöllig & Axhausen, 2015) as well as DELTA, PECAS and MUSSA – CUBE LAND (Bentley Systems, 2024; Qisheng Pan & Soheil Sharifi-Asl, 2022; Simmonds, 2019b). Moreover, according to Wegener and Fürst (1999) multimodal trips can also be modelled in RELU-TRAN as shown in the analysis of Anas and Hiramatsu (2013), in ILUMASS in the analysis of Strauch *et al.* (2004) and in RAMBLAS (Veldhuisen, Timmermans & Kapoen, 2005). Moreover, ILUTE has been developed to allow for multimodal trips (Salvini, 2003). The transport model of METRONAMICA is based on the classical four-step modelling approach (RIKS, 2011; Navarro Cerrillo *et al.*, 2020) and if it is not adapted or extended to do so with additional data and modelling techniques, it cannot be considered as a model that simulates multimodal trips. Finally, it should be noted that the transport model of METROSIM is the Metropolitan Transportation Commission (MTC) travel model (Zondag, Kroes & Gunn, 2001), which allows for simulating multimodal trips (Circella *et al.*, 2022).

Employment Modelling

New technologies and business models in the transportation sector are expected to also affect the number of jobs and thus the way that a model treats employment is important for the purposes of this research. Moreover, different employment sectors have different needs in terms of transport, thus detail in this aspect will offer more analytical results in terms of employment changes and consequently the urban structure and economic cores.

According to Waddell (2002) URBANSIM appears to have a limitation here as it can only have 10 – 20 employment sectors, while it is also stated that this is not the case for MEPLAN and TRANUS. The employment sectors in these two models are user defined (Waddell, 2002). Moreover, MUSSA has four employment sectors (Martínez, 2007) wherever it has been applied and it is not mentioned if it has been increased, even in its more recent version MUSSA – CUBE LAND (Bentley Systems, 2024), thus in this thesis it cannot be assumed that this LUTI model has the advantage of flexibility in terms of employment. PECAS is mentioned to be a derivative of TRANUS and MEPLAN in terms of the employment sectors (Hunt et al., 2003) and also it is disaggregated by occupation and sector (Qisheng Pan & Soheil Sharifi-Asl, 2022). DELTA and METROSIM have the advantage of including a separate model specifically for employment (Simmonds, Preston & Pagliara, 2010; Timmermans, 2003; Pfaffenbichler, 2003; Bates & Oosterhaven, 1999). Furthermore, Harmon and Miller (2018) mention that the employment sectors in ILUTE are fixed and categorised (Harmon & Miller, 2018) and thus not providing the opportunity to the modeller to define them. ILUMASS, on the other hand includes an employment model that provides the opportunity flexibility in the number of employment sectors (Harmon & Miller, 2018). In RAMBLAS the number of employment sectors is user defined but not predicted, as it involves employment only as an input and does not provide results in changes in employment (Veldhuisen et al., 2005), making the model not suitable for this research. SILO in terms of employment, depends on exogenous forecasts, which introduces a limitation to the model. It is mentioned however, that in the future this is a parameter that is expected to be expanded (Technical University Munich, 2018). Finally, RELU-TRAN provides the opportunity to the modeller to define the number of sectors (Anas & Liu, 2007) and METRONAMICA can examine spatial transitions for many different employment sectors based on the case study (Navarro Cerrillo *et al.*, 2020).

Detail in of the Land Use Component

According to Acheampong & Silva (2015) the land – use component of LUTI models is a key part and there are multiple aspects that can affect it. Adopting approaches that change land use multi-dimensionally is a difficult procedure, but represents the realistic interdependence (Acheampong & Silva, 2015) and the final outcomes are closer to reality. Using a LUTI model with an advanced land use component, with many components that simulate something different in the urban economic system, is expected to be more suitable for this project.

MEPLAN, TRANUS and PECAS do not have a number of land use sub-models, whereas DELTA has sub-models in the land use part and is much more analytic (Hunt & Abraham., 2003). MUSSA has only one land use component (Martínez, 2001), whereas on the other hand, models that are suitable and have analytic land use components are METROSIM (Oryani et al., 1997) and URBANSIM (Efthymiou, 2014). Furthermore, ILUTE and ILUMASS both include a number of sub-models in their land use part (Nicolai, 2013), thus deemed appropriate in this respect. RAMBLAS includes three land use sub-models (Anas, 2014), which could provide realistic results as it is detailed. SILO includes four sub-models for land use (Synthetic population, Demography, Household Relocation and Real Estate) (Technical University Munich, 2018), and METRONANICA includes three sub-models specified for land-use as shown in Table 2.3, making both of them analytic in this respect. Finally, RELU-TRAN only consists of one land use component (Anas, 2014), which makes it not suitable for the scope of the study.

Modelling Car Ownership

Another important advantage for incorporating new vehicle technologies and business models is the existence of a car ownership model in the structure of the selected LUTI model. Specifically, Basu and Ferreira (2020) mention that impacts of autonomous vehicles that are of primary interest to policy makers are those related to land use and to car ownership levels (Basu & Ferreira, 2020). Hence, the existence of a separate car ownership model integrated in the current structure of a LUTI model and affecting land use, would provide important insights to final results and conclusions of this research.

Interestingly, even though car ownership is a very important element in the modelling procedure and for everyday travel patterns, it is only simulated in two of the examined LUTI models, which are DELTA (Simmonds, 2019b) and ILUTE (Salvini & Miller, 2005). This provides an important advantage for these two models for this research.

Modelling Accessibility

According to Russo (2022) new innovative transport business models can be crucial in affecting accessibility in urban and regional areas and this change in accessibility affects components of the transport and the land use model, for example modal split and residential location (Russo & Comi, 2011; Engelberg *et al.*, 2020; Soteropoulos, Berger & Ciari, 2018). Accessibility based models provide outputs regarding land use in the future and then the results are used for modification of the transport component (Bates et al., 1999). Moreover, activity-based models have the advantage of disaggregation and microsimulation, which gives the ability of understanding the responses to transport changes and policies better (Shiftan *et al.*, 2003). On the other hand, spatial interaction location models produce interaction matrices that are later converted in travel demand matrices. This introduces a limitation for many transport aspects, such as travel time, mode choice and route choice. When introducing modes like autonomous vehicles, that have not been yet used, it is essential that there should be as fewer limitations in the transport model as possible, in order to have in overall the most realistic results possible. Thus, it would be even more beneficial that the chosen model to either be accessibility based or activity-based category, in order to consider the concept of accessibility in more depth. For the models analysed in this section, some do not have the advantage of considering accessibility at a high level of detail. More specifically, METROSIM, MEPLAN and TRANUS are based on spatial interaction location modelling and thus do not simulate accessibility (Jones, 2016; Bates et al., 1999).

Based on the aforementioned statements Table 2.6 is created presenting concisely which of the models have advantages that would benefit the modelling procedure in the research, using a plus (+) sign if the model provides this advantage and a minus (–) sign if not.

Table 2.6: Table of Model Characteristics for the Project

LUTI Model	Dynamic modelling	Modelling Time periods	Geographical Level of analysis	Integration of Land use and Transport	Intermodality	Employment Modelling	Detail in of the Land Use	Modelling Car Ownership	Modelling Accessibility
MEPLAN	+	+	+	-	+	+	-	-	-
TRANUS	+	+	+	-	+	+	-	-	-
MUSSA – CUBE LAND	+	+	-	+	+	-	-	-	+
METROSIM	+/-	+	+	-	+	+	+	-	-
URBANSIM	+	+	-	+	+	-	+	-	+
DELTA	+	+	+	+	+	+	+	+	+
PECAS	+	+	+	+	+	+	-	-	+
ILUMASS	+	-	+	-	+	+	+	-	+
ILUTE	+	+	-	-	+	-	+	+	+
RAMBLAS	+	+	+	-	+	-	+	-	+
SILO	+	+	+	+	+	-	+	-	+
RELU-TRAN	+	+	+	-	+	+	-	-	+
METRONAMICA	+	-	+	-	-	+	+	-	+

From the conclusions drawn in Table 2.6, it is clear that an appropriate model for this study is DELTA, as it fulfils the aforementioned requirements. Moreover, DELTA has some more beneficial elements for this project, as it also consists of SimDELTA as well, which gives an extra flexibility in modelling. Finally, DELTA has a high impact on land use and vacant spaces (Rantasila, 2015).

Chapter 3 Innovations in the transportation sector

3.1 Critical vehicle technologies and business models

New innovative vehicle technologies and business models related to shared mobility have seen rapid growth in recent years and have created many new possibilities for future transport. However, these technological advancements pose new difficulties for the existing transport modelling tools (Burrieza-Galan *et al.*, 2021) and they also increase the competition for urban space (Louen *et al.*, 2023), leading essentially to new challenges in transport and land use planning. Many opportunities arise from the existence of these new emerging technologies. For example, as mentioned by Merkert & Wong (2020), the association of smartphones with new transport business models (e.g. MaaS) has led to sharing big data related to transport preferences, making transport business models customisable to the users of the transport network. These opportunities can change both the public and the private transportation sector (Merkert & Wong, 2020).

According to the Joint Research Centre (JRC) of the European Commission (2019) automated, connected and electric vehicles as well as business models related to shared mobility are specifically mentioned as the emerging technologies that should be further researched, because they do not just affect the transport sector but they may bring many other societal implications, such as implications for economy, employment, energy use and land use. The same technologies and business models have been also identified as critical for decision making related to household and residential location by Mingzhu (2019). It essential to mention, there are many other technological innovations which are not examined in this thesis, such as last-mile delivery with drones (Garg *et al.*, 2023), micro mobility (Reck, Martin & Axhausen, 2022) and hyperloop and high-speed rail (Rajendran & Sinha, 2023). Since the core of the thesis is based on passenger trips of the road/rail network at an urban scale of analysis, drones, hyperloop and high-speed rail have not been considered. Moreover, the aim is to examine land use effects on both regional and urban levels of analysis, thus since micro-mobility modes have significantly the smaller trip lengths to the other modes (Ho & Tirachini, 2024), it is expected that land use may only be influenced at a scale of a number of spatial units of analysis (Sarri *et al.*, 2022) and not regionally, which out of the scope of this research. Of course, enriching a modelling framework with the aforementioned transport innovations that have not been considered, would provide more information on land use effects. However, in this analysis only new vehicle technologies and business models for passenger trips in the road network are examined, as they form already a standalone group of emerging technologies that require further research

More specifically, according to the literature there are different levels of uncertainty that arise from this rapid change in transport with new vehicle technologies and business models (Acheampong *et al.*, 2023) and fundamental questions that the current literature aims to answer in different ways (Louen et al., 2023). These uncertainties and questions are, among others, related to the effect the innovations may have on land use (Pangbourne *et al.*, 2020; Muller *et al.*, 2021; Sunitiyoso *et al.*, 2023; Natvig, Stav & Vennesland, 2023), accessibility (Acheampong *et al.*, 2023; Esztergár-Kiss, 2023; Makarova *et al.*, 2023; Chen, Wang & Tian, 2023), traffic (Mitropoulos *et al.*, 2023; Chen & Acheampong, 2023; Nemoto *et al.*, 2023; Alanazi, 2023) and car ownership levels (Liu *et al.*, 2023; Seker & Aydin, 2023; Lopez-Carreiro, Monzon & Lopez, 2024), elements which are integral for this research. As a result, since the importance for the examination of vehicle automation, connectivity, electrification, and shared mobility has been presented in this section, it now essential to define in more depth these innovations and present their basic characteristics as well as noteworthy applications of them worldwide.

3.2 New Vehicle technologies

3.2.1 Autonomous Vehicles (AVs)

Autonomous vehicles are the cars that do not require human control in order to drive. They have the ability of driving closer to each other, which means that they can increase the capacity of the road network (van den Berg et al., 2016). Autonomy in vehicles has been separated into levels, in order to identify the interim levels between no autonomy to full autonomy (Davidson et al., 2015). These are presented in Table 3.1.

Table 3.1: Levels of Automation

Level of Automation	Description
Level 0: Driver only	The human driver has complete control over the vehicle.
Level 1: Assisted automation	One automated function is performed by the vehicle, but the human still has the complete control.
Level 2: Partial automation	Two automated functions are performed by the vehicle, but the human still has the complete control.
Level 3: Conditional automation	All of the functions are completed by an automated driving system. However, the human has to respond to emergency circumstances if the conditions that the vehicle is designed for are not met.
Level 4: High automation	All of the functions are completed by an automated driving system. In this case, the human does not have to respond to emergency circumstances if the conditions that the vehicle is designed for are not met.
Level 5: Full automation	All of the functions are completed by an automated driving system and the system has been designed for all conditions.

Source: Adapted from SAE International (2021)

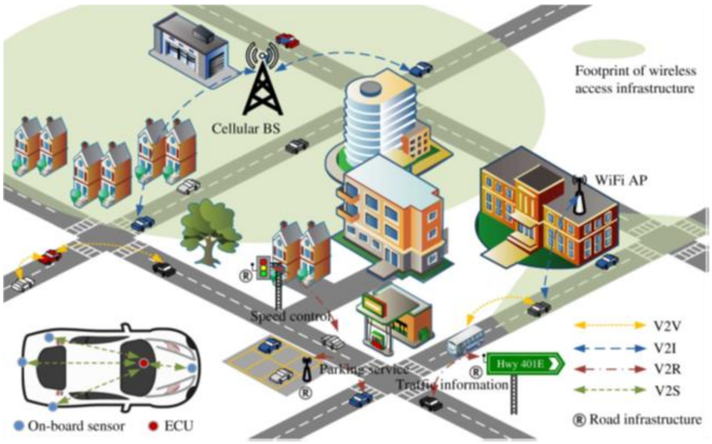
Autonomous cars are expected according to Litman (2019) to follow three operational models, which are Personal autonomous vehicles, shared autonomous vehicles (self- driving taxis) and Shared autonomous rides (self- driving vans). Obviously, personal autonomous vehicles are very convenient, but are expected to be very expensive and people that will purchase them will not choose other vehicles for travelling. Shared autonomous vehicles have the advantage of choosing autonomous vehicles for minimising door to door journey, but because of the higher demand and limited service it is expected that people will have to wait. Finally, shared autonomous rides are the most financially sufficient option of the three, but comfort, speed and convenience is not an advantage in this case (Litman, 2019a).

Autonomous vehicles are also important to have equipment like sensors, Wi-Fi network, GPS automated controls and power supplies. Shared autonomous vehicles, more specifically, will need to have services like fleet management, insurance, security, cleaning, and repairs. These are additional costs that are expected to influence their usage (Litman, 2019a).

3.2.2 Connected Vehicles (CVs)

The development of Information and Communication Technologies (ICT) has influenced vehicles by introducing communication abilities that were not available in the past. The vehicles that have the ability of wireless connectivity are called connected vehicles, or also known as Cooperative Intelligent Transport Systems (C-ITS) (Guériau *et al.*, 2016), and they support many types of interactions (Lu *et al.*, 2014):

- V2S (Vehicle to Sensor): Vehicles exchange data with sensors onboard (Lu *et al.*, 2014).
- V2V (Vehicle to Vehicle): Vehicles exchange data with the other vehicles
- V2R (Vehicle to Infrastructure): Vehicles exchange data with the roadside
- V2I (Vehicle to Internet): Vehicles exchange data with the remote infrastructure
- V2X (Vehicle to Everything): Vehicles exchange data with other elements in their environment, like pedestrians, cyclists or charging points (Amadeo et al., 2016).



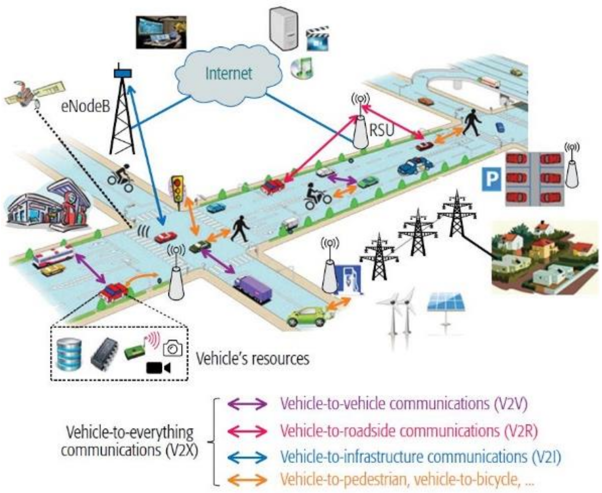


Figure 3.1: Connected Vehicles Interactions

Source: Lu *et al.* (2014) Source: Amadeo et al. (2016)

A vehicle may be connected, autonomous or both. A connected vehicle that does not have elements of automation will be exclusively controlled by a human driver. It will, however, transmit or receive data. On the other hand, autonomous vehicles, that do are not connected will be partially of fully self-driven. The combination of the two elements leads to Connected and Autonomous Vehicles (CAVs), which most papers in the literature refer to, and these vehicles will have the ability to self-drive, partially of completely, and receive and provide information (Jadaan et al., 2017).

3.2.3 Electric vehicles (EVs)

Even though electric vehicles are researched intensively nowadays, they have a lot of history the past decades. The first ever electric car was developed in 1834, but because the combustion engine is more efficient in respect to cost (Høyer, 2008) and electric vehicles had limitations in respect to weight and range efficiency (Ajanovic & Haas, 2016), battery charging time and lack of supply or recharge infrastructure (Sinigaglia, Eduardo Santos Martins & Cezar Mairesse Siluk, 2022), internal combustion engine vehicles became more popular (Høyer, 2008; Sinigaglia, Eduardo Santos Martins & Cezar Mairesse Siluk, 2022; Ajanovic & Haas, 2016). Electric Vehicles can be separated into three main categories, and these are Battery electric vehicles (EVs), Hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) (Clement-Nyns et al., 2010).

Battery electric vehicles use battery instead of tanks of gasoline and the motor is not a classical combustion engine, but an electric motor (United States Environmental Protection Agency, 2015). The electric propulsion is the key element of a battery electric vehicle (EV) and its development is based on the rapid growth of new technologies and more specifically power electronics, control strategies and microelectronics (Chan & Wong, 2004).

Hybrid electric vehicles (HEVs) are a combination of conventional vehicles and electric vehicles. These vehicles provide more flexibility, as they can meet the driver's demand but also minimise fuel consumption. Thus, in respect to a conventional vehicle or an EV there are more degrees of freedom (Borhan *et al.*, 2009).

A plug-in hybrid electric vehicle (PHEV) is essentially an HEV that has the ability to recharge for electromagnetic energy from a source that is off-board. Moreover, a PHEV can use fuels that are alternative to diesel or gasoline, such as biofuels is hydrogen. The batteries of PHEVs last typically longer than those of HEVs. Usually, PHEVs can also be seen as PHEVx, with the term x being a number that defines the total amount of miles that a PHEV, which is fully charged, can operate before starting to use the engine. For example, if the term PHEV20 is given, this means that the vehicle can drive for 20 miles (equal to 32 kilometres) only on the electric power (Markel & Simpson, 2007).

Electric vehicles can be found in many places around the world with their sales significantly increasing the past decade, as can be seen in Figure 3.2, especially in China, where the need for sustainable energy sources is imperative (International Energy Agency, 2023).

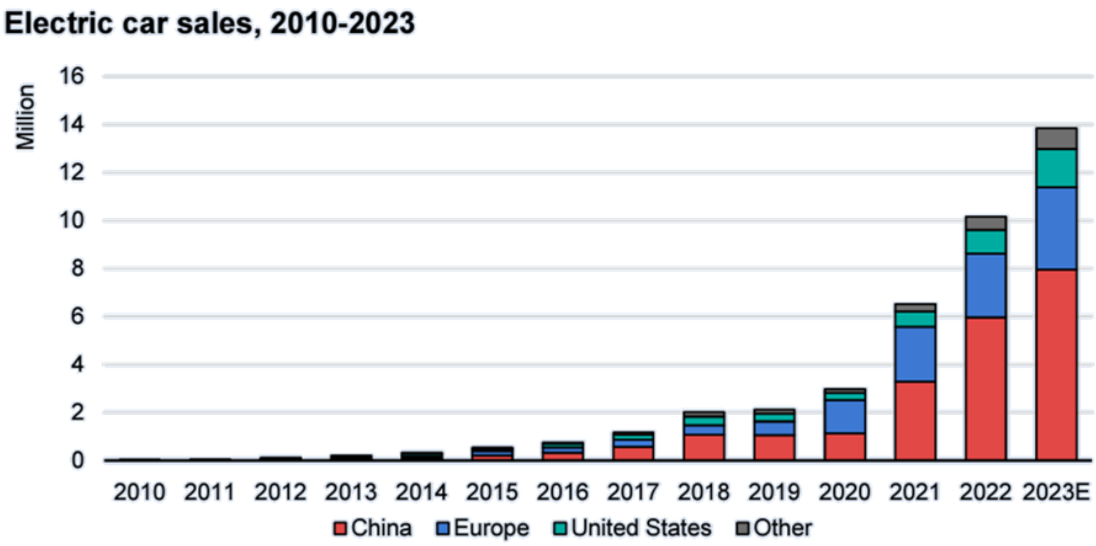


Figure 3.2: Global Sales of EVs

Source: Adapted from International Energy Agency (2023)

3.3 New Transport Business Models

3.3.1 Mobility as a Service (MaaS)

Mobility as a Service (MaaS) is a business model, in which the main goal is that the consumer will purchase mobility services or packages instead of traditional means of transport. The services can be provided by the same or even different operators and the transaction happens through a platform with one only payment. The journeys in MaaS are usually intermodal and also provide real time information (Kamargianni *et al.*, 2016).

The three pillars that MaaS is based on are:

1. *Payment integration*: In order to use the service only one account is charged and a smart card or a ticket is used for access.
2. *Mobility package*: For an option of the services that consumer has prepaid an amount of money, either in distance or time.
3. *ICT integration*: An online interface of an application is used to access the information regarding the services (Kamargianni *et al.*, 2016).

According to ITS Australia (2018) MaaS has four main advantages:

1. Transport becomes integrated and personalised for the MaaS users
2. There are multiple transportation options, depending on the journeys and needs of the customers.
3. The providers that run this may be many and not a monopoly.
4. Payment and booking are practical, as they can be made with a single interface (ITS Australia, 2018).

Figure 3.3: Areas the MaaS Affects

Source: ITS Australia (2018)

MaaS has been applied to many different places around the world and with different characteristics regarding the modes and the way that integration has happened. Just a few important applications of MaaS are Whim (Helsinki, West Midlands), UbiGo (Gothenburg), Qixxit (Germany), Hannovermobil (Hannover), Radiuz Total Mobility (Netherlands) and Switchh (Hamburg) (Kamargianni *et al.*, 2016).

It is important to distinguish MaaS from public transport subscription schemes, like the Oyster Card from TfL in London, as MaaS is generally a more holistic solution. It can offer personalised mobility packages, can provide access to all different modes of transport from different operators, not just public transport and can utilise real time information and intermodal journey planner in order to deliver seamless mobility (Kamargianni *et al.*, 2015).

3.3.2 Car Sharing

Car sharing is a solution that has been designed to tackle challenges like private vehicle ownership, fuel dependency, pollution and problems that occur from parking. The main concept behind this idea is that vehicles have many new characteristics and capabilities, but they are underutilised up to 90% of the time, as they are parked (Maurer *et al.*, 2015). Within this business model, the main principle behind car sharing is that the individuals have all the benefits of owning a car, without having to pay for costs of ownership (Shaheen et al., 1998). Car Sharing is a business model, where the operators provide to the customers a shot-term access to vehicles. The customers pay either per hour or per mile, and this includes many costs such as insurance and fuel. The distinction between car rental and car sharing, is that in the first case there is a contract for a long period of time and the distribution of car happens from a specified location (Stillwater et al., 2009). Car sharing is the connection between private cars and public transit and can also be the link among many different modes. In Europe and North America, the early experiments of this business model were considered successful (Shaheen & Sperling, 1998). Currently, with the use of a cyber map, the payment registration of the business model and the evaluation of the system, all users can have access to the service (Stone, 2017). Moreover, it is important to mention that the model has been applied elsewhere and it has been found that in Korea, for example, the model has significant socioeconomic cost-savings, which affect traffic demand (Do & Jung, 2018). However, even though car sharing exists in the Western world for more than twenty years, it can be still considered as a niche phenomenon and its users as early adopters. The main obstacle to attracting more mainstream users is the difficulty to change mobility behaviour towards traditional vehicle ownership (Münzel *et al.*, 2019).

Interestingly, if car sharing is combined with alternative cars like electric vehicles, the major problem of oil dependency and pollution starts to be addressed. Another advantage is that it provides personal mobility at any time, unlike taxi or one-way carpooling. However, there are limitations, for example origins and destinations in urban areas are not evenly distributed and this leads to uneven supply in urban areas. Finally, it is argued that maybe car sharing is not a solution to congestion as the exact same number of vehicle miles will be travelled with the same distribution of origin and destination (Maurer *et al.*, 2015).

There are numerous places that have adopted car sharing. Concisely, some of these are Toronto (Canada), Washington (USA), Oregon (USA), Minnesota (USA) (Millard-Ball, 2016). Figure 3.4 shows the car sharing users and vehicles in 2016.

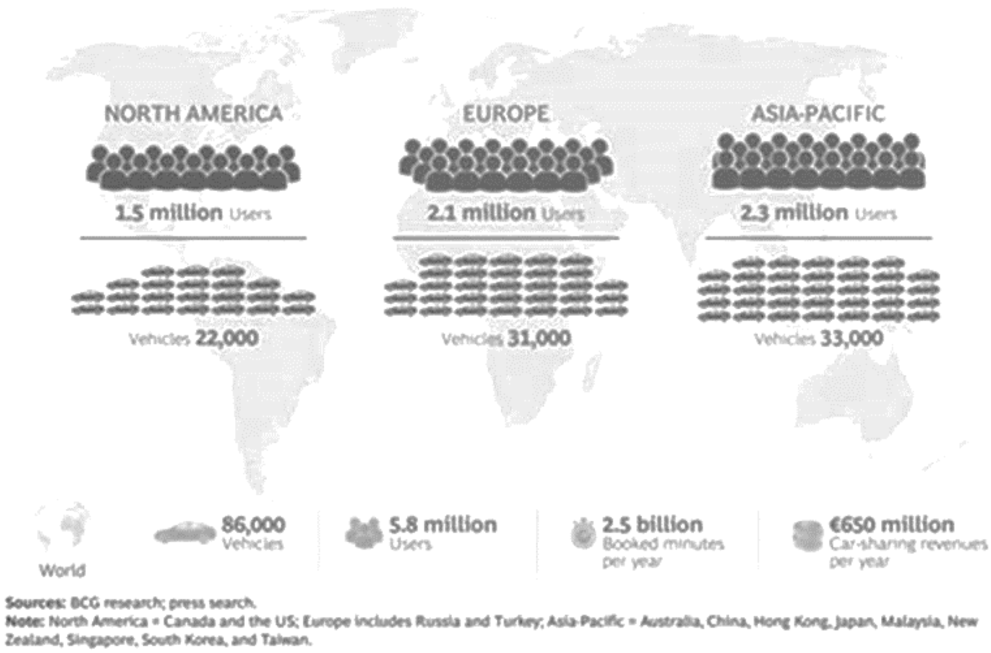


Figure 3.4: Carsharing and Users around the World

Source: https://bit.ly/2LcEOpR (Boston Consulting Group, 2016)

It is essential to also present that since this is an emerging business model, there is an upward trend in its adoption rates. This trend is evident in Figure 3.5, which shows the adoption trends of car sharing in terms of cars and users in Germany over the last decade (Kolleck, 2021).

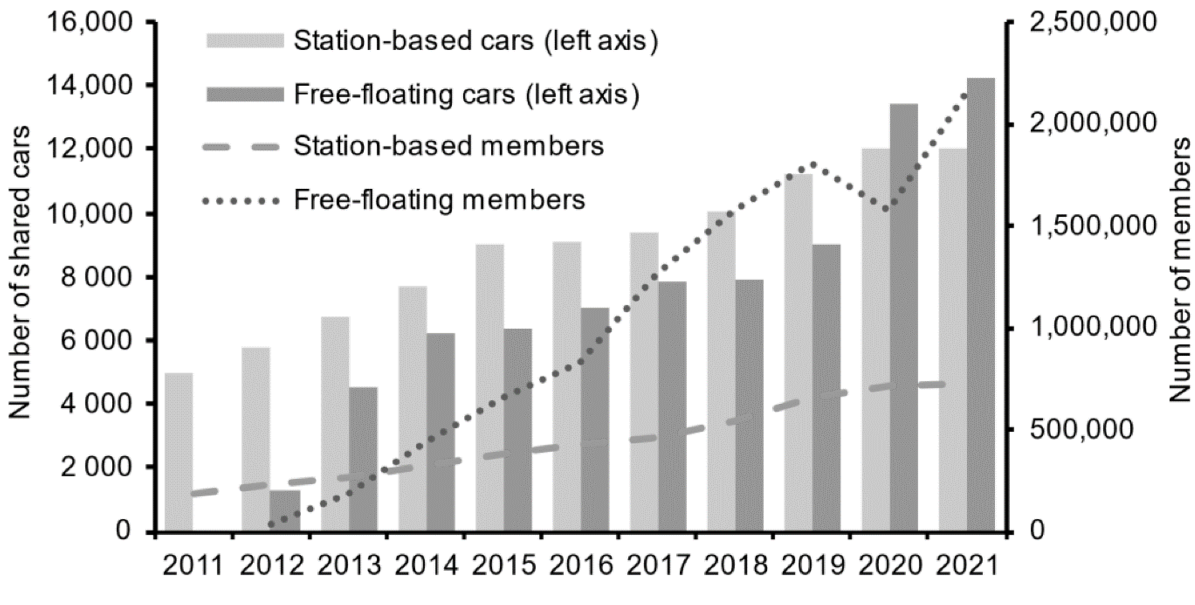


Figure 3.5: Adoption of car sharing in Germany

Source: Adapted from Kolleck (2021)

3.3.3 On demand transport

On demand transport is a system that provides services from a regular taxi, a regular passenger vehicle or a charter vehicle. The most important advantage of this system is that the passenger has the flexibility regarding the route they would like to take and the time that they spend travelling. In this system passengers or hirers determine the exact location of the origin and destination of the journey, while also determine the approximate time of travel. The payment is based on a cost model that is able to forecast the operational cost of the service. In Australia, this cost model is created by the Department of Transport (Australian Department of Transport, 2019).

The providers of this business model use mobile platforms in order to increase utility of the final destinations. This gives the customer advantages like position tracking of the vehicle, booking, easy payment and security. Moreover, this system has driver ratings and maintains an overall quality (Jenk, 2015), that are not always self-evident is the regular taxi industry.

According to Jenk (2015), an analysis carried out by MIT for the Manhattan taxi journeys shows that the reduction of travel time while using on demand transport in comparison to traditional taxi ranges from 20 % to 30 %, as the availability is increased, and the time spent to search for a taxi is reduced. Moreover, this analysis was expanded with a four-day field test in Las Vegas conducted by a mobile taxi app operator and it is noted that, within these four days, the costs were reduced by 18000 USD, the carbon emissions by 1000 lbs (453.59 kg) and the average travel time by 32% (Jenk, 2015). Of course, these numbers may vary depending every time on the area that the service is provided and its economic and social characteristics.

Unlike other technologies mentioned in this chapter, on demand transport has been implemented in many places around the world and in some places has been partially or completely banned, as the legal framework is not updated everywhere for such as service. The most notable example is Uber, as it is one of the most influential companies for on-demand transport services. The places where Uber operates in 2023 are presented in Figure 3.6

Figure 3.6: Places that Uber operates in 2023

Source: Adapted from Uber (2023)

Another type of on-demand transport, that should be mentioned is the system of demand responsive public transport, which is considered a useful choice for areas with low or fluctuating demand. In situations like these, fixed bus schedules lead to either empty or overfull vehicles, thus being able to adapt frequencies and timetables to actual demand leads to a more efficient and service (Vansteenwegen *et al.*, 2022). Of course, demand in traditional public transport is determined based on historical data and is reliable, but the relationship of supply and demand in the traditional systems is collective and long-term (Schöbel, 2012), and this system provides an opportunity for public transport to adapt its schedules based on individual users and short-term demand.

3.4 Conclusions

The technologies and business models presented are characteristic new innovations in the passenger transport network. The presentation given, includes a definition and applications in order to examine their core characteristics and functions. As mentioned, there are many innovations for transportation as well, such as for example drones, hyperloop, high speed rail and micro-mobility, which are not included in this study, as the core of this project is focused on passenger trips in the road network. It is essential to mention that these innovations exist, or are planned to exist, not just as presented, but also as combinations. For example, in Malta a car sharing scheme called GoTo utilises electric vehicles (Goto.com.mt, 2019). The exact structure of possible combinations depends on the modelling scenario which will be tested.

Chapter 4 Key elements affected by new technologies

It is now essential to find which factors are related mathematically to transport demand in LUTI models and then analyse whether or not the technologies and business models presented before, affect these factors and how. There are many factors that affect transport demand, some of them being qualitative (Litman, 2019b), however, since the thesis is based on incorporating new vehicle technologies and business models in LUTI models, it is important ensure that the developed methodology is built on the factors included in LUTI models. Once the list of factors is determined, a review of the current research is conducted to identify conclusions on how they are altered and also possible ways they can be incorporated into a LUTI model.

4.1 Identifying common transport related factors across LUTI models

The final methodology needs to be as applicable as it can be to any LUTI model. For this reason, the factors that should be selected for the methodology, should not just belong to the transportation module of just one LUTI model, but these factors should be common in the majority of the different transport modelling methods LUTI models use. Analysing the structure of transport module of LUTI models can provide a comprehensive list of factors.

Of course, all LUTI models are different, thus adaptation based on the platform may be expected and the specifications of the model that will be used should not be taken into account. However, the goal is to provide insight to the most important and necessary factors to a modeller that will use the developed methodology in any LUTI model.

Thus, this is not an evaluation of LUTI platforms, as they are not in any way compared to find modelling advantages. Instead, three completely different LUTI models were identified, and this is a separate examination only of their transport modules, in order to ensure that that the factors identified from the examination, belong to different modelling platforms and thus their selection contributes to the applicability of the developed methodology in a variety of different LUTI frameworks.

Moreover, as justified in Chapter 2, DELTA is an appropriate modelling framework for this analysis and thus essential to be used for the identification of factors for the developed methodology.

To identify factors that belong to most LUTI models, the transport models of DELTA, TRANUS and URBANSIM were studied, as those models are completely different and also their documentation is analytic. As mentioned before TRANUS is fully integrated, as its transport model is only developed and incorporated to TRANUS, but DELTA and URBANSIM are not. For example, MATSIM which is usually integrated with URBANSIM (Nicolai, 2013), can also be integrated with SILO, or even work as a standalone transport model. On the other hand, there is a variety of transportation models used for DELTA, including the Highly Strategic Transport Model (HSTM), London Transportation Studies (LTS) and START (Davidsimmonds.com, 2019). The HSTM is a highly aggregate transport model, implemented to produce the broad results of the Policy Responsive Integrated Strategy Model PRISM (West Midlands Combined Authority, 2016) and is chosen for the analysis from all the transport models of DELTA, because it can provide reliable results, while not running for a long time (Simmonds, 2019a). Documentation regarding the structure of HSTM has been provided by the David Simmonds Consultancy Ltd and its structure has been analysed to complete Table 4.1.

Table 4.1: Factors in LUTI models related mathematically to transport demand

Factor	Simulation Model	Definition - Description
Accessibility measures	TRANUS, URBANSIM(MATSIM), DELTA(HSTM)	Measures that show the ease to reach destinations (Niemeier, 1997). They can be Infrastructure based, location – based, Person-based and Utility - based (Geurs et al., 2013).
Car Ownership/ Car availability	TRANUS, URBANSIM(MATSIM), DELTA(HSTM)	Number of Cars or Driving Licences owned/ available per household or agent (de Jong *et al.*, 2004)
Comfort level of public transport	URBANSIM(MATSIM)	Ride comfort, Ambient conditions, Facilities, and ergonomics (Imre et al., 2017)
Disutility of additional waiting time	URBANSIM(MATSIM)	The Negative utility of waiting for a public transport service without any displacement (Hunt et al., 2011)
Generalised Cost	TRANUS, URBANSIM(MATSIM), DELTA(HSTM)	Combined travel time and financial cost (Litman et al., 2013).
In-Vehicle Time	URBANSIM(MATSIM)	Travel time spent in the main vehicle of a trip (Björklund et al., 2015)
Network Capacity	URBANSIM(MATSIM)	The maximum amount of traffic that a transportation network is able to accommodate (Mathew et al., 2007)
Number of Transfers	URBANSIM(MATSIM)	The number of times passengers had to change between different routes to reach destination (Han *et al.*, 2018)
Trip Purposes	TRANUS, URBANSIM(MATSIM), DELTA(HSTM)	Different reasons that trips occur. Home based trips and non- home-based trips to work or services (Pupier, 2013).
Trip Rates	TRANUS, URBANSIM(MATSIM), DELTA(HSTM)	The intensity of travel due to a development, either in trips to size of the development or in trips per unit of time (planningni.gov.uk, 2019)

Source: Adapted from Axhausen et al. (2016), Unpublished DSC documentation (2016) and de la Barra (2012)

Some of the factors are correlated, for example, waiting time, in-vehicle time, the disutility of additional waiting time and generalised cost. However, the reason that some of them are specifically mentioned in the table, is that they are separately used in the equations of the models (TRANUS, HSTM and MATSIM) and thus deemed that these should be separately mentioned as well.

In conclusion the factors that belong to all three transport modules are:

1. *Generalised Cost*
2. *Trip Rates*
3. *Accessibility*
4. *Car Ownership*

Here it is important to mention that accessibility is an element that is related to transport demand, but belongs to a separate sub-model of DELTA, in the land use part (David Simmonds Consultancy Ltd, 2017). Moreover, regarding car ownership it should also be noted that in some models like TRANUS only the cost of ownership is included in the transport model (de la Barra, 2011) and in others like DELTA it is a separate sub-model, that predicts probabilities of different car ownership levels per zone (David Simmonds Consultancy Ltd, 2017). Thus, in the analysis that follows both *car ownership models* and *total costs of ownership* are examined. In conclusion, the aforementioned indicate that changes need to be made in both transport and land use sub-models to incorporate new transport innovations.

At this stage, it is essential to determine exactly what these factors are, how they affect LUTI models and most importantly what are the conclusions on the effect that new transport innovations will have at them from the literature.

4.2 Generalised Cost

4.2.1 Definition

The generalised cost has been defined as the disutility that the passenger faces when travelling and is sensitive to a number of factors such as, trip purpose, mode and time spent travelling. This measure has been important for transportation demand analysis since 1970s (Pienaar, 1997). According to Wardman and Toner (2020) the measure of generalised cost of a transportation alternative represents its overall attractiveness or disutility and it can be expressed in both money and time units (Wardman & Toner, 2020). The use of generalised cost and transportation demand modelling is so popular because in overall, travel demand functions with generalised cost have been proved to be more realistic (Bruzelius, 1981). The procedure for calculating the generalised cost (GC) for road transport, based on the guidance from DfT (2019) is conducted as follows:

1. Estimation of the Non- Fuel Costs in (£/km) (NFC)
2. Estimation of the Fuel Costs in (£/km) (FC)
3. Estimation of the Value of Time (£/h) (VoT)
4. Estimation of the distance in (km) (D)
5. Estimation of the journey time in (h) (JT)
6. Usage of equation (1) to estimate the generalised cost per trip for every vehicle type.

$$GC = (NFC + FC) * D + VoT * JT \qquad (1)$$

Source: DfT (2019)

4.2.2 Generalised cost and LUTI Modelling

Transport costs have been found to affect land use both directly, by devoting for example less or more space for transport infrastructure, and indirectly, by changing the development patterns and encourage urban sprawl or densification (Litman, 1995). The measure of generalised cost in Land Use and Transportation modelling is a factor that is highly influential, as it connects the two modules of land use and transport, in different methodological procedures according to the LUTI model. In principle, generalised cost is essential as it affects the transportation models in trip distribution and sometimes in modal split, if it is part of the utility function. Moreover, it affects the land use module, as with changes in generalised cost, changes in accessibility occur, which results to the redistribution of activities within the geographical units of analysis (de la Barra, 1989).

It is useful at this point to describe different procedures of some LUTI models that the generalised cost is an integral part of. In MEPLAN generalised cost inputs change population distribution and spatial costs (Ma & Jin, 2016). In TRANUS the generalised cost is transformed into a composite cost of all modes by demand category which then affects trip generation, modal split, and assignment (de la Barra, 2012). Another example is TELUM, in which the generalised cost with a number of other variables as well, is used initially for the allocation of employment and household and subsequently, since it is a dynamic model, it is also used for reallocations of the different land use sectors (New

Jersey Institute of Technology, 2005). DELTA uses generalised costs as the utility function for the accessibility measures (Bates & Oosterhaven, 1999), which affects a number of land use models of DELTA such as the location model and the employment model (Simmonds & Feldman, 2009). Finally, in URBANSIM the generalised costs are obtained from many mathematical interactions, and they are also used for accessibility calculations (Waldeck & Van Heerden, 2017).

4.2.3 Generalised cost for new mobility options

New mobility options are expected to change generalised cost of travel, thus the change that will be occurred in other factors, which are affected by generalised cost, needs to be examined thoroughly.

To begin with, autonomous vehicles are expected to have differences specifically in values of time in comparison with non-automated vehicles. This decrease in the value of time will cause reduction of generalised cost and thus when modelling autonomous vehicles this effect needs to be incorporated (Perrine et al. , 2020). For example, Kolarova *et al.* (2018) conducted a study for predicting mode choice and values of time with the scenario of privately owned automated cars and of a Shared Autonomous Vehicles (SAVs) scheme. Their analysis was based on different income levels and interestingly in all income levels the privately owned autonomous option and the SAV option was found to have a lower value of time in comparison with the privately owned non-automated car. They claim that these results occurred because the person can use the in-vehicle time for other activities, but this of course depends a lot on the duration of the trip (Kolarova *et al.*, 2018). It is important to mention however, that these results need to be further investigated, as the methodological limitations of the classical MNL model need to be surpassed for such an experiment and the analysis is carried out in Germany, thus it is not mentioned if the conclusions are transferable to other case studies.

de Looff *et al.* (2018) focused on the value of time percentage change for commute trips, by developing a discrete choice model and concluded that the value of time, that was related to autonomous vehicles, was lower than the one of conventional cars. An indicator to ensure that the model was validated and that their results are reliable, was that value of time for conventional cars was similar to the one of the Dutch government (de Looff *et al.*, 2018). Moreover, Correia *et al.* (2019) further expanded the investigation of de Looff *et al.* (2018) on the effects of autonomous vehicles to the value of time for both work trips and leisure trips. By using microeconomics models of utility maximisation, they found that the value of time is reduced from automated vehicles to conventional vehicles for work trips but for leisure trips the values of time remained the same. Following, they conducted a stated preference study to analyse data for a discrete choice model with the alternatives of conventional car, autonomous vehicle with an office interior and autonomous vehicle with leisure interior. The autonomous vehicle used for work purposes was found to have the lower value of time, however interestingly the value of time of the autonomous car for leisure had the highest value of time (Correia *et al.*, 2019). In both analyses leisure trips with AVs seem to have the higher value of time in comparison with work trips with AVs and trips with conventional vehicles, something that has not been mentioned elsewhere in the literature and thus cannot be validated. Hence, there is some scepticism regarding the stated preference experiment and how participants understood the information. For this reason, even though these results are indeed interesting, they cannot be adopted in this research.

Wadud et al. (2016) analysed the energy and carbon impacts of autonomous vehicles and even though in this specific study the generalised cost was not analytically estimated, the reduction that was used for further calculations was 5% for level 2 autonomous vehicles and 50-80% for level 3 and 4 autonomous vehicles. This indicates that when the level of automation gets higher the reduction of cost is increased (Wadud et al., 2016). The assumptions of Wadud et al. (2016) are in line with the implications presented by Davidson & Spinoulas (2015) and also the results of Becker & Axhausen (2018), in which the values of travel time for both private autonomous vehicles and shared autonomous vehicles are lower than other modes. As they mention, even though this is a pretest and these results should be expanded, the main conclusion is that the burden of driving is removed from travellers, making the journey more comfortable (Becker & Axhausen, 2018). An essential element that needs to be mentioned here is that the assumptions of Wadud et al. (2016) and Davidson & Spinoulas (2015) are not based on solid evidence or estimations, but they are in line with the conclusions from the rest of the literature.

Andersson & Ivehammar (2019) quantified benefits from autonomous trucks and cars, focusing on generalised cost. There are limitations regarding the costs benefit analysis they conducted, as some values could not be quantified with absolute certainty. However, according to their results benefits of autonomous vehicles exceed costs for both passenger and freight transport and the most important factor for passenger transport is change in value of time. Another important conclusion is that it is proposed, is that since autonomous vehicles produce benefits for both consumers and producers, subsidies may not be necessary, as the mechanisms of the market will lead to the adoption of autonomous vehicles (Andersson & Ivehammar, 2019).

Medina-Tapia & Robusté (2019) modelled connected and autonomous vehicles in circular city considering different surfaces of spatial and transport demand. Their results showed that congestion is decreased, and urban sprawl increased the size of the city, while the value of time was reduced by 20% (Medina-Tapia & Robusté, 2019). Two important limitations of this analysis though are that the homogeneity in travel demand is assumed and that results from a real case study could provide further information.

Since all these are at an early research stage, there are no exact estimations of generalised costs of AVs without any limitation or assumption. For example, the analysis of Tajaddini & Vu (2023) assumes reduction of the value of time of AVs by 30% in their modelling procedure.

Even though the studies presented, have their differences and limitations, the conclusion that is important for this research is that overall, there is an agreement with respect to the fact that the value of time for CAVs will most probably be lower to the value of time for conventional vehicles drivers.

Electric vehicles are also expected to have a different generalised cost, mainly due to changes in vehicle operating costs. Based on the data from UK Department of Transport (2020) the distance related costs (non-fuel and fuel costs in traditional cars – energy consumption costs for electric cars) are smaller than those of the internal combustion engine car, resulting into a smaller generalised cost. This phenomenon according to Langbroek (2016) is likely to increase adoption rates of electric vehicles. In this study, it is also mentioned that different incentives for policies have reduced the generalised cost of electric vehicles even more, in order to make them more attractive to the public.

Car sharing is a business model that has seen a lot of attraction from the public the past years. In the study of Hu *et al.* (2018) station-based car sharing systems are examined. It is mentioned that the generalised cost of a car sharing driver is competitive to the generalised cost of taxi or private car, which made the sharing scheme attractive (Hu *et al.*, 2018). An element that introduces a limitation and it has not been acknowledged by the authors is that their conclusions on generalised cost are based entirely on subscription costs and not on changes in other variables, yet the results are interesting. According to their results if the car sharing stations are based close to areas of demand, like shopping areas, it is expected that more car sharing users will subscribe. Moreover, population density, percentage of adults, mixed land use, housing price and transit proximity are highly associated with car usage. Finally, it was also concluded that car sharing stations with more parking spaces have a higher probability of attracting more subscribers (Hu *et al.*, 2018).

Ciari et al. (2013) examined demand of car sharing using a microsimulation activity-based model. More specifically, they used MATSIM and their case study was the greater metropolitan area of Zurich. The disutility function that is used to represent the generalised cost of car sharing in their model includes the variables of travel time, the cost of car sharing per kilometre, reservation time, access and egress time and the minimum cost of car sharing (Ciari et al., 2013; Ciari & Balac, 2016). Their validation method was *historical validation* based on data from Mobility Switzerland (Ciari et al. , 2013). A following research study by Balac et al. (2016), which used the methodology and disutility function for generalised cost compared round trip car sharing a one-way trip car sharing in the same case study. Their results indicated that by replacing round trip car sharing with one way has numerous benefits, as it generates less trips, is more convenient for the user for work trips, however availability of parking spaces is essential (Balac et al., 2016). For the research of this thesis, an adaptation of the developed function of car sharing generalised cost from the aforementioned analyses to other popular transportation models, such as the classical four-stage model, would have been useful and would ensure the applicability of the new generalised cost function(s) for car sharing schemes across a wide range of transportation models.

Santos (2018) mentions however that in some cases the generalised cost of car sharing may not be lower than private car, especially when it is firstly introduced to the public. More specifically, it is mentioned that some incentives need to be designed to reduce generalised costs. These incentives have been separated in three groups, namely financial, regulatory and incentives that can persuade travellers to switch to shared mobility (Santos, 2018). Quantitative statements of these conclusions are not provided or estimated; thus, it would have been essential to support these with numeric data.

As mentioned by Carreyre *et al.* (2023) reduction of generalised cost of SAVs comparing to privately owned vehicles. The analysis of Choi *et al.* (2023) on privately owned AVs and SAVs is indeed interesting, as it provides insight on the effects of these two modes on value of time. As mentioned in the results of the paper, privately owned AVs have lower value of time in comparison with conventional cars, but this is not the same with SAVs for local trips. However, for inter-city trips conventional cars have the highest value of time comparing to privately owned AVs and SAVs. The fact that trip distances provide different results for the value of time of SAVs compared with conventional vehicles, is inconsistent with the rest of the literature, and thus cannot be particularly used for this research. Essentially, for macroscopic modelling like the one in this research, the value of time usually is inserted as one variable and thus does not change dynamically with distance. The rest of the results however are indeed particularly useful for this analysis.

On-Demand transport has been very popular attracting passengers from public transport, but according to Schwieterman (2019) microeconomic analysis has not been extensive on these services, for example research on pricing strategies and price fluctuations. In this paper, the analysis was carried out in Chicago, and it was concluded that on-demand transport services like Uber and Lyft have the ability to save travel time, which very important for the calculation of generalised cost. However, it is suggested that for estimating generalised cost for on-demand transport services non-monetary factors should be considered as well, like quality, safety, availability an efficiency (Schwieterman, 2019). Moreover, based on the review of Xiao and Kang (2023), shared mobility schemes, like on demand transport or SAVs have the potential to improve user experience and reduce waiting time, which has indeed a positive effect on generalised cost.

Finally, MaaS has been researched extensively the past years, as it is a new concept that is expected to change mobility patterns and affect transportation systems. According to Müller & Liedtke (2019) MaaS may reduce the GC of travel, which will lead to higher demand for transport; however, a limit in the growth may be the reduced speeds and the limits of the existing transport infrastructure (Müller & Liedtke, 2019). Hörcher & Graham (2020) developed a microeconomic model to test hypotheses on MaaS subscriptions. The social welfare function that they defined was the sum of the consumer surplus and profit functions. In the consumer surplus calculations, a utility function containing GC was defined. The GC was estimated over every available option in MaaS, which in the modelled case was private car, public transport, and CS. Their results showed that subscribers tended to over-use the alternatives within the MaaS scheme and, as a result of crowding on public transport, non-subscribers tended to increase car use (Hörcher & Graham, 2020).

Becker *et al.* (2020) developed a model in MATSIM that included bike sharing, CS, and ride hailing, as well as traditional transportation modes in Zurich, in order to simulate changes that may occur from MaaS, which will include all of these mobility schemes. The GC in this study was represented by the combined disutility of the model for every trip, which is different from every mode or option of travel. The GC cost in this case, as well as travel time in the network and the energy consumption, were used as validation factors. According to the results, when the MaaS option included SM in the set of the mobility package, accessibility and network efficiency increased, while energy consumption reduced (Becker *et al.*, 2020). When analysing and modelling MaaS there is also the issue of designing the actual mobility packages. This has been researched in the analysis of Reck & Axhausen (2020), where a revealed preference experiment was used to examine the viability of different mobility packages. Regarding GC, it was concluded that MaaS packages should substitute the car GC by including SM options in order to be attractive (Reck & Axhausen, 2020; Tsouros et al., 2021). Similar conclusions were also reached by Aifadopoulou et al. (2020), where it was found that there is a wide range of willingness to pay for taxi sharing as part of MaaS, but attention should be paid for the estimation of values of times when analysing the GC of MaaS, as due to the increase in comfort it might be different than the values currently used (Aifadopoulou *et al.*, 2020). Moreover, when considering the effect of MaaS in the generalised cost of the users, including the generalised cost of urban rail transit is also an integral element, as emerging new sharing schemes feed more passengers to the urban rail network (Qin *et al.*, 2023; Carreyre *et al.*, 2023).

It is now essential to present the numerical values of the elements presented and these are presented in Table 4.2. The data presented in this table are comparative to the do-nothing scenario in each paper respectively (for example to the existence of CAVs and non-existence). Comparative numerical results are useful to understand in more depth the impact of each technology and business models. Moreover, these numerical values were presented only in cases where this was possible, as in some analyses the numerical values were not necessarily provided.

Table 4.2: Quantitative Presentation of Values – Generalised Cost

Mobility Option	***Quantitative Effect***	***Estimation or Assumption***	***Reference***
CAVs	50% lower 12$/h 6$/h	Assumption	(Perrine, Kockelman & Huang, 2020).
CAVs	Low Income PV 2.84 €/h PAV 1.29 €/h (-54.58%) SAV 1.96 €/h (-30.99%) Middle Income PV 4.49 €/h PAV 1.99 €/h (-55.68%) SAV 3.02 €/h (-32.74%) High Income PV 4.72 €/h	Estimation	(Kolarova *et al.*, 2018)

Mobility Option	*Quantitative Effect*	*Estimation or Assumption*	*Reference*
	PAV 2.73 €/h (-42.16%) SAV 4.14 €/h (-12.29%)		
CAVs	Base MNL model Conventional car 7.99 €/h AV-Office 4.99 €/h (-37.55%) AV-Leisure 9.94 €/h (+24.41%) Extended MNL Model Conventional car 7.91 €/h AV-Office 4.97 €/h (-37.17%) AV-Leisure 10.47 €/h (+32.36%) ML model Conventional car 8.37 €/h AV-Office 6.26 €/h (-25.21%) AV-Leisure 10.82 €/h (+29.27%)	Estimation	(de Looff *et al.*, 2018)
CAVs	5% (Level 2) 50% – 80% (Level 3 & 4)	Estimation	(Wadud et al., 2016)
CAVs	By 2021 VoT of AV 75%-95% VoT of PV By 2031 VoT of AV 50%-90% VoT of PV	Assumption	(Davidson & Spinoulas, 2015)
CAVs	Conventional Car 17.143 ₣/h PAV 12 ₣/h (-30%) Public Transport 18.555 ₣/h	Estimation	(Becker & Axhausen, 2018)

Mobility Option	***Quantitative Effect***	***Estimation or Assumption***	***Reference***
	Public Transport with SAV 16.739 ₣/h (-9.79%) SAV 10.588 ₣/h (-42.94%)		
CAVs	Following Swedish Transport Administration - difference in VoT between car and train 30 % travel time is assumed devoted to work in an AV By 2025 -31% in Social Generalised Cost By 2040 -39% in Social Generalised Cost	Estimation of GC	(Andersson & Ivehammar, 2019)
CAVs	Average VOT model outputs Conventional car 7.47 €/h AV-Office 5.50 €/h (-23.29%) AV-Leisure 8.17 €/h (+13.95%)	Estimation	(Correia *et al.*, 2019)
CAVs	20% lower VOT	Assumption	(Medina-Tapia & Robusté, 2019)
CAVs	30% lower VOT	Assumption	(Tajaddini & Vu, 2023)
Car Sharing	Costs of car sharing: 0.094$/min & 0.156$ to 0.469$ for insurance Cost of private car not mentioned		(Hu *et al.*, 2018)
SAVs	Average VOT model outputs in (KRW/hour)	Estimation	(Choi *et al.*, 2023)

Mobility Option	*Quantitative Effect*	*Estimation or Assumption*	*Reference*
	Local travel (short) Conventional car 10,549 KRW/hour AV privately owned 7898 KRW/hour SAV 20,073 KRW/hour Inter-city travel (long) Conventional car 12,371 KRW/hour AV privately owned 9090 KRW/hour SAV 10,496 KRW/hour		

4.3 Trip rates

4.3.1 Definition

Trip generation is the first step of a classical four-stage model, and it can provide the foundations for a travel demand model. Consequently, the entire process of travel demand modelling depends on this step. Trip generation rates are considered the basis of this process (Al-Masaeid & Fayyad, 2018). As already mentioned, trip rates are included in the key factors identified, because they affect the spatial distribution of activities (Cordera *et al.*, 2017). It is also crucial to mention that different types of trips, from different market segments or trip purposes, may have a different effect from these technologies. Thus, these effects, for all types of trip rates, should be incorporated in the methodology, to provide the most realistic results.

4.3.2 Trip rates and new mobility options

Different innovations in transport change the way people travel and they can result to different trip generation rates. Harney (2019) presented research on the impact that may occur from new transportation technologies, such as electrification, automation, and business with ICT in transportation, like MaaS in Australia. The analysis was conducted for many different aspects of transport analysis, however here the focus is on trip generation. For electric vehicles it is also concluded that VMT are increased over time (Harney, 2019), resulting to lower trip rates, as VMT and trip rates are inversely correlated (Williams *et al.*, 2016). For autonomous vehicles 5.24% additional trips are expected as more people have access to autonomy, in the hypothetical situation of 100% affordable access to Level 5 AVs from all people over 12 years in the paper. Finally, it is mentioned that the relationship between VMT and MaaS is still an unclear subject. In the MaaS framework there are elements that decrease generation, by increasing VMT (Harney, 2019). One important element that should be however mentioned regarding this analysis is that their results are highly influenced from the penetration rates of new vehicle technologies in the fleet, and this always introduces an important limitation. Moreover, in general the literature provides evidence that attempt to justify the potential increase of VMT from EVs, however according to Habla, Huwe & Kesternich (2021) more scientific evidence is needed and the relatable sources are still limited.

Regarding vehicle autonomy and trip rates the paper of Dias *et al.* (2020) attempted to incorporate autonomous vehicles in the classical four-stage model. In the trip generation stage, it is suggested that because of less inconveniences related to driving and latent demand, autonomous vehicles become more desirable, and this leads potentially to more vehicle trips. The assumption in this paper is an increase of 5%. This assumption is also in line with the 10% found by Truong *et al.* (2017), where trip generation impacts of autonomous vehicles were analysed in Victoria, Australia by introducing a new model to estimate trip rates, also considering vehicle autonomy (Truong *et al.*, 2017).

Bernardin *et al.* (2019) developed a comprehensive modelling framework to simulate connected and autonomous vehicles and MaaS. It is mentioned in the analysis that the lack of modelling frameworks of new vehicle technologies and business models is a main problem for transport policy makers. This problem has occurred due to lack of real data on impacts of these innovations. In this study an important contribution that is made is the incorporation of Zero Occupancy Vehicle (ZOV) Trips. It is suggested that trip generation rates should be increased after the incorporation of new technologies, as barriers in mobility will be reduced and they assume a 5% increase in their model for disabled people, children, and seniors (Bernardin *et al.*, 2019). Finally, in the analysis of Tajaddini & Vu (2023) the results indicate a 10% shift of trips from active modes and public transport to car trips, and an increase of 20% in vehicle kilometres in Victoria’s Road network after the incorporation of AVs in the modelling framework. Hence, it is evident from all these analyses, that an increase in trip rates can be assumed. Even though the results and assumptions from the scientific community vary and are still uncertain, mainly due to the fact that vehicle autonomation is a major scientific breakthrough in the industry and the effects may be multidimensional, the patterns remain the same across different analyses.

Jiao et al. (2020) analysed the impact of bike sharing, car sharing and on-demand transport on trip generation in the US. They conducted this research, by developing a regression model. According to their results, car sharing does not increase trips, mainly due to the high levels of car ownership in the US and the burden that occurs from renting a vehicle for a short period of time. Increase in trips were found by bike sharing, but they claim that walking trips and public transport trips are substituted by these new trips in bike sharing. Finally, it worth mentioning that their conclusions on on-demand transport were that there is a clear positive association that such services produce more trips, as they are comfortable and convenient (Jiao et al., 2020). The conclusion of Jiao et al. (2020) is in contrast with the conclusion of Kortum (2014) on car sharing, as it was found that car sharing members that belong in the age category 20 to 39 increased trip rates. Interestingly, it was also found that males make more trips with car sharing rather than females and that land use density has a positive effect to the number of trips taken by car sharing (Kortum, 2014). Statistical models with different samples and case studies may provide different results and conclusions, thus more research is indeed essential regarding the subject. This conclusion from this review, has also been mentioned the review of Wang and Yang (2023) on the effects of vehicle electrification, automation and sharing on modelling behaviour and demand. As they mention the effect of these technologies on trip generation is still uncertain and requires further research and quantification (Wang & Yang, 2023).

To provide further information to the order of magnitude of the numerical values on trip rates, a presentation of the values of the aforementioned sources is presented in Table 4.3.

Table 4.3: Quantitative Presentation of Values – Trip Rates

Mobility Option	***Quantitative Effect***	***Estimation or Assumption***	***Reference***
EVs, AVs and MaaS	EVs By 2051 +3.6% in VKT AVs By 2051	Estimations	(Harney, 2019)

Mobility Option	***Quantitative Effect***	***Estimation or Assumption***	***Reference***
	Market penetration 45% +3.7% trip generation increase <u>MaaS</u> Unclear		
AVs	+5% trip generation increase	Assumption	(Dias *et al.*, 2020)
AVs	+10% trip generation increase	Assumption	(Truong *et al.*, 2017)
AVs	+5% trip generation increase	Assumption	(Bernardin *et al.*, 2019)
AVs	+10% increase in vehicle trips	Estimation	(Tajaddini & Vu, 2023)
Car sharing and On Demand Transport	Positive and statistically significant coefficient in NB model for Ride-hailing (On Demand Transport) Weekdays: 0.004 Weekends: 0.005	Estimation	(Jiao et al., 2020)
Car sharing	Positive and statistically significant coefficient in OLS model for Car Sharing Percent of population aged 20-39: 0.062 Household density per acre: 0.0014 Percent of population that is male: 0.108	Estimation	(Kortum, 2014)

4.4 Accessibility

4.4.1 Definition of accessibility and relationships with LUTI models

The concept of accessibility is an important element of the environment of an urban core, and it is a key for spatial interaction (Rastogi & Krishna Rao, 2003) and spatial justice (Farrington & Farrington, 2005) and it is considered quite difficult to defined (Hanson, 1986). A first definition states that accessibility is an opportunity for interaction (Hansen, 1959), another presents it as the ease with which a point can be reached (Gregory, 1986) while a third states that accessibility means the ability of someone to reach another part of the city from a given point by some transport means (Handy and Niemeier, 1997;Dalvi, 1978).

The last definition makes it clear that accessibility refers to a starting point, a given transport system as well as specific land uses / activities (O'Sullivan et al., 2000). Also, accessibility according to Ingram (1971) is divided into two sub-elements: the *relative accessibility* which is defined as the degree to which two areas or points of the same surface are connected and the *total accessibility* which is referred to as the possibility of approaching a point in space from all the remaining points on the same surface (Ingram, 1971).

In Land Use and Transport Interaction models the concept of accessibility is one of the most important components as it acts as the connector between the land use and the transportation modules. More specifically according to Acheampong and Silva (2015) opportunities are created from the transportation system, which are measured through the use of accessibility measures and later accessibility is distributed over space and time in the urban system to determine the final geographical location of activities. As a result, the land use system is changed (Acheampong & Silva, 2015). Figure 4.1 is a representation of a functional LUTI model and in which accessibility is clearly an important element.

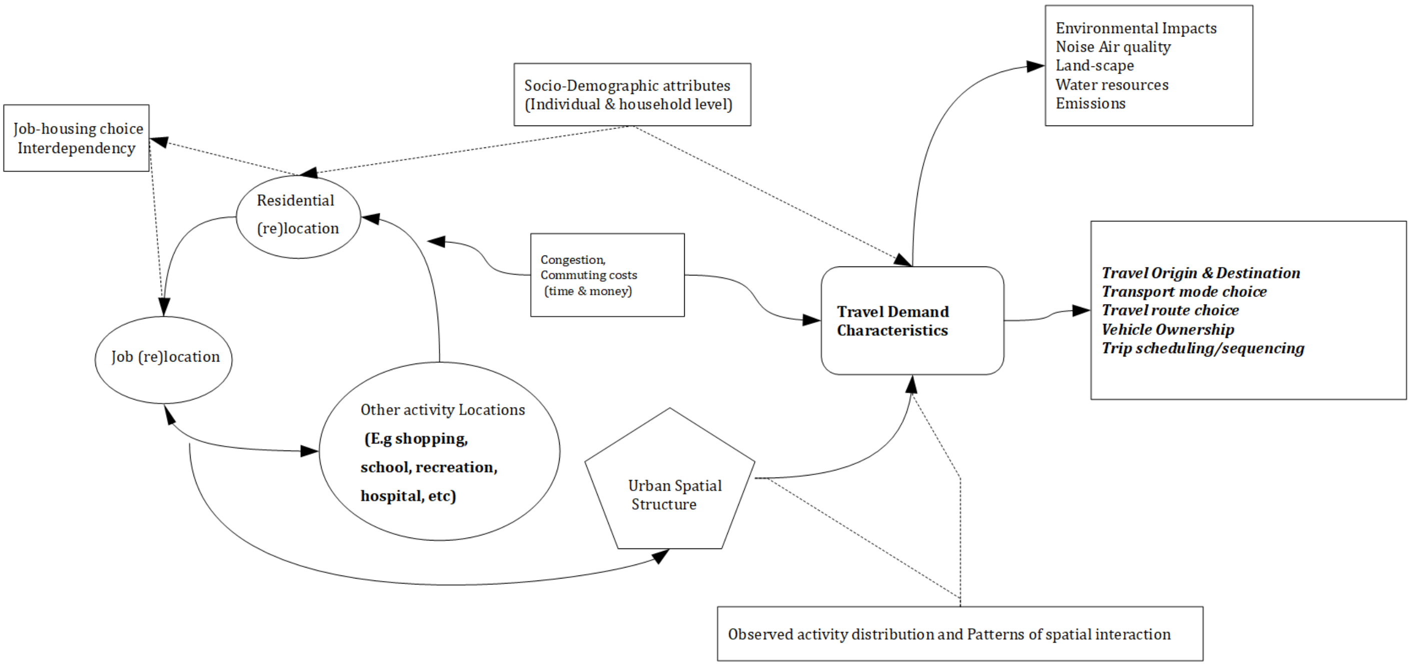


Figure 4.1: A Conceptual Representation of a Land Use and Transportation Interaction Model

Source: Adapted from Acheampong and Silva (2015)

4.4.2 Accessibility measures

Accessibility measures are mathematical formulas that express how easily one can visit different locations with different activities. The concept of accessibility influences residential location choice (Vandenbulcke et al., 2009), which results in changes in prices of household (Ibeas *et al.*, 2012). According to Linneker and Spence (1996) the M25 London Orbital Motorway influenced accessibility and contributed to the overall regional development (Linneker and Spence, 1996 cited in: Efthymiou, 2014). Another notable example is the study of Gutiérrez and Urbano (1996). This study refers to the Trans- European Road network expansion that was planned to have been implemented by 2002 and the methodology is based on using an index based on GDP and the from country to country impedance, in order to forecast accessibility (Gutiérrez and Urbano, 1996 cited in: Efthymiou, 2014).

Accessibility measures traditionally follow a methodological approach that is "trip-based", namely they quantify accessibility per single trip (Dong *et al.*, 2006). There are many reviews that attend to classify accessibility measures. In the review of Geurs and van Wee (2004) the first element was to identify components of different accessibility measures and based on these characteristics they later classified them as:

- Infrastructure based
- Person based
- Utility based
- Location based (Geurs & van Wee, 2004)

According to Handy and Niemeier (1997) there are three main categories of accessibility measures and these are:

- *Isochrone* (Handy & Niemeier, 1997)

In this category the number of opportunities within a specified travel distance, time or generalised cost is counted. The most typical mathematical formula for this is presented in equation (4.1):

$$Acc_i = \sum_j W_j \, a_j \tag{4.1}$$

Acc_i: Accessibility in zone i

W_j: Weight which is equal to 1 or 0, based on the measure of impedance and the pre-determined range that it should be between zone i and zone j

a_j: Opportunities in zone j v(Dong *et al.*, 2006)

- *Gravity based* (Handy & Niemeier, 1997)

Accessibility in this case is considered to be a function of the number of opportunities, which are reachable and available to the travellers (Efthymiou, 2014). Gravity based measures represent the joint effect of land use and transport on the concept of accessibility, but they cannot realistically show variations of accessibility across individuals (Dong *et al.*, 2006). The mathematical formula is presented in equation (4.2):

$$Acc_i = \sum_j a_j \, f(c_{ij}) \tag{4.2}$$

Acc_i: Accessibility in zone i

$f(c_{ij})$: The impedance function of the cost c_{ij} from zone i and zone j

a_j: Opportunities in zone j (Dong *et al.*, 2006)

Here it is important to mention that the isochrone category is just a special case of the gravity-based model, with the factor W_j taking the place of $f(c_{ij})$. Defining the impedance function $f(c_{ij})$ is not always possible, but usually it is a negative exponential function with the independent variable being travel time (Dong *et al.*, 2006).

- *Utility based* (Handy & Niemeier, 1997)

According to Ben-Akiva and Lerman (1985) accessibility can be expressed as the consumer surplus, being equal to the maximum average travel utility (Ben-Akiva and Lerman, 1985 cited in: Efthymiou, 2014) and later McFadden (2001) proved that when the utility function is linear a *logsum* formula can represent the different measures of consumer surplus (McFadden, 2001 cited in: Efthymiou, 2014). Von Haefen (2003) presented a methodology which uses the Random Utility Theory and considerrs the observed choice of the individual in oder to measure walfare (Von Haefen, 2003 cited in: Efthymiou, 2014). According to Don*g et al*. (2006) utility based accessibility measures derive from the random utility theory, because in this case accessibility represents the worth of travel alternatives. MNL models or nested logit models are usualy the basis for such measures (Dong *et al.*, 2006). A main benefit that comes from these measures is that indivisual prefernce is also included (Pirie, 1979 cited in:Don*g et al*., 2006).

In different LUTI models, accessibility is expressed through different *logsum* functions. In URBANSIM for example the accessibilities per zone are expressed in a logsum based mathematical equation presented in (4.3):

$$A_i = \frac{1}{\beta_{scale}} \ln(\sum_{j=1}^{j} (W_j e^{(-\beta_{scale^*} c_{ij})})) \qquad (4.3)$$

Where:

A_i: The work accessibility in zone i

β_{scale}: The scale factor

c_{ij}: The generalised cost from a zone j to zone i

W_j: Weight that represents the number of jobs per zone j (Nicolai & Nagel, 2011)

According to Simmonds et al. (2010) in DELTA accessibilities follow a similar *logsum* function presented in equation (4.4):

$$A_i = \frac{1}{-{\lambda_t}^{Dp}} (\ln(\sum_{j=1}^{j} \left({W_{tj}}^{p} e^{\left(-{\lambda_t}^{Dp} * {gc_{ij}}^{po}\right)} \right) - K^P) \qquad (4.4)$$

Where:

A_i: The accessibility in zone i

λ_t^{Dp}: The coefficient of the destination choice for purpose p at a time t

gc_{ij}^{po}: The generalised cost from a zone j to zone i for purpose p at car ownership level o and at time t

W_{tj}^{p}: Weight that represents the opportunities per zone j for purpose p at a time t

K^P: A constant for purpose p (Simmonds et al., 2010)

Moreover, another category introduced by Dong *et al*. (2006) is the *activity based accessibility,* which also has it roots from rundom utility theory but it also incorporates the concept of trip chaining and the fact that within a day a set of activities is done by the individual (Dong *et al.*, 2006). It should mentioned that a lot of interesting work has been conducted in the field with Levinson & Wu (2020) expanding on the accessibility concept with measures for all modes, places, times and purposes over the lifecycle of a project. However, even though accessibility has been such an important element of LUTI models, it can not capture all possible effects especially when it comes to social aspects such as equity. For such analysis future modelling developements are needed (Engelberg *et al.*, 2020)

4.4.3 Accessibility and new mobility options

Automation is expected to affect accessibility, and this has been researched and confirmed by multiple studies. According to Childress et al. (2015) accessibility could be enhanced by the replacement of conventional vehicles with automated vehicles across all areas in a region. To reach this conclusion the researchers used an activity-based model in Seattle, USA, by increasing road capacity and reducing travel time. However, the differentiation of capacity based on street types could provide even more informative results on the subject (Childress *et al.*, 2015). The authors recognise that their research has several limitations as the one mentioned before, because with the available modelling tools the capability to simulate new vehicle technologies is restricted. This is of course an essential comment for this research, as by improving the current modelling techniques, the effect of vehicle automation to accessibility could be estimated with more accuracy.

Moreover, according to Meyer *et al.* (2017) automation will not only change dramatically transport but the urban form as well. Their study was based on the evaluation of change of accessibility that will occur from automation. Their accessibility model was based on the theory of gravity models and according to their results the change of accessibility causes urban sprawl and reduces the attractiveness of public transport (Meyer *et al.*, 2017b). Luo *et al.* (2019) also investigated the same subject, but the method that was used was agent-based microsimulation modelling. The two options that were modelled, were privately owned connected autonomous vehicles and SAVs in Gunma Prefecture, Japan. The way these were modelled was by altering the operating costs and the values of time. Based on their results, accessibility is increased in all scenarios of co-existence of privately owned connected autonomous vehicles and SAVs, causing further suburbanisation and urban sprawl (Luo *et al.*, 2019). Even though different assumptions and methods were made in both cases, which always introduce limitations and have impacts on the final results, the conclusions regarding accessibility should be considered for this research, in order to provide more insight into the effect of vehicle automation on accessibility.

Milakis et al. (2018) also investigated the changes of accessibility from automation. Initially, a conceptual framework was developed on the effects that automation may have on land use, transport, individuals and finally how these will occur over time and in the end change accessibility. Subsequently, Q-method was used to explore heterogeity among experts regarding the impacts of automation to accessibility. Three main conclusions were extracted from this research. The first is that the benefits that will occur from accessibility are not certain, because the improvement in comfort and safety is associated with increased travel demand. Thus, the savings from travel time and costs, may be balanced out from increased travel demand in the long run. The second conclusion, is that the existence of SAVs, is very likely to cause to opposing implications simultaneously, which are on the one hand urban sprawl but densification of the urban centre as well. SAVs will reduce car ownership levels and thus parking demand, which will lead to enchantment of density in the urban centres (Milakis et al., 2018; Narayanan et al., 2020). On the other hand, they will also lead to further urban sprawl, due to the lower generalised cost. Finally, the third point was that automation will only benefit those who can afford it, thus causing negative implications to social equity (Milakis, et al., 2018). These conclusions are in line with the conclusions from Papa & Ferreira (2018) and Cohen & Cavoli (2019), where those possible negative implications of automation are discussed as well.

Nahmias-Biran *et al.* (2020) investigated the impact of Automated Mobility On-Demand (AMoD) schemes in accessibility, using activity-based accessibility measures. The modelling procedure was developed in Sim-Mobility and the case study was Singapore. Two scenarios were tested, one having

AMoD only in the city centre and On-Demand Transport with manual vehicles everywhere in the city and one with AMoD everywhere in the city. Their results showed that the second scenario increases accessibility especially to low-income individuals. Moreover, it was found that from the results of the first scenario, that there is a disbenefit if AMoD only operates in the urban centre, as High-income individuals that live in the suburbs and rely on On-Demand Transport will not be able to use the service and mid-income individuals will public transport to reach the urban centre (Nahmias-Biran *et al.*, 2020). It is essential to mention that an element that should be addressed in future research regarding the subject is an application of the modelling technique to a real case study, as a prototype virtual city, which is used in this research, introduces limitations.

Samaranayake *et al.* (2024) initially mentions that based on the literature accessibility is increased with the incorporation of CAVs in a transport system. Following using travel time reliability metrics for various market penetration rates of CAVs and based on the results of the study, from 0% to 100% penetration rates the expected travel time decreased by 28% (Samaranayake *et al.*, 2024). As already mentioned, travel time is highly correlated with accessibility, thus this analysis provides important insight. Similar conclusions regarding accessibility have also mentioned by Mnyakin (2023).

He et al. (2020) investigated the interrelation between accessibility and the adoption of EVs and concluded that the density of charging points and how accessible these are to residential location play a major role for EV adoption (He et al, 2020). This conclusion is also mentioned in the paper of Sweda & Klabjan (2012), Brost et al. (2018) and Kłos & Sierpiński (2023).

Regarding Car Sharing, Sarasini et al. (2017) mentions that such mobility schemes have been characterised in the literature as being sustainable and improving energy efficiency and accessibility (Greenblatt & Saxena, 2015;Greenblatt & Shaheen, 2015; Ryden & Morin, 2005 cited in: Sarasini et al., 2017; Briceno et al., 2005). The fact that that car is not owned but "borrowed" provides the opportunity to offer a cheaper service and for a wider number of people to use, thus increasing accessibility (Roblek, Meško & Podbregar, 2021). The same is also found by the UK Department for Transport (2005), namely that CS can increase accessibility for people that do not currently have access to a car (UK Department for Transport, 2005).

Car Sharing also has the ability to complement the public transport system, as it can be used for travelling from station to station (Ceccato & Diana, 2018). For example, in the spatio-temporal model of CS in Québec, Canada by Coll et al. (2014), it was found that demand for CS was correlated with accessibility to work by bus. This indicates that public transport and CS can be combined in policies to increase accessibility and reduce transport costs. One element that is quite unique regarding the analysis of Coll et al. (2014) is the fact that the spatial evolution of CS membership is taken into account in the modelling procedure, which is usually neglected and indeed very insightfully for this research as well as it highly affects accessibility.

Another factor that is found to increase accessibility in the literature for CS users is the time saved from parking when driving a privately owned vehicle, if there is a reserved parking spot (Paundra *et al.*, 2017). Comparing the nature of free-floating car sharing and station-based car sharing, Becker et al. (2017) found that origin accessibility was higher for households that lived in areas with insufficient public transport if they used free-floating car sharing. Moreover, Nemoto et al. (2021) investigated the impacts of a car sharing business models that utilised AVs and EVs and found that combining these emerging technologies has the potential of improving accessibility.

The study of Liu *et al.* (2024) provides a very interesting outcome regarding the joint effect of SAVs and road congestion pricing on accessibility. Based on their results, if there is no optimisation in the pricing policy, regional accessibility may be decreased, but the opposite result is possible if an optimal pricing strategy can be achieved (Liu *et al.*, 2024). As already acknowledged in Chapter 2 of this thesis, dynamic modelling is important and has not been used in the study of Liu *et al.* (2024), thus analysis on the effect over time is indeed important.

The literature indicates that services like On-demand transport have the potential of increasing accessibility, either by complementing insufficient public transport systems (Jin et al., 2019) or by reducing congestion (Li et al., 2016). The issue of insufficient public transport and ODT has been discussed by Park et al. (2020), who researched how On-demand transport can help increase accessibility for tourists in places with insufficient public transport provision, such as sub-Saharan Africa. Indeed, global services, such as Uber, are well-known to different people from around the world and could help surpass the uncertainty caused by unreliable public transport systems (Park, Kim & Pan, 2020). In case studies however, with sufficient public transport like cities in the UK for example, the effect of ODT on accessibility may be different and this poses an important research gap, related to the research question of this thesis. Travel time data from On-demand transport services could also be useful for the evaluation of accessibility to jobs, as conducted in the analysis of Sun et al. (2020), especially if combined with data from current public transport systems.

Wang & Mu (2018) conducted a statistical analysis in Atlanta (USA) to examine which factors affect accessibility with ODT and how scientists should measure and understand it. It was found that commuting time, population density and road network density are highly associated with accessibility when using On-demand transport, while the socioeconomic factors of race and wealth play a much less significant part (Wang & Mu, 2018). The same conclusions were also reached in the study by Jiang et al. (2018). Origin accessibility has also been researched by Shokoohyar et al. (2020) in Philadelphia using K-means clustering to explore which socioeconomic and infrastructure-related factors affect origin accessibility of On-demand transport. It was concluded that origin accessibility with On-demand transport is higher in places with higher density (as in Wang & Mu, (2018)), but also with fewer amenities within walking distance, with high crime rates and with better public transport. Similar conclusions were also reached in the study by Sabouri et al. (2020), in addition to the fact that the demand for using On-demand transport is negatively correlated with destination accessibility (Sabouri *et al.*, 2020), essentially because ride-sourcing is expected to be more attractive to destinations with limited public transport or lower density road network. For origin accessibility Alemi et al. (2018) found results that indicate that a higher land use mix and regional accessibility could also contribute positively to ODT demand, which increases origin accessibility.

The subject of origin accessibility by On-demand transport for vulnerable groups has also been studied. More specifically, the issue of accessibility through the use of ODT for visually impaired people was analysed by Brewer & Kameswaran (2019) and it was shown that the even though this group values independence and accessibility, the lack of trust can be an important issue for subscribing to such a service. On the other hand, elderly people are more likely to use ODT as an alternative, because usually they depend on cars for their transport and their ability to drive deteriorates with ageing. This lack of accessibility that occurs with driving impairment can be surpassed with On-demand transport. On the ccontrary to the conclusions of Brewer & Kameswaran (2019), it was also noted that the variability of the drivers of On-demand transport does not affect demand for the service in this group (Leistner & Steiner, 2017). An important limitation, regarding the analysis of Brewer & Kameswaran (2019), is that the sample only included population which had recently used ODT, which should be avoided in future research but also in this thesis for surveys that may be conducted and distributed.

Studies have found that due to reduced congestion, MaaS generally has a beneficial effect on accessibility (Sarasini et al., 2017; Schweiger, 2017). Mulley et al. (2018) mentions that the concept of “integrated mobility”, that is the basis of MaaS (Kamargianni *et al.*, 2016), can also improve accessibility because of the ease that is brought from ICT (e.g. easier payments and information). Another factor that could potentially increase accessibility in an area that a MaaS scheme is offered is the reduced number of privately owned cars, due to the inclusion of CS in MaaS packages

(Utriainen & Pöllänen, 2018). It would have been important that quantitative results to have been provided in the aforementioned studies to support these conclusions.

Melis et al. (2018) also found that urban accessibility could be increased for people with disabilities due to the personalised experience that could be offered from a service like MaaS; however, the digitalisation of mobility could, on the other hand, be a barrier for vulnerable groups, as the systems may appear complex to negotiate (Durand *et al.*, 2021).

Sochor et al. (2018) examined the integration stages of MaaS by reviewing the literature and through an expert workshop. In their analysis they found that MaaS could both bring sustainable accessibility from a societal perspective, as well as increase accessibility of the users due to lower door-to-door journeys and personalised experience (Sochor *et al.*, 2018). Geurs et al. (2018) examined the potential of MaaS not in an urban area, but in the rural and depopulating area of Oost-Gelre in the Netherlands, under the conjecture that MaaS in such an area could be an effective tool to improve accessibility (Geurs *et al.*, 2018). Polydoropoulou et al. (2020) gathered qualitative data from Greater Manchester, Budapest, and Luxembourg to explore MaaS, and found that the cooperation of public and private stakeholders led to flexibility and sustainability in mobility, and as a result increased accessibility. Jittrapirom et al. (2020) followed a Delphi method to examine the future implementations of MaaS from various aspects and found that local authorities will promote the scheme to increase accessibility, but unlike the study of Geurs et al. (2018), one of the conclusions was that accessibility for vulnerable population groups and accessibility in rural areas may be a major issue for the implementation of MaaS.

Moreover, in the analysis of Pritchard (2022) it is mentioned that the integration of demand responsive shared mobility schemes with public transport in MaaS packages can increase the accessibility in both urban and rural areas. Similar conclusions were also mentioned by Papaioannou *et al.* (2023) for MaaS schemes in islands. However, in both cases the analyses do not include quantitative results, which is an essential element that should be considered in this research to support the existing literature.

Hasselwander *et al.* (2023) analyses the effects of MaaS on transit accessibility and concludes on an overall increase in this respect. An element that should be mentioned for the research of Hasselwander *et al.* (2023) and it is important for this research as well is this research as well, is the fact that some data sources are outdated.

To expand on the analysis of accessibility results, the numerical values from the results of the papers presented are shown analytically in Table 4.4. Since all the papers followed different methodologies, their results are not necessarily of the same type, as some are percentage changes, other refer to generalised time and other to coefficients of statistical models. However, it is still essential to present these, as they can provide further insight.

Table 4.4: Quantitative Presentation of Values – Accessibility

Mobility Option	***Quantitative Effect***	***Reference***
AVs	Accessibility increases in a range 2.9%–26% With class 10.6%–26% - rural areas	(Childress *et al.*, 2015)
AVs	Accessibility increases up to 28%	(Meyer *et al.*, 2017b)
AVs	Accessibility increases on average in all four scenarios 23.2%, 31.8%, 36.3% and 36.3% respectively	(Liu *et al.*, 2024)
AVs	Accessibility changes a range (-20) – (+14) minutes (-9.2) – (+4) SG$	(Nahmias-Biran *et al.*, 2020)
AVs	Comparison of weighted average travel time - 100% market penetration rates of CAVs to 0% market penetration rates of CAVs Maximum weighted average travel time decrease by 29% Minimum weighted average travel time decrease by 8%,	(Samaranayake *et al.*, 2024)
Car Sharing	Positive values of estimations CC (ZINB) model Accessibility to destinations Workplace by bus: 2.4406 Workplace by foot: 2.0855 Shopping by foot: 0.7314	(Coll et al., 2014)
Car Sharing	Accessibility - 5 min walking distance from parking spot (parking convenience) Chi- Square test: Participants in parking convenience condition recalled successfully parking convenience ($\chi^2 = 19.67$, $p < 0.01$)	(Paundra *et al.*, 2017)

Mobility Option	*Quantitative Effect*	*Reference*
Car Sharing	Positive predictor of estimations for Ordered probit model Transit zone A (<5min or 500 meters distance to transit): -0.233	(Becker et al., 2017)
SAVs	Regional accessibility increases by 40%	(Liu *et al.*, 2024)
On demand transport	Negative coefficient for travel time having considered Uber introduction to the system: -0.00237 Difference-in-differences (diff-in-diff) method	(Li et al., 2016)
MaaS	Introduction Of MaaS could improve transit accessibility from 23.9 % to 65.0 %	(Hasselwander *et al.*, 2023)

4.5 Car Ownership Models

4.5.1 Definition and classifications

A key feature of any transportation system is car ownership, as it effects travel behaviour and also the participation in activities out of home. If car ownership is increased there are direct links to increases in energy consumption and to the effects on air quality. As a result, transportation planners, urban planners and policy makers have developed models that predict car ownership using different methodologies. Those models are called Car Ownership models, and they can be part of a LUTI model or even standalone models that are useful for various applications (Potoglou & Susilo, 2008).

The classic four stage model does not include a car ownership model, however car ownership models are essential for many applications, for example mode choice and trip generation (de Jong *et al.*, 2004). According to Potoglou and Susilo (2008) there are two main categories of car ownership models, which are aggregate and disaggregate models (Potoglou & Susilo, 2008). Aggregate models provide results on car ownership that represent the cumulative household decisions at many different geographical scales of analysis, whereas disaggregate models provide results at a household level of analysis. Because of their details in terms of behavioural structure and advantages in identifying causal relationships, disaggregated models have dominated over the aggregate models (Bunch & Chen, 2007 cited in: Potoglou & Susilo, 2008). Also, aggregate models are less attractive as they have limitations, in respect to the explanatory variables, large standard errors and the fact that they are not compatible with new modelling techniques, such as agent-based modelling (Miller, Kriger & Hunt, 1999 cited in: Potoglou & Susilo, 2008). In the study of de Jong *et al.* (2004) a more analytic classification was made, separating aggregate and disaggregate models into different sub-categories based on their methodologies.

Table 4.5: Car Ownership Model Categories

Car Ownership Model Category	**Level of Aggregation**
Aggregate Time series Models	Aggregate
Aggregate Cohort Models	Aggregate
Aggregate Car market models	Aggregate
Heuristic Simulation Models	Disaggregate
Static Disaggregate Car Ownership Models	Disaggregate
Car Ownership and Use Models of Indirect Utility	Disaggregate
Static Disaggregate Car-type Choice Model	Disaggregate
(Pseudo)-panel Methods	Aggregate / Disaggregate
Dynamic Car Transactions Models with Vehicle Type Conditional on Transaction	Disaggregate

Source: Adapted from de Jong *et al.* (2004) and Potoglou and Susilo (2008)

It is important to mention at this point that validation of the results of the car ownership is definitely needed as different case studies provide different results. For example, in the US the probability of a household owning 2+ car is higher than the probability of owning 1 car, whereas in some countries in Europe the situation is the opposite (Giuliano & Dargay, 2006).

Car Ownership Model Categories:

- Aggregate Time series Models

These models include a sigmoid-shape function for car ownership over time. This function's independent variables are income or GDP. The National Road Traffic Forecasts (NRTF) in the UK contains an aggregate model which applies a logistic curve for saturation and is an example. Other important variables for these models are: population density, network density, fuel prices and time trends. Their data requirements are not light in comparison with other model types, and it is not feasible to forecast socio-demographic impacts from these models (de Jong *et al.*, 2004).

- Aggregate Cohort Models

Population is separated into groups and there is a shift of these cohorts into the future, describing how the cohorts, as they become older, acquire, keep, and lose cars. Such models do not require a lot of data, but can provide useful conclusions on socio-demographic changes, based on car ownership, as the modeller can add more variables, which can be included in a cohort (de Jong *et al.*, 2004).

- Aggregate Car market models

This category is different than other categories, as both demand and supply are modelled, though an equilibrium mechanism. These models have to ability to forecast over time, making them dynamic. Two main drawbacks of these models are that since it is hard to include additional variables in the modelling procedure, impacts on socio-demographic variables cannot be modelled directly (de Jong *et al.*, 2004). TREMOVE is a model that belongs in this category and it is designed to examine cost and emission effects of a wide range of measures, which were both technical and not technical, with the aim to reduce emission from road transport (K.U. Leuven Standard & Poor's DRI, 1999).

- Heuristic Simulation Models

The main assumption in this car ownership model category is the stability of the transport budget of a household over time. A well-known example of such a model is the FACTS model (de Jong *et al.*, 2004). This model is used in Netherlands to forecast emission and energy use and also predict the total number of cars. The procedure developed for the FACTS model is based on the hypothesis that the modelled households are not willing to give up on total annual milage. This is a main drawback for the model as this reflects a cost maximising behaviour. Finally, it is important to mention that the FACTS model includes a demand-supply equilibrium, has moderate demands on data required, provides static results and as in the aggregate car market models it is not feasible to model using additional variables (RAND, 2002).

- Static Disaggregate Car Ownership Models

The mathematical procedure followed in these models is based on the theory of discrete choice models. These are used in order to predict number of cars per household. Some notable examples are the model developed by Whelan (2007) and the model developed by Rich and Nielsen (2001).

For the model of Whelan (2007) the hierarchical dogit model has been introduced, which incorporates market saturation at each level of car ownership. The main drawback is that the dogit model does not always conform with the utility maximisation theory, as happens in a MNL model. The main factors that are included in the model are:

1. <u>Household Income</u>: It is very common that houses with higher income own more vehicles.

2. Household structure: The number of working adults is likely to be a factor that highly influences the numbers of owned vehicles in the household. Moreover, strong correlations are found between the two variables, namely income and employment.
3. Motoring Costs: The inclusion of motoring costs in a car ownership model can provide realistic conclusions on demand for car ownership.
4. Accessibility: The lifestyle in an area, the existing public transport and the general accessibility that is derived from these, are very influential for the determination of car ownership levels in an area. The reason is that it has been noted that households would not choose to own a vehicle, if they do not need one.
5. Company Cars: It is very common that the employers will provide company cars. Households that have been provided a company car will most probably own a second vehicle.
6 Licence Holding: The average licence holding among the population is essential to be included as it can be a critical factor for determining car ownership (Whelan, 2007).

- Car Ownership and Use Models of Indirect Utility

In this category car ownership and car use are modelled through an integrated microeconomic framework. More specifically, the decisions that households make on both car ownership and car use are correlated and modelled simultaneously (de Jong *et al.*, 2004). Models that belong in this category use indirect utility functions for the different car ownership levels that are modelled and demand functions that represent household car use. Modelling this interrelation with indirect utility functions and demand functions maintains a consistency with economic theory. Households in these models choose the optimal combination of car use and car ownership that provides them the highest utility (Train, 1986). Finally, an important element is that these models can also be a part of a wider modelling framework that also includes other variables, such as the choice of car type and they can be both static and dynamic (Hensher *et al.*, 1992).

- Static Disaggregate Car-type Choice Model

The car ownership is a given variable for these models because these models deal with car type choice with the use of discrete choice models. These kinds of models are disaggregate and they are usually standalone models that are useful to provide information for car fleet, car use and emissions (de Jong *et al.*, 2004). However, this does not mean they in some cases they are not part of a larger framework and can provide a valuable input for multimodal transportation systems, such an example is the model TRESIS (Hensher & Ton, 2002). For implementing these models revealed preference surveys, stated preference surveys or combinations of these can be used (Brownstone et al. , 2000).

- (Pseudo)-panel Methods

The pseudo panel approach is an econometric method that examines dynamically transport demand models and in pseudo panel dataset the data are artificial panel data that have occurred from expected means of cross sections. As expected, a pseudo panel data has restrictions before being treated as a reliable an actual data set. The cohorts that the pseudo panel data come from, should be defined based on variables that stay the same over time and another important element is to have homogeneity within the cohorts and between them as well. For these models since values are averaged, the disaggregated information per individual is lost (de Jong *et al.*, 2004).

- Dynamic Car Transactions Models with Vehicle Type Conditional on Transaction

In this category the vehicle number per household in predicted given the current ownership level of the household. Such models predict time until the next vehicle transaction, which can be of any type, for example disposal, replacement or buying a new vehicle. Such models are based on discrete steps related to time, which makes them dynamic. Moreover, these models have strong theoretical links to random utility theory while also requiring a large amount of data. Finally, additional variables can be examined in the model with the modification of the questionnaire used to ask for more information (Hague Consulting Group, 1995 cited in: de Jong *et al.*, 2004).

According to RAND Europe (2002) these models consist of the following sub models:

- Hazard-based duration models for the time between two vehicle transactions of one household.
- Vehicle type choice models, which especially refer to households extending or changing their existing vehicle fleet. Vehicle types are different depending on the brand, model or vintage and for each combination of these three characteristics, different vehicle variables which are known (fuel efficiency and costs for example), are used in this MNL choice model. The outputs of the model are aggregated.
- An annual model of car use
- A driving style model, which determines possible differences from the average fuel efficiency (RAND Europe, 2002; de Jong *et al.*, 2004).

4.5.2 Car ownership and new mobility options

The technological advancements in terms of ticketing, planning, booking, and payment are widely used by people in today's transportation systems. Moreover, breakthroughs in technologies such as electrification, connectivity and automation are expected to influence transport (Oxford Institute of Energy Studies, 2018). All these new elements have contributed to a change in car manufacturer's investment, as car sales is not the only element but also new mobility conspectus and new mobility services (CBInsights, 2017), changing in the end the whole business ecosystem of the transportation sector (Kamargianni & Matyas, 2017).

Soft measures included in new transportation business models, such as ODT and MaaS, that aim to reduce car ownership and increase public transport usage seem to be effective. These soft measures are often called mobility management tools and they include smart cars, bus passes or even the availability to purchase bulk tickets (Kamargianni *et al.*, 2016). According to NEA *et al.* (2003) the season ticket to the Paris Carte Orange increased ridership by 33% (NEA *et al.*, 2003). Moreover, in the study of Scott and Axhausen (2006) it was found that if the number of cars owned decreased, the number of season tickets in Germany increased, proving the correlation between car ownership levels and demand for public transport season tickets (Scott & Axhausen, 2006). Another study with similar conclusions is the one from Loder and Axhausen (2018), in which their model predicted that by increasing accessibility by public transport and job accessibility, the probability of owning a car faces a decrease whereas at the same time the probability of owning a season ticket to public transport is increased (Loder & Axhausen, 2018). Finally, according to Matyas and Kamargianni (2019), where the concept of MaaS was investigated, the conclusions revealed that there is a steady and but slow shift to on-demand transport and sharing schemes, as the technological advancements assist for this shift and the app-based trips appear to be more reliable (Matyas & Kamargianni, 2019).

4.6 Total Cost of Ownership

4.6.1 Definition

Purchase decisions of vehicles are based on a number of factors, which can be separated into two groups. The first group refers to situational factors and the second to psychological factors. Situational factors include a number of objective elements, such as vehicle economics and performance as well as suitability and existing infrastructure. Psychological factors often represent self-image or lifestyle, and they are difficult to be quantified (Lane and Potter, 2007cited in: Wadud, 2017). In this study the literature and methodology will be based on the first group, namely the situational factors, as the mathematical modelling in LUTI models requires factors that can be quantified.

One of the situational factors is the Total Cost of Ownership (TCO). During its life, a product has costs associated with its ownership. TCO provides a way to compare all these costs (Bickert and Kuckshinrichs, 2011 cited in: Letmathe and Suares, 2017). TCO analysis is a procedure of quantifying and comparing economic benefits from different technologies and it is very popular for analysing internal combustion engine vehicles with vehicles of different powertrains, (Palmer *et al.*, 2018) but it has also been used to quantify vehicle economics of autonomous vehicles as well (Wadud, 2017).

TCO methods can be applied from two different perspectives, in which different methods apply to. The first is the consumer -oriented method and the second the society-oriented (Lebeau *et al.*, 2013 cited in: Letmathe and Suares, 2017).

- *Consumer – Oriented*: TCO in this case refers to all costs associated with the initial purchase price and the costs that the owner would be obligated to pay while having it.
- *Society – Oriented*: TCO in this case has a totally different definition. It is essentially a way to compare capital, environmental costs, and operating expenditure (Letmathe & Suares, 2017).

This study aims to analyse TCO of different vehicle technologies, using the consumer-oriented method, as TCO is an important factor to determine if a consumer would invest in owning it. It is apparent from the literature that different studies include different costs, as there is no standardised method for estimating consumer based TCO.

4.6.2 Change of TCO with new transportation technologies

Wu et al. (2015) analysed TCO for EVs and PHEVs and compared it with TCO of ICE vehicles in Germany. The main conclusions from this study were that TCO is highly sensitive to annual mileage and vehicle class and that with R&D and investments, TCO could be substantially reduced, and this could affect the adoption of electric vehicles to a large extend. Societal costs that affect the national economy, such as environmental and societal costs, have not been considered, and this is mentioned as a limitation in the paper (Wu et al., 2015). However, since these costs do not directly affect the TCO of the individual vehicle owner and as a result their purchase decisions, this is not necessarily a drawback for the research purposes of this thesis.

Bubeck et al. (2016) introduced a consumer oriented TCO model where all costs of the life of a product were included, namely from purchase to ownership. The costs not included in the model are external costs and the analysis was conducted for the years 2015, 2030 and 2050. The prices used were 2010-year prices. The modelled technologies were different powertrains and energy storages (Fuel, BEV, HEV etc) and the mathematical formulation is presented in equation (4.5):

$$TCO_j = \frac{r(1+r)^n}{((1+r)^n - 1) * (1+r)} * \sum_{t=1}^{n} \frac{I_t + F_t + M_t + S_t + T_t}{(1+r)^{t-j}} \tag{4.5}$$

Where:

TCO_j: Total Cost of Ownership	I_t: Investment Cost
r: real discount rate	F_t: Fuel Cost
n: Final year of ownership	M_t: Maintenance Cost
t: Year modelled	S_t: Insurance Cost
j: Investment year (2015, 2030 or 2050)	T_t: Vehicle Tax

Their results lead to the conclusions that even if subsidies from the government did not exist, for some users full or partially hybrid vehicles could be a feasible economic option. In the future however, namely 2030 and 2050, electric mobility becomes an option for more users, as it provides more economic savings (Bubeck et al., 2016).

Mitropoulos et al. (2017) developed a method in which life cycle pollutants from vehicles and life cycle costs were analysed in detail to conduct TCO analysis. HEVs were found to have a lower TCO and thus it was concluded that HEVs could be a transitional technology before moving to electric mobility exclusively. The analysis also showed that some barriers such as infrastructure, familiarity with the technology and maintenance cannot decrease the penetration of HEVs in the market. Finally, it was concluded that combinations of transportation policies with electric mobility, can help for the creation of influential decisions for mobility and help to structure improved Sustainable Urban Mobility Plans (SUMPs) (Mitropoulos et al., 2017). Including more criteria for assessment and monetization, could have been beneficial, however still those results are indeed useful for consideration in this thesis. Moreover, the incorporation of vehicle automation with electrification could more pronounced results in this respect.

Letmathe and Suares (2017) conducted a comprehensive literature review on methods that have been formulated to calculate consumer based TCO. They separated two kinds of expenditure, namely capital expenditure, and operational expenditure. Capital expenditure includes, initial vehicle price, initial battery price as well as the resale values of vehicle and battery. Operational expenditure includes energy consumption, insurance, Maintenance & Repair, vehicle tax and discount factor. Their conclusions showed EVs have financial benefits for drivers with low annual mileage and HEVs are more suitable for drivers, who use their car more frequently. As a result, people who are residents of urban areas, are more likely to own EVs and taxi fleets or residents of rural areas are more likely to own HEVs. They also found that a major constraint for the consumer is the battery and its costs and thus they propose that this element should be included in a TCO analysis (Letmathe & Suares, 2017). The analysis of Letmathe and Suares (2017) is referring to country-specific aspects and as result is focused on a specific market. The methodology developed in this thesis could be benefited from a more universal and applicable approach.

According to van Velzen *et al.* (2019) there are many factors that can affect the penetration of electric vehicles in the future and the total cost of ownership of these vehicles. The study conducted a literature review of different TCO analyses and concluded that the procedure for estimating TCO is a more complex procedure than just adding the costs or applying a curve. Feedback loops and reinforcing cycles and other more qualitative factors play a major role are very important and are proposed to be included in TCO analysis. In total 34 factors were identified and some relationships among them were proposed, leading into a whole explanatory theoretical framework for assisting future research on TCO. They also concluded that indirect factors that affect TCO can be included, as for example they may change willingness to purchase. Finally, according to this study, governments will play an important role for the EVs to be incorporated in the current transportation systems, specifically by contributing to the adoption rates (van Velzen *et al.*, 2019).

In the analyses of Palmer *et al.* (2018) and Baek *et al.* (2021) a mathematical framework was developed to estimate TCO of BEVs, PHEVs and HEVs across Japan, US, and the UK, while also investigating the relationship of market shares and TCO of HEVs. The mathematical framework is presented in equation (4.6). It was found that TCO was very sensitive with the change of depreciation rates and that in states like California were the income is higher, residents can afford extra costs that occur from low-emission vehicles. Moreover, factors that cannot be quantified are important, such as the fact that in California people who owned low-emission vehicles could apply for access in HOV lanes. In Japan, as smaller cars are more favoured, the Prius is one of the most popular vehicles and as the government has invested highly on changing the existing infrastructure, electric vehicles are expected to become more and more attractive to the people. In the UK, the strategic planning for changing the existing infrastructure has been essential for the uptake of electric vehicles, with the Prius being one of the most popular vehicles for rent in London. In conclusion, there is an important connection between TCO and market shares of electric vehicles, but there are a many more factors that affect market shares and purchase decisions across all three cases studies (Palmer *et al.*, 2018).

$$TCO_{Tech} = \sum_{t=1}^{3}((D_t + E_t + T_t + F_t + M_t + I_t)/(1+r)^t) \quad (4.6)$$

where:

TCO_{Tech}: TCO for a specific vehicle technology type

D_t: Depreciation costs per year

E_t: Fuel costs per year

T_t: Tax

F_t: Financing costs per year

M_t: Maintenance costs per year

I_t: Insurance costs per year

r: Discount rates

t: Year of vehicle ownership

Again, as previously mentioned social costs of are not considered, however this analysis can be applied in multiple case studies and it is not case study specific, which provides an essential advantage in respect to the research question of this thesis.

According to the analysis of Liu *et al.* (2024) which compares BEVs to ICEVs based on TCO, it was found that the initial cost of BEVs, which is generally higher to ICEVs, can be recovered in only 5 years, especially for BEVs with shorter driving ranges (Liu *et al.*, 2024). Having incorporated possible subsidies that tend to reduce the initial price, would have provided more pronounced results in this respect, which should be considered for this thesis. As mentioned by Sontakke et al. (2023) government incentives for BEVs are essential to their overall acceptance in most cases around the world.

Another important study is the one of Wadud (2017) where the total cost of ownership of autonomous vehicles was examined in order to investigate early adoption. The main research question in this study, was whether or not automation will provide financial benefits for consumers. According to the conclusions of the study household with high income will not gain substantial benefits, however on-demand transport business models like Uber or Lyft could benefit much more. Another topic researched is the spatial distribution of the adoption, and it was found that mobility options providers could benefit financially but adopting full automation in small spatial scales rather in large spatial units simultaneously. Finally, it was concluded that income per household, travel patterns and vehicle choices are correlated and thus average households per income cohort were used for the TCO analysis and that households that have the highest values of time are more likely to have financial benefits from automation. For the concept of automation, the other psychological factors that affect the market shares are essential to be considered, but TCO analysis is an appropriate tool for identifying early potential owners and investors (Wadud, 2017). This analysis could have been improved with the incorporation of factors related to income, as household's travel patterns are different in this respect. Income is a crucial element that should be examined in this thesis as well.

Finally, Zhu *et al.* (2024) mentions that cumulative total costs of ownership for CAVs will be reduced by more than ¥200 billion from the year 2023 to 2050. Always in such analyses a major issue is the assumption that inevitably is made on the forecasted penetration rates of CAVs Zhu *et al.* (2024), which may be a limitation to this research as well.

Finally, in Table 4.6 the estimated values of TCO of new vehicle technologies and comparative results to the TCO of conventional vehicles are presented, where possible.

Table 4.6: Quantitative Presentation of Values – TCO

Mobility Option	***Quantitative Effect***	***Reference***
EVs	Short distances ICEV 54 €/km BEV 62.5 €/km Long distances ICEV 30 €/km BEV 27 €/km	(Wu et al., 2015)
EVs	Differences in TCO BEV to ICEV (DTCO) Medium car	(Bubeck et al., 2016)

Mobility Option	*Quantitative Effect*	*Reference*
	2030 DTCO = -2.2 EUR_{2010}/km Medium car 2050 DTCO = -5.8 EUR_{2010}/km	
EVs	<u>**ICEV HEV EV Costs in 2015$**</u> <u>Retail cost</u> ICEV 27,130 $ HEV 27,642 $ EV 31,590 $ <u>Fuel cost</u> ICEV 11,024 $ HEV 5,053 $ EV 3,367 $ <u>Operation cost</u> ICEV 24,497 $ HEV 21,820 $ EV 23,840 $ <u>Total cost of ownership</u> ICEV 62,651 $ HEV 54,515 $ EV 58,797 $ Assumption: 10.6 years of ownership and annual mileage of 11,300.	(Mitropoulos et al., 2017)
EVs	By 2030 TCO of BEV £36000 TCO of ICEV £45000	(van Velzen *et al.*, 2019)

Mobility Option	***Quantitative Effect***	***Reference***
EVs	Case Study presented (UK) - Prices in £2015 <u>Petrol</u> Depreciation £6717 Tax £369 Maintenance £354 Insurance £783 Petrol cost £4062 <u>BEV</u> Depreciation £9078 Tax £0 Maintenance £273 Insurance £783 Electric cost £653	(Palmer *et al.*, 2018)
EVs	For 10000km Annual Travel Petrol and Diesel vehicles have a TCO of more that 3 ₹/km - EVs have less than 3 ₹/km	(Sontakke et al., 2023)
AVs	Full AVs TCO 36729 £/year	(Wadud, 2017)

4.7 Conclusions

In conclusion after analysing the different LUTI models four factors that belong to all three transport modules (TRANUS, DELTA (HSTM) and URBANSIM (MATSIM)) are found and the effects from the new emerging technologies are summarised:

1. *Generalised Cost*

Changes in the GC for AVs occur from decreases in values of time, especially for work purposes. On the other hand, for EVs, changes occur from operating costs. Thus, if the impact of a combined technological offer is examined, changes in both operating costs and values of time per level of automation should be included. Regarding mobility schemes, their GC has the ability to competitive to other modes, making them attractive. In respect to MaaS, the reduction of the combined GC of different options may even lead to overuse of the mobility options of the package.

2. *Trip Rates*

In general, the effect on trip rates from new vehicle technologies and business models is still a scientific topic that needs extensive research. The literature suggests that the effect that EVs have on trip rates is inverse from that of automation, as it was found that trip rates decrease with electric vehicles and increase with automation. On the other hand, it is still debatable whether new mobility services increase or decrease trip rates, as research conclusions contradict at this point.

3. *Accessibility*

ODT, CS and MaaS have been found to generally increase accessibility, especially when combined with automation. It is also concluded that even privately owned AVs could lead to benefits in accessibility. Finally, when it comes to EVs, the research usually is focused on accessibility of charging stations, as it is an important factor for their adoption.

4. *Car Ownership*

- *Car Ownership Models*

Business models in transportation reduce the need for car ownership, and lead to an era of higher car use. This happens, because the costs of car ownership are higher and the accessibility with new mobility options is increased.

- *Total Cost of Ownership*

Regarding electric vehicles the costs of ownership have been found to be lower than those of the conventional car, in multiple studies, if combined with subsidies and other incentives. On the other hand, CAVs have been found to be more expensive for private owners, in comparison with non-automated vehicles, but could potentially benefit the companies willing to adopt them for mobility services.

Chapter 5 Methodology

The proposed methodology is presented in this chapter. The aim of this methodology is to provide a framework that enables the simulation of new transportation vehicle technologies and business models to a LUTI model by assessing different elements in the modelling framework and receiving land use and transport results. These results could be used by transportation planners and practitioners in the field of urban and regional planning, decision makers and researchers, as they could be essential forecasts for the future of our cities and transportation systems.

5.1 Aim of the proposed methodology

Based on the literature review there are many different technologies and business models that will change transportation and land use in the future. However, it was noted that they have either been examined individually or in combinations of two or three. It is expected that these will occur simultaneously in time and thus need to modelled this way.

Moreover, new transportation innovations will affect land use and thus as they will co-exist in the future it is essential to also determine the land use effect of their co-existence. Their effect on land use is still a subject that needs to be investigated further, as the methodologies that have been followed by different researchers may focus on different aspects, such as transport, welfare, or environmental impacts.

The methodological framework presented shows essentially the principles that should be followed by the modeller before attempting to simulate new transportation innovations, in order to receive results on land use effects. The current framework is the conceptual framework that the modeller should follow to receive reliable land use and transport results, which have been derived by models with a solid scientific background and have been extensively validated, in order to draw conclusions.

5.2 Identification of the appropriate modelling framework and examination of the current transportation innovations

To find an appropriate framework, it is important to review the bibliography that is available and firstly identify the modelling methodology or methodologies that may be appropriate for simulating new transportation technologies and receiving the results on land use. Following, a comparison of the models that follow the selected methodologies will allow for further understanding of their functions. Finally, criteria for the purpose of analysis need to be formulated to find which of the models may be suitable for incorporating emerging technologies in transportation. Based on the analysis conducted in the literature review of Chapter 2 the internal structures and characteristics of different LUTI models were compared to identify an appropriate model and DELTA was deemed appropriate for this research.

Reviewing the literature and understanding the characteristics of the current transportation innovations is essential in order to have more insight on the possible effects on either transport or land use.

5.3 Development of methodological framework for the incorporation of innovations to the modelling framework

5.3.1 Methodological framework for this research

At this stage, the methodological framework developed for this research is presented and it the core of the methodology aims to achieve the incorporation of new vehicle technologies and business models in a LUTI model.

5.3.1.1 Identification of elements

In Chapter 4 the factors that are related to transport demand in the mathematical expressions of different LUTI models were identified and these are:

1. Generalised Cost per purpose.
2. Trip Rates.
3. Accessibility.
4. Car Ownership models.
5. Total Cost of Ownership.

At this stage, it is essential to identify which of them belong to the transportation module and which of them in the land use module of the selected LUTI model. Generalised Costs and Trip rates are inputs to HSTM, thus belong to the transport module of DELTA (Unpublished DSC documentation, 2016a). Accessibility and car ownership are two elements that belong to the land use module of DELTA (Simmonds, 1999).

5.3.1.2 Identification of variables and procedures

The next stage is to find how these elements change through the literature, which was extensively investigated in Chapter 4. The methodology at this stage follows the principles of the framework presented in Dias *et al.* (2018), where autonomous vehicles and ride hailing scenarios are incorporated to the traditional four stage model (Dias *et al.*, 2018). However, it is extended by also considering accessibility and car ownership in the land use part of a LUTI model, to capture changes in the land use part as well.

According to the framework presented in Dias *et al.* (2018), to incorporate autonomous vehicles and ride hailing, these changes should be implemented:

- *Trip Generation*: Creation of trip rate scenarios for allowing more or less trips to occur with the new technologies, based on the literature.
- *Trip Distribution*: Consideration of changes in the impedance function
- *Modal split*: Inclusion of the new options in the choice set and consideration of changes in In-vehicle time
- *Assignment*: Consideration of changes in roadway capacity that occurs from connectivity (Dias *et al.*, 2018).

Connecting this framework with the transport changes examined here:

- *Trip Generation*: The trip rates scenarios will be created to be used for validation as they have also been used for this procedure in other studies in the literature as well, for example Bernardin *et al.* (2019) and Dias *et al.* (2020, 2018).
- *Trip Distribution*: Generalised Cost is the dependent variable of the impedance function, thus changes here are included.
- *Modal split*: The options are incorporated in the generalised costs, thus incorporated in the choice set
- *Assignment*: Changes will be considered in Passenger Car Units (PCU) by evaluating changes in headway distances. Even though network capacity is not a factor that has the same meaning in HSTM like MATsim, because it is highly aggregate, the O-D matrices are created in PCU. Thus, this step could be essential for considering connectivity.

The land use variables changed here are:

- Accessibility: This is a factor affected by changes in the model and thus it is essential to be used for evaluation and validation. Similar procedures were also followed by Nahmias-Biran *et al.* (2020) and Luo *et al.* (2019).
- *Car ownership:* Car ownership should be changed in various ways. To begin with, the Total Cost of Ownership changes for different vehicle technologies, as shown in the literature (Palmer *et al.*, 2018; Mitropoulos, Prevedouros & Kopelias, 2017; Wadud, 2017). Thus, estimations are considered at this stage for each vehicle technology. Moreover, car ownership is expected to change from the existence of new mobility options (Matyas & Kamargianni, 2019; Scott & Axhausen, 2006), thus it is essential to estimate this change with the use of discrete choice modelling, for estimations of car ownership probabilities.

Thus, in the traditional conceptual framework of a LUTI model the aforementioned changes result into a holistic change in the transport section as presented in Figure 5.1. The changes in car ownership and generalised costs (underlined in red in Figure 5.1) belong to the two opposite ends of the transport section, thus affecting the whole framework and providing results in land use. As mentioned, trip rates and accessibility will be used for validation scenarios, resulting to a changed model, that can adopt new technologies.

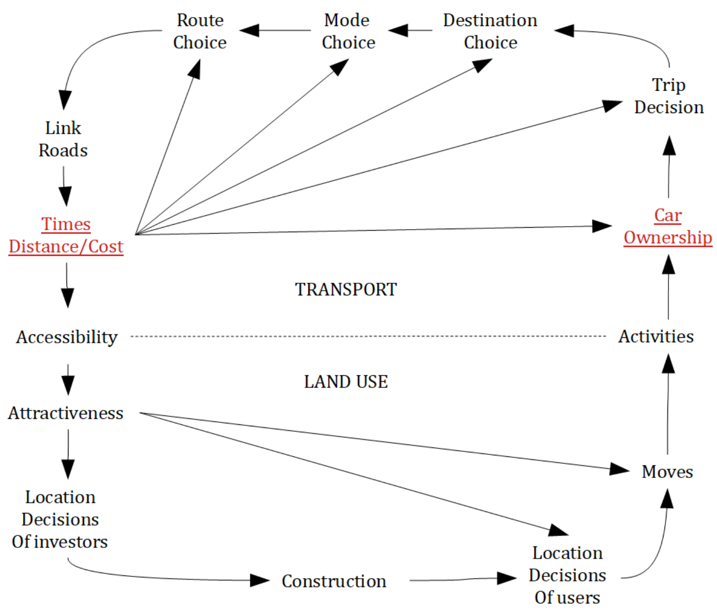


Figure 5.1: Interventions in the conceptual LUTI framework to model new technologies and business models

Source: Adapted from Wegener and Fürst (1999)

Finally, it should be mentioned that appropriate modelling time periods are simulation years as the impact of the incorporation of new transportation vehicle technologies and business models on land use will occur over a number of years and this change is not radical.

5.3.1.3 Parameters estimation and modelling alterations

5.3.1.3.1 Generalised Cost for new transportation technologies

It is expected that new vehicle technologies will have different generalised cost from conventional vehicles. The technologies entering the model are CAVs and EVs. EVs will use a different energy source and thus have different vehicle operating costs. AVs are expected to allow productive time while travelling, thus reducing this way the value of time (Litman, 2019;Frost and Sullivan, 2019). The procedure for calculating the generalised cost (GC_Y^{Tech}) for each vehicle technology type (^{Tech}) and for each simulation year ($_Y$) is conducted based on the procedure of DfT (2019) but also slightly modified to include new vehicle technologies, as follows:

1. Estimation of the Non- Fuel Costs in (£/km) for each vehicle type for each simulation year (NFC_Y^{Tech})
2. Estimation of the Fuel Costs in (£/km) for each vehicle type for each simulation year (FC_Y^{Tech})
3. Estimation of the Value of Time (£/h) for each vehicle type for each simulation year (VoT_Y^{Tech})
4. Estimation of the distance in (km) for each trip (D) of every zone pair
5. Estimation of the journey time in (h) for each trip (JT) of every zone pair
6. Use of equation (5.1) to estimate the generalised cost per trip for every vehicle type for each simulation year.

$$GC_Y^{Tech} = \left(NFC_Y^{Tech} + FC_Y^{Tech}\right) * D + VoT_Y^{Tech} * JT \qquad (5.1)$$

For example, for calculating the generalised cost of a *CAV level 4-5 Electric vehicle*, a change would occur in *value of time*, as time can be used productively, as well as the different *operating costs* that it may occur because it is electric.

The generalised cost for each vehicle technology type (^{Tech}) and for each simulation year ($_Y$) in DELTA ($GC_{Y,D}^{Tech}$), presented in equation (5.2), is used to calculate measures of accessibility in minutes (David

Simmonds Consultancy Ltd, 2017). To change the units from monetary costs to minutes, generalised cost (GC_Y^{Tech}) is divided by the average value of time per purpose (VoT $_{purpose}$), for which values are taken from the UK Department for Transport (2012).

$$GC_{Y,D}^{Tech} = \frac{GC_Y^{Tech}}{VoT_{purpose}} \qquad (5.2)$$

This procedure needs to be completed for both work and non-work trips, for every year and for every zone pair.

The proportions of new technologies in the national passenger car fleet at a subsequent level are multiplied with the generalised cost of each vehicle technology. Knowing that there is a mixture of vehicle types in one year, the multiplied proportions with the generalised costs per vehicle type are added, to find the total generalised cost of private car for each transportation simulation year. This procedure is mathematically presented as equation (5.3).

$$TGC_D = \sum_Y^{Tech}(P_Y^{Tech} * GC_{Y,D}^{Tech}) \qquad (5.3)$$

Where:

- TGC_D: Total generalised cost of the private car mode for each transportation simulation year in DELTA
- P_Y^{Tech}: Proportion of each vehicle technology in the fleet for each simulation year
- $GC_{Y,D}^{Tech}$: Generalised cost for each vehicle technology type and for each simulation year in DELTA

Subscripts Y and Tech refer to simulation year and vehicle technology, respectively.

It is essential to mention that TGC_D is calculated for both work and non-work purpose trips but also for every zone pair. Each purpose of travel has different generalised costs based on the differences of value of time and each zone pair has a different generalised cost, based on the distance between the centroids of these zones.

This aggregated procedure for estimating generalised cost for autonomous vehicles was adopted in the analysis of Kröger et al. (2019). In this study, a diffusion model was developed to estimate proportions of AVs in the national passenger car fleet and after reducing the values of time, the households with the highest mileage in the model were assigned with AVs, until the proportion that was found was reached (Kröger et al. , 2019). A main difference that this research project has from the study of Kröger et al. (2019) are that a diffusion model would not be appropriate, as there are many new options modelled and not just two. Diffusion models are used for two choice decisions tasks (Bass, 1969). Thus, forecasts for the different proportions of vehicle technologies from a variety data sources, will be combined, and used in this project.

The accessibility measures that affect land use in DELTA, use the generalised costs estimated by optimally estimating their average through a logsum function (Simmonds, Preston & Pagliara, 2010). It would be possible to incorporate these technologies as separate transport modes and use a more disaggregated approach of predicting and modelling modal splits, using for example discrete choice modelling. However, there would be a high degree of uncertainty of this procedure, as the public is not familiar with the aspects of these technologies and safety or trust issues would need to be reflected in this type of analysis. It is also possible that in the future those issues of safety and trust of new vehicles technologies may not exist in the degree that exist now, which indicates that percentages in modal split may significantly change in the future. Thus, available proportions of new vehicle technologies in the fleet in the literature can provide an efficient way of modelling private CAVs and EVs in aggregated transport models, which are incorporated to IUMs.

5.3.1.3.2 Integrating business models with generalised cost

The current public transport mode represents a nest that includes modes such as bus, train, and other public transport options in HSTM. With the incorporation of new business models, the result would be to have more alternatives in this nest that provide also the option of travelling with the business models in a zone per year and per purpose. A similar approach was adopted by Martínez *et al.* (2017), in which car sharing was modelled in an agent-based model. Car sharing was incorporated in the nest of public transport as an alternative (Martínez *et al.*, 2017). Since the public transport mode will now include business models as well, the name is changed to “Transit” mode.

The first step is to find the generalised cost per transit option. For this purpose, three generalised cost functions are proposed for this methodology, which are based on the principles of generalised costs as previously presented but changed based on the specific circumstances of a business model. As previously presented, to match the specifications in DELTA, which require generalised costs to be estimated in minutes, it is essential to also change the units from monetary costs to minutes. For this reason, it is evident that equations (5.4) (5.5) and (5.6) have the denominator of the average value of time per purpose ($VoT_{purpose}$).

- **For On-Demand Transport**

$$gc_{ODTlm}^{k} = \frac{T_{lm} * (VOT^{k}{}_{passenger} + ODTCharge)}{VoT_{purpose}} \tag{5.4}$$

Where:

gc_{ODTlm}^{k}: The generalised cost of On-Demand transport from zone l to zone m for purpose k

T_{lm}: Time spent by travelling with On-Demand transport from zone l to zone m

$VOT^{k}{}_{passenger}$: The value of time being a passenger in the car for purpose k

$ODTCharge$: the charge per unit of time of the On-Demand transport scheme

$VoT_{purpose}$: The value of time per purpose k

- **For Car-Sharing**

$$gc_{car-sharing,lm}^{k} = \sum_{Tech=1}^{N} (GC_{lm}^{Tech,k} * P^{Tech,CS}) + \frac{CarsharingFeei * T_{lm}}{VoT_{purpose}} \tag{5.5}$$

Where:

$gc_{car-sharing,lm}^{k}$: Generalised cost of travelling with Car Sharing from zone l to zone m for purpose k

Tech: Each vehicle technology modelled in the car sharing scheme, varies from 1 to N

N: the total number of vehicle technologies included in the car sharing scheme

$GC_{lm}^{Tech,k}$: Generalised cost for each vehicle technology type from zone l to zone m in DELTA for purpose k

$P^{Tech,CS}$: Percentage of supply of the vehicle technology in the whole car sharing fleet.

$CarsharingFeei$: The cost of travelling with car sharing per unit of time

T_{lm}: Time spent travelling with Car Sharing from zone l to zone m

$VoT_{purpose}$: The value of time per purpose k

- **For Mobility as a Service**

$$gc^{k}_{MaaS,lm} = T_{lm} * MaaS_{Cost} + \frac{\sum_{O}^{n} T_o * VOT^{k}{}_{o}}{VoT_{purpose}} \quad (5.6)$$

$gc^{k}_{MaaS,lm}$: The Generalised cost of travelling with MaaS from zone l to zone m for purpose k

$MaaS_{Cost}$: The Subscription cost of MaaS per unit of time

T_{lm}: Time spent travelling with MaaS from zone l to zone m

O: Options included in MaaS

T_o: Time spent travelling with MaaS from zone l to zone m for each option *O* offered in the MaaS package.

$VOT^{k}{}_{o}$: Value of time per option in MaaS for purpose k

$VoT_{purpose}$: The value of time per purpose k

To calculate the Subscription cost of MaaS per unit of time ($MaaS_{Cost}$) the modelled subscription cost for MaaS, which is monthly or annual, should be converted to the unit of time used to calculate the generalised cost.

The incorporation of all the generalised costs into an integrated Transit option is going to be calculated by using the *logsum* function, as this is an efficient way of averaging generalised cost over modes. The procedure is shown in (5.7).

$$GC\ (TR)^{k}_{lm} = \frac{1}{-\lambda} \ln \sum_{tr=1}^{4} \exp\left(-\lambda * gc_{tr}{}^{k}_{lm} \right) \quad (5.7)$$

Where:

$GC\ (TR)^{k}_{lm}$: generalised cost of travelling with transit options from zone l to zone m for purpose k

λ : The spread parameter of the corresponding distribution model (describing the sensitivity of the distribution to differences in generalised cost);

tr: The four transit options of the “transit” nest

$gc_{tr}{}^{k}_{lm}$: generalised cost of travelling with a transit option tr from zone l to zone m for purpose k

This generalised cost, presented in equation (5.7), can be used to examine if in the end having business models in an area can help in decreasing generalised cost of travelling and as a result increase accessibility.

5.3.1.3.3 Changes in PCU for incorporation of connectivity

Tientrakool et al. (2011) conducted research to determine the changes in highway capacity from the existence of connectivity in vehicles. To achieve this, the safe distance D_f that would be kept from vehicle to vehicle was estimated:

- In case neither the vehicle in front nor following vehicle could communicate (Case 1).
- In case the following vehicle could communicate, but the proceeding vehicle could not (Case 2).
- In case the preceding vehicle could communicate (Case 3).

The variables used for the estimation of D_f in this research are speeds, decelerations and different time components from human reactions and vehicle communication characteristics (Tientrakool et al., 2011).

Dias *et al.* (2020) used the functions from this research to then develop an estimate the ratio of the capacity consumed by CAVs and by manually driven vehicles. Their formula is presented in (5.8):

$$F_{AV\_PCU} = \frac{l_{AV} + D_{AV}}{l_s + D_s} \tag{5.8}$$

Where:

F_{AV_PCU}: The ratio of capacity

l_{AV}: vehicle length of a CAV

D_{AV}: Headway maintained from CAVs

l_s: vehicle length of a vehicle of 1 PCU

D_s: Headway maintained from a 1 PCU vehicle

From a range of 20 m/h (32 km/h) to 82 m/h (128.7 km/h) the PCU values varied from 0.56 to 0.76, respectively. Since an aggregate transport model does not allow for speed dependant PCU, they followed a more conservative approach and used the value 0.7 (Dias *et al.*, 2020). Moreover, a PCU factor equal to 0.8 was also applied in the analysis of connected and autonomous vehicles in the paper of Luo *et al.* (2019).

5.3.1.3.4 Car Ownership for integrating vehicles

An important factor that will determine car ownership after the incorporation of new vehicles in the system is their cost of ownership. The TCO method used in this study is the one developed by Palmer *et al.* (2018) and Baek *et al.*(2021) presented in the section 4.6. This cost methodology for the estimation of TCO has been selected, due to the fact that it is based on examples from different countries, which makes it applicable to multiple geographical case studies as well as to different vehicle technologies.

An element not mentioned in the selected TCO estimation method of Palmer *et al.* (2018) and Baek *et al.*(2021), is the difference of TCO for new and used vehicles. This is considered in the thesis, in order to include possible cost differences. More specifically, it is important to include the percentages of new and used vehicles in the national passenger vehicle fleet. These are:

- $P_{N,Y}$: Proportion of new vehicles the national passenger car fleet and for each simulation year Y
- $P_{U,Y}$: Proportion of used vehicles the national passenger car fleet and for each simulation year Y

The summation of these two proportions is equal to 100% ($P_{N,Y} + P_{U,Y} = 100\%$), as it represents the whole national passenger vehicle fleet.

Since there will be a mixture of vehicle technologies in one simulation year Y, it essential to consider the internal proportions of each vehicle technology for both new and used vehicles in the fleet for each one simulation year Y. The summation of these internal proportions should be equal to $P_{N,Y}$ for new vehicles and $P_{U,Y}$ for used vehicles, respectively. These are represented mathematically in equations (5.9) and (5.10) respectively.

$$P_{N,Y} = \sum_{Tech} {P_{N,Y}}^{Tech} \qquad (5.9)$$

$$P_{U,Y} = \sum_{Tech} {P_{U,Y}}^{Tech} \tag{5.10}$$

Where:

- $P_{N,Y}$: Proportion of new vehicles in the national passenger car fleet and for each simulation year Y
- $P_{U,Y}$: Proportion of used vehicles in the national passenger car fleet and for each simulation year Y
- ${P_{N,Y}}^{Tech}$: Proportion of new vehicles of each vehicle technology in the national passenger car fleet (including only new vehicles) and for each simulation year Y
- ${P_{U,Y}}^{Tech}$ Proportion of used vehicles of each vehicle technology in the national passenger car fleet (including only used vehicles) and for each simulation year Y

Based on the aforementioned, the TCO of new cars of each vehicle technology is multiplied with each respective percentage and then added to find the total TCO of owning a new car in the simulation year. This procedure is mathematically presented as equation (5.11).

$$TCO_{N,Y} = \sum_{Y}^{Tech} ({P_{N,Y}}^{Tech} * TCO_{N,Y}^{Tech}) \tag{5.11}$$

Where:

- $TCO_{N,Y}$: Total Cost of Ownership of new vehicles for each transportation simulation year Y
- $TCO_{N,Y}^{Tech}$: Total Cost of Ownership of new vehicles for each vehicle technology for the specific simulation year Y

Again, subscripts Y and Tech refer to simulation year and vehicle technology, respectively.

Applying the same procedure for used vehicles the resulting equation is (5.12):

$$TCO_{U,Y} = \sum_{Y}^{Tech} ({P_{U,Y}}^{Tech} * TCO_{U,Y}^{Tech}) \tag{5.12}$$

Where:

- $TCO_{U,Y}$: Total Cost of Ownership of used vehicles for each transportation simulation year Y
- $TCO_{U,Y}^{Tech}$: Total Cost of Ownership of used vehicles for each vehicle technology for the specific simulation year Y

The proportions will be found directly from the data sources, used in this project. Finally, the expected TCO of owning a car for the simulation year Y (TCO_Y) can be found by adding the two components, as shown in (5.13):

$$TCO_Y = TCO_{N,Y} + TCO_{U,Y} \tag{5.13}$$

Finally, it should be mentioned that the GDP deflator should be used to bring all costs mentioned, namely generalised costs and costs of ownership, in the prices of the base year of a simulation model.

5.3.1.3.5 Car Ownership for integrating business models

The current car ownership model in DELTA follows the structure of the Whelan (2007) model, which is a static disaggregate car ownership model. The parameters in the current model are only related to private vehicles and household characteristics. Thus, the car ownership model needs to change in order to incorporate new business models. The new name of the new model is “Mobility Investment Model” (MIM), as it investigates willingness to invest in new transport business models and/or car ownership of new vehicle technologies, given that households have different characteristics.

For the purposes of this research project a nested logit (NL) model structure was considered as appropriate, in order to explore if a household q would own 0, 1 or 2+ cars. The model is expanding on the model of Whelan structure, which is the basis for the national car ownership model for Great Britain and current car ownership model of DELTA (Whelan, 2007; Fox *et al.*, 2016). As a result, three alternatives are formulated, which correspond to the ownership of 0 cars for alternative 1, the ownership 1 car for alternative 2 and the ownership of 2+ cars for alternative 3. The proposed model structure is presented in Figure 5.2.

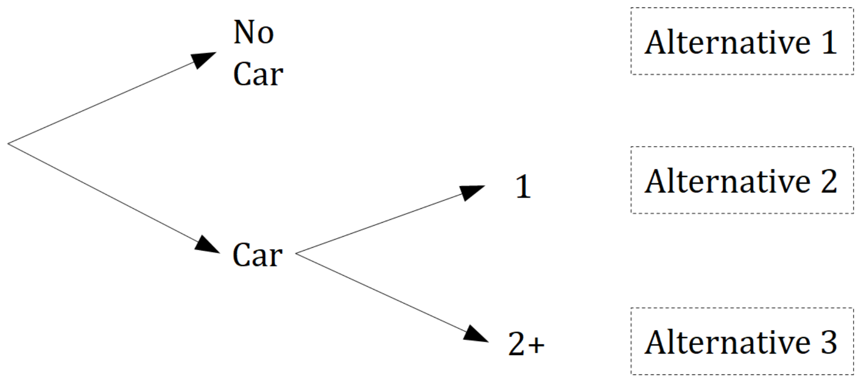


Figure 5.2: MIM model structure

Regarding the independent variables of the model, there are some that are alternative specific for each alternative j, and some that are household specific for each household q. It should be noted that the alternative specific independent variables are mainly cost based, which is inspired from the on the national car ownership model for Great Britain that predominantly uses in the utility functions of the model cost based variables (Fox *et al.*, 2016). The independent variables are presented in Table 5.1.

Table 5.1: Independent Variables

Independent Variables	**Description**
COC_j	Car operation cost of alternative j
MC_j	Mobility cost for MaaS of alternative j
PT_j	Public transport cost of alternative j
CC_j	Car club cost of alternative j
ODT_j	On Demand Transport cost of alternative j
Y_q	Income per household q
ZT_q	Zone type per household q (1 if urban, 0 if not)
R_q	Retired household (1 if yes, 0 if not)

Different versions for this model were tested, including an MNL model with three alternatives, normalising the values with the mean income and including each cost variable separately in each utility. The structure that resulted to the best fitting model form of the observed utilities V_1 , V_2 and V_3 of alternatives 1, 2 and 3 respectively, is presented in (5.14), (5.15) and (5.16):

$$V_1 = \text{asc}_1 + \beta_{ZT,1} * ZT + \beta_{R,1} * R + \beta_{PT\ cost,1} * PT / Y_q + \beta_{CM\ cost,1} * (ODT + CC) / Y_q + \beta_{MC\ cost,1} * MC / Y_q \tag{5.14}$$

$$V_2 = \text{asc}_2 + \beta_{ZT,2} * ZT + \beta_{R,2} * R + \beta_{COC\ cost,2} * COC / Y_q + \beta_{transport\ cost,2} * (MC + CC + ODT + PT) / Y_q \tag{5.15}$$

$$V_3 = \text{asc}_3 + \beta_{ZT,3} * ZT + \beta_{R,3} * R + \beta_{COC\ cost,3} * COC / Y_q + \beta_{transport\ cost,3} * (MC + CC + ODT + PT) / Y_q \tag{5.16}$$

where:

asc_1 : alternative specific constant for alternative 1

asc_2: alternative specific constant for alternative 2

asc_3 : alternative specific constant for alternative 3

$\beta_{ZT,1}$: Zone type coefficient for alternative 1

$\beta_{ZT,2}$: Zone type coefficient for alternative 2

$\beta_{ZT,3}$: Zone type coefficient for alternative 3

$\beta_{R,1}$: Retired household coefficient for alternative 1

$\beta_{R,2}$: Retired household coefficient for alternative 2

$\beta_{R,3}$: Retired household coefficient for alternative 3

$\beta_{PT\ cost,1}$: Public Transport coefficient for alternative 1

$\beta_{CM\ cost,1}$: On Demand Transport and Car Clubs coefficient for alternative 1

$\beta_{MC\ cost,1}$: MaaS Cost coefficient for alternative 1

$\beta_{transport\ cost,2}$: Combined Transport cost coefficient for alternative 2

$\beta_{COC\ cost,2}$: Car Operation Cost coefficient for alternative 2

$\beta_{transport\ cost,3}$: Combined Transport cost coefficient for alternative 3

$\beta_{COC\ cost,3}$: Car Operation Cost coefficient for alternative 3

In the procedure of calibrating the model it is very important to determine the parameter λ_{car}, which is the lambda coefficient for the car nest

The costs in V_1 are considered separately to determine through an analytic procedure which services would affect alternative 1 and at which level. For the other two alternatives the mobility business costs are combined, even though private car related costs are considered separately. The reason for this mathematical choice is that this how mobility business model's costs are perceived by a household. It is important to mention that all costs in this model are divided by the income of each household q, as suggested in (Train, 2003), as income is the socioeconomic variable that changes the perceived costs of each alternative. As a result, income should not be considered as dependent of the costs included in the utilities of the alternatives.

The next steps of the analysis are to determine the attributes and their levels, though an investigation of mobility costs in the selected case study area. Moreover, a stated preference experiment, using the principals of stated preference design, needs to be carried out to make respondents respond to hypothetical scenarios that include new vehicle technologies and business models. To analyse the concept of stated preference designs it is essential to provide some information here to justify why this method has been chosen. There are two categories of surveys that are used for data collection in discrete choice modelling. The first category includes revealed preference surveys and the second stated preference surveys. Revealed preference surveys have been created to illustrate and reflect the actual choices and tastes of people in the real world. However, very often researchers investigate hypothetical alternatives in their models that do not exist. For this purpose, stated preference surveys are more appropriate, in which the respondents have to state their choice among different hypothetical scenarios (Train, 2003). Both categories, based on their characteristics, have advantages and disadvantages. Revealed preference data are realistic, as they provide the actual choice among alternatives, but do not give flexibility to the modeller to investigate something new. Stated preference data provide this flexibility, as they allow for the modeller to manipulate variables of the hypothetical options with statistical efficiency (Bonnel *et al.*, 2009). However, often the respondents are not aware of what they would have done in hypothetical cases, so depending on the case there might be a bias, often referred as "hypothetical bias" (Hafeez & Huddart, 2017; Gschwandtner *et al.*, 2021). Since the concepts analysed are not fully available in the network a stated preference experiment is an appropriate method for this experiment.

Having completed the experiment, the examination of the sample characteristics is essential to determine if the sample is representative, reliable, and adequate and if there are dominant scenarios. Finally, the estimation of the simulation results and their analysis are the last steps for the creation of such a model.

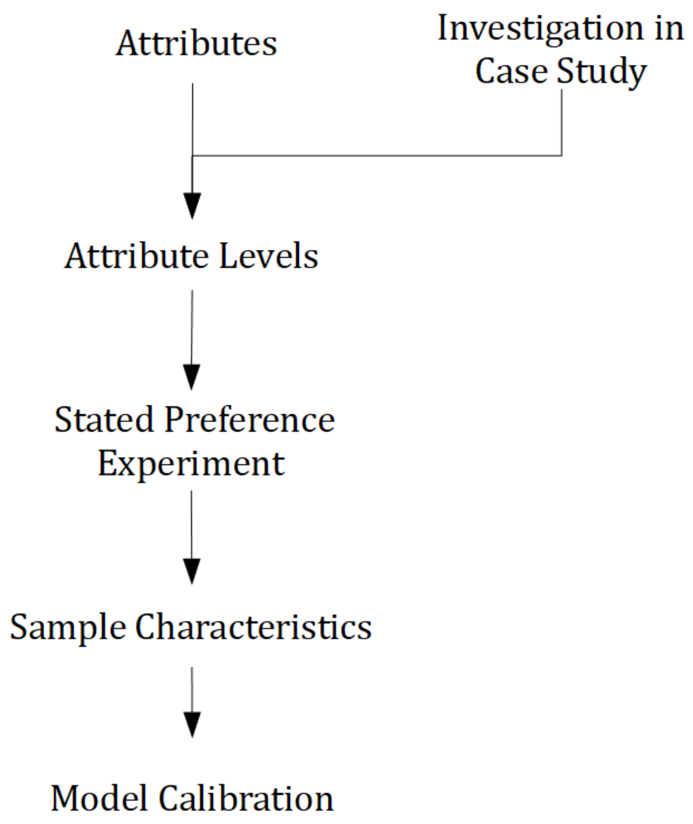


Figure 5.3: Procedure for calibration of the model

The calibrated model is important to be validated by comparing the results of the probabilities with the produced probabilities from the current car ownership model of DELTA in the Business as Usual (BAU) Scenario for the selected case study when the methodology is applied.

Overall, the presented structure is flexible as it allows for change in the generalised costs and in the utility function to incorporate different vehicle types in business models. For example, if the car sharing scheme includes only autonomous cars, namely being an SAV business model, the generalised cost of using autonomous vehicles should be used in the car sharing generalised costs. Also, in the utility function of the choice model the subscription cost would change. Another example is that in case that an option does not exist in an area then the generalised cost will be zero for this business model, and as a result will not be tested in this area. This form allows for many scenarios to be tested, which may include different structures and costs as well as different modes in the business models.

5.3.1.4 Interaction of the scenario

In conclusion, the changes that will happen in DELTA (original form presented in Figure 5.4) are in the transportation module and in the car ownership model that will be changed to the Mobility Investment Model (MIM), as shown in Figure 5.5, which originally shows how all the models of DELTA interact with each other and the elements that are changed are noted in red.

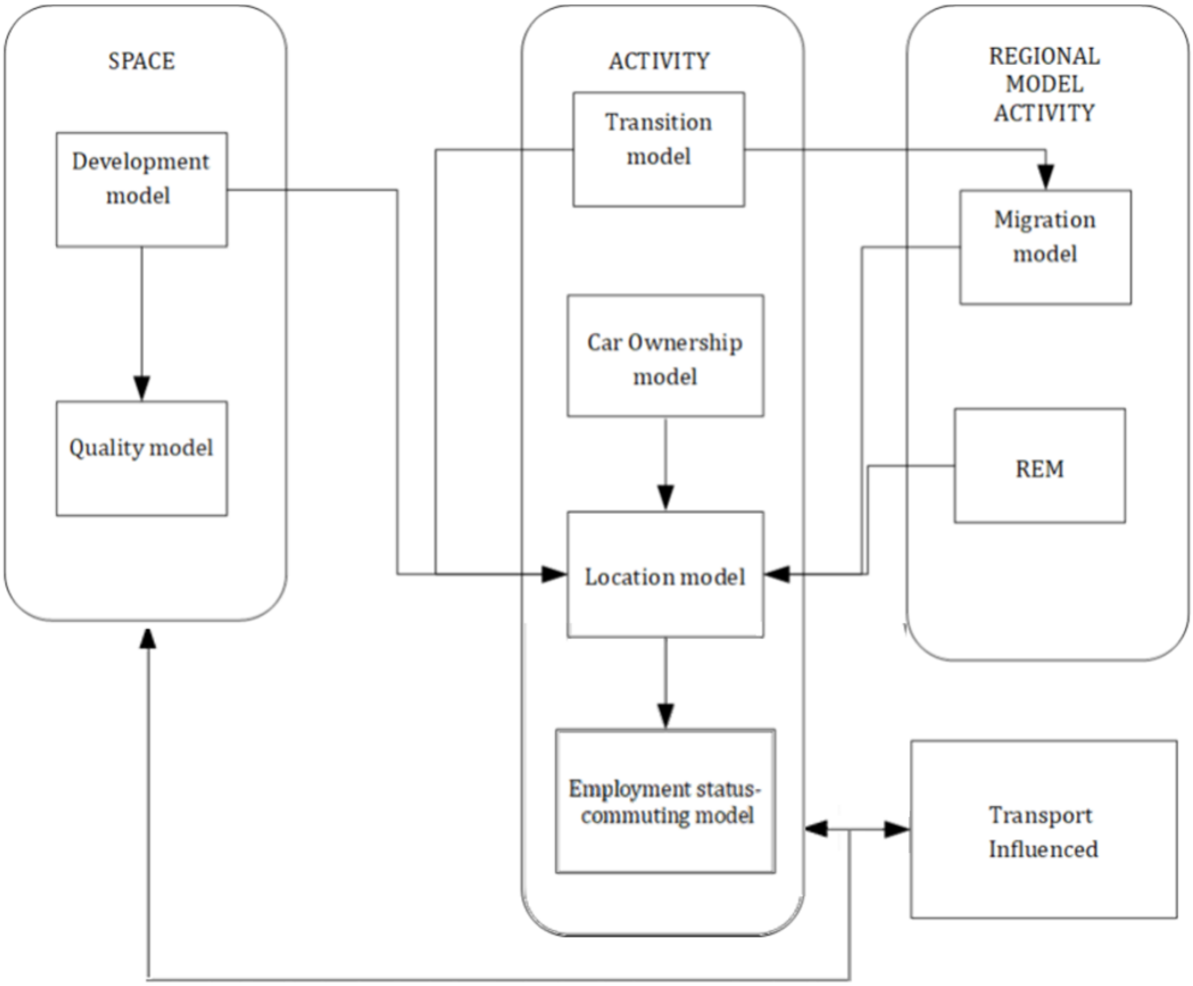


Figure 5.4: Sub-models of DELTA

Source: Adapted from Simmonds & Feldman (2009) and Simmonds et al. (2010)

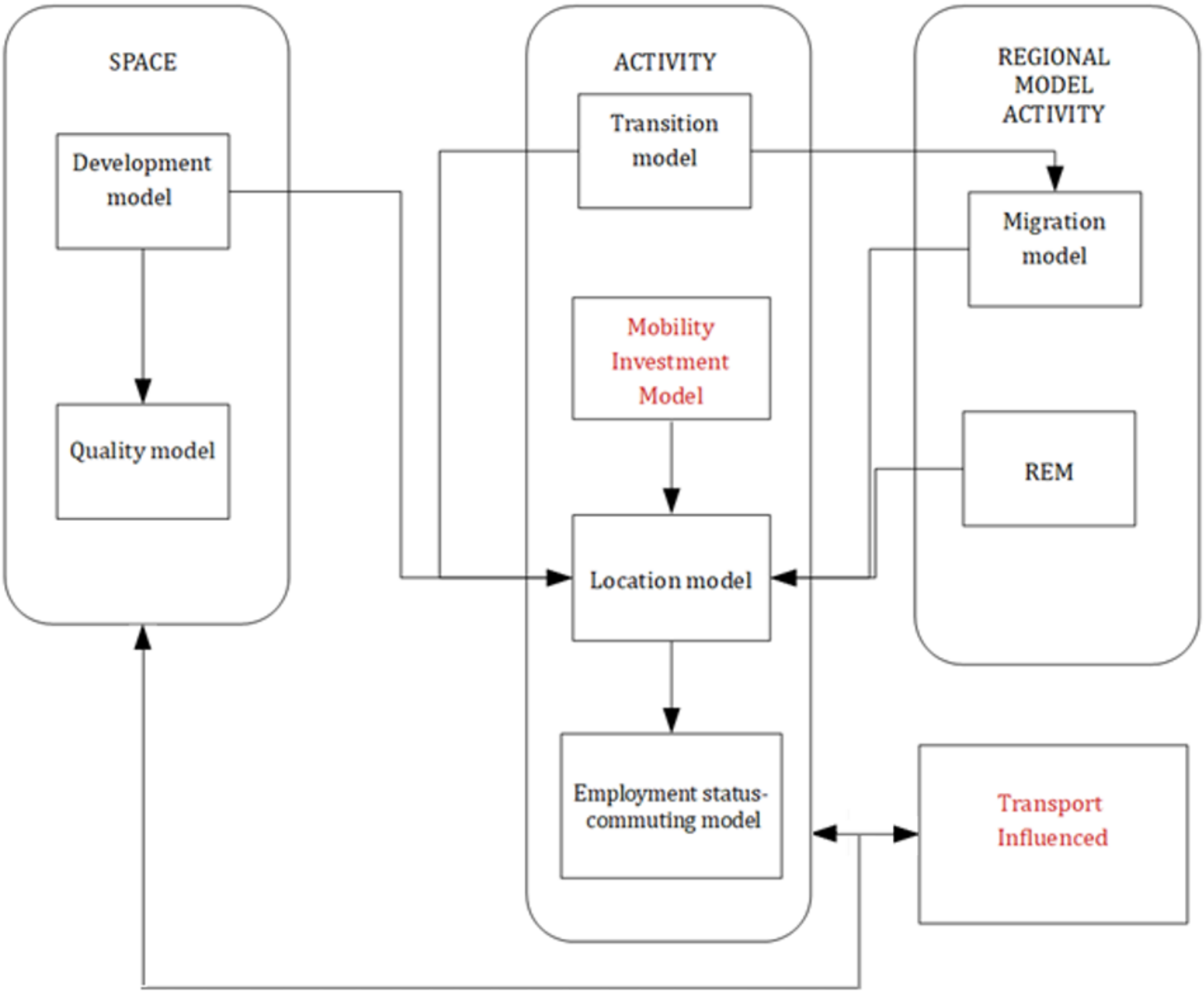


Figure 5.5: Graph of Methodological Changes in DELTA

Source: Adapted from Simmonds & Feldman (2009) and Simmonds et al. (2010)

To implement these changes for multiple simulation years three main elements, need to be added. These are:

1. Inputs with the combinations of proportions of each vehicle technology in the national passenger car fleet, generalised costs, total costs of ownership, trip rates and changes in road capacity for every simulation year.
2. A method before the Mobility Investment Model that gathers all the data from the previous models and structures in a table that has all the variables for the utility function of each alternative
3. The Mobility Investment Model, in which the probabilities of the different car ownership levels are estimated for household type and for each zone.

5.3.1.4.1 Incorporating MIM to DELTA

To incorporate MIM to DELTA a new custom software is created and runs simultaneously with DELTA. The software takes as inputs:

1. The estimated income for household type, zone, simulation year and scenario.
2. The data file that includes the values of the variables of the utility functions for each alternative, which are determined by the modeller.

The outputs of the software are:

1. An updated data file that includes the calculation of the utilities and probabilities of the models
2. Probabilities file: A file that used by DELTA, in which the probabilities produced by the current car ownership model have been replaced with the probabilities produced by MIM
3. Car Ownership Cost file: A file that used by DELTA, in which the estimated car ownership costs is calculated using the probabilities produced by MIM and the cost of owning 1 car.

This procedure is presented in Figure 5.6.

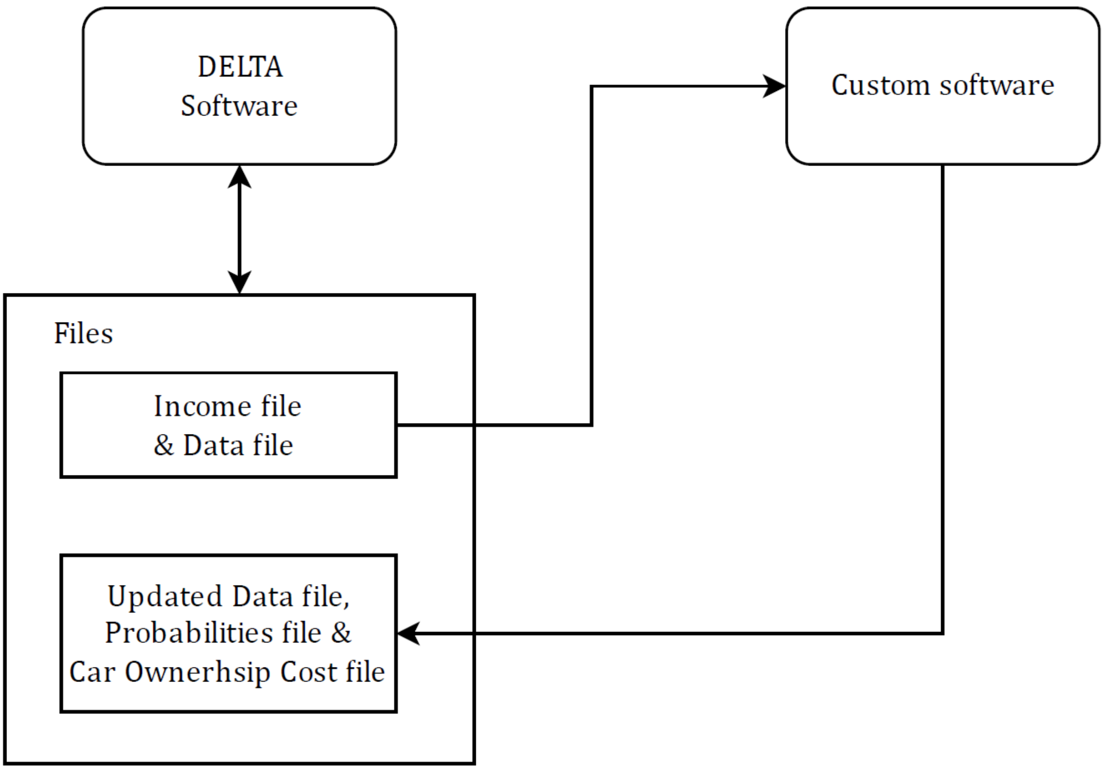


Figure 5.6: Incorporation of MIM to DELTA

The customised software includes three modes. The first mode reads the data and income files and after finding the household types and zones that match, it incorporates the income for each household type q in each zone (Y_q) in the data file and saves it. The flow chart of this mode is presented in Figure 5.7.

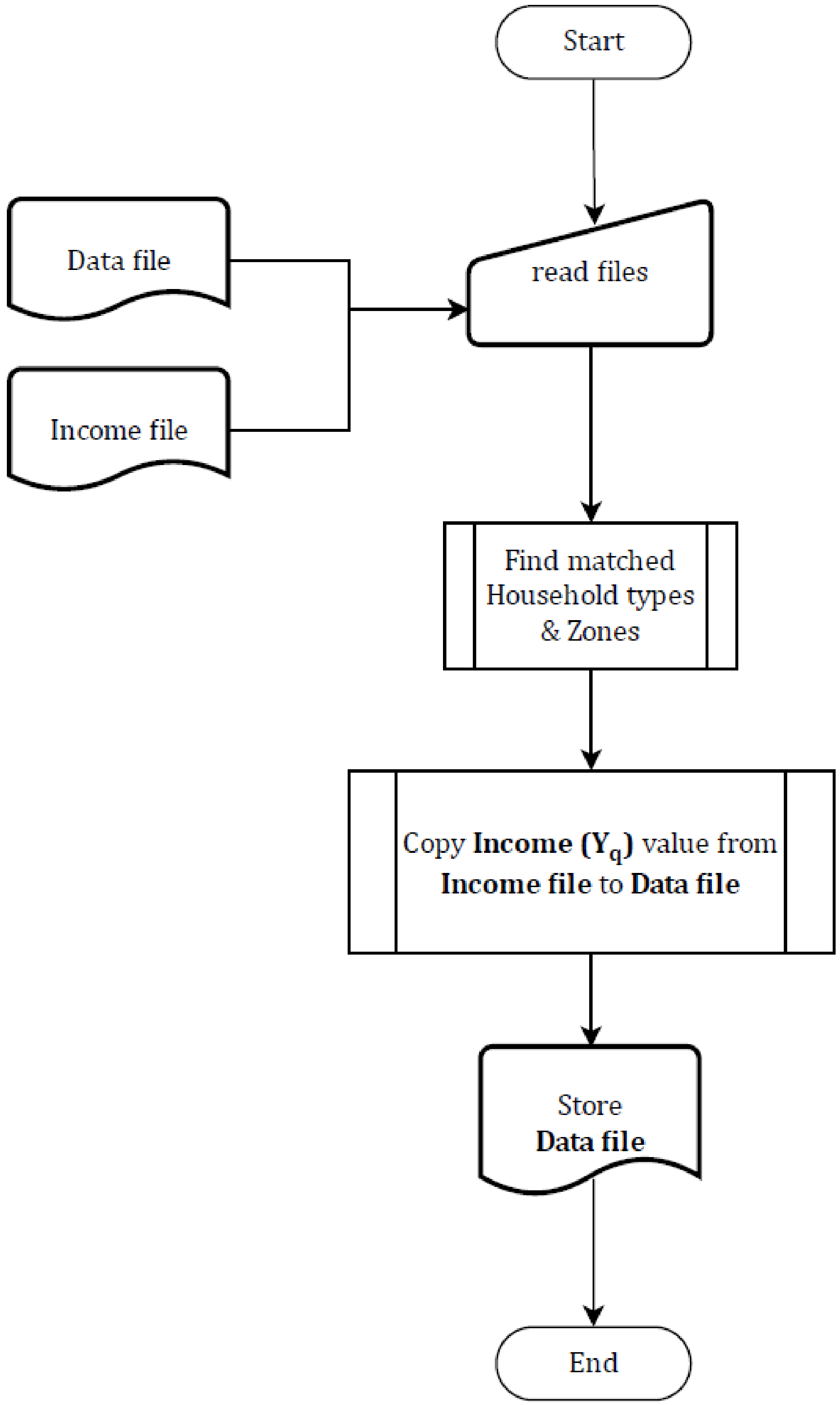


Figure 5.7: Incorporation of MIM to DELTA (mode 1)

The second mode initially reads the updated data file from mode 1, calculates the utilities V_1, V_2 and V_3 of the three alternatives and subsequently estimates probabilities and costs.

$$p_{2|car} = \frac{e^{V_2}}{e^{V_2} + e^{V_3}} \tag{5.17}$$

Where:

$p_{2|car}$: The conditional probability of alternative 2 in the “car” nest of MIM

$$p_{3|car} = \frac{e^{V_3}}{e^{V_2} + e^{V_3}} \tag{5.18}$$

Where:

$p_{3|car}$: The conditional probability of alternative 3 in the “car” nest of MIM

$$carEMU = \lambda_0 * (\log (e^{V_2} + e^{V_3})) \tag{5.19}$$

Where:

$carEMU$: The utility of the “car” nest of MIM

λ_0: The nesting parameter of the “car” nest of MIM ($0 < \lambda_0 \leq 1$)

$$p_1 = \frac{e^{V_1}}{e^{V_1} + e^{carEMU}} \tag{5.20}$$

Where:

p_1: The probability of alternative 1

$$p_2 = p_{2|car} * (\frac{e^{carEMU}}{e^{V_1} + e^{carEMU}}) \tag{5.21}$$

Where:

p_2: The probability of alternative 2

$$p_3 = p_{3|car} * (\frac{e^{carEMU}}{e^{V_1} + e^{carEMU}}) \tag{5.22}$$

Where:

p_3: The probability of alternative 3

$$\text{COCO} = p_2 * TCO + p_3 * TCO \tag{5.23}$$

Where:

COCO: The car ownership cost of a household type q of a zone

The flow chart of this mode is presented in Figure 5.8

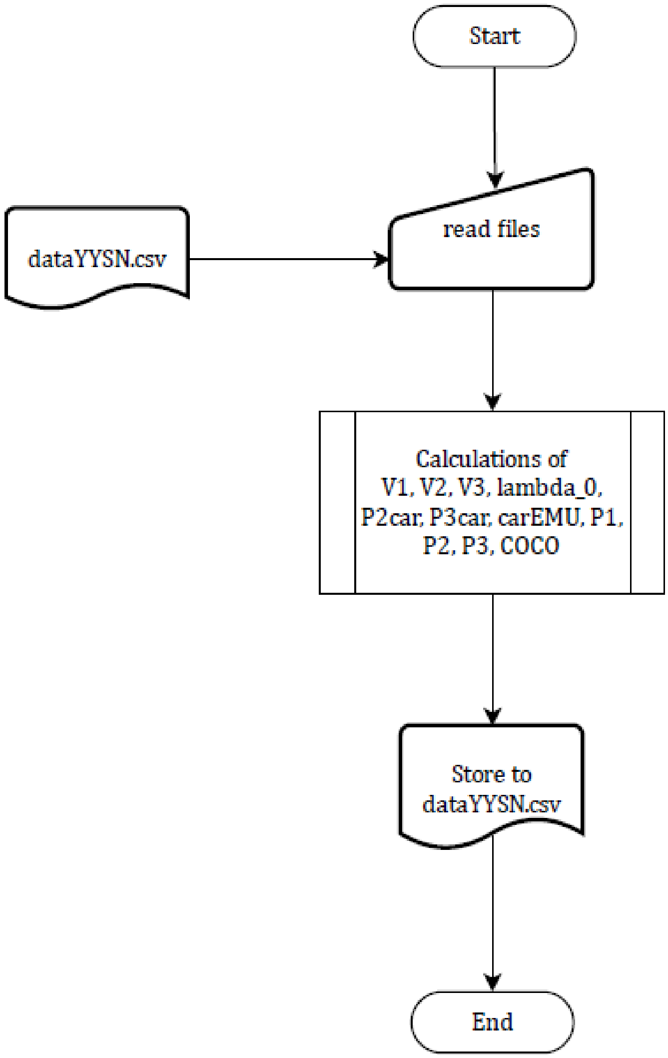


Figure 5.8: Incorporation of MIM to DELTA (mode 2)

The third and final mode of the customised software includes two steps. The first step replaces the estimated probabilities from MIM to the probabilities file from the current car ownership model for the household types and zones of the selected case study area. The second step follows the same procedure, to replace the estimated car ownership cost the household types and zones of the selected case study area.

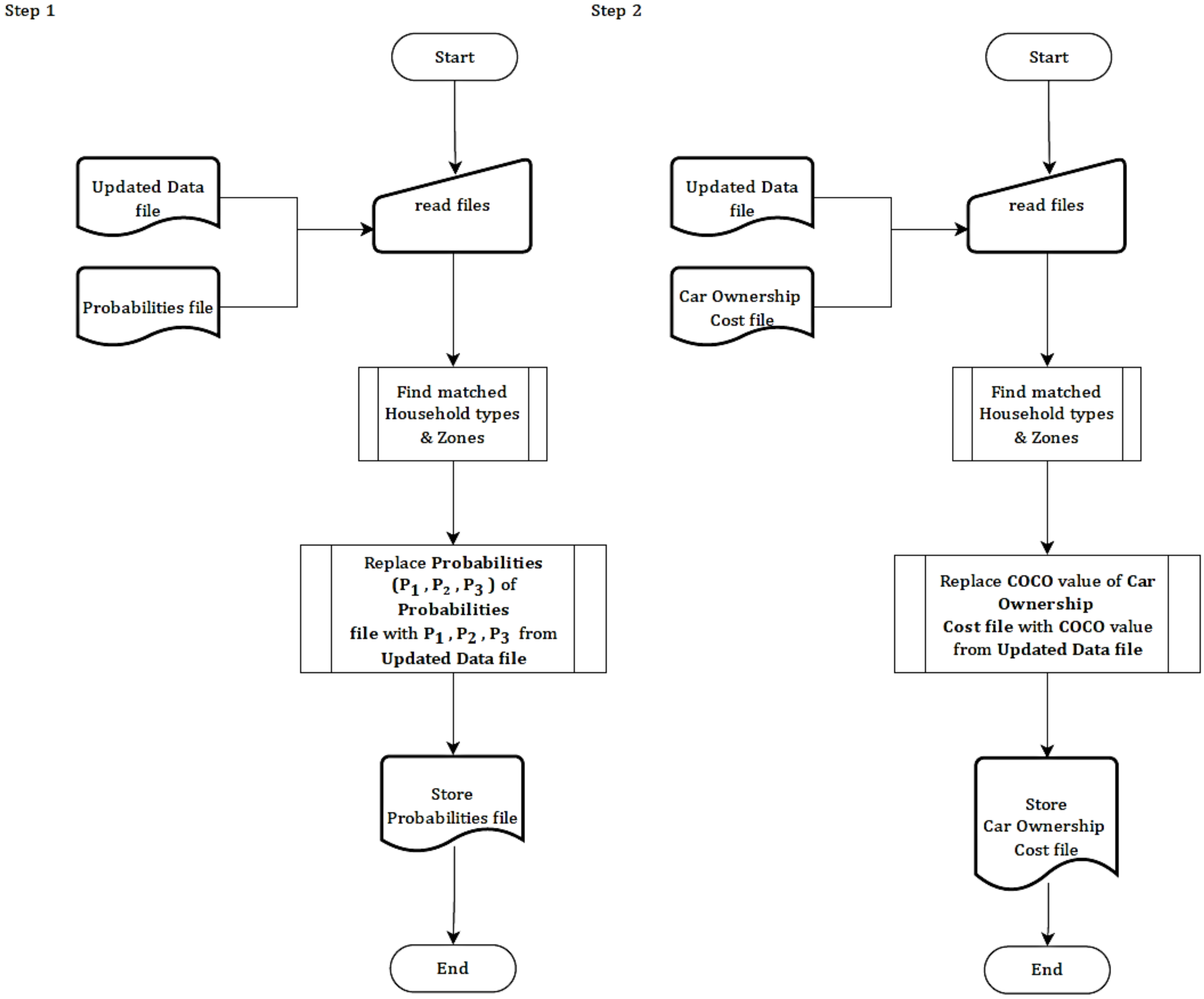


Figure 5.9: Incorporation of MIM to DELTA (mode 3)

Figure 5.10 shows the interaction procedure with the new parameters in DELTA.

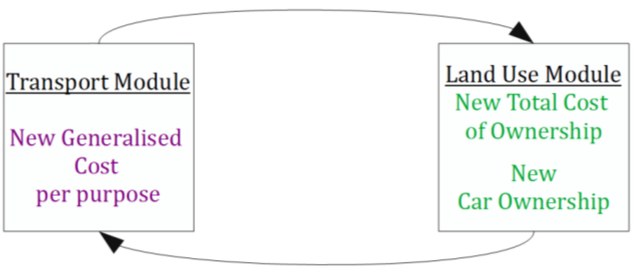


Figure 5.10: Interaction with Changes in DELTA

5.3.1.5 Validation procedure

At this point, to ensure that the model predicts reliable results, a validation is needed as also suggested by (UK Department for Transport, 2014b). Focusing on the concept of validation, according to Bonnel *et al.* (2014) there are many methods of validating a LUTI model. there are:

1. *Validation using the calibration data:* According to this method the model is validated if the there is a match of the model's outputs and the observed values. This has been criticised by Bonnel *et al.* (2014) as a method that does not provide valuable conclusions, since the values that are observed are almost always used for the calibration procedure (Bonnel *et al.*, 2014).
2. *Historical validation:* This is the most frequent method for validating the model, as the model gets calibrated for a year t and then is tested against another simulation year or against another time interval. Even though is highly acceptable, due to data requirements it can be very data demanding (Bonnel *et al.*, 2014).
3. *Uncertainty Analysis:* This method is designed to determine if the data uncertainty is an element also defused in the values of the calibrated parameters (Bonnel *et al.*, 2014).
4. *Sensitivity Analysis:* This form of validation is usually based on different test scenarios (Nicolai *et al.*, 2011), and it is very likely that this kind of analysis is a reliable method as it increases the scientific value of the procedure followed to model as well as the understating of the whole process by the modeller and as a result overcomes the black box effect (Saujot *et al.*, 2016).
5. *Validation by experts:* This procedure usually requires a group of experts in the field such as planning and administrative authorities (Debrezion, Pels and Rietveld, 2006 cited in: Pozoukidou et al. , 2017). One way of implementing this research is by creating a focus group of experts, usually led by one of them (Lane *et al.*, 2001), in order through their interactions to validate the results of a methodology (Aladağ & Işık, 2019). Another method used for the validation by experts is the Delphi method, which is an iterative and systematic method, in which experts keep their anonymity and answer questions to validate the results (Perveen et al., 2019).

From these methods, a combination of two methods has been selected for this research. The first method is "*sensitivity analysis",* as the transportation innovations that are modelled do not exist, thus historical validation could not be an option. Moreover, the "*validation by experts"* approach will be used, in order to receive multiple views by experts in the field on the applied methodology and the final results from the simulation. For such new innovations, being able to understand multidimensionally the results can be a key for the validity of the model.

5.3.1.5.1 Changes in accessibility and trip rates

The aim of conducting the sensitivity analysis is to examine if by simulating scenarios from the literature, which are modelled using different frameworks, inputs and for different case studies, the trends of the results are similar. This can indicate that the applied methodology can provide reliable results.

For the selection of scenarios for the sensitivity analysis, some criteria should be fulfilled in order for them to be deemed appropriate. Firstly, they should include the transportation innovations analysed in this research or at least some of them. As mentioned previously, trip rates and accessibility will be used as parameters for scenarios from the literature, hence the analysis of these scenarios and their conclusions should be conducted by investigations results from trip rates and accessibility, in order to draw conclusions on the validity of the results from the developed modelling methodology in this research project. Finally, since simulation results should have the same trends, it is not required that the modelling frameworks should have the same mathematical background and it is beneficial if results from the selected scenarios have been analysed on different scales of analysis, as this methodology is applicable to different scales.

5.3.1.5.2 Validation by experts

The procedure that will be followed for completing the "validation by experts" approach is the Delphi method. The method was initially developed by RAND corporation and based on the consensus of experts of a scientific field in different questions, the aim was to achieve realistic and reliable results and conclusions (Gupta & Clarke, 1996). The method consists of a structured methodology, and it is generally considered to be a more advanced procedure, comparing to just a data collection mechanism (Williamson *et al.*, 2002). To understand the method even further the two main definitions of the Delphi method are presented:

1. "Delphi may be characterised as a method for structuring a group communication process, so that the process is effective in allowing a group of individuals, as a whole to deal with complex problems" (Linstone & Turoff, 1975).
2. "The Delphi technique of futures research is an attempt to use the science - rather than the art - of prophecy by gathering a consensus of experts' opinions using several rounds of questionnaires or interviews and providing controlled feedback of results between rounds as a means of forecasting

future trends" (Sproull, 1988) . Here it is important to mention that interviews are not a commonly used procedure in the method (Williamson *et al.*, 2002).

A disadvantage of similar methodologies to the Delphi method, used for the "validation by experts" approach, is the limited influence of more experienced and dominant members of a selected focus group to other members (Dalkey, 1969; Perveen, Kamruzzaman & Yigitcanlar, 2017), due to the anonymity of each panellist (Robinson, 1991). Anonymity in the method is essential, as the answers are not in any way personalised, and it is the only way to avoid issues of expression that are present in face-to-face expert groups. The status and the experience of one panellist cannot affect the other panellists, allowing more creative answers and freedom for out of the box opinions (Lilja, Laakso & Palomki, 2011).

Another positive element of the Delphi method is the fact that the methodology is flexible enough to allow for qualitative feedback of the experts but also include a quantitative analysis, which in end provides an in-depth understanding regarding the problem that the method aims to provide answers to (Schoenbaum, McNeil & Kavet, 1976). The procedure includes several different loops, which are implemented until consensus among the experts is reached (Still, 1995b). The flowchart of the procedure is presented in Figure 5.11.

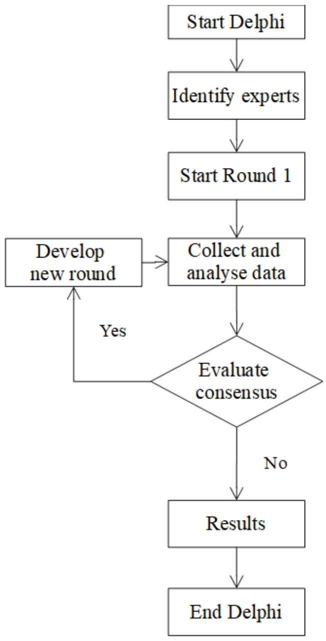


Figure 5.11: The Delphi method

Adapted from: Alaloul, Liew & Zawawi (2016)

The method has been widely used to provide answers to transportation related problems for both passenger and freight (Julsrud & Priya Uteng, 2015; Tapio, 2003). Some examples are presented here:

- The analysis of Hopkins & Schwanen (2023) used the method to determine impacts of CAVs to mobility and resource use for both passenger and freight (Hopkins & Schwanen, 2023).
- The Delphi method was also used to determine future adoption of BEVs in Finland (Nair *et al.*, 2024)
- Regarding car sharing and CAVs, an additional example of the use of the Delphi method includes the analysis of Turoń & Kubik (2020), as in their research the participants were asked to rank the most important economic factors that are influenced by future transportation business models (Turoń & Kubik, 2020).
- Regarding MaaS, which has been a major research topic (Natvig, Stav & Vennesland, 2023) a Delphi experiment was carried out to find characteristics of its early adopters (Jittrapirom *et al.*, 2020).

As a result, the method can be an important tool for this research. The questionnaire in this methodology is based on the scenarios that are formed in the sensitivity analysis and the effects on factors that have been identified in the literature review.

- **Creation of the survey**

The first step of the Delphi method is to determine a list of experts for the experiment, by analysing their profiles. Hence, a set of criteria needed to be adopted and these were retrieved from the analysis of Perveen, Kamruzzaman & Yigitcanlar (2019) and presented here:

1. The experts are expected to be practitioners in the fields related to survey.

3. The experts should work land use, transport, or a combination of the two to achieve sectorial diversity.

2. The experts should be in different locations to achieve geographical diversity.

In total 38 experts were invited to participate to the experiment and, to achieve reliability of the results, their profiles were very carefully analysed. To begin with, 50% of the experts work explicitly in the field of transportation planning and engineering, and the other 50% are mainly experienced in regional and urban planning with some experience in transport as well. Another element that was examined was the percentage of participants working academia and the percentage of participants working in the industry. The concepts presented in this survey are very innovative and thus the goal was to recruit more experts that are occupied in academia, because they are more familiar with the research regarding these innovations. However, the practical perspective from experts in the industry is useful as well. Hence, 74% of the invited experts were from academia and 26% from the industry. The experience of the invited experts was also an important factor that was analysed. Finally, professional experience was also examined for inviting participants. Highly experienced participants, that might have more than 10 years of experience in a field, can provide well justified answers. On the other hand, younger participants have a different perceptive regarding new technologies as they are more familiar with technological innovations (Saxena & Panwar, 2016), and they can provide a different perspective as for example they have different levels of trust in CAVs (Lee *et al.*, 2017). Thus, 43% of the experts had less than 10 years of professional experience and 57% were highly experienced professionals.

The experiment was international inviting professionals from many different counties in Europe and Latin America. More specifically, these countries were the UK, Germany, Finland, Greece, Switzerland, Türkiye, Venezuela, and Brazil. The geographical diversity of the experts provides an important advantage to the experiments, as these countries have different transport systems, policies, economies, and land use systems. Hence, the conclusions from this analysis can be applicable to many different case studies in both the developed and the developing world.

According to Still (1995), the next step is to create and issue a questionnaire to each respondent. Following the example of Perveen, Kamruzzaman & Yigitcanlar (2019) a number of indicators were selected in order to determine the basic structure of the questionnaire, which are presented in Table 5.2. These indicators were selected in order to eliminate a possible degree of uncertainty related to the formulation of the future scenarios and to the results that are expected from simulation. Consistency is important to be ensured in the survey, thus multiple-choice questions were created related to the indicators and as shown by Schuckmann *et al.* (2012) consensus for categorical values is achieved when the probability of occurrence is higher than 50%. This method was followed in this analysis as well for each question. The introductory page of the survey and some of the questions are presented in Figure 5.12 and in Figure 5.13 respectively. The survey received ethics approval from the Faculty Research Ethics Committee (FREC) at the University of Southampton (Ethics/ERGO Number: 76855) and it was initially distributed during the winter of 2022/23.

Table 5.2: Indicators of the Delphi survey

Indicator type	Indicator
Transportation	Value of time
	Road Capacity
	Car ownership Cost
	Car ownership levels
	Total number of trips
	Average trip lengths
	Trip rates
Socioeconomic	Forecasting period
	Possibility of adoption of new transport vehicle technologies and business models
	Spatial distribution of adoption of new transport vehicle technologies and business models
Land Use	Population
	Employment
	Accessibility

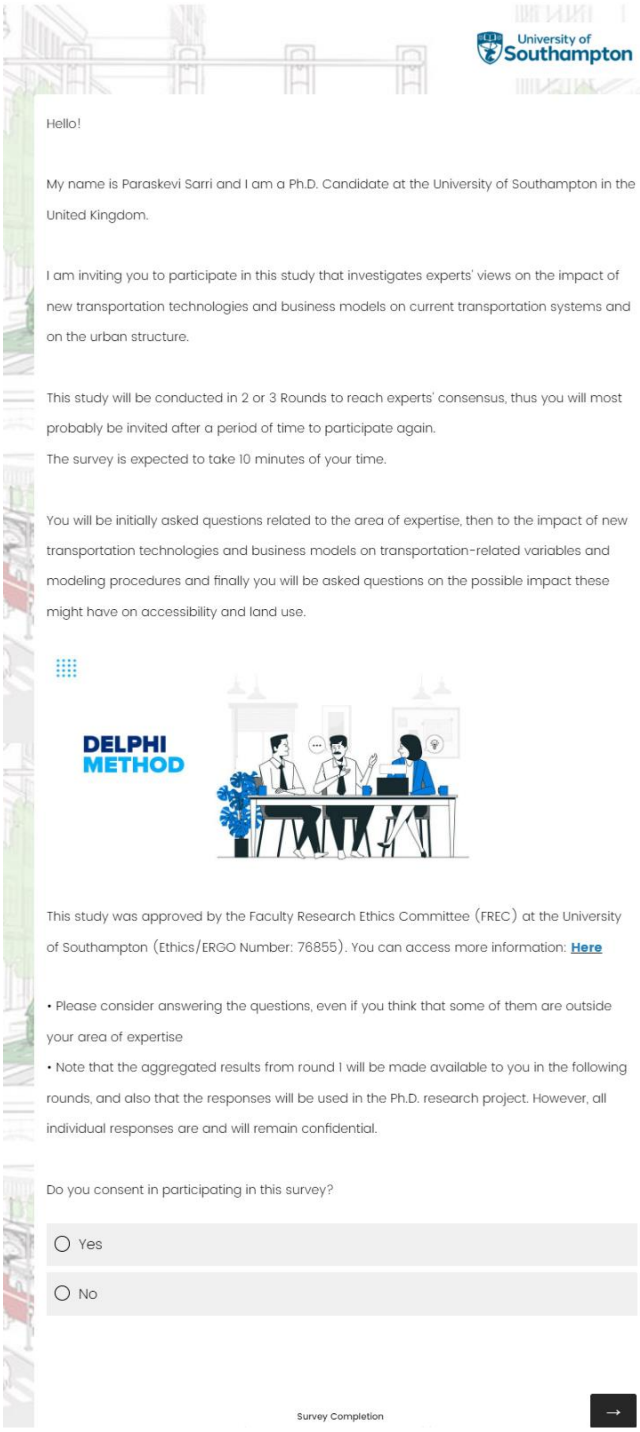


Figure 5.12: Online survey

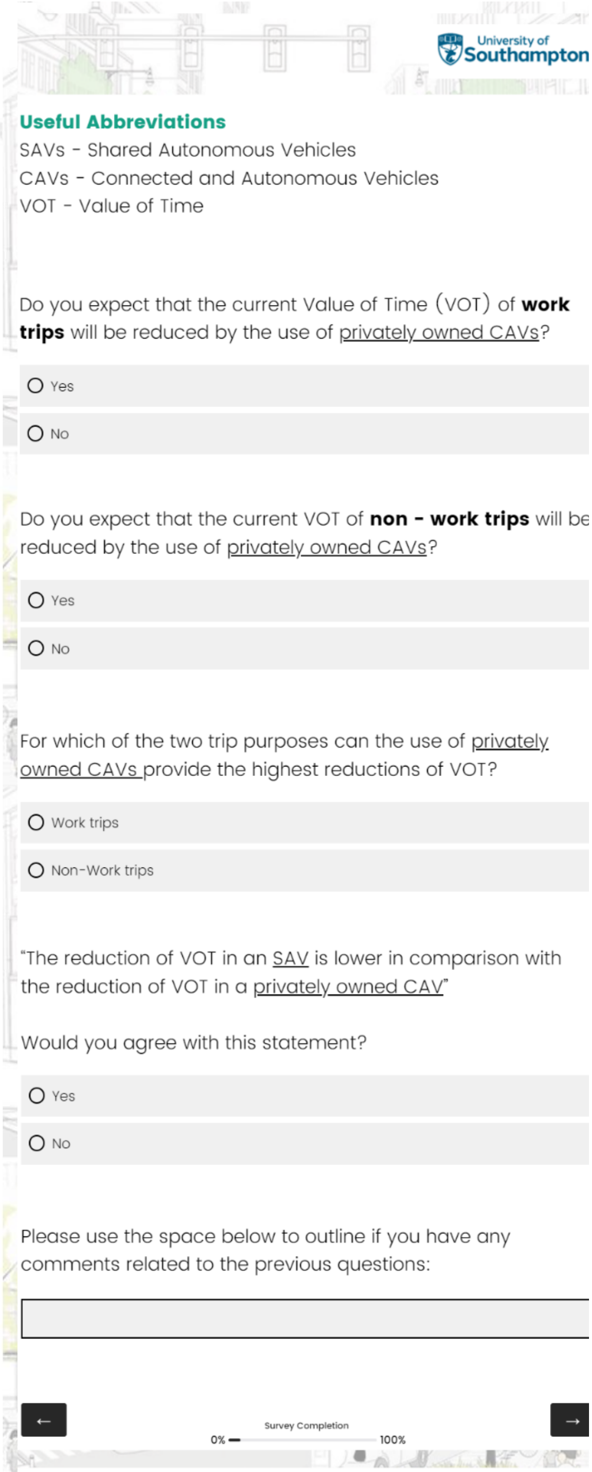


Figure 5.13:Question page

The questions of this survey are generic in order to determine general trends of impacts of new vehicle technologies and business models, from the validation exercise, and not case study specific trends, as these are useful for multiple modelling experiments and case studies.

- **Rounds and results**

The responses were collected and analysed to continue to the second round. In the second and final round respondents were asked to review their answers based on the aggregated results from the first round, in order to reach consensus. Even though the responses were completely anonymous, the respondents were informed in the invitation email and through the inductor page of the survey that the aggregated results and answers from the first round will become known to them in the following rounds. It should be noted that in the first round, respondents could write comments related to the questions and their answers to avoid bias, but this was not an option in the second round, as the aim of the survey was to explore expert's views on the subject but also maintain consistency with the questions. The total number of respondents in the first round were 21 (55% response rate) and 17 in the second round (19% attrition rate), which is expected based on the fact number of participants in the first and second rounds of Sforza & Ortolano (1984); Kiba-Janiak (2016) and Radeljak Kaufmann (2016).

Based on the Results from Round 1 and Round 2 presented in Table 5.3, it can be seen that consensus was reached for almost all questions regarding the indicators from Round 1 and was even higher in Round 2, essentially when the aggregated results from Round 1 were presented to the participants. The two questions for which no consensus was achieved in Round 1 are the following:

1. In which regional areas do you expect higher penetration rates of CAVs (including both private and shared) in the fleet to occur sooner?
2. Given that new vehicle technologies and business models will affect accessibility in the future compared to the accessibility of the BAU Scenario, in which regional areas would you expect the highest differences in accessibility?

Table 5.3: Results of the survey in both rounds.

Question	***Answers***	***Results (Round 1)***	***Results (Round 2)***
Please select your stakeholder category:	Industry	19.05%	17.65%
	Research and Academia	71.43%	82.35%
	Public Authorities	9.52%	0.00%
Please select your areas of work/ research interest: You may choose multiple answers - Selected Choice	Urban and Regional Planning	4.76%	0.00%
	Transportation Planning and Engineering	57.14%	58.82%
	Urban and Regional Planning, Transportation Planning and Engineering	28.57%	35.29%
	Other (Please define in the text block below)	4.76%	0.00%
	Transportation Planning and Engineering, Other (Please define in the text block below)	4.76%	5.88%
Do you expect that the current Value of Time (VOT) of work trips will be reduced by the use of privately owned CAVs?	Yes	85.71%	94.12%
	No	14.29%	5.88%
Do you expect that the current VOT of non - work trips will be reduced by the use of privately owned CAVs?	Yes	66.67%	94.12%
	No	33.33%	5.88%
For which of the two trip purposes can the use of privately owned CAVs provide the highest reductions of VOT?	Work trips	76.19%	94.12%
	Non-Work trips	23.81%	5.88%
The reduction of VOT in an SAV is lower in comparison with the reduction of VOT in a privately owned CAV Would you agree with this statement?	Yes	76.19%	94.12%
	No	23.81%	5.88%
"Forecasting land use and transport effects of new transportation technologies and business models over a 15-year modelling period can provide valuable simulation results" Would you agree that this simulation period can provide adequate results to forecast such effects?	Yes	71.43%	70.59%
	No	28.57%	29.41%
How much do you expect the average penetration of CAVs (including both private and shared) in the fleet to be by 2035 in the UK?	Less than 40%	95.24%	100.00%
	More than 40%	4.76%	0.00%

Question	*Answers*	*Results (Round 1)*	*Results (Round 2)*
It has been observed in the literature that vehicle connectivity may reduce headways. Based on this fact, should planners and modelers anticipate higher road network capacities from the existence vehicle automation in the fleet?	Yes	52.38%	47.06%
	No	47.62%	52.94%
Do you think the statements below are True or False ? - Car Ownership costs of privately owned CAVs are higher than conventional vehicles	TRUE	95.24%	100.00%
	FALSE	4.76%	0.00%
Do you think the statements below are True or False ? - Car Ownership costs of privately owned EVs are higher than conventional vehicles	TRUE	71.43%	94.12%
	FALSE	28.57%	5.88%
Will the existence of CAVs (including both private and shared) in the fleet increase the total number of trips?	Yes	66.67%	88.24%
	No	33.33%	11.76%
Will the existence of CAVs (including both private and shared) in the fleet increase average trip lengths?	Yes	47.62%	58.82%
	No	52.38%	41.18%
Is an increase of trips by children and elderly expected, resulting from the existence of CAVs (including both private and shared) ?	Yes	85.71%	94.12%
	No	14.29%	5.88%
Is an increase of for Zero-occupant Vehicle (ZOV) trips expected, resulting from the existence of CAVs (including both private and shared) ?	Yes	85.71%	100.00%
	No	14.29%	0.00%
Which of the following transportation business models may reduce car ownership? You may choose multiple answers!	Public Transport Subscription Schemes	80.95%	82.35%
	Car Sharing	76.19%	76.47%
	On Demand Transport (i.e. Uber/Lyft)	76.19%	70.59%
	MaaS	80.95%	47.06%
Based on current household needs, would households consider giving up at least 1 of their privately owned vehicles in order to subscribe to one or more new transportation business models?	Yes	71.43%	76.47%
	No	28.57%	23.53%

Question	***Answers***	***Results (Round 1)***	***Results (Round 2)***
"MaaS Packages should be personalized based on market segment characteristics, residential location and working from home" Would you agree with this statement?	Yes	100.00%	100%
	No	0.00%	0.00%
Which of the following can potentially reduce car ownership? You may choose multiple answers!	Increasing car ownership costs	85.71%	94.12%
	Lowering subscription costs for Car sharing or On Demand Transport	71.43%	76.47%
	Lowering subscription costs for MaaS	66.67%	52.94%
	Lowering subscription costs for Public Transportation	57.14%	76.47%
In which regional areas do you expect higher penetration rates of CAVs (including both private and shared) in the fleet to occur sooner?	Central Business Districts (CBDs) of Urban Cores with the highest regional population rates	38.10%	58.82%
	Urban Cores with the highest regional population rates (including CBDs and Suburbs)	28.57%	29.41%
	Rural Areas	9.52%	11.76%
	Remaining Regional Areas	19.05%	0.00%
	None of the above (similar and simultaneous penetration rates regionally)	4.76%	0.00%
Are regions in the UK (e.g. West Midlands) expected to adopt innovative transport business models in the next 15 years?	Yes	95.24%	100.00%
	No	4.76%	0.00%
Are regions in the UK (e.g. West Midlands) expected to adopt new vehicle technologies in the next 15 years?	Yes	76.19%	82.35%
	No	23.81%	17.65%
"Residential location choices may be affected from the increasing rates of people working from home" Would you agree with this statement?	Yes	95.24%	0.00%
	No	4.76%	0.00%
"Employment, retail or working location choices may be affected from the increasing rates of people working from home" Would you agree with this statement?	Yes	95.24%	100.00%
	No	4.76%	0.00%

Question	Answers	Results (Round 1)	Results (Round 2)
"New vehicle technologies and transport business models may increase accessibility to work and services (estimated in generalized minutes) in the future compared to the regional accessibility patterns of the BAU Scenario" Would you agree with this statement?	Yes	95.24%	0.00%
	No	4.76%	0.00%
Which of the following options do you think will influence accessibility the most, if compared to the accessibility patterns of the BAU Scenario?	Transport Business models	38.10%	23.53%
	New Vehicle technologies	9.52%	17.65%
	Both	52.38%	58.82%
Given that new vehicle technologies and business models will affect accessibility in the future compared to the accessibility of the BAU Scenario, in which regional areas would you expect the highest differences in accessibility?	CBDs of Urban Cores with the highest regional population rates	38.10%	35.29%
	Urban outskirts and suburbs	38.10%	52.94%
	Regional areas with the lowest road and rail connectivity	23.81%	11.76%
"New vehicle technologies and business models may increase the total regional population in the future, compared to the future total regional population of the BAU Scenario" Would you agree with this statement?	Yes	57.14%	0.00%
	No	42.86%	0.00%
Do you expect that, in future scenarios that include new vehicle technologies and business models, areas such as, urban outskirts and peripheral regional areas, will attract more population, compared to the spatial distribution of population of the BAU Scenario?	Yes	85.71%	82.35%
	No	14.29%	17.65%
Which of the following market segments is more likely to change residential location, due to the aforementioned innovative transport interventions?	Working Adults	90.48%	100.00%
	Retired Population	9.52%	0.00%
"New vehicle technologies and business models may increase the total regional employment in the future, compared to the future total regional employment of the BAU Scenario" Would you agree with this statement?	Yes	61.90%	0.00%
	No	38.10%	0.00%
Do you expect that the existence of new vehicle technologies and business models will attract employment from peripheral areas outside of the region?	Yes	61.90%	70.59%
	No	38.10%	29.41%

Question	*Answers*	*Results (Round 1)*	*Results (Round 2)*
Given that new vehicle technologies and business models will affect employment rates, in comparison with the future employment rates of the BAU Scenario, what kind of effect do you expect in the areas mentioned below? - CBDs of Urban Cores with the highest regional population rates	Increase	38.10%	17.65%
	Decrease	61.90%	82.35%
Given that new vehicle technologies and business models will affect employment rates, in comparison with the future employment rates of the BAU Scenario, what kind of effect do you expect in the areas mentioned below? - Urban outskirts and suburbs	Increase	90.48%	94.12%
	Decrease	9.52%	5.88%
Given that new vehicle technologies and business models will affect employment rates, in comparison with the future employment rates of the BAU Scenario, what kind of effect do you expect in the areas mentioned below? - Regional areas with the lowest road and rail connectivity	Increase	66.67%	82.35%
	Decrease	33.33%	17.65%

- **Conclusions from the Delphi survey**

The conclusions from the Delphi survey are presented in this section. Of course, these results are not definite as the questions refer to elements that are highly experimental and under research. Moreover, the number of experts could be increased in future research to increase their validity. However, an important advantage is they generally agree with the literature review in Chapter 4 and the probabilities of occurrence when consensus was reached are high, elements that indeed provide a level of trust to the result.

<u>Comments of the experts from Round 1</u>

Based on the answers that participants provided in the first round it concluded that:

1. A 15-year modelling period may provide both adequate or inadequate results, and this is based data availability, forecasting practices as well as the aim of the modelling procedure, for which it should be determined whether it examines short-term, mid-term or long-term land use impacts.

2. If there will be a reduction of headways based on increased road capacity that may occur from vehicle connectivity, attention should be paid to urban road space, as in contradiction with motor ways, vulnerable road users should be given more urban space.
3. The ownership cost of EVs depends on policies (for example subsidies) but also on operation costs related to batteries and the availability of at-home charging facilities in the future.
4. Penetration rates of CAVs depend on economic parameters, as for example higher income households may adopt them sooner and also depend on safety as wider adoption practices may require long transition time.
5. If employment is increased, due to the existence of new vehicle technologies and business models, this may subsequently increase population.

The results from this analysis provide a very interesting perceptive for a number of different variables that influence the future of today's transportation systems and the development of land use in regions and urban cores.

Transportation Related Conclusions

Initially, the answers regarding the indicators related to transport are analysed. Starting with generalised cost, which has already been mentioned that is expected to be affected from new vehicle technologies, the conclusions are indicative of the effect that may be examined. The answers from the experts indicated that CAVs will have lower values of time for different trip purposes comparing to conventional vehicles. An interesting point, that was evident from the answers of the experts, was that the reduction of value of time may be different based on the trip purpose. More specifically, work trips with CAVs compared to conventional vehicles seem to have higher reduction in values of travel time than non-work trips. Moreover, it was also shown that SAVs may also have lower values of time compared to conventional vehicles, however the value of time reduction that is expected from the experts from privately owned CAVs is higher. A very important element regarding this analysis is that the experts were not asked to quantify their answers, as the numerical changes in values of time are different based on the case study, the market segment, and the level of automation (Kolarova *et al.*, 2018; Wadud, 2017; Tajaddini & Vu, 2023). With these conclusions however, a trend on the impacts is evident.

Following, an additional topic that was examined in this research was the impact of new vehicle technologies and transport business models on car ownership. The first conclusions from the responses are that the car ownership costs for both EVs and CAVs can be higher compared to conventional vehicles, which in the long run can lead to lower car ownership levels. Moreover, the majority of the panellists suggest that new transportation business models can have an impact on car ownership. In the experiment, the experts were asked to indicate which of the business models presented could influence car ownership the most and based on their answers the two most influential business models on car ownership were car sharing and on demand transport. Another notable conclusion from the analysis, is that based on the needs of today's households, trading a privately owned vehicle to subscribe to a transport business model is a possibility. Of course, this highly depends on the business model, its price, and its service. Finally, it was noted from the panellists that personalised packages for MaaS, based on the differences of market segments, if members of a household work from home and their residential location, could be an important factor to take into account for making MaaS an attractive transport business model. Hence, the combination of increasing car ownership costs, lowering the subscription costs of transportation business model and improving the services, can contribute significantly to lowering car ownership levels.

New vehicle transportation technologies and business models were examined additionally on their impact on everyday traffic. The responses from the experiment show a tendency of increase in the total number of trips, average trip lengths and trip rates, given the existence of SAVs and privately owned CAVs. An important factor that contributes to this increase, is the increased accessibility to market segments that could not independently ride a vehicles, like the underaged and the elderly, and also zero-occupancy trips. A very interesting topic from this research is the effect of new vehicle technologies on road capacity due to smaller headways, as the experts are still uncertain in this respect.

The examination of penetration rates of CAVs in the fleet was also examined and at this point a case study was selected in order to have a point of reference. The UK has been selected as it is indeed a very interesting case study because it has an advanced transportation system and the adoption of CAVs in the UK is an element that is examined by both the government (UK Department for Transport, 2023b) and by the academic community (Post *et al.*, 2024). The experts agreed on the fact that by 2025 the average penetration of CAVs in the national passenger vehicle fleet is expected to be smaller than 40%. Hence, a 15-year simulation period is reasonable for evaluating land use and transportation impacts from new transportation technologies and business as a number of technological innovations may be implemented in the future that currently may not be considered or known adequately enough.

Land Use Related Conclusions

Regarding land use, the first examined element is the future allocation of higher CAVs adoption rates at a regional and urban scale of analysis. Based on the gathered responses, it is expected that residents of CBDs are more likely to adopt CAVs earlier comparing with remote regional areas. Moreover, an additional factor to new transportation innovations that can affect many different land use sectors such as employment, residential location and working location choices is increasing rates of people working from home.

Furthermore, based on the answers of the experts it is expected that new vehicle technologies and business models may increase the total regional population in the future and can attract more population in urban outskirts and peripheral regional areas. Finally, it was noted in the survey that working adults is more likely to change residential location comparing to retired population, due to the aforementioned innovative transport interventions. Another important element that was concluded was that new vehicle technologies and business models may increase the total regional employment in the future. Moreover, given that new vehicle technologies and business models will affect employment rates, CBDs of urban cores with the highest regional population rates will have decreased employment rates, which may not be the case in other regional areas. It should also be mentioned that from the results of the survey it was concluded that new vehicle technologies and transport business models may increase accessibility to work and services in the future, with the highest differences in accessibility to be expected in urban outskirts and suburbs.

5.4 Software and data sources

To execute the methodological procedure described there are tools that are expected to be used, and these are software and data.

Table 5.4: Software Requirements

Type of Software	**Examples**
LUTI Model	DELTA, TRANUS, URBANSIM
Application Programming Interface (API)	Whim API, Directions API
Command Line Interpreter	Command Prompt
Word Processor	Microsoft Word
Spreadsheets	Microsoft Excel
Package/ Library for Discrete Choice Analysis	Pandas Biogeme, NLOGIT, Apollo
Integrated Development Environment (IDE) For Coding	Spyder
Geographic Information System	ArcGIS, QGIS
Geographic Information System Extensions Related to Transport Analysis	Network Analyst (ArcGIS) Travel Time (QGIS)
Web Browser	Google Chrome, Internet Explorer
Reference Manager	Mendeley, EndNote
Simple Text Editor	TextPad, NotePad
Online survey tools	Qualtrics, I-Survey, Microsoft forms
Statistical analysis software	SPSS, JMP

A number of different data sources are essential for implementing the aforementioned methodology. These are listed analytically here:

- LUTI application model

To apply the methodology presented and test different scenarios, an application model is important. A LUTI application model, which consists of several years of modelling, as well as the licence for the software of DELTA was supplied by the David Simmonds Consultancy Ltd.

- UK central government, local authorities, and public and private bodies

This data source is also main source for the implementation of this project. More specifically data that should be obtained, are:

1. Values that refer to in the transport analysis guidance (namely WebTAG). e.g. (UK Department of Transport, 2020)
2. Subsidies and grants for new vehicle technologies e.g. (data.gov.uk, 2020b)
3. Annual Mileage data e.g. (data.gov.uk, 2020d)
4. Maintenance Cost and Vehicle Insurance Data e.g. (data.gov.uk, 2020a)
5. Vehicle tax Data e.g. (data.gov.uk, 2020e)
6. Fleet Forecasts e.g. (data.gov.uk, 2020c; National Atmospheric Emissions Inventory, 2019)
7. Costs of different transport subscription schemes (Uber, 2022; co-wheels.org.uk, 2022; Swift, 2022)

- Vehicle Purchase prices and model specifications

For the estimation of Total Costs of Ownership, the initial purchase price and the vehicle efficiencies should be determined. The first step is to identify the models and following this data for these two variables should be obtained by the companies of the car models selected. For example, some sources would be Nissan UK (2020), Toyota UK (2020) and Ford (2020). Such data are free and available online.

5.5 Conclusions

The methodology presented in this chapter is a demonstration of incorporating new vehicle technologies and business models in DELTA. Figure 5.14 is a graphical representation the whole methodology.

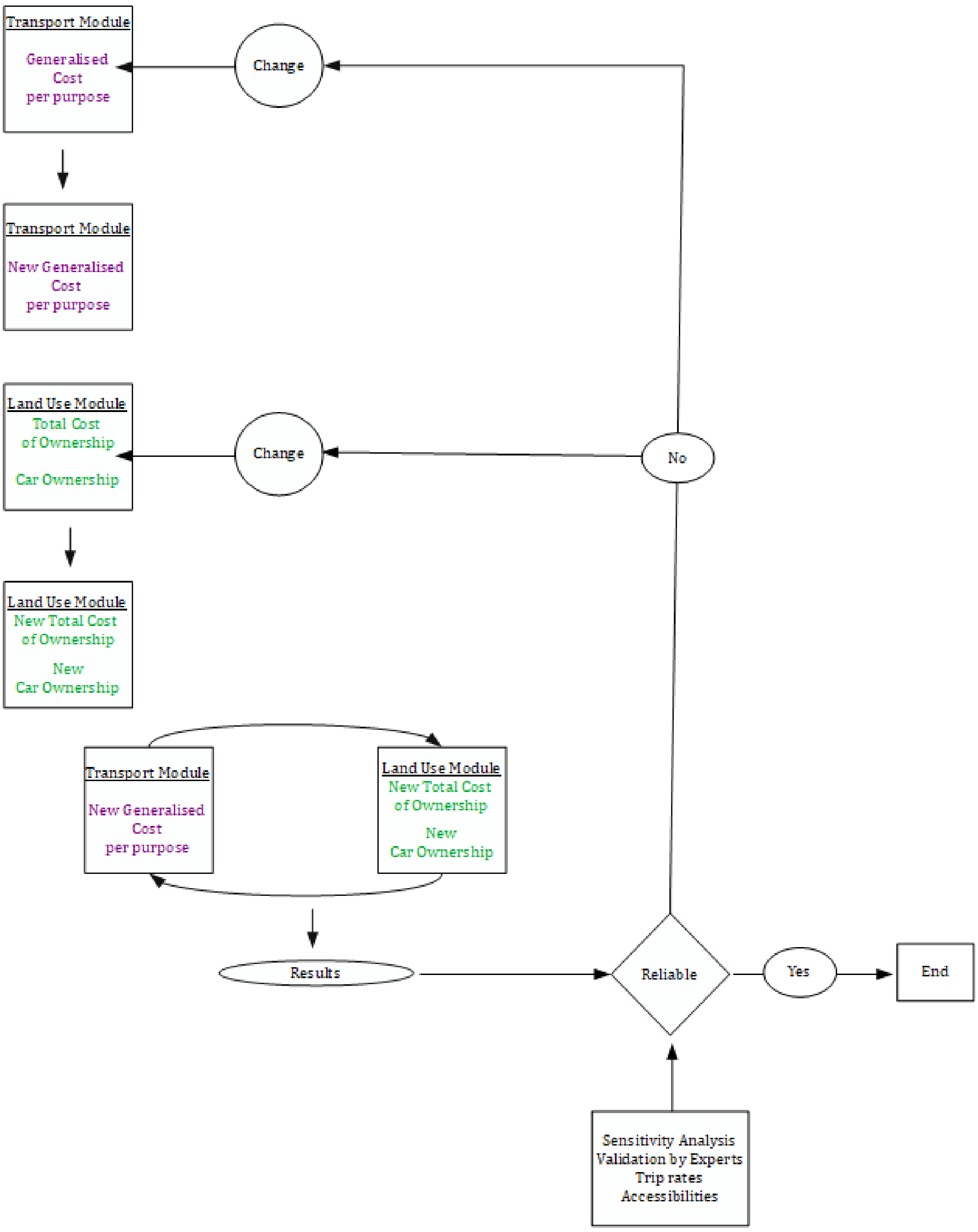


Figure 5.14: Graphical representation of the developed methodology

Understanding the results of the model is the key for the final conclusions. Maps of differences in land use and accessibility and timeseries of the estimated results are essential to finally conclude on the effects that new transportation innovations have on land use.

The methodology needs to be modified based on the LUTI model selected and the technologies which are modelled. This is expected, because all LUTI models have a different mathematical structure and are based on different scientific principles, thus it is not feasible to create one methodology that would be applicable to all LUTI models, for all transport innovations and for all case studies. However, the rationale behind this methodology is universal and can be applied to all models, for all innovations and for all case studies.

Essentially the procedure presented here includes sequence of exercises that need to be conducted. Initially, the elements and models of the LUTI model that are affected from the incorporation of new transport innovations are identified from the literature. Subsequently, appropriate methods and quantitative values are used to alter the elements identified previously in the current land use and transport modules of a LUTI model. Having completed this procedure, the simulation should be compiled over a modelling time period. Finally, by identifying and applying appropriate validation methodologies, the results are evaluated and subsequently the procedure is either complete or parts of it need to be conducted again to have validated results.

Hence, this procedure is not based on a LUTI model, can be used for a number of different innovations and it is not case study specific. For example, if DELTA was used to simulate the same technologies and business models in two different case studies, values of time, vehicle operating costs, proportions of vehicle technologies in the fleet, total costs of ownership and the calibration of MIM would need to be implemented separately for each case study. Another example is the case of using two different LUTI models to simulate the same technologies and business models in the same case study. In this case, the elements shown in this chapter would need to be taken into account as they belong to most LUTI models, which is shown in Table 4.1, however it is advised that this procedure should be conducted from the beginning to identify elements now presented here.

Chapter 6 Applying the Methodology

In this chapter the methodology principles previously described are applied to a selected case study. The purpose is to demonstrate the application procedure and to complete the simulation in order to produce results that aim to answer the main research question, which is "how can new transportation vehicle technologies and new business models affect the spatial pattern of land uses and activities?." Initially, the selected case study and the reasons for selecting it are presented and, following this, the possible future scenarios are formulated. Subsequently, the estimation procedure of inputs such as generalised costs, proportions of technologies and total costs of ownership is examined. Moreover, MIM is calibrated for the selected case study and incorporated in DELTA. Finally, the methodology is validated for the selected case study by conducting the sensitivity analysis and by examining its procedure with the conclusions derived from the validation by experts.

6.1 Choice of modelling area and scenarios

West Midlands is the region in the UK that has been selected for this research. The region borders with Wales as well as with the South West, South East, East Midlands and North West regions of England. The urban areas of the highest importance in the region are Birmingham and Coventry (Medland, 2012). The location of the West Midlands region is illustrated in Figure 6.1.

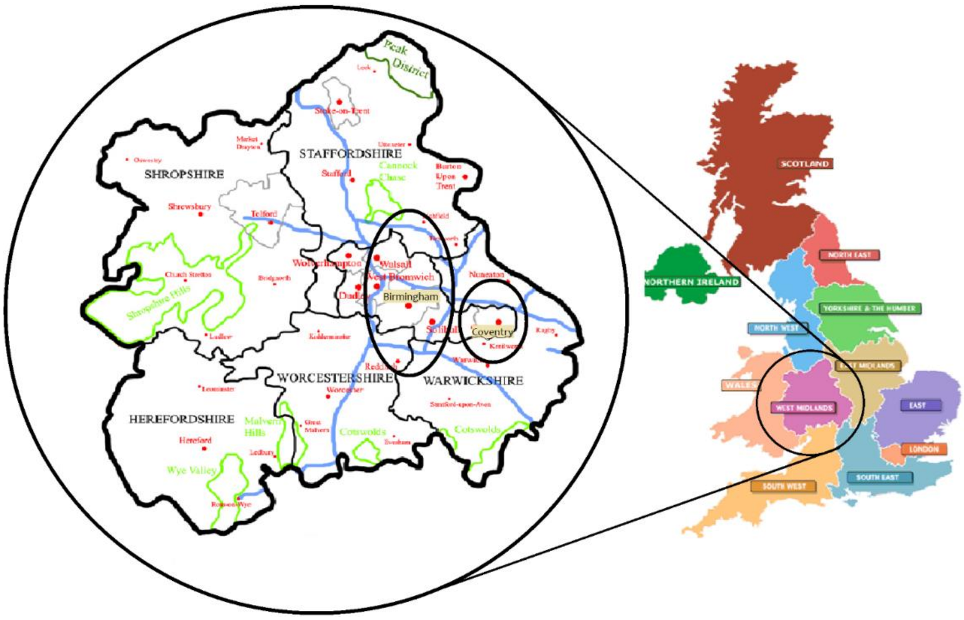


Figure 6.1: The region of West Midlands (UK)

Source: Adapted from wikiwand.com (2021)

Analysing explanatory variables (population, employment, and income) are essential to be included in urban and regional analysis for understanding characteristics and spatial heterogeneity in depth (Mason, Pearce & Cummins, 2021). The region has total population that exceeds 5 million people. It consists of six counties in total, the distribution of population in each county is shown in Table 6.1 and The GDHI (Gross Disposable Household Income)/ person surpasses £15,000/year, which is shown in Figure 6.2.

Table 6.1: Population in counties of the West Midlands region

West Midlands Region	Population
Herefordshire	187,100
Shropshire	509,200
Staffordshire	1,134,500
Warwickshire	596,800
West Midlands (Metropolitan County)	2,919,600
Worcestershire	603,600

Source: Adapted from UK Office for National Statistics (2021)

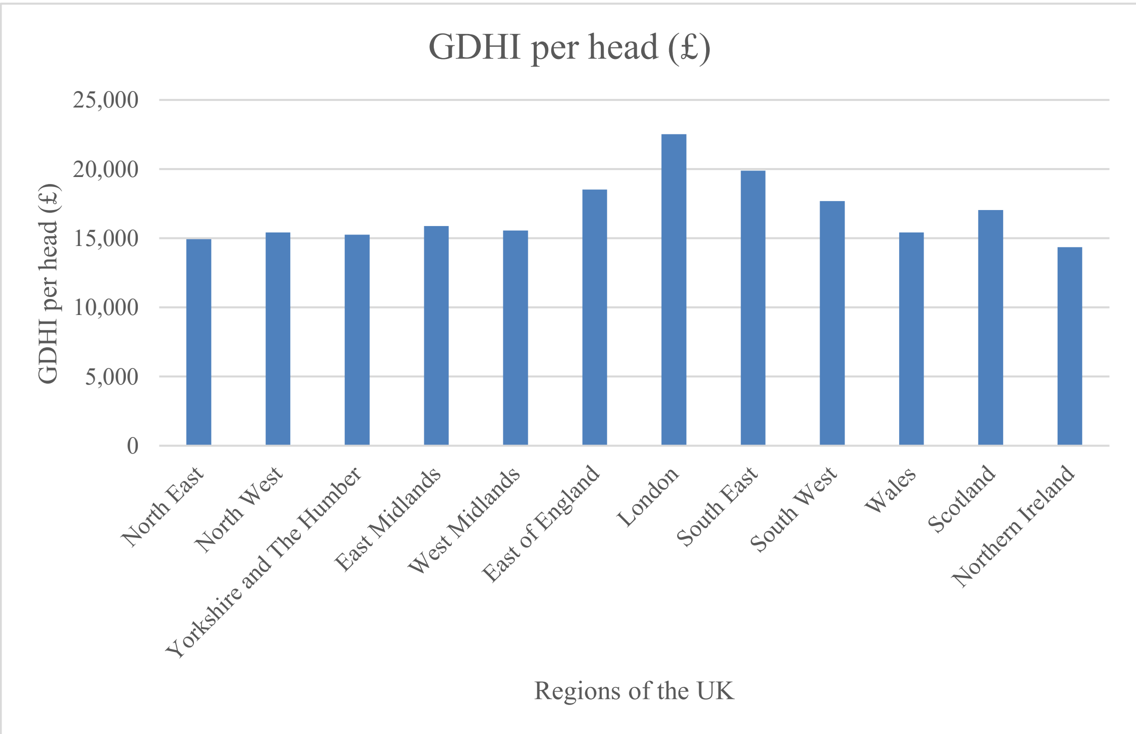


Figure 6.2: GDHI per person in the UK (£)

Source: Adapted from UK Office for National Statistics (2021)

Regarding employment, based on the latest UK census (UK Office for National Statistics, 2021), the trends indicate that the total number of working population has been increasing since 2002, as shown in Figure 6.3

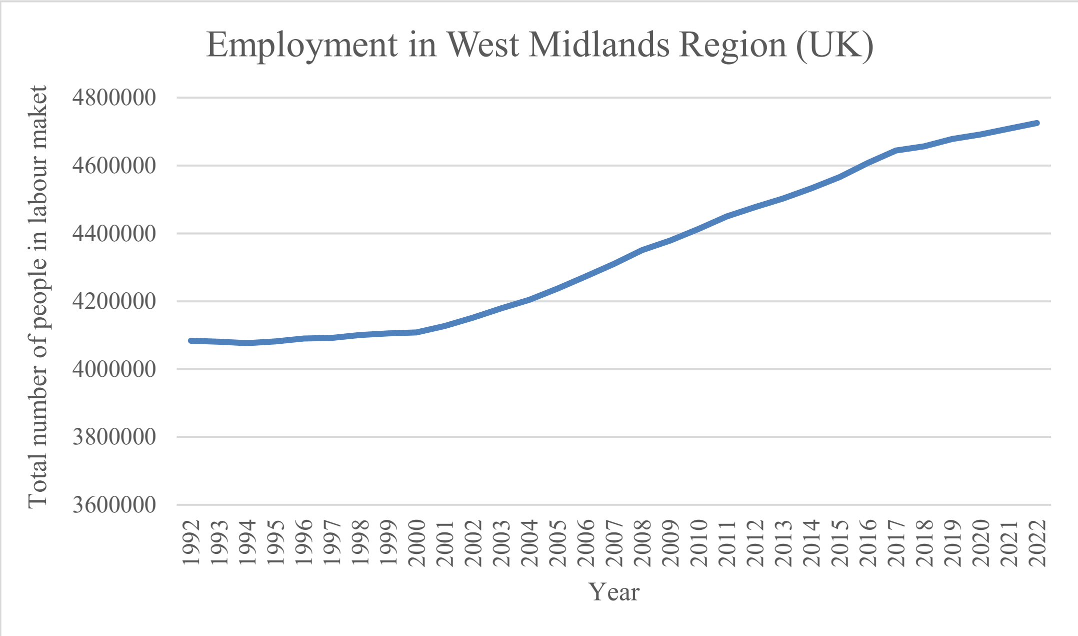


Figure 6.3: Employment trends in West Midlands (UK)

Source: Adapted from UK Office for National Statistics (2021)

Overall, the region is well connected, as it is served by a road network that is advanced and includes main highways such as, the M6, which connects West Midlands with the North West region, the M5, through which the South West region can be accessed and the A5, which connects southeast with northwest parts of the region (UK National Highways, 2022). Furthermore, the region includes a railway network that has major stations in its cities and creates links with the rest of the UK (NetworkRail, 2022). It is very important to note that under the HS2 project, plans regarding implementation and operation of high-speed rail have been conducted (UK National Highways, 2022). The density of both the road and railway networks is high in the east of West Midlands, comparing it with the west and north (UK National Highways, 2022; NetworkRail, 2022). This phenomenon affects accessibility with other regions. Finally, Birmingham has an international airport, which on average has more than 9 million passengers every year and there are direct flights with 180 destinations worldwide (Medland, 2012).

While the region is mainly served by bus services in its urban areas, urban public transport is more advanced in the West Midlands County, which has bus services and light rail (Transport for West

Midlands Combined Authority, 2021; PLUSBUS, 2022). Depending on the characteristics of the transportation system of each city in the region, the modal shares have differences. For example, in Birmingham for AM peak trips the modal share is 0.8% cycle, 1.7% heavy vehicles, 4.6% light vehicles, 41.2% car and 51.7% public transport and in Coventry it is 0.8% cycle, 1.9% heavy vehicles, 9.5% light vehicle trips, 16.6% for public transport and 71.2% car (Transport for West Midlands Combined Authority, 2021).

The case study consists of different land uses and has different geographical and spatial characteristics. For example, in this analysis of Owen *et al.* (2006), which is a land classification utilising the method of principal component and cluster analysis, the West Midlands County comprises of eight urban land-cover classes, as shown in Figure 6.4. Thus, introducing new vehicle technologies and business models in West Midlands, makes it feasible to evaluate effects on accessibility and land use in a variety of spatial cores, with different characteristics. These conclusions could be essential for developing sustainable policies of urban mobility. Moreover, because of its location, results from this analysis are important for other regions in the UK, however, regions of similar structure around the world could benefit from the outcome of this analysis. Ruhr in Germany is an example, as it has and advanced transport a network, consists of several urban cores and its rates on population and employment are similar with those of the West Midlands region (De Ridder *et al.*, 2008). As a result, the transferability of conclusions from this case study is an important factor that led to selecting it. Finally, it should be noted that, that results and conclusions from this research will be essential to transport practitioners, as there is a high interest of investors in transport industry for the region (Brand, Hill & Munday, 2000)

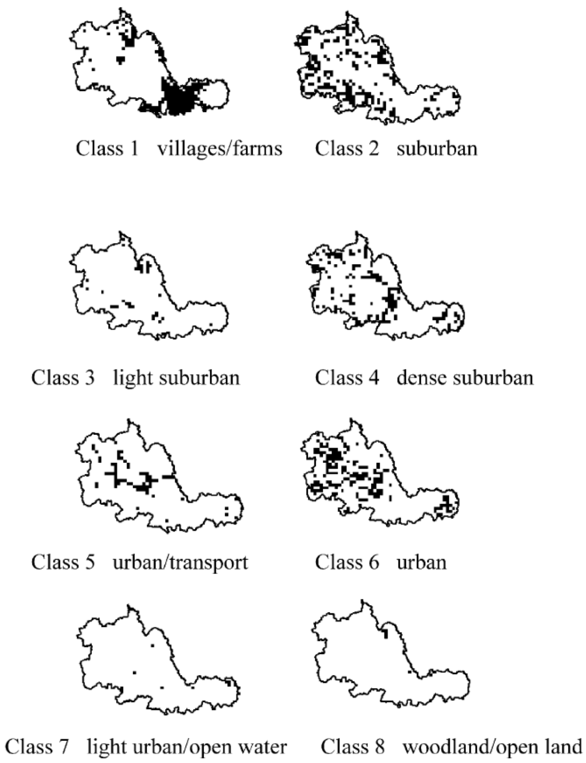


Figure 6.4: Spatial distribution of classes in the metropolitan area of West Midlands

Source: Adapted from Owen *et al.*, (2006)

6.2 Formulation of future scenarios

The scenarios compared in this analysis is the Business as Usual (BAU) scenario and four future scenarios for the region and the results were forecasted for a 15-year simulation period. In all future scenarios it is assumed that there is an adoption of private CAVs and EVs, as well as an incorporation of transportation business models in the transportation system. The first two scenarios, namely F1 and F2, test the case of the adoption rates of new vehicle technologies being the same in all zones of the region. On the other hand, in scenarios F3 and F4, the adoption rates of new vehicle technologies in the fleet are higher in the CBDs in comparison to other areas in the region. Even though it is expected that adoption rates of new technologies vary spatially, as mentioned by Bansal (2015), the examination of the impacts on land use from the different spatial adoption rates of new vehicle technologies has not been yet examined in depth. Most analyses assume a universal adoption rate of CAVs and EVs in the fleet, including May *et al.* (2020), Cordera *et al.* (2021), Luo *et al.* (2019), Nahmias-Biran *et al.*(2020) and Emberger & Pfaffenbichler (2020). Thus, including this parameter as well in the scenario formulation could provide higher level of understanding of the impacts and more in-depth conclusions.

It should also be noted that working from home is expected to influence land use patterns, as shown in the analyses, Beck and Hensher (2021) and Hensher *et al.* (2024) and presented in the conclusions of concluded in the Delphi survey. Hence, in scenarios F1 and F3 there is no increase in working from home through the simulation period and in scenarios F2 and F4, an increase of 30% of people working from home is assumed, which was the percentage of people working from home during the COVID19 quarantine in 2020 (UK Office for National Statistics, 2020). This formulation of scenarios essentially considers the existence of new vehicle technologies and business models in different circumstances, in a way that has not been researched in the literature. As a result, by examining all of them, more in-depth results can be derived and differentiations among scenarios could lead to valuable conclusions.

The procedure followed is the one described in Chapter 5 for modelling new vehicles technologies and business models. This methodology includes calibration of the inputs and MIM for West Midlands and validation based on the results of the sensitivity analysis and the conclusions from the Delphi survey.

Table 6.2: Future modelling scenarios of new vehicle technologies

Future Scenario name	**Higher adoption rates of CAVs and EVs in the fleet in the CBDs**	**Same adoption rates of CAVs and EVs in the fleet across region**	**Higher rates of people working from home**
F1		✓	
F2		✓	✓
F3	✓		
F4	✓		✓

6.3 Proportions of each vehicle technology

The proportions of different vehicle technologies in the fleet are important to be found for the incorporation of new vehicle technologies in the transportation system. However, there is a high degree of uncertainty in respect to such predictions, as they have not been predicted from a governmental source. For this reason, the forecasts from Atkins (2016); KPMG (2019); SMMT (2020) and Statista (2019) were compared until the end of the simulation period to distinguish if those predictions had similar results. From this analysis it was found that by 2035 the highest penetration rate of CAVs in the fleet belongs in a range from 30% to 40%, and the lowest penetration rate is up to 15%. For EVs, on the other hand, the UK Department for Transport (2021b) had predicted penetration rates in the fleet of 24.2% until 2035. This proportion has its basis on the objectives of the UK Transportation Decarbonation Plan, based on which the sale of conventional vehicles will be banned by 2030 (UK Department of Transport, 2020a). This percentage (24.2%) of EVs is used for the modelling procedure.

For the reasons previously presented two cases are examined. The first examines a 15% penetration rate of CAVs in the fleet for all spatial units of analysis by 2035 and the second, includes a percentage of 35% penetration rate of CAVs in the CBDs of the regional urban cores, while maintaining 15% in the other zones of the region.

As a result, based on the characteristics of the vehicle technologies, four categories were distinguished, which are used for the analysis of the scenarios. These categories are:

- Low level autonomous vehicles electric (Low-electric)
- Low level autonomous vehicles non- electric (Low-non electric)
- High level autonomous vehicles electric (High-electric)
- High level autonomous vehicles non-electric (High-non electric)

6.4 Changes in network capacity

As already mentioned, a reduction in the PCU factor by 20% or 30% could be beneficial for simulating the effect of vehicle connectivity. On the other hand, there are attempts in the literature to simulate such technologies and this effect from connectivity is not included, as for example in the analysis of Thakur, Kinghorn & Grace (2016). It could be expected that because of the small proportion of new vehicle technologies in the fleet, the PCU values may not be affected. However, improved traffic control of CAVs can increase capacity even with penetration rates in the fleet of 10%, as mentioned by Rafter (2020). As a result, the incorporation of this effect on capacity can provide insightful results relative to accessibility and land use and for this reason a 0.8 PCU factor is adopted for this analysis.

6.5 Generalised costs of new vehicle technologies

The procedure to estimate generalised costs was analysed in 5.3.1.3 and since the breakdown of vehicle technologies in the fleet is included in 6.3, this section includes details for the elements that need to be estimated to follow the procedure of 5.3.1.3. More specifically, analysis is conducted for the estimated time and distance from each origin to each destination, the vehicle operating costs and the value of time.

6.5.1 Time and distance from origins to destinations

The first step for estimating the generalised cost is to estimate the travel distances and travel times using the road network of the study area. For this reason, the Network Analyst of ArcGIS Pro was used, which uses an online network dataset stored in the ArcGIS Online cloud (ArcGIS Pro, 2022) . By inserting the origins and destinations of the modelled area, it is feasible to obtain travel times and distances based on the current road network.

6.5.2 Vehicle Operating Costs

The next step was the calculation of vehicle operating costs for the different propulsion types analysed in this project. The procedure that was followed and the data used are those described and provided by the UK Department of Transport (2020). The vehicle operating costs consist of two types of costs, more specifically the fuel consumption costs and the non – fuel costs and the variable of the average speed is essential to estimate these. For this variable, the average speed found from each origin to each destination from the network analyst is used for the calculations.

6.5.2.1 Fuel costs

To estimate fuel costs, initially fuel consumption should be calculated, and the formula of fuel consumption is presented is equation (6.1). The formula and data for this formula for different propulsion types was found in table A.1.3.12 for travelling for work purpose and A.1.3.13 for travelling for non-work purpose in the data of UK Department for Transport (2021b). Following, the formula and data were used for calculations for each zone pair for both purposes. Finally, the result was uplifted using the Value Added Tax (VAT) for each propulsion type, which is found by table A.1.3.7 of the UK Department for Transport (2021b):

$$L = \frac{a}{V} + b + c \times V + d \times V^2 \qquad (6.1)$$

where:

L: Fuel consumption expressed in pence/km

V: the average speed in km/hr

a, b, c, d: the parameters defined by each vehicle category and purpose

6.5.2.2 Non-Fuel costs

Following the non-fuel costs should be estimated, which are relevant to tyres, maintenance, vehicle capital saving etc. The formula for non-fuel costs can be found in table A.1.3.15 of the UK Department for Transport (2021b) and is presented (6.2):

$$C = a_1 + \frac{b_1}{V} \quad (6.2)$$

Where:

C: Cost in pence per km

V: the average speed in km/hr

a_1: a parameter for distance related costs defined by vehicle category and purpose

b_1: a parameter for vehicle capital saving defined by vehicle category purpose

Both the fuel and the non-fuel costs were converted to 2011 prices, using the GDP deflator, as 2011 is the base year of the model.

6.5.3 Value of Time

Following the value of time needs to be multiplied with the journey time in order to obtain the journey time in monetary values for each zone pair for both work and non-work purposes. The value of time was found from the table A1.3.5 of the UK Department for Transport (2021b). Moreover, it is adjusted with the year income because the income level of each person influenced the value of time of the individual. In order to find the value of time for all the transportation simulation years, the real income growth was calculated annually and then multiplied it with the price found from the previous year.

As mentioned in 4.2.3 the value of time changes with vehicle autonomy and in order to incorporate this, it was assumed that the value of time of high level CAVs is 50% smaller than the one of low level CAVs for work trips, and 80% smaller for non-work trips (Wadud et al., 2016).

6.6 Generalised Costs of new transport business models

The procedure for estimating the generalised costs of the business models was analytically described in section 5.3.1.3.2. Thus, in this section an investigation of the current costs was conducted for the case study area and in the literature, to estimate the generalised costs.

- **For On-Demand Transport**

An On-Demand transport service operator in West Midlands is Uber (Uber, 2022), thus the costs regarding the pricing of the service has been gathered from the website of this operator to maintain consistency with the pricing in the specific case study. Regarding the value of time, it was again gathered from the table A1.3.5 of the UK Department for Transport (2021b).

- **For Car-Sharing**

West Midlands has several car clubs' operators and here the one used here is Co-Wheels (co-wheels.org.uk, 2022), because the pricing of this operator is representative for the area. The cost is comprised from a weekly membership fee of £1.25 and the cost of £0.20/ mile, including costs such as fuel costs, road tax and other related driving costs (co-wheels.org.uk, 2022). The value of time was found in table A1.3.5 of the UK Department for Transport (2021b).

Modelling Shared Autonomous Vehicles (SAVs) is an integral part of this research. Since car sharing can include autonomous vehicles and as a result, became an SAV scheme, pricing was essential to be incorporated for the estimation of generalised cost. The analysis conducted by Kaddoura, Bischoff & Nagel (2020) for Berlin in Germany includes car sharing scenarios with non-automated vehicles and scenarios with SAVs. The pricing presented in this analysis is 0.35€/km for SAVs and 0.20 €/ km for car sharing with non-automated vehicles. Considering that the pricing of Co-Wheels for conventional vehicles is £0.20 per mile, it was be assumed that the pricing for SAVs in West Midlands will be £0.35 per mile, because the two cases have similar prices for the case of conventional vehicles, advanced transportation networks and are both European cities.

An interesting observation has been made in the literature in respect to the value of time in an SAV in comparison to the private autonomous vehicle. The space in a private vehicle is highly appreciated by the drivers, as they own the vehicle (Mattioli, 2016). As a result, they can use the time in a private autonomous vehicle more productively, in comparison with the time spent for a work trip in an SAV. Hence, the value of travel time savings is lower when using an SAV rather than when using a private autonomous vehicle (Steck *et al.*, 2018; Wadud & Mattioli, 2021). According to Steck *et al.* (2018) this reduction in value of travel time savings can be three time lower and according to Wadud & Mattioli (2021) two times lower. In this research the second approach has been adopted.

- **For Mobility as a Service**

In the West Midlands region currently, Whim (Whim, 2022) is the available MaaS operator, which is offered on a "Pay-as-you-Go" basis. Based on the literature, fixed plans for MaaS ("Pay-as-a-Package" options) can be more attractive to consumers comparing to "Pay-as-you-Go" due to lower marginal costs (Kamargianni *et al.*, 2016). Moreover, fixed plans make shared mobility options more attractive (Matyas & Kamargianni, 2019) and contribute to sustainability (Xi *et al.*, 2023). Since the objective of the present study is to examine people's willingness to trade one or more of their cars in exchange for MaaS, it makes more sense to focus on fixed plans (or packages/bundles) that consumers can choose from.

As already stated, the region consists of several counties. To implement fixed plans, it was essential to first investigate public transport costs in all counties, for all market segments and consider all private operators that serve each county (Arriva, 2022; PLUSBUS, 2022; Swift, 2022; First Bus, 2022; Diamond Bus, 2022; National Express West Midlands, 2022). Having processed the data, it was concluded that the average price for bus users in a week in West Midlands County is £15.30 and for public transport users, which includes bus and light rail is £24.50. The prices are different for the counties outside of the West Midlands County, as in these areas bus is the main mode of public transport and the average weekly price is £12. Moreover, the average weekly price for students that reside in the West Midlands County is £17 and outside of the West Midlands County £7.50.

Having explored the prices of all the transport business models, the prices of the MaaS packages were created. These prices are based on the market segments, the number of days household members work from home, the county they households are located and also on the fact that SAVs may be offered in the package. The packages are presented in Table 6.3.

The reason that these plans are personalised at this level, is that firstly, as stated, public transport costs differ significantly among counties. Moreover, students are entitled to discounts that working population is not entitled to. Packages should be attractive to people that work from home and their travel needs are different from people that do not work from home. Here it should be noted that the absence of a reliable trip rate estimates for students and retired users, led to the assumption that they travel on all days of the week. Specifically, regarding retired users in the UK, it has been found that they increase their number of trips just after retirement, which means that they travel all days of the week. This phenomenon, however, gradually tails off due to potential disabilities and aging (Schmöcker *et al.*, 2005). This analysis supports further the assumption made, as the created packages in this research need to be attractive to the potential users.

Table 6.3: Maas Plans developed for the West Midlands region

County	Market Segment	Number of days work from home	Mobility Package Description	Final weekly cost	Mobility Package Description	Final weekly cost
West Midlands County	Working adults	0	PT £20 & Unlimited Car clubs £10 & Unlimited ODT £25	£55	PT £20 & Unlimited SAVs £12 & Unlimited ODT £25	£57
		1	PT £20 & Unlimited Car clubs £10 & Unlimited ODT £25	£55	PT £20 & Unlimited SAVs £12 & Unlimited ODT £25	£57
		2	PT £20 & 2 x 5-mile rides with Car clubs £5 & 2 x 5-mile ODT £22	£47	PT £20 & 2 x 5-mile rides with SAVs £6 & 2 x 5-mile ODT £22	£48
		3	PT £20 & 2 x 5-mile rides with Car clubs £5 & 1 x 5-mile ODT £11	£36	PT £20 & 2 x 5-mile rides with SAVs £6 & 1 x 5-mile ODT £11	£37
		4	PT £20 & 2 x 5-mile rides with Car clubs £5	£25	PT £20 & 2 x 5-mile rides with SAVs £6	£26
		5	PT £20 & 1 x 5-mile ride with Car clubs £2.25	£22.5	PT £20 & 1 x 5-mile ride with SAVs £3	£23
	Students	0	PT £17 &1 x 5-mile ride Car clubs £2.5 &1 x 5-mile ODT £11	£30.5	PT £17 &1 x 5-mile ride SAVs £3 &1 x 5-mile ODT £11	£31
	Retired	0	PT £20 & Unlimited Car clubs £10 & Unlimited ODT £25	£55	PT £20 & Unlimited SAVs £12 & Unlimited ODT £25	£57
Other counties	Working adults	0	PT £12 & Unlimited Car clubs £10 & Unlimited ODT £25	£47	PT £12 & Unlimited SAVs £12 & Unlimited ODT £25	£49
		1	PT £12 & Unlimited Car clubs £10 & Unlimited ODT £25	£47	PT £12 & Unlimited SAVs £12 & Unlimited ODT £25	£49
		2	PT £12 & 2 x 5-mile rides with Car clubs £5 & 2 x 5-mile ODT £22	£39	PT £12 & 2 x 5-mile rides with SAVs £6 & 2 x 5-mile ODT £22	£40
		3	PT £12 & 2 x 5-mile rides with Car clubs £5 & 1 x 5-mile ODT £11	£28	PT £12 & 2 x 5-mile rides with SAVs £6 & 1 x 5-mile ODT £11	£29
		4	PT £12 & 2 x 5-mile rides with Car clubs £5	£17	PT £12 & 2 x 5-mile rides with SAVs £6	£18
		5	PT £12 & 1 x 5-mile ride with Car clubs £2.5	£14.5	PT £12 & 1 x 5-mile ride with SAVs £3	£15
	Students	0	PT £7.5 &1 x 5-mile ride Car clubs £2.5 &1 x 5-mile ODT £11	£21	PT £7.5 &1 x 5-mile ride SAVs £3 &1 x 5-mile ODT £11	£21.5
	Retired	0	PT £12 & Unlimited Car clubs £10 & Unlimited ODT £25	£21.5	PT £12 & Unlimited SAVs £12 & Unlimited ODT £25	£49

6.7 Total Cost of Ownership

The model of TCO that is used in this analysis is that of Palmer *et al.* (2018) and Baek *et al.* (2021), as described in section 4.6.2. In this section an explanation of all the related costs used for the estimation of TCO for each vehicle technology follows:

Table 6.4: TCO related costs

Variable	**Value - Description**	**Reference**
Depreciation rate	The depreciation rate was assumed to be -0.215, and the depreciation model was deemed geometric rather than linear, because according to Storchmann (2004) this model appears to be an apporpriate approxiamtion of the real depreciation rate. The value is specifically choosen for the UK.	(Storchmann, 2004)
Discount rate	3.5%	(HM Treasury, 2018; Palmer *et al.*, 2018)
Subsidies	£3,000 for electric vehicles	(data.gov.uk, 2020b)
Annual Mileage	The data for annual mileage were found in table nts0901 and were forecasted until the last transport simulation year, which is 2035.	Table nts0901 in data.gov.uk (2020c)
Annual Fuel/ Electricity Costs	Similarly, the average fuel prices were found until 2019 and were forecasted until the 2035.	Table 4.1.2 of the UK Department for Business Energy & Industrial Strategy (2020)
Maintenance Data	£54.85/ year	(data.gov.uk, 2020a)
Insurance Data	£450/year is the average vehicle insurance	(Association of British Insurers, 2019)
Vehicle tax Data[1]	£150/year	(data.gov.uk, 2020e)

[1] In this analysis only the TCO of privately owned cars is estimated. The TCO for motorcycles or other types of vehicles was not estimated. As a result, the figure corresponds only to this vehicle type.

6.7.1 Years of ownership and proportions

The years of ownership are essential for the estimation of TCO. According to Leibling (2008) four years is the average ownership time length of a vehicle in the UK (Leibling, 2008) and in this analysis, it has been assumed that this applies to both new and used vehicles. This information is important for the model of Palmer *et al.* (2018), as in this TCO model all the costs are added annually for the total number of years of ownership of a vehicle. However, this TCO model has not been applied for used cars, which is a difference from this research, as it is going to be the basis of estimation of TCO for used cars as well, but with a different initial purchase price. Finally, by using the data on used vehicles by SMMT (2020b) and for new cars by data.gov.uk (2020c), the proportion of used and new cars in the fleet were estimated.

6.7.2 Vehicle cost data

The two highest costs related to vehicle ownership are the purchase price and costs related to fuel consumption. In order to estimate these costs for the different vehicle technology categories, models available in the market for each category were selected as examples. Since the category that includes low level automation vehicles is very broad, three example models were selected for low-electric and for low-non-electric. An important criterion for selecting these models was to be able to incorporate vehicles from all price ranges in each category. Here it should be noted that vehicles with high levels of automation are not widely available in the market yet, as a result for estimating the prices it was assumed that they would be similar to those of a level 3 autonomous vehicles with the addition of costs related to equipment for higher automation.

6.7.2.1 Low level of automation

Table 6.5 included the information for initial price of vehicles as new and as used, as well as for vehicle efficiency per model. The models selected, include different technical characteristics in order to have representative costs for the category and are selected as they are high is sales in the UK. For the initial purchase price of used cars, the information from the companies, that the models belong to, were used. The only exception is regarding the models of Mercedes which are not sold as used yet, thus the initial price was reduced by 47%, as the same reduction was found that Nissan leaf and Nissan Tekna had from price as new to price as used.

Table 6.5: Initial price and vehicle efficiency for different car models

Vehicle Technology Category	Models	Initial Price (New)	Initial Price (Used)	Vehicle Efficiency	
Low-electric	Nissan Leaf	£26,845	£13,995	0.238095	kWh/mile
	Nissan Tekna	£29,845	£15,559	0.238095	kWh/mile
	Mercedes A250e	£32,980	£17,193	0.234964	kWh/mile
Low-non electric	Ford Fiesta	£16,640	£9,474	53.3	mpg
	Toyota Corolla	£27,455	£14,995	57.6	mpg
	Mercedes A250	£31,135	£16,231	41.5	mpg

Source: Adapted from Nissan UK (2020), Ford (2020), Mercedes-Benz (2020) and Toyota UK (2020)

6.7.2.2 High level of automation

Full automation requires a number of technological equipment which make the initial price higher. Some of them are GPS, LiDAR, and cameras. Lee (2013) mentions that the additional cost could be equal to £5000 (Lee, 2013), on the other hand Bansal & Kockelman (2017) mention an additional cost of £16,400 (23950$) (Bansal & Kockelman, 2017). In the case of Lee (2013) the result is very optimistic, whereas in the case of Bansal & Kockelman (2017) the cost is very high to have commercial success. The estimate of Wadud (2017), which is based on the data of the study of Mosquet *et al.* (2015), is an intermediate price of £9400 (Wadud, 2017). This value is used here additionally to initial purchase price of Mercedes A250 and Mercedes A250e, as these two models are those with the highest level of automation in the low-level category.

Finally, it should be mentioned that the GDP deflator is used to bring all costs mentioned in 6.7 in 2011 prices, which is the base year of analysis in the model.

6.7.3 Results

In Figure 6.5 the results from the calculation of the TCO are presented for each vehicle category.

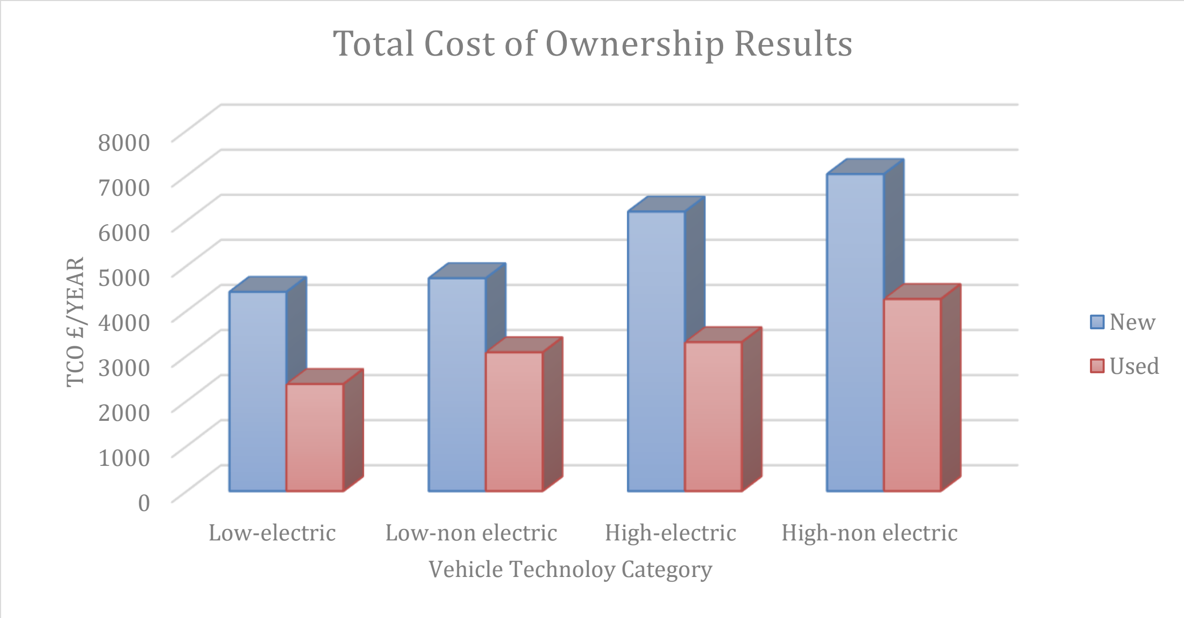


Figure 6.5: Total Cost of Ownership Results

Based on these results, it should be noted that:

- The results indicate that the TCO of the low-level automation categories is lower in comparison with those of the high-level, as the additional costs for full automation make them less affordable.
- Electric vehicles have lower TCOs comparing to non-electric vehicles, due to the subsidies provided. If those subsidies are not included in the estimation procedure, the results indicated that electric vehicles can be more expensive.
- Used vehicles have lower ownership costs in comparison to new vehicles, as the initial purchase price is lower. Interestingly, the cost patterns that the used vehicle follow are the same with new vehicles, in terms of distinguishing the costs of the different vehicle categories.

6.8 Car ownership for integrating business models

The next step of the analysis is the calibrate MIM, the structure of which was mathematically analysed in section 5.3.1.3.5. The independent variables are presented in Table 5.1, thus it is essential to determine attributes and attribute levels in order to calibrate the model for the West Midlands Region.

6.8.1 Attribute levels

Starting with the car operation cost, data from the estimation of the TCO were used, however, costs related to the initial purchase price, depreciation rates or subsidies were not included. The costs related to operation are firstly fuel costs, parking costs, costs related to car maintenance, vehicle taxes and insurance costs. The required data were gathered from the sources also used in the section for the estimation of TCO (UK Department for Business Energy & Industrial Strategy, 2020; data.gov.uk, 2020a; Association of British Insurers, 2019; data.gov.uk, 2020e; West Midlands Railway, 2022). An important factor that can substantially change the car operation cost (COC) is the number of days that different household workers may work from home. Half a tank has been assumed to be consumed in one week, which is 35.7 litres (L) /week (5.1 L/day). The basis of this assumption is that many different cases needed to be considered for an average COC, such as cases with higher annual mileage, vehicles with low fuel efficiency or multiple household members.

As a result, based on the data and on the weekly fuel consumption, the COC on a weekly basis is:

- £25/week (household members only work from home and travel during the weekend)
- £30/week (household members work from home 4 days and travel during the weekend)
- £35/week (household members work from home 3 days and travel during the weekend)
- £40/week (household members work from home 2 days and travel during the weekend)
- £45/week (household members work from home 1 day and travel during the weekend)
- £50/week (household members do not work from home)

The analysis conducted in section 6.6 for the estimation of generalised cost for the new transportation business models is also useful for the determination of the attribute levels in this section. The Car operation cost (COC), Mobility cost for MaaS (MC), and Car club cost (CC) have three levels and the public transport cost (PT) and On Demand Transport cost (ODT) have two. Of course, the actual values assigned to the attribute levels are different based on the sociodemographic characteristics of the respondents. For a working adult that does not work from home and resides in the West Midlands County, the attribute levels are defined as follows:

- Car operation cost (COC) –£0 for no car, £50 for 1 car and £100 for 2 cars
- Mobility cost for MaaS (MC) – £0 for no MaaS subscription, £55 for a MaaS package and £57 for a MaaS package that includes SAVs
- Public transport cost (PT) – £0 for no subscription to public transport and £20 for public transport subscription

- Car club cost (CC) – £0 for no subscription to car clubs, £2.50 for one trip using car clubs and £3 for a trip using SAVs
- On Demand Transport cost (ODT) – £0 for no subscription to ODT and £11 for one trip

6.8.2 Stated preference (SP) experiment

A Stated Preference (SP) experiment in the case study area was essential to examine if people would be willing to trade at least one their cars in order to subscribe to one or multiple transportation business models. In SP experiments, participants are given a set of hypothetical scenarios to choose from, and such experiments are used when revealed preference approaches are not available (Alyamani, Pappelis & Kamargianni, 2024).

There are different designs for creating a stated preference experiment, including the fractional factorial designs and the D-optimal designs (Tazliqoh, Wigena & Syafitri, 2019). Both types could have been used in this experiment. D-optimal designs require prior estimates of the parameters, which are not available in this experiment. This is because the perceptions of individuals and households on CAVs and MaaS are not known, as people may not be very familiar with these technologies (Sharma & Mishra, 2023). Prior estimates are very important, as based on the analysis of Walker *et al.* (2018) the current literature on D-optimal designs examines conditions in which the prior estimates used for generating the efficient design are assumed to be accurate. Moreover, D-optimal designs have the advantage of minimising mean square errors (Carlsson & Martinsson, 2003), which is needed in discrete choice models especially when the income elasticity is used and the income is normalised by the mean income of the sample. Since, no priors were available, the model structure does not necessarily require for minimisation of the mean square errors and in order to retrieve the smallest number of choice sets, a fractional factorial orthogonal design was generated using the statistical software package of SPSS, which is presented in Appendix B. The analysis of Street, Burgess and Louviere (2005) suggests six strategies for creating optimal choice sets for stated choice experiments. Using this analysis, the first strategy has been used for this research. The developed fractional factorial design included 16 choice sets and by combining them in groups of two in one question, eight scenarios of two options each (A and B) are created. This is shown in Table 6.6, which shows the aforementioned example of a working adult in the West Midlands County that travels daily to work.

Table 6.6: Fractional Factorial design

Scenario	COC	MC	PT	CC	ODT	Alternative	Option
1	50	55	0	0	11	2	A
	0	55	0	3	0	1	B
2	50	0	0	2.5	11	2	A
	0	57	0	0	11	1	B
3	100	0	0	0	0	3	A
	0	57	20	0	11	1	B
4	50	0	20	0	0	2	A
	0	0	0	3	11	1	B
5	0	0	0	0	0	1	A
	0	0	20	0	0	1	B
6	100	57	0	2.5	0	3	A
	50	57	20	3	0	2	B
7	100	55	20	0	11	3	A
	0	55	20	2.5	0	1	B
8	100	0	20	3	11	3	A
	0	0	20	2.5	11	1	B

6.8.3 Questionnaire

In this section, the distributed questionnaire is analytically presented. However, before presenting the final version of the distributed survey, (included in Appendix A) it is essential to analyse the elements considered from the pilot surveys that led to the final version. Initially, a draft survey was created and two pilot surveys were distributed to members of the Transportation Research Group (TRG) of the University of Southampton, to improve it and ensure that it has a clear structure. The first version of survey was created in Microsoft Forms and some important comments were that:

- Microsoft Forms does not allow for randomisation, which was essential to avoid bias. Hence, the second version was created in Qualtrics.
- The first version of the survey was presented with a lot of quantitative values that were not entirely understandable. Moreover, the questions needed to be more concise, to ensure that respondents would not provide any random answers. As a result, in the second version the presentation was entirely changed to include more concise and understandable questions.
- Changes were necessary in the introductory page to ensure that the survey fully conforms with the University's regulations from the Faculty Research Ethics Committee.
- It would be important to also provide a total cost for each option in the scenarios, which was not included in the first version and makes the questions clearer to participants.

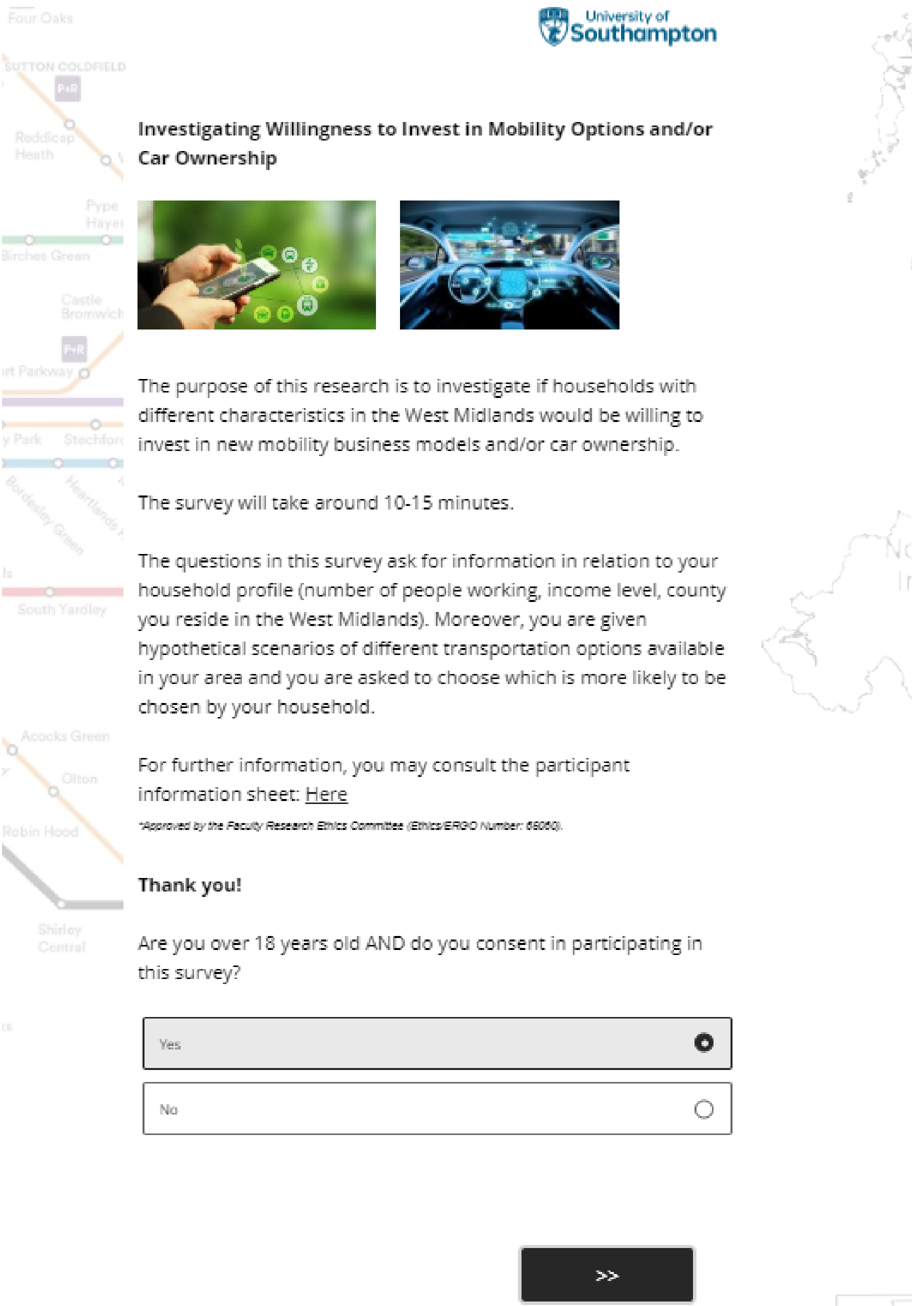
- Some grammatical errors and presentational comments were also noted and considered.

These comments were crucial and indeed very important for the improvement of the survey. As mentioned, the second version was created in Qualtrics, which most importantly allows for randomisation of questions in the blocks of scenarios. Having considered the comments from the first pilot survey to the second version of the questionnaire, a second pilot survey was distributed to TRG members. In this version the most important comments were that:

- The number of scenarios, which was 11 in this version, was relatively high. This was leading to some of the participants being impatient to answer all of them carefully, and either quitting the survey or providing random answers. Hence, the number of scenarios was reduced to 8, to ensure that the model could be calibrated, and the survey would have higher quality of answers.
- According to some of the participants, in some scenarios neither option A nor B was rational to be selected, as both options were not attractive. This was an additional reason to recreate the scenarios, and apart from reducing their number, also ensure that both options are attractive.
- The survey could also be improved, in order to become more visible and understandable from different devices, including PC monitors, Laptops, tablets and smartphones.

The final version, which was distributed to the public, included all the possible improvements from these comments.

The target group of the survey are adults that reside in the West Midlands region and all responses were anonymous. Since there is no other requirement regarding the market segments of the sample, it is very important that final sample characteristics match the characteristics of the population. These characteristics are available from the UK Office for National Statistics. More specifically, since the population in the West Midlands County is higher comparing to other counties (UK Office for National Statistics, 2019), it would be beneficial to receive more answers from residents of this county. Another factor that plays a crucial role for the sample to be representative of the population, is the income and it should be representative of the regional annual income. The survey received ethics approval from the Faculty Research Ethics Committee (FREC) at the University of Southampton (Ethics/ERGO Number: 65060) and the introductory page of the survey is presented in Figure 6.6.


University of Southampton

Investigating Willingness to Invest in Mobility Options and/or Car Ownership

The purpose of this research is to investigate if households with different characteristics in the West Midlands would be willing to invest in new mobility business models and/or car ownership.

The survey will take around 10-15 minutes.

The questions in this survey ask for information in relation to your household profile (number of people working, income level, county you reside in the West Midlands). Moreover, you are given hypothetical scenarios of different transportation options available in your area and you are asked to choose which is more likely to be chosen by your household.

For further information, you may consult the participant information sheet: Here

*Approved by the Faculty Research Ethics Committee (Ethics/ERGO Number: 66060).

Thank you!

Are you over 18 years old AND do you consent in participating in this survey?

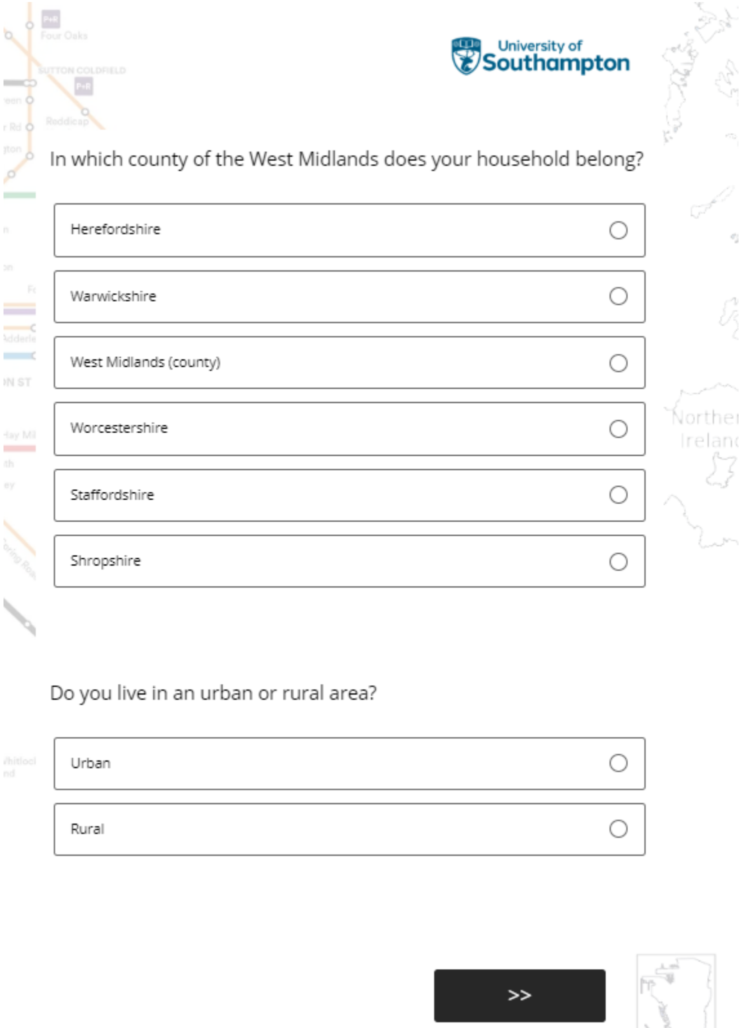
Yes

No

>>

Figure 6.6: Introductory page of the Stated Preference Survey

Participants were initially asked questions, in order to determine their sociodemographic characteristics for example, the county they reside in, the number of days they work from home or their income level. Examples of these questions in the survey are presented in presented in Figure 6.7 and Figure 6.8.



University of Southampton

In which county of the West Midlands does your household belong?

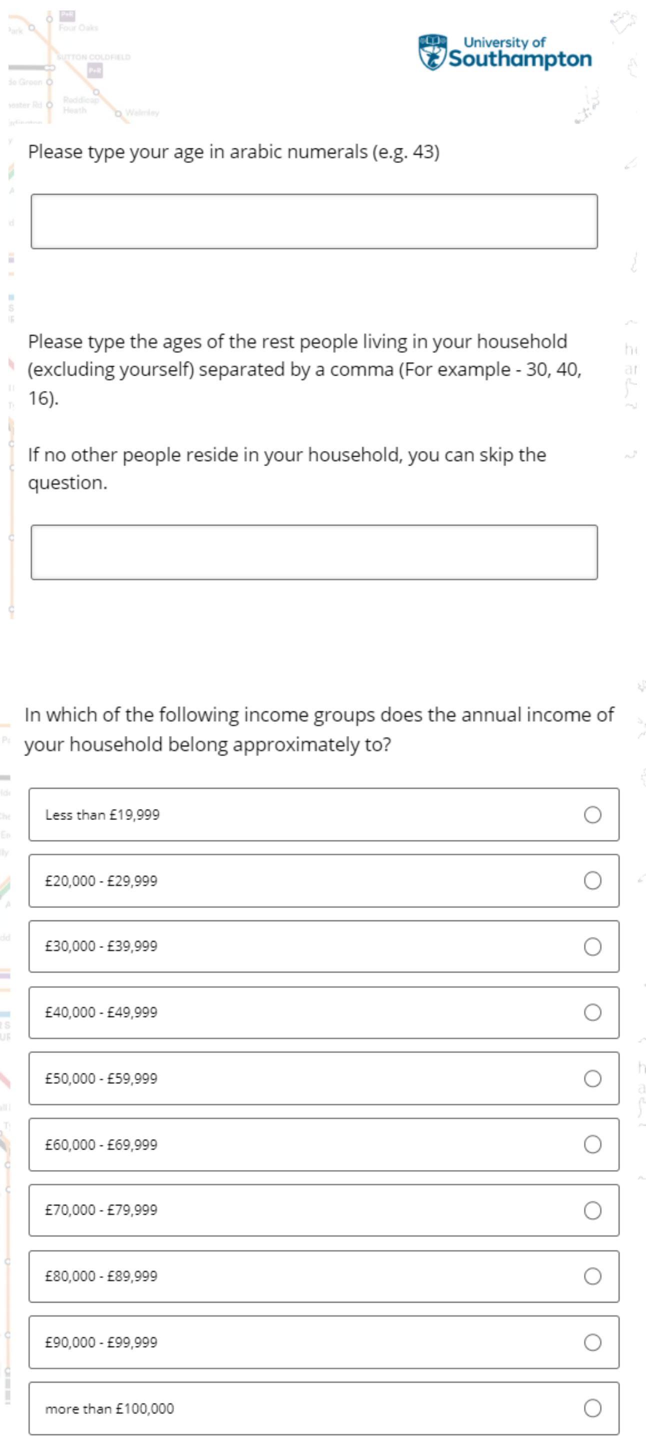
- Herefordshire
- Warwickshire
- West Midlands (county)
- Worcestershire
- Staffordshire
- Shropshire

Do you live in an urban or rural area?

- Urban
- Rural

>>

Figure 6.7: Questions regarding residential location in the Stated Preference Survey



University of Southampton

Please type your age in arabic numerals (e.g. 43)

Please type the ages of the rest people living in your household (excluding yourself) separated by a comma (For example - 30, 40, 16).

If no other people reside in your household, you can skip the question.

In which of the following income groups does the annual income of your household belong approximately to?

- Less than £19,999
- £20,000 - £29,999
- £30,000 - £39,999
- £40,000 - £49,999
- £50,000 - £59,999
- £60,000 - £69,999
- £70,000 - £79,999
- £80,000 - £89,999
- £90,000 - £99,999
- more than £100,000

Figure 6.8: Questions regarding the age and income in the Stated Preference Survey

Based on the answers provided by the participants in these questions, they were subsequently directed to an introductory page that initially explained the task of choosing between options in the following section, determined that there is no right or wrong answer and defined the terms "Mobility Solution" and "self-driving cars", which refer to MaaS and CAVs respectively. This part of the survey is presented in Figure 6.9 and Figure 6.10 respectively.

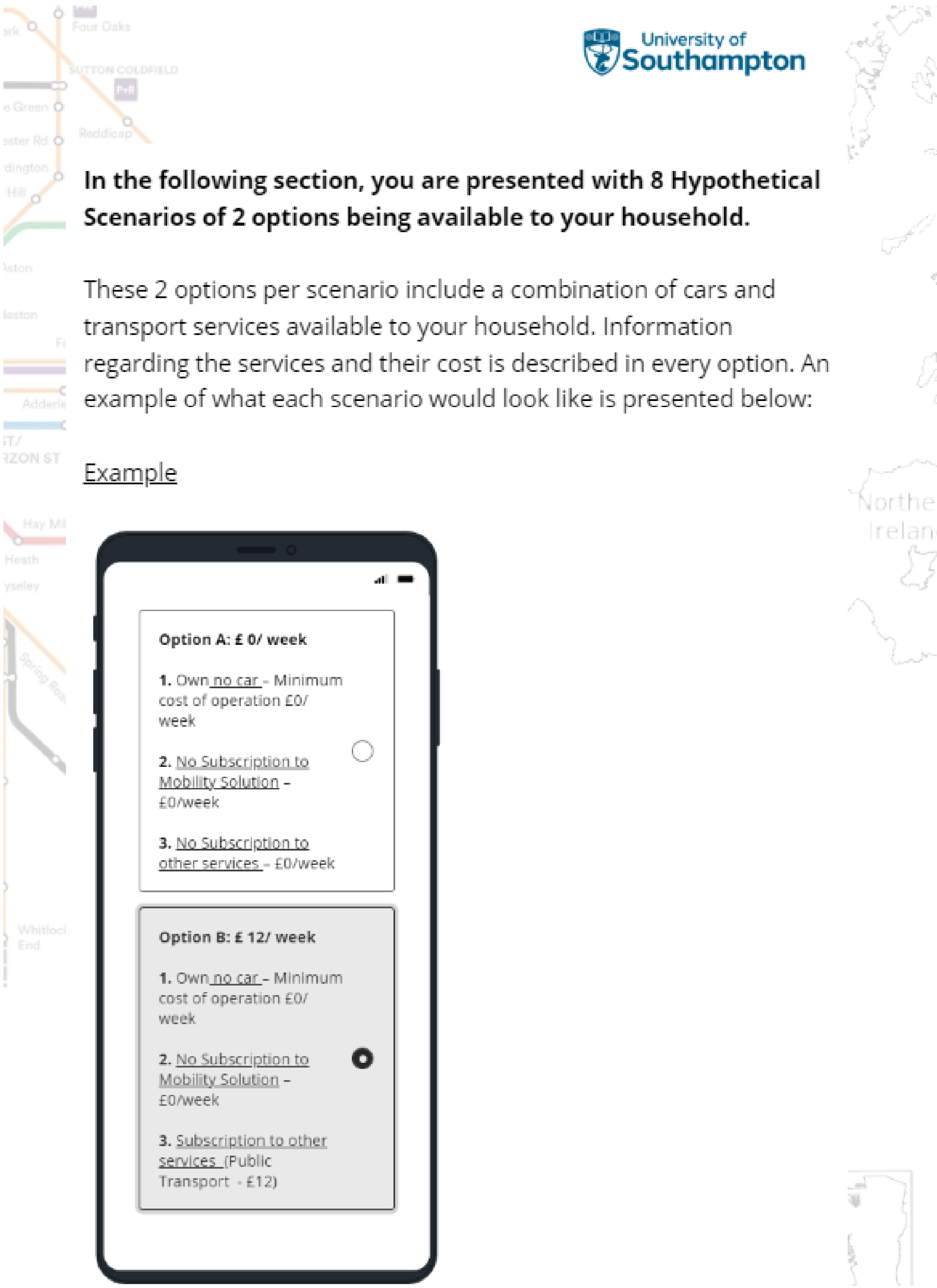
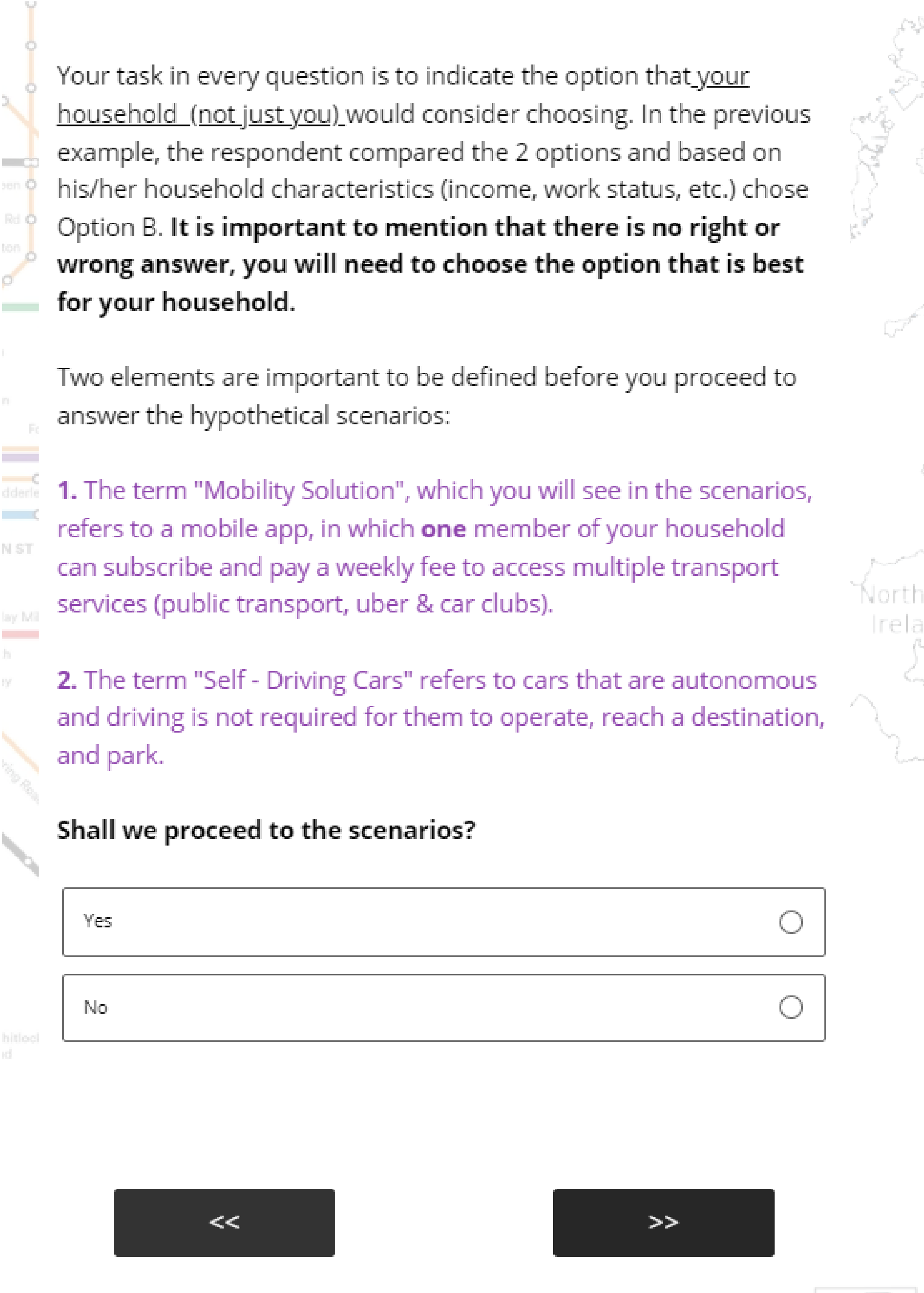


Figure 6.9: Introductory page to scenarios in the Stated Preference Survey (part 1)



Your task in every question is to indicate the option that your household (not just you) would consider choosing. In the previous example, the respondent compared the 2 options and based on his/her household characteristics (income, work status, etc.) chose Option B. **It is important to mention that there is no right or wrong answer, you will need to choose the option that is best for your household.**

Two elements are important to be defined before you proceed to answer the hypothetical scenarios:

1. The term "Mobility Solution", which you will see in the scenarios, refers to a mobile app, in which **one** member of your household can subscribe and pay a weekly fee to access multiple transport services (public transport, uber & car clubs).

2. The term "Self - Driving Cars" refers to cars that are autonomous and driving is not required for them to operate, reach a destination, and park.

Shall we proceed to the scenarios?

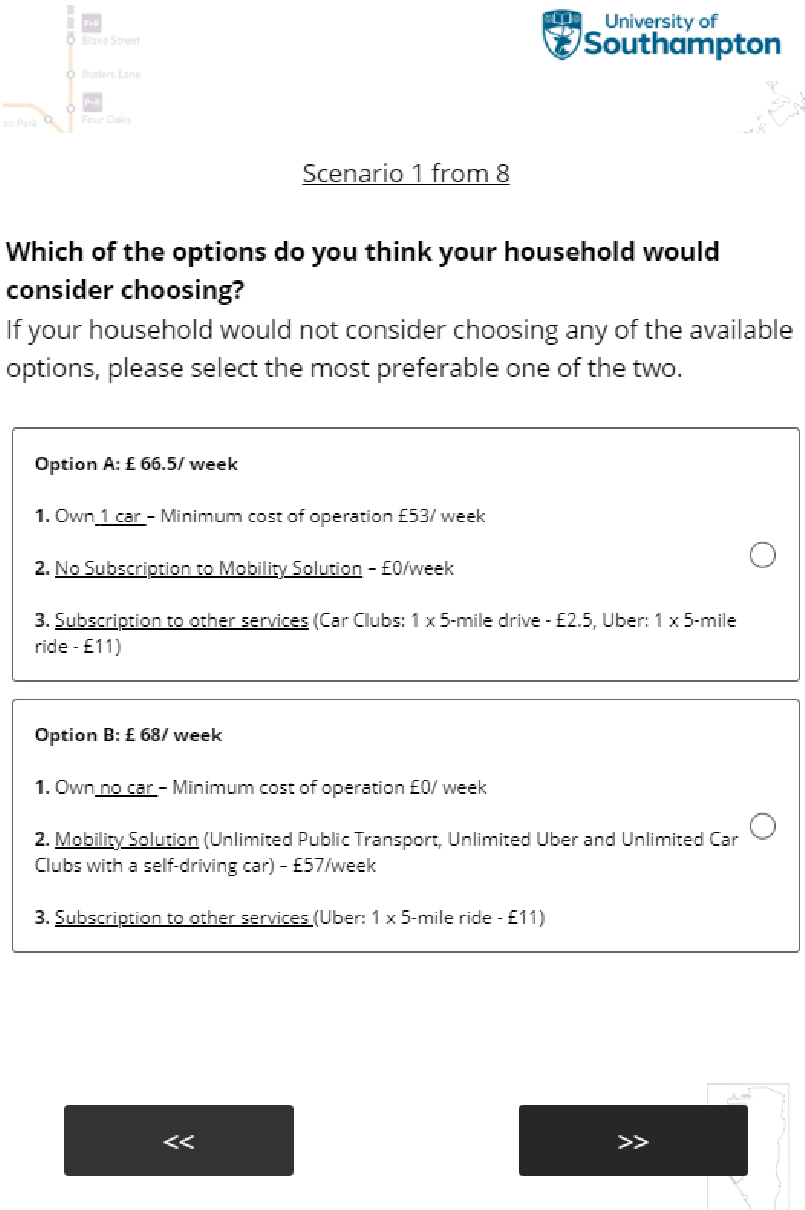
Yes

No

<<   >>

Figure 6.10: Introductory page to scenarios in the Stated Preference Survey (part 2)

Having consented on proceeding to the scenarios, the respondents were directed to the corresponding scenarios respective to their demographic characteristics. As it can be inferred from the fractional factorial design of the experiment, in total participants were presented with eight choice scenarios. To avoid bias, the scenarios were randomised when presented scenarios to each participant. An example of a scenario page is shown in Figure 6.11. Since, there may have been respondents that may would not have preferred any of the respective options and since the option of not choosing any of them was not available in the survey, the phrasing used for the question led the respondent to choose the most preferable option. Choosing none of the two options does not provide a clear answer of which alternative has been chosen by the respondent and as a result, the model could not have been calibrated if the respondent could choose none of the two options.


University of Southampton

Scenario 1 from 8

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

Option A: £ 66.5/ week

1. Own 1 car – Minimum cost of operation £53/ week

2. No Subscription to Mobility Solution – £0/week

3. Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11)

Option B: £ 68/ week

1. Own no car – Minimum cost of operation £0/ week

2. Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week

3. Subscription to other services (Uber: 1 x 5-mile ride - £11)

<< >>

Figure 6.11:Scenario page

In total 18 versions of the 8 scenarios were created and are presented in the survey flow in Figure 6.12. Using skip logic, the respondents were directed to the appropriate block of hypothetical scenarios based on whether or not the participant:

- was from a working, retired or student household;
- resides in the West Midlands County or not and;
- works from home and how many days, given that it is a working household.

The respective blocks in the survey flow have a structure in their titles that assists in defining for which market segment they were created. The term “WM” refers to residents of the West Midlands County and the term “NWM” refers to residents of other counties. Following, the number that follows represents the number of days the participant works from home. Finally, the term “Work” refers to working households, the term “R” to retired household and the term “St” to Student households.

The final version of the survey, presented in Appendix A, was distributed through the market research panel of Prolific, Transport for West Midlands and through social media.

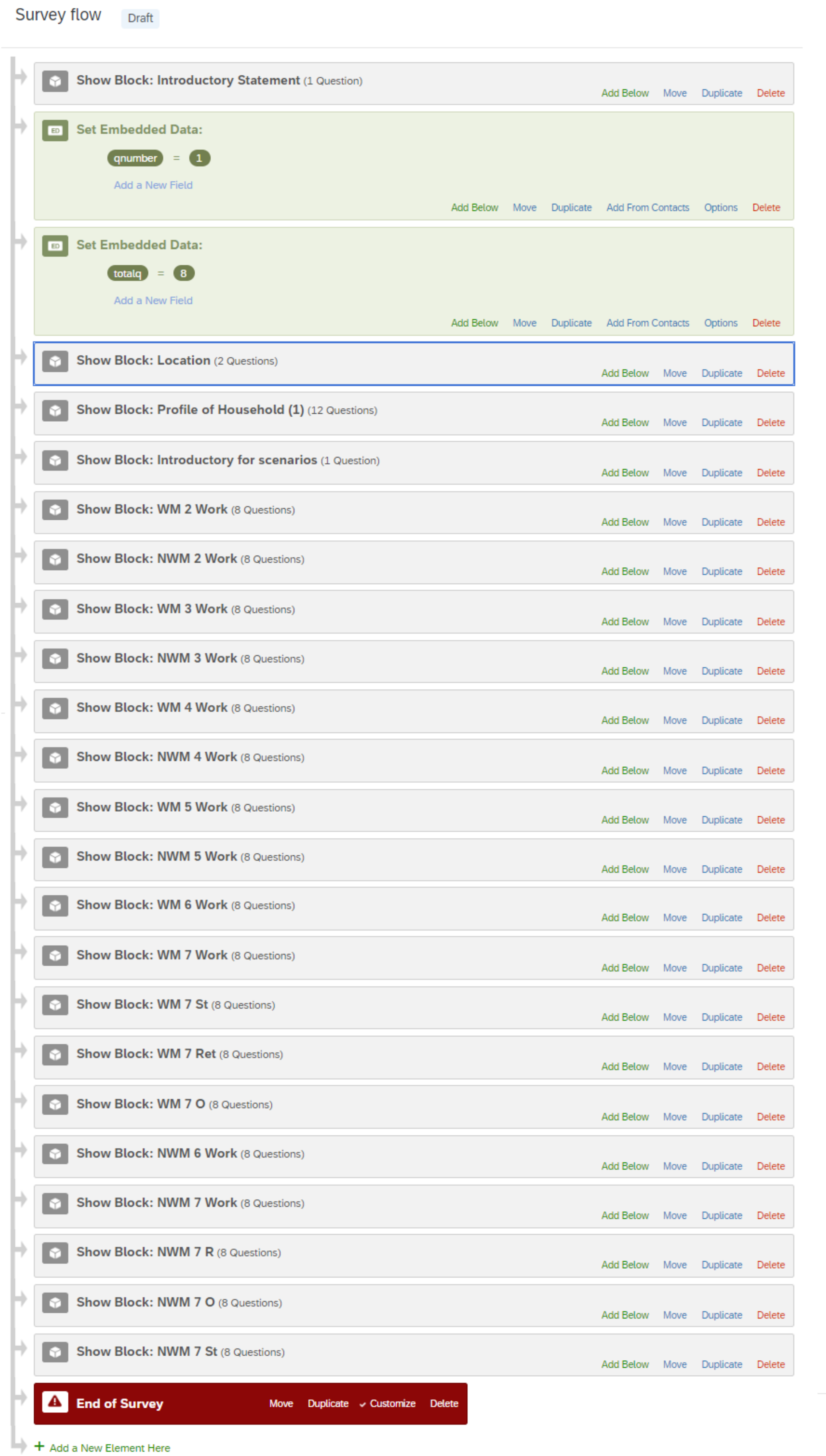


Figure 6.12: Survey flow of the Stated Preference Survey

6.8.4 Results and discussion

6.8.4.1 Sample characteristics

The total number of responses in the final distribution of the survey was 541, but only 464 were considered adequate for calibration the model. To conclude on that number of responses, some needed to be eliminated as they were not able to provide solid and reliable evidence. For this reason, the quality of responses was considered, as it was essential to ensure that the final sample included responses that could provide reliable results. The first criterion that was assessed was the time that the respondents took to complete the survey, as for example completing the survey in some seconds of in 1 minute, indicates that the survey was completed by selecting random answers. Another criterion was the elimination of the incomplete responses and the elimination of responses with irrational responses, such as the repeated selection of one option (for example A) in all scenarios, which is also correlated with low completion time of the survey.

It is clear from the results shown in Figure 6.13 there is an adequate balance between the sample size for each county, household type and for all income levels, thus sample has been deemed representative based on the demographic characteristics of the region. More specifically, the most populous county in the region is the West Midlands County, most households in the region fall into the category of working households (UK Office for National Statistics, 2019), and finally the mean regional annual income is £36,000 (UK Office for National Statistics, 2018). Thus, it is expected that in the respective categories the number of respondents is higher compared to the other categories.

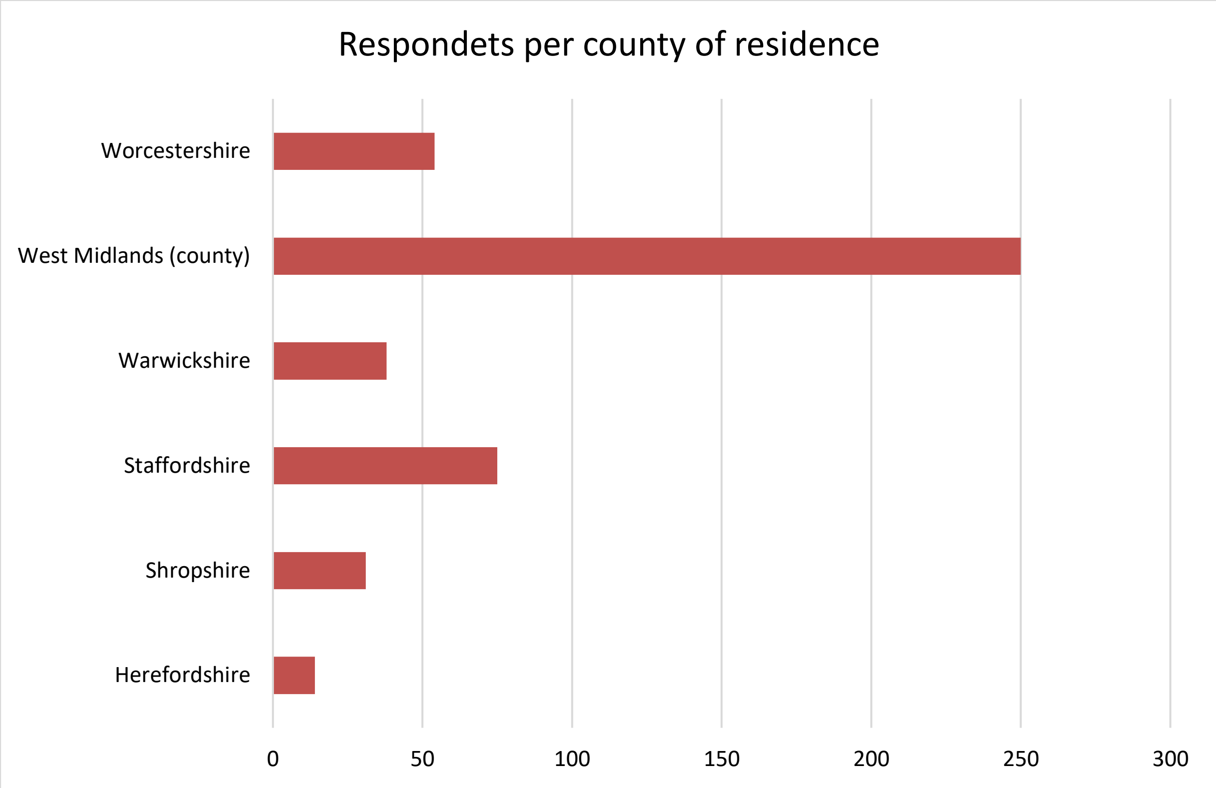


Figure 6.13: County of residence

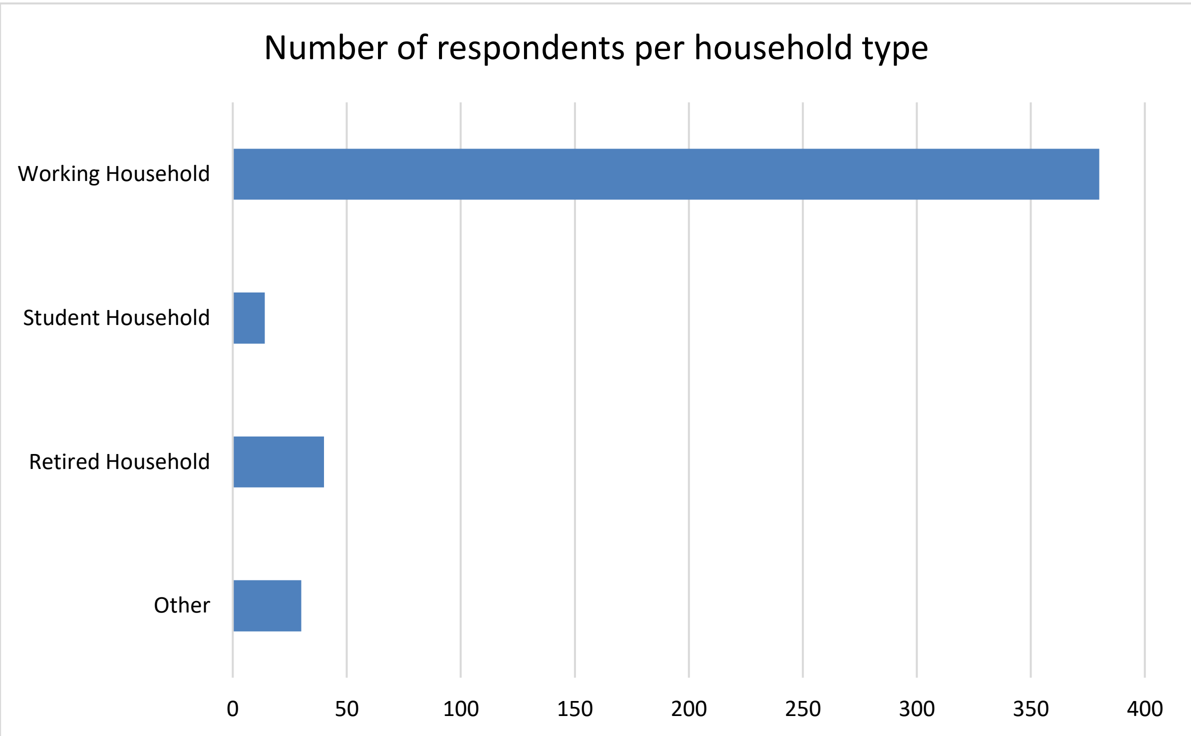


Figure 6.14: Household types

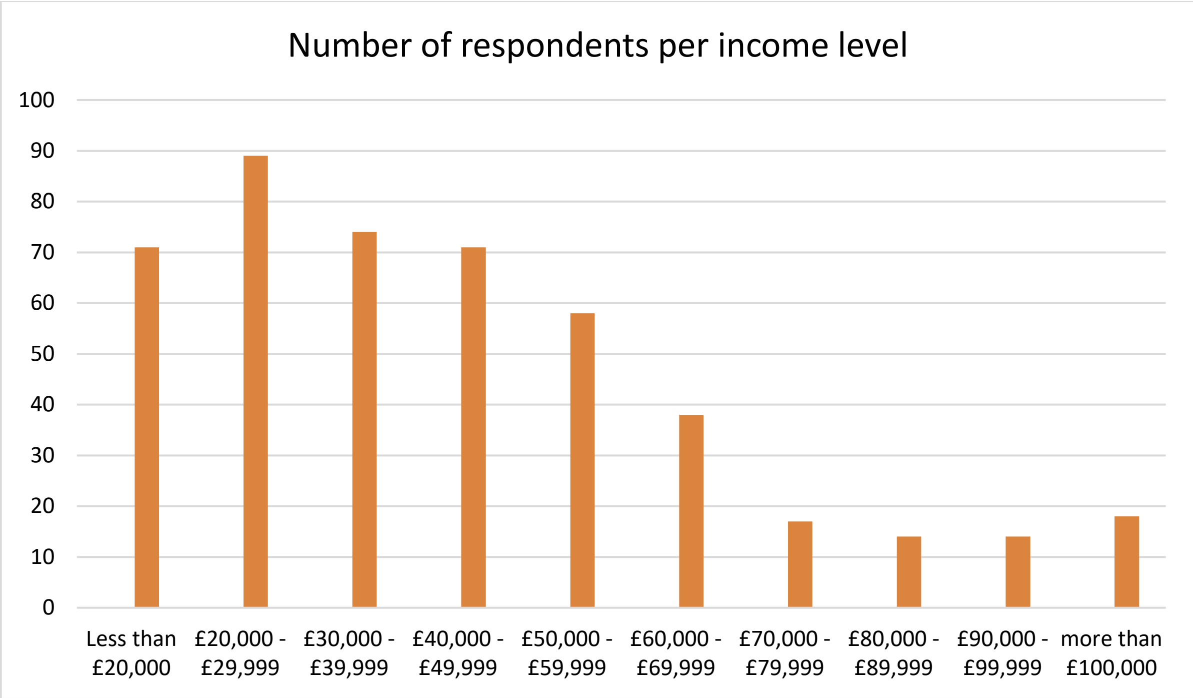


Figure 6.15: Income levels

A dominant scenario, is a scenario that one option has clear superiority among other options and respondents consistently choose it, and as a result there is no variation among the choices of the alternatives of the model (Scott, 2002). It should also be mentioned that none of the scenarios presented in the survey was dominant, because the lowest proportion of one option chosen by any one of them is 20%.

6.8.4.2 Results

Based on the structure of the model presented in 5.3.1.3.5 (also presented in Figure 6.16) and the data received from the stated preference survey the model was calibrated using the library of Apollo using R in the environment of RStudio (Hess & Palma, 2019) in two rounds. The complete R scripts and the results of the two rounds are presented in Appendix B. In Table 6.7 the final results from the calibration procedure of the model, which are statistically significant at a 5% level, are presented. The coefficients of categorical variables and the alternative specific constants were considered equal to zero for the first alternative. This was essential to calibrate the rest of the coefficients and as a result no standard errors or p-values are presented for the respective coefficients in the table.

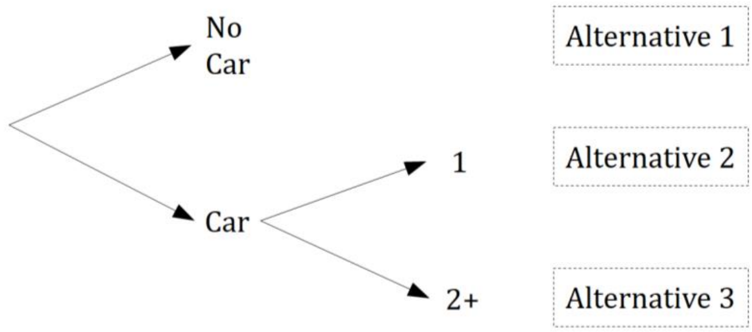


Figure 6.16: Structure of MIM

Table 6.7: Estimated results (statistically significant effects only)

	Estimate	**Std. Error**	**p-value**
asc_1	0.0000	NA	NA
asc_2	2.0987	0.1466	0.00000
asc_3	1.9990	0.1459	0.00000
$\beta_{ZT,1}$	0.0000	NA	NA
$\beta_{ZT,2}$:	-0.7955	0.1834	0.00001
$\beta_{ZT,3}$	-0.6627	0.2022	0.00052
$\beta_{R,1}$	0.0000	NA	NA
$\beta_{R,2}$	-0.7358	0.1440	0.00000
$\beta_{R,3}$	-0.9677	0.1381	0.00000
$\beta_{PT\ cost,1}$	-10.6108	6.1374	0.04191
$\beta_{COC\ cost,3}$	-7.0078	1.0240	0.00000
$\beta_{transport\ cost,2}$	-11.9407	1.1908	0.00000
$\beta_{transport\ cost,3}$	-8.5032	1.2483	0.00000
λ_{car}	0.6480	0.1566	0.00002
Initial Log-Likelihood	-2251.342		
Log-Likelihood	-1856.989		
R^2	0.1752		

First of all, it is important to mention that R^2 is suggested that it should be between 0.2 and 0.4 to represent a good fit (McFadden, 1979; Hensher & Stopher, 2021) and in this case it is 0.1752. However, this might be expected in highly hypothetical experiments such as this one.

Alternatives 2 and 3 have positive alternative specific constants, because most working households need at least one car, and it should also be noted that for both alternatives the utility function tends to decrease if a household q is located in a zone of an urban area, as the existence of advanced urban transport networks, which include public transport, increases accessibility and as a result lessens the necessity for a household q to own a car. Moreover, alternatives 2 and 3 have negative coefficients for retired users, which can be explained as in the UK working households tend to have higher levels of car ownership compared to retired households (Fox et al., 2016).

Alternative 1 has a negative coefficient for public transport, as with an increased cost of public transport subscription becomes less affordable for the public. Moreover, the absolute value of this coefficient is high as for household that do not own a car public transport is the most preferable and affordable mode of transport thus it has an important effect to the utility f alternative 1. Finally, it should be mentioned that based on the estimated results, as car ownerships costs or transport costs related to mobility services increase, the utilities of alternatives 2 and 3 decrease. This phenomenon can be expected as vehicle ownership becomes less affordable and transportation business models become more attractive. Hence, there is a decrease in the utilities of the respective alternatives, as households may shift from vehicle ownership to subscribing to transport business models that include partially car use.

The probabilities are estimated using the principles for nested logit models as presented by Daly (1987). Based on the estimated results, the highest probability for all market segments is the one of alternative 2. The results for the coefficients of the utility functions indicate that if there is an increase in COC, people may shift towards subscribing to transportation business models and because the probability of alternative 1 increases a minority would even consider giving up their car. The probability of alternative 1 also increases if the transportation business models have increases in their costs, which also leads to the decrease of the probabilities of alternatives 2 and 3. In any case, however, the probability of alternative 2 is always the highest. These conclusions have also been mentioned in the work of (Becker, Ciari & Axhausen, 2018; Chapman, Eyckmans & Van Acker, 2020; Bekka, Louvet & Adoue, 2020), because they show that in the West Midlands Region, new transportation business models can become an important competitor to car ownership.

Following an elasticity analysis was completed to validate further those conclusions. The arc elasticities of the probabilities of the calibrated model were calculated, for an increase of 10% in PT and for an increase of 10% in COC. The results from this analysis indicated that the elasticities of alternative 2 were 0.15 for the 10% increase in COC and 0.01 for the 10% increase in PT, which shows that the probability of alternative 2 is inelastic with respect to both of these increases. Thus, price increase would not lead to a substantial car ownership change for the households that own one car. The respective elasticities for alternative 1 are 0.08 and -0.05 and for alternative 3 -0.38 and 0.09. These results show that the demand is inelastic. Hence, in the short-term car ownership is not likely to decrease significantly due to price changes and as a result additional interventions need to be implemented in order for car ownership to become less attractive.

Finally, it should be noted that for validating the produced results of MIM, the probabilities were compared to the results of the current car ownership model of DELTA of the BAU scenario. In the event that no new business models would be simulated in the system and that the costs related to car ownership and operation would remain equal to those of the BAU scenario, the trends of the probabilities of both models were similar for all market segments of the selected case study area. An example of the produced results for the household type of young employees in professional and managerial occupations is presented in Table 6.8.

Table 6.8: Probabilities of MIM and of car ownership model of DELTA

Household Type	Probabilities from MIM			Probabilities from existing car ownership model		
	Probability of owning no car	Probability of owning 1 car	Probability of owning 2+ cars	Probability of owning no car	Probability of owning 1 car	Probability of owning 2+ cars
Young employees in Professional and managerial occupations	0.21472	0.42115	0.36413	0.204058	0.497791	0.298151

6.9 Validation of the results from the selected case study

6.9.1 Selected scenarios for the sensitivity analysis

In this section the sensitivity analysis carried out for the validation of the produced results is presented. In total nine scenarios were created based on the assumptions made from the literature.

More specifically, two scenarios were created for analysing increasing trip rates and seven scenarios were created for analysing effects on accessibility.

Table 7.9 includes the scenarios related to changes in trip rates and the reason that these scenarios are chosen, is because they refer to all kinds of vehicle technologies examined in this project, as well as the options of SAVs. Moreover, they are specified for different age groups, which can provide interesting and realistic results, when modelling in a LUTI model like DELTA, as the adoption rates of different transport innovations change among different age groups.

Table 6.10 consists of the scenario details for accessibility evaluation. The examination by Nahmias-Biran *et al.* (2020) is focused on scenarios of different spatial adoption in an urban area of automated mobility on-demand service (Nahmias-Biran *et al.*, 2020). These scenarios combine a new vehicle technology as well as a business model examined in this project and the results would be important for the analysis on the urban scale. However, scenarios on the regional scale of analysis should be included as well and Luo *et al.* (2019) investigates accessibility scenarios in both regional and urban levels of analysis, while considering private automation and the adoption of automated mobility of demand (Luo *et al.*, 2019). Being able to investigate changes in accessibility in different scale levels of analysis is essential for this project

Table 6.9: Trip Rates Scenarios

Trip Rate Scenarios	**Reference**	**Results**
Scenario 1: Increase of 5% for trips by children and the elderly as a result of both privately owned CAVs and SAVs.	Bernardin et al. (2019)	Increase in total number of trips
Scenario 2: Increase of 10% in trip rates for work trips as a result of automation (Lavieri & Bhat, 2019).	Truong et al. (2017) and Lavieri & Bhat (2019) cited in: Dias et al. (2020)	Scenario 2: Increase in total number of trips CAVs

Table 6.10: Accessibility Scenarios

Scenarios for Accessibility	Reference	Results
<u>Scenario 1:</u> AMoD/SAVs applied only in urban centres with ODT in other urban areas <u>Scenario 2:</u> AMoD/SAVs applied city-wide without ODT in other urban areas	Nahmias-Biran et al. (2020)	<u>Scenario 1:</u> Higher accessibility to the city centre, but disbenefit for residents of the suburbs <u>Scenario 2:</u> Higher accessibility in the whole modelling area
<u>Scenario 1:</u> Low trust in automation with 10% of people owning a CAV and 2% AMoD/SAV until 2030. <u>Scenario 2 – 4:</u> Higher level of trust in automation, with number of shares for both privately owned CAVs and AMoD/SAV increasing from scenario 2 to 4 util 2030. <u>Scenario 5:</u> Exclusive sharing autonomy with no both privately owned CAV and high level of trust until 2030. *This analysis was conducted a regional basis.*	Luo et al. (2019)	<u>Scenario 1 – 5:</u> Accessibility being higher (across all scenarios) gradually in remote areas across the region, in remote areas which encourages people to travel further and cause urban sprawl in the urban cores of the region.

6.9.2 Trends from trip rates scenarios

Starting the analysis from the paper of Bernardin et al. (2019) it is evident from the results that there is an 44.89% increase in the total number of trips, this trend also occurs at a percentage of 6.67% based on the modelled results for West Midlands when simulating Scenario 1 from the paper of Bernardin et al. (2019). Moreover, the same trends can be found in respect to trip lengths. More specifically, the analysis of Bernardin et al. (2019) indicates that the average trip length is decreasing by 13.29% and the total VHT have an increase by 43.75%. The same trends are found in the simulation scenario for the sensitivity analysis compared to the BAU scenario, as the average trip length is decreasing by 8.2% and the total VHT have an increase by 11.19%.

Following with the analysis of Dias et al. (2020) the scenario of increased trip generation is modelled and compared to BAU scenario. Similar to the results of Bernardin et al. (2019), the results from the modelled scenario of Dias et al. (2020) indicated an increase of 2.92% in the total number of trips and an increase by 2.81% in total VHT. The produced results from the sensitivity analysis simulation scenario for West Midlands in DELTA, which was created based on the assumptions of the respective scenario of Dias et al. (2020), follow the same trends for the total number of trips and the total VHT. More specifically, the total number of trips increased by 2.95%, the total VHT increased by 5.55%

It should be noted here that it is expected that the percentage changes from the sensitivity analysis scenarios to the BAU scenario for West Midlands will not be similar to the exact percentages found in the selected research papers, however having similar trends is an indicator that the modelling procedure provides reliable results.

6.9.3 Trends from accessibility-based scenarios

Figure 6.17 includes cartographical representations of the results regarding accessibility changes in the scenarios that were created in DELTA, based on the assumptions by Nahmias-Biran et al. (2020), compared to the BAU scenario.

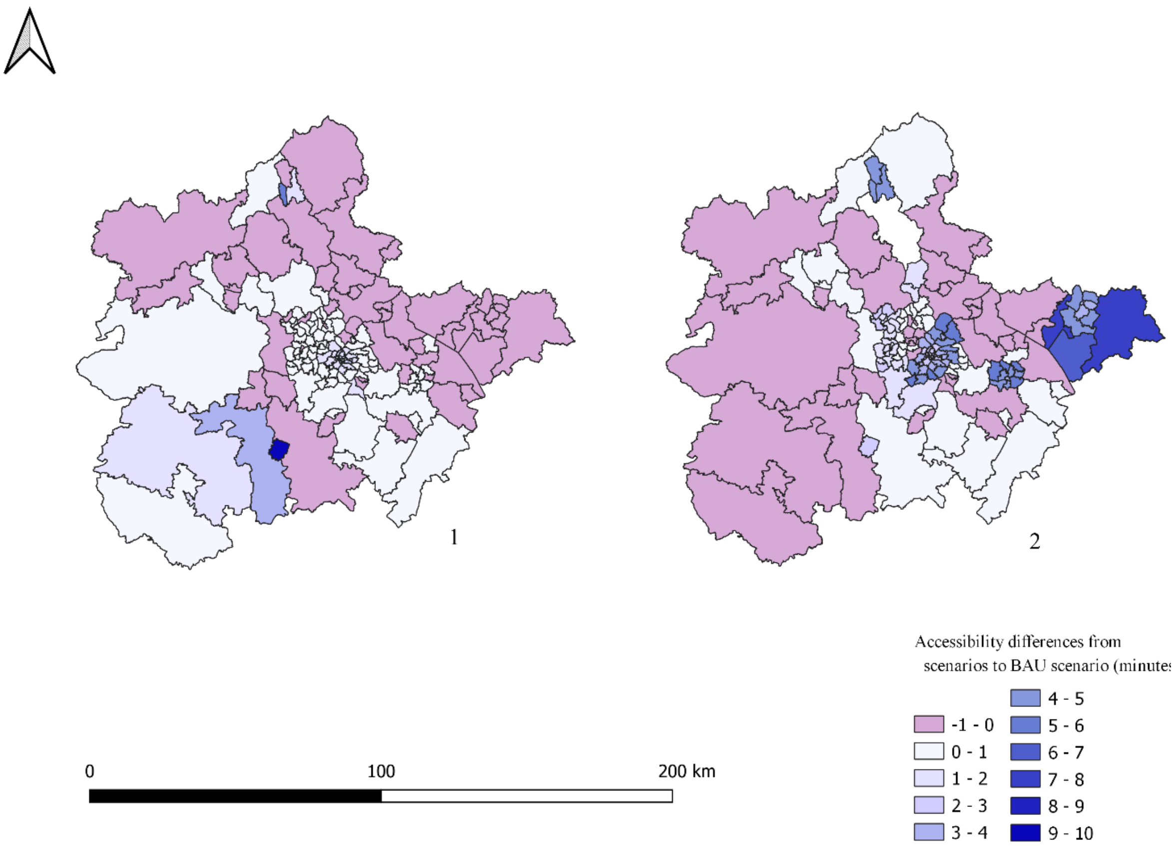


Figure 6.17: Validation by Sensitivity analysis, Accessibility scenarios based on the assumptions of Nahmias-Biran et al. (2020)

The analysis of Nahmias-Biran et al. (2020), is conducted at an urban scale to simulate Singapore, thus the comparison of results regarding accessibility for this sensitivity analysis are mainly focused for the two major urban cores of the West Midlands region, namely Birmingham and Coventry.

The time-based accessibility changes in the study of Nahmias-Biran et al. (2020) from both test scenarios to the BAU scenario, follow the same patterns to the scenarios created in DELTA. It is evident from the maps that in the first test scenario, the urban areas of Birmingham and Coventry have an increased accessibility in the CBDs, but the accessibility in the outskirts of the cities has been decreased by 1 minute. On the other hand, when the assumptions of scenario 2 of Nahmias-Biran et al. (2020) are modelled in DELTA and compared to the BAU scenario, accessibility is increased in all zones of Birmingham and Coventry.

In Figure 6.18 the results of accessibility changes in the scenarios that were created, based on the assumptions by Luo et al. (2019), compared to the BAU scenario are presented.

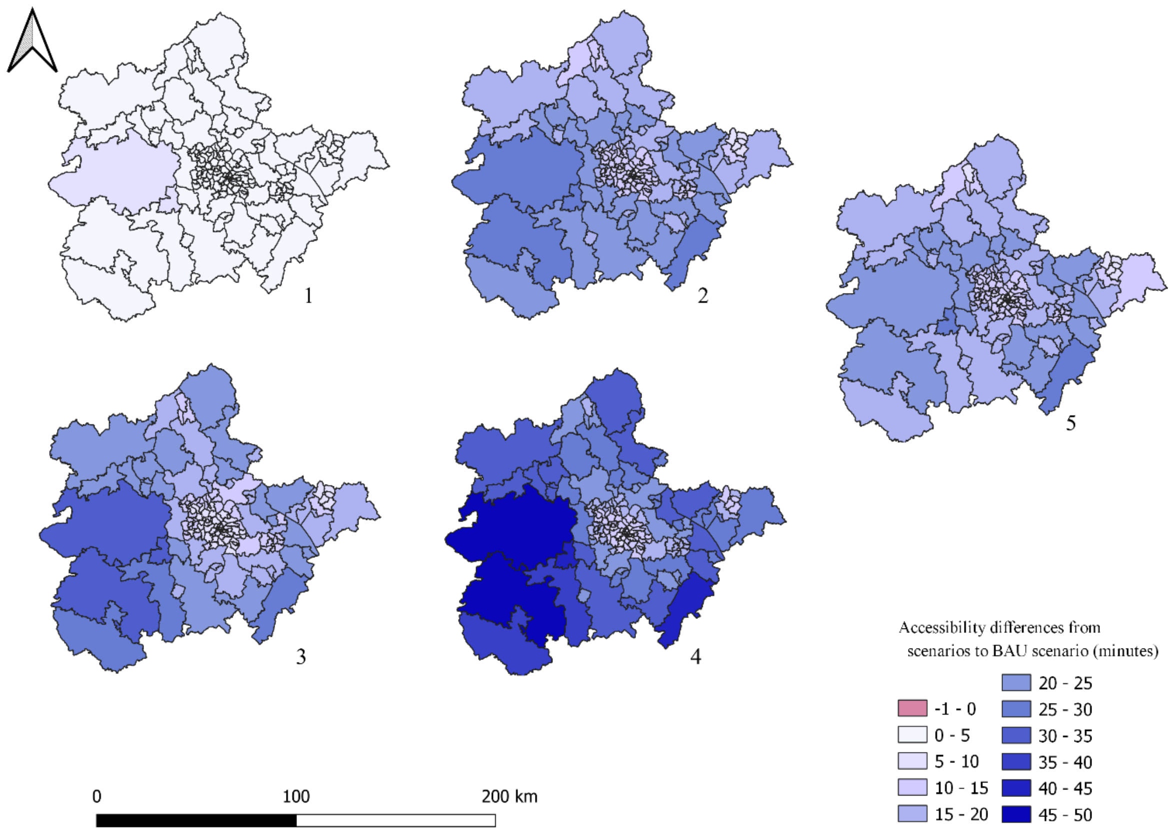


Figure 6.18: Validation by Sensitivity analysis, Accessibility scenarios based on the assumptions of Luo et al. (2019)

Five scenarios were created in DELTA for West Midlands, based on the assumptions made in the respective scenarios by Luo et al. (2019). The results from this analysis are in line with the conclusions of Luo et al. (2019), because it can be seen from the accessibility maps of the Figure 6.18 the increase of accessibility is proportional to the increase of private autonomous vehicles and to the increase in SAVs. More specifically, as also concluded for the Gunma Prefecture in Japan by Luo et al. (2019), accessibility gains are higher in remote areas in the region, while at the same time accessibility is also increasing in cities but at smaller rates.

6.10 Discussion on the application of the new methodological framework and its principles

As it can be inferred, from the analysis discussed in this chapter, the application process of the methodological principles, for elements such as the value of time of CAVs and SAVs for different trip purposes, car ownership costs and levels, trip rates, road capacity and penetrations of new vehicle technologies in the fleet, is in line with the conclusions derived from the analysis of the literature, but also with the conclusions from the Delphi method presented in 5.3.1.5.2.

However, further attention is paid to elements of the Delphi analysis for which there were lower levels of consensus. More specifically, from the conclusions of the Delphi survey it is evident that there is uncertainty, regarding the reduction of road capacity due to connectivity. For this reason, a sensitivity analysis was conducted to understand further the effects of changes in the PCU value, by applying the methodological framework presented in the West Midlands region for modelling new vehicle technologies. The results from this analysis indicated that the scenarios with increased road capacity, had higher changes in population and employment, however the spatial redistribution of activities in space in the future will not be as balanced as in the scenarios that the PCU value remained equal to 1. Moreover, it should be noted, that scenarios with increased road capacity indicated a higher financial benefit for the regional urban cores. Finally, it was also found that higher urban sprawl regarding the residential location of retired population could be expected. Further information regarding this analysis can be found in Sarri *et al.* (2023). This effect of more pronounced results from increased road capacity could be beneficial to policy makers, thus this provides and additional reason for incorporating a lower PCU value in the modelling procedure.

Chapter 7 Results

In this chapter, the results of the future scenarios are compared those of the Business as Usual (BAU) scenario, in order to identify land use effects from the change that can occur with the existence of the new vehicle technologies and new transportation business models. Analysing these results will be an important step for drawing conclusions.

7.1 Results and Discussion

7.1.1 Results

The examination of the results will be based on two elements. The first is the examination of time series of population and employment in the whole region of West Midlands and also specifically Birmingham and Coventry for the selected modelled time period. The two cities are examined as well as the region, because the analysis is conducted for both the regional level of analysis and the urban level of analysis and these two cities are two important financial cores with the largest populations in the region (West Midlands Combined Authority, 2015). Assessment of population and employment change is often used for urban and regional analysis and planning (Small & Song, 1994), because they influence a number of elements in an area, for example economic activity, road safety (Kim et al., 2006), accessibility, and the environment (Quirós & Mehndiratta, 2015), which can lead to different decisions regarding regional, urban and transport policies.

The second element is the investigation of the spatial distribution of these changes for Birmingham, West Midlands, and Coventry. For this purpose, cartographical representations of the final results have been created. The variables represented in the maps are employment, population, and housing rent. Population, however, is separated into resident working adults and retired, because these groups, depending on the area, might to have opposite trends, because they seek accessibility for different areas (Zondag & Pieters, 2005).

7.1.2 Graphical representations

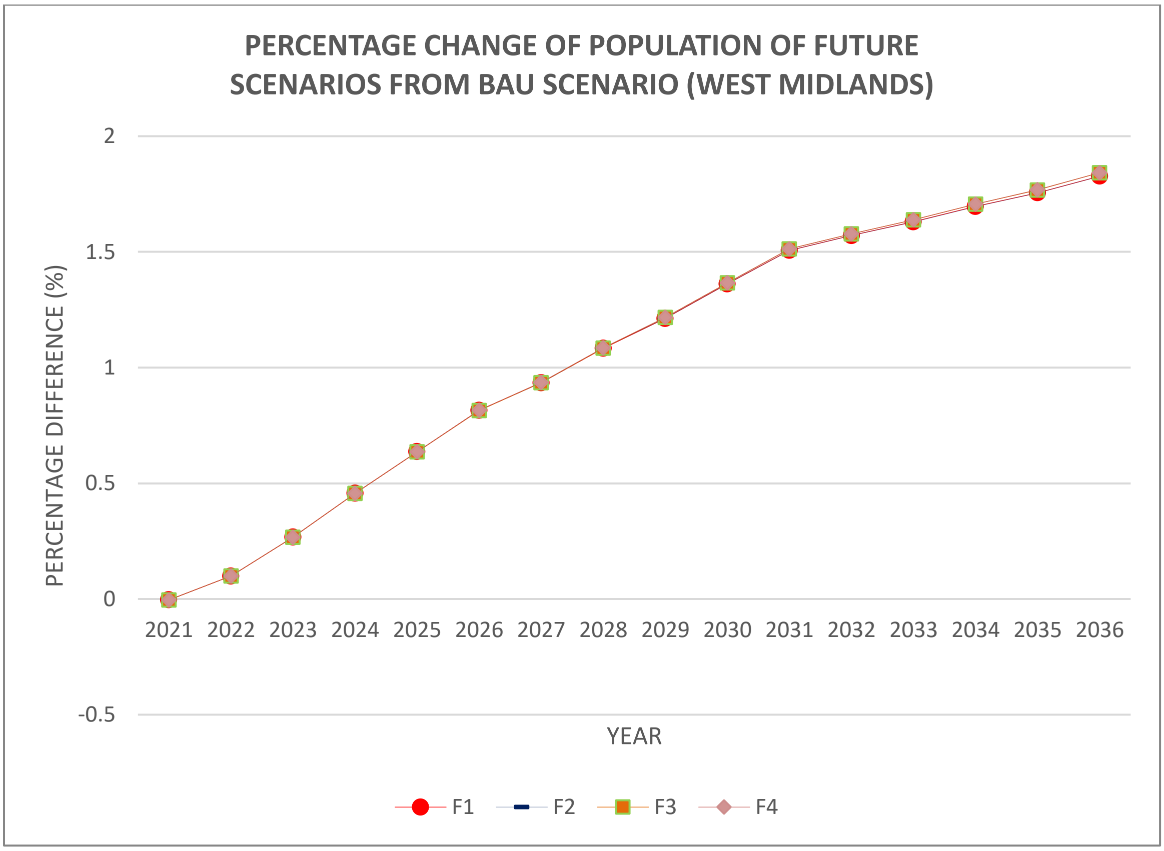


Figure 7.1: Percentage change of population of future scenarios to BAU scenario for the region of West Midlands

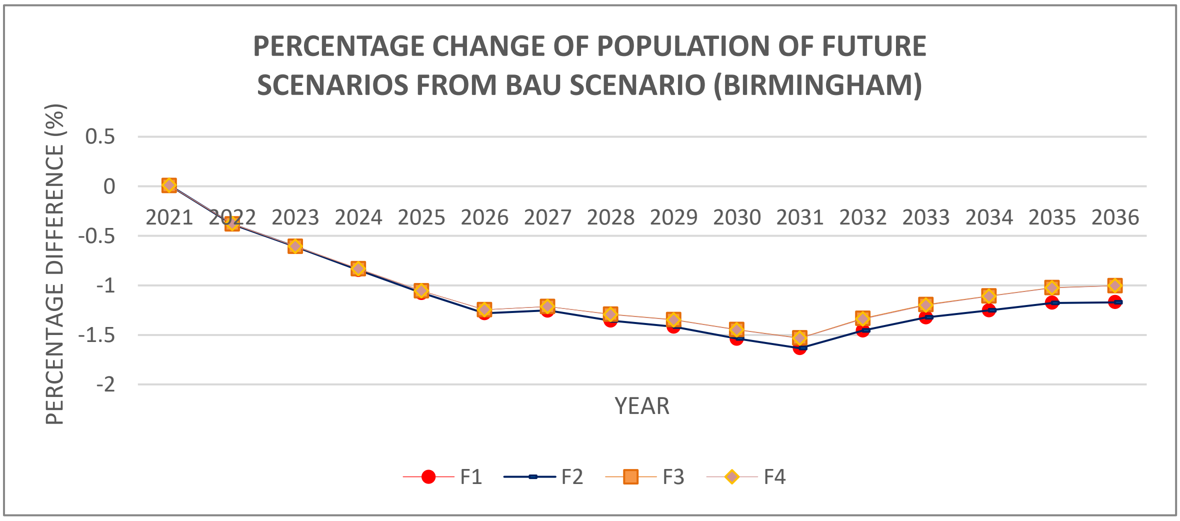


Figure 7.2: Percentage change of population of future scenarios to BAU scenario for the city of Birmingham

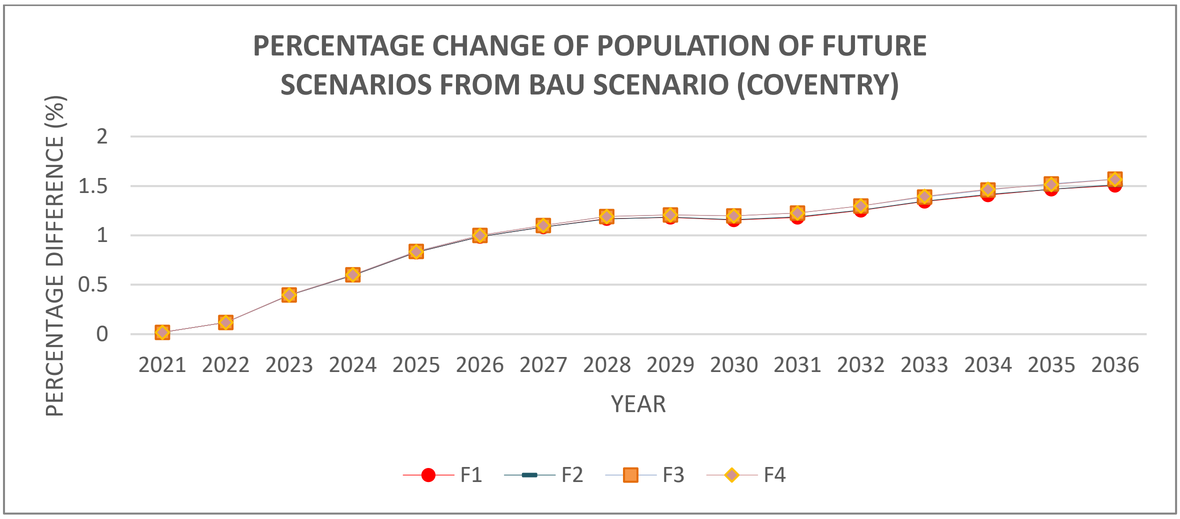


Figure 7.3: Percentage change of population of future scenarios to BAU scenario for the city of Coventry

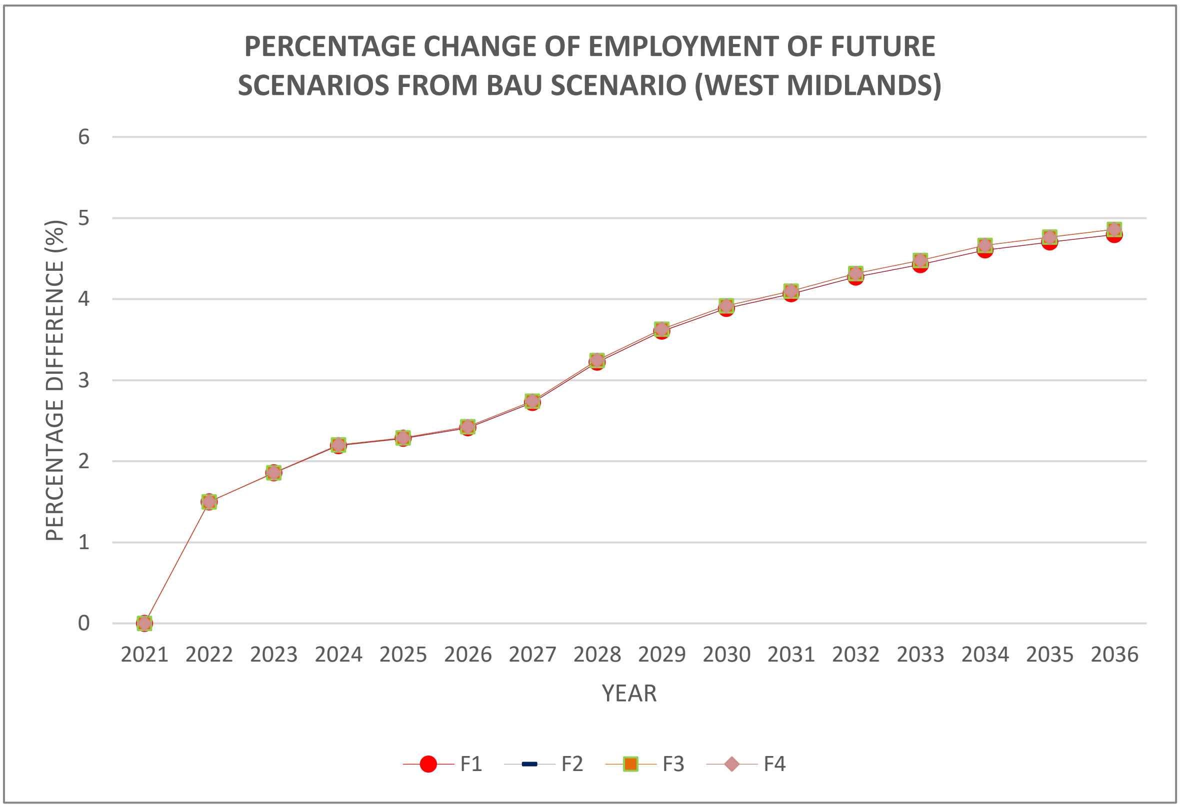


Figure 7.4: Percentage change of Employment of future scenarios to BAU scenario for the region of West Midlands

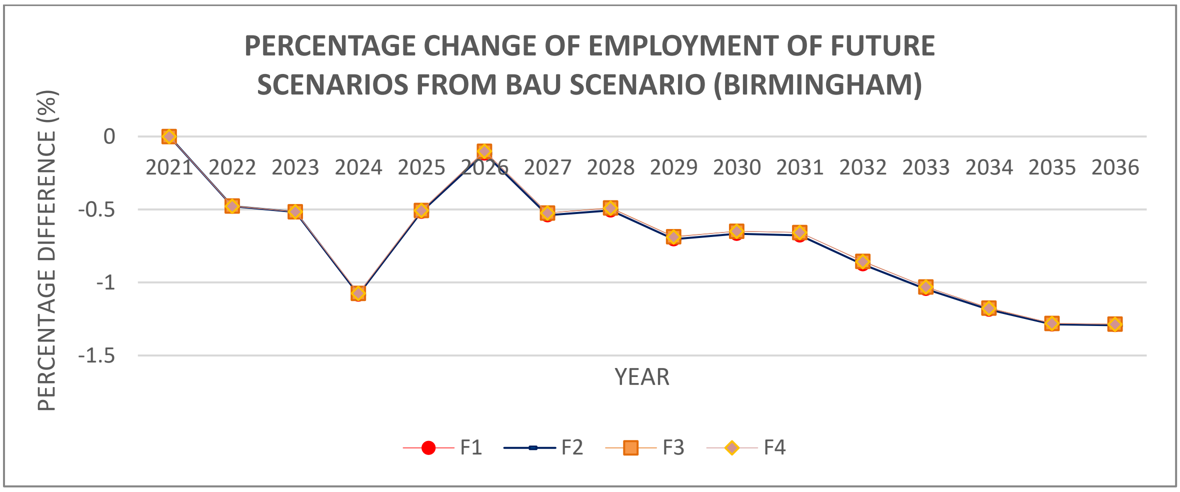


Figure 7.5: Percentage change of Employment of future scenarios to BAU scenario for the city of Birmingham

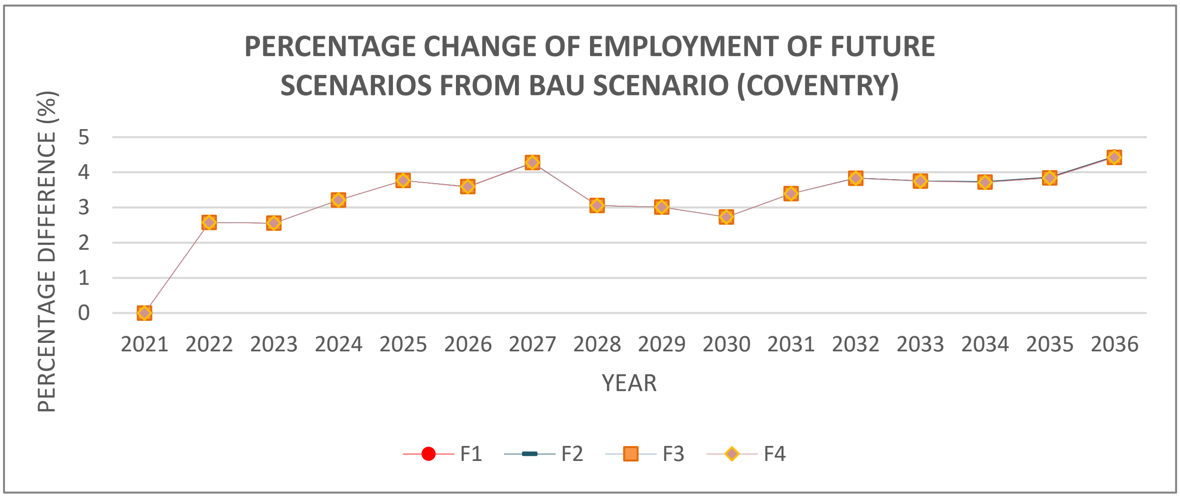


Figure 7.6: Percentage change of Employment of future scenarios to BAU scenario for the city of Coventry

The figures in this section represent timeseries with population and employment changes in the study area. It should be noted that the trends in all four future scenarios, namely F1, F2, F3 and F4, compared to the BAU scenario are similar. This is an indicator that neither higher adoption rates in the CBDs nor working from home up to 30%, may have an additional effect on regional and urban total population and employment trends and that the results are not sensitive to those elements.

Regionally, population and employment are increasing in comparison with the BAU scenario in all future scenarios. Here it should be noted that population and employment would increase even if none of the new transport technologies and business models were incorporated in the transportation system, based on the results of the BAU scenario. This is because of competition with different regions and also migration and it can be further validated by examining the estimated data of Birmingham City Council (2018). The results from this analysis indicate that by 2033 total regional population in West Midlands expected to be more than 6,560,000 (Birmingham City Council, 2018). However, the existence of new transportation technologies and business models has brought an additional gain to these increasing trends.

Employment is regionally changing more rapidly than population and thus higher percentage changes occur. Overall, for both variables there is an upward trend for each simulation year. The reduced generalised costs for the private car and the existence of alternative transport options (i.e. MaaS, On Demand Transport and Car Sharing) has increased accessibility and brought financial opportunities in the whole region (Volpati & Barthelemy, 2020; Rantasila, 2015). These results are in line with the conclusions of Gelauff, Ossokina & Teulings (2019) and Rantasila (2015).

At an urban level, the results are different from the total regional results as the trends of population and employment in Birmingham are decreasing and in Coventry are increasing. Differences in forecasts of population and employment based on whether the cities in a regional area are core or medium, caused from shared or private CAVs, were also captured in the analysis of Llorca *et al.*(2022). This indicates that there is a tendency for urban sprawl from Birmingham because the city with the highest population and employment in the region is losing financial power. However, the trends of Birmingham are not and high is absolute value as in Coventry. For example, for population the results of the final simulation year indicate a -1% decrease in Birmingham and a 1.5% increase in Coventry and even more interesting is the effect on employment, for which in the last simulation year there is a decrease of less than 1.5% in Birmingham and an increase of more than 4% in Coventry. Those results at the urban scale indicate that the existence of new transport technologies and new transport business models may provide a benefit to the smaller urban cores in the region, while at the same time the major urban areas face a slight decrease, which does not however indicate a change of form. The results from the analysis of Luo et al. (2019) agrees with these results, as the lowest increase in accessibility after vehicle automation in the region of Gunma in Japan occurred in Maebashi, which is that capital of the region (Luo et al., 2019).

Another interesting element regarding employment, is that from 2024 to 2026 in Birmingham the downward trend and the results is equal to those of the BAU scenario. In the following years, there is again a decreasing trend in employment in the city. Interestingly, this phenomenon happens for the simulation years that the slope of the total regional employment (Figure 7.4) is the smallest from all simulation years. Thus, for the years that employment is disproportionate comparing the regional results to the results of Birmingham. Moreover, it should be noted that in

2030 the slopes in all the presented graphical representations are higher comparing to the previous simulation years. This is expected, as in the UK by 2030 the sales of new petrol and diesel vehicles will not be allowed, which leads to higher proportions of EVs in the fleet and as a result higher rates of reduced generalised costs.

As a result, it is evident that the region has some financial advantage from the adoption of new vehicle technologies and new transportation business models, but the result on the urban cores may vary. To examine this holistically the spatial distribution of these results is essential to be investigated.

7.1.3 Cartographical representations

In this section the results are examined spatialy to determine the effects on the redistribution of activities in the region. For this reason, cartographical representations were created and all of them and were projected in the projection system of British National Grid (OSGB 1936), with Greenwich as prime median and Airy 1830 ellipsoid (Olliver, 2012).

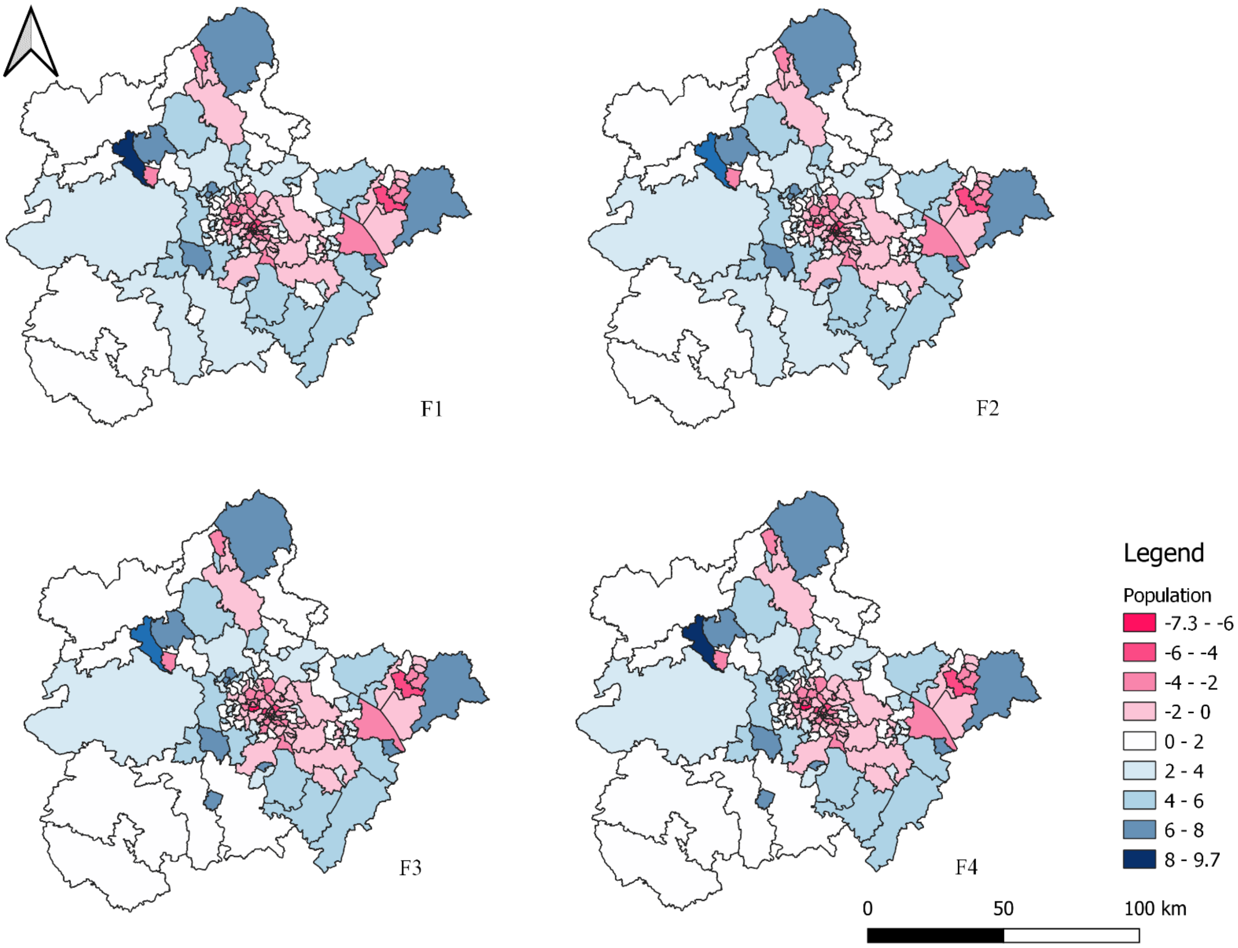


Figure 7.7: Spatial distribution of Percentage change of Population of future scenarios to BAU scenario for the final simulation year

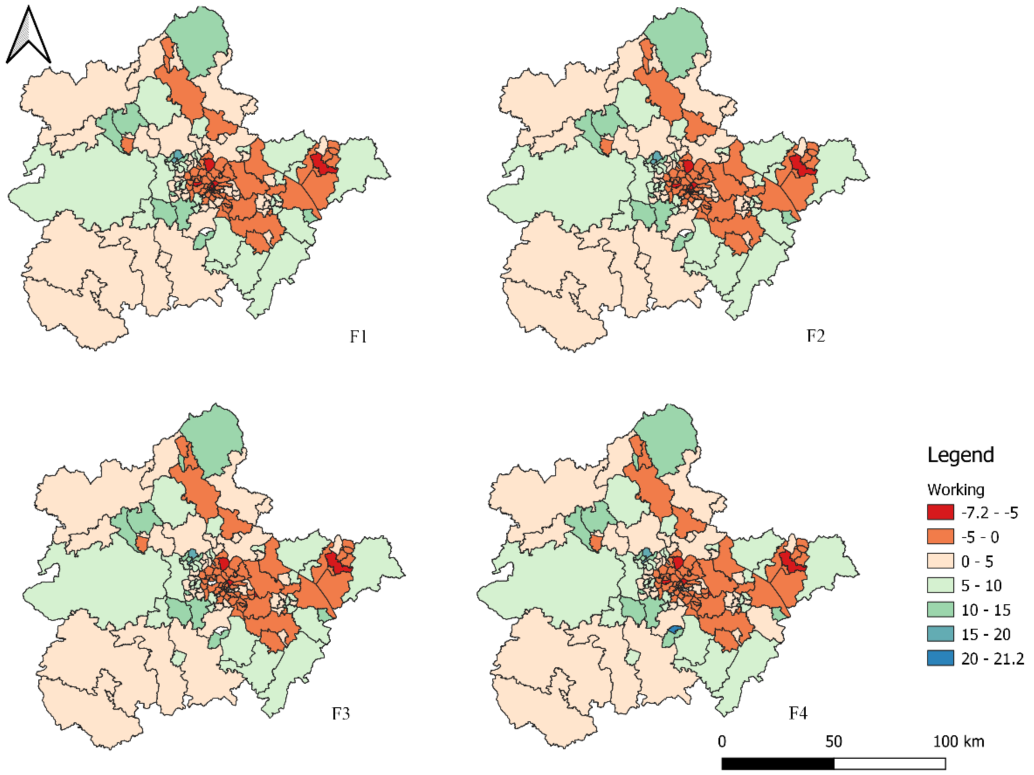


Figure 7.8: Spatial distribution of Percentage change of Working Adults of future scenarios to BAU scenario for the final simulation year

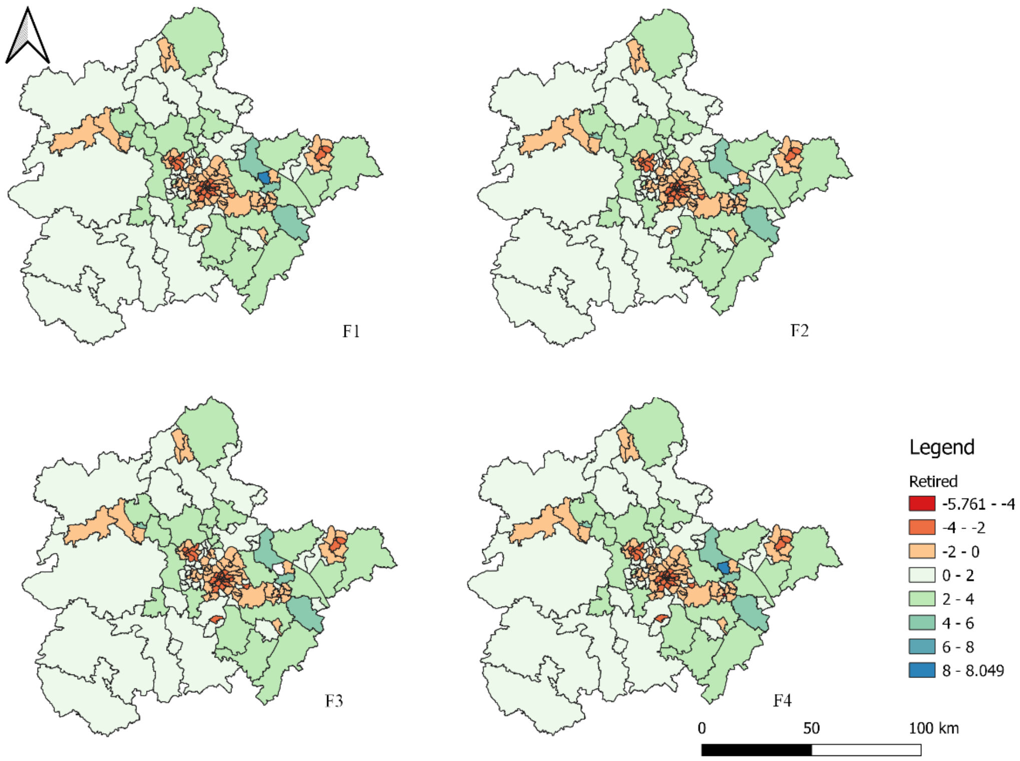


Figure 7.9: Spatial distribution of Percentage change of Retired Population of future scenarios to BAU scenario for the final simulation year

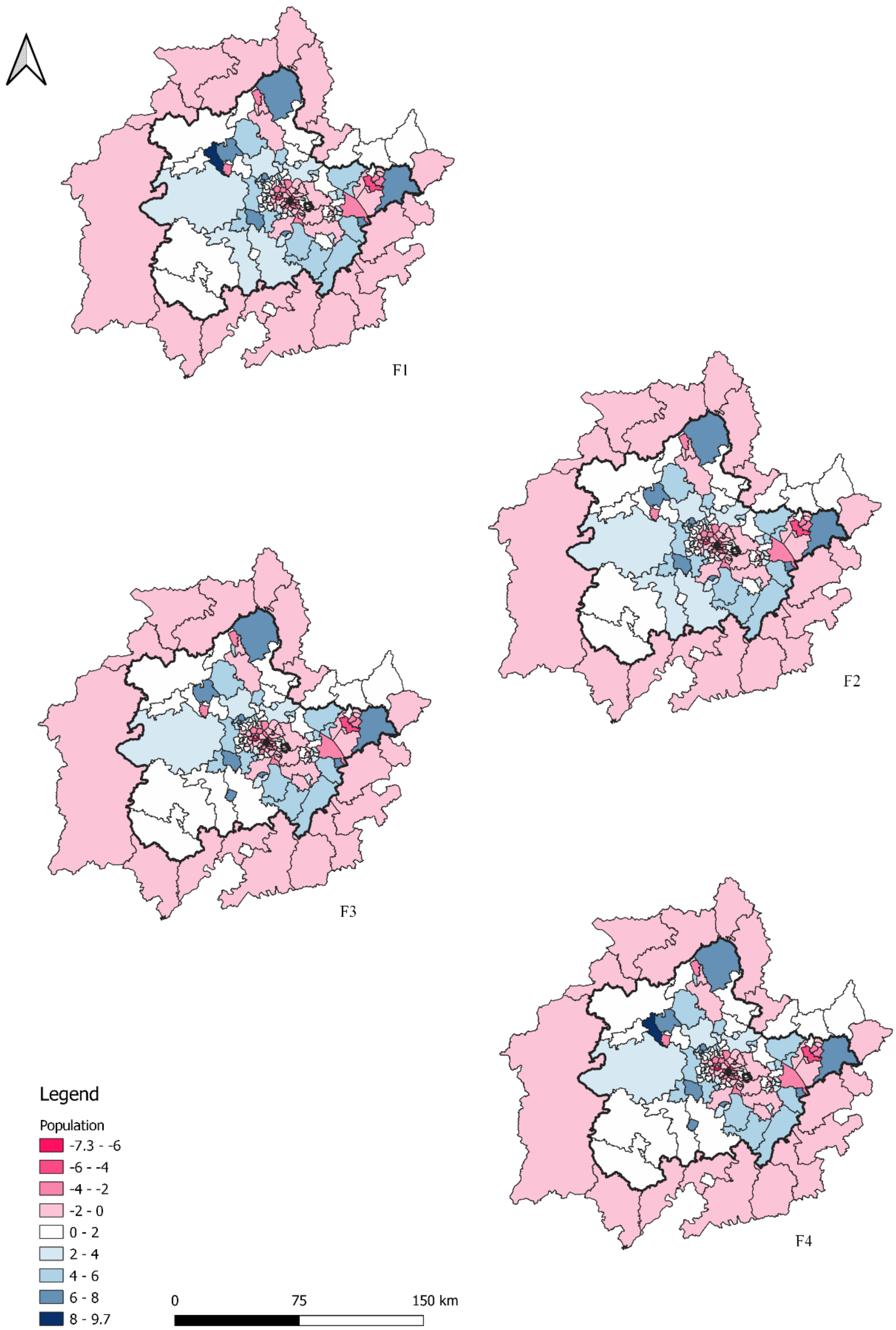


Figure 7.10: Spatial distribution of Percentage change of Population of future scenarios to BAU scenario for the final simulation year (Buffer Zone Examination)

The spatial distribution of the results of population are presented in Figure 7.7, Figure 7.8, Figure 7.9 and Figure 7.10. From Figure 7.7 t is evident that all four future scenarios follow similar patterns in terms of future spatial distribution of population, however, there are some differences. Firstly, in the west external zone of Shrewsbury there is a slightly higher increase of population in scenarios F1 and F4 comparison with F2 and F3. Overall, population is decreasing in Birmingham, Stoke-on-Trent and Warwick and increasing in Coventry, Wolverhampton, and Worcester. Interestingly, the existence of higher adoptions rates of CAVs in the fleet, simulated in scenarios F3 and F4, has provided a benefit to the city of Worcester, which is a main urban core in the south of the region. It also important to note that based on results of the scenarios F3 and F4 the two external zones of Worcester are affected for the higher adoption of CAVs in the CBDs, as they have been classified to have an increase of 0% to 2%, which is different from scenarios F1 and F2, in which these zones have been classified to the next higher cluster of population increase. Moreover, even though as seen in the previous section total population is increasing in Coventry, the spatial distribution of population indicates that population is increasing in the east zones of the city, while on the western zones of Coventry there is either a minor decrease or no change. It is very interesting to note that in all cases the external zones of the West Midlands County have increased population and the majority of the zones in the West Midlands County have population decreasing, with the exception of Coventry and Wolverhampton, that however belong in the outskirts of the county. These trends indicate urban sprawl in terms of population from the main urban cores to smaller urban centres or to other rural areas. Similar conclusions were also derived in the respective scenarios from the analysis of Coppola & Silvestri (2019), as in the metropolitan area of Rome, the city centre has some minor reduction of population, but the urban outskirts face significant increases of population (Coppola & Silvestri, 2019).

To examine the results of population in more depth, the spatial distribution of population and employment for Working adults and Retied population for the last simulation year was cartographically represented in Figure 7.8 and Figure 7.9. Working population follows similar patterns of spatial distribution to the general population presented in Figure 7.7, which can be expected as the majority of population in the region has been classified as Working adults by UK Office for National Statistics (2019). However, the spatial distribution of Retired population is different from the previous categories. From Figure 7.9 it is evident that regardless the size of the city, all urban cores have decreased retired population and increased retired population has been seen in peripheral zones of cities, with more attractive being the zones on between cities and not the western zones that neighbour with Wales and generally have lower density in the road and rail network.

Finally, since he available DELTA application model considers the influence of external zones to the West Midlands region and vice versa, an examination of the buffer zones surrounding the region is conducted and represented in Figure 7.10 to investigate possible effects from new transportation technologies and business models to the regions that neighbour with the selected case study. Based on these results, the increased total population in the region can be further explained as it is evident that population has been attracted to the region from the adjacent zones.

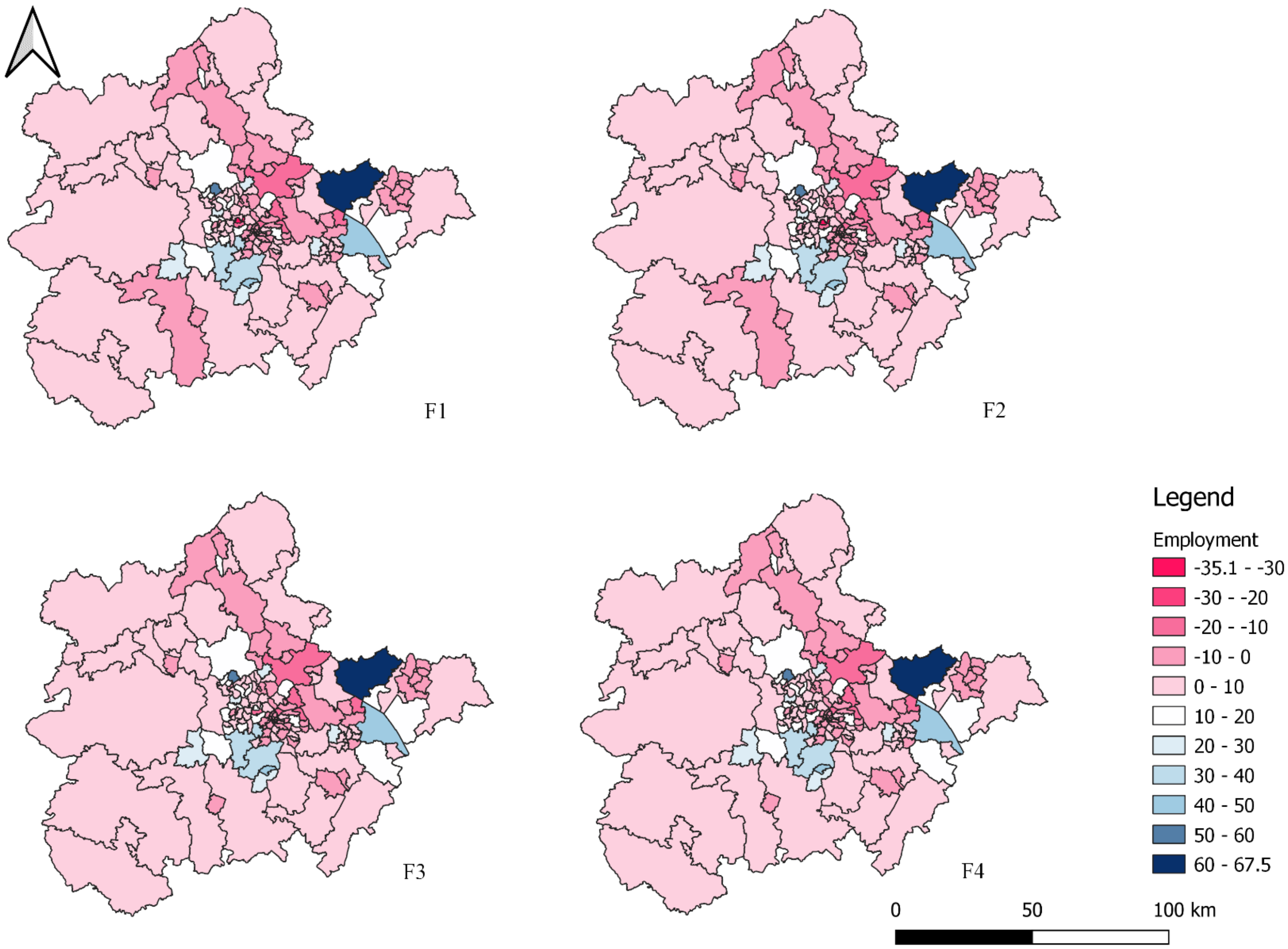


Figure 7.11: Spatial distribution of Percentage change of Employment of future scenarios to BAU scenario for the final simulation year

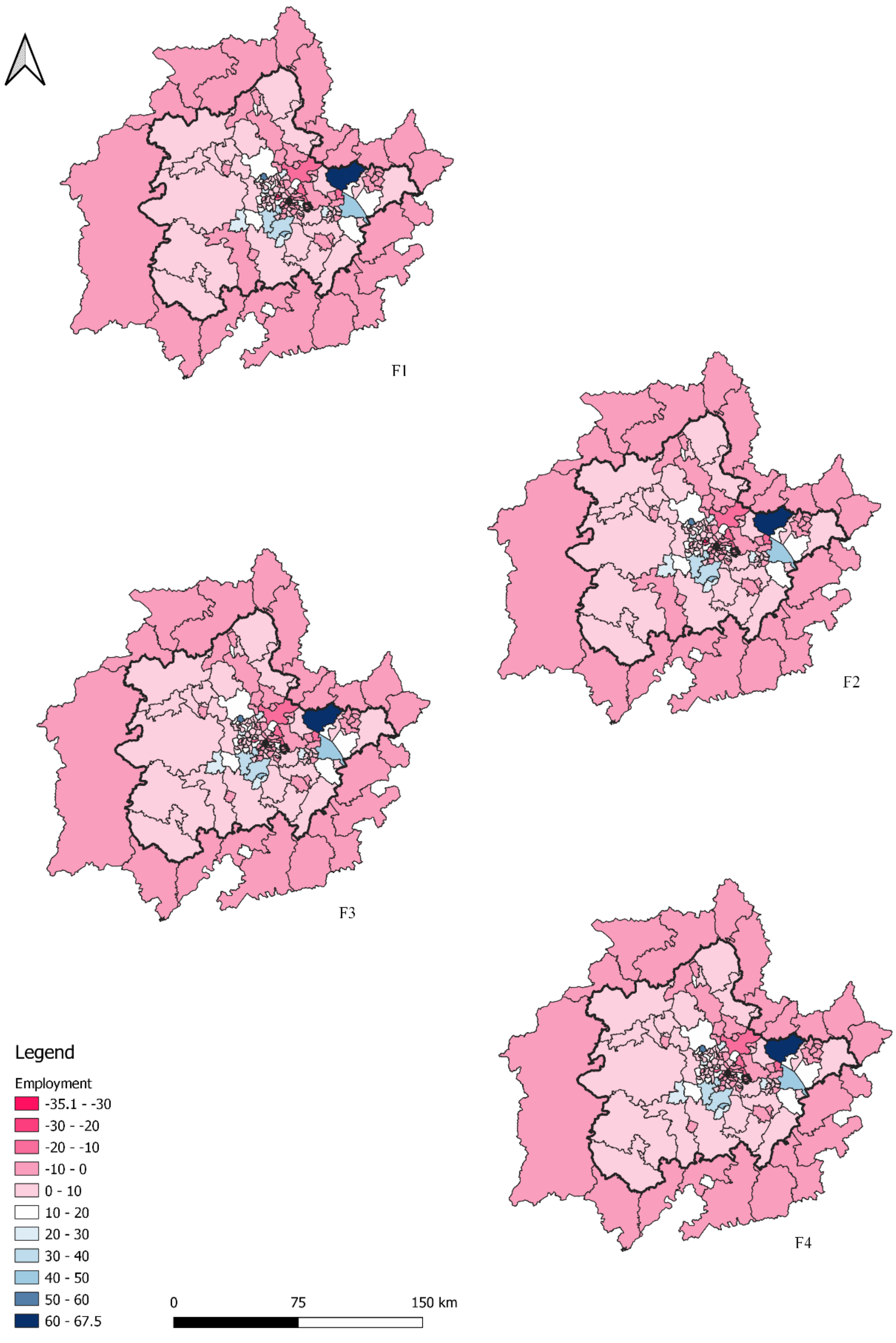


Figure 7.12: Spatial distribution of Percentage change of Employment of future scenarios to BAU scenario for the final simulation year (Buffer Zone Examination)

The results regarding the spatial distribution of employment are presented in Figure 7.11 and Figure 7.12. The spatial distribution of employment in the region follows different patterns to spatial distribution of population. It is evident that the zones in the outskirts of the region and CBDs have reduced employment by the end of the simulation period comparing with the results of the BAU scenario, especially those close to the most populous urban cores, namely Birmingham and Coventry. The zones that have increased employment are located in areas between major urban cores, for example between Birmingham and Worcester, Wolverhampton, and Stoke-on-Trent and to the zones northwest to Coventry and Birmingham. This shows that urban cores across the region attract employment. Thus, even though the total employment in the region in increased, as shown in section Figure 7.4, the development is not balanced. This phenomenon is not evident regionally, but at an urban scale as well. For example, as already mentioned total employment in Coventry is increasing, but as it is evident from Figure 7.11, this increase is in the westerns zones that belong in the outskirts of the city, whereas the CBD has decreased values of employment for all future scenarios. Moreover, in scenarios F1 and F3, where there was not further adoption of CAVs in the fleet, the zone west of Worcester has a higher reduction of employment in comparison with scenarios F3 and F4 and this slight difference can also be seen in the graphical representation of total regional population in Figure 7.4, as there is slightly smaller increase for scenarios F1 and F2. As a result, the increased accessibility from new transportation business models led to increased employment in the outskirts of the cities in the region.

As also conducted for population, the adjacent zones that neighbour with the West Midlands region are presented in Figure 7.12. It is evident that employment is decreasing in these zones and as a result attracted to the region, which is similar to the effect of population.

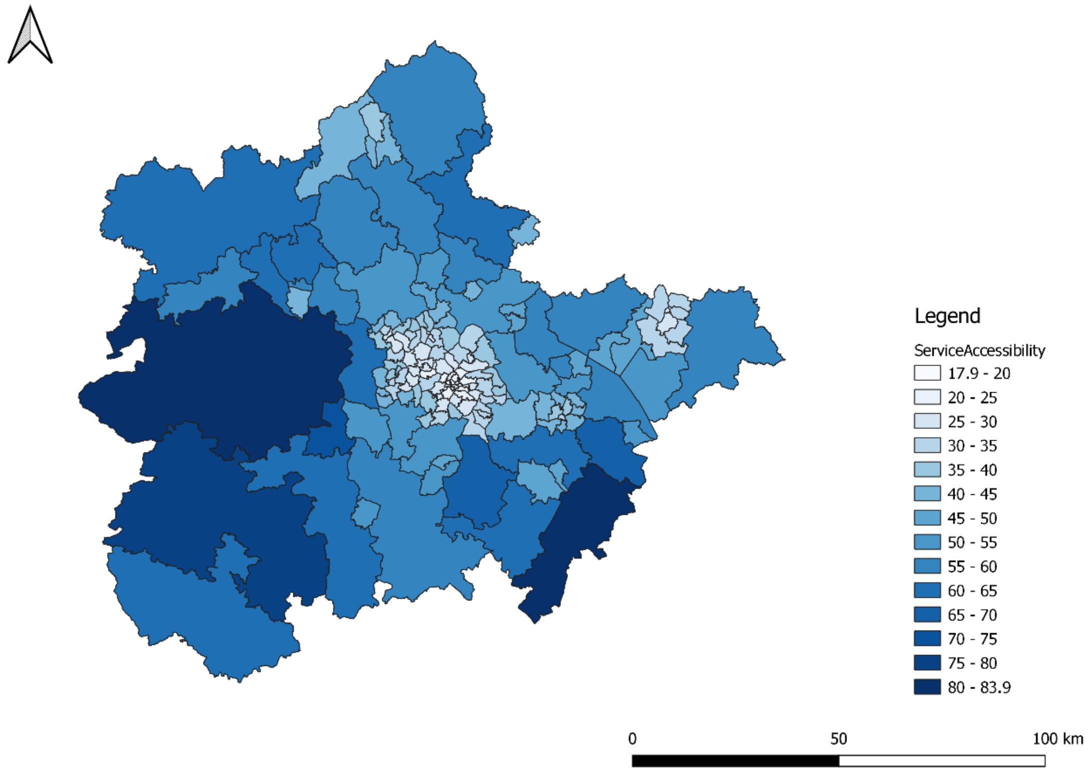


Figure 7.13: Spatial distribution of generalised time difference of Accessibility to Services of future scenarios to BAU scenario for the final simulation year

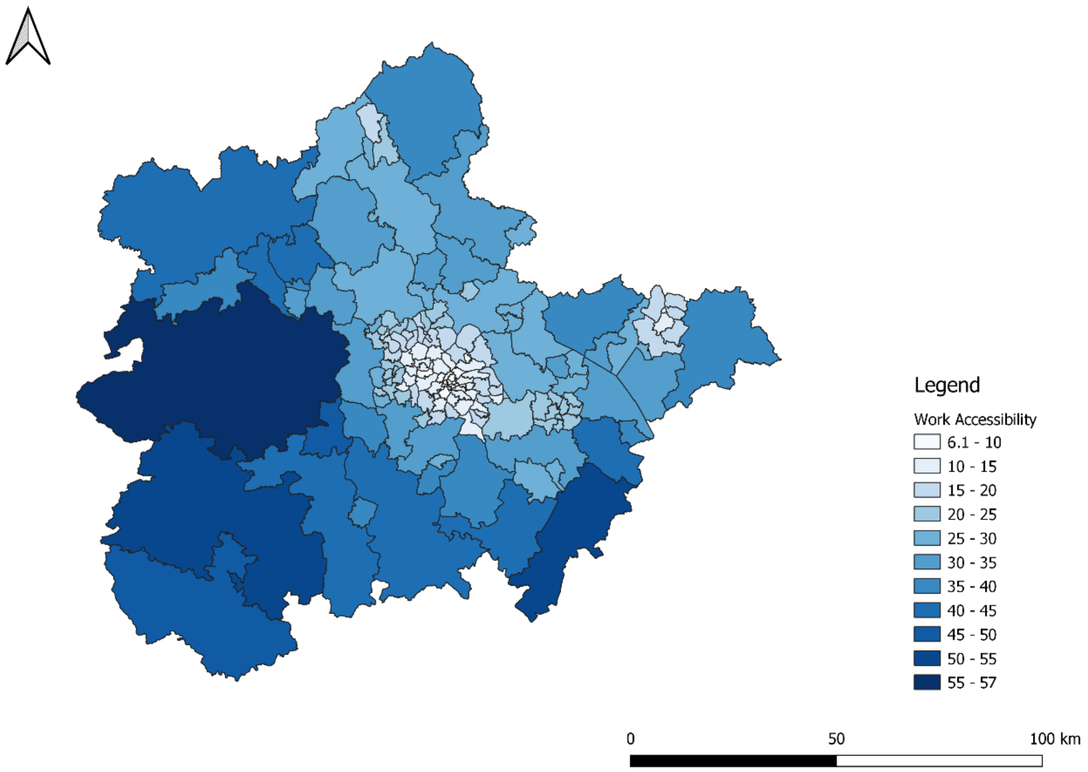


Figure 7.14: Spatial distribution of generalised time difference in Accessibility to Work of future scenarios to BAU scenario for the final simulation year

In Figure 7.13 and Figure 7.14 accessibility to work and accessibility to services is cartographically presented showing the differences in generalised minutes from the future scenarios to the BAU scenario. The reason why in the two figures only one map is presented is because for all future scenarios the cartographical representations spatial distribution of generalised time difference in accessibilities were similar, indicating that the differences in land use across scenarios did not occur from the accessibility differences, which are directly linked to generalised cost in DELTA, but from the differences in the other modelled variables, for example car ownership cost or trip rates. Both accessibility to work and accessibility to services are increasing, especially in the outskirts of the region, where the road and rail network are not dense. Comparing these results, to the analysis conducted by Sarri *et al.* (2023) where only new vehicles technologies were modelled in the system, it should be mentioned that the increases in accessibility are much higher in the same case study, and this can be linked to the co-existence of new transportation vehicle technologies and new business models, which allowed more people to travel with lower costs to more remote areas of the region.

7.1.4 Discussing the validity of the produced results based on the conclusions from the Delphi survey

As already presented in section 6.9 the developed methodology produces results that can be reliable. However, it also very important to compare the results with the conclusions that were derived from the Delphi survey, presented in section 5.3.1.5.2, regarding the effects of new transport technologies and business models on land use and accessibility.

Initially, it was concluded that residential and employment location choices would be affected from the increasing rates of people working from home. However, the results from this analysis are not sensitive to this phenomenon in terms of residential and employment location choices. There are two main reasons why activity location was not affected by the increased rates of people working from home. Firstly, as already mentioned the rate of people working from home was deemed 30% and it is possible that with a higher rate the spatial distribution of activities would have been further affected. Moreover, the land use impacts require long term simulations to indicate all differences among different test scenarios and thus a longer simulation period with a combination of higher rates of people working from home, could potentially indicate differences in term of residential and employment location choices.

Other important conclusions regarding land use impacts that were mentioned in the Delphi survey, were that new vehicle technologies and business models would increase total regional population and employment, which is in line with the results from the modelling procedure. Moreover, residential location choices of working adults changed at higher percentages in comparison with those of the retired population, phenomenon that agrees with the conclusions of the Delphi survey. Following, another important aspect mentioned in the validation by experts analysis is that the incorporation of transport business models and CAVs and EVs could attract population to peripheral regional zones and urban outskirts and this is evident in the results presented from the modelling procedure, in all future scenarios. Subsequently, the conclusions from the section 5.3.1.5.2 indicate that employment rates will be decreased in urban areas with high population and employment, which can be confirmed based on the simulation results related to employment. Finally, based on the accessibility results, it can be confirmed, based on the discussed conclusions from the Delphi method, the that both new vehicle technologies and business models increase accessibility and that higher accessibility is expected in the regional outskirts

Chapter 8 Conclusions

8.1 Summary and contributions

Transportation is changing in many different ways, with new technologies influencing the development of new vehicle types and business models related to transportation. These developments have been heavily researched by the academic community, in terms of the effects that they will have on different aspects of people's lives. This research project is focused on the effects of new vehicle technologies and business models on one of these aspects and more specifically land use. To investigate this subject in more depth five objectives have been formulated and the research at subsequent levels is based on these objectives.

Initially it was noted from the literature that land use and transport interact and that models that combine the two aspects, namely Land Use and Transportation Interaction (LUTI) models, have been useful for projects that aim to predict land use or transport effects from different innovations. The methodological aspects of these models were analysed, in order to identify an LUTI model that would be appropriate for this analysis. After conducting a comparative analysis of different LUTI models, it was concluded that a model which is dynamic, not-fully integrated, able to work with multiple scales of analysis and employment sectors and that includes analytic land use processing, should be used for this project and this model is DELTA. The next section referred to identification of the specific technologies that the examination should be based on. There are many different new technologies and business models in the transportation sector, but since this thesis aimed to examine effects of passenger trips and also in order to investigate in depth interactions of urban cores a higher scale of analysis is used, a list of new transportation technologies and business models was specified. More specifically, new transportation vehicle technologies that refer to automation, connectivity and electrification, business models that rely on the principles of On-Demand Transport, Car Sharing and Mobility as a Service or combinations of these were discussed and presented. Subsequently, to connect these technologies within the chosen LUTI model, key elements that belong in LUTI models and are altered with the existence of new transport technologies and business models needed to be identified. After the examination of the transportation structure of three different LUTI models the identified key elements are generalised cost, trip rates, accessibility, and car ownership. Following this, a review on the effects that the selected transport innovations have on these elements was conducted. The conclusions of this examination were that generalised costs are reduced with the existence of new innovations, while it is expected that there will be benefits on accessibility. Moreover, it was also concluded that there are multiple effects on trip generation rates by these innovations and that the costs of owning a vehicle with new technological improvements is increased, but the level of ownership is decreased as a result of the higher accessibility from the new transport business models. The last element of the literature review was an examination of the types of surveys used for modelling the selected transportation technologies and business models and it was found in the literature that stated preference surveys or combined revealed preference and stated preference surveys are more suitable for such applications. Furthermore, after a review on the validation methods for LUTI models it was observed that sensitivity analysis is the method most used by different cases, especially for hypothetical situations where historical validation is not an option. Finally, based on the recommendations for future research by a number of research papers related to the subject, a gap in research related to this project was found. This gap refers to the holistic impact of the co-existence of new vehicle technologies and new transportation business models on land use and accessibility at different scales of analysis.

The methodology is the second element of this thesis, starting with the methodology principles and following with the application of the methodology principles in the specific context of this thesis. The chapter of the methodology principles was included to introduce the main structure and logic as well as the mathematical formulations of the new methodological framework.

Initially, it was noted that the for the model calibration, the concepts of generalised cost and car ownership should be used and that for validation, trip rates and accessibility scenarios should be formed, as the last two elements are used for such purposes in the literature. For vehicle technologies, the equation of generalised costs remains the same, while changing the values of vehicle operating costs and values of time based on the technology modelled. For business models, generalised costs functions were created to include the direct and perceived costs of a journey. To include the effect of vehicle connectivity in the transportation system, changes in road capacity were also introduced based on the conclusions from the literature. Continuing with car ownership, the total costs of ownership are estimated using a model from the literature and the concept of used and old cars is incorporated in this case to make the modelling more realistic. For business models a nested logit model, named Mobility Investment model (MIM), has been developed that aims to predict the probabilities of car ownership given the existence of new mobility services, as this element seemed to be of importance in the literature, thus deemed essential to be incorporated. Following this, an algorithm was developed so that the new model could be incorporated in DELTA and replace the current car ownership model of DELTA. For the validation procedure a combination of sensitivity analysis and validation by experts is proposed, in order to maximise the validity of the procedure and the produced results. At this stage, the procedure that should be followed when applying the procedure to a case study for the sensitivity analysis is introduced. Essentially, selected scenarios from the literature should be modelled to investigate if the produced results have similar trends to those of the literature. Moreover, a Delphi survey was completed in two rounds, and after consensus was reached conclusions regarding the calibration process and the final results were made. Finally, the software and data needed for the project are listed.

The final element of this thesis was the analysis of the modelling procedure followed to incorporate new vehicle technologies and business models, based on the aforementioned methodology. The selected case study was West Midlands, as it is an area rich in spatial information, attractive for investors and can produce transferrable results. Four future scenarios were formulated, in order to capture and examine land use effects of different spatial penetration rates of new vehicle technologies in the fleet and also of the increasing phenomenon of people working from home, which became much more commonplace since the onset of the COVID-19 pandemic. At this stage, the whole calibration procedure for generalised costs, road capacity, trip rates and car ownership were presented. It should be noted that the methodology was applied by investigating current transportation costs from the selected case study and governmental sources while also making some assumptions that were in line with the literature and the conclusions from the Delphi method. Moreover, MIM was calibrated by conducting a stated preference survey in the West Midlands and based on its results, it was found that working households need at least one car, residing in urban areas lessens the need for car ownership and that the retired population has lower trends of reducing car ownership levels. Moreover, it was found that more affordable subscription costs of new transportation business models and increased car ownership costs can reduce car ownership levels, but still more interventions are needed to significantly reduce car ownership and car dependence. It is important to mention that these conclusions were also expected based on the results of the Delphi analysis. Moreover, the probabilities of the calibrated MIM were estimated for the case that no new transport business models were incorporated in the system and compared to probabilities of the BAU scenario of the current car ownership model of DELTA and it was found that they follow similar trends. Following-on, the validation by sensitivity analysis was conducted by selecting different cases from the literature, recreating the same scenarios for West Midlands, and comparing the trends of the results for different trip rate scenarios and changes in accessibility. The fact that similar trends were observed between the results from the literature and the produced results was essential to show that the developed methodology can provide reliable results. Moreover, as it was noted from the conclusions of the Delphi survey there was an uncertainty regarding the effect of connectivity on road capacity, a sensitivity analysis regarding this aspect indicated the importance of the examination of this element in the modelling procedure. Finally, the applicability of the methodological principles was shown, as the methodology was also applied to a different case study and a different LUTI model to model electrification in Southampton (Gouge, Sarri & Kaparias, 2022).

The results from the modelling procedure initially indicated that for all four future scenarios total regional population and employment was increased in the region, but at an urban level the trends are not similar to those of the regional level, as total regional employment in Birmingham is decreasing and in Coventry is increasing, phenomena that indicate urban sprawl from the major regional areas. Moreover, it was found that the results regarding residential and employment location choice of all four scenarios were not very sensitive to increased penetration rates of new vehicle technologies in the CBDs or increased rates of people working from home, with only some minor changes shown in the cartographical representations. Interestingly, the spatial results of population and employment, do not follow the same patterns, as there is a balanced increase of population in the outskirts of the region with its urban cores not losing high percentages of population but areas with increased employment are concentrated to specific zones in the region and not evenly distributed. It is important to mention that these trends in residential location choices were mainly caused due to the working population, as changes in residential location of retired population were not as pronounced as those of working adults in the region. Moreover, it was noted that there was a negative effect to the peripheral zones of the region, as population and employment are attracted to the region from areas that neighbour with the West Midlands region. Both new vehicle technologies and business models increase accessibility to work and services in the region, especially in remote areas with lower densities of road and rail networks.

Finally, the overall contribution of the thesis is that the possible land use and accessibility effects of new transportation technologies and business models were forecasted at a regional and urban level of analysis, using a new developed methodology that includes applicable to different LUTI models principles. Being able to forecast the future spatial distribution of land uses in cities and regions can indeed provide an important tool to researchers, policy makers and intervention designers in order to plan towards sustainability and ensure that through their policies the negative effects could be avoided.

8.2 Limitations and future work

Limitations of this research are mainly related to data availability, as in many aspects, assumptions were made based on the literature. However, it should be noted that this always is an issue with LUTI modelling. More specifically, starting with the review and comparison of LUTI models, which was entirely based on the available literature, a broader examination that would include experts' opinions on their selection would have provided a more in-depth analysis on the subject. Moreover, having additional data regarding trip rates, it is arguable that a regression model may have been a more advanced and appropriate method. Regarding MIM the most important limitation is that the variables of the model are only cost–based, hence, variables related to comfort or reliability could be included in future research. On this subject it should also be mentioned that the variable of zone types (ZT) could have been extended to describe in more depth the land use characteristics of the zone of the household. Furthermore, the data gathered for public transport costs from the available operators in West Midlands included only bus and light rail related costs and not rail. This cost can be substantial based on the suburban rail network in the West Midlands. On the creation of the MaaS packages, weekly fees from car sharing operators were not included, because the packages needed to be competitive to the private car, leading to relatively low costs for especially for the unlimited car sharing option of the packages. Hence, a more in-depth analysis for creating attractive packages should be conducted. Additionally, it should be mentioned that for this research the assumption of four years for the average ownership time length of a vehicle in the UK, which was based on the analysis of Leibling (2008). A more recent analysis regarding average ownership time length should be conducted and utilised. Subsequently, it is also important to note on the assumption of fuel consumption of 35.7 litres (L) per week, that an additional analysis that would utilise data from the West Midlands region and linked with annual mileage, would have provided analytic results. Regarding the results, additional scenarios with higher simulation periods may be needed to clarify why higher adoption rates of CAVs in the CBDs or working from home up to 30%, did not affect regional and urban total population and employment trends. Additionally, regarding the analysis on the buffer zones, the assumption was that the innovations were only implemented in the region, however, a national LUTI model that would incorporate the innovations to all zones of the UK would have provided improved results for the effects of the buffer zones. Finally, the technologies analysed do not refer to micro mobility, which is also an important innovation in passenger trips at an urban level and the modelling procedure should be adapted for case studies in the developing world.

Thus, future work on surpassing all the technical limitations related to costs and assumptions should be conducted. Moreover, additional scenarios could include higher simulation periods, scenarios with other transportation options related to micro mobility and new technologies in freight transportation, such as drones. Furthermore, an interesting field for future research is the investigation of the adaptation of the developed methodology for different case studies, as for example for countries of the developing world. Moreover, the methodology could also become more advanced by including in the modelling procedure data regarding the availability of transport business models, as in the current methodology full availability is assumed. Finally, this analysis could be enhanced with parking scenarios for CAVs which was not included in this research, as the analysis was conducted at a large scale of analysis.

Publications resulting from this work

Peer-reviewed academic journals

Sarri, P., Kaparias, I., Preston, J. & Simmonds, D. (2023) Using Land Use and Transportation Interaction (LUTI) models to determine land use effects from new vehicle transportation technologies; a regional scale of analysis. Transport Policy. [Online] 135, 91–111. Available from: doi:10.1016/J.TRANPOL.2023.03.012

Sarri, P., Kaparias, I. & Preston, J. (n.d.) How will emerging technologies and business models affect generalised cost, and accessibility? : a Comprehensive Review. Transport Reviews (in progress)

Sarri, P., Kaparias, I., Preston, J. & Simmonds, D. (n.d.) Examination of the effects of new mobility business plans on land use: A Simulation approach. Environment and Planning B: Urban Analytics and City Science (in progress)

Conference proceedings

Sarri, P., Kaparias, I., Preston, J. & Simmonds, D. (2020) Identifying the land use effects of new transportation technologies. The case of West Midlands. In: 9th Symposium of the European Association for Research in Transportation. 2020 .

Sarri, P., Kaparias, I., Preston, J. & Simmonds, D. (2021) A simulation approach to compare urban growth in different cities in the new transportation era of connectivity, automation and electrification. In: 10th INTERNATIONAL CONGRESS ON TRANSPORTATION RESEARCH. 2021 Rodes, Greece.

Sarri, P., Kaparias, I., Preston J. (2023) Effects of Shared Vehicle Schemes and Mobility as a Service on Car Ownership: A cost-based analysis. In: 8th International Conference on Models and Technologies for Intelligent Transportation Systems, Nice, France (to be presented).

Sarri, P., Kaparias, I., Preston, J. & Simmonds, D. (2023) Modelling New Transport Vehicle Technologies and Business Models to Forecast Regional Land Use and Accessibility Impacts. In: 11th INTERNATIONAL CONGRESS ON TRANSPORTATION RESEARCH. 2023 Heraklion, Greece. (to be presented).

Other related publications

Peer-reviewed academic journals

Sarri, P., Tzouras, P., Tsigdinos, S., Kaparias, I. & Kepaptsoglou K. (n.d.) Incorporating Land Use and Transport Interactions Models to Evaluate Active Mobility Measures and Interventions in Urban Areas: A case study in Southampton, UK. Cities (in progress)

Conference proceedings

Sarri, P., Kaparias, I., Kepaptsoglou, K. & Leon, A. (2019) Using LUTI Models to Develop Key Performance Indicators (KPIs) For Evaluating Land Use Impacts. *9th International Congress On Transportation Research*.

Sarri, P., Tzouras, P., Tsigdinos, S., Kaparias, I & Kepaptsoglou K. (2022) Exploring The Land Use And Transport Interaction Effects Of City-Wide Active Travel Schemes. Transportation Research Board (TRB) Annual Meeting

Gouge, V., Sarri, P. & Kaparias, I. (2022) The uptake of electrification and its transport and land use impacts; The case of Southampton (UK). In: hEART | European Association for Research in Transportation.

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Appendix A Stated Preference Survey

Start of Block: Introductory Statement

Q1 **Investigating Willingness to Invest in Mobility Options and/or Car Ownership** The purpose of this research is to investigate if households with different characteristics in the West Midlands would be willing to invest in new mobility business models and/or car ownership.
The survey will take around 10-15 minutes.

The questions in this survey ask for information in relation to your household profile (number of people working, income level, county you reside in the West Midlands). Moreover, you are given hypothetical scenarios of different transportation options available in your area and you are asked to choose which is more likely to be chosen by your household.
For further information, you may consult the participant information sheet: Here
**Approved by the Faculty Research Ethics Committee (Ethics/ERGO Number: 65060).*

Thank you!

Are you over 18 years old AND do you consent in participating in this survey?

- o Yes (1)
- o No (2)

Skip To: End of Block If What is the research about?Hello! My name is Paraskevi Sarri and I am a Ph.D. Candidate at the Univ = Yes
Skip To: End of Survey If What is the research about?Hello! My name is Paraskevi Sarri and I am a Ph.D. Candidate at the Univ = No

End of Block: Introductory Statement

Start of Block: Prolific ID

Q342 What is your Prolific ID?

____

End of Block: Prolific ID

Start of Block: Location

Q2 In which county of the West Midlands does your household belong?

- o Herefordshire (1)
- o Warwickshire (2)
- o West Midlands (county) (3)
- o Worcestershire (4)
- o Staffordshire (5)
- o Shropshire (6)

Q3 Do you live in an urban or rural area?

- o Urban (1)
- o Rural (2)

End of Block: Location

Start of Block: Profile of Household (1)

Q4 Please type your age in arabic numerals (e.g. 43)

____

Q5 Please type the ages of the rest people living in your household (excluding yourself) separated by a comma (For example - 30, 40, 16).

If no other people reside in your household, you can skip the question.

____

Q6 In which of the following income groups does the annual income of your household belong approximately to?

- Less than £19,999 (1)
- £20,000 - £29,999 (2)
- £30,000 - £39,999 (3)
- £40,000 - £49,999 (4)
- £50,000 - £59,999 (5)
- £60,000 - £69,999 (7)
- £70,000 - £79,999 (8)
- £80,000 - £89,999 (9)
- £90,000 - £99,999 (10)
- more than £100,000 (6)

Q7 Which of the following describes better your household?

- Working Household (4)
- Student Household (1)
- Retired Household (2)
- Other (3)

Skip To: End of Block If Which of the following describes better your household? = Student Household
Skip To: End of Block If Which of the following describes better your household? = Other

Display This Question:
If Which of the following describes better your household? = Working Household

Q8 How many people work in your household ?

- 1 (2)
- 2 (3)
- 3+ (4)

Display This Question:
If Which of the following describes better your household? = Working Household

Q148 What is the minimum number of days that any worker of your household works from home?

If no member of your household works from home please select 0.

- 0 (1)
- 1 (2)
- 2 (3)
- 3 (4)
- 4 (5)
- 5 (6)

Display This Question:
If Which of the following describes better your household? = Working Household

Q9 Which of the following describes better the employment status for the workers of your household?

You can choose multiple answers to include the employment status of all the members of your household who are working if different!

- ○ Full-Time Employee (1)
- ○ Part-Time Employee (defined as 30 hours or less per week) (2)
- ○ Self Employed (3)
- ○ Other (4)

Display This Question:
If Which of the following describes better your household? = Working Household

Q10 Please type the title of the occupations of the workers of your household separated by a comma (e.g. teacher, doctor)

If there is only one member working in your household, please type the title without a comma.

____

Display This Question:
If Which of the following describes better your household? = Working Household

Q11 Does any worker in your household supervise any employees?

- ○ Yes (1)
- ○ No (2)

Skip To: End of Block If Does any worker in your household supervise any employees? = Yes
Skip To: End of Block If Does any worker in your household supervise any employees? = No

---

Display This Question:
If Which of the following describes better your household? = Retired Household

Q12 Which of the following describes better the employment status for the people who were working in your household before pension?

You can choose multiple answers if

- ○ Full-Time Employee (1)
- ○ Part-Time Employee (defined as 30 hours or less per week) (2)
- ○ Self Employed (3)
- ○ Other (4)

Display This Question:
If Which of the following describes better your household? = Retired Household

Q13 Please type the title of the occupations of the people who were working in your household before pension, separated by a comma (e.g. teacher, doctor)

If there was only one member working in your household, please type the title without a comma.

____

Display This Question:
If Which of the following describes better your household? = Retired Household

Q14 Did any member in your household supervise any employees before pension?

- ○ Yes (1)
- ○ No (2)

End of Block: Profile of Household (1)

Start of Block: Introductory for scenarios

Q15

In the following section, you are presented with 8 Hypothetical Scenarios of 2 options being available to your household.

These 2 options per scenario include a combination of cars and transport services available to your household. Information regarding the services and their cost is described in every option. An example of what each scenario would look like is presented below:

Example

Your task in every question is to indicate the option that your household (not just you) would consider choosing. In the previous example, the respondent compared the 2 options and based on his/her household characteristics (income, work status, etc.) chose Option B. **It is important to mention that there is no right or wrong answer, you will need to choose the option that is best for your household.**

Two elements are important to be defined before you proceed to answer the hypothetical scenarios:

1. The term "Mobility Solution", which you will see in the scenarios, refers to a mobile app, in which **one** member of your household can subscribe and pay a weekly fee to access multiple transport services (public transport, uber & car clubs).

2. The term "Self - Driving Cars" refers to cars that are autonomous and driving is not required for them to operate, reach a destination, and park.

Shall we proceed to the scenarios?

- Yes (1)
- No (2)

Skip To: End of Survey If In the following section, you are presented with 8 Hypothetical Scenarios of 2 options being avai... = No

End of Block: Introductory for scenarios

Start of Block: WM 2 Work

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q16

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 61.5/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive) – £22.5/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (6)
- **Option B: £ 25.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive) – £22.5/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q17
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 41.5/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 34/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive with a self-driving car) – £23/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q18
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 56/ week** **1.** Own 2 cars – Minimum cost of operation £56/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 54/ week** **1.** Own no car – Minimum cost of operation £0/ week **1.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive with a self-driving car) – £23/week **2.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q19
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 48/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q20
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 20/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q21
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 81.5/ week** **1.** Own 2 cars – Minimum cost of operation £56/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive with a self-driving car) – £23/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 74/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive with a self-driving car) – £23/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q22
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 109.5/ week** **1.** Own 2 cars – Minimum cost of operation £56/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive) – £22.5/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 45/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive) – £22.5/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q24

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 90/ week** **1.** Own 2 cars – Minimum cost of operation £56/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 33.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 2 Work

Start of Block: NWM 2 Work

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q289

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 53.5/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive) – £14.5/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 17.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive) – £14.5/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

Q290

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 41.5/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 26/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive with a self-driving car) – £15/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

Q291

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 56/ week** **1.** Own 2 cars – Minimum cost of operation £56/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 38/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive with a self-driving car) – £15/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

Q292

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 40/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q293

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 12/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q294

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 73.5/ week** **1.** Own 2 cars – Minimum cost of operation £56/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive with a self-driving car) – £15/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 58/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive with a self-driving car) – £15/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q295

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 93.5/ week** **1.** Own 2 cars – Minimum cost of operation £56/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive) – £14.5/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 29/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 1 x 5-mile drive) – £14.5/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 5

JS

Q296
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 82/ week** **1.** Own 2 cars – Minimum cost of operation £56/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 25.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 2 Work

Start of Block: WM 3 Work

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q233
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 69/ week** **1.** Own 1 car – Minimum cost of operation £33/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives) – £25/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 28/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives) – £25/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q234

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 46.5/ week** **1.** Own 1 car – Minimum cost of operation £33/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 37/ week** **1.** Own no car – Minimum cost of operation £0/ week **2 .** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives with a self-driving car) – £26/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (4)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q235

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66/ week** **1.** Own 2 cars – Minimum cost of operation £66/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 57/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives with a self-driving car) – £26/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q236

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 53/ week** **1.** Own 1 car – Minimum cost of operation £33/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q237
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 20/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q238
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 94.5/ week** **1.** Own 2 cars – Minimum cost of operation £66/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives with a self-driving car) – £26/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 82/ week** **1.** Own 1 car – Minimum cost of operation £33/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives with a self-driving car) – £26/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q239
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 122/ week 1.** Own 2 cars – Minimum cost of operation £66/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives) – £25/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 47.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives) – £25/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

Q240
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 100/ week 1.** Own 2 cars – Minimum cost of operation £66/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 33.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 3 Work

Start of Block: NWM 3 Work

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

Q297
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 61/ week 1.** Own 1 car – Minimum cost of operation £33/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives) – £17/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 20/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives) – £17/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q298

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 46.5/ week 1.** Own 1 car – Minimum cost of operation £33/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 29/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives with a self-driving car) – £18/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q299

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66/ week 1.** Own 2 cars – Minimum cost of operation £66/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 41/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives with a self-driving car) – £18/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q300

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 45/ week** **1.** Own 1 car – Minimum cost of operation £33/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q301

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 12/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q302

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 86.5/ week** **1.** Own 2 cars – Minimum cost of operation £66/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives with a self-driving car) – £18/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £66/ week** **1.** Own 1 car – Minimum cost of operation £33/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives with a self-driving car) – £18/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q303

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- ○ **Option A: £ 106/ week 1.** Own 2 cars – Minimum cost of operation £66/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives) – £17/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (1)
- ○ **Option B: £ 31.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport and Car Clubs: 2 x 5-mile drives) – £17/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 4

JS

Q304
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- ○ **Option A: £ 92/ week 1.** Own 2 cars – Minimum cost of operation £66/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- ○ **Option B: £ 25.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 3 Work

Start of Block: WM 4 Work

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q241
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- ○ **Option A: £ 85/ week 1.** Own 1 car – Minimum cost of operation £38/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives) – £36/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (1)
- ○ **Option B: £ 39/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives) – £36/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q242

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 51.5/ week 1.** Own 1 car – Minimum cost of operation £38/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 48/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives with a self-driving car) – £37/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q243

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 76/ week 1.** Own 2 cars – Minimum cost of operation £76/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 68/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives with a self-driving car) – £37/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q244

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 58/ week** **1.** Own 1 car – Minimum cost of operation £38/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q245

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 20/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q246

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 115.5/ week** **1.** Own 2 cars – Minimum cost of operation £76/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives with a self-driving car) – £37/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 98/ week** **1.** Own 1 car – Minimum cost of operation £38/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives with a self-driving car) – £37/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q247

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 143/ week** **1.** Own 2 cars – Minimum cost of operation £76/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives) – £36/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 58.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives) – £36/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q248
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 110/ week** **1.** Own 2 cars – Minimum cost of operation £76/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 33.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 4 Work

Start of Block: NWM 4 Work

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q305
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 77/ week** **1.** Own 1 car – Minimum cost of operation £38/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives) – £28/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 31/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives) – £28/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q306
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 51.5/ week 1.** Own 1 car – Minimum cost of operation £38/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 40/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives with a self-driving car) – £29/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q307
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 76/ week 1.** Own 2 cars – Minimum cost of operation £76/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 52/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives with a self-driving car) – £29/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q308
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 50/ week** **1.** Own 1 car – Minimum cost of operation £38/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q309

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 12/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q310

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 107.5/ week** **1.** Own 2 cars – Minimum cost of operation £76/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives with a self-driving car) – £29/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 82/ week** **1.** Own 1 car – Minimum cost of operation £38/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives with a self-driving car) – £29/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q311

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 127/ week 1.** Own 2 cars – Minimum cost of operation £76/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives) – £28/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 42.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 2 x 5-mile drives) – £28/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 3

JS

Q312
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 102/ week 1.** Own 2 cars – Minimum cost of operation £76/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 25.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 4 Work

Start of Block: WM 5 Work

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q249
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 101/ week 1.** Own 1 car – Minimum cost of operation £43/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £47/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 50/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £47/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q250
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 56.5/ week** **1.** Own 1 car – Minimum cost of operation £43/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 59/ week** **1.** Own no car – Minimum cost of operation £0/ week **1.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives with a self-driving car) – £48/week **2.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q251
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 86/ week** **1.** Own 2 cars – Minimum cost of operation £86/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 79/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives with a self-driving car) – £48/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q252
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 63/ week** **1.** Own 1 car – Minimum cost of operation £43/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drives with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q253

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 20/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q254

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 136.5/ week** **1.** Own 2 cars – Minimum cost of operation £86/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives with a self-driving car) – £48/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 114/ week** **1.** Own 1 car – Minimum cost of operation £43/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives with a self-driving car) – £48/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q255

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 164/ week 1.** Own 2 cars – Minimum cost of operation £86/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £47/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 69.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £47/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q256
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 120/ week 1.** Own 2 cars – Minimum cost of operation £86/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 33.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 5 Work

Start of Block: NWM 5 Work

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q313
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 93/ week 1.** Own 1 car – Minimum cost of operation £43/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £39/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 42/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £39/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q314

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 56.5/ week 1.** Own 1 car – Minimum cost of operation £43/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 51/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £40/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q315

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 86/ week 1.** Own 2 cars – Minimum cost of operation £86/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £63/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £40/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q316

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 55/ week** **1.** Own 1 car – Minimum cost of operation £43/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q317

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 12/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q318

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 128.5/ week** **1.** Own 2 cars – Minimum cost of operation £86/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives with a self-driving car) – £40/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 98/ week** **1.** Own 1 car – Minimum cost of operation £28/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives with a self-driving car) – £40/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q319

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 148/ week 1.** Own 2 cars – Minimum cost of operation £86/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £39/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 53.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 2 x 5-mile rides and Car Clubs: 2 x 5-mile drives) – £39/week **2.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 2

JS

Q320
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 112/ week 1.** Own 2 cars – Minimum cost of operation £86/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 25.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 5 Work

Start of Block: WM 6 Work

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q257
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 114/ week 1.** Own 1 car – Minimum cost of operation £48/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 58/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q258

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 61.5/ week 1.** Own 1 car – Minimum cost of operation £48/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 68/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q259

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 96/ week 1.** Own 2 cars – Minimum cost of operation £96/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 88/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **2.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q260

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 68/ week 1.** Own 1 car – Minimum cost of operation £48/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (1)
- **Option B: £ 14/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q261
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 20/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q262
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 155.5/ week 1.** Own 2 cars – Minimum cost of operation £96/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 128/ week 1.** Own 1 car – Minimum cost of operation £48/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q263
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 182/ week 1.** Own 2 cars – Minimum cost of operation £96/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 77.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q264
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 130/ week 1.** Own 2 cars – Minimum cost of operation £96/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 33.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 6 Work

Start of Block: WM 7 Work

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q361
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 119/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 58/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q362
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66.5/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 68/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q363
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 107/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 88/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q364
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 73/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q365
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 20/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q366
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 166.5/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 133/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q367
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 193/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 77.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q368
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 141/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 33.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 7 Work

Start of Block: WM 7 St

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q393
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 94.5/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive) – £30.5/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 33.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive) – £30.5/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Student Household

JS

Q394

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- ○ **Option A: £ 66.5/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.**Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- ○ **Option B: £ 42/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive with a self-driving car) – £31/week **2.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Student Household

JS

Q395

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- ○ **Option A: £ 107/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- ○ **Option B: £ 59/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive with a self-driving car) – £31/week **2.** Subscription to other services (Public Transport - £17 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Student Household

JS

Q396

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 70/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £17) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Student Household

JS

Q397

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 17/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £17) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Student Household

JS

Q398

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 140.5/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive with a self-driving car) – £31/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 104/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive with a self-driving car) – £31/week **3.** Subscription to other services (Public Transport - £17 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Student Household

JS

Q399

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 165.5/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive) – £30.5/week **3.** Subscription to other services (Public Transport - £17 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 50/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive) – £30.5/week **3.** Subscription to other services (Public Transport - £17 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q400
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 138/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £17, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 30.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £17, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 7 St

Start of Block: WM 7 Ret

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q377
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 119/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 58/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q378
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66.5/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 68/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q379
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 107/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 88/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q380
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 73/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Retired Household

JS

Q381

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 20/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Retired Household

JS

Q382

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 166.5/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 133/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Retired Household

JS

Q383

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 193/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 77.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Retired Household

JS

Q384

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 141/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 33.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 7 Ret

Start of Block: WM 7 O

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Other

JS

Q435

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 119/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 58/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? = West Midlands (county)

And Which of the following describes better your household? = Other

JS

Q436

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66.5/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 68/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q437
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 107/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 88/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q438
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 73/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q439
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 20/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q440
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 166.5/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 133/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £57/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q441
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 193/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Public Transport - £20 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 77.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £55/week **3.** Subscription to other services (Public Transport - £20 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? = West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q442
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 141/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 33.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £20, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: WM 7 O

Start of Block: NWM 6 Work

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q353
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 104/ week 1.** Own 1 car – Minimum cost of operation £48/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 48/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q354
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 61.5/ week 1.** Own 1 car – Minimum cost of operation £48/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 57/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q355

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 96/ week** **1.** Own 2 cars – Minimum cost of operation £96/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 69/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q356

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 60/ week** **1.** Own 1 car – Minimum cost of operation £48/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

JS

Q357

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 12/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

Q358

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 144.5/ week** **1.** Own 2 cars – Minimum cost of operation £96/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 109/ week** **1.** Own 1 car – Minimum cost of operation £48/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

Q359

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 164/ week** **1.** Own 2 cars – Minimum cost of operation £96/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 59.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Working Household

And What is the minimum number of days that any worker of your household works from home? If no membe... = 1

Q360

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 122/ week** **1.** Own 2 cars – Minimum cost of operation £96/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 25.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 6 Work

Start of Block: NWM 7 Work

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q369
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 109/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 48/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q370
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66.5/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 57/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

Q371
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 107/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 69/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

Q372
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 65/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

Q373
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 12/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q374
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 155.5/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 114/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q375
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 175/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 59.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Working Household
And What is the minimum number of days that any worker of your household works from home? If no membe... = 0

JS

Q376
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 133/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 25.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 7 Work

Start of Block: NWM 7 R

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q443
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 109/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 48/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q444
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66.5/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 57/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q445
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 107/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 69/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q446
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 65/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (1)
- **Option B: £ 14/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Retired Household

JS

Q447
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 12/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Retired Household

JS

Q448

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 155.5/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 114/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Retired Household

JS

Q449

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 175/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 59.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Retired Household

JS

Q450

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 133/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 25.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 7 R

Start of Block: NWM 7 O

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Other

JS

Q451

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 109/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 48/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Other

JS

Q452

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66.5/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 57/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:

If In which county of the West Midlands does your household belong? != West Midlands (county)

And Which of the following describes better your household? = Other

JS

Q453

Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 107/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 69/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q454
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 65/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (1)
- **Option B: £ 14/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q455
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 12/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q456
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 155.5/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 114/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs with a self-driving car) – £46/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q457
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 175/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Public Transport - £12 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 59.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Unlimited Uber and Unlimited Car Clubs) – £45/week **3.** Subscription to other services (Public Transport - £12 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Other

JS

Q458
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 133/ week** **1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 25.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £12, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 7 O

Start of Block: NWM 7 St

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q401
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 85/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive) – £21/week **3.** Subscription to other services (Uber: 1 x 5-mile drive - £11) (1)
- **Option B: £ 24/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive) – £21/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q402
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 66.5/ week** **1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)
- **Option B: £ 32.5/ week** **1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive with a self-driving car) – £21.5/week **3.** Subscription to other services (Uber: 1 x 5-mile ride - £11) (3)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q403
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 107/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 40/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive with a self-driving car) – £21.5/week **3.** Subscription to other services (Public Transport - £7.5 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q404
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 60.5/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £7.5) (1)
- **Option B: £ 14/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive with a self-driving car - £3 and Uber: 1 x 5-mile ride - £11) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q405
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 0/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** No Subscription to other services – £0/week (1)
- **Option B: £ 7.5/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £7.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q406
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?

If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 131/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive with a self-driving car) – £21.5/week **3.** Subscription to other services (Car Clubs: 1 x 5-mile drive - £2.5) (1)
- **Option B: £ 85/ week 1.** Own 1 car – Minimum cost of operation £53/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive with a self-driving car) – £21.5/week **3.** Subscription to other services (Public Transport - £7.5 and Car Clubs: 1 x 5-mile drive with a self-driving car - £3) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q407
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 146.5/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive) – £21/week **3.** Subscription to other services (Public Transport - £7.5 and Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 31/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** Mobility Solution (Unlimited Public Transport, Uber: 1 x 5-mile ride and Car Clubs: 1 x 5-mile drive) – £21/week **3.** Subscription to other services (Public Transport - £7.5 and Car Clubs: 1 x 5-mile drive - £2.5) (2)

Display This Question:
If In which county of the West Midlands does your household belong? != West Midlands (county)
And Which of the following describes better your household? = Student Household

JS

Q408
Scenario ${e://Field/qnumber} from ${e://Field/totalq}

Which of the options do you think your household would consider choosing?
If your household would not consider choosing any of the available options, please select the most preferable one of the two.

- **Option A: £ 128.5/ week 1.** Own 2 cars – Minimum cost of operation £107/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £7.5, Car Clubs: 1 x 5-mile drive with a self-driving car - £3, Uber: 1 x 5-mile ride - £11) (1)
- **Option B: £ 21/ week 1.** Own no car – Minimum cost of operation £0/ week **2.** No Subscription to Mobility Solution – £0/week **3.** Subscription to other services (Public Transport - £7.5, Car Clubs: 1 x 5-mile drive - £2.5, Uber: 1 x 5-mile ride - £11) (2)

End of Block: NWM 7 St

Appendix B R Scripts and Fractional Factorial Design

ROUND 1 (R Script)

```
# ################################################################# #
#### LOAD LIBRARY AND DEFINE CORE SETTINGS                       ####
# ################################################################# #

### Clear memory
rm(list = ls())

### Load Apollo library
library(apollo)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ='small_mim',
  modelDescr ='NL model with socio-demographics on mode choice SP data',
  indivID    ='i'
)

# ################################################################# #
#### LOAD DATA AND APPLY ANY TRANSFORMATIONS                     ####
# ################################################################# #

database = read.csv('G://Mobility Investment Model//R//data.csv',header=TRUE)


# ################################################################# #
#### DEFINE MODEL PARAMETERS                                     ####
# #################################################################
#### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(ASC_1 = 0      ,
              ASC_2 = 0      ,
              ASC_3 = 0      ,
              BETA_S_1  = 0  ,
              BETA_S_2  = 0  ,
              BETA_S_3  = 0  ,
              BETA_R_1  = 0  ,
              BETA_R_2  = 0  ,
              BETA_R_3  = 0  ,
              BETA_ZT_1 = 0  ,
              BETA_ZT_2 = 0  ,
              BETA_ZT_3 = 0  ,
              BETA_O_1 = 0       ,
              BETA_MC_1 = 0      ,
              BETA_P_1 = 0       ,
              BETA_TCO_2 = 0     ,
              BETA_TCO_3 = 0     ,
              BETA_CC_2 = 0      ,
              BETA_CC_3 = 0,
              lambda_car=1)

### Vector with names (in quotes) of parameters to be kept fixed at their starting value
 in apollo_beta, use apollo_beta_fixed = c() if none
apollo_fixed = c('ASC_1', 'BETA_S_1','BETA_R_1','BETA_ZT_1')

# ################################################################# #
#### GROUP AND VALIDATE INPUTS                                   ####
# ################################################################# #
apollo_inputs = apollo_validateInputs()

# ################################################################# #
#### DEFINE MODEL AND LIKELIHOOD FUNCTION                        ####
```

```
# ################################################################# #

apollo_probabilities=function(apollo_beta, apollo_inputs, functionality='estimate'){

  ### Attach inputs and detach after function exit
  apollo_attach(apollo_beta, apollo_inputs)
  on.exit(apollo_detach(apollo_beta, apollo_inputs))

  ### Create list of probabilities P
  P = list()



  ### Create alternative specific constants and coefficients using interactions with soc
io-demographics
  ASC_1_SP = ASC_1   + BETA_S_1 * S + BETA_R_1 * R + BETA_ZT_1 * ZT
  ASC_2_SP = ASC_2   + BETA_S_2 * S + BETA_R_2 * R + BETA_ZT_2 * ZT
  ASC_3_SP = ASC_3   + BETA_S_3 * S + BETA_R_3 * R + BETA_ZT_3 * ZT




  ### List of utilities: these must use the same names as in nl_settings, order is irrel
evant
  V = list()
  V[['1']] = ASC_1_SP + BETA_MC_1 * MC1/Y + BETA_P_1 * PT1/Y + BETA_O_1 * (CC1 + UB1)/Y
  V[['2']] = ASC_2_SP + BETA_TCO_2 * TCO2/Y +BETA_CC_2 * (MC2 + PT2 + CC2 +UB2)/Y
  V[['3']] = ASC_3_SP + BETA_TCO_3 * TCO3/Y +BETA_CC_3 * (MC3 + PT3 + CC3 +UB3)/Y

  ### Specify nests for NL model
  nlNests      = list(root=1, car=lambda_car)

  ### Specify tree structure for NL model
  nlStructure= list()
  nlStructure[["root"]]   = c("1","car")
  nlStructure[["car"]]     = c("2","3")

  ### Define settings for NL model
  nl_settings <- list(
    alternatives = c('1'=1,'2'=2,'3'=3),
    avail        = list('1'=av1,'2'=av2,'3'=av3),
    choiceVar    = choice,
    V            = V,
    nlNests      = nlNests,
    nlStructure  = nlStructure

  )

  ### Compute probabilities using NL model
  P[["model"]] = apollo_nl(nl_settings, functionality)



  ### Prepare and return outputs of function
  P = apollo_prepareProb(P, apollo_inputs, functionality)
  return(P)
}

# ################################################################# #
#### MODEL ESTIMATION                                            ####
# ################################################################# #

model = apollo_estimate(apollo_beta, apollo_fixed, apollo_probabilities, apollo_inputs)

# ################################################################# #
#### MODEL OUTPUTS                                               ####
# ################################################################# #
```

```
# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO SCREEN)                               ----
# ----------------------------------------------------------------- #
apollo_modelOutput(model, modelOutput_settings = list(printPVal=TRUE))

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO FILE, using model name)               ----
# ----------------------------------------------------------------- #
apollo_saveOutput(model, saveOutput_settings = list(printPVal=TRUE) )

# ################################################################# #
##### POST-PROCESSING                                            ####
# ################################################################# #
### Print outputs of additional diagnostics to new output file (remember to clo
se file writing when complete)
apollo_sink()

# ----------------------------------------------------------------- #
#---- LR TEST AGAINST MNL MODEL                                  ----
# ----------------------------------------------------------------- #
apollo_lrTest("../1 NL/output/NL_SP_covariates", model)

# ----------------------------------------------------------------- #
#---- switch off writing to file                                 ----
# ----------------------------------------------------------------- #
apollo_sink()
```

ROUND 1 (Results)

```
Model run using Apollo for R, version 0.2.3 on Windows by vivi
www.ApolloChoiceModelling.com

Model name                       : small_mim
Model description                : NL model with socio-demographics on mode choice SP data
Model run at                     : 2023-10-14 12:08:18
Estimation method                : bfgs
Model diagnosis                  : successful convergence
Number of individuals            : 3712
Number of rows in database       : 3712
Number of modelled outcomes      : 3712

Number of cores used             :  1
Model without mixing

LL(start)                        : -2251.342
LL(0)                            : -2251.342
LL(final)                        : -1846.801
Rho-square (0)                   :  0.1797
Adj.Rho-square (0)               :  0.1726
AIC                              :  3725.6
BIC                              :  3825.11


Estimated parameters             :  16
Time taken (hh:mm:ss)            :  00:00:34.6
     pre-estimation              :  00:00:0.95
     estimation                  :  00:00:17.94
     post-estimation             :  00:00:15.7
Iterations                       :  37
Min abs eigenvalue of Hessian    :  0.011746

Estimates:
```

	Estimate	s.e.	t.rat.(0)	p(1-sided)	Rob.s.e.	Rob.t.rat.(0)	p(1-sided)
ASC_1	0.0000	NA	NA	NA	NA	NA	NA
ASC_2	2.2750	0.1680	13.5393	0.000000	0.1821	12.4911	0.000000
ASC_3	2.0766	0.1562	13.2946	0.000000	0.1734	11.9747	0.000000
BETA_S_1	0.0000	NA	NA	NA	NA	NA	NA
BETA_S_2	-0.5145	0.3130	-1.6438	0.050105	0.3187	-1.6143	0.053230
BETA_S_3	0.5491	0.3412	1.6093	0.053779	0.3532	1.5543	0.060054
BETA_R_1	0.0000	NA	NA	NA	NA	NA	NA
BETA_R_2	-0.7213	0.1912	-3.7731	8.060e-05	0.1848	-3.9030	4.751e-05
BETA_R_3	-0.5520	0.2102	-2.6258	0.004323	0.2137	-2.5832	0.004895
BETA_ZT_1	0.0000	NA	NA	NA	NA	NA	NA
BETA_ZT_2	-0.7076	0.1495	-4.7320	1.111e-06	0.1509	-4.6897	1.368e-06
BETA_ZT_3	-0.9641	0.1424	-6.7712	6.387e-12	0.1522	-6.3325	1.206e-10
BETA_O_1	4.8704	8.1813	0.5953	0.275819	8.9551	0.5439	0.293267
BETA_MC_1	0.8391	1.4340	0.5852	0.279212	1.4833	0.5657	0.285791
BETA_P_1	-12.6362	6.6670	-1.8953	0.029023	6.6587	-1.8977	0.028867
BETA_TCO_2	-2.2687	2.9499	-0.7691	0.220931	3.3267	-0.6820	0.247633
BETA_TCO_3	-7.1871	1.4192	-5.0642	2.051e-07	1.5108	-4.7572	9.815e-07
BETA_CC_2	-10.0951	2.0397	-4.9493	3.724e-07	2.1889	-4.6120	1.994e-06
BETA_CC_3	-8.7496	1.5749	-5.5558	1.382e-08	1.6986	-5.1511	1.295e-07
lambda_car	0.7522	0.1884	3.9933	3.258e-05	0.2097	3.5868	1.6740e-04

```
Nesting structure for NL model component :
Nest: root (1)
|----Alternative: 1
'-Nest: car (0.7522)
   |-Alternative: 2
   '-Alternative: 3


Overview of choices for NL model component :
```

	1	2	3
Times available	3248	1856.00	1856.00
Times chosen	1559	1327.00	826.00
Percentage chosen overall	42	35.75	22.25
Percentage chosen when available	48	71.50	44.50

ROUND 2 (R Script)

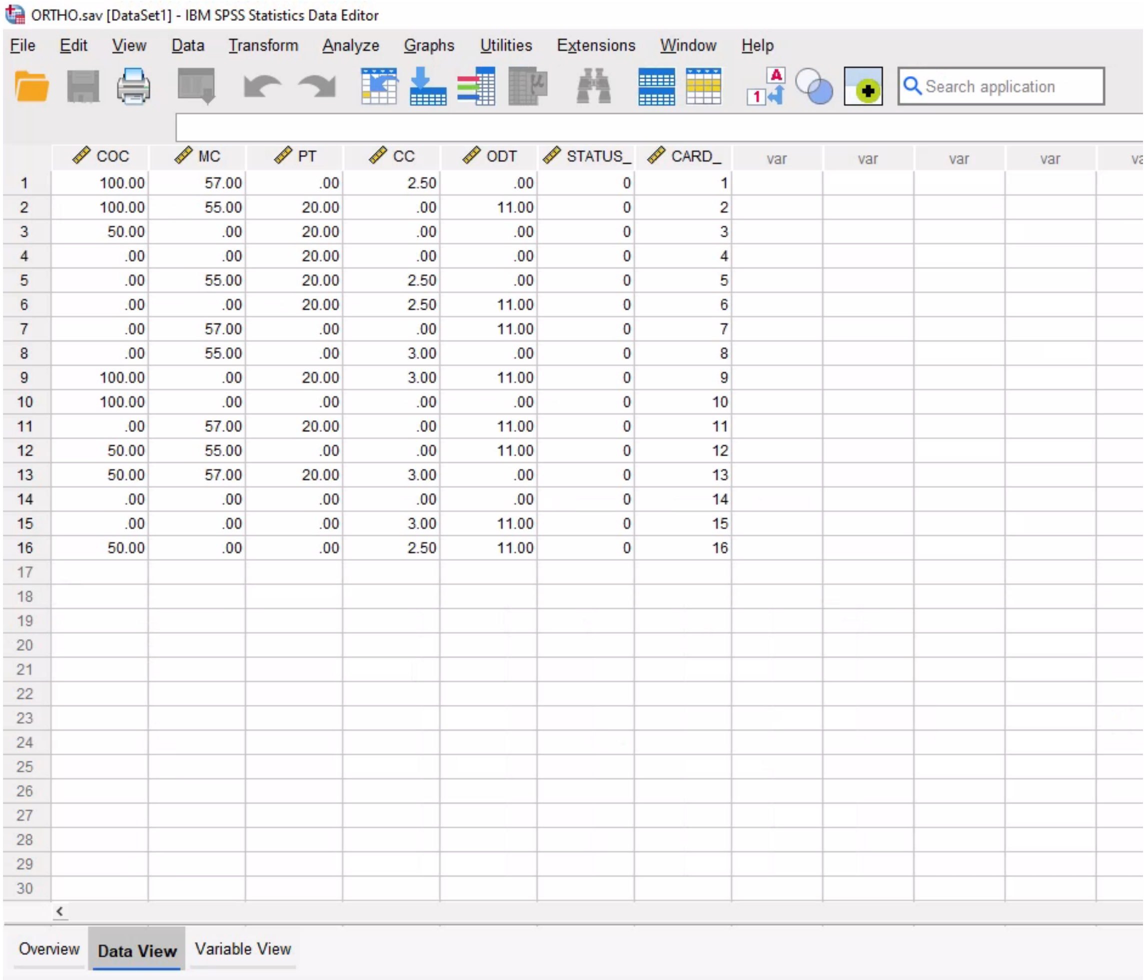
```
# ################################################################# #
#### LOAD LIBRARY AND DEFINE CORE SETTINGS                       ####
# ################################################################# #
### Clear memory
rm(list = ls())
### Load Apollo library
library(apollo)
### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ='small_mim R2',
  modelDescr ='NL model with socio-demographics on mode choice SP data',
  indivID    ='i'
)
# ################################################################# #
#### LOAD DATA AND APPLY ANY TRANSFORMATIONS                     ####
# ################################################################# #

database = read.csv('G://Mobility Investment Model//R//data.csv',header=TRUE)
# ################################################################# #
#### DEFINE MODEL PARAMETERS                                     ####
# #################################################################
#### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(ASC_1 = 0      ,
              ASC_2 = 0      ,
              ASC_3 = 0      ,
              BETA_R_1  = 0  ,
              BETA_R_2  = 0  ,
              BETA_R_3  = 0  ,
              BETA_ZT_1 = 0  ,
              BETA_ZT_2 = 0  ,
              BETA_ZT_3 = 0  ,
              BETA_P_1 = 0       ,
              BETA_TCO_3 = 0     ,
              BETA_CC_2 = 0      ,
              BETA_CC_3 = 0,
              lambda_car=1)
### Vector with names (in quotes) of parameters to be kept fixed at their starting value
 in apollo_beta, use apollo_beta_fixed = c() if none
apollo_fixed = c('ASC_1', 'BETA_R_1','BETA_ZT_1')

# ################################################################# #
#### GROUP AND VALIDATE INPUTS                                   ####
# ################################################################# #
apollo_inputs = apollo_validateInputs()

# ################################################################# #
#### DEFINE MODEL AND LIKELIHOOD FUNCTION                        ####
# ################################################################# #
apollo_probabilities=function(apollo_beta, apollo_inputs, functionality='estimate'){

  ### Attach inputs and detach after function exit
  apollo_attach(apollo_beta, apollo_inputs)
  on.exit(apollo_detach(apollo_beta, apollo_inputs))

  ### Create list of probabilities P
  P = list()

    ### Create alternative specific constants and coefficients using interactions with s
ocio-demographics
  ASC_1_SP = ASC_1   + BETA_R_1 * R + BETA_ZT_1 * ZT
  ASC_2_SP = ASC_2   + BETA_R_2 * R + BETA_ZT_2 * ZT
  ASC_3_SP = ASC_3   + BETA_R_3 * R + BETA_ZT_3 * ZT
```

```
      ### List of utilities: these must use the same names as in nl_settings, order is i
rrelevant
  V = list()
  V[['1']] = ASC_1_SP   + BETA_P_1 * PT1/Y
  V[['2']] = ASC_2_SP   + BETA_CC_2 * (MC2 + PT2 + CC2 +UB2)/Y
  V[['3']] = ASC_3_SP   + BETA_TCO_3 * TCO3/Y +BETA_CC_3 * (MC3 + PT3 + CC3 +UB3)/Y

  ### Specify nests for NL model
  nlNests      = list(root=1, car=lambda_car)

  ### Specify tree structure for NL model
  nlStructure= list()
  nlStructure[["root"]]   = c("1","car")
  nlStructure[["car"]]     = c("2","3")

  ### Define settings for NL model
  nl_settings <- list(
    alternatives = c('1'=1,'2'=2,'3'=3),
    avail        = list('1'=av1,'2'=av2,'3'=av3),
    choiceVar    = choice,
    V            = V,
    nlNests      = nlNests,
    nlStructure  = nlStructure
  )
  ### Compute probabilities using NL model
  P[["model"]] = apollo_nl(nl_settings, functionality)
  ### Prepare and return outputs of function
  P = apollo_prepareProb(P, apollo_inputs, functionality)
  return(P)
}
# ################################################################# #
#### MODEL ESTIMATION                                            ####
# ################################################################# #
model = apollo_estimate(apollo_beta, apollo_fixed, apollo_probabilities, apollo_inputs)

# ################################################################# #
#### MODEL OUTPUTS                                               ####
# ################################################################# #

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO SCREEN)                               ----
# ----------------------------------------------------------------- #
apollo_modelOutput(model, modelOutput_settings = list(printPVal=TRUE))

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO FILE, using model name)               ----
# ----------------------------------------------------------------- #
apollo_saveOutput(model, saveOutput_settings = list(printPVal=TRUE) )

# ################################################################# #
##### POST-PROCESSING                                            ####
# ################################################################# #
### Print outputs of additional diagnostics to new output file (remember to close file w
riting when complete)
apollo_sink()
# ----------------------------------------------------------------- #
#---- LR TEST AGAINST MNL MODEL                               ----
# ----------------------------------------------------------------- #
apollo_lrTest("../1 NL/output/NL_SP_covariates", model)
# ----------------------------------------------------------------- #
#---- switch off writing to file                                 ----
# ----------------------------------------------------------------- #
apollo_sink()
```

ROUND 2 (Results)

```
Model run using Apollo for R, version 0.2.3 on Windows by vivi
www.ApolloChoiceModelling.com

Model name                       : small_mim R2
Model description                : NL model with socio-demographics on mode choice SP data
Model run at                     : 2023-10-14 12:12:59
Estimation method                : bfgs
Model diagnosis                  : successful convergence
Number of individuals            : 3712
Number of rows in database       : 3712
Number of modelled outcomes      : 3712

Number of cores used             :  1
Model without mixing

LL(start)                        : -2251.342
LL(0)                            : -2251.342
LL(final)                        : -1856.989
Rho-square (0)                   :  0.1752
Adj.Rho-square (0)               :  0.1703
AIC                              :  3735.98
BIC                              :  3804.39


Estimated parameters             :  11
Time taken (hh:mm:ss)            :  00:00:17.98
     pre-estimation              :  00:00:0.72
     estimation                  :  00:00:9.1
     post-estimation             :  00:00:8.16
Iterations                       :  27
Min abs eigenvalue of Hessian    :  0.026004

Estimates:
              Estimate        s.e.   t.rat.(0)  p(1-sided)    Rob.s.e. Rob.t.rat.(0)  p(1-sided)
ASC_1           0.0000          NA          NA          NA          NA            NA          NA
ASC_2           2.0987      0.1466      14.314     0.00000      0.1490        14.081     0.00000
ASC_3           1.9990      0.1459      13.698     0.00000      0.1585        12.615     0.00000
BETA_R_1        0.0000          NA          NA          NA          NA            NA          NA
BETA_R_2       -0.7955      0.1834      -4.338   7.192e-06      0.1815        -4.384   5.829e-06
BETA_R_3       -0.6627      0.2022      -3.277  5.2450e-04      0.2057        -3.221  6.3924e-04
BETA_ZT_1       0.0000          NA          NA          NA          NA            NA          NA
BETA_ZT_2      -0.7358      0.1440      -5.110   1.607e-07      0.1447        -5.085   1.835e-07
BETA_ZT_3      -0.9677      0.1381      -7.007   1.214e-12      0.1461        -6.623   1.755e-11
BETA_P_1      -10.6108      6.1374      -1.729     0.04191      6.1929        -1.713     0.04332
BETA_TCO_3     -7.0078      1.0240      -6.844   3.861e-12      1.0484        -6.684   1.160e-11
BETA_CC_2     -11.9407      1.1908     -10.028     0.00000      1.1697       -10.208     0.00000
BETA_CC_3      -8.5032      1.2483      -6.812   4.816e-12      1.3516        -6.291   1.573e-10
lambda_car      0.6480      0.1566       4.138   1.750e-05      0.1663         3.897   4.875e-05

Nesting structure for NL model component :
Nest: root (1)
|----Alternative: 1
'-Nest: car (0.648)
   |-Alternative: 2
   '-Alternative: 3


Overview of choices for NL model component :
                                   1       2       3
Times available                 3248 1856.00 1856.00
Times chosen                    1559 1327.00  826.00
Percentage chosen overall         42   35.75   22.25
Percentage chosen when available  48   71.50   44.50
```

Fractional Factorial Design in SPSS



	COC	MC	PT	CC	ODT	STATUS_	CARD_
1	100.00	57.00	.00	2.50	.00	0	1
2	100.00	55.00	20.00	.00	11.00	0	2
3	50.00	.00	20.00	.00	.00	0	3
4	.00	.00	20.00	.00	.00	0	4
5	.00	55.00	20.00	2.50	.00	0	5
6	.00	.00	20.00	2.50	11.00	0	6
7	.00	57.00	.00	.00	11.00	0	7
8	.00	55.00	.00	3.00	.00	0	8
9	100.00	.00	20.00	3.00	11.00	0	9
10	100.00	.00	.00	.00	.00	0	10
11	.00	57.00	20.00	.00	11.00	0	11
12	50.00	55.00	.00	.00	11.00	0	12
13	50.00	57.00	20.00	3.00	.00	0	13
14	.00	.00	.00	.00	.00	0	14
15	.00	.00	.00	3.00	11.00	0	15
16	50.00	.00	.00	2.50	11.00	0	16