TO UNDERSTAND, MODEL AND DESIGN AN E-MOBILITY SYSTEM IN ITS URBAN CONTEXT

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To Nadia, Amr and my father in Heaven

ABSTRACT

The electric vehicles (EVs) are emerging as an alternative solution to the conventional gasoline vehicles. The EV market faces different issues related to limited range, which are associated with the battery technology and the charging network. A clear emphasis is placed on how well the supporting recharging facilities (RFs) are deployed in order to reduce the limited range. The aim of this study is to investigate how suitably the locations for RFs can be chosen in order to satisfy the demand. Charging demand is a multifaceted problem, the majority of them charge at home and do not experience the maximum range of the EV in an attempt to avoid being stranded with a flat battery, and the deployment of rapid chargers is costly. A desired balance between supply and demand can be achieved by identifying the most influential factors affecting the design and use of the RFs. The fundamental monitoring of the use of RFs would reflect the quality of design, highlight the emerging design needs, and assist with the strategic deployment of the RFs. The interest in alternative transport is shaped primarily by consumer perceptions and users' feedback. This thesis integrates visual and statistical elements in order to understand the end-user emerging design needs and to model the RFs. In this thesis, over 12,725 charging events were analysed in conjunction to 20 interviews with EV users and stakeholders. With the use of an agent-based modelling technique, it has been possible to capture and simulate the electric-mobility system. By means of integrated spatiotemporal modelling, the results indicated that the proposed model is capable of identifying candidate locations for deploying RFs. A multi method approach is presented to understand the concepts of, model and design the RFs. The outcome of this research should be of interest to planning authorities and policy makers of alternative means of transport.

Keywords: *Agent architecture, charging behaviour, charging infrastructure, clustering analysis, EV users, recharging facilities, simulation modelling, space syntax*

LIST OF PUBLICATIONS

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15. ElBanhawy, E. Y., *Analysis of Space-Time Behaviour of Electric Vehicle Potential User and Commuter*, IEEE Transportation Electrification, 2014
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ABBREVIATIONS AND ACRONYMS

A	Average Time Spent
AAWT	Average Annual Weekday Traffic
ABM	Agent Based Modelling
ADZ	Accelerated Development Zone (ADZ)
AI	Artificial Intelligence
Anylogic	Simulation Software
ASA	Angular Segmental Analysis
AutoCAD	Computer Aided Design Software
BEV	Battery Electric Vehicle
C	Connectivity Value
CAD	Computer Aided Design
CP	Charging Points
CSUCP	Core Strategy and Urban Core Plan
CYC	Charge Your Car
DE	Discrete Event
DfT	Department of Transport
DSZ	Driving Safe Zone
DV	Dependent Variable
EDINA	National Data Centre designated by the Joint Information System Committee (JISC) in the UK
E-Mobility	Electric Mobility
EREV	Extended Range Electric Vehicle
EV	Electric Vehicle
EVRA	Electric Vehicle Range Anxiety
EVSE	Electric Vehicle Supply Equipment
GA	Genetic Algorithms
GHG	Green House Gases
GIS	Geographic Information System
GPS	Global Positioning System

H	History
HPEV	Hybrid Plugged in Electric Vehicle
I	Integration Value
ICE	Internal Combustion Engine
ICT	Information and Communications Technology
IEA	International Energy Agency
ITS	Intelligent Transportation Systems
IV	Independent Variable
LCEV	Low Carbon emissions vehicles
LDF	Local Development Frameworks
LoA	Level of Awareness
LoD	Level of Details
LOS	Level of Services
M	Most Frequent Time
MCU	Multi Charing Unit
MD	Mean Depth value
NHTS	National Household Travel Survey
NSR	North Sea Region
O	On and Off Street Attribute
OCED	Organisation of Economic-Co-operation and development
OD	Origin and Destination
OEMs	Automotive Original Equipment Manufacturers
OLEV	Office of Low Emissions Vehicles
PHEV	Plugged-in Hybrid Electric Vehicle
PiP	Plugged in Places
PV	Photovoltaic Cells
R&D	Research and Development
RA	Range Anxiety
RF	Recharging Facility
SoB	State of Battery

SoC	State of Charge
TAZ	Traffic Analysis Zones (TAZs)
TMS	Traffic Management Systems
TORG	Transport Operations Research Group
UI	User Interface
V2G	Vehicle to Grid
VCM	Virtual City Model
VQS	Vehicle Quality Survey
η	Number of users
I	Transactions
I	Distance from centres
Λ	Total Energy Used
τ	Transactions
ω	Weekdays

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The last thing to say, quoting the good old saying of Socrates: “The more you know the more you realise you know nothing”

Author’s declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Faculty Ethics Committee / University Ethics Committee / external committee.

I declare that the Word Count of this Thesis is 86,038 words

Name:

Signature:

Date:

CHAPTER 1. INTRODUCTION

"The time is right for electric cars - in fact the time is critical."

By Carlos Ghosn, Chief Executive of Renault-Nissan (2013)

One of the main economic issues related to urban areas is transportation. The interrelationships between community economic development, transportation, urban revitalisation, energy efficiency, land use and environmental protection form the urban communities Holmes, 1997). It is crucial for the movement of goods and people around the countries, and it allows access to services, education, and leisure activities (HM Government; Schäfer & Dray, 2011). Transport provides employment itself and contributes to countries' economies (Gray, 2014); it liaises with businesses to expand and create wealth and employment (Herbert, 2011). Especially in countries of the developing world, enhancing mobility for poor and vulnerable groups is one of the most important preconditions of development (Pardo et al., 2012). Cities represent a crucial battlefield for societies to meet the challenges of sustainable development mainly the creation of new low-carbon economies. Cities' growth patterns are undergoing qualitative change; studying and analysing urban transportation networks, modes and transit systems operating in cities becomes essential and has been gaining more attention in recent years (Quigley, 2008; Xia, 2005; Anas et al., 1998). Economic and social development spanning the past forty years has contributed to the expansion of cities into the suburbs (Frade et al., 2011). Accordingly, individual motorised transport has increased to alter the pattern of urban mobility. People desire to live and work in different cohesive and vibrant neighbourhoods and at the same time increase the diversity in their social lives via mobility. They acquire high-quality transit service that gives them convenient lower-impact ways of getting around (USGBC, 2010; Smith, 2008; Filmanowicz, 2007).

A projected look into the future indicates a higher population growth rate, and an increase in urban trends where the automobile population is growing at a much faster rate than before (OLEV, 2011; Proost, 2000).
Transport represents one of the fastest growing sectors of the economy in terms of energy use and the environmental burden of conventional means of transport (Foley et al., 2013). The Internal Combustion Engine (ICE) has a considerable environmental footprint and the reliance on oil and other fossil fuels contributes to the worldwide pollution that causes global warming, which also threatens economic and national security (Rio, 2012).

The transport sector, road-based emissions, was responsible for approximately 14 % of the Global Greenhouse Gas (GHG) emissions as per IEA (2007). In recent years, the environmental burden of the UK urban road traffic has been of concern to governments and authorities of developed countries (OLEV, 2013; 2011) with an increasing interest in mitigating this (Orsato, 2009; Michaelis, 1996), as well as to develop and (re-) design cities to make them more liveable (Breithaupt, 2010). Between the years 2004 - 2010, road transport in the UK contributed more than 66.6% to climate change and 68% from the overall energy consumption (DfT, 2011). In 2012, the transport sector contributed 24.6% of the total carbon dioxide emissions (DECC, 2014). This implies that the current transportation system is unsustainable (Frade et al., 2011; Kousoulidou et al., 2008) and indicates the need for a major transformation in performance along with a societal change to deliver a more sustainable and accessible transport system (Gray, 2014). It highlights the urgent need for an efficient and integrated mobility system, which utilises alternative smart means, tools and methods that will overcome the barriers for switching from ICE vehicles to e-mobility (Beeton, 2014).

Across the Organisation of Economic Co-operation and Development (OCED), Transport-sector CO2 emissions represent 30% of overall CO2 emissions from fossil fuel combustion (OCED, 2010). Stakeholders across the OECD countries (IEA, 2011; 1993) and across the EU (Grunig et al., 2011; COWI, 2002) have started to focus on low carbon emission vehicle industry and markets by considering alternative means of transportation (IMechE, 2000) e.g. hybrid, electric, hydrogen/fuel cell (Herbert, 2011) with the attention to the expected depletion of fuels. These democracies work together to understand and respond to new developments and concerns (Wee et al., 2012; Strange & Bayley, 2008; Garling, 2001). Throughout Europe representatives of the energy industry, manufacturing, politics and research are participating in several programs to advance the integration of clean means of transport (Raab, 2011). Due to the urgent challenges presented by carbon reduction targets, climate change concerns, air quality goals, and resources depletion threats; most developed economies are conducting low-carbon policies and initiatives to make Europe’s electricity cleaner via investing on efficient energy and low carbon technologies in addition to clean coal, gas, and nuclear power. As for the matter of transport matter, they are relying heavily on the electrification of road vehicles, especially in a single vehicle owner to achieve carbon reduction goals (Morton et al., 2011). Efficient electric technologies in transport and buildings, combined with the development of smart grids play a key role in reducing fossil fuel consumption and making electricity more sustainable (EURELECTRIC, 2014). Smart Grid is a solution for the existing electrical grid that is ill-equipped to handle the demand of the end-users as well as renewable sources of energy which are intermittent and less predictable than fossil fuel based generators (Hicks, 2012). It integrates several methods of coordination between the grid and the loads which in turn could help avoid network congestion (Abedi et al., 2014 ; ElBanhawy et al., 2012; Rodriguez, 2010).

1.1 Mobility Technology and Advanced Systems

The transport sector is an emerging market that endures a wide range of technologies. It is already well imbued with Information and Communications Technology (ICT) and technologies such as GPS (Global positioning Systems) (ElBanhawy et al., 2012; Beeton, 2012). Research on Intelligent Transport Systems (ITS) covers a wide field, as it comprises a combination of communication, computer and control technology developed and applied in transport to improve efficiency and system performance and to facilitate mobility. To vehicles, innovative technologies can be applied as well as transport infrastructure and used by stakeholders embracing transport organisation, information technology (real-time information, tracking and vehicle-to-vehicle communication) and passengers to improve service quality and transport management (TRIP, 2014). In addition, transport management is where effort is being directed to changing the ways air, rail, road and waterborne transport systems, particularly the infrastructure, are used. It includes increasing or reducing capacity, reallocating capacity and changes in the operation of public transport (TRIP, 2014). It can be considered as a platform for exporting and commercializing services and ICT resulting in business growth (ElBanhawy et al., 2012; Beeton, 2012; 2011).

Internationally and across Europe, there is a range of technology opportunities and strategies available for the smart transportation modes in the 21st Century (Schäfer & Dray, 2011). Electric Vehicles (EVs) and the related infrastructure are being developed rapidly (Guo et al., 2012). It enables vehicle-based, battery, charging types and charging supply chain technologies (Bongardt & Schmid, 2011) which in return impacts the long-term future strategies for EVs. In particular, battery technology and charging types are evolving very rapidly to meet the desired energy savings threshold, ranges, and speeds (European Commision, 2011). Moreover, the sector facilitates having a stream of transferred knowledge and technologies between regions and particularly adopting technologies to local contexts of developing countries and emerging economics (Bongardt & Schmid, 2011; Hodges & Bell, 2011).

In the UK, in order to develop an integrated regional recharging infrastructure, the Office of Low Emission Vehicles launched Plug in Places (PiP) fund in 2010 (OLEV, 2011). Successful PiP regions are situated in the North East, Milton Keynes, London, the East of England, Greater Manchester, the Midlands, Scotland and Northern Ireland (DfT, 2013a). Moreover, UK infrastructure development started to expand outside these regions as a part of the development strategy plan, see (Figure 1-1). Each city has its own strategy to promote and support the EV market. London had developed the EV Delivery Plan setting out a comprehensive strategy to stimulate the market for EV in London (Yarrow, 2009).

Increasingly, the USA, both at state and federal level, (CEC, 2011; Doyle et al., 2011; Kemp, 2005) is initiating and accelerating current plans to move towards more clean, alternatively fuelled, i.e. non- ICE (Wiesenthal et al., 2010; Thomas, 2009; Tate et al., 2008; IMechE, 2000) and smart and intelligent means of transportation (Bell, 2006) at city, regional and global scales (Small, José, & Gómez-Ibáñez, 2005). Despite some false starts not so long ago (Deventer, 2011; Dings, 2009; Anderson & Anderson, 2005; Mom, 2004), effective support from the public level (Ahman, 2006) and the commercial and technological competition race for capturing market share and commercialised Research and Development (R&D) leads (Altenburg & Fischer, 2012; Pilkington & Dyerson, 2006; Magnusson & Berggren, 2001) might deliver breakthrough (Serra, 2012; OLEV, 2011; Deventer, 2011; Sandalow, 2009; Cowan & Hultén, 2001; Hulten & Cowan, 2000); Wakenfield, 1998; Sperling et al., 1994).

Figure 1-1: Active regions of national charging network in the UK

1.2 Calls for Cross- Country Smart Transport

There are barriers to innovation in transport, which includes road, air and railway sectors. With a particular focus on the road-based sector, the lack of facilities of demonstration and validation at scale and in the real world is a major issue (Gray, 2014). In the context of urgent challenges presented by carbon reduction targets and air quality goals, the EV industry is seen by developed countries to be a viable solution (Morton et al., 2011). EVs are currently being discussed intensively around the world especially in European and North-American countries but also in emerging economies such as China and India (TU Delft, 2014). These proactive countries have launched initiatives and programmes to support the EV market. The European Commission, through different agencies and framework programmes, has provided support for initiatives, which are directly aimed at supporting the adoption of EVs and clean energy solutions. One such program is a project lead by the University of Hamburg of Applied Science and has stakeholders and partners from Sweden, The Netherlands, UK, Belgium, Denmark, Germany and Norway. This project titled North Sea Region Electric Mobility Network (E-Mobility NSR), was launched in April 2011. It aims at promoting e-mobility within the North Sea region, defining current technological and end-users' barriers, and supporting the market. The project investigates the development of a transnational route for EV drivers across these countries, whether via land or sea, see (Figure 1-2). For example, if an EV driver is commuting from Oslo to London, they can consider driving their car and not worrying about recharging their batteries somewhere during their route. It has seven work packages one of which focuses on developing a transitional plan of e-mobility (NSR, 2011).

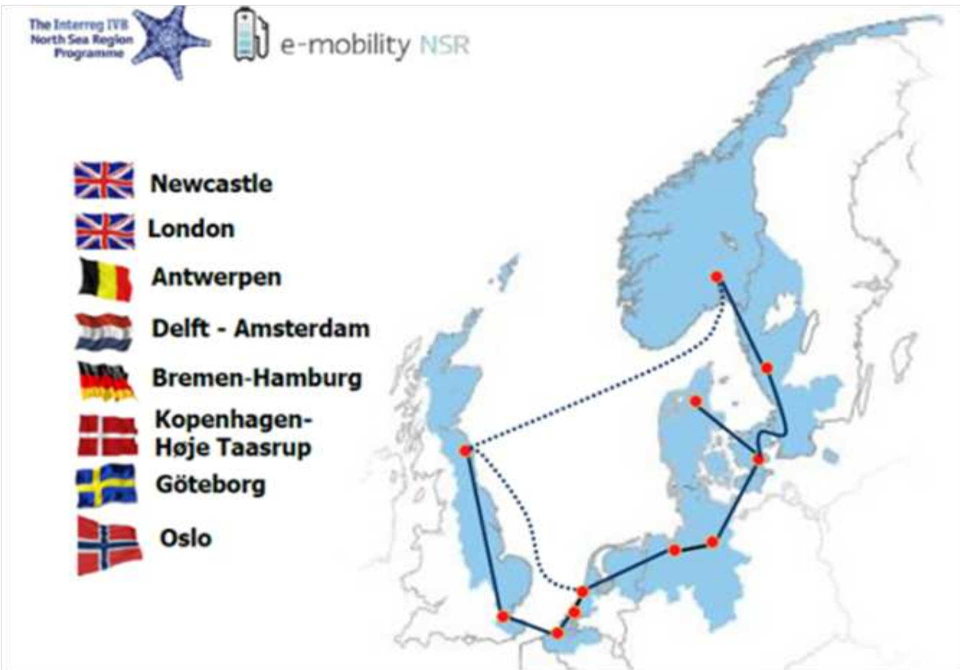


Figure 1-2: NSR map (NSR, 2011)

It is perceived that the electrification of mobility is the most efficient mean of transport compared with ICE vehicles with the smallest CO2 footprint. Much attention has been devoted to electric drive vehicles as a solution to the problem of fuel consumption and carbon dioxide emissions (Egbue & Long, 2012; Frade et al., 2011; Logica, 2011; Kristoffersen et al., 2011; Barkenbus, 2009; IMechE, 2000).

1.3 Electric Drive Vehicles

Even though EVs have existed for some decades, the term is still thought of as a new technology (Hjorthol, 2013). Electric Mobility (E-mobility) offers considerable potential to make progress in a variety of wider environmental, societal and economic objectives (Wee et al., 2012), which accelerates the development of smarter cities (Lozano, 2012). Overall, there are three major reasons for e-mobility (Bradley et al., 2009): the first reason is to recognize the potential of reducing Greenhouse Gases (GHG) and CO2 emissions, which is in part predicated on de-carbonising the electricity generation and input (RAoE, 2010). The impetus for EVs stems from the long term environmental and socio economic benefits by providing smart transport. As well as their overall lifecycle environmental footprint (depending on manufacturing inputs and recycling); (DeLuchi et al., 1989). This is linked to ICT, traffic demand and flow management, which in turn could reduce the environmental impacts (Kudoh et al., 2001). However, EVs will never become a full substitute for public transport, due mainly to land take and the inefficient use of infrastructure (Wee et al., 2012). The second reason is a public health dimension with regard to urban air pollution levels and respiratory diseases (Woodcock, 2009). Finally, the third reason is to create and grow the new green-low carbon industries. Some of these benefits can be recognized and communicated as co-benefits, where low carbon mobility can link to other issues of value as well as other policy areas (health, safety, economy, time, planning and society), and at an aggregate city level, see the CATCH project final report (CATCH, 2012). According to statistics, only 1,021 electric cars were sold in the UK in the year leading up to October 2011, while in the year leading up to October 2012, this figure had shrunk to 950 (Boyce, 2012).

Electric drive vehicles compromise all vehicle technologies with an electric drive train. These include Battery Electric Vehicle (BEV or EV), Plug –in Hybrid Electric Vehicle (PHEV) and Fuel Cell Electric Vehicle (FCV).

- BEVs: This type of motors is powered by electricity stored in batteries within the vehicles. It uses electric motors and motor controllers instead of ICEs for propulsion, which is less expensive than the use of liquid fossil fuels (Kristoffersen et al., 2011).

- Extended range Electric Vehicles (E-REV): This type is a more transitional form of conventional hybrids vehicles whereas in conventional hybrids, the wheels are turned by an electric motor, a gasoline engine, or both, the wheels in these cars are turned only by a large electric motor. For short trips, the motor will run only on battery power; whereas, for longer trips, a gasoline-powered generator kicks in to supply electricity. It has a plug-in battery pack and electric motor and an internal combustion engine (Go Ultra Low, 2015; Kristoffersen et al., 2011).

- Plug-in hybrid electric vehicles (PHEVs): This type of vehicle is powered by a combination of electricity stored in a battery and an ICE. The batteries in conventional Hybrid Electric Vehicles (HEVs) are recharged automatically as the vehicle is being driven. However, PHEVs have much larger batteries, which are recharged from the grid, giving them a greater electric-only capability. HEVs are the most popular EV choice in all three scenarios as they rapidly gain market share (Sweda & Diego, 2012).

1.3.2 E-mobility

In this context, an e-mobility system is defined as the car, driver, charging infrastructure, and all related regulations and standardisation. In other words, it means the soft-scape and hard-scape elements of the system. Softscape refers to consumer profiles, potential users, sales forecasts, market barriers and incentives, public policies, regulations (Kodjak, 2012), and all purchasing and operational behaviours related matters. Hardscape includes the urban context, batteries, utilities, and all related system functionality and practical matters. In this thesis, it will be referred to as EV system.

Regardless of the insignificant market share today, automotive companies predict that EVs will progressively gain popularity due to environmental and social-economic factors (Cooper, 2014; Lehner, 2013; Beltramello, 2012; ElBanhawy et al., 2012; Billmaier, 2010; Gao et al., 2007). In the next 20 years the number of EV, will exponentially increase (Mauri & Valsecch, 2012; Tan et al., 2012). The diffusion of purely EVs is on the forefront of the non-conventional power-train technology developments (Dijk et al., 2013). Stakeholders and EV advocates claim that EVs are winning broader consumer acceptance and the options are growing for potential users to join the market. Nissan reported rising demand for its LEAF from a broader range of consumers (Frades, 2014). Nissan claims that they are currently beyond the early adopters phase and they are selling for practically minded consumers who are looking at the monthly economic savings of mobility. The opportunities and issues that e-mobility brings will have lifestyle implications for large parts of the population (IET, 2011). The wide-scale adoption of privately owned low carbon emission vehicles certainly would provide an improvement (Anable et al., 2011; Morton et al., 2011) (Graham et al., 2012); (Element Energy Limited, 2013). EVs Offer real potential to make cities smarter and more sustainable (ElBanhawy, 2014; Beeton, 2014; 2012; 2011) Although the potential EVs have to resolve many sustainability issues related to the transport sector, there are also many uncertainties from technology development, economic viability, consumer satisfaction and environmental sustainability perspectives (Earley & Green-weiskel, 2011). Significant regional logistics demonstrate future opportunities to introduce clean means of transport. However, a considerable amount of research and feasibility work is still needed/ to be undertaken before action can be taken (ENEVATE, 2014).

In the UK, the government recognised that understanding drivers' requirements for Recharging Facilities (RFs) and how best to support an emerging infrastructure market was the key to the success for low emission vehicle uptake (DfT, 2013a; 2013b). There is a growing momentum behind owning EVs. However, it is too early to ascertain whether electrification will dominate the alternative equivalent vehicle market. Automotive Original Equipment Manufacturers (OEMs) must recognize the growth strategy and the way to position themselves to win while alternative fuel technologies and infrastructure continue to mature. When considering these strategies, OEMs should recognize the complexities of merging the utility, automotive, battery and charging infrastructure value chains. New infrastructure and new business models must be considered (Accenture, 2011b). EV has become a real option for a number of major car manufacturers who are launching high quality EV models into the market (Lane et al., 2013).

1.3.2 Diffusion of EV models in the market

Innovation of diffusion and the pattern of market penetration for innovative technologies were first introduced by Rogers (1963). Rogers recognised four main predominant factors that influence the spread of a technology:

- i) the innovation itself;
- ii) the communication channels used to diffuse the technology;
- iii) the social atmosphere in which the technology circulated;
- iv) time

The EV market is dynamic and has unanticipated market changes; various studies were carried out addressing the diffusion of EV (Cooper, 2014, Eppstein et al, 2011); Cooper (2014) addressed the diffusion in four periods spanning past, present and future via two necessary strands: majority technological acceptance and majority societal acceptance. This included the political factors, which are important to consider rather than purely technical analysis of the EV emergence. Innovation can be measured through adoptive behaviour, communication activities, and psychological inclination which require a degree of interaction (Morton et al, 2012; Rogers, 1963). As per Thiel et al. (2010) a game model (game theory based model) was developed considering i) charging choice, ii) EV model price, iii) ownership, and iv) vehicle model preference and compared this to a conventional vehicle model. Furthermore, an investor-decision model was developed considering i) location of the Charging Point (CPs), ii) market share, iii) charging price, iv) number of EV drivers using the CP, and v) operation and maintenance costs. Another way to determine the market penetration is the total cost of ownership (TCO). Higgins et al. (2012) developed an innovative diffusion model incorporating multi-criteria features in order to estimate the adoption of these technology options across various consumers. The model was tested to forecast the market share of EVs in different regions while considering geographical and technical differences (Higgins et al., 2012).

The EV diffusion is facing technical and social barriers; inadequate charging facilities (non domestic), limited range, premium price, and immaturity of battery technologies are the primary technical issues associated with owning an EV. Another facet is the demographic aspect, which is a product of education, level of awareness, availability, road network, driving pattern, daily mileage, employment status, and household income. After applying Rogers' theory to the EV context, see (Figure 1-3), where the current EV market stands can be identified.

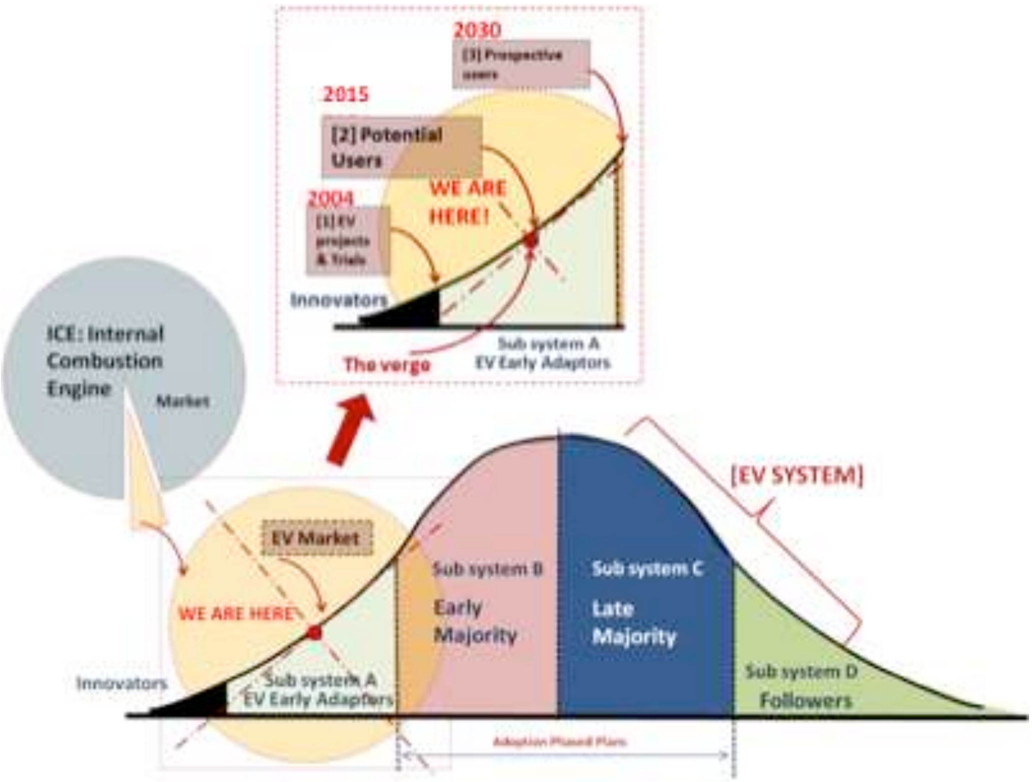


Figure 1-3: Diffusion of EV

The EV is on the verge of the first level of maturity (early adapters); whereas, early majority is where the perspective consumers are. In order to increase the market penetration and reach 2030 environmental targets (Kousoulidou et al., 2008), the stakeholders and especially the planning authorities and policy makers, should:

- develop deployment and operation plans that take into account the user experience (The power of end-user feedback, experience and social influence are overlooked);

- provide detailed business cases with a clear vision of how the end-user perceives the market (potential and current).

- Propose creative solutions as design interventions should follow a user-centred based approach.

1.3.3 E-mobility infrastructure

In this context, the e-mobility charging infrastructure refers to the non-domestic charging service which can be On Street or Off Street CPs. This embraces all publically available CPs, including the shopping centre and workplace car park. CPs can be also referred to as refuelling stations, the charging network, or the RFs (PRP, 2012). The On Street one can be like the CP outside the side door of a restaurant. An Off street bay that compromises a CP shared with another bay in case of two sockets, see (Figure 1-4).

Figure 1-4: Off Street and On Street CPs

On Street CPs, may refer to as "opportunity charge" (Conway, 2011). This type continues to be rolled out across the UK whether using a pay as you go scheme or the membership scheme (CYC, 2010). There are dedicated bays reserved for EVs; between 8:30 AM and 6:30 PM, the maximum stay periods applies (e.g., two hours maximum in the City Road), outside of these times, drivers can stay longer. As per the Charge Your Car Ltd. (CYC) website (CYC, 2010), the availability of all the active CPs are indicated, see (Figure 1-5). CYC is an EV local service provider for UK's North East region. All CP's related data as well as anonymous EV users information were provided by CYC for this research purpose. CYC is the UK's '*pay as you go'* charging network for EVs (CYC, 2010).

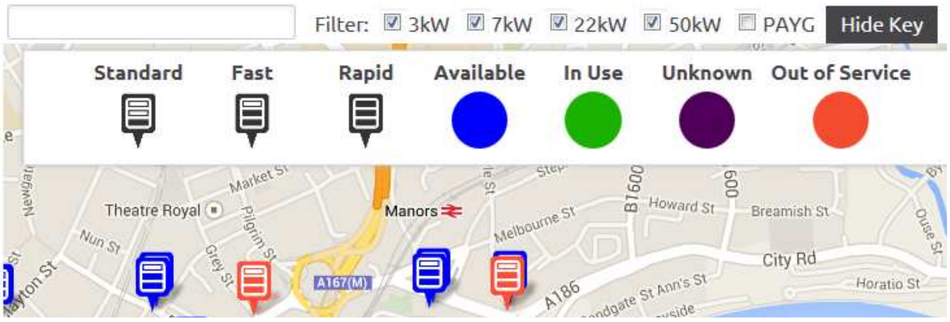


Figure 1-5: RF status updates

On and Off street CPs are usually 7 KW or 3 KW both with 13 Amp and 32 Amp sockets so they are compatible with all EVs. Drivers can plug in their cars in Off street and leave it for approximately three hours and a half if they want to have a full charge as per their battery capacity (Nissan LEAF battery is 21 KW capacity) using a 7KW charge or seven hours in case of 3 KW. The actual charging time will depend upon the on-board type of charger, type and the level of CP including the initial State of Charge (SoC), at arrival.

1.3.4 Charging options

There are many ways and advanced technologies to recharge EVs' batteries: plugged in (domestic/ public), electrified roads, wireless charging stations, wireless charging under the roads (Lindblad, 2012), and battery swapping (ElBanhawy & Nassar, 2013). There is a rising demand for RFs to support the e-mobility system in its urban context. Studies have showed that investments in publically available CPs would better support the EV market. Having an integrated reliable network should promote the EV market as this should slow the rapid increase of the upfront cost of the EV due to the marginal cost of expanding the car range and increasing EV battery capacity (Chen et al., 2013). Automotive manufacturers are working on extending the range to 250 miles or more in the EVs. Planners and policy makers have to economically design integrated RFs that can support the demand and secure the way for potential users to join the market.

There are three types of chargers:

- Standard (3kw) points: can top up a battery in a couple of hours and charge a battery from flat to full in six to eight hours. (seven hours to get a full charge-Nissan LEAF)

- Fast (7 – 46kw) points: These are able to top up points in 30 minutes, and charge from flat to full in less than four hours. (three hours to get a full charge Nissan LEAF)

- Quick (50 – 250kw) chargers: This type of charging is very limited as it acts as an emergency to be utilised when drivers have a near-empty battery. This is due to the high level of infrastructure required for the technology to operate safety, and as a result these will be located in strategic off road locations.

Ultimately, the time taken for an EV battery to be charged depends on the initial SoC, the battery capacity, age of the battery, and the power capability of the CP. With the new models on the market, most vehicles will have the ability to travel for approximately 100 miles before a recharge is needed (NissanLEAF, 2014b).

1.3.5 The EV dashboard and some facts about the EV battery

There is basic information about the battery, charging types and rates which the driver should be aware of. Each EV model has its own designed user interface (UI). UIs of EVs show the charging information, see example of Nissan LEAF, (Figure 1-6). The SoC may be in cells or in percentages, see (Figure 1-7).

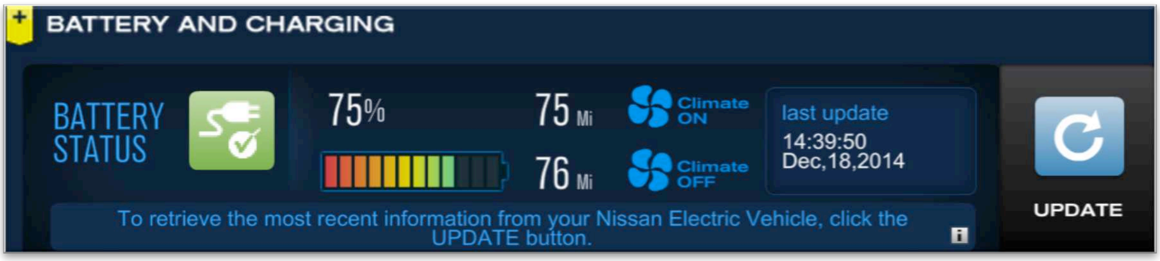


Figure 1-6: Nissan LEAF UI showing battery status

This information is fundamental as it justifies the charging patterns and profiles. Starting with the battery, EV battery has 48 modules with 192 cells. An arbitrary display of 12 cells is in the car UI. In case of full charge, the 12 cells will flash in green, the last cell from top displays from 12% to 15%, depending on the model. Each following cell displays 8%-5% of the charge, depending on the model, see (Figure 1-7).

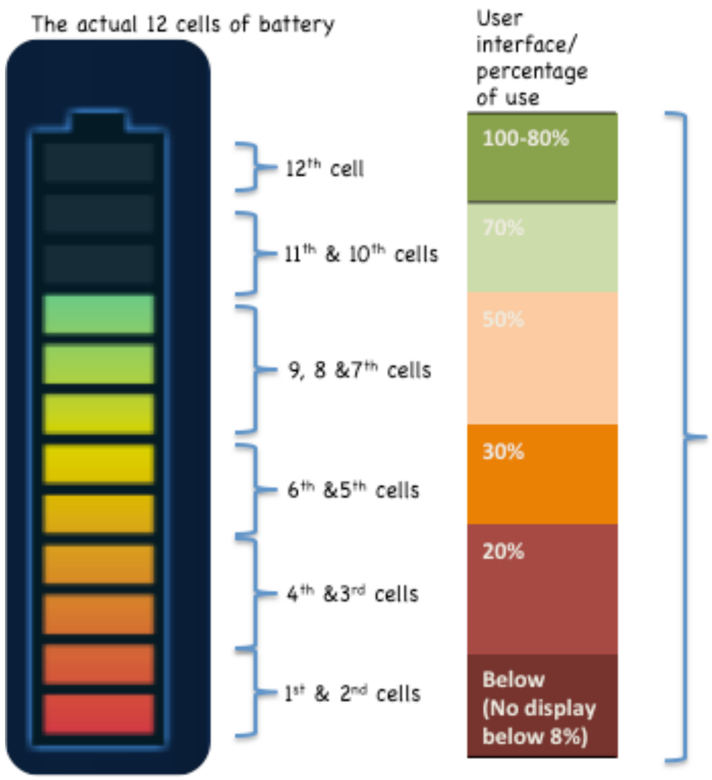


Figure 1-7: EV battery arbitrary cells and the percentage display

1.4 Research Question(s)

This research reports on understanding, analysing and designing of RFs for alternative means of transport. The remit of this research is to offer valuable information for power providers and infrastructure deployment decisions' makers. On the basis of the previous studies and while employing a multi method approach, this thesis illuminates the following questions:

- RQ1: What are the influential spatial and behavioural attributes affecting the design and the use of e-mobility charging network?
- RQ2: How useful are the user studies in the context of EV use?
- RQ3: What are the main paradigms of e-mobility compared to conventional transport?
- RQ4: Is it possible to depict the social practice and the system's mechanisms in a simulation model? And if yes, what is the recommended modelling technique?
- RQ5: For planning purposes, how could stakeholders forecast the charging behaviour and locations for a better e-mobility diffusion?

1.5 Research Aims and Objectives

The primary aim of this thesis is to document a practical guide to the exploration and understanding of spatial and behavioural issues of EV systems. The research questions are addressed so as to meet the following objectives:

- Objective 1: Identify and quantify the spatial and behavioural attributes in order to investigate the correlation between the spatial features of the network and the charging patterns of EV users;
- Objective 2: Explore the charging pattern, profiles and personas of EV users which responds to the diminished range anxiety issue of driving an EV;
- Objective 3: Design an agent architecture that corresponds to the EV system dynamics and messaging protocol between the users themselves and the built environment.
- Objective 4: Exploit a hybrid-modelling technique to simulate the EV system (urban and behavioural layers).

1.6 Thesis Structure

The thesis started with a brief introduction to the interdisciplinary area of research. Due to the various issues and points the research is challenged to address, the thesis has three strands stems from the title: understand, model and design, see (Figure 1-8).

1.6.1 Section I: understand e-mobility

This section includes the understanding of e-mobility in its urban context. Chapter 2 covers the e-mobility previous work and Chapter 3 covers the vehicular movement prediction techniques and simulation modelling approach. Following the literature review, Chapter 4 presents the research methodological approach. It outlines the multi methods being employed throughout the thesis. Chapter 5 contains a meta analysis of the consumer and EV user studies which works as a prerequisite to the user study presented in chapter 6.

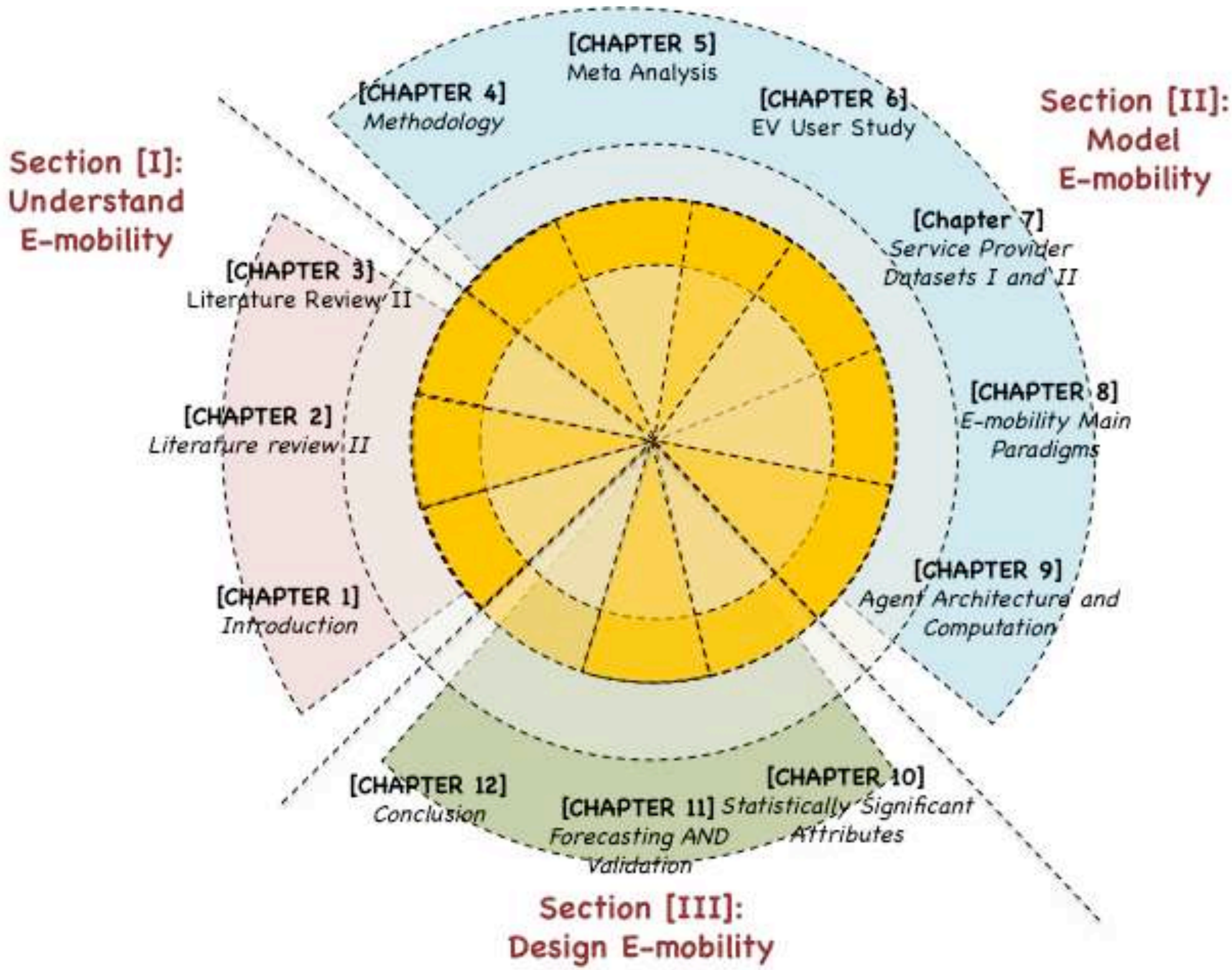


Figure 1-8: The research three strands

1.6.2 Section II: model e-mobility

The section starts with Chapter 6, which presents the first user study carried out in Q4 2014. A total of 20 interviews were carried out with EV users and fleet managers (microscale analysis). Chapter 7 incorporates the service provider dataset and its relevant analysis of the charging network. The chapter goes through the behaviour related attributes. At a macroscale level of analysis, the EV users charging personas are presented and analysed. Chapter 8 presents the main paradigms of the e-mobility simulation modelling and provides a review of the platform selection process, Anylogic software. Chapter 9 discusses the state of the art agent architecture of an EV system modelling and how this is reflected in modelling.

1.6.3 Section III: design e-mobility

Chapter 10 carries out a statistical model that identifies the percentage of variance in the design process with regards to different spatial and behavioural attributes. Chapter 11 covers the forecasting models. The first part of the chapter presents a time series model to predict the users' charging patterns. The second part proposes a simulation based-design support tool to identify the preferred RF's locations. This is followed by validation of the data driven model. And finally, Chapter 12 overarches the three sections and summarises the key points of the research fulfilling the aim and objectives.

CHAPTER 2. LITRATURE REVIEW PART 1

"The UK has multiple regional networks of charge points in closed membership schemes, which is delaying the adoption of electric vehicles in the UK."

Alexandra Prescott, Operations Manager, Charge Your Car Ltd. (2012)

The EV as a land based road means of transport is a sociotechnical system (Geels, 2005) that includes technology, regulations, user practice, infrastructure, utility provider, management and service provider, maintenance network, supply network, and markets. It integrates sociotechnical, business, and economic and technical dimensions. The main body of the literature is divided into Chapters 2 and 3. Previous work of EV consumer and user studies is presented in Chapter 5. Over 65 EV softscape-related studies and 70 hardscape-related studies are compiled in this chapter including EV trials and diary-based studies. With a thematic approach, the review is presented as follows:

- EV social aspect (Chapter 2);
- EV softscape (Chapter2);
- EV hardscape, charging infrastructure (Chapter2);
- EV modelling and simulation (Chapter 3);
- EV consumer and user studies (Chapter 5).

2.1 The Social Aspect of EV Use

The charging pattern (behavioural layer) related analysis and system functionality. Analysing the behavioural element of an existing EV system, the system and the level of interaction with the infrastructure, will assist in designing future EV users (Elbanhawy, 2014; Pasaoglu et al., 2013). Before reviewing the previous work of the social practice, there are some socio-technical common phrases in the context of EVs that need to be highlighted. These elements form the mechanism of the e-mobility social practice, see (Figure 2-1).

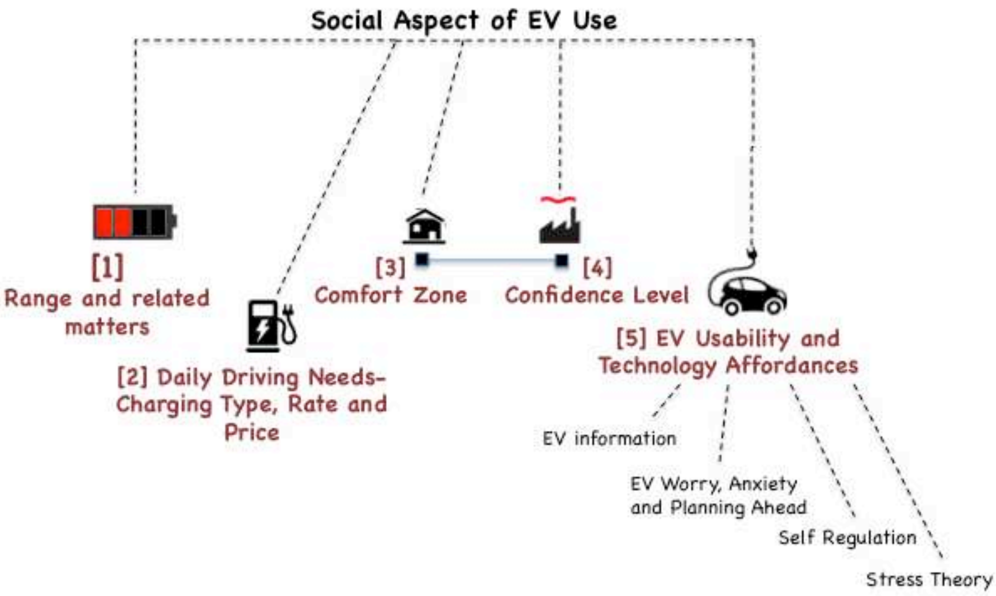


Figure 2-1: The social aspect of EV use diagram

2.1.1 E-mobility range and related matters

The range of EVs has been one of the major barriers in accepting the e-mobility (Franke et al., 2012; Thomas; Kitamura & Hagiwara, 2010). The perception of limited mobility resources is a purchase barrier (Ziefle et al., 2014; Bunch at al., 1993). Franke et al. (2012; 2013; 2014) raised a very valid question after reviewing recent studies on range issue and how good does the EV meet the travel needs (Cocron et al.; Dimitropoulos et al., 2011; Garling, 2001), which is:

> *"the experience of range is a barrier in itself or is it all about a psychological issue? Or both?"*

This question supports the approach of dealing with the generally imposed barrier instead of focusing only on improving the battery performance. Several factors pertinent to EVs' battery range appear to influence users' anxiety during driving; known as Electric Vehicle Range Anxiety- EVRA (Rauh et al., 2014; Nilsson, 2011). The phenomenon of EVRA has been heavily discussed in the literature (Krupa et al., 2014; Nilsson, 2011; Rahim, 2010; Tate, et al., 2008). It emerged as a concept in the late 1990s and captured a drivers' concern of not reaching their destination while travelling in an EV (Nilsson, 2011). EVRA describes consumers' fear that their electric car battery will run out mid-route and poses a major barrier to EV adoption. The full electric range is a term that describes the maximum distance that can be commuted relying only on the battery before accessing any CP. Automotive companies when selling their cars usually indicate this value as a way to attract more potential users. However, it is usually measured under certain conditions, which makes it difficult to reach this range in most of the cases.

The limited range is projected into the maximum road trip driven. The older EV models have driving capacity of 60-80 kms as a trip interval between two charges. With the advanced battery technology and the employment of Li-lon batteries, this range has increased to hit 120-180 kms (Christensen et at., 2010). However, this is theoretical; in the real world, the practical range is different due to the physiological and technical factors involved. There is a discrepancy between the maximum available range and the maximum range the driver is comfortable in reaching. This means that the use of EV is not only governed by cars specifications or experience, the avoidance of the range stress is a factor (Franke et al., 2014). The less and easier the charging event and the less it takes place, the more it is used. It has been noticed that the use of fast chargers extends the road trip hence widening the comfort zone of the EV driver for convenience and easiness.

The EVRA depends on the average daily mileage as well. Based on the region and the urban context, the calculation of the average daily mileage differs from one country to another. For example, in the USA, the average daily mileage is 40 miles where in the UK it is 10 miles (Brain, 2012). This shows that with the current technology and available structure, it is more convenient for UK drivers to own EVs rather than US drivers. Regular commuting trips will match EV properties: a routine journey where the driver is aware of the distance, congestions, road conditions and parking availability (Lane et al., 2013).

Full-electric range is the maximum distance that a vehicle could travel without the need to charge (Eppstein et al., 2011). Therefore, it can be said that providing an accessible and highly visible charging network (Beeton, 2011) generates interest amongst consumers and encourages uptake (Element Energy Ltd, 2009). Towards developing a unified ecosystem and smart cities, investigating and predicting the consumers' response is a significant challenge that EV marketers face (Strahan, 2012; Beeton, 2011). However, the roll out of an intelligent infrastructure, creation of innovative service models and changes in consumer behaviour are all positive transformations that indicate that this is a growing market (Beeton, 2011) with a positive effect on climate change (Herbert, 2011).

2.1.2 EV actual daily driving needs

The lack of understanding range and recharging issues, leads to conflicting intentions. Consumers do not have sufficient knowledge of how the range limit would affect their daily routine. This is observed from the i) barriers of diffusion, ii) potential users' concerns (Steinhilber et al., 2013, Delang & Cheng, 2012), iii) current users limited experience of full electric range (Rolim et al., 2014; Franke et al., 2014 ; 2013; 2012). Limited range is treated by avoidance (Franke et al., 2013), range anxiety is not experienced driving most of the time the car is being used (Rauh et al., 2014). For everyday EV use, range anxiety is more of a perception problem than a real hurdle (Todd et al., 2013). The battery takes around eight hours to be fully charged using a 13 Amp outlet, the SoC affects the time needed to top up. Figure 2-2 illustrates the differences; it elucidates the four possible charging rates via domestic and non-domestic charging access.

If the EV driver arrives at a CP with a flat battery, which is a very rare situation due to the psychological barriers, the charge rate will be higher, almost double the case of 40% SoC. The charging rate is non-linear; it decreases as the function of current SoC, see (Figure 2-2). It also depends on the charger power, battery SoC and temperature, the amount of charge and the time needed to charge the car. In the case of Type 2, which is the case of the non-domestic slow chargers, and in particularly 7 kw, one-hour charge is enough to commute for 2 consecutive days with no further charging.

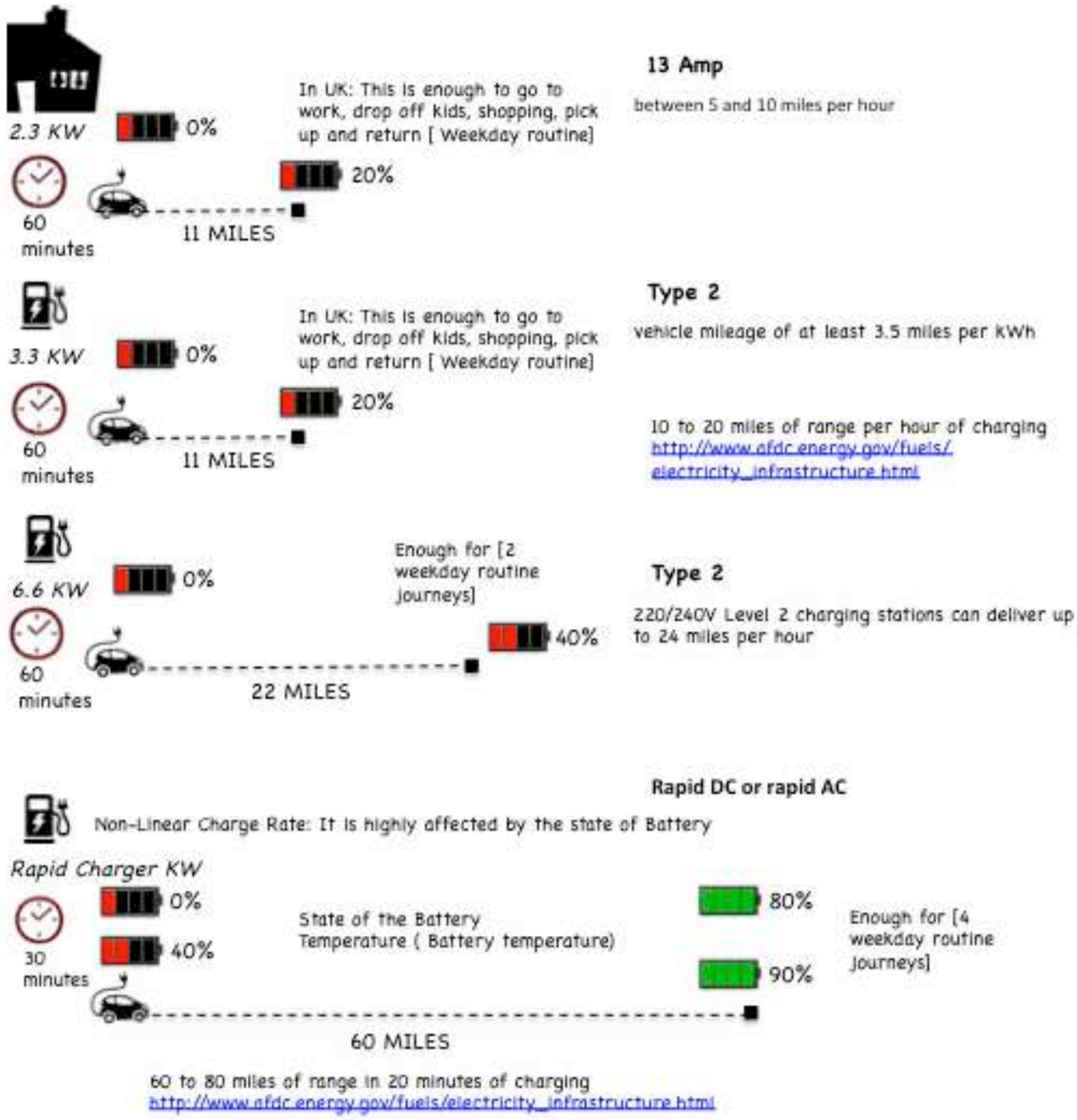


Figure 2-2: Charging rates

2.1.3 EV comfort zone

Comfort zone concept is derived from the proxemics approach and it is widely applied in the field of psychology. The proxemics approach is the scenario to social science, which evolves around the spatial behaviour of individuals (Hall, 1966). The comfort zone of an EV driver is about the individual's psychological boundaries they draw to themselves. Franke et al. (2012) have explained this zone from a psychological point of view as the comfortable range. Elbanhawy (2014a) has defined it as:

> *"the zone (metric, time or defined destinations), within which the driver will not worry about the battery."*

The range of these boundaries is a product of technical awareness, confidence level, mental comfort, analytical thinking, road network layout, and quality of charging services' locations and size. This definition needs to be more precise, as the driver may gain access to non-domestic CP, hence the zone will be expanded.

The definition is to be modified as: the zone (metric, time or defined destinations), within which the EV driver will not worry about the battery with no access to any nearby RF. Figure 2-3 illustrates the home in the centre (Origin), and the destinations (multiple: school, work, leisure, etc.) are the randomly spotted dots. The EV driver tends to tolerate short trips, which vary from one to another. The origin is the last place that has access to a RF. The first circle from inside is the comfort zone of the users. The road trip can be directed to any of the directions, as the destinations are denoted as black, green, and red circles. The comfort zone is relatively small compared to conventional means of transport. Will remain smaller until the stakeholders and policy makers pick up charging service difficulties.

The comfort zone is coupled with the confidence level of the users, which is the area between the first and the second circle. This area has an irregular curvature shape; it can be extended to cover even beyond the boundaries of the second circle, in which case the confidence level scores the highest levels of certainty. The black circle represents destination A, which is a destination that falls within the comfort zone. The green circle is destination B, which is relatively far compared to destination A, and it might be reached if the comfort zone of the driver is wide enough to reach it. The red circles are the destinations where the EV driver needs to have access to public CPs throughout their road trip. The wider the comfort zone, the less worried the driver would be. To get a wider comfort zone, the routes need to be supported by charging services so as to cover the routes to destination C for instance.

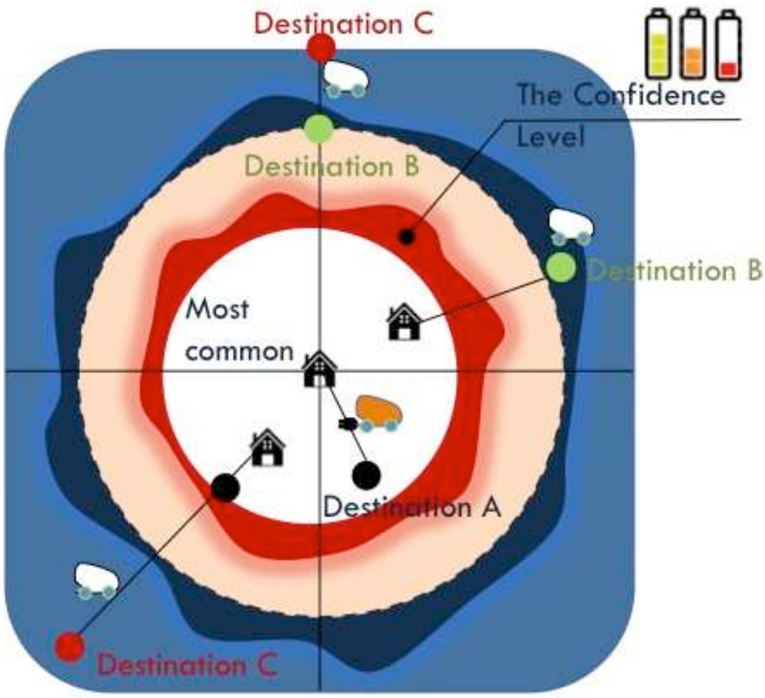


Figure 2-3: EV comfort zone

2.1.4 EV confidence level

The comfort zone is driven by the confidence level of the EV user. The confidence level as defined by ElBanhawy. (2014a) is:

> *"how comfortable are the EV users driving their cars to as many as they can commute relying on the EV."*

It is a product of the number of years using the car, technical consideration, charging pattern, RFs (domestic and non-domestic), the number of miles commuted using an EV, medium and long road trips that would allow the user to experience the full electric range of the car. It has an elastic nature; it gets bigger and extends with practice (Franke et al., 2014; Burgess et al., 2013).

2.1.5 EV usability and technology affordances

The production of new technology can be divided into a number of periods corresponding to the different social groups (Callon, 1980). The Technology development is a user-centred design based approach, which is driven by the usability, affordances, and difficulties. As per Preece et al. (2015), usability refers to:

> *"ensuring that interactive product are easy to learn, effective to use and enjoyable from the user' perspective."[Preece et al., 2015]*

User experience (UX) is a phrase that reflects how a product behaves and is used by consumers in the real world, which is central to interaction design. All aspects of the end's user' interaction with a system (Nielsen & Norman, 2014). Collecting information of a user's performance is a key compotent of usability testing. Applying this in the e-mobility context, carrying out user studies and analysing real information about users provides insights into the charging behaviour and the use and usability of the EV system (car and infrastructure). Affordance is a term that refers to:

> *"an attribute of an object that allows people to know how to use it."[Preece et al., 2015]*

As Norman (1988) simplified its meaning as "to give a clue". Affordance as a term has been used in the interaction design and is being used to describe how interfaces should make it obvious as to what can be done using them. UI or vehicle dashboard, is conceptualised as a perceived affordance, it is a screen-based interface which is different than real affordance of physical objects. The variety of technological solutions and the link between them and socio-political choices lead to the emergence of the design interventions (Callon,1980). This refers to the Actor Network Theory (ANT) introduced by Callon (1980). ANT is "the progressive constitution of a network in which both human and non-human actors assume identities according to prevailing strategies of interaction" (Callon, 1986). Cressman (2009) added that "ANT seeks a symmetrical account of the social and the non-social in describing how and why we have the technologies we do". In the context of EV use, the overall system is complex with different protocols and interactions between the users themselves and the built environment.

EV driver information

Driver information and assistance systems for range estimation and eco-driving can improve the range usability and the user e-mobility experience (Franke et al., 2013). There is a tension between the tasks and technologies in interface design (Gaver, 1991). Automotive affordance was introduced by Gibson, (1982) suggesting an embodied relationship between the driver and the car. EV has demonstrated how technology acceptance changes over time (Verbeek & Slob, 2006). Users are able transform the technology to better meet their goals (Callon, 1986). The driver deals with Advanced Transport Telematics (ATT) (Verwey, 2000) which includes the navigation systems, route guidance systems, collision avoidance systems and intelligent cruise control, and all kind, of on-board information systems. An EV driver, has to deal with the charging interface on top of the above list (Verwey, 2000). Not only monitoring the SoC (may refer to as State of the Battery (SoB)), but also navigating and estimating time needed to charge the car, if needed. All these systems may overload the mental state of the driver and distract him during the road journey. An optimally designed driver-vehicle interface is desirable to suffice for a technology affordances objective. In the case of multiple ATT systems, handling these interfaces is not easy. A coordination between separate ATTs is needed to control the flow of information to the driver to avoid overloads (Verwey, 2000). By looking into the relation between the battery and the driver, there are factors that relate to driving an EV or a non EV, displayed in (Figure 2-4) on the upper side of the road, expect RA (mental side). The lower side illustrates the battery-related factors (visual side).

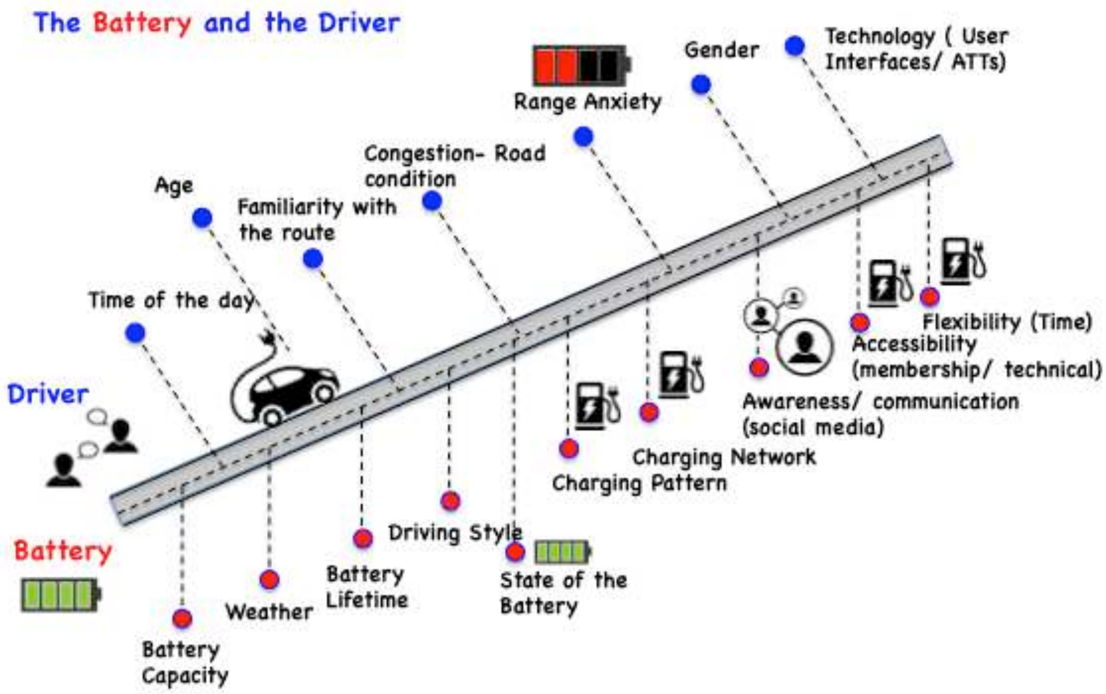


Figure 2-4: The EV driver and battery sides

EV worry, anxiety and planning ahead

In anxiety research, worry differs than anxiety (Liebert & Morris, 1967). Worry causes anxiety. Worry is a frequent phenomenon in the everyday lives of a normal individual which is convinced of as a constructive activity that helps us to analyse problems and motivates us to overcome hurdles (Joormann & Stober, 1997). However, it is responsible for emotional discomfort, exaggerates problems and leads to a pessimistic vision of things (Tallis et al., 1994). As a result, the planning ahead of a trip is one of the main paradigms of owning an EV. However, daily mobility routines require no explicit form of planning.

EV self-regulation

Self-regulation theory (SRT) depends on a limited resource (Baumeister & Vohs, 2007). In driving practices, adoption of different self-regulatory behaviour enhances safety and minimises risk. The theory implies that the driver make adjustments in their driving style and the associated workload (Rauh et al., 2014; Charlton et al., 2003). As defined by Baumesiter et al. (1994), SRT says:

> *"that we expend effort in control of what we think, say and do, trying to be the person we want to be, both in particular situations and in the longer-term."*

Previous work related the SRT to older drivers and how they self regulate their driving behaviour to minimise their risk of crashing (Charlton et al., 2003). As per Carver and Scheier, (Carver & Scheier, 1982) an automatic process of self-regulation is seen in car driving where the driver keeps adjusting the car on the road by continually monitoring its position in relation to other cars and to the roadsides. Self regulation theory (Bandura, 1991) encompasses the self-efficiency mechanism, which plays a key role in the exercise of personal agency by its strong impact on motivation, action, thought and affect. Owning or leasing an EV is considered as a pro-environmental change. In the field of pro-environmental changes and actions, behaviours amongst individuals are explored. Started by Kollmuss & Agymen (2002), and proved in the literature, holding a pro-environmental attitude does not necessarily lead to pro environmental behaviour, which is referred to as (value-action gap). This gap attracts researchers to build models investigating the behavioural aspects of different systems while explaining and predicting environmental behaviours of individuals. The development of these model for explaining and predicting environmental behaviours has become a key issue of social science environmental research (Bamberg & Schmidt, 2003). Models of behaviour which are feedback-based models, present behavioural outcomes as part of an on going flow of activity, in which internal and external factors interact to shape how we behave (Darnton, 2008).

EV stress theory

The EV user avoids critical and potentially stressful stress limitation situations planning for substantial range buffer (Franke & Krems, 2013). Running low battery is conceived as having low mobility resource, which is needed to meet the individual's demand. Moreover, the worrying and over thinking about the journey, distance between the origin (your current location) and destination(s), route choice, congestions, traffic management, etc.). Reducing stressors (range limit) is the way to cope with undesired stressful situations (Franke et al., 2012). Expanding the range is a product of battery technology and deployment of charging infrastructure. According to ISO, (2000) psychological stress is defined as "the total assessable influence impinging upon a human being from external sources and affecting it mentally", whereas strain is defined as:

> *"the immediate effect of mental stress on the individual (not the long-term effect) depending on his/her individual habitual and actual preconditions, including individual coping styles." [Schiessl, 2006]*

As driving an EV is associated with more driving workload, the mental and visual loads can be depicted by the following example, see (Figure 2-5).

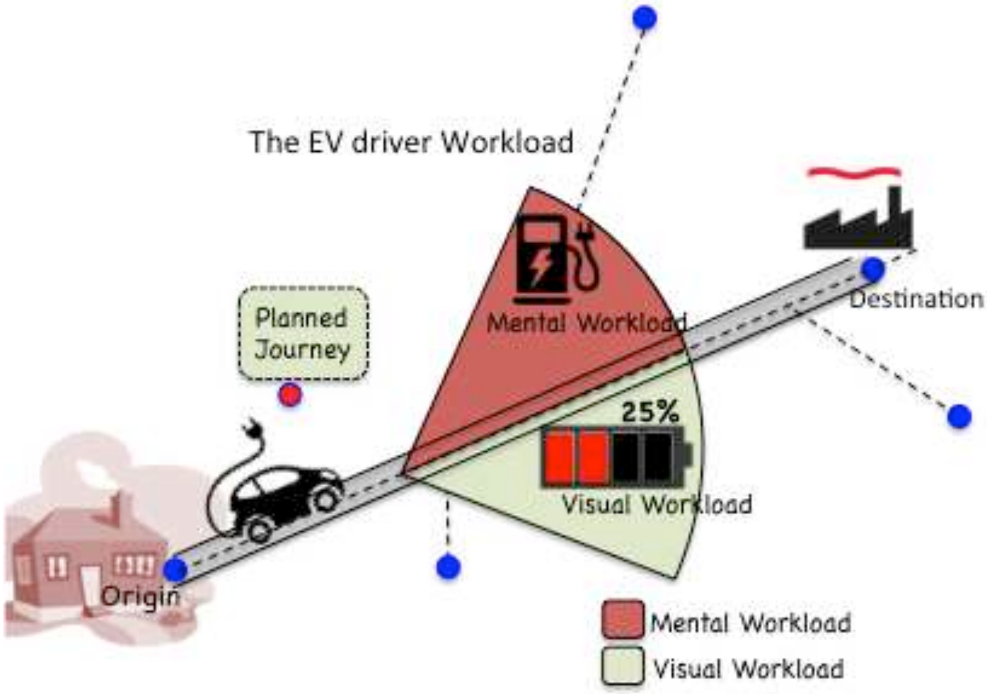


Figure 2-5: Mental and visual workloads of EV driver visualisation

2.2 EV Social Aspect-Previous Work

In the context of EV, there is no pre-existing preference that users can follow; users are being introduced to novel attributes of a new system (Axsen et al., 2013). The users adapt to the new technology differently (Craig et al., 2012). Little literature can be found exploring and analysing the system with all associated factors. Due to the lack of sufficient historical representative data on driving pattern, other similar data and assumptions are used for forecasting. These studies are carried out using different methods and perspectives, which made it difficult to compare results across countries and studies (Pasaoglu et al., 2013). EVs have not come on the market in large numbers; there is very little recorded information about usage and stated preferences is very limited (Shin et al., 2012). Preferences are made by early adoption through learning and exposure, and it is always conveyed by word of mouth (WoM) and social interaction and media (Axsen et al., 2013a).

In a report published by the International Economic Development Council in 2013, four influential factors were evaluated as those affecting the EV market: economical, social, R&D, and infrastructure (Sierzchula et al., 2014). Lane and Potter (Ben & Potter, 2007) classified the factors into technology related matters and end-user related matters. Factors like education level, fuel price, and environmental concerns were identified. Charging time was spotted as an influential factor that has a negative impact on adoption rate (Pasaoglu et al., 2013; Ben & Potter, 2007) alongside the limited range (Franke, 2013b) and the poor level of integration of the existing RFs (ElBanhawy et al., Egbue & Long, 2012; Woodcock, 2009). Another factor taken into account is the number of years EVs have been available for purchase (Eppstein et al., 2011).

In 2010, a study was conducted in Denmark to investigate if EV is able to fulfil the travel behavioural needs of customers (Christensen et al., 2010). In addition, it investigates which type of charging is needed to meet the end-user demand. Due to data limitation, the study was conducted based on conventional car passenger data. The problem with this study was the high-anticipated random error relying on the study outcomes. The travel demand and the driving pattern will change in case of EVs; in addition, it will not be a random selection in the case of the current and likely near future EV population.

Other recent studies addressed the driving pattern and range (Rauh et al., 2014). Rauh et al. (2014) carried out a trial on understanding the phenomenon of range anxiety and tried to determine the degree to which practical experience with EV reduces its different levels. Franke & Kerms (2013a) reported on the impact of limited resources on the psychology of the driver and their driving patterns. In another study by Franke & Krems (2013b), a better understanding of the factors that influence the range preference of potential EV users was carried out. Through dairy methods and data loggers, (n=75) customers driving EVs were tracked for 3 months. Participants had a fair knowledge and had maybe tried before driving an EV was acquired. The study highlighted on the adoption with limited resources and how the driver can still accept the technology and deal with the limited resources (availability of RFs, range, capacity and speed). Neaimeh et al. (2013) released a study on the effect of the topology and traffic conditions of a given urban context on the energy consumed by an EV. This was a part of SwitchEV trial (discussed in Chapter 5). A similar study for a different context, Guo et al. (2013) presented a study on how stressful the driving can be on older drivers. This study gave a methodological approach to examine the anxiety and worrying issue of finding a charging station and how this affects the driving pattern and safety A slightly different study was conducted on the freight and how the delivery system can contribute a lot to the carbon emissions (Browne et al., 2011).

2.3 EV Softscape-Previous Work

Mapping the previous work and all analytically corroborated studies over the time, helps us elicit a clear image of the nature of the study and how other have tackled it from different aspects over the years, see (Figure 2-6).

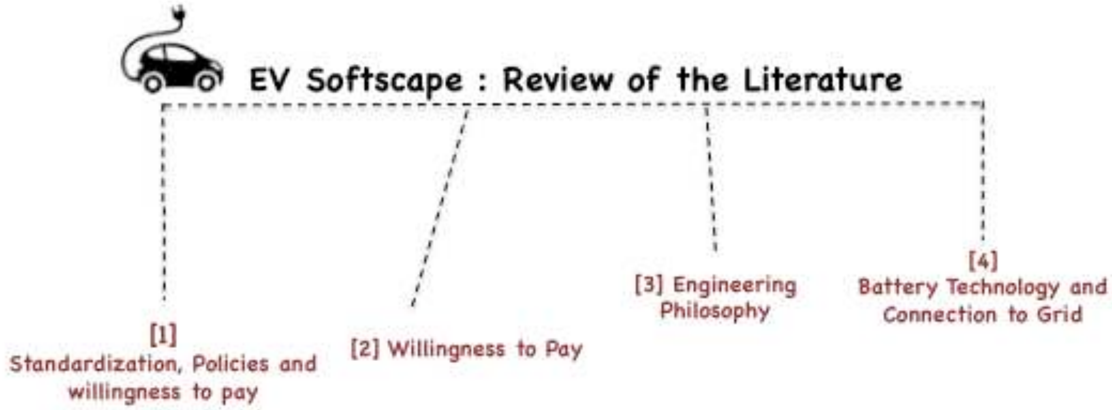


Figure 2-6: EV softscape thematic order of review

2.3.1 EV standardisation, policies, willingness to pay and adoption

In 2003, a study discussed the standardization of various domains of technology such as electric motors, storage batteries, power converters, and general automotive technology were published. The research reviewed technical, safety, and performance standards (Bosschi, 2003). Brown et al., (2010) emphasised the important role of standards in the EV emerging market. The study focused on the batteries, charging infrastructure, electricity distribution, and system requirements (standards, training, and certification). Another study focused on battery technology and how the driving patterns, the charging strategies, and energy management affect the battery and it is performance (Neubauer et al., 2013). Chan & Wong (2004) stressed on the critical rule of governments, society and industry, research and development, and local authorities to overcome the EV challenges and achieve better market penetration. This study raised questions about the required strategies to meet the theory and actual practice. Hatton et al. (2009) presented the characteristics of the EV system in terms of electric motor, control, and the battery. The study tried to elicit the whole framework of designing a system and a product as the former is the RFs and the latter is the car with all its technicalities and attributes.

Another qualitative-based study was undertaken by Steinhilber et al. (2013) on how the public in the UK and Germany perceive new technologies and innovations and highlights on the adoption and diffusion of innovation. The study captures effective and behavioural responses observed by the key stakeholders when launching alternative means of transport within the automotive sector in the UK and Germany. It also identifies the strategies they employ and their opinion and perceptions of the current investments, regulations, standardization, and government incentives and schemes. Further studies focus on interviewing early adopters (Franke & Krems, 2013b; Pierre et al., 2011) to conclude the end-user feedback and document their experience driving an EV.

Another study analysed the economics of EV charging network and investigated the logic behind the environment and collaboration of concerned companies and parties through a dynamic behavioural social model. This is to draw policy recommendations and split of tasks between government and private sector in the electrification of transport (Kearney, 2011). Documentation of the previous and current EV relevant drafted policies and regulations started to be more legible and accurate. Reports and collective studies have been recently released overarching the policies, regulations and proposed frameworks of different regions (Tomás ; Schäfer & Dray ; Shukla et al., 2011, Zheng et al, Schroeder & Traber; Beeton, 2012).

2.3.2 EV willingness to pay

A few studies were conducted on the purchase motives of alternative means of transport, particularly concerning HEVs in developed regions (Heffner et al., 2007); (Klein, 2007); (De Haan et al., 2006). Egbue & Long (2012) identified potential socio-technical barriers to consumer adoption of EVs through a web-based survey of what affects their choice of purchase. The choice of purchasing of a smart car is seen as a response to the increase in gas prices and governments' incentives, and a way to reduce carbon emissions as well as energy consumption (Ozaki & Sevastyanova, 2013).

Other studies were carried out reporting on the factors that have an impact on the customers willingness to pay a premium for clean transport (Erdem et al., 2010). One of the studies was conducted via a national survey asking the public to choose between their preferred EV versions estimating the willingness to pay for: driving range, fuel cost saving, charging time, performance, and pollution reduction (Hidrue et al., 2011). Propfe et al, (2013) identified the possible future market share of EV in the German new car fleet. They proposed three different scenarios i) vehicle technology, ii) business as usual parameters (purchase price incentives and substantial (OEM) mark-up reductions) and iii) external conditions. Another use of simulation modelling was the agent-based model (ABM) developed by Sweda & Diego (2012) in the context of EV. An agent based information system was developed to identify patterns in private EV ownership and driving activities to enable a better constructive and strategic deployment of RFs.

2.3.3 EV engineering philosophy

In the last decade, a number of studies were published regarding the engineering philosophy, key technologies, and standardization. Nansai et al., (2001) investigated the life cycle analysis of RFs. Their objective was to assess and calculate the overall process of installing a CP starting with the production to transportation to installation. They calculated all the air pollutant emissions during the transportation phase. The developed model was designed to compare the gas station to charging station and determine if the latter has a lesser contribution to emissions and whether it assists in lessening the environmental footprint of transportation. Another study was looking into the environmental and economic benefits of PHEV and the effect of the battery weight and charging profiles (Shiau et al., 2009). A similar study by Banjac et al. (2009) focused on the characteristics of hybrid cars' test cycles that lead to improved energy conservation efficiency. The study explored the electric storage devices and how influential the management of the energy flow to energy conversion efficiency.

2.3.4 EV battery technology and connection to grid

Conversely, studies were carried out to investigate the extra loads and the impact of charging alternative means of transport on the distribution networks. The impact is determined through regional grid analysis based on the number of users, charging profile, and the effect of charging on the supply and demand. The study discussed the driving patterns of the users, charging characteristics, and timing, daily mileage and number of registered cars (Green et al., 2011). Also, Stroehle et al., (2011) conducted a similar study investigating four different generic charging strategies for the EV in southern Germany. The four strategies were: simple charging, smart charging, vehicle to grids charging, and heuristic Vehicle to Grid (V2G) charging. Another similar study in Japan was investigated on the smart grid and connection to the emerging market of EVs and its diffusion (R et al., 2011).

2.4 RF's Location and Planning-Previous Work

This part of the chapter discusses studies and analyses related to evaluating and selecting the candidate locations for RFs. This includes all different methods: grid partitioning, hierarchical modeling, mathematical models, statistical models, spatial analysis, grid distraction and more of what the author has explored in the planning of RFs related analysis and studies. Mainly this group is reporting on the performance of existing systems (EV or even conventional transport systems), see (Figure 2-7).

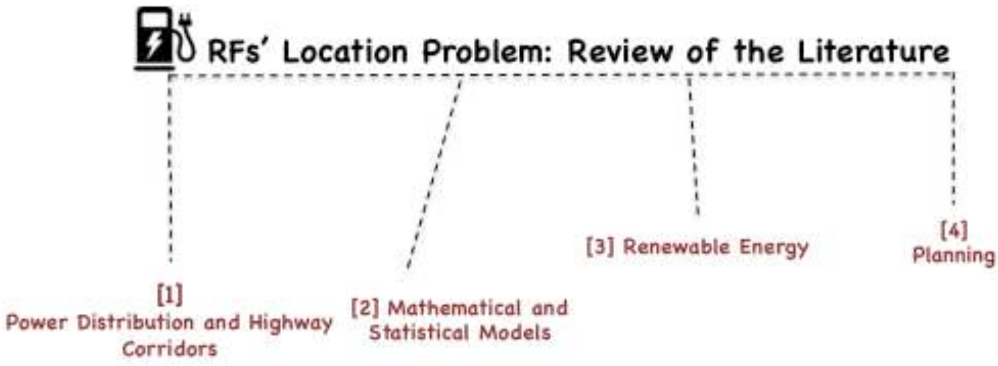


Figure 2-7: RF's location problem classification of studies diagram

The problem of sizing and placing RFs is a new topic that recently has been receiving some attention. This is considered as a major issue, especially for full electric car passengers due to the sole dependency on batteries as a source of power hence range limits and longer recharging time (Namdeo et al., 2013). A few important strides have been made to tackle this problem particularly, in late 2012 and 2013 (Chen et al., 2013). Several documentations and reports have been published and released, containing phased plans, initiatives and long-term development of recharging infrastructure (OLEV, 2011). However, these reports do not share how the presented size and location of RFs were determined (Wirges & Linder, 2012). Very recent literature covers previous studies, which were conducted to solve the RFs deployment. The location problem has been seen differently and each of the proposed solutions is concerned by an aspect; power, emissions, facility management, or comfort zone. Lam et al. (2014) discussed the candidate locations and suggested sizes of RFs in different urban contexts and have tackled the planning problem, following two previous studies.

2.4.1 RF's locations: power distribution and highway corridors studies

Allocating RFs on the highways was a point of focus in the literature (Nie & Ghamami, 2013). A study was based on the power system factors: power, voltage, and current, capacity, e.g. where the authors adopted particle swarm optimization to compute the solution. A similar study was conducted by Liu et al. (2013) looking into the network losses and degradation in voltage profiles, which might happen as a result of poorly or insufficient distribution of CPs in urban networks.

Another study was based on circuits topologies and grid while discussing the power architectures and power electronics (Lam et al., 2014). Moreover, an enhanced study was conducted by Lam et al. (2014) using a nodes and links method based on the charging stations coverage and the convenience of drivers. Chen et al. (2013) revealed a study about proposing solutions for the station location problem, which is a function of identified travel demand, possible parking lots and the time needed for charging. A facility location model aided by a GIS was developed by Xu et al. (2013) to identify locations for and size of the network of charging stations. The study proposed a geometric reasoning method for identifying ideal charging location in urban areas. A macroscopic RFs planning model was proposed by He et al. (2013) to maximize social welfare associated with both transport and power networks. A mathematical based model is developed there to locate the charging stations.

A study on the installed RFs in a low voltage distribution network was released by Cresta et al. (2012) showed the reliability and efficiency of current distribution networks in central Italy to accommodate fast charging stations. The study investigated the other operational constraints such as feeder voltage profiles and studied the consequences of loading slow and fast CPs to a network and the effect of the charging patterns over the day and night time. Also Lozano (2012) published a study on optimal charging to distribution networks. The study presented an algorithm to determine the ordinary cost and normal loading condition of the system while the second one included the EV and calculated the total cost of the system (Lozano, 2012).

Another study (Lindblad, 2012) was conducted to address the problem using grid partition method. It divides the urban layer into partitions, and calculates the electricity loads adding the charging demands of each partition. Genetic algorithm is deployed in order to optimally locate the RFs while considering electricity cost and the travel time cost, to optimise the travel cost finding a RF. A different study was conducted by Dong et al. (2014)where the genetic algorithm is applied to find the optimal locations of RFs. A similar study (GE et al, 2011) was carried out where the traffic density, and charging stations capacity were taken into account. Recently, another study has been undertaken finding the optimal location and the number of RFs for compressed natural gas fuelled vehicles on toll roads in the north-eastern United States (Hwang et al., 2013). A different research study was undertaken in Germany regarding the carbon emissions associated with the transport sector and the use of hybrid model of simulation and optimization to find candidate-charging locations (Turan et al., 2013). This study takes into account the spatial design features of the system as variables alongside other charging behavioural elements.

In 2013, a number of publications were released reporting on the optimal deployment of RFs. An equilibrium modelling framework has been developed to capture the interactions between the recharging opportunities, prices of electricity, route choice of EV, and destination (He et al.; Xi & Sioshansi 2013) used simulation and optimisation modelling to determine the candidate locations for RFs in metropolitan areas. Xi & Sioshansi, (2013) carried out a case study in mid-Ohio region that demonstrated the combination of the level one and two chargers with a limited deployment budget. Previously, a decision support system was developed to help city planners efficiently invest in placing charging infrastructure where it was truly essential. The model is regression-based and works on determining factors that influence the utilization of CPs (Sebastion et al., Elbanhawy et al., 2014)

2.4.2 RF's locations: mathematical and statistical models-related studies

Several studies recently focused on the optimal deployment of CPs in different urban contexts. Ip et al. (2010) proposed a statistical model to assist with planning for EV RFs allocation problem. The model aims at placing the CPs in urbanised areas where they are usually characterised by dense traffic concentrations, restricted street spaces, and other complex factors. Optimization was applied to meet the supply and demand profiles while considering the cost model, the clustering analysis of the urban context and finding the optimal locations. Villez et al. (2011) presented a very useful study by proposing candidate locations for CPs based on performance optimisation. They used the facility location problem to find the optimal locations then they incorporated the power and grid performance so that the locations would avoid any failure probabilities for individual elements in the network. Shukla et al. (2011) employed mathematical modelling to determine the best locations for installing RFs. The study's notion was to site the RFs at locations, which maximise the number of vehicles served while staying within budget constraints.

A further study was conducted by Hess et al. (2012) where the authors depicted the EV with the battery depletion, CPs, and vehicle mobility. Wireless communication was between the users and the public RFs to update them with necessary information regarding the occupancy, best time of charging and time needed. Via genetic programming and simulation, the car selects the optimal location/ preferred CP.

Many studies reported on the connection to grid, calculating the load and monitoring the performance before and after the recharging loads. Some of which integrated the deployment of RFs with the installation of other clean source of electricity such as solar cells. A study was completed by Xu et al. (2013) about the optimal configuration of centralised charging stations and connecting the EVs into the grid. A mathematical model was also used to formulate the initial placement problem with minimum total transportation distance.

2.4.3 RF's locations: renewable energy-related studies

Denholm et al. (2013) explored the co-benefit of deploying large-scale plug–in EV system and photovoltaic in a populous city, Texas. In 2011 a study was carried out within the Electric Reliability Council of Taxes (ERCOT), which serves about 23 million individuals. The study was to deploy a large-scale EV system coupled with Photovoltaic Cells (PV) technology to Texas grid and analyse its benefits. The simulation modelling was employed to perform the impact and stimulate the grid and the implications via Advisor and REFlex, platforms, respectively. Another study elaborated on the integration of EV and PV carried out by Yamagata & Seya (2013). The study looked into the potential link between the solar photovoltaic panels to the long parked cars. A huge potential if these cars are EV, to create battery storages using V2G at a community level.

2.5 Identifying the Gap in the Literature

EV owners may desire to charge their EVs while at work in addition to domestic charging (Jewell, Bai, Naber, & Mclntyre, 2014). Studies show that the vast majority of current users rely on domestic charging (Cattaneo et al.; AVTA; Keros, 2014; BEES; Calstart, 2013; Boyce; Mcdonald, 2012; Housely, 2010) . In the UK, recent research claims that around 80% of UK EV drivers rely on domestic charging (50% urban, 70% suburban, and > 95% rural) (Lane et al.; Warburton, 2013; McDonald, 2012). Even so, in order for EVs to gain widespread consumer adoption, it is critical to have an existing integrated charging infrastructure in urban areas (Xu et al., 2013; Chapin et al., 2000).

To ensure e-mobility is widely recognised as a viable transport option (ENEVATE, 2014) and in order to expand the low carbon emission vehicle market, the potential users need to be confident about the vehicle, the use of the vehicle (Elbanhawy, 2014b) and the provision of the necessary services and facilities to support their uptake and use which formulate the problems this research is tackling. The problem with planners and policy makers is that they deal with locating and sizing the recharging infrastructure network as a static location planning problem (Wirges & Linder, 2012).

This includes cities, across cities and countries; having supported routes (down centres and motorways) that have guaranteed reliable charging services is a perquisite for any potential shift to a mainstream market. A niche car and system can't promote for a mainstream mean of transport (ENEVATE, 2014). As per the user study which is presented in Chapter 6, in this thesis, the EV owners indicated that if they do not have access to domestic charging, they will reconsider the whole idea of owning an EV. This reflects that the most convenient means of charging is to have direct access to domestic charging in their garages or Off street parking areas. This leads to another intrinsic question, what will be the case of multi-unit residential neighbourhoods? This group is and will be facing a problem in accessing domestic over-night charge and finding a convenient place to charge their vehicles every day, this group is referred to as Garage Orphans (PRP, 2012). A daily irritating anxiety will show up due to the limitation and unreliable on street/Off street RFs. The planning for a non-domestic charging network is an existing problem that is gaining more attention particularly in the last three years (Sathaye & Kelley, Nie & Ghamami, 2013; GE et al., 2012); Many studies and analysis are carried out by professional bodies as it is a critical business case (Chargemaster, 2015; Carroll & Walsh, 2013; Logica, AECOM, 2011; Klein, 2007; Element Energy Ltd, 2009; CYC, 2010).

Despite major technological developments in various EV areas of research, there is a list of issues needs to be addressed. Among these, the need for a reliable and diverse charging infrastructure, which meets different user requirements, is placed at the forefront. Several economical, ecological, and political ambitions lie behind the shift to EV market, EV technology adaption, and the placement of EV charging infrastructure (Brenna, Dolara, Foiadelli, & Leva, 2014). The uncertainty of having a reliable and integrated charging infrastructure slows down the growing trend of smart ecosystems and sustainable urban communities as whole. The strategic location of publicly available CPs will help with paving the way for a better market penetration. The second problem is the standardisation. There should be links with a wider regional network (ENEVATE, 2014). The standardisation of the current charging network is also another problem.

From a closer look into the literature, there were several ways of tackling this planning issue. Geographic information systems, connection to grid, ownership preference and business need, modelling and clustering market segmentation, or genetic algorithm-based solutions solving layout faculty management and more (Wang, 2005).

The planning of RFs is a learning process (Kostic & Jovanovic, 2012). With pure logic, the location of RFs might be based on the dense or the most commonly shared urban areas by all inhabitants. However, the location problem is neither a facility location problem nor a pure social and behavioural inquiry. It is a combination of different factors, the more these factors are considered, the better the vision of the system. These factors and attributes have to be identified and quantified after a prolonged phase of investigation of the system and its variables. These predictors vary in nature; behavioural variation within the population is crucial as per several examples. The practice of driving an EV is an influential factor that affect the charging pattern of the driver hence its interpretability and use of the system.

2.6 Charging Profiles

There is a need of exploring the future market of EV, in order to address the imperative environmental and societal challenges of the EV system(Warth et al., 2012). Considering the findings of national and international research into EV uptake, detailed knowledge about the future charging profiles of EVs appears to be missing in the literature (Celli et al., 2014; ENEVATE, 2014) as well as the lack of comparable studies across countries and years (Hjorthol, 2013). Analysing current systems show cases the variant consumers' profiles and preferences, charging behaviour, and supply and demand records. It provides insights on prices, technologies, barriers and incentives and standardisation (ElBanhawy, 2014 ; Markel, 2012). Moreover, associating the charging behaviour of EV owners with the potential flexibility of charging time would assist with the great challenge the power system would accommodate with the large scale EV use (Guo et al., 2012).

In recent literature, the models that were proposed were based on real data of current travel behaviour of ICE vehicle drivers. Mobility profiles, arrival time at RFs, departure time and daily average distance may lead to biased observations. Given the uncertainties that characterise the e-mobility system, the majority of these approaches are based on probabilistic calculations and replication, which stems from behaviour and responses of a different mobility system. ICE driver do not take into account the probable changing in the behaviour (at individual and emergent scale) (Celli et al., 2014; Mauri & Valsecch, 2012; Simpson, 2012). Due to the range and charging requirements, EVs do not necessarily provide a direct replacement for ICE; therefore, e-mobility tends to include alternative approaches to vehicle ownership and use (ENEVATE, 2014). Statistics indicated that private buyers represent around 60% of the UK car and van market. This leaves 40% representing fleet and employers who are more likely to consider the total cost of ownership and practical issues nevertheless, not considered with the brand and image (ElementEnergyLimited, 2013), fleet electrification alone will not solve the pressing energy security challenges (Rio, 2012). This indicates the importance of the end-user's feedback and perspective in the evaluation process of a motor-based system.

With meaningful market share changes on the horizon, an ability to predict which EV neighbourhoods are most likely to own an EV can provide important insights an opportunities for power grid planning, transportation investments, and air quality policy making.

2.7 Concluding Remarks

The chapter has reviewed the literature taking a thematic approach. In total there were over 120 studies in the context of EV use, compiled. The dependencies in the EV research are strong and inevitable due to the interdisciplinary and evolving nature of e-mobility. The following graph, (Figure 2-8) summarises the studies in a chronological order to show how the research has evolved through the years. In Figure 2-8, the behaviour and social based analyses and studies conducted in the context of alternative transport areas are highlighted in blue (EV softscape) and studies related to the planning and policy making of the RFs are highlighted in red (EV hardscape). In 2013, several studies were published reporting on both categories. Chapter 3 discusses the second part of the literature.

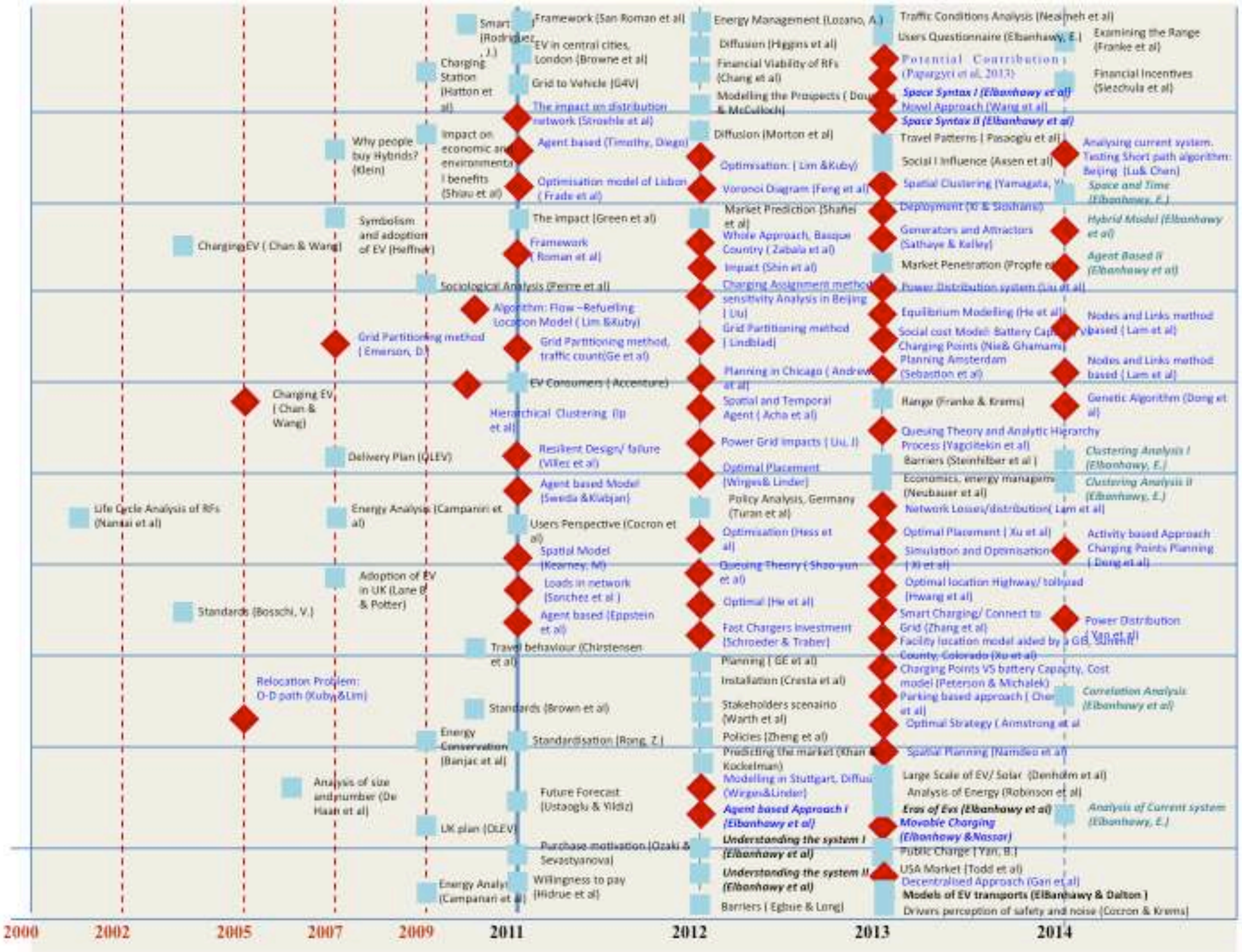


Figure 2-8: EV behaviour-related studies

CHAPTER 3. LITRATURE REVIEW PART 2

"On battery development I wouldn't be quite so pessimistic. Do not forget that the internal combustion engine has had over a 100 years of development and we're barely beginning with battery EVs."

By Richard Bruce, Office for Low Emissions Vehicles (2014)

This chapter discusses the simulation modelling in the context of vehicular movement. The chapter has two main parts: i) simulation and ii) vehicular movement prediction, see (Figure 3-1).

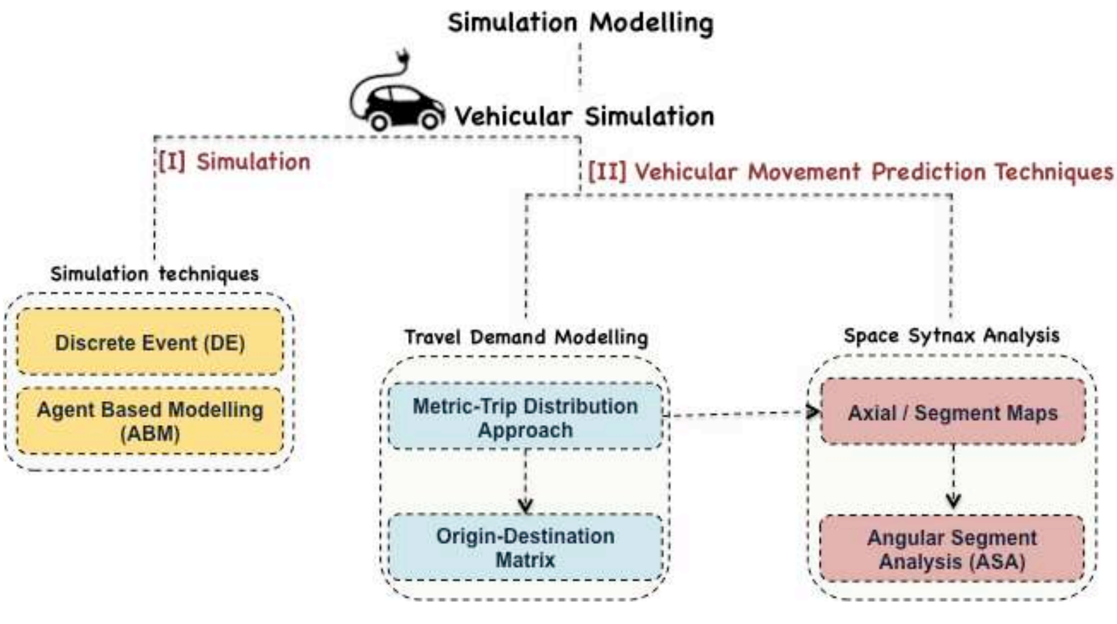


Figure 3-1: Chapter flowchart

Simulation of human behaviour in space is a powerful research tool, it advances the understanding of the interaction between the users and their environment (Gimblett & Itami, 1997). The more the understanding of cities improves, the wiser the individuals are about the ways they intervene with growth and function (Batty, 2005). Simulation can be an effective tool for discovering unexpected consequences of simple assumptions (Axelrod, 2005). Modelling and simulation have been commonly used in the context of transportation, urban planning, and land use as being the basic tool for planners and policy makers (Bravo et al., 2010; Feldman et al., 2009; Lacono et al., 2008). Simulation has been widely used in social sciences (Epstein, 2007; Wang, 2005; Davidsson, 2002; Gilbert & Troitzsch, 1999). Simulation modelling has passed through different stages of development to replicate social sciences (Troitzsch, 1997). The representation of dense dynamic environments such as populated cities remains a problem (Haase et al., 2010; Tecchia 2001). These environments are highly complex entities to be virtually presented using real-world metropolitan data (Sindram & Kolbe, 2014). Complex systems compose of i) large number of entities, ii) non-trivial interactions networks with non-linear impact and in the overall behaviour of these systems tends to display emergent characteristics (Balestrini-Robinson et al., 2009). It is:

> *"a large number of components or 'agents,' interacting in some way such that their collective behaviour is not a simple combination of their individual behaviour, which is the case in transportation networks." [Newman, 2001]*

For real-time systems, simulation is preferred compared to analytical and mathematical solutions as it can stimulate the fourth dimension, time (state changes, discrete events and discontinuous equation) and flowcharts. (Borshchev & Filippov, Lombardo & Petri, 2004). Simulation models with high level of abstraction may capture detailed elements, especially when coupled with Intelligent Transportation Systems (ITS) (Borshchev & Filippov, 2004).

Vehicular simulation is one of the advanced applications that is capable of simulating mobility population, behavioural characteristic and interaction while allowing a better understanding of observations (Helbing & Balietti, 2011). This type of simulation is achievable via two different approaches; mathematical (centralised) or behavioural (de-centralised). In the centralised approach, car-following laws and scheduling techniques are used which are not generic and cannot portray many traffic phenomena, facets, and behavioural characteristics of the system. On the other hand, a de-centralised simulation is more sensible to population behaviour being simulated (Doniec, 2008). Microscopic simulation (Ehlert, 2001) is one of the de-centralised, bottom-up based, examples. It depicts realistic driving behaviour under low, medium, and high intersection traffic demands (López-Neri et al., Fellendorf & Vortisch, 2010; Doniec et al., 2008; Tonndorf & Vorotovic, 2007; Burghout, 2004)

In vehicular simulation (Valverde & Sol'e, 2002) and particularly in the context of EVs, it is very useful to study and analyse the emergent behaviour. This behaviour is a collective movement at macro-scale level which takes the bottom-up approach (Crooks et al., 2008) resulting from agents' coordination (Li et al., 2006; Bonabeau, 2002). Analysing the effects of a system and its complexities is essential to understand how technologies, policies and regulations will affect the system's emergent behaviour (Osmundson et al., 2008). The emergent behaviour was defined by Dyson (1997) as:

> *"the behaviour which cannot be predicted through analysis at any level simpler than that of the system as a whole. Emergent behaviour, by definition, is what left after everything else has been explained."*

A wide range of applications and research studies has focused on the conventional mode of transport and traffic management using micro-scale simulation (Nomden et al., 2009; Doniec et al.; Khalesian & Delavar, 2008; Ali & Moulin, 2007). Little literature was conducted in the area of simulation of e-mobility. However, in recent years, e-mobility and its related charging network had gained attention (ElBanhawy et al. 2014, Xi et al., 2013; Gao et al., 2007). (simulation modelling will be discussed in Chapter 8 of this thesis).

3.1 Simulation Techniques

Simulation modelling has several techniques, which can be summed up as: Discrete Event (DE), Agent Based Modelling (ABM), and System Dynamics (SD). The latter is used in the area of engineering design process.

3.1.1 Discrete Event (DE) technique

This type of modelling has its roots in the 1960s and is used to portray entities of flow and resource sharing which are useful in problems like services, manufacturing, logistics, and business processes. DE mainly revolves around the concept of entities, resources, and block charts. Queuing, servicing, and processing events occur while the system changes instantaneously in response to certain events (Maria, 1997). In DE, entities can be people, products, documents, calls, or tasks (Borshchev & Filippov, 2004). ABM is a decentralised approach of portraying the emergent behaviour of a crowd (Narzisi, 2008). In comparison to SD and DE, no global system behaviour would be defined though an emergent behaviour of a particular number of the population can be depicted. This is based on individual autonomous heterogeneous agents and that is why it is called the bottom-up approach (Li et al., 2006).

3.1.2 Agent Based Modelling (ABM) technique

Wooldridge, (2002) defined the agents, as:

> *"a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives."*

ABM offers a perfect media and a powerful way to undertake interdisciplinary areas of research; moreover, to study the connections and interactions phenomena in social sciences (Epstein, 2007). Independent perceptions and individual decisions are taken and virtually presented (Li et al., 2006). ABM is capable of maintaining preference, acting differently (Summala, 2005), being opportunistic (Björklund & Aberg, 2005) anticipating situations (Doniec, 2008). Agents are capable of:

i) sense and act upon their environment,
ii) try to fulfil a set of goals in a complex-dynamic environment (Schelhorn, 1999);
iii) involve both goals and constraints forming and emerging the overall complex network (Frank, 2001)
iv) work together to find the best solution for a problem (Chen & Wang, 2009), v) learn from their experience
v) adapt to better suit their environment (Macal & North, 2010).

Using ABM does not require knowing a lot about the level of dependencies and global sequence at an aggregate level. By having enough knowledge about individual participant's performance, the phenomenon can be depicted (Borshchev & Filippov, 2004).

The use of integrated ABM in the area of social sciences that involves behaviour of human beings has been analytically corroborated in many literatures (L et al., 2012). Pedestrian simulation is one of the more popular studies that shows physical interactions and congestions among people and the spatial environment regardless of the main aim of the simulation (Lee, 2010). ABM has been used to simulate various mobility patterns such as transportation, logistics, medicine, and entertainment (Wang, 2005). Road traffic is one application that simulates the moves of road users (behaviour) on a road network and employ ABM to generate a realistic traffic environment (Doniec, 2008). Previous studies employed ABM in real-time problems, which are associated with social and spatial interaction decisions (Chen et al., 2009). Moreover, it was used to integrate between a simulated EV-system environment and energy and power flow studies (Acha et al., 2011) and was applied to conventional vehicle movement and traffic management researches integrating air-quality and noise analysis by the Transport Operations Research Group-TORG (Robinson et al., 2013). ABM was also applied to city models investigating geo-spatial and urban topographies phenomena by Crooks et al. (2008). This is in addition to a wide range of simulation purposes (Borshchev & Filippov, 2004).

ABM paradigm is rapidly emerging as one of the powerful technologies for the development of large-scale systems dealing with the uncertainty in dynamic environments. Various studies reported on applying agent approaches to traffic and transportation systems (Chen & Cheng, 2010). Some of these studies addressed the traffic detection and management attempting to provide traffic route recommendations for humans.

Vehicular simulation using ABM was applied by Trannois et al. (1998) where it was an adoption of the well-known blackboard system for planning agents' action within the simulation environment. The second significant trial was by (Paruchuri et al., 2002) where they created autonomous agents making own decisions using fine-tuning parameters. Bazzan, (2005) proposed a de-centralised traffic control. According to (Doniec et al. (2008), the first model was not presenting autonomous agents' behaviours and the second one was having limitation due to the supervised and controlled situation by an external centralised process. Doniec (2008) developed a more realistic behavioural model by simulating drivers' behaviour in a real simulator depicting their local autonomous behaviours while applying opportunistic and anticipation traits. Zhang et al. (2009) developed an ABM to analyse the simultaneous and interactive changes of land use and transportation systems over time. Studying vehicular movement at microscale level of simulation modelling, provides a better understanding of the reasons underlying real driver decision-making, revealing specific facets and characteristics of driving behaviour and patterns (Summala, 2005).

3.2 Vehicular Movement Prediction Techniques

Spatial social science recognizes the key role that spatial concepts, such as a neighbourhood, proximity, distance, location, and region play in human society (CSISS, 2004). Vehicular movement network simulation and analysis have been conducted for several applications (Lu, 2011), (e.g., traffic management (Hodges & Bell, 2011), urban goods movement (Polimeni et al., 2010), carbon content of trips (Robinson et al., 2013), and noise (Bell & Galatioto, 2009). Transportation network growth is correlated to the land use and economic activities, both affecting the cars passengers' route choices. This chapter discusses the urban pattern and movement prediction techniques in simulation environments. Travel modelling is a necessary component of comprehensive transportation planning.

The lack of comprehensive planning has resulted in development of transportation networks that have largely failed to meet the mobility demand, behaviour change, and the expansion of urban areas (Kaltenbach, 1972). In literature, the vehicular movement prediction techniques of flow simulation fall under two main categories: i) metric (origin-destination matrixes based) and ii) topological (space syntax and other models which utilise configurational or network-based analyses).

3.2.1 Metric-trip distribution approach

The metric based approach follows the trip assignment theory. The first travel modelling efforts were made in 1950's. Metric based travel models consist of:

- Generation (determination where the journey starts);
- Attraction (determination where the journey ends);
- Assignment (determination of the route);
- Modal split (determination of the mode of travel).

The movement is understood as an origin and destination (O-D) matrix, where the origin is the production point of trips (trips generator) and the destination is the attraction point. The O-D matrix is a trip distribution process generated from the attraction and production list for the given area. The trip assignment theory determines the trip volumes of all routes between an O-D pair. The distance and the time spent to move from O to D is affected by the volume and the location of both ends. Kaltenbach (1972) provided a review of the literature and summarised the main factors influencing the travel demand: i) population, ii) characteristics of population, iii) characteristics of origin and destinations (e.g., land use), and iv) accessibility to attraction areas. Multi regression models were developed to interrogate the relationships between these factors and the trip distribution (Martin & McGuckin, 1998).

Vehicular traffic estimation

In transport research, there are two approaches to analyse the network:

i) All–or-Nothing (AON)
ii) User Equilibrium (UE)

Daganzo & Sheffi (1981) explained All-or-Nothing approach as:

> *"when two or more routes are available between an O-D pair, the all-or-nothing (AON) approach assigns all O-D trips to a route that requires the least free-flow travel time among all other alternatives routes."*

In this method the trips from any O to D are loaded onto a single, minimum cost, path between them. Smith (1978) introduced User Equilibrium (UE) and Sheffi (1985) defined it as that traffic distribution is in an User Equilibrium state when no driver has a less costly alternative route giving an example:

> *"consider a single driver who has travelled at least once today. He may use the same routes tomorrow. However if he does change a route then he must change to a route, which today was cheaper than the one he actually used today." [Sheffi, 1985]*

However, the two techniques acquire an O-D matrix (Paul, 2009). Due to the difficulty collecting OD data (time and cost), an alternative approach was needed to predict the movement.

TAZs

In the theory of trip assignment, the urban layer is divided as traffic zones. The flow pattern between zones can be determined by modelling travel decisions and congestion (Sheffi, 1985). These zones are known as Traffic Analysis Zones (TAZs). In the 1060s, the first insight into spatial data aggregation was developed. Ward (1963) developed a procedure to form hierarchical groups of mutually exclusive subtests based on similarities of specified characteristics, which was in the 1970s by several authors e.g., (Batty, 1976).

The first systematic algorithm attempt for the definition of TAZ was pursued by Openshaw (1977). The level of congestion counts for the free-flow of each route. Congestion is calculated via the equilibrium analysis expressed by the Level of Services (LOS) that a network would have. LOS is a qualitative measure of traffic congestion, and it is categorized in six groups from A to F (Paul, 2009; Abishai & Shefer, 1984). Regions and countries define LOS categories differently. These LOSs are linked to the volume and capacity (V/C) of routes and arteries, see (Figure 3-2). The free flow as defined by Sheffi (1985) is:

> *"the travel time at zero flow is known as the free-flow travel time. At this point, a traveling car would not be delayed because of interaction with any other car moving along the link. The only source of delay at this point is the*

time associated with traversing the link and the expected delay associated with the probability of being stopped by a red signal indication."

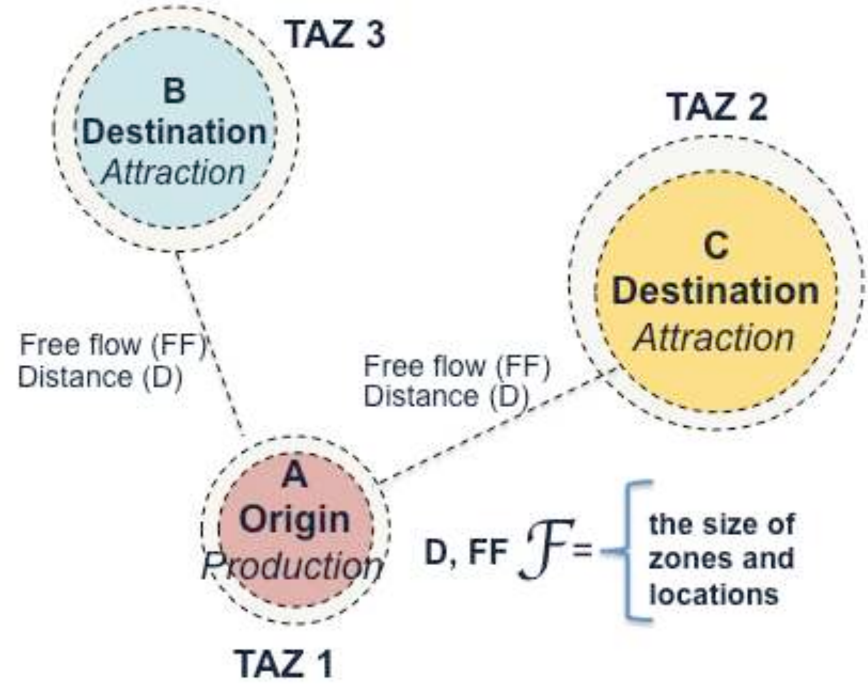


Figure 3-2: Trip makers

Trip distribution models can be Growth Factor or Gravity based. A Growth Factor model (Matthias, 1966) takes into account the population growth rate to predict the number of trips based on historical data as it involves extension of present travel patterns by application of growth factor. It is mainly utilized primarily to update existing matrices (McNally, 2007).The drawback of this model is that it does not account for substantial changes in land use patterns or in the transport network.

The Gravity model (Voorhees, 1955) technique based its theory on Newton's law of gravitation forming a simple equation where the force of attraction between two TAZs is directly proportional to the masses (mass TAZ1 multiplied by TAZ2) and inversely proportional to the square of the distance (Mathew et al., 2006; Erlander & Stewart, 1990; Wills, 1986). It is based on the relative amount of activity and spatial separation of TAZ (Fricker & Whitford, 2004). Using TAZs to draft policies and set strategies of urban development has some key deficiencies:

i) the zone boundary should coincide with the edges of census tracts;
ii) the lack of behavioural consideration at the individual level;
iii) policy makers and planners do not generate activity-based models although these models are more accurate (higher level of abstraction) (Eom, 2007).

As per Stouffer (1940) a third model was developed, Intervening Opportunities model. The model is based on the concept that the tripmaker prefers to take the shortest path possible to reach their destination (Matthias, 1966). It proposes an idea:

> *"the number of persons going a given distance is directly proportional to the number of opportunities at that distance and inversely proportional to the number of intervening opportunities."[Mattias, 1966]*

It does not require O-D matrix, and counts more on probabilities; it looks at the factors causing travel (Stouffer, 1940). Distribution models (factor, gravity, and opportunities) require the number of trips due to attraction and production of transport nodes. The opportunities model opened a channel to spatial configurational models.

Trips

Simulation speculates having particular trip purposes as per Golob (1986) which can be summarized in 5 types. Conventional traffic models replicate these spatial patterns in a real time simulation platform forming trip-based travel forecast models. Classified these trips as home based work (HBW), home based school (HBS), home based other (HBO), and non-home based (NHB). Trips associated with traveller's home may refer to as *trip productions* and the trips' ends associated with non-home are *trip attractions* (Martin & McGuckin 1998), see (Figure 3-3).

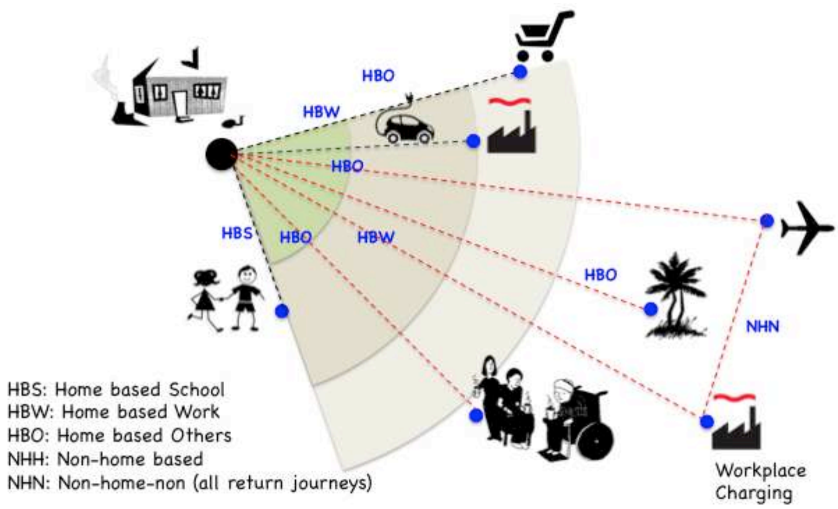


Figure 3-3: Trip purposes

The survey process of obtaining these O-D trip data is very cost intensive and time consuming (Paul, 2011; 2009; Penn et al., 1998). Therefore, there is a fundamental need of approaches for transitioning from traditional models to behaviour-based models. These approaches should be capable of simulating vehicular movement networks without using O-D trip data. The next section introduces topological approach in the context of vehicular movement prediction.

3.2.2 Topological-spatial configuration approach

Topological analysis refers to the way the streets and build environment relate to each other and to the whole network. According to Medeiros (2006), topology is:

> *"the study of space relationships that do not depend on shape and size, but on the connection between parts, whereas geometry is the description of physical elements in terms of its dimensions, proportions, scales etc."*

A theory developed by Hillier and Hanson (1984) called Space Syntax is based on the use of computer techniques to analyse urban configuration. In the words of Hillier et al. (1987):

> *"Space syntax is a set of techniques for the representation, quantification, and interpretation of spatial configuration in buildings and settlements. Configuration is defined in general as, at least, the relation between two spaces taking into account a third, and, at most, as the relations among spaces in a complex taking into account all other spaces in the complex. Spatial configuration is thus a more complex idea than spatial relation, which need invoke no more than a pair of related spaces." [Hillier et., 1987]*

The modification of any single spatial relation will have an affect on the whole configuration (Dalton & Hölscher, 2006). Various measures of urban configuration are correlated with aspects of social life (Ratti, 2004). This theory aims to study the social implications of architectural spaces (Pereira et al., 2012) and incorporates the space topological relationships, considering the city shape and its influence in the distribution of movement flows within the space (Barros et al., 2007), see (Figure 3-4). Spatial analysis techniques characterise the system on the basis of the ways in which spaces are related rather than through metric distances (Wineman & Peponis, 2010). Recently, this versatile method of urban analysis started being used in simulation (Ratti, 2004).

Movement prediction

Space syntax has been found to be an alternative, or even complementary approach to transportation demand modelling as being a less cost intensive and more time efficient approach. The capability of space syntax to indicate the potential movement of pedestrians and vehicles on the various routes of the urban grid has been widely explored (Medeiros, 2006; Holanda, 2002; Medeiros & Trigueiro, 2001; Penn et al., 1998; Hillier et al., 1996, 1993). The most integrated streets are those with higher potential flow generation, topologically. Thus, they are the most likely to be used (Barros et al., 2007).

Figure 3-4: Spatial accessibility analysis-Nicosia, Cyprus (source: Charalambous & Mavridou, 2012)

Simplest way not shortest way (spatial distance)

Configurational modelling is therefore faster (Barros et al., 2007), less cumbersome, and less prone to incorrect assumptions than either Movement Assignment or Dynamic Entity modelling (Murrain, 2013). The spatial layout of urban places exerts a powerful influence on human behaviour. The way the spaces connect is directly related to the way people move, interact, and transact. Urban space can organise the movement to, through, and within spaces. From a behavioural point of view, this assumption postulates that the cognitive complexity of the route, described as the number of directional changes on a route, is the primary consideration in path choice, even more so than metric distance (Stonor, 2011). Individuals choose the most continuous routes between O-Ds rather than the route with the shortest metric distance (Hillier & Iida, 2005). The angle of turns during a pedestrian journey affects the perception of its distance (Montello 1997; Sadalla & Montello 1989) and the behaviour and route choice (Turner & Dalton, 2005). People linearize their route taking the shallower turns towards their goals (Dalton, 2001). Thus, it is expected to prefer routes that involve less turns (simple and more direct) along the way, rather than complex and indirect, even if the complex route is shorter (Hillier et al., 2007).

Former studies and analyses carried out in space syntax have shown that people tend to take the simplest path/ least angle change rather than shortest metric path between two nodes (Dalton, 2001). Dalton (2001) showed that when individuals take a route, they linearise it by taking the shallower turns towards their goal. As for vehicular movement, Duckham and Kulik (2003) proposed that the minimum angular path might be useful to help direct drivers to their destination more simply. As shown in (Figure 3-5), the fewest number of turns path from A to B (right figure), in segmentation theory, is cognitively shorter.

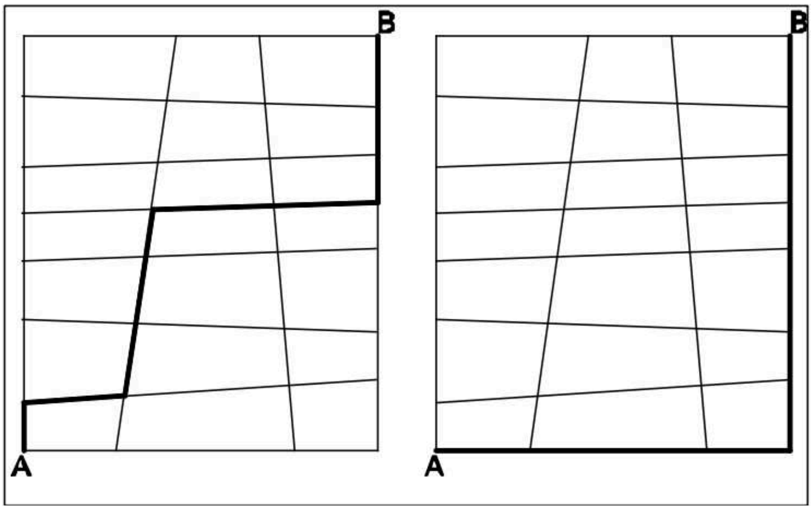


Figure 3-5: Shortest path versus the simplest path between points A & B. (source: (Turner & Dalton, 2005).

Axial representation

The most used space syntax technique at urban level is the axial map. According to Hillier (1999):

> *"In the study of cities, one representation and one type of measure has proved more consistently fruitful than others: the representation of urban space as matrix of the `longest and fewest' lines, the `axial map', and the analysis of this by translating the line matrix into a graph, and use of the various versions of the `topological' (that is, nonmetric) measure of patterns of line connectivity called `Integration'."*

Segmental m ap

An extended version of an axial line is a segment line. Segmental map is where both junctions and turns break the lines (roads) into segments (Turner & Dalton, 2005). For transport modelling, the segmentation of axial lines would better serve as it presents coincident characteristics (assignment). Configurational tools such as the space syntax segmental map can contribute to transport studies especially in early stages of planning and zoning and forecasting potential vehicular flows (Barros et al., 2007). The segmental map is an improved version of the axial map as it processes the network into street segments (Turner, 2004). Space syntax typically ignores traffic flow directions, representing the network by means of a set of line segments (Barros et al., 2007). Barros et al. (2007) stated that the segment analysis applies better for transport studies, because of its logic structuring based on segments between nodes, not only on continuous lines, as it happens with traditional axial maps. With a different spatial calculation, segmental maps use measures of centrality (which include Depth, Mean Depth (MD), and Integration), Depth to evaluate segments and MD to evaluate the whole network.

However, dealing with segments is associated with a weight problem. When axial lines, are broken into segments, the segments associate higher transfer 'cost' than the straight line would have, because each step to the next segment incurs a penalty. One response is to make the segments continuous, by joining lines that continue in the current direction to create threads (Thomson, 2003; Dalton, 2001) or continuity lines (Figueiredo & Amorim, 2005). Another response is to use Angular Segmental Analysis (ASA).

Angular analysis

Space syntax follows most network analysis as it translates the network map into a graph, then a graph analysis is performed in order to predict the subject's movement at individual nodes (Turner & Dalton, 2005). Angular analysis is a spatial analysis technique that is based on space syntax methods. It originates from (Turner, 2000) and it was also implemented as an extension of axial analysis by Dalton (2001). Turner (2001) explained the Angular Analysis as:

> *"it uses a weighted graph to calculate space syntactic metrics rather than the non-weighted standard measures".*

It is easiest to think of it in terms of an axial map, as proposed by Dalton (2001):

> *"when calculating the path length from A to B, as one would to calculate integration for example, rather than count the number of edges (that is, connections) between those locations, calculate instead the weighted sum of the edges, where each edge is weighted by the angle of connection."*

The cost of transfer from one segment to another is treated as the angle from one segment to another (Turner & Dalton, 2005).

Angular Segmental Analysis (ASA)

Turner (2001) introduced the Angular Segmental Analysis (ASA). It is:

> *"the shortest angular path about each pair of origin-destination segments was obtained from segmented axial map representing specific built-environment-usually generated from the load-centre line of GIS."*

As shown in Figure (3-7), it starts with drawing the axial map/ centre line of the streets. Streets will be drawn as segments; each should be connected to the other by intersection angle in a graph. The entry direction of the flow/ pedestrian/ vehicles is important as this will count for the calculations. Doubling back among one segment cannot be done to take advantage of the shallow angle link (Turner & Dalton 2005).

In ASA, because there is no angular turn to another segment that leads straight on, there is no associated cost, and thus a path that continues in the current direction is by definition continuous across the junction (Turner, 2007). Figure 3-6 illustrates the ASA way of calculation between the two axial lines A and B. At an angle of incidence 48 degrees might have a weight of 0.53, while the intersection of the other two axial lines (B and E) is 43 degrees, which is 0.47. An example of central London ASA map, see (Figure 3-7).

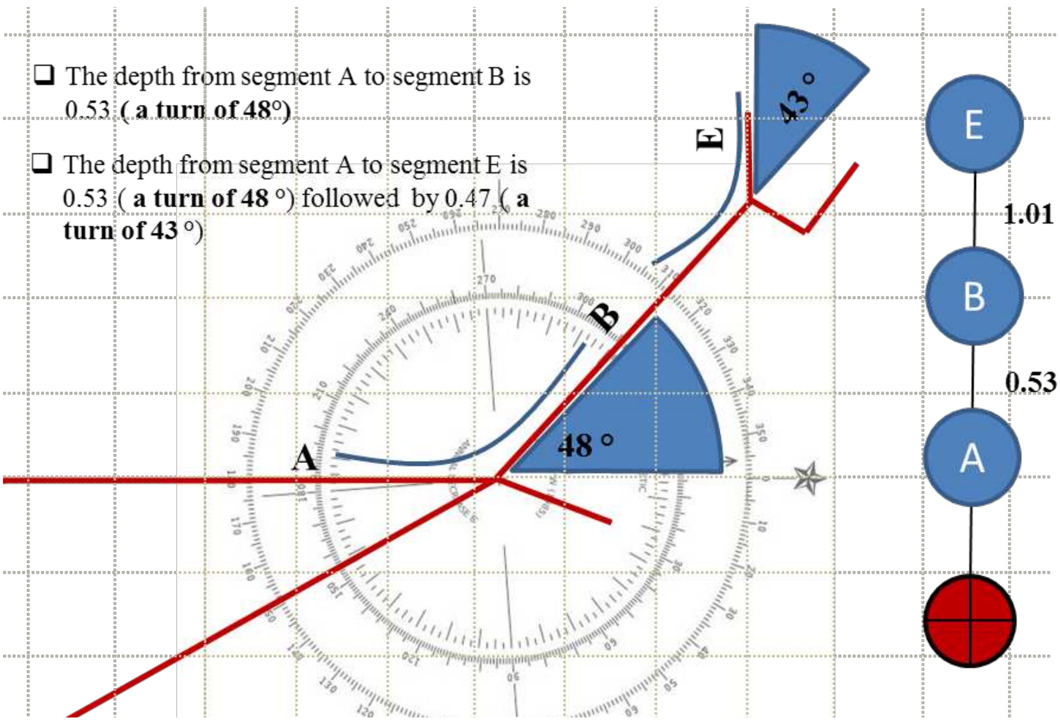


Figure 3-6: Angular analysis calculation

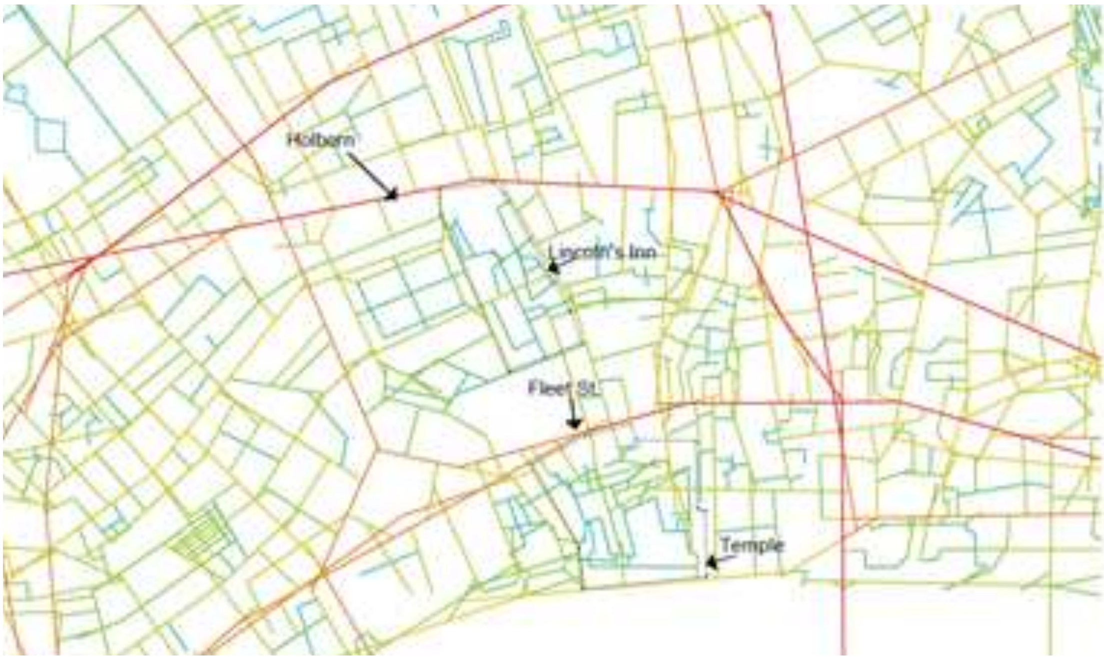


Figure 3-7: ASA of central London, red as high integration, blue as low integration (source: Ahmadi 2007)

3.3 Identifying the Gap in the Literature

The chapter reviewed the literature of vehicular simulation modelling. The first part focused on the simulation techniques where the second part discussed the vehicular movement predictions technique. A gap in the literature is the use of hybrid model to depict the individual patterns of EV users. Integrating space syntax analysis with simulation techniques to simulate e-mobility system may be a proposed approach.

CHAPTER 4. METHODOLOGY

"You need to follow not what the consumer is telling you they want, but what are the trends for the consumer. Not what they are asking from you today, but what they are going to be asking for you tomorrow; and that is why you need to prepare for it"

By Carlos Ghosn, Chief Executive of Renault-Nissan (2015)

This chapter presents the research study area and introduces the multi method approach employed. First, the study boundary and its existing charging infrastructure are described. The inner urban core of Newcastle-Gateshead area is the focus of the study. A combination of research methods is applied to different datasets: i) empirical data provided by the charging network management company, CYC Ltd., and ii) data collected through interviewing 15 EV users and 5 stakeholders, and a map-based survey with 55 potential EV user. All these studies wee conducted in the Newcastle-Gateshead area.

4.1 Study Area: Background and E-Mobility System

Newcastle upon Tyne city is located in the North-East of England. The city is divided into 64 postal districts, see (Figure 4-1). The inner urban core is mainly the area around the river Tyne, which is defined by the postal district boundaries of NE1 ($6KM^2$), NE4 ($14KM^2$), and NE8 ($16KM^2$), The inner urban core of NE1 is the chosen area for the pilot study, see (Figure 4-2).

Newcastle is considered one of the greenest cities in the UK, attempting to work towards sustainable development and implementing progressive plans towards resilience concepts (BBC, 2010; Jha, 2009). The city has an existing EV charging infrastructure and there are plans to install more CPs around the Newcastle and Gateshead metropolitan area over the next two years (2015-2016). According to CYC Ltd. company, 1,500 CPs are installed for the public use (CYC, 2014).

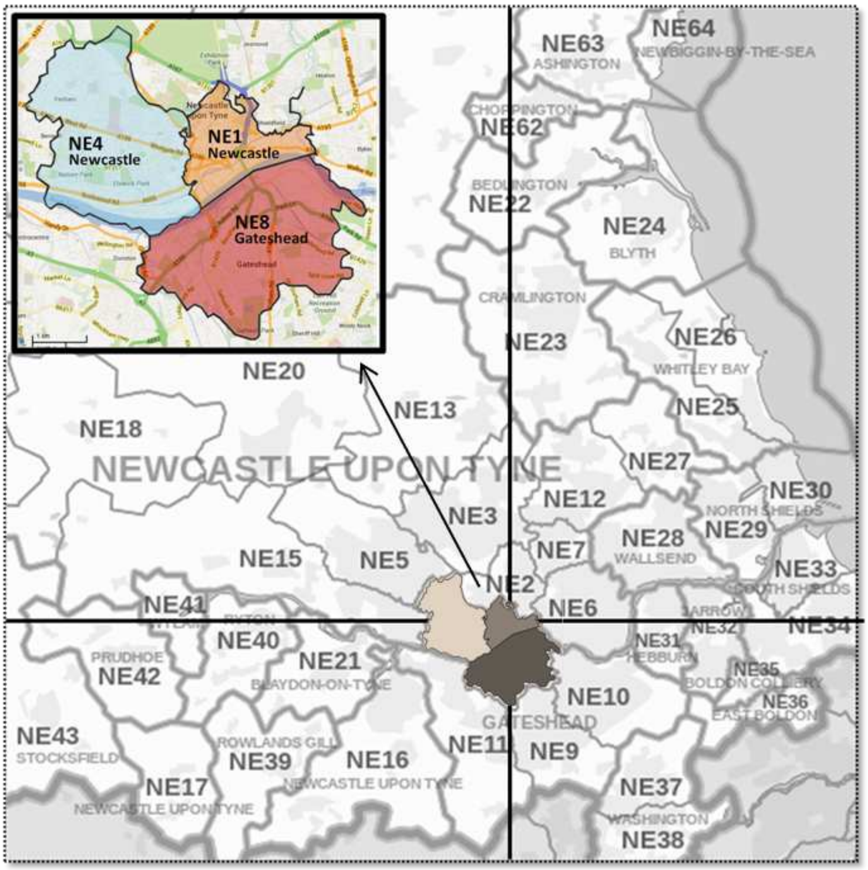


Figure 4-1: Postal districts of Newcastle and the case study boundaries (NG, 2011)

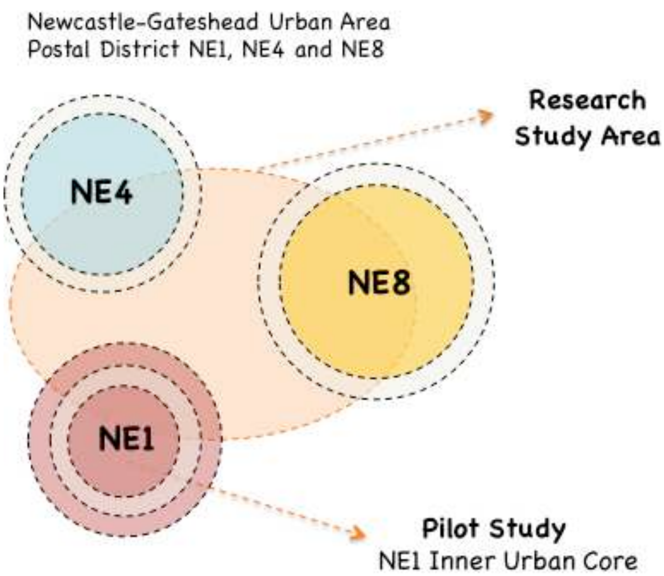


Figure 4-2: Newcastle area of study

The inner urban core is a hotspot for inhabitants and visitors who are flying or sailing to Newcastle. The area contains the city centre; it has the main traffic arteries of the city and 50 publicly available CPs, see (Figure4-3). Parking in the city centre (NE1) is free of charge after five o'clock in the evening, which reflects more flow and crowded avenues to get away from the business district network (NE1, 2009). Tyne and Wear Metropolitan County contains five metropolitan boroughs: Gateshead, City of Newcastle upon Tyne, North

Tyneside, South Tyneside, and City of Sunderland. The case study considers the first two boroughs.

The Newcastle-Gateshead area has a rich charging network. The majority, 26 RFs, are located in NE1; while there are 7 RFs in NE4, and 10 RFs in NE8. Some of these points are deactivated, which pulls the numbers down to 25 RFs in NE1 and 5 RFs each in NE4 and NE8, see (Figure 4-3). Figure 4-4 shows the bar chart of the RF distribution in Newcastle upon Tyne by postal district. It shows the well-covered areas such as NE1, NE4 and NE8; other more distant areas from the Tyne and the City Centre have almost no RFs.

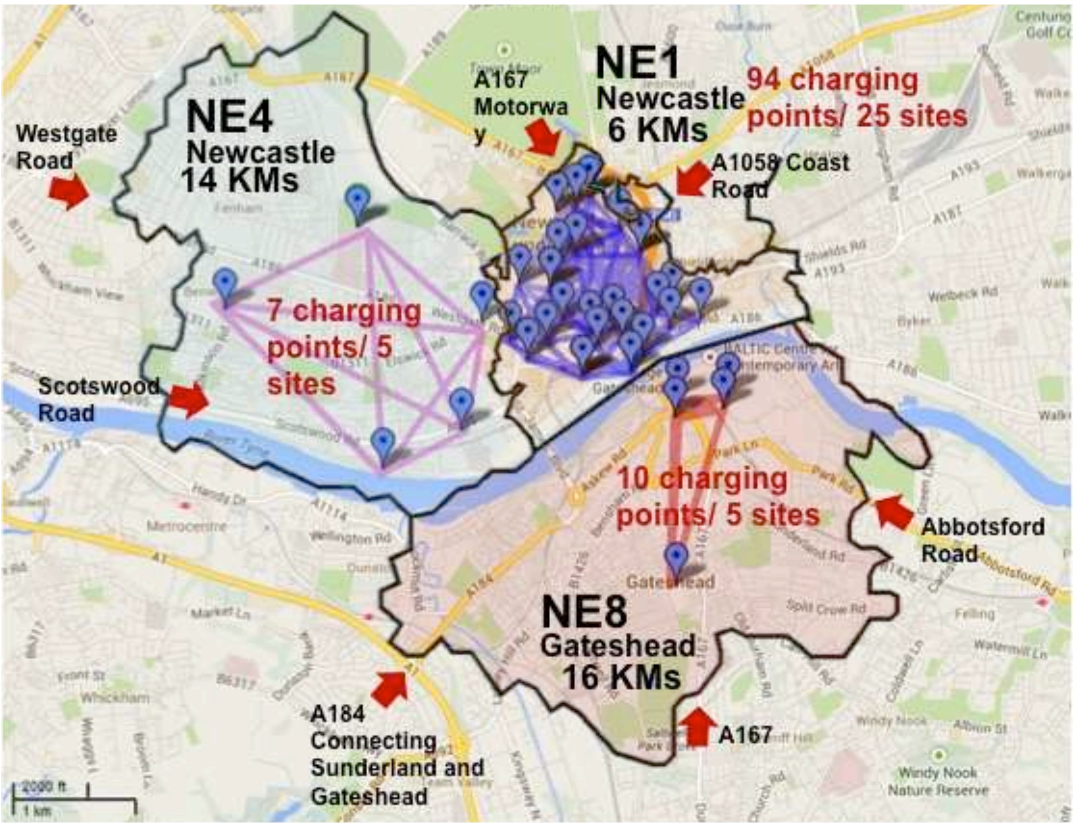


Figure 4-3: RF's distribution Newcastle upon Tyne (CYC) (source: Google map, 2014)

The urban pattern has an organic pattern with high mobility flow. According to Newcastle City Council-NCC and the Highway Authority for Newcastle upon Tyne, there are seven road types (principal road, classified road, local distributor road, collector street, residential street, shared surface street and home zone). As for the purpose of the study, the first three types are displayed, see (Figure 4-5).

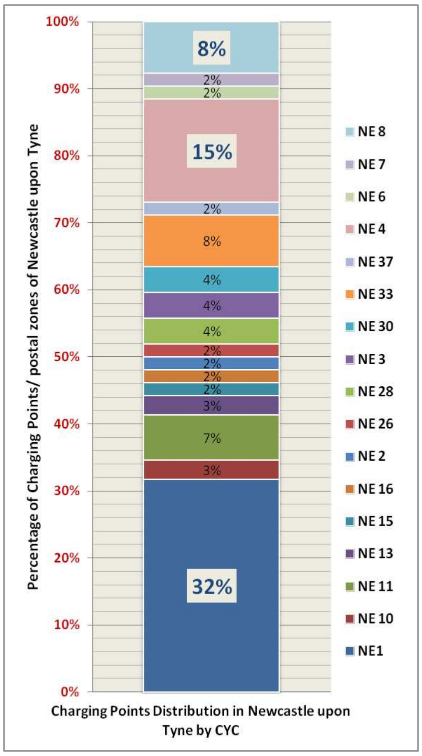


Figure 4-4: RF's distribution Newcastle upon Tyne (CYC) bar chart

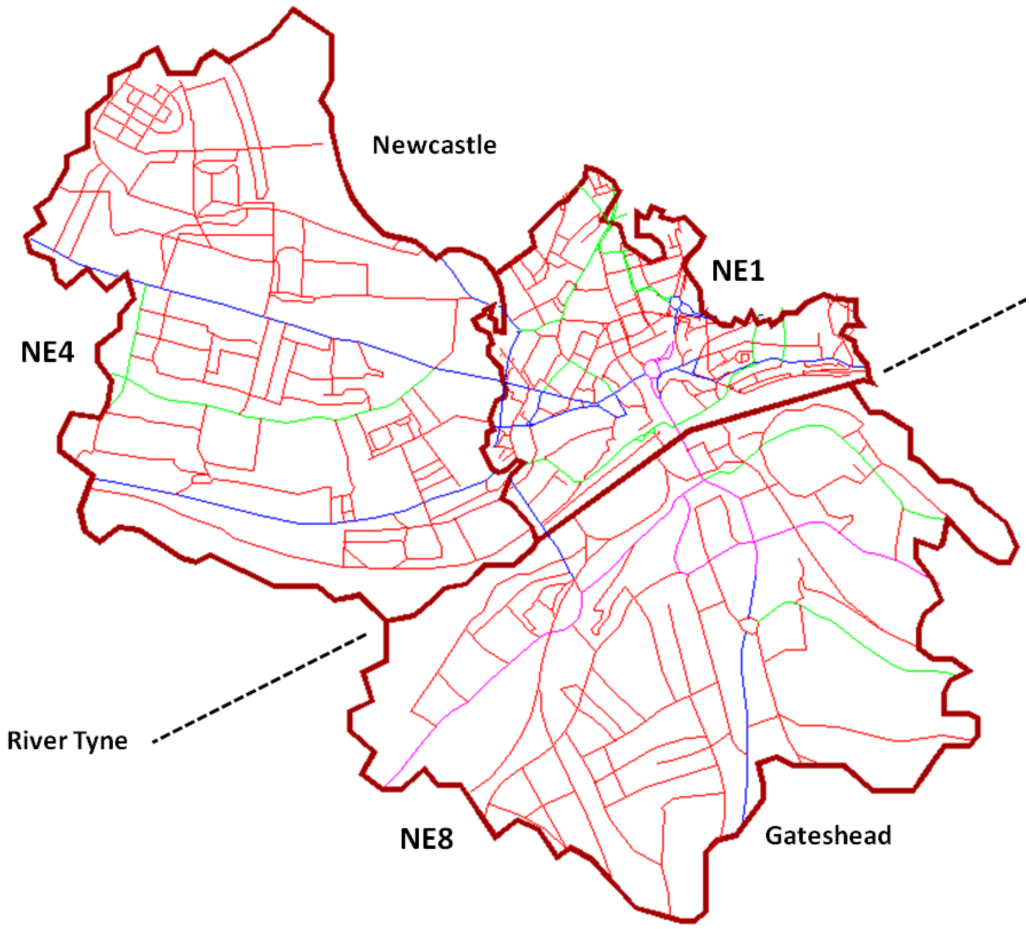


Figure 4-5: Road-centreline map_NE1, NE4 and NE8 (Edina, 2013)

The three categories are the middle ones in terms of size, service and speed. Trucks and principal roads are secluded as well as shared surfaces and home zone accesses are eliminated. It starts from:

i) collectors/ residential street (Access) 6.00 meter standard width, red colour;
ii) local distributor road (Local) standard width, 6.75m standard (3.45m lanes), green colour (this level is used to identify the location of RFs in this thesis);
iii) classified road (District), 7.30m standard width (3.65m lanes), blue colour.

NE1 contains versatile land use and busy avenues and streams of movement, either vehicular or pedestrian. It contains several express and arterial long roads, which vary in width and capacity. In NE1, there are two universities, schools, shopping and recreational areas, commercial buildings, a train station, public squares, parks, and some of the busiest residential wards of the Newcastle area. NE1 accommodates around 3959 residents. RFs in NE1 serve inhabitants and visitors to NE1 coming from different areas around the city for (work, study, and entertainment).

4.2 The Multi Method Approach

The thesis takes a multi method approach, which consists of four main strands. Each method is employed separately to analyse and investigate different aspects of the Newcastle-Gateshead area e-mobility system. In this chapter, each method is presented with a proceeding discussion in the consecutive chapters, see (Figure 4-6).

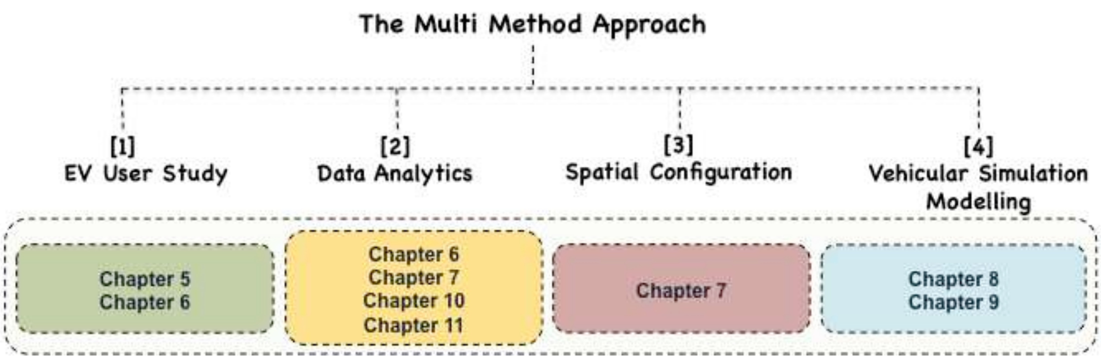


Figure 4-6: Research approach diagram

4.3 First Method: EV User Study

The initial method is a survey-based approach. It is employed to investigate the end-user preferences and design needs and to classify charging patterns and profiles. Prior to conducting the study, a meta analysis of the previous consumer and user studies was carried out, see (Figure 4-7).

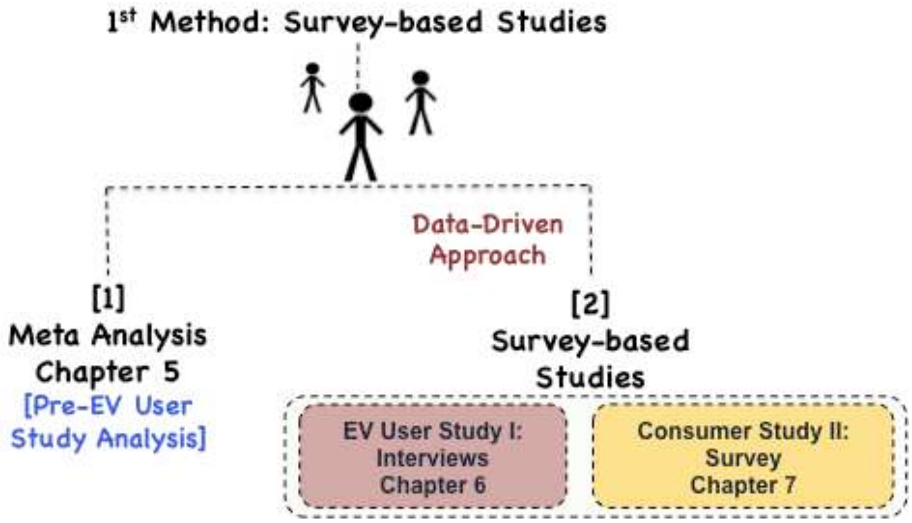


Figure 4-7: Survey-based approach

The meta analysis is a part of the methodology as it was employed to investigate the usefulness of different types of these consumer and user studies by how successful was the design to meet the aim and objectives of each study. A comparative analysis is presented by mapping 60 EV published user studies over the last twelve years.

The meta analysis as defined by Sandelowski et al. (1997) as:

> *"a distinctive category of synthesis in which the findings from completed qualitative studies in a target area are formally combined. Both an analytic process and an interpretive product, qualitative meta-analysis is analogous to quantitative meta-analysis in its intent to ascertain systematically, comprehensively, and transparently the state of knowledge in a field of study."*

In Chapter 5, studies are compared, analysed and compiled using different data filters. The review is used as a stand-alone resource for readers, researchers or policy makers with an interest in EV uptake and related policies. It provides a useful review to undertake further user studies. This is followed by Chapter 6, which presents the research EV user study. Chapter 7 presents a consumer level of awareness spatial survey.

The user studies vary between interviews, questionnaires, surveys, or trials. Each of these methods can be applied to different focus groups (potential, current or stakeholder). The use of surveys and questionnaires is a commonly used research tool to swiftly collect data and scan the environment in an easy and affordable way, see (Table 4-1).

Table 4-1: Methods of data collection (quantitative and qualitative) in the context of EV

Method	Abstraction level	Pros	Cons
Survey	It can be anything from a short paper-and-pencil feedback form to an intensive interview. Macro-scale level. It tries to reach many respondents with less personal and detailed feedback. National travel survey is the most common one in transportation area. Likret scale usually is used.	Quick, bigger sample size (n), self explanatory, can be done online (in different languages).	Biased due to self-selection, online access, type of questions cannot be very personal (broader), no recording, ended questions (open-ended questions are not recommended). Incomplete responses.
Questionnaire	Micro, meso or macro-scale. Depends it is online or not. Likret scale usually is used.	Relatively big sample size, questions regarding individual pattern can be addressed.	
Interview	Used more as an ethnographic study as it may have more in depth/ personal questions seeking justifications: Ex. *Why you do not use that particular CP?*	Follow-up questions can be asked; provide better understanding of the answers of the respondents. Can be over the phone; however, it has to be consistent.	Time-consuming, respondents may not have public-listed phone numbers or no telephones at all.
Trial	A field study is a general method for collecting data about users, user needs, and product requirements that involves observation and interviewing (Rosenbaum, 2002). In EV research area, a trial can be for a 7 day long and up to a year. The longer the time, the less abstraction is the trial. Monitoring is not on a daily basis in case of long trial; however, GPS would be used to track the car to meet the trial objective *(e.g., long distances, number of destinations, charging places, etc.).*	The EV trial is considered as a short-term direct expereince; however, it allows the potential user to have better insight of driving an EV. In some cases especailly when it is applied to current user, it is for a longer time and may capture the usability of en EV (car & infrastructure). *A trial can be for charging pattern, driving style. Provide better visions due to the direct interaction.*	Demanding, frequent update is needed, needs higher level of motivation to attract participants. In case of potential users, hypothetical scenarios are built and based on it, future demand and observations are formed.

A poorly designed questionnaire may only gain unusable responses or none at all. A clear image of what is to be achieved, is the first step to a well-designed opinion poll. Due to the lack of control and wording are often confusing in internet-based questionnaires (Potoglou & Kanaroglou, 2007), the clarity of the questions has to be tested prior to dissemination. The major issue with the meta-analysis of EV is the temporal validity.

The EV technology, which affects the user feedback and market penetration is under strong development. For example, quick chargers change the patterns of charging as in 15 minutes, the user can replenish their battery. The lack of future time perspectives and robust assessment conclusions affect the diffusion of different EV models in the market. Clearly stated purposes, geographical and time scope studies provide design and planning guidelines for stakeholders.

4.4 Second Method: E-Mobility Data Analytics

The second method employed is spatiotemporal analyses. Various models and analyses are conducted within the remit of this research, see (Figure 4-8). Content analysis was employed to gather insights into charging patterns and users opinions and perceptions of the current and future charging network. Based on the empirical data collected, the user charging personas were created. This is followed by a clustering model, which was developed to assist the planning authorities and policy makers understanding the users' preferences. Another clustering model was developed interrogating the relation between design and behaviour features of driving an EV. Out of all the spatial and behavioural measures, there are significant key measures that would affect the design of RFs. In order to identify these attributes, a regression model is designed, and a time series model is developed to forecast the charging patterns of EV drivers using non-domestic (public and workplace) CPs.

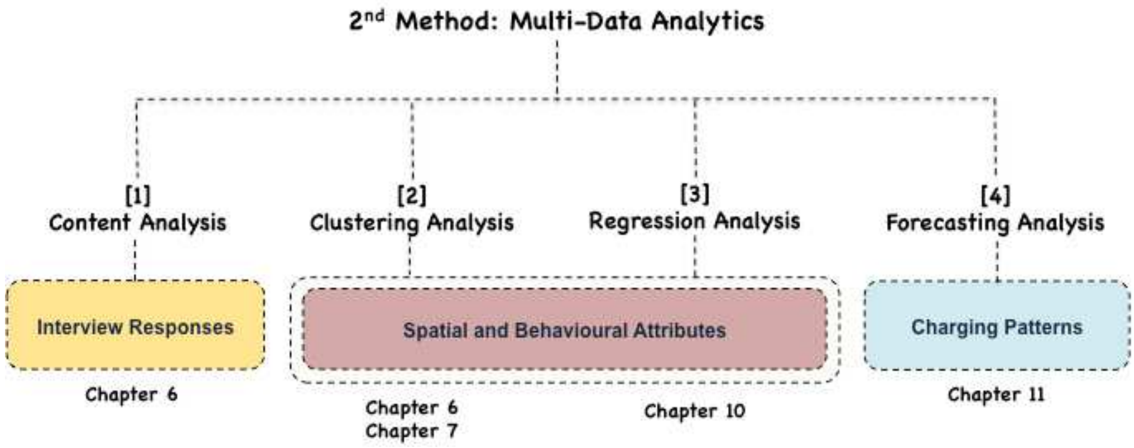


Figure 4-8: Multi-data analytics

4.4.1 Content analysis

This research focuses on the use of the data analytics as a dimensional analysis technique for data mining and significant analysis of quantitative and qualitative datasets. The sheer size and complexity of the dataset sometimes makes the analysis process daunting; however, large data set yields richer and more useful information (Namey, 2007). Hence, a meaningful interpretation and an overall picture can be drawn depicting the desired phenomenon.

The first technique employed is the content (systematic) analysis. Content analysis was first defined by Berelson (1952) as:

> *"a systematic, replicable technique for compressing many words of text into fewer content categories based on explicit rules of classification."*

A Further broad definition of the content analysis evolved over the years as:

> *"a technique for systematically describing written, spoken and visual communication. It provides a quantitative description for open-ended responses of an interview or survey questions." [Holsti, 1969]*

To kick-start the process of collecting insights into EV user's driving patterns and charging behaviours, explorative interviews were conducted with EV users [n=15]. Structured interviews aimed to explore motivations and practices surrounding EV usage and observe opinions towards the current RFs. In total, 9.15 hours of interviews were carried out, documented and analysed based on a thematic analysis, which revealed various common experiences that were stated by the different participants. During the interviews, questions were posed and included

"What motivated you to drive an EV?" and "Why did you...?"

Additionally closed questions were included such as:

"How many times you charge your car a week?"

Both quantitative and qualitative responses were incorporated in the clustering model.

4.4.2 Data mining

The second technique is the clustering analysis of different datasets; two models were conducted with different objectives. When datasets are large or complex, adequate data mining approach is needed for analysis. The basic concept is the reduction of pedantic amounts of data down to the meaningful parts. Data reduction techniques can include simple tabulation, aggregation via computing descriptive statistics or more sophisticated techniques dealing with multivariate data like factor analysis, principle component, correspondence analysis and clustering analysis. Factor analysis, is to express the original variables as linear functions of a smaller set of underlying variables that account for the original variables and their inter-correlations. Principal components analysis is "finding a small set of linear combinations of the original variables that summarizes most of the variation in the data". Correspondence analysis is:

> *"a graphical technique in order to represent the information in a two-way contingency table, which contains the counts (frequencies) of items for a cross-classification of two categorical variables."[Rencher, 2002]*

4.4.3 Clustering analysis as a research tool

Data clustering is employed to classify EV users profiles and group the spatial and behavioural attributes of the EV charging network by examining the best set up that would generate optimal profits, see (Figure 4-9). Data simplification allows researchers to focus their attention on the descriptive and crucial details of qualitative and empirical data.

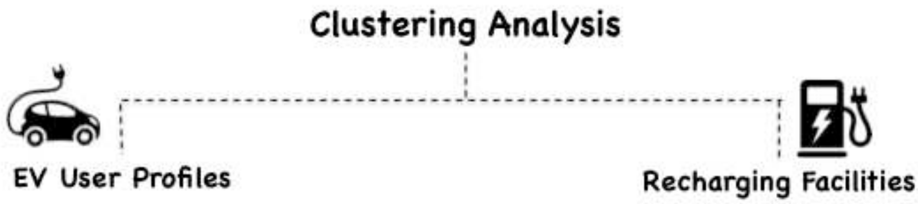


Figure 4-9: E-mobility clustering models

Before conducting the data spatial clustering analysis, some basics about the EV users data, variables and the clustering techniques are discussed. Data clustering is a continuous fine-tuned process of grouping sets of data. It is a convenient method for identifying homogeneous groups of objects, called clusters (Mooi & Sarstedt, 2011). It identifies the groups within the data while being able to analyse groups of similar observations instead of individual observations (Caccam & Refran, 2012). It is finding a group of similar objects sharing many characteristics and qualities, which are unrelated to other objects not belonging to that group aiming to reduce the size of the large data sets. These objects (cases, or observations) (Mooi & Sarstedt, 2011) can be e.g., customers, products, employees, users, or clients. It is to analyse their behaviours, preferences, patterns, usage or any other quantified parameter and classify them into groups (Larson et al., 2005). To cluster the observations, many techniques begin with similarities between all pairs of observations (Schaeffer, 2007).

Measuring similarity or dissimilarity

There are a few ways to compute the distance between observations such as: Euclidean (square route), city-block distance (absolute), or Chebychev distance (maximum of the absolute). In this research, the Euclidean distance is discussed. Euclidean distance can be presented in a table (proximity table) where the diagonal presents the distance between the object and itself, zero, and the non-diagonal values represent the distance between the pairs, see (Figure 4-10). In this proximity matrix, the lower and upper diagonal elements are the same, mirrored over the diagonal (Schaeffer, 2007). The d (Euclidean) can be measured, see (Equation 4-1).

Equation 4-1: Measuring Euclidean distance

$$d(ID{:}004, ID{:}007) = \sqrt{(X_{007} - X_{004})^2 + (X_{007} - X_{004})^2}$$

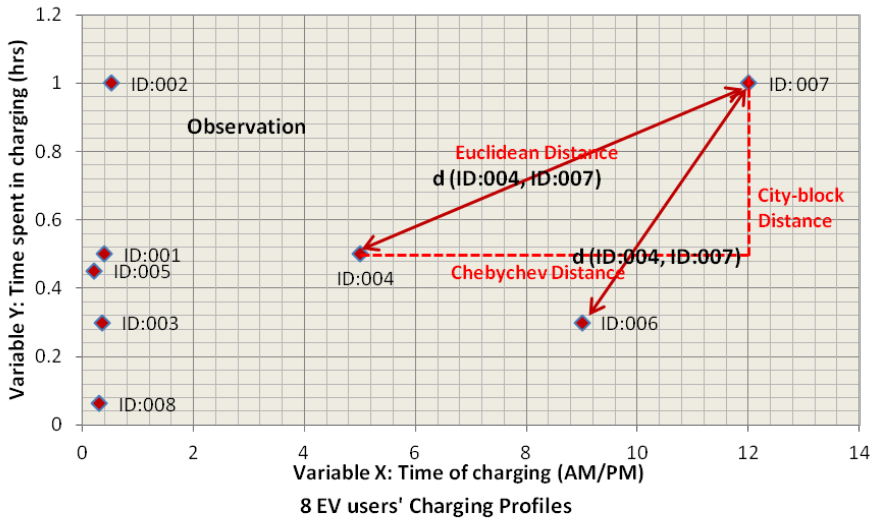


Figure 4-10: An example of measuring similarity between CPs using Euclidean distance

The number of clusters

The number of clusters should be as few as possible in order to be easy to understand and executable. On the other hand, having many clusters allows us to identify more segments and more subtle differences between segments. The number of clusters can be selected based on the percentage of variance, as adding another cluster does not always provide enhanced data mining. Percentage of variance is the ratio of the between group variance to the total variance. In other words, if the number of clusters is tabulate against the percentage of variance by clusters, the first time the change in the number of cluster does not show a significant variance (marginal gain), is when the number of clusters are chosen (Mooi & Sarstedt, 2011).

Data types in statistics

The research problem contains different statistical types of data which vary between: quantitative or measurable data is metric, numerical or continuous set of observations, which allows statisticians to perform various arithmetic operations to find parameters of a population like: time spent in charging, time arriving the recharging facility and some spatial configuration values of the road network. The types can be summarised as follows:

- Discrete data: where the values or counts can constitute a sequence of isolated or separated points on the real number line. Each observation therefore takes a value from a discrete list of options like the number of the points in each site, popularity of the CP and the frequency of use (weekend/weekday ratio).

- Discrete qualitative (nominal) data: it is a set of significant categories or groups like: the user ID, the location of the CP (Off street or on street) and the direction of the majority using a CP. There is no accepted scheme to put these categories in any meaningful order, as there are no ranking differences to be determined.

- Continuous quantitative data: it results from infinitely many possible values. Continuous data types involve the uncountable kind of infinity, which is frequently referred to as the number of points on a number line (or an interval on a number line). The observations can be like the total number of transactions and total number of users.

- Categorical data (qualitative or nominal): it results from placing individuals into groups or categories (Montclair State University, 2013). The data collected contains categorical data, which was converted into binary and ordinal data for easiness. Several descriptive and spatial statistical analyses can be conducted. Quantitative data allows us to find population or sample parameters like mean, variance, and standard deviation. Discrete ordinal data that may be arranged in some order or succession, but differences between values are meaningless; however, relative comparisons made about the differences between the ordinal levels.

Univariate and multivariate methods

There are two methods to classify the data in terms of abstraction level. Univariate methods where the response variable is influenced by only one other factor and multivariate methods is where the response variable is influenced by multiple factors (and even combinations of factors) and set of tools is utilized to analyse multiple variables in an integrated and powerful way. In this research, the multivariate is employed. This is due to the variety of observed attributes and measured values needed to examine the recharging facility and usage pattern. Multivariate method allows better and more realistic assessment of designs and systems being examined by traditional univariate methods having one outcome and a very few Independent Variables (IVs).

These methods facilitate analysis of a complex array of variables and provide greater assurance and meaningful interpretation of the whole data set rather than analysing variables in isolation likewise the univariate methods analysis technique. Hence the researcher would reach some synthesizing conclusions with less error and more validity (Mike, 2013).

Selection of variables

Researchers often overlook the fact that the choice of clustering variables is closely connected to data quality. This is very important if a segmentation solution has to be managerially useful (Mooi & Sarstedt, 2011). A clear definition of the selection of variables for clustering analysis process was described as:

> *"a process of selecting only those variables that ensure that high quality data may be included in the analysis. For ease of understanding and efficiency, typically what is needed is the fewest number of variables that will explain the most."[Mooi& Sarstedt, 2011]*

The selection of the variables should help on differentiating between segments for a specific objective (the initial objective of the data clustering). There should be significant differences between the DVs across the clusters. If the variables are highly correlated, specific aspects will be overrepresented, which does not help identify the distinct segments. Therefore, the variables have to be non-redundant because the clustering process does not differentiate between the clustering variables in a conceptual sense.

Variables have many types and can be classified as general and specific and can also be observable and unobservable:

- General and observable: directly measured and not related to objects: origins of the users.
- General and unobservable: inferred and not related to objects: driver profile.

- Specific and observable: directly measured and related to objects: usage frequency. Specific and unobservable: inferred and related to objects: aspect of behaviour, charging patterns and preferences (Wedel & Kamakura, 2000).

While choosing the clustering variables, there are four considerations to be noted: the cost, availability, meaningfulness, and theory. Whichever clustering variables are chosen, it is important to select those that provide a clear cut differentiation between the segments regarding a specific managerial objective (Tonks, 2009). There should be significant differences between the DV(s) across the clusters; it is essential that the clustering variables distinguish the dependent variables (DVs) significantly.

4.4.4 An overview of possible algorithms and techniques

To explain the approach chosen to conduct the data clustering mechanism, a quick overview of the possible available algorithms/ techniques is presented, highlighting the one being used. The classification of the data clustering algorithms can be in different shapes. In this thesis, the classification is presented as per the platform being used, SPSS Statistics 21, a predictive analytics software, is the commercial platform is being used.

SPSS has three techniques with different algorithms: K-means (Partitioning or Flat-Hierarchical) clustering, Hierarchical clustering and TwoStep. The first one works on dividing the data into non-overlapping subsets, see (Figure 4-11). The second one is dividing them into nested clusters organized as a hierarchical tree. The last method is a combined technique that has two steps, partitioning and hierarchal.

K-means clustering

This is a flat hierarchical method, which attempts to find a user-specified number of clusters (k), which are represented by their centroids. The centroid is the mean of the points in the cluster. The initial centroid is randomly assigned and keeps changing. The centroid's position is recalculated every time a component is added to the cluster. Iterations and computation takes place until the centroids do not change, thus forming the final required number of clusters. Usually, the convergence happens in the first few iterations and the Euclidean distance measures the closeness.

Hierarchical clustering

Agglomerative and divisive techniques are used in this method, see (Figure 4-12). The first one starts with creating clusters from individual objects. The longer the process continues, the bigger the size of the cluster as a merging process takes place. The convergence of similar objects continues in a bottom up approach. The divisive approach is the other way around where the start is one single large sized cluster, and the iterations gradually split up the cluster. This reflects the nature of hierarchical clustering: an object is assigned to only one cluster. The higher level of hierarchy always encompasses the lower levels (Mooi and Sarstedt, 2011)

Combining both methods

A combined approach can be implemented by employing a hierarchical approach, followed by flat hierarchal approach, see (Figure 4-11). The first is used to determine the number of clusters and profiles' centroids that would serve as an initial cluster formation in the partitioning one. The second phase would take place to provide more accurate cluster membership (as the K-means clustering needs to identify the number of clusters as an initial step). This enables the advantage of the hierarchal methods to complement the partitioning method in being able to refine the results by allowing the switching of the cluster membership.

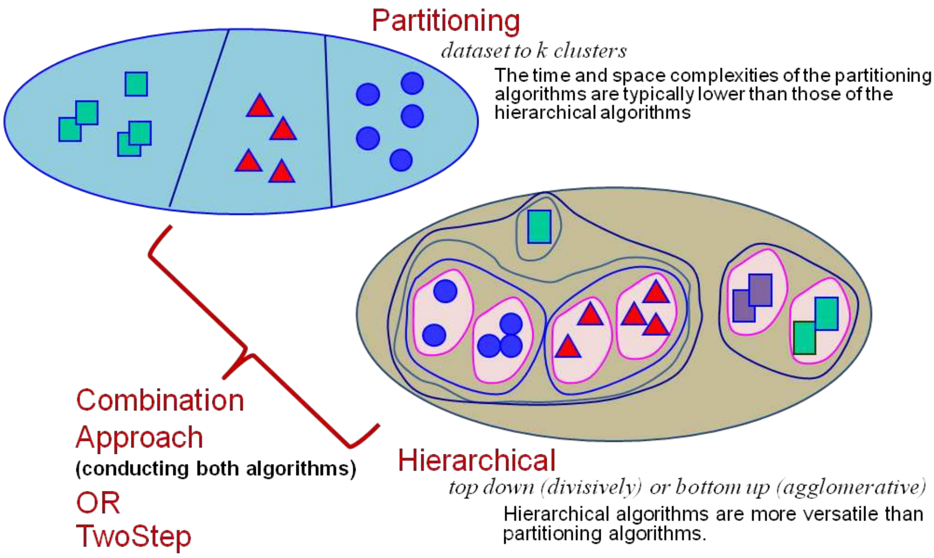


Figure 4-11: Clustering techniques

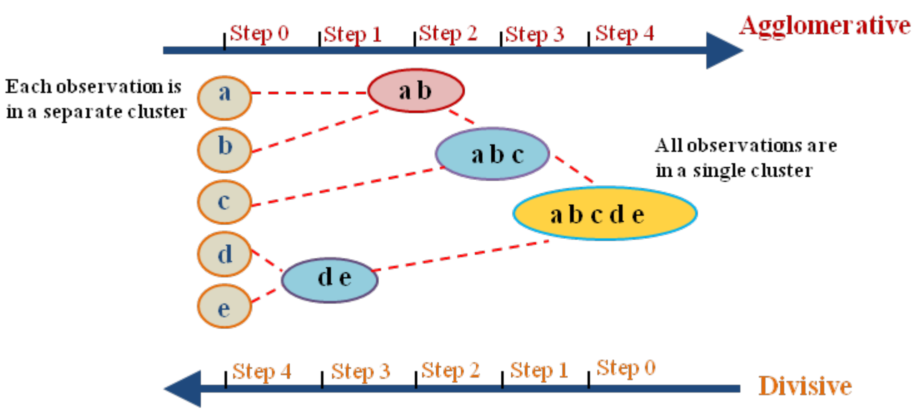


Figure 4-12: Agglomerative and divisive approaches of clustering

TwoStep model

TwoStep clustering model, using SPSS Statistics 21 software, was developed for the analysis of large data sets (Chiu et al., 2001). This is an exploratory tool designed to reveal natural groupings within the dataset, see (Figure 4-12). The algorithm employed has several features that give credit to this technique compared to traditional clustering techniques. This hybrid method creates clusters based on both continuous and categorical variables. It has the ability of automatically selecting the number of clusters as well as analysing large data files in an efficient manner (Caccam and Refran, 2012). It requires only one pass of data and it can produce solutions based on mixtures of continuous and categorical variables, and for varying numbers of clusters. The clustering algorithm is based on a distance measure that yields the best results if all variables are independent, and it deals with continuous and categorical data set. Continuous variables have a normal distribution, and categorical variables have a multinomial distribution (Mooi and Sarstedt, 2011).

The procedure consists of two steps: pre clustering and clustering. The first is the formation of pre-clusters. It is a sequential approach, which is used to pre-cluster the cases. The goal of pre-clustering is to reduce the size of the matrix that contains distances between all possible pairs of cases. Pre-clusters are just clusters of the original cases that are used in place of the raw data in the hierarchical clustering. As a case is read, the algorithm decides – based on a distance measure if the current case should be merged with a previously formed pre-cluster or whether to start a new pre-cluster. When pre-clustering is complete, all cases in the same pre-cluster are treated as a single entity. The size of the distance matrix is no longer dependent on the number of cases but instead on the number of pre-clusters. The second step is where the hierarchical technique is applied. Similar to agglomerative hierarchical techniques, the pre-clusters are merged stepwise until all pre-clusters are in one cluster. Unlike agglomerative hierarchical techniques, an underlying statistical model is used. Forming clusters hierarchically lets one explore a range of solutions with different numbers of clusters (Mooi and Sarstedt, 2011).

4.4.5 Regression analysis

The third technique is developing a regression model. The design process of the EV charging infrastructure is very similar to the petrol stations location problem. Both processes cannot be dealt with as static as location allocation problem. Location allocation problems can be purely based on spatial and metric calculations tabulated in optimization model. This approach is irrelevant to RF's location problem due to the behaviroula and spatiotemporal elememts of the system.

As part of the multi method approach, a regression model is employed as a statistical measure, which was defined by Pearson (1903) as

> *"an attempt to determine the strength of the relationship between one dependent variable (usually denoted by Y) and a series of other changing variables (known as independent variables)."*

A regression model relates Y to a function of X and β, see (Equation 4-2).

Equation 4-2: Linear regression equation

$$Y \approx f\ (X, \beta)$$

Where

β	parameters	
X	independent variables	(spatial and behavioural attributes)
Y	dependent variable	(the use of RF which may be indicated by the profit generated)

An integrated model that accounts for a multi-parameter complex system is required. A model that can link between the two sets of predictors (spatial and behavioural attributes), see (Figure 4-13). In this thesis, a multi linear regression model is developed to study the relationship between the various variables. Chapter 10 presents the regression model and highlights the most influential variables that affect the use of RFs.

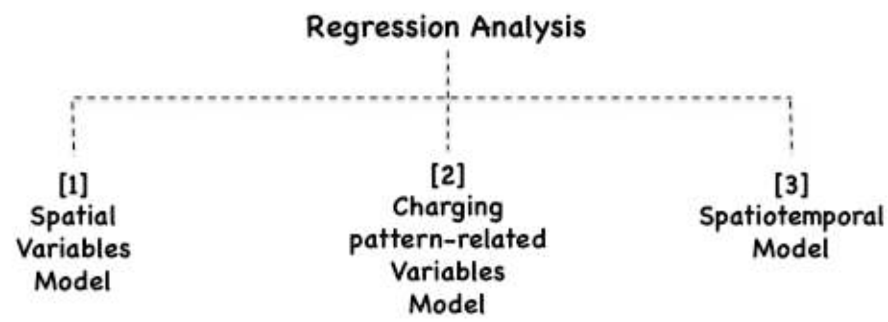


Figure 4-13: Regression models diagram

4.4.6 Forecasting analysis

The fourth technique is forecasting analysis. As a thesis outcome, giving insights into the e-mobility system that assist with assessment, planning and designing is fundamental. Predicting the future demand comes at the latest stage after analysing the current system and understanding the main features of the e-mobility system. This thesis presents two models:

i) Forcasting the behaviour
ii) Forecasting the location

A Time Series model is developed in Chapter 11. The Time Series analysis is:

> *"a time series analysis is a stochastic process where a sequence of observations of a random variable is followed. It is a set of procedures to estimate the parameters of a model being used to allocate limited resources or to describe random processes." [Ruddock, 1995]*

It is a set of observations obtained by measuring a single variable regularly over a period of time. This method is a successive measurement to the size or value of a variable over time (Ruddock, 1995). One of the most important reasons for establishing a Time Series model is to forecast the future values of the series. The forecasting technique is based on modelling the past values to predict whether and how much the next few values will increase or decrease (using SPSS Statistics 21 software). The ability to make such predictions successfully is important to stakeholders (Elbanhawy, 2015).

The second forecasting is conducted using a simulation model. An integrated summation model is designed and employed to assist the planning authorities and policy makers with the RFs location allocation problem. The model can be used for both assessment and planning, see (Figure 4-14). It is developed based on collected data of active EV users in Newcastle-Gateshead area. Through a case study (Chapter 11) the model is proposed as an assessment tool to evaluate the current e-mobility system and provide recommendation for improvements. Moreover, the model with different simulation constructs (two paragons are explained in Chapter 9) provides a methodological approach for further applications.

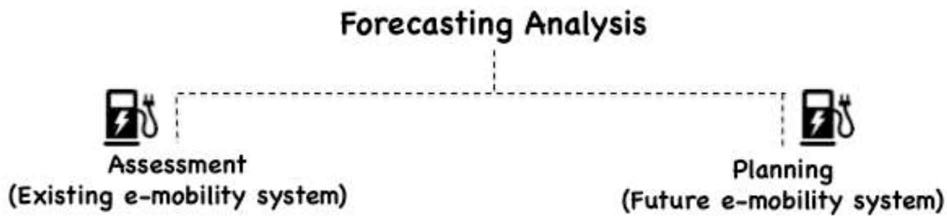


Figure 4-14: Forecasting analysis for assessment and planning

4.5 Third Method: Spatial Configuration

The importance of the configurational properties of an environment to wayfinding was noted by Passini (1992), where he stated:

> *"although the architecture and the spatial configuration of a building generate the wayfinding problems people have to solve, they are also a wayfinding support system in that they contain the information necessary to solve the problem."*

In this thesis, the spatial configuration is employed twice. The first application is in Chapter 7 to calculate the syntactic measures of the RFs. The second application is to predict the vehicle movement in the simulation modelling in Chapter 9 and 11, (Figure 4-15).

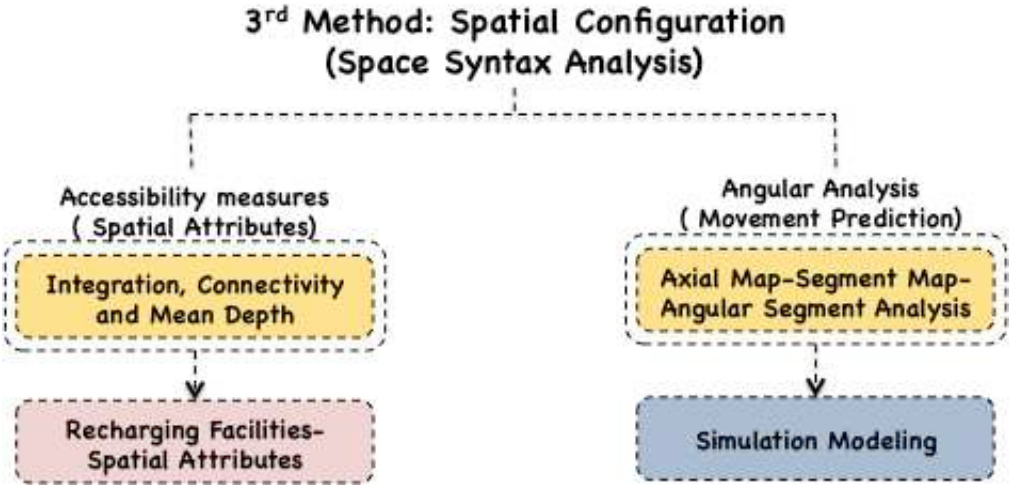


Figure 4-15: the two applications of spatial configuration

4.5.1 Syntactic measures

The axial representation, see (Figure 4-16), of the area provides the opportunity to measure some morphological properties: connectivity indexes, control value and integration. Although space syntax was not originally developed as a tool to predict movement, it has been found that there does exist a powerful relationship between movement and spatial structure. It is this predictive ability of space syntax analyses that has caused it to be adopted as a design tool (Dalton & Hölscher, 2006). The procedure employed by space syntax analysis is to represent and quantify aspects of the built environment (Penn, 2003) and then using these as the independent variables in statistical models of observed behaviour patterns.

In the theory of space syntax, movement is understood through the accessibility measures of settlement roads (Abhijit, 2011; 2009). There are previous studies carried out investigating the correlation between the design features and the spatial behaviour of individuals. Gil et al. (2009) and Larson et al. (2005) employed data reduction technique, clustering analysis, to explore the shoppers' traces to identify similar strategies to move inside a store. One of the limitations of previous research exploring the effects of spatial layout on movement patterns has been the lack of rigorous tools for assessing the characteristics of spatial configuration (Wineman & Peponis, 2010).

A configurational model represents a spatial system as a series of smaller spatial units or as a system of lines of potential movement between these spatial units (Wineman et al., 2000). Such analysis involves the study of patterns of connections:

- Integration: the relationship of each spatial (unit or line) to the entire spatial system (a global measure of centrality);
- Connectivity: the relationship of each spatial (unit or line) to its immediate neighbours measured by variables (local measure).

4.5.2 Integration

In space syntax, accessibility, commonly known as Integration, which represents how well integrated the initial segment is in the global system. A higher Integration value means greater accessibility, see (Figure 4-16). As Hillier et al. (1993) stated that the most integrated lines are

> *"those from which all others are shallowest on average, and the most segregated are those from which they are deepest."*

Syntactically a system of spaces is more integrated if spaces can be easily reached from one another (Wineman et al., 2000). Hillier et al. (1993) defined the Integration value of a line:

> *"is proportional to its depth from all other lines in the network and is a sort of generalisation of the concept of average distance. During the second normalisation process values are also inverted, in order to produce high values of integration when the total depth is low, and vice versa."*

Integration is most commonly used measure for axial map analysis. Hillier (1996) stressed on the importance of the Integration values as these values are of great importance in understanding how urban systems function. How much movement passes down each line is very strongly influenced by its `Integration value'. The distribution of movement of both vehicles and pedestrians that passes through each line is strongly dependent on its value. This measure is often times related to pedestrian flow where higher accessibility is related to higher pedestrian flows and lower accessibility is related to lower pedestrian flows (Law et al, 2012). The Integration value is a measure for relational asymmetry (a symmetric relation when the relation between a and b is the same as the relation of b and a), see (Equation 4-3). Integration is measured with Relative Asymmetry (RA) as follows:

Equation 4-3: Relative asymmetry calculation

$$RA_i = \frac{2(MD-1)}{(n-2)}$$

Where MD is the Mean Depth (the depth either local or global divided by the number of nodes involved minus one leads to local or global MD (Kruger, 1989) and n is the number of axial lines of an urban system. Based on this calculation, and by using DepthMap, the Integration values of the roads having the RFs were calculated and tabulated for data analytics, see (Figure 4-19).

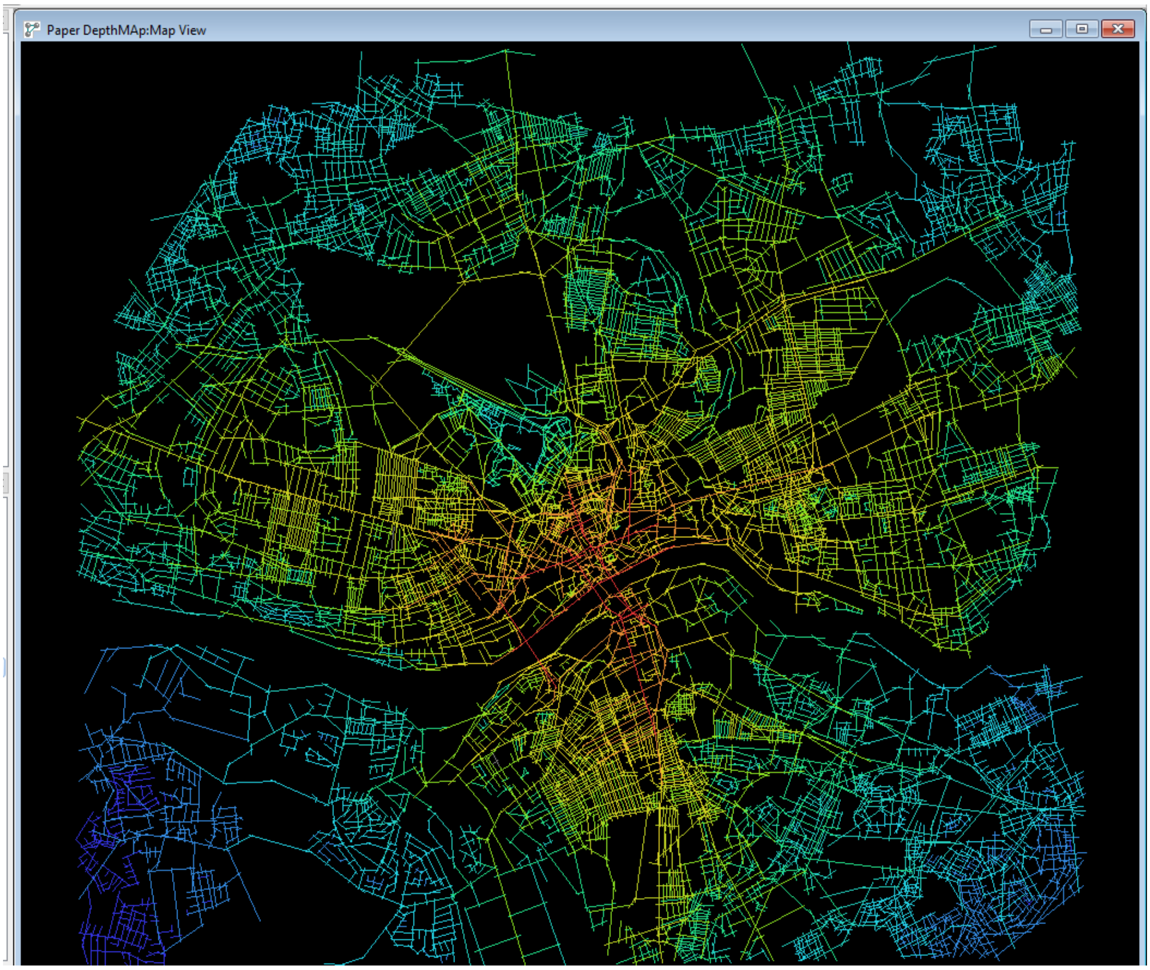


Figure 4-16: Spatial accessibility axial map-Newcastle (red reflects high spatial accessibility) (source: Space Syntax Ltd.)

4.5.3 Depth and connectivity

In practice, the generation of an axial map for a reasonably large city is a very tedious process, as there is no efficient automatic solution yet. Cybris et al. (1998) stated:

> *"according to the principles of configurational models, street segments with high accessibility indexes present a high connectivity with other links, thus constituting streets with high potential uses."*

The depth of an axial line is defined by the number of lines distant from a given number of steps to that axial line. Depth considers K neighborhoods while connectivity considers immediate neighbours (Jiang & Claremunt, 2002), see (Figure 4-17). Connectivity is the measure of how well an axial line is intersected by others, see (Figure 4-18).

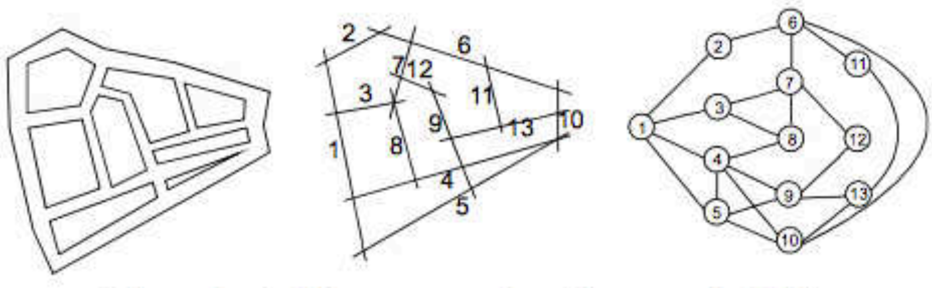


Figure 4-17: Axial representation (street system (a), its axial map (b) and connectivity graph (c) (source: Jiang et al., 2000)

In order to introduce the calculation principle of Depth and Connectivity, taking (Figure 4-17c), the axial lines and line interactions from an axial map are presented as nodes and links.

For any particular node in the Connectivity graph, the shortest distance (steps) far from the node is denoted by s, the number of nodes with the shortest distances s is denoted by Ns, the maximum shortest distance is denoted by I, see expression (Equation 4-4):

Equation 4-4: Configurational measures

$$\sum_{s=1}^{m} s \; x \; N_s = \int \begin{matrix} Connectivity & iff & m = 1 \\ local\ depth & iff & m = k \\ global\ depth & iff & m = I \end{matrix}$$

Figure 4-18: Connectivity measures (source: Space Syntax Ltd.)

After calculating the Integration, Connectivity and (MD) of the area, the streets that contain RFs are selected, and the relevant values are calculated, see (Figure 4-19). These values are to be used in the empirical analysis.

Figure 4-19: RFs with the three configuration design attributes (source: Space Syntax Ltd.)

4.6 Fourth Method: Vehicular Simulation Modelling

The fourth method is the use of simulation modelling in the context of EV. To employ simulation, the vehicular movement prediction is to be selected, see (Figure 4-20).

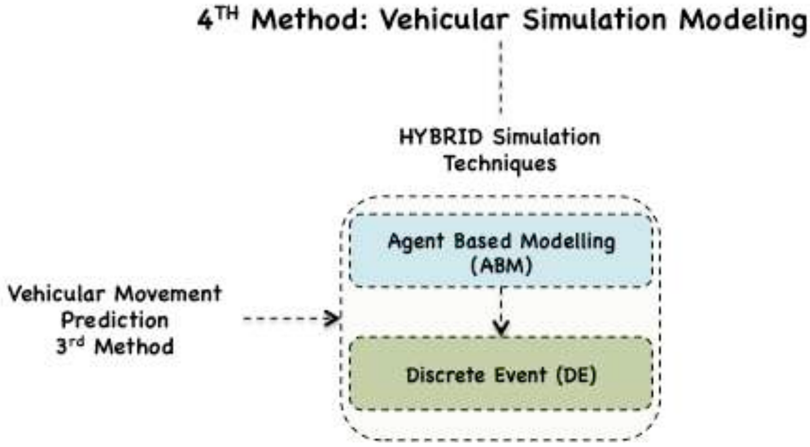


Figure 4-20: Vehicular simulation modelling topics diagram

4.6.1 Vehicular movement prediction

As previously discussed in Chapter 3, space syntax based modelling permits analysis of complex environments in a straightforward and cost-effective manner likewise transport system (Penn et al., 1998). There is an emerging demand for the ability to provide rapid qualitatively correct evaluation of the design proposals and the ability to address individual aspects. For these applications, conventional demand modelling techniques have begun to show their limitations. As space syntax research suggests that there is a strong relationship between the configuration of the road network and pedestrian vehicular mobility, ASA is employed as a vehicular movement technique. Space syntax approach is taken to predict the movement of EVs within the road network as such approach does not rely on O-D matrix, but does integrate spatial layout and transport attraction characteristics (Penn et al, 1998). By using spatial values (ASA), the vehicle tends to take the less angular depth (less effort) cumulatively in its trip. The model calculates this at each point (holistic approach) rather than (individually) by measuring the total Angular Depth of all possible routes, and choose the smallest individually.

The Pilot study

The first step was to simulate a two dimensional model where changes and amendments are easy, quick and costless (Crooks et al., 2008; Wang, 2005; Burghout, 2004; Maria, 1997). This direction was proven successful by previous research in depicting variant phenomena of social sciences (Jiang et al.; Wang, 2005; Lombardo & Petri, 2004; Gilbert &

Troitzsch, 1999; Troitzsch, 1997) and demonstrating systems in cities as flows and networks (Batty, 2013).

The pilot study provided an initial exploratory analysis, which helped to explore and test the technical and behavioural issues involved in EV research. It showed promising results in terms of the platform's selection criteria and the overall methodological approach (ElBanhawy et al., 2013; 2012; Burghout, 2004). The model was built on a probabilistic approach (ElBanhawy et al., 2013) such as predicting urban core areas, using normal distribution to predict the number of EVs generated from a residential area, state of charge, peak time, and simulation time to real time ratio. The inner urban core of NE1 is the pilot study as illustrated in (Figure 4-2). The area highlighted in green, see (Figure 4-21). It contains main arteries (road-segments). To run configuration analysis, a minimum of (road-segments= 100) is required. The green area consists of 100 road-segments. A centre-line map was converted to axial map using DepthMap, refer to (Figure 4-16). From the axial map, the segmental map was produced.

The segmental map was generated using DepthMap for the green zone and the surrounding buffer zone (400 segments), see (Figure 4-22). The process was repeated and reviewed several times to ensure reaching the finest and most accurate version of the syntactic map. The process involved defining the area, getting a scaled map of the selected area, drawing it in a 2D road-centre lines map while trimming edges, verifying intersection points, deleting duplicate lines/layers/dots, and converting the drawn map into a segmental map. For example, segments spaces Syntax ID (127, 128, and 130) are denoted as AutoCAD ID#11, see (Figure 4-23). Afterwards, ASA was conducted, see (Figure 4-24).

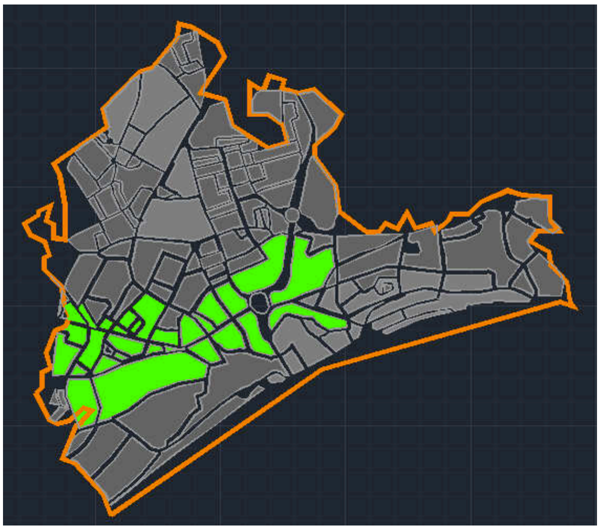


Figure 4-21: Pilot study_NE1 inner urban core

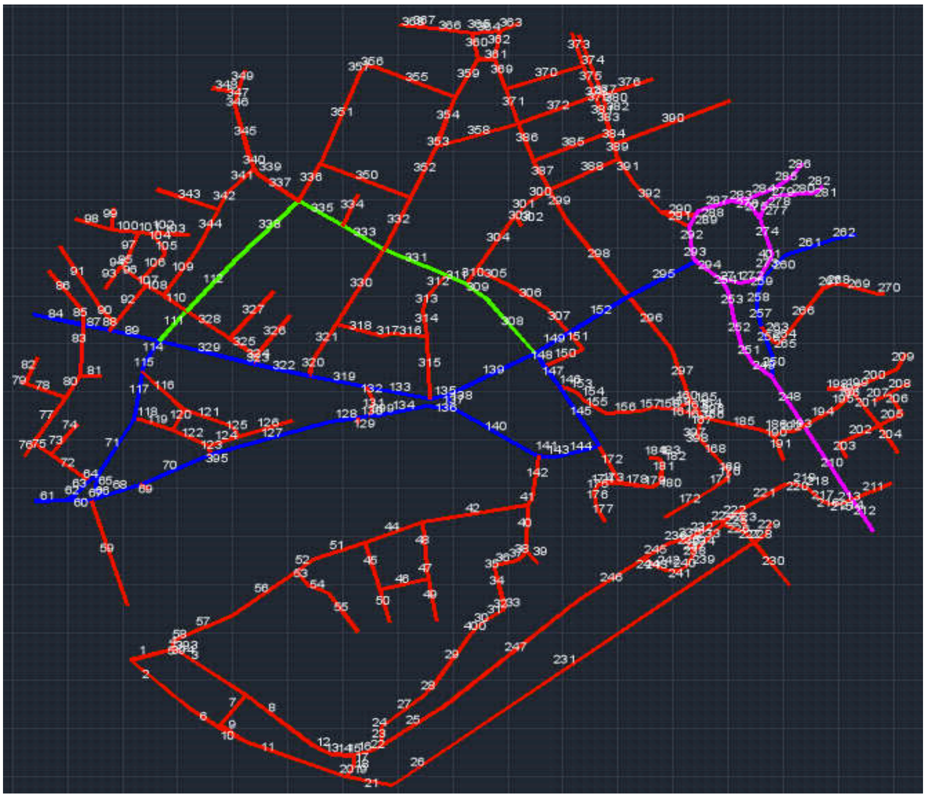


Figure 4-22: Pilot study buffer zone segmental map

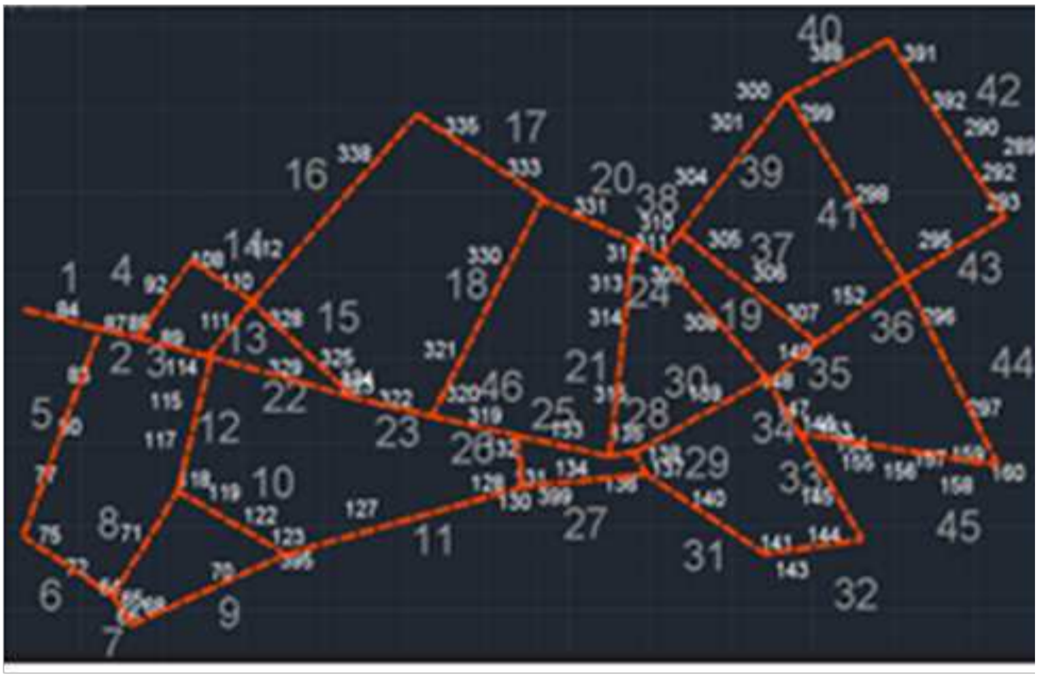
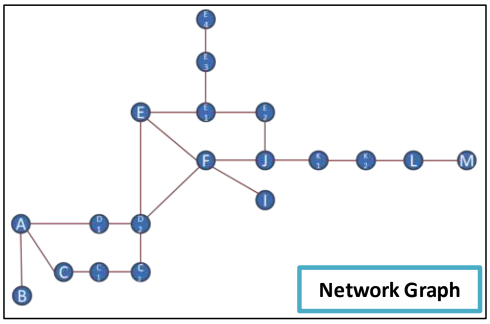


Figure 4-23: Segmental map (with segment's collectors)

Newcastle Inner Urban Core main street network Angular Segment Analysis (ASA)

Total #	Line	Distance	Angle	Lida & Hillier's Convention	Depth
1	A-B	5.5	150	1.667	1.67
2	A-C	1.4	20	0.222	0.22
3	A-C1	1.1	38	0.422	0.64
4	A-C2	1.7	118	1.311	1.96
5	A-D1	2.7	48	0.533	0.53
6	**A-D2**	1.5	180	2.000	2.53
7	A-E	1	43	0.478	3.01
8	A-E1	1.5	70	0.778	3.79
9	A-E2	1	66	0.733	4.52
10	A-E3	3.2	70	0.778	4.57
11	A-E4	6.8	78	0.867	5.43
12	A-F	0.8	93	1.033	**3.57**
13	A-J	1.2	90	1.000	4.57
14	A-I	4	16	0.178	3.74
15	A-K1	1.2	170	1.889	6.46
16	**A-K2**	5.6	180	2.000	8.46
17	A-L	5.5	44	0.489	6.94
18	A-M	5.5	48	0.533	5.33

Newcastle upon Tyne Inner urban core (main streets network)



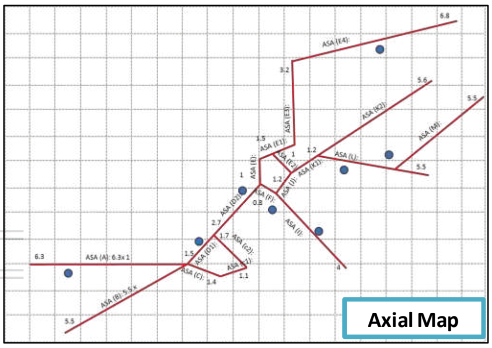


Figure 4-24: Pilot study_NE1_ASA calculation sheet

4.6.2 Hybrid simulation modelling approach

Within the remit of this thesis it continues to investigate the appropriate technique to simulate EV population. A hybrid model that combines meso-scale (emergent behaviour of infrastructure usage) and micro-scale (related to individual charging behaviour) using decentralised ABM while adding artificial intelligent/intelligence (AI) rules and learning algorithms to find the system evolution (Lombardo & Petri, 2004). The micro scale deals with the individual vehicle behaviour while the macro deals with the vehicles stream. The simulation is trying to depict the charging pattern of individual users, see (Figure 4-25).

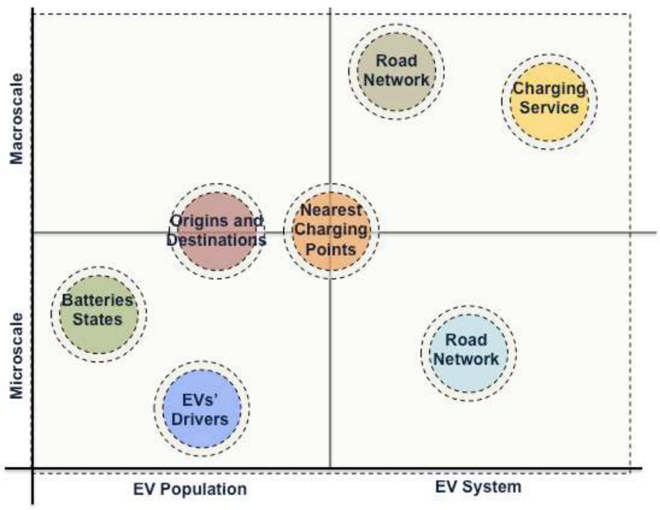


Figure 4-25: Level of abstraction

Going hybrid

The fourth method employed in this thesis is to embed metropolitan area's vehicular movements into hybrid simulation while incorporating space syntax analysis (Batty et al., 2000). After reviewing the possible simulation techniques, a hybrid model is proposed as it is thought to better serve the present research problem. The e-mobility system is seen as a large-group simulation of active objects that have timing, sequential events, and individual behaviours. A model that integrates ABM and DE with space syntax attributes is proposed.

To depict complex systems, a high level of abstraction modelling specifications (model designed to solve problems related to multiple session attributes) can be applied. However, this can result in a model that can be difficult to specify and develop because of the confounding disparities in formulating vehicle and agent dynamics. For example, vehicle dynamics and decision policies can be identified using either DE or mathematical logic. Relatively complex models for vehicle movement with simple routing schemes can be prepared using a DE modelling and simulation framework. Similarly, mathematical logic can be used to model complex plans and simple vehicle dynamics. However, neither, lends itself to describing both procedural and declarative behaviours of vehicles and agents in their respective modelling (Sarjoughian, & Dongping, 2005). In EV simulation, these entities are the EV agents where the charging behaviour and driving patterns of each driver can be denoted. Having such a hybrid model, where the creation of the entity corresponds to the agent creation enables the model to realistically simulate the EV population, see (Figure 4-26).

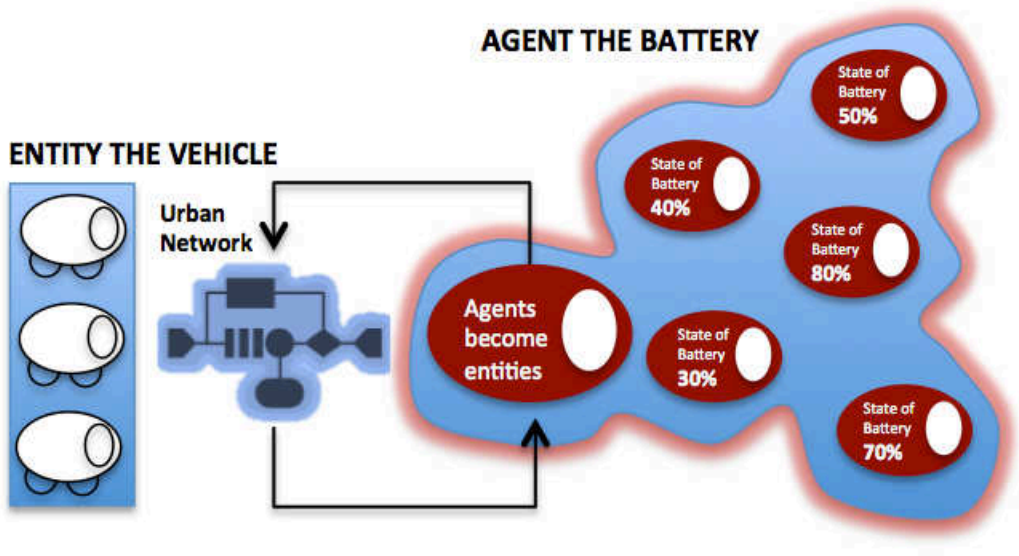


Figure 4-26: Employed multi method simulation architecture

4.6.3 Modelling and simulation layers

Denoting the EV population simulates a journey over a space. The first step to build the simulation environment is to understand the role of each element and abstractly draw their architecture. The simulation elements are the EVs, the road-networks, charging patterns of the users, and finally the RFs. Each element has a special and spatial characteristic and interacts with other elements and the environment intuitively, separately, and differently. The simulation mode consists of two main layers:

i) The urban layer that represents the road network and prediction of the vehicle movement. In this layer the understanding and integration of configurational and syntactic modelling takes place;

ii) The behaviour mode of the driver layer. It forms the emergent behaviour characteristics of the simulation. Nevertheless, by plotting the occurrence of this layer.

4.7 Concluding Remarks

This thesis takes a hybrid inductive and deductive methodological approach. The inductive approach is employed in two branches of Figure 4-27 named data driven approach and empirical data from service provider. The first branch refers to the user and consumer studies (interviews and survey), which are presented in Chapters 6 and 7.

The second branch refers to analysing the dataset provided by the service provider. This dataset provides information about RF's usage is mixed (qualitative and quantitative). It ranges from nominal data (charging point IDs, time of charge) to ordinal data (traffic counts, distance from urban cores), and continuous data (number of users, number of transactions, number of the transactions made in each CP). The data is collected and analysed without any preconceived ideas of what will be found. For example, the most frequent time people charge their car using RFs and the average time they spend charging are not known. The charging patterns and their relation to urban space design are phenomenal statistics that need further investigation. Once the data analysis is completed, observations and interpretations are drawn to display a trend or a theory of users' charging patterns and profiles.

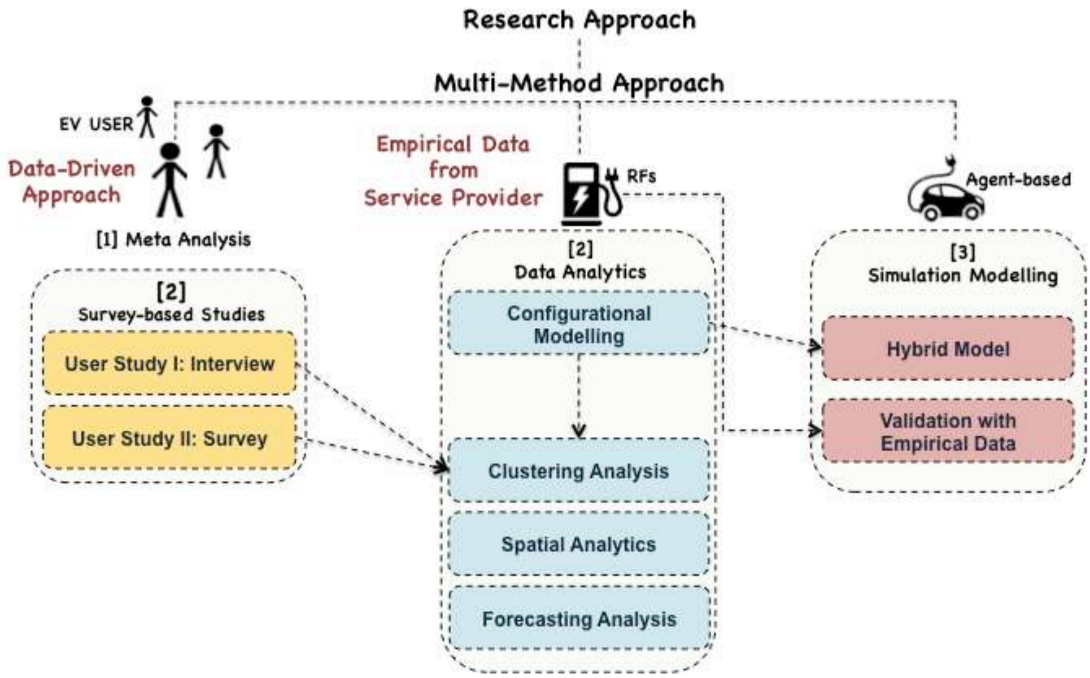


Figure 4-27: Research data flow diagram

Finally, the third branch named agent based, is the simulation modelling of the e-mobility system. Unlike the first two branches, it takes a deductive approach. The analysis starts with a theory, and the application is testing the theory. For example, the simulation model employed special techniques to depict particular strand of the system, the outcome of the model is based on these techniques' mechanisms and architecture.

CHAPTER 5. META ANALYSIS OF EV CONSUMER AND USER STUDIES

"My EV diary: 9:00 AM I reached the Workplace charging point and my battery was 50% charged."

By an anonymous EV driver, Newcastle upon Tyne (2014)

This chapter presents the meta analysis of previous consumer and user studies in the context of EV use. This review was undertaken with the primary purpose of informing the design of survey-based EV user studies of e-mobility and related charging infrastructure. Moreover, this review could be used as a stand- alone resource for readers, researchers or policy makers with an interest in EV uptake and related policies. This chapter, through meta analysis, provides the needed background, indentifies the gap in the literature, and draws broad design guidelines for the EV user study, which is presented in Chapter 6, see (Figure 5-1).

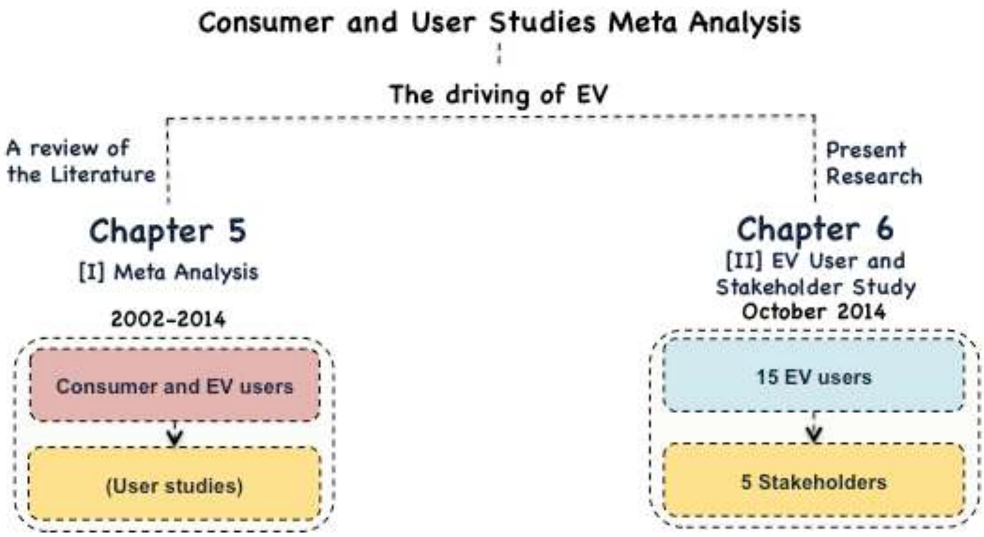


Figure 5-1: Research flow (Chapters 5 and 6)

In order to investigate the usefulness of different types of EV related studies, a total of 60 consumer and user studies is included. The chapter is divided into two parts: EV potential user (consumer) and EV user, see (Figure 5-2). The importance of this review stems from the lack of sufficient historical representative data on driving patterns and charging behaviour with EVs (Pasaoglu et al., 2013). It provides an overview of the main studies that had influence on development and contribution to knowledge of e-mobility covering not only Europe (Austria, Belgium, France, Germany, Italy, Netherlands, Spain, Sweden, Portugal, UK (London and North of England)) but also the USA, South America and Asia (China, Hong Kong, Taiwan, South Korea, Japan, and India). In this review, qualitative and quantitative analyses are carried out by identifying the scope, design, main findings of each study, and comparing the studies' outcomes. The review includes studies conducted by industrial managers, government agencies and local authorities, or other institutions including grey literature (universities and established research institutes have been included when sufficient documentation has been found).

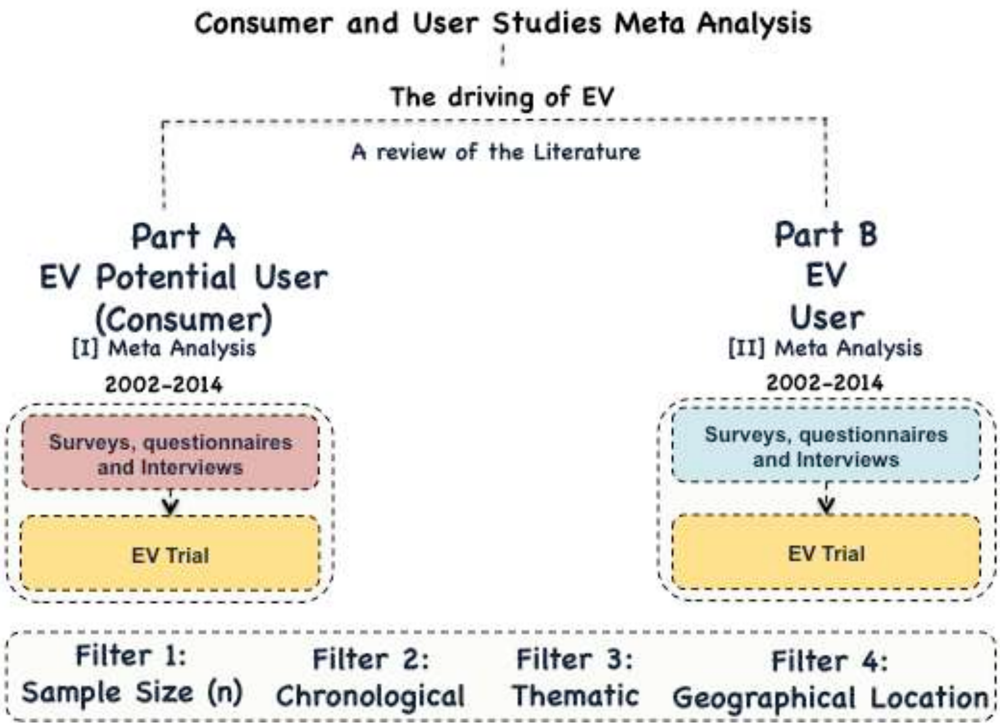


Figure 5-2: Chapter structure

5.1 Bibliometric Structure

The 60 studies were published in scientific articles, conference papers, theses, research or business reports. The user studies' different methods and designs are the main focus of this chapter. There are several approaches to view the previous work: chronolgical, relation to the study work, funnling or thematic, or problem-cause-solution order. In this thesis, a multi apporach is employed, a thematic-chronological apporach. The review is presented, through selected fliters, see (Figure 5-2). For the two parts of the chapter, the four filters are applied. The first filter is the chronological order. A summary of each study is drawn emphisising the main issues with a brief of main findings. For each identified period of time, a summary of studies is provided showing the focus of the study (filter 2: thematic) alongside the sample size (filter 3) and geographical locations (filter 4). The set of questions addressed in each study or period of time, reflects a gap or an important matter. Viewing the studies in such order will help stakeholders:

i) explore how opinions about driving an EV differ from a perception to action;
ii) review and compare previous studies, iii) provide design guidelines for user studies;
iii) point out the gaps in the literature, and v) identify the various interests of stakeholders.

In the literature, there are consumer studies, which are based on perception and attitude. Some studies are conduced based on the travel survey and experience driving conventional means of transport. EV user studies have more tendency and confidence level of eliciting real behaviour. The sub class of each category is the chronological order. The reason behind this structure is to show the mechanism of the e-mobility system and reflects on how the market is emerging. A previous review was carried out by Hjorthol (2013) exploring the attributes, ownership and use of EV. The review surveyed the literature in a different order as it aimed at shedding light on the appropriate role of the Norwegian Government in the take off stage of the EV market. This review showed the results of surveyed work related to users profiles and potential users preferences and segmentation to identify the common socio demographic characteristics across countries. LCA works carried out a study to evaluate the technological progress and economic viability of EV. The report was published by Contestabile et al. (2012), to synthesise the most recent and relevant literature relating to the technological progress and economic viability of EVs. A review of the most important results of recent studies was presented by Globisch et al. (2013) and was classified as: population surveys, potential and private owners (short and long trials). Taking the thematic approach, another study was carried out by Nordelof et al. (2014) investigating the usefulness of life cycle assessment previous studies in the EV context.

5.2 Consumer Studies (Attitude)

This section reviews 24 potential user (consumer) studies and seven EV trials. All participants were not active EV users at the time of these studies. Some of the following studies address consumer-informed estimates of residential access to EV charging as questions may include EV demand, use, and energy impacts. Whereas, other surveys are online and self selection-based which does not guarantee participant's prior knowledge of EV. At the end of each section, a meta analysis is used to provide helpful insights by combining results of several studies. Providing helpful insights into the overall effectiveness and main findings of these studies; nevertheless, comparing them to each other, would help with triangulation and validation of analysed studies. In the cases of contradictory results, meta-analysis offers a tool to help integrate this. Hence, reliable conclusions and recommendations can be drawn. The consumer studies are divided into three main sections. The first section is the years between 2005 and 2009.

5.2.1 Consumer studies (2005-2009)

The first period is between 2005 and 2009. It starts with an online survey that was published by Potoglou & Kanaroglou (2007). In April 2005, an EV survey was carried out to investigate the choices of gasoline and alternative fuelled vehicles. Potoglou & Kanaroglou (2007) examined the factors and incentives most likely to affect Canadians' uptake of cleaner vehicles. The survey collected (n=602) responses of attitudinal choices. It tested responses to vehicles' attributes, personal and household variations, and willingness to pay via a discrete choice nested logit model (Potoglou & Kanaroglou, 2007). The survey addressed five different questions: i) the vehicle attributes (Purchase prices, annual fuel cost, annual maintenance, fuel availability, acceleration, invectives, and pollution level. ii) inquiries about personal and demographic data (gender, age, education, number of household members, and annual income) and iii) fuel type options by vehicle type (hybrid, compact cars, subcompact, midsize, large car van, and pickup truck), and iv) the willingness to pay, considering income; the five expenditure items were mentioned (maintenance, fuel, acceleration, incentives, and pollution level). The outcome of this survey showed that reductions in monetary costs, purchase tax relief and low emission rates might encourage households to adopt cleaner vehicles. However, incentives such as free parking and permission to drive in high occupancy vehicle lanes were not found to have significant effects. High income householders are willing to pay more to acquire benefits and were less concerned with the purchase price (Potoglou & Kanaroglou, 2007).

As part of RAND Europe project, Burge et al. (2007) conducted a stated preference survey with (n=1,100) car passengers to central London, investigating likely vehicle purchasing choice and other traveller responses under various emissions-based charging schemes. It aimed at determining the potential uptake of EVs and in this regard, respondents were asked to trade-off car purchasing cost with car size, acceleration, top speed, fuel economy and level of charge for driving in to central London (Tsang et al., 2012). Burge et al. found that fuel efficiency, speed and acceleration were less important when compared alongside attributes such as congestion charges. The study stated that consumer's perception changes given the continuous advancement in automotive technology and the rise in oil prices.

Other studies investigate the feasibility of alternative charging options starting with domestic charging. In December 2007, the first part of a study was carried out by (Axsen & Kurani, 2012) surveyed (n=2,373) new car buy householders in San Diego County, USA. The respondents were asked to record travel data for one of their conventional vehicles for a 24-hour period starting with their first vehicle trips of their assigned diary days. Diary days were assigned randomly to all respondents to cover all the days of the week, timing and distance of each trip, with parking locations and proximity of level 1, 2.4 kw (may take 10 hours charging from empty to full), CPs in the urban context.

The second part of the study, in 2011, assessed access to 2.4 kw and level 2.7 kw (fast AC charging which may take three hours from empty to charge), among (n =548) new vehicle buyers of San Diego County in California, 2011. The survey reported on the potential obstacles the EV commuter might encounter finding level 2 CPs. The survey was in the form of a series of questions that culminated in a cost estimate for installing a level 2 charging station: i) do the commuters already have a vehicle charging station available at their home?, ii) do they have a reliable home parking space such as garage, driveway carport or otherwise? And iii) if they have a reliable parking sport and have an authority to install a level 2 CP? (Axsen & Kurani, 2012). The focus was given to home charge facility and the feasibility of installing it (room and cost). The study showed that 20% of the respondents are willing to pay the costs required to install level 2 chargers at home.

In June, a survey was carried out to determine the factors that have any impact on consumers' willingness to purchase an EV (Erdem et al., 2010). It focused on EV market in Turkey. The survey was a random web-based and it was conducted in different regions of Turkey. Participants (n=1,974) completed the questionnaire (Likert-scale), and their responses were analysed. A total of 21 variables included in the analysis, the questionnaire covered the main following topics: i) willingness to pay, awareness of HEVs, and environmental pollution, ii) how they consider themselves (early adopters, early majority, or late majority) and iii) some demographic and personal data about the respondents. The study stated that mainly gender, income, education, choice of high performance on the car, and global warming had statistically significant impact on the purchase intention. Consumers who have high income, high educational level, and are concerned about global warming are more likely to be willing to pay for alternatively fuelled vehicles.

A stated-preference study of EV choice using data from a nationwide survey was carried out in 2009 (Hidrue et al., 2011). The sample was selected to be representative of USA residents. A choice experiment of (n=3,029) respondents (43% males) were asked to choose between their preferred gasoline vehicle and two electric versions of the same preferred vehicle (EV1 and EV2). The survey aimed to evaluate vehicle attributes (price, range, time needed to charge, acceleration, pollution and fuel cost). The survey had four sections: i) background questions on car ownership and driving habits, ii) description of conventional EVs followed by two choice questions, iii) description of vehicle-to-grid Evs followed by two more choice questions, and iv) a series of attitudinal and demographic questions. The study was conducted to predict the diffusion of EV models, the outcomes confirmed some of the findings of previous studies likewise the fact that driving range, charging time and high purchase price are the main concerns about EV. Adults aged 18 to 35 are more likely to be EV oriented, people making more long journeys would be less included to drive an EV, multicar households are more amenable to Evs than single car households, respondents pay more importance to expected fuel savings than to the desire to be environmentally friendly, and finally no USA significant regional differences.

An online survey (three month period of time) was carried out reporting on (n=809) Portuguese inhabitants. Baptista et al. (2012) published the survey; it addressed car ownership, mobility patterns, and awareness of EV technology, and potential buyers' attitudes regarding charging their batteries. The survey had five main sections: i) personal information, ii) private car users' driving patterns, daily and annual driving distances, type of the road network used, trips' distances, and parking places, iii) EV potential users' attitudes towards a variety of attributes to be considered before purchasing or leasing an EV. Asking respondents about their preferences of main locations of charging (domestic, workplace or public), choice of charging when the battery is flat, half charge, less than half charge), time of charge during the day, time to charge, and the perception of the duration of charging needed for a certain road trip. And the last section was iv) the awareness level of alternative means of transport in terms of (e.g., technology, more environmentally friendly, and willingness to pay).

5.2.2 2005-2009 meta analysis

Across five countries, with an exception of San Diego County study, which had a second phase in 2011, a total of six studies were conducted between 2005 and 2009 collecting a total number of (m=9,887) responses. With a special focus on charging options and the purchase intentions, the two largest sample sizes were in USA through 2 separate consumer studies in 2007 and 2009. In Europe, Portugal and Turkey consumers participated in another two studies in 2009 with a total number of sample sizes (m=2,783), see (Figure 5-3). The large study in Turkey stressed on high education, income and concerns about global warming, as these three elements appeared to have positive impact on the willingness to pay a premium. Gender was another influential factor; the study showed that males are more likely to pay the highest premium. RAND study managed to collect feedback from (n=1100) commuters to central London and it shed light on the impact of high performance vehicles, which may bring about a change in the public's perception of Evs. To conclude this period, studies emphasised on the purchase subsides in order to overcome a number of consumer barriers to wider EV uptake.

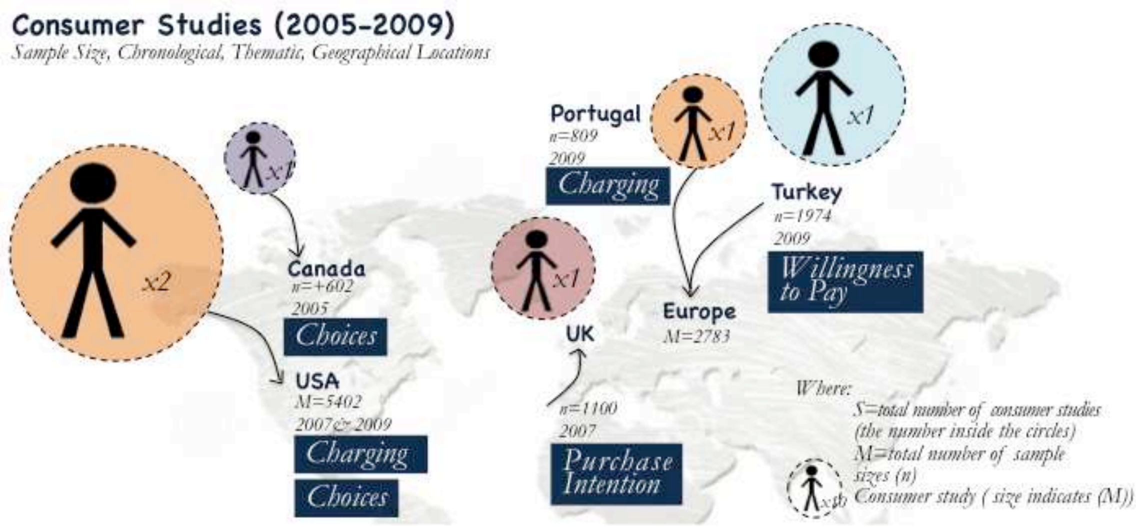


Figure 5-3: Mapping consumer studies 2005-2009

5.2.3 Consumer studies (2010)

In Hong Kong, a survey was conducted to gauge the attitudes of potential users towards the environmental aspects of Evs. In February, (n=200) car drivers, who 82% of them were males, completed the survey. Respondents with specific demographic criteria were recruited. At five shopping centres' car parks, the respondents were asked to complete a multiple-choice questionnaire included the following sections: i) environmental benefits of Evs; ii) possible negative environmental issues of Evs, and iii) opinions on the environmental significance of Evs. The survey indicated the slow adoption of EV is related to the wrong perception of the potential users. People think Evs have a limited positive impact on the environment, negative environmental impact of battery waste, and the emissions caused by the production of electricity (Delang & Cheng, 2012).

Deloitte Ltd. Conducted a consumer analysis on EV trends. A 15- minute online survey was sent to over (n=13,000) individuals in 17 countries (India, Italy, Japan, Korea, Spain Taiwan, Turkey, UK, USA, Argentina, Australia, Belgium, Brazil, Canada, China, France, and Germany). A total of 46 multiple-answer questions were randomly disseminated among potential users to provide the widest possible view of what consumers really believe in access to Evs may give to them (Giffi et al., 2011; Deloitte, 2010). The survey was designed to inquire into willingness, interest and intent to purchase an EV, and questions related to Evs' major selling points. The questions addressed: consumer interest, consumer profiles and preferences, EV awareness, models, factors affecting the purchase decisions (lease or own) of potential users (range, time, premium price, and efficiency), EV range matters, EV financial issues, EV level of convenience, perception of charging timings and intervals, as well as demographic and personal data. The survey showed that consumers are not willing to pay a price premium, and therefore want EV prices to match the price of equivalent gasoline cars.

He et al, (2011) analysed the EV usage and consumer profile attributes extracted from both National Household Travel Survey (NHTS) and Vehicle Quality Survey (VQS) data. In 2010, the survey was carried out to understand the impact of vehicle usage upon consumers' choices of HEVs in the USA. NHTS includes demographic characteristics of households, people, vehicles (n=309,163), and detailed information on daily travel in the USA for all purposes by all modes. The survey addressed the potential user profile, vehicle design variables, usage attributes and desired attributes.

In September, Nielsen's survey on Evs was conducted among more than (n=2,300) people in the USA and UK It showed that inflated gas prices continue to weigh on the minds of recession-weary consumers when considering the purchase of a new car. In fact, despite the global push towards choosing more fuel-efficient and environmentally friendly cars, 78% of consumers in both the USA and UK stated the main reason for wanting to buy an electric car was to save on fuel costs. In the USA and UK, 35% and 24% of the consumers said they are willing to pay more for an EV. Nielsen mentioned stressed on the importance of advisement:

> *"The increase in advertising is a sign of a rebound in the auto industry, which has struggled amidst the prolonged recession and weak consumer confidence [Nielsen, 2010].*

In December, Zpryme research and consulting company carried out a web-based survey about EV industry development in the US. It was among (n=1,046) USA drivers aged 18 to 65 years to assess their overall interests in EV, various reasons to purchase EV, and charging preferences. The outcomes highlighted some recommendations for stakeholders' the EV should be more integrated with the Internet (smart grid), more charging stations are needed to be in place, the need of rapid development of low cost batteries hence less often charging events requirements, and finally raising awareness as educating consumers about the car is the heart of the EV adoption (Tan et al., 2014; Coxworth, 2011; Rodriguez, 2010).

Another online global survey of consumer opinions and preferences toward Evs and supporting services was carried out in December. A 20-minute survey of (n=7,003) individuals across 13 countries (Australia, Canada, China, France, Germany, Italy, Japan, Netherlands, South Korea, Spain, Sweden, UK, and USA) addressing the following topics: i) domestic charging, ii) battery range, iii) purchase and driving costs, and iv) fast charger. It reported the feedback on the benefit of potential EV purchasing decision. This survey covered EV awareness, intention to purchase, factors affecting the purchase decision, charging preference and type of clean transport preference (Pike, 2012 ; Accenture, 2011). The results showed various levels of awareness across the countries (lowest in Japan 20 % and highest in China 44%) with an average of 30% of consumers understand enough about Evs to buy one. The following factors were identified as important in the motivation to buy an EV: domestic charging, battery range, total cost of purchasing and running the car and option for fast charge. Finally, the top three incentives were: no tax on car, free parking, and toll discount.

5.2.4 2010 meta analysis

A total of six consumer studies were conducted in 2010 across Canada, the USA, South America, UK, eight European countries and six Asian countries and Australia with a total number of (m=332,712) responses, see (Figure 5-4). In total, five studies were carried out in the USA having (m=+315,000) participants. Another three studies were carried out in the UK having (m=+2,500), covering Europe, USA, South America, India, China and South Korea, two large scale studies were carried out having (m=30,002) participants in total, see (Figure 5-4). Following the previous studies of 2005-2009, 2010 studies' focus was the purchase attention; in addition to, EV choices and willingness to pay. Willingness to pay is slightly different from purchase intention as it focuses on cost rather than other factors that affect the feasibility of driving an EV (e.g., range, capacity, shape, RFs, and incentives).

Some meaningful observations can be attained from 2010 studies. He et al. (2010) emphasised the consumer's choices and how understanding their preferences is challenging due to other involved aspects beyond comparing vehicles specifications. Also the study suggested that household income and education level may contribute to the choice behaviour. This confirms 2005-2009 studies' outcomes; high income & education have a highly significant positive impact on e-mobility. Other demographic and consumer profiles (e.g., age, marital status, and number of children) may play a role in consumers' choices. The second largest survey by Deloitte Ltd. Revealed some facts based on the data collected:

> *"The reason for preferring Evs was the lower running costs. Whereas, for not choosing an EV are related to insufficient battery range, lacking availability of RFs, and the charging time."[Accenture, 2010]*

This contradicts with the insights into Hong Kong market by Delang & Cheng study, which reported opinions on the negative impact of battery waste and emissions caused by production of electricity. With regard to large (n) surveys' outcomes, despite the fact that national survey data provides detailed information about households, individuals, vehicles, and daily trips, information about the individual choice considered during the vehicle purchasing process is not available. This survey has the largest sample size spanning all the 60 studies included in this review; however, it does not reflect behaviours nor provide insights into the consumer preferences. Combining these surveys with Vehicle Quality Survey (VQS) can be an indicative tool that can provide rich demographic data to predict who will drive an EV. Contradicting with Edrem et al. study in 2009, Nielson's survey stressed on the rational behind thinking of an EV saying:

> *"Despite the global calls for choosing clean transport, (78%) of consumers in both the USA and UK declared the main reason of owing an EV is to save on fuel costs."[Nielsen, 2010]*

And finally, with regard to the design of EV survey, it is common to include socio-economic factors to the willingness to pay as was indicated by Nayga et. (2002). In particular, consumer-based studies' participants may lack knowledge about Evs, a short explanation about EV features and economic and environmental benefits is commonly given at the beginning of these surveys.

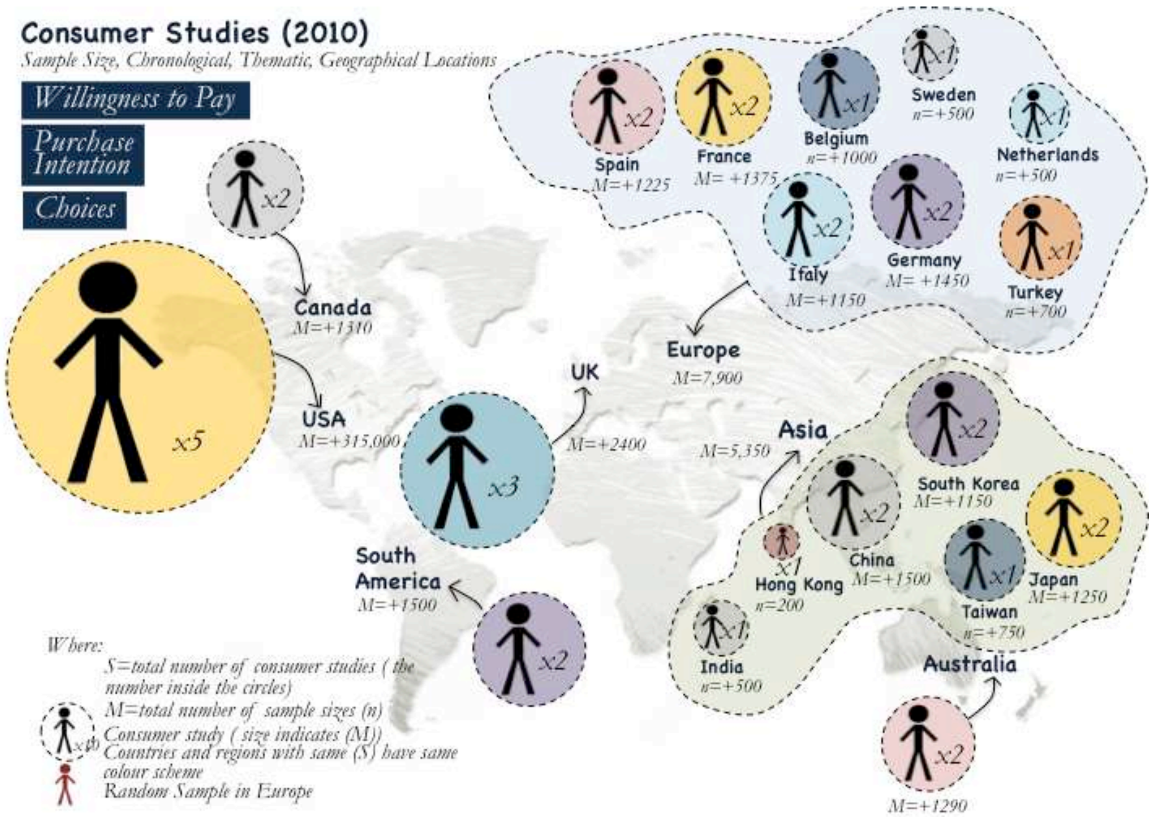


Figure 5-4: Mapping consumer studies 2010

5.2.5 Consumer studies (2011)

In March, Vehicle to Grid (V2G) research project carried out an online survey. The survey was designed to evaluate the economic, environmental, regulatory and social aspects of owning an EV, provide an insight on the preferred charging locations, and investigate the acceptance of delayed charging schemes, off peak, and V2G service. Bunzeck et al. (2011) reported the study that aimed at collecting responses from public and potential users of EV. The survey covered Portugal (n=489), Spain (n=422), Sweden (n=311), Netherlands (n=216), Italy (n=181), Germany (n=148), France (n=78), and UK (n=54). The first step of the data collection was to arrive at a fair idea of current car possession (willing to use a car, owning or leasing) and parking behaviour via an online survey. The survey showed that car density in 2011 and willingness to buy newly manufactured cars can be an indicator for a future mass market; parking preference can indicate candidate locations for EV public chargers. In total, (n=1899) responses were received online through the project website, respective partners, Social media and networking over three month period. The survey covered EVs, electricity demand peaks, electricity prices, and battery leasing related questions. The result showed that the minimum acceptable range of an electric car where respondents would consider a purchase was 308 km (on average over the eight European countries). Where 80% of the European respondents declare to drive less than 100 km per day on average. The results were formed into clusters based on the desired EV specifications the respondents demand.

Eurotax Glass's with Harris Interactive Ltd. released a large scale consumer survey as an outcome of the joint research (Kleber, 2011). A total of (n=8,417) EV users were interviewed in France (n=5,253), Germany (n=1,102), Spain (n=1,006), and UK (n=1,056). Respondents (aged between 16-64 years old) data has been weighted and projected to the general population in the big five European markets. The study addressed five questions: i) which of the following actions have you ever undertaken in relation to EV? (Researched facts and figures, obtained pricing, obtained technical information, test drove, or purchase consideration), ii) which makes or models of EV can you think of?, iii) what are the main reasons for owing an EV?, iv) how much do you know about EVs, which one of the following statements best applies to you: (Know a lot, know quite a bit and know a little). And, v) how likely is that that your next car will be an EV?, how much of a saving in running cost do you expect an EV to yield compared to a conventional car?, and would you be willing to pay a premium for an EV as compared to a conventional one?. The questionnaire revealed that the openness of the consumer towards alternative means of transports is much higher than the current market shares of EVs and hybrids. With the current cost structure, EVs will not reach economic viability with an annual mileage of 10.000km (Kleber, 2011).

In April, as part of ELVA project, a public costumer survey was carried out. It aimed to receive a direct input concerning mobility and the overall acceptance of EV requirements (n=1,100) European participants. Respondents completed a questionnaire (88% males), answering questions regarding: i) expected range, ii) expected advantages and disadvantages of EVs, and iii) EV trade-offs (e.g., safety, roominess, cost, fast refill, climate comfort and preference). The responses revealed the little willingness for compromise in terms of range, key features of the car (number of seats) and extra cost (Lesemann et al., 2011; Lesemann, 2010).

In September, another survey was conducted in the USA and published by Carley et al. (2013). The survey (2 months) was designed to elicit consumer perceptions of EV, as well as their general vehicle preferences, car-purchasing and travel behaviour, and awareness of available public policies that promote EV ownership and use. Data was collected via an online survey administered to a random and representative sample (n=2,302) of individuals over 18 years old (a valid driver's license). Residents were sampled from the largest 21 urban areas in the USA. The study outcomes showed that more than 50% of the sample believed that EV price is a major barrier to their decision to purchase or lease.

To assess consumer demand, preferences, and price sensitivity for EV charging infrastructure, Pike Research conducted a web-based survey of (n=1,051) USA consumers in 2011. Using a structured online questionnaire, a nationally representative and demographically balanced sample (members of a large online panel) was collected. Price sensitivity analysis was conducted using the Van Westendorp Price Sensitivity Meter methodology (Vyas et al., 2011). The results indicated that participants didn't agree to a single prototype, prioritising: i) EV model, ii) range, and iii) price options, they did not state a clear preference to particular choice. Out of the choices offered, the EV model with 100-mile range had the greatest number of respondents 24% showing interest. Whereas, another 25% of respondents stated that they would not purchase any of the options provided.

A preference study in Germany was carried out by Lieven et al. (2011). The survey targeted consumer market (n=1,152). Lieven et al. (2011) forecasted the EV market potential in Germany based on a stated preference survey. Purchase-relevant vehicle criteria of 14 categories (e.g., type, use, price and range matters of driving an EV) were addressed to identify barriers of consumers' purchase intention in the market. With extended miles

(200) advantage, participants in the survey could have had a higher priority for range, and not perceive it as a limitation but rather as supporting the purchase criteria. The analysis revealed that price and range were barriers to EV purchase. The use a vehicle is believed to play a role in the EV decision process due to its limited range. Price and range were issues for the majority of participants, range was important for their specific use. This study has identified potential categories of EV buyers (use and type were prioritised).

In December 2011, an online consumer survey revealed some important views regarding the EV top brands in the USA market by the Consumer Reports National Research Centre. The study lasted for five days, a random nationwide telephone survey of (n= 2,045) adults and collected from (n=1,702) adults in households that had at least one car. The scores reflected how consumers rated each brand in seven chosen categories: safety, quality value, environmentally friendly, green, technology and innovation, performance and design style. Considering all these factors in the total brand-perception score reflected the brand's image as perceived by end-user. The questions were designed to elicit as to how important each factor was to the respondents in making an EV purchasing decision. As for performance associated with the fully electric range of the vehicle, BMW and Ford were receiving the highest scores (Conway, 2012).

Anable et al. (2011) published a study that was designed to identify the characteristics of those consumers most likely to adopt an EV in the UK and to understand the characteristics and preferences of mainstream consumers as the market begins to mature. The aim was to identify the instrumental, affective, symbolic and contextual (e.g., demographic) factors most closely associated with a self-reported likelihood to adopt an EV, and to segment the market. It contained two parts: i) a questionnaire (n=4,240) including a pilot study (n=101) and ii) a survey (n=2,729). The questionnaire (wave 1) consisted of sections on current car ownership, car use and general travel patterns, parking and charging capacity at home, attitudes towards owning and driving a car, attitudes towards new cars and technology including questions from the literature to test 'innovativeness' personality characteristics, demographics and self-reported knowledge about EVs and likelihood to adopt an EV the next five years. As a filter process, only those who purchased within the last 5 years were eligible for the study. The survey (wave 2) asked people whether they had spent time reading extra information about EVs, about their experience of using EVs, thoughts about plug-in cars in general, about EVs. It then repeated the four 'likelihood questions' and how this might change in the light of various policy incentives, before finishing by asking about general attitudes towards environmental issues. Results were split in a way that would help the stakeholders understanding the users' needs: i) likelihood of adoption and the impact of information and non- conscious processing, ii) underlying attitudinal constructs, iii) predictors of 'likelihood' of adoption, and iv) potential consumer segments (Anable et al., 2011).

5.2.6 2011 meta analysis

A total of nine studies were conducted in 2011 with a total number of (m=25,711) responses. The UK market was surveyed in three studies, (m=+6,400) forming the largest sample in 2011, see (Figure 5-5). Seven European countries were surveyed by V2G research; whereas, three of these countries (France, Germany and Spain) were surveyed by Eurotax Glass. France and UK studies collected the largest numbers of responses, (m=5,333) and (m=5,240). In the USA, three studies were carried out with (m=3,901). Carley et al. study focused on consumer perception; whereas, Axsen & Kurani conducted the second phase of San Diego County study with a special focus on domestic charging. The study revealed that about half of USA new vehicle buyers have the Level 1 home access suitable for EVs, stating:

> *"Consumer-informed estimates of home recharge potential can improve understanding of EV demand, use, and energy impacts, and prioritizations for developing EV recharge infrastructure." [Axsen& Kurani, 2012]*

Pike Research's survey reported on EV brands. The results indicated that a single prototype does not meet all consumers' EV preferences. Besides willingness to pay, purchase intention and choices, two new themes were added by 2011 studies, consumer's attitude and brand perceptions. Attitudinal factors, in particular related to technology are stronger predictors of the likelihood to adopt than demographic factors. As different motivations may lie beneath the purchase intention, adoption of new technology, technology diffusion or socio-technical transitions were introduced in this study. The results showed that consumer interested in hybrid and EV technology is most likely motivated jointly by concerns about the environment, increases in the price of fuel and a desire to be less dependent on petrol. Anable et al. (2011) results and observations on UK market were primary; nevertheless, clear indications are emerging and confirming empirical findings with regard to purchase intention, motivations and choices.

Building on the 2005-2009 studies' recommendations, in particular on RAND project research, on how challenging is to understand the consumer's choices and perception, Carley et. al. mentioned that statements about intent to purchase a product are rarely validated with data on actual purchasing decisions. Carley et al. confirmed previous conclusions on EV potential users being highly educated. Also it seconded Erdem et al., (2010) in finding environmentally sensitive and concerned about dependence on oil people are the potential users. Contradicting with Hidrue et al. (2011), (USA, n=3,029) and

Accenture study in 2011 (USA and other 12 countries, m=7,003), Carley et al. study (USA, n=2,302) indicated that charging time is least problematic matter when considering owning or leasing an EV. From previously listed studies, a positive response is thus better interpreted as an indication of the consumer's willingness to consider a new technology or product than as an indication of future purchasing behaviour.

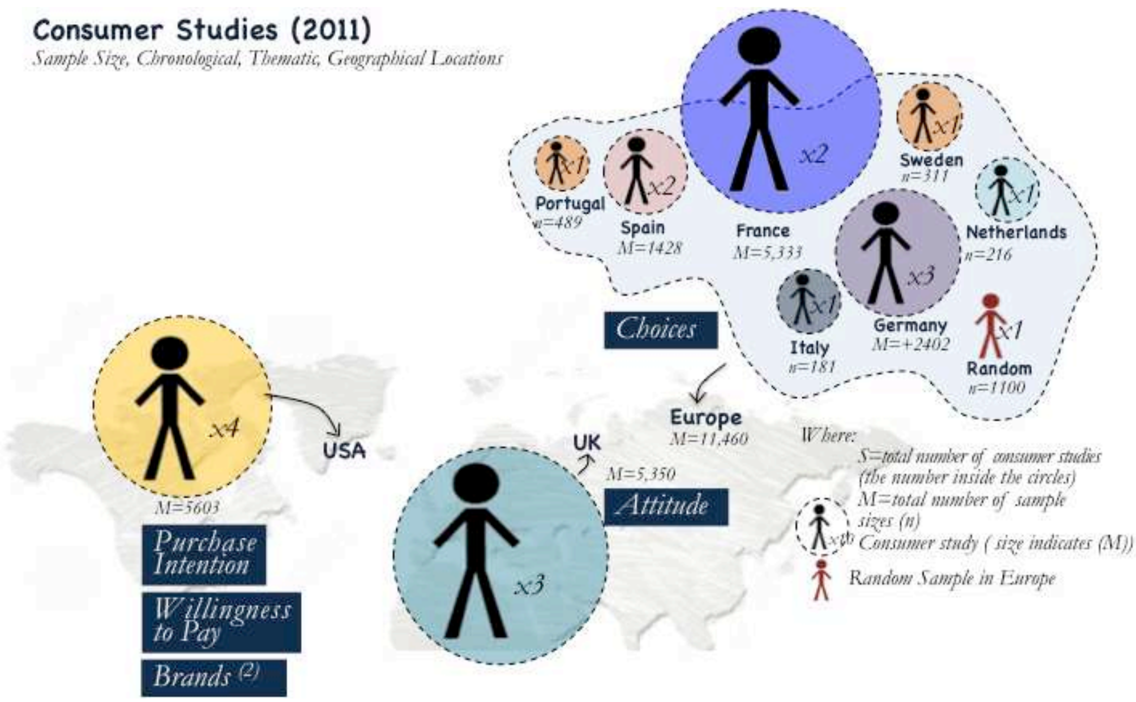


Figure 5-5: Mapping consumer studies 2011

5.2.7 Consumer studies (2012-2014)

This section starts with a study that was conducted in South Korea. Shin et al. (2012) conducted and reported a questionnaire across (n=250) households to investigate the influence of EV on the usage on the exiting cars. The sample was chosen with respect to region, income level and demographic characteristics of the sample that reflected the overall population. Results showed that 85% of the respondents have one car, and 40% used to drive for more than 20,000 km. The measured attributes included fuel type cost, purchaser price and maintenance and ii) access to RFs. By employing scenario analysis, the results estimated that consumers prefer EVs to hybrid. The results of the accessibility to RFs showed that the purchase intention regarding the EV increases as accessibility increases.

In November 2012, a web-based survey (n=1,785) was conducted by Lo (2013) to solicit views from Chinese residents for two days. This study aimed at understanding the reasons for this policy failure through surveying the public attitudes towards EVs. In order to focus on the potential consumer, respondents younger than 21 and those without a monthly income were eliminated. In addition, the sampling is confined to those with access to the Internet and therefore not representative of the population of China. Even though the government subsides, especially of EVs, the results have been disappointing. The greatest barrier was inconvenience to charge. The findings indicated that: i) although the majority of respondents were interested in EVs and were aware of their advantages, they were unsure about purchasing an EV. This was due to concerns over charging locations and times, battery longevity, range and price. The results showed that the level of interest, perception, and demands are significantly influenced by gender, education, income, age, and car ownership.

In December 2012, as a part of a 2-year span North-West European research project, ENEVATE, a questionnaire and follow-up survey was carried out, the study was published by Newman et al., (2012). There were (n=234) questionnaires completed in nine counties followed by a survey (n=97) from (Belgium (n=2), England (n=8), France (n=8), Germany (n=28), Ireland (n=2), Netherlands (n=27), Northern Ireland (n=3), Scotland (n=6), and Wales (n=13). The sample size wasn't encompassing specific social segment; whoever was interested in exploring EV was welcomed. The questionnaire included the following segments: i) car ownership motivation (environmental factors, purchase cost, performance, size and running cost), ii) incentivisation of EVs (purchase cost subsidy, tax reduction, priority lanes and parking, government support, private organisation involvement), and iii) future EV intentions and purchase prediction. The follow-up survey was disseminated among the same sample of the initial questionnaire respondents. The participants were presented with four different EV usage scenarios and asked for the feedback (Newman et al., 2012).

In 2013, a meta study was published by Pasaoglu et al. (2013) and was carried out in California based on (n=3,000) new car buyers. The study aimed at examining if the existing travel national surveys can be a potential source of data to investigate the requirements needed to deploy EV charging infrastructure and the effect of this on the power grid in general. The study was a part of a data mining process, which started with compiling major existing surveys at national, regional and local scale to identify all possible sources of data. Pasaoglu et al. (2013) characterised the surveys' methodologies and scopes. An assessment was made of the collected travel survey against a matrix of parameters to determine possible gaps in the Travel National Surveys (NTSs). The focus of the meta-analysis of the NTSs were European, publically available studies and relatively large scale travel mobility surveys. The summary of the study is basically the findings from analysing the selected NTSs. The analysis categorised the surveys into eight categories: i) type (interviews, web-based surveys, telephone or in person questionnaire or trip diaries), ii) aggregation level (emergent or individual), iii) survey period, vi) parking details (duration, not less than 10 minutes and place), v) individual details (demographic and personal information), vi) living area (urban or rural context), and vii) geographical coverage. This reflects the importance of a direct mobility survey for EU Member States in order to better assess the impact of EV usage on the grid, energy market and infrastructural investments (Pasaoglu et al., 2013).

In September 2013, Navigant Research project team in the USA carried out a web-based EV consumer's attitudes, opinions and preferences survey (n=1,084) (Navicant, 2013). It aimed at providing a better understanding of consumer attitudes towards alternative means of transport, how interested the public is in owing an EV, and their EV and RFs readiness and receptiveness, as well as their overall vehicle considerations. The survey mainly covered the consumers' views of alternative fuel vehicles, their brands and models and which power type they prefer. Also questions on vehicle features were included, such as the most interesting features to them that would attract them, the public charging network readiness, and the willingness to pay for it. The key findings of this study that 33% of respondents preferred hybrid cars whereas 30% preferred EVs. A further 41% of consumers were interested in RFs locations.

In June 2014, the UK Department of Transport conducted a survey of public attitudes to EVs (Anderson, 2014). The survey was a random probability-based survey of (n=962) adults living in households in Great Britain. The first part of the survey was about knowledge and attitudes to electric cars and vans. The respondents were asked about the willingness of purchasing an electric car or van, 5% said they were thinking about owning one where 56% said they had not thought about it. A further 14% said although they thought of it, they had decided not to buy (reasons were not documented). In addition the respondents were asked about the most important things they consider when purchasing a car (e.g., cost, reliability, safety, comfort), as well as the most important factors that deter potential users from purchasing one (recharging, distance travel on a battery, cost and lack of knowledge). The drivers were asked about the most important factor that encourages them to buy an electric car or even a van (cost, distance travel on charge, recharging and environmentally friendly). The majority of respondents were car passengers and some were using public transport. They were asked about the frequency of use of both car and public transport (Anderson, 2014).

In September 2014, Energy Solutions conducted an online survey on the factors that motivates costumers to buy and EV in Germany and the UK through the Institute of Transport Research within the German Aerospace Centre (DLR). The study was about the usage of EVs owners (n=3,000) where 63% are private users. It attempted to identify the influencing factors for a wider adoption and assessing the implemented measures in both countries. The questionnaire covered the following areas: the experience prior to owing an EV, the number of cars per household, the extent of the daily mileage, the type of usual trips, parking preferences, driving behaviour, charging preferences and pattern, EV owners' ideas about full electric range, and route planning. Most of the private users were males (89%), highly educated and have an above average income. According to this survey the interest in the innovative technology and the reduction of the pollution is the main reason of the purchase. Almost 60% of private users charge daily in close proximity to their homes. Limitations in driving like time needed to charge, weather affecting the battery, holiday long trips were issues for 30% of private users (Lenz, 2014).

5.2.8 Meta analysis-consumer studies

A total of eight studies were conducted between March 2012 and October 2014 across four European countries (Belgium, France, Germany, and Netherlands), the UK, the USA, China and South Korea, see (Figure 5-6). The themes of these studies varied between purchase intentions, willingness to pay, attitude and a newly addressed topic, the impact. The impact on the non EV market was addressed by Shin et al. (2012) in South Korea and the impact on the grid was studied by (Pasaoglu et al., 2013) in California as well as previously mentioned by Bunzeck et al. (2011) in their Europe study. As per the commonly cited advantages of EVs, confirming Carley et al. study, high fuel economy and lower energy costs, a positive environmental image, and the ability to be at the cutting edge of new vehicle technology. Shin et al. (2012) and Pasaoglu et al. (2013) both studies emphasised the positive correlation between the RF's accessibility and increase purchase intention.

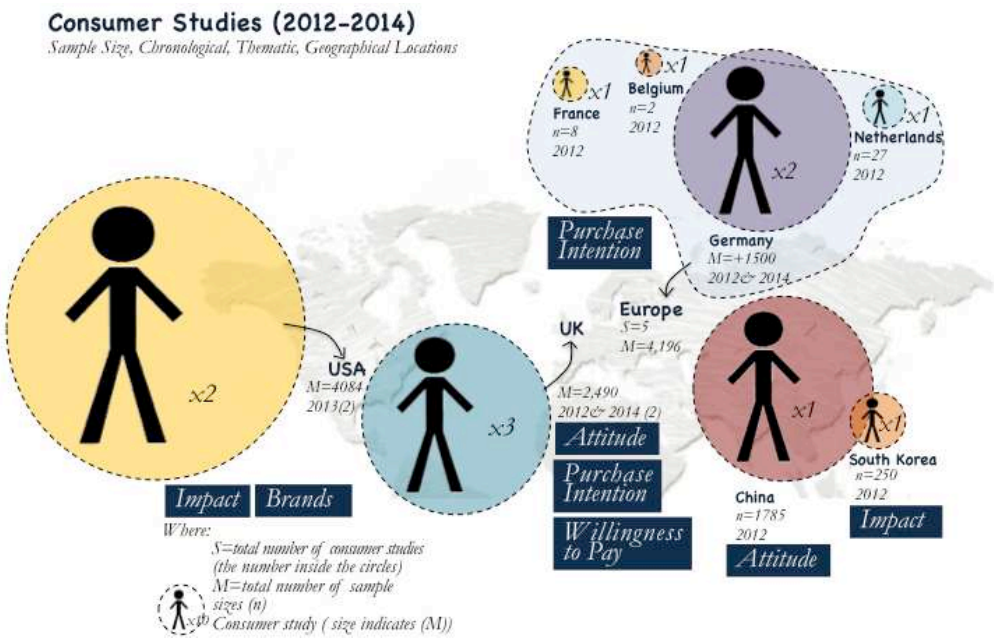


Figure 5-6: Mapping consumer studies 2012-2014

Charging location–related questions

EV charging topic may be addressed as: i) time to charge preference, ii) willingness to spend time charging, iii) charging locations. Focusing on the latter, charging location-related questions were addressed in six different research projects, see (Figure 5-7). These studies were investigating the importance of having non-domestic charging network for potential users and the candidate locations for proposed network. Responses to charging-related questions should roughly indicate the potential locations of RFs to planning authority and policy makers. In part B, a further study by Rebate project is presented. The study was conducted in 2012 reporting on charging in the USA market (n=1,151).

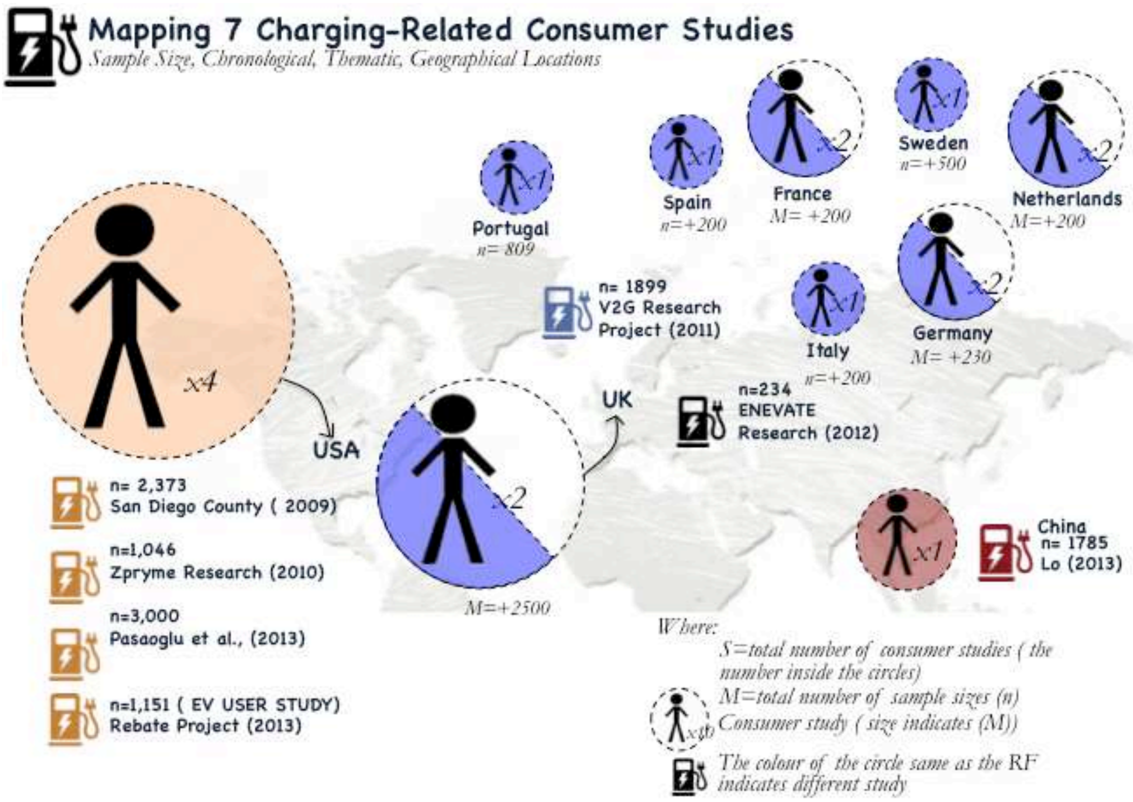


Figure 5-7: Mapping of charging-related studies

Facts and descriptive analysis

In total, 69 studies were conducted in 26 consumer studies across 22 countries, collecting (m=371,420) responses, see (Figure 5-8). These studies are at macro scale level targeting the entire population, which in some studies was (n=8,000) covering four European countries, (n=13,000) covering 13 countries, and (n=200) recording the smallest sample size surveyed by Delong& Cheng (2010). Some of the above studies, through the filtration process (e.g., age, income, demographic location, prior knowledge, new car buyer, number of households cars), attempted to target a smaller group by nearly focusing on potential users. Based on literature, these filters were observed as to form the EV focus group that would have high tendency to consider driving (owning or leasing) an EV. On the other hand, in 2010, Nielson conducted a study based on national survey NHTS in the USA and the largest sample size which was (n=309,163).

These last two years, followed previously studied surveys' themes. Navigant (2013) survey addressed the EV brands. Dislike on Pike Research's, Chevrolet Volt and Nissan LEAF were surveyed. A further 44% of consumers were familiar with Volt and 31% with LEAF. Moreover, the study reported on the fuel cost confirming ENEVATE and Anderson previous studies. Nearly 50% of consumers said high fuel economy was the most important EV feature.

All these surveys were carried out online, which allowed a margin of biasness due to the self-selection criterion. Due to anonymity of the respondents, some bias was created in the studies' samples. It was not been possible to judge whether respondents have had (a lot of) additional previous knowledge on the topic. In total, 20% of consumer studies were carried out in the USA at a nationwide scale and 40% was conduced in Europe and 10% focused on the UK. By excluding NHTS-based study, the sample size ranged between 200 respondents to 4,240 per country.

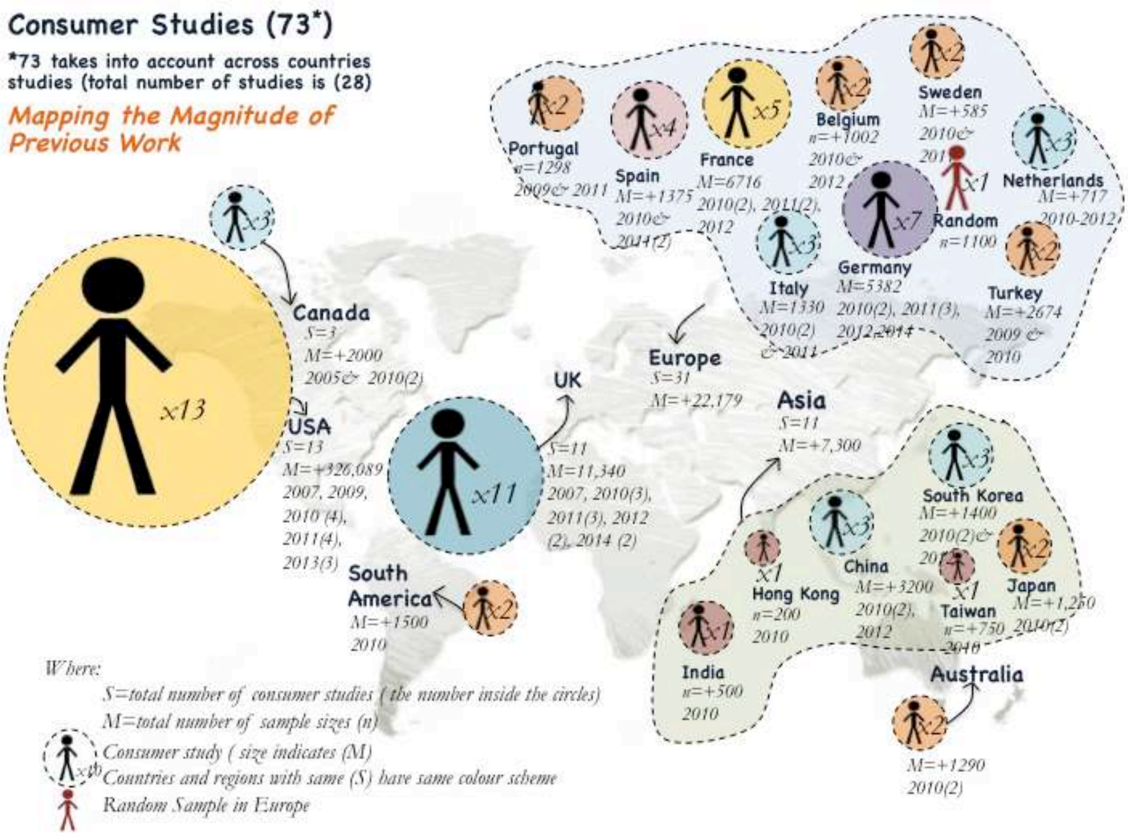


Figure 5-8: An overview of consumer studies (with thematic and sample size filters)

To conclude this section, the meta analysis of all mentioned previous studies in this chapter showed that:

i) there is a need to study of EV uptake as Anable et al. (2011) indicated:

> *"EVs are disruptive they require a significant shift in behaviour by consumers. The literature suggests that the early adopters of EVs do not necessarily hold the key to understanding the early majority and thus it is important to understand the potentially unique characteristics of each group of EV consumers in order to more accurately inform those interested in the development of the EV market (e.g., the Government, vehicle manufacturers and energy suppliers)." [Anable, 2011]*

ii) different people appear to be attracted to hybrids and EVs, each for different reasons. Despite the possible segmentation and prediction of potential users, consumers change their perceptions and views. E-mobility systems have a temporal element. Such nature needs more research and development. In order to understand the dynamic processes of attitudinal and behavioural change in this area:

i) Investigating EV technologies, public perception and technology adaption;
ii) Achieving large enough sample sizes to be able to segment the market;
iii) Stringent selection criteria for surveys and interviews;
iv) Conducting ethnographic studies with potential users (avoiding random selection/self-selection);
v) Investigating the EV user behaviour not the consumer attitudes.

iii) The strength of consumer studies to stakeholders is to indicate and provide primarily understandings of consumers' main trend and preferences. With innovative approaches, combining information about potential users (purchase intention and willingness to pay) with their demographic data (e.g., national surveys) and access to domestic charging, may predict the EV owners (locations and size). The next section presents consumer EV trials.

Considerations

There are some points have to be considered when reading the meta analysis:

i) The (n) does not represent the general public as self-selection technique opens the survey to those who are interested in EVs which justifies the positive feedback;
ii) The (n) of each country, leads to deviated answers compared to the average population. In some studies that are cross country, a country may have (n=2) and the other one has (n=27), like ENEVATE project;

iii) In some cases the time lag between the study and the time of publication is two years. This lag is of limited use to those responsible for Research and Development (R&D) and knowledge transfer in such an evolving research area like smart mobility;

iv) The analysis needs to be carried out on a high time-resolution database of vehicle use, which is previously collected in order to study traffic patterns, driver behaviour, and vehicle emissions. NHTS data are not fully reliable for determining EV range capabilities (Pearre et al., 2010).

To summarise this section, the themes of previously presented consumer studies are: willingness to pay, purchase intention, choices, brands, attitudes, impact of driving an EV, and charging. The next section presents consumer trials.

5.3 EV Trial: Consumer

This section presents a selection of EV trials. These trials were designed to explore and test consumer experience through the applications of a wide range of methods. Although EV field trials have a long tradition, knowledge of how users experience EVs is lacking. There are seven trials complied in this section which start with SmartMove research project.

In 2007, SmartMove (2010) carried out a trial followed by a questionnaire to explore the performance and acceptance of EV into public (n=113) and private sector fleet (n=190) in the UK. The trial was for 6 months and it was published by Walsh et al (2010). For the fleet users, the trial tested the hypothesis that organisations that operate vehicle pools and fleets are ideal candidates as early adopters of EVs. As a post-trial phase, the questionnaire was investigating how useful the trial was motivating the potential users (employees) to partake in the smart move trial. It also assessed the significant adjustments required to make the conventional fleet to accommodate the electric smart(s). The survey addressed whether the organisation (the city council) benefits, how so and by how much from operating the EVs and the main disadvantages of using the EVs fleet/car pool EVs. From EV trial data, results showed different aspects of using an EV:

i) EV perception: 58% of fleet users felt more positive about EVs after taking part in the trial (users in their 20s experience the highest opinion shift);

ii) EV range (observed that only 7% of users undertook the trial journeys when the range was below 50%);

iii) EV performance: users rated the overall performance of the EV as ‘Good’, most variation in answers was observed in the noise category;

iv) EV charging: users rated their charging experience as 'Good', finding vehicle charging easy, safe and reliable.

A further 73% of users in fleets with access to dedicated recharging infrastructure found the vehicle on charge before use compared to 42% of users who operated in fleet without dedicated infrastructure. As for the public, the trial aimed at accelerating the adoption of EVs, carbon footprint, and performance of the vehicles. It quantified how drivers can interact with EVs to enhance their range performance. Participants were instructed to drive using their standard driving. The key findings were drawn from a robust data sample as 72% of participants stated that they would use an EV as their regular car after their test drive. A further 82% of the public participants would consider owning an EV compared with 56% from a captive test-drive audience (Carroll & Walsh, 2010).

In 2011, a 12-month of high-resolution driving data survey from (n=448) out of 470 instrumented gasoline vehicles in the USA is used to analyse daily driving patterns, and from those infer the range requirements of EVs. Vehicles were selected for the study by random stratified sampling from 13 counties in Atlanta, Georgia greater metropolitan area. Researchers performed an empirical GPS-assisted observation of the 448 vehicles were monitored for more than 50 days. The study conservatively assumed that that EV drivers would not change their current gasoline-fuelled driving patterns and that they would charge only once daily, typically at home overnight. The survey consisted of three main sections:

i) daily driving distances;
ii) days of vehicle use and mileage;
iii) time of the day driving pattern via the research question: are battery-range; limitations compatible with the gasoline-enabled driving habits?.

The analysis showed that even with limited range, the EV could provide a large fraction of transportation needs. When an EV user has the ability to adjust on a few days per year, by substituting alternative transportation or charging during the day, short-range EV models can be satisfactory for a significant fraction of the population (Pearre et al., 2010).

Smith et al. (2011) with the help of GPS data loggers, collected data from (n=76) drivers in Winnipeg, Canada, to characterise driving behaviour for EV consumption and charging evaluation. The data gathered (over a year) was used to develop a daily driving profile approximating actual driving power demand and parking times for charging these vehicles. The trial explored the possibility of paying lowest cost of charging when relying only on domestic and workplace facilities. Opportunity charging is recommended to use the battery as a storage device for peak time on the grid (V2G).

Cocron et al. (2011) released a thorough analysis of actual safety implications of EVs in Berlin. This debate arose due to the quiet motor of the EV, which is more difficult for pedestrians to hear compared to ICE cars and may compromise traffic safety. A driver-sample (n=70) was surveyed via interview and a trial (participants were first time driving an EV). The interviews took place once after three months of the trial, and once more after six months. The attitudes remained positive during the first three months of EV use. Cocron et al. (2011) conducted two studies: i) safety-relevant incidents and reported the degree of hazard related to these incidents and ii) if drivers adjusted their perceived risk of harming other road users over time.

As a segment of research carried out by the Joint Research Centre, funded by the European Commission in 2012, a survey was designed to test the attitude of potential users to see if there were any potential users ready to switch to EV market of European car drivers towards EVs (Pasaoglu et al., 2013; Thiel et al., 2012). It formed part of a full report relating to driving and parking patterns of European car drivers. The survey methodology was to collect car trip diaries in six European countries (UK (n=623), France (n=623), Germany (n=606), Poland (n=548), Spain (n=617), and Italy (n=613) via pilot and baseline surveys (Pasaoglu et al., 2012). The baseline survey was divided into three sections: prior to the trial, dairy and post-trial. The diaries constituted individual data collected over a 24 hours/7 day period. Parking was reported in terms of duration and place.

In the pre-trial questionnaire, each participant had to report socio-economic features and demographic data, in addition to the vehicle size and age. In each the countries, car drivers' characteristics in terms of gender, age, and employment was identified in charts in comparison with the overall population. The diary format had instructions to avoid biased or inconsistent responses. If the car was parked for more than 10 minutes, then the trips before and after were considered as two different road trips. Arrival and departure times and distance of each trip were to be monitored and reported. The respondents had to answer daily questions related to: the car use, day's weather, the number of trips, the origin and destination of each trip, the trip distance, parking slot location and time, and the number of stops and passengers (Thiel et al., 2012). However, in the post-trial survey, after one week of dairies being recorded, the respondents were asked to complete a questionnaire on: familiarity with EVs, some questions on the environmental burdens of the transport sector, government incentives, current features of EVs, willingness to pay, factors affecting purchasing decisions, their idea of the number of sold EVs and future petrol prices (Thiel et al., 2012).

In 2013, Future Transport Systems Ltd. launched a trial (as part of the SwitchEV project) in Northumbria University. In total, (n=12) staff members participated in the EV trial for a month which aimed at depicting the charging patterns of the participants having access to two onsite CPs. Travelling to work brings with it environmental and sustainability challenges. The survey aimed at raising awareness and informing people about EVs and available charging facilities around the two campuses. The trial was followed by a survey capturing respondents' feedback and their EV perception before and after the trial.

5.4 EV Trial: Consumer (Summary)

In total, seven EV trials were conducted between 2007-2013 through 12 sample sizes across North America, the UK (four samples), Spain, Italy and Germany (two samples). The total number of participants were (m=4,509), see (Figure 5-9). Out of these trials, Thiel et al. (2012) reported the largest sample size spanning six countries with an average of (n=600) in each country. SmartMove interviewed (n=190) fleet users in 2010 and workplace practice was surveyed in consumer studies (ICE, 2013) and (OFAS, 2014). Positive feedback was received from fleet users regarding the use of workplace charging. Walsh et al. (2010) stated that drive efficiency improved when the SoC is reduced to 50% suggesting that EV users modify their driving style as the vehicle SoC reduces. Same positive feedback was attained from Cocron et al.; Smith et al. (2011) trials' participants mentioning that relying on workplace charging facilities besides domestic charging may add more pressure in the beginning but saves money on the long term. To conclude, there are some points of considerations while reporting consumer EV trials that have to be clear:

i) A defined method is to be employed to identify factors influencing the acceptance of EVs and to outline changes;
ii) The findings of counties in same region may be contradicting;
iii) Replication and generalisation of findings and outcomes have to be interpreted with caution;
iv) Long-term monitoring of vehicles in trials is important to document the distribution of trips through a period of time for each vehicle.

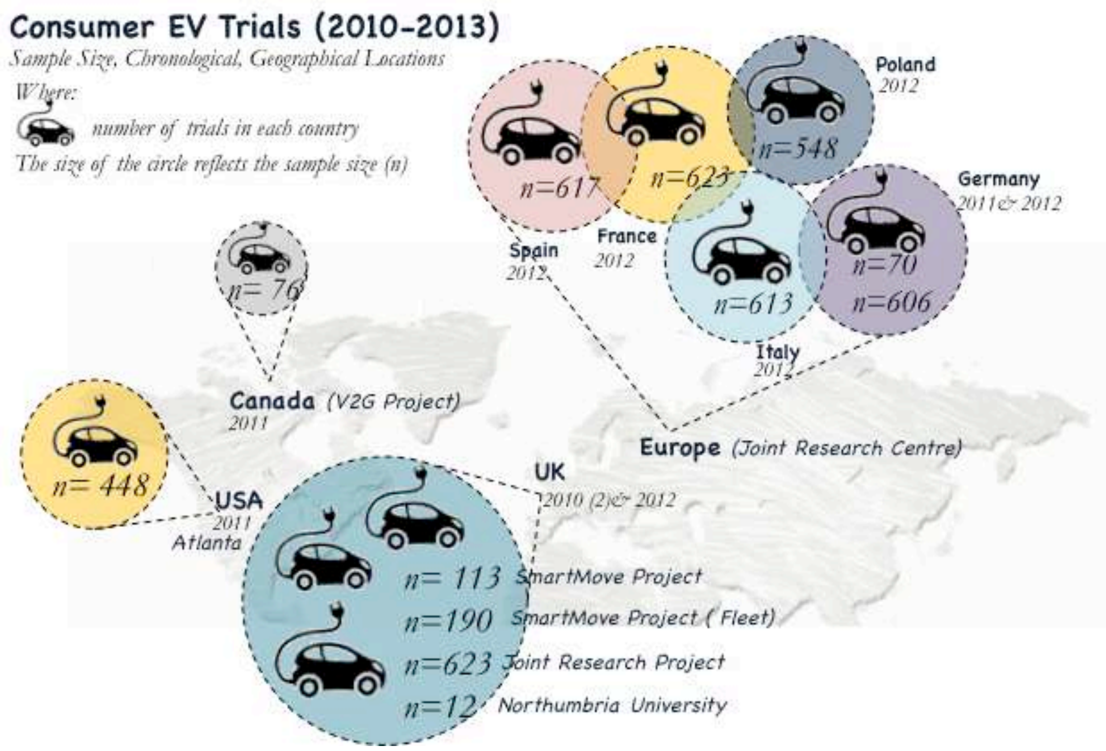


Figure 5-9: Mapping of consumer EV trials

This is the end of part A, which summarised 28 studies and seven EV trials collecting a total of (m=375,929) responses. The next part of the chapter presents the EV user studies, see (Table 5-1) end of this chapter.

5.5 EV Users (Behaviour)

This section discusses 19 user studies. As it was previously discussed in chapter 2, e-mobility system has a unique social practice. The EV driver has to plan prior to their non-routine long journey or unusual event to secure enough charge; this has to do with the psychological and mental state the driver. This might occur two-three times a month; however, it is a concern. Due to the system instability and immature monitoring systems and available database, a fault in a non-domestic CP is not yet reflected in the service provider active map. This level of abstraction will not be observed from an online survey or potential user EV trial. There are some elements of the system, which can only be captured when a well-planned trial is carried out by recruiting active EV users and monitoring the charging patterns and profiles of those users.

5.5.1 EV user studies (2001-2011)

In this section, the majority of the presented studies were conducted in 2011 with an exception to three studies in 2001, 2009, and 2010, respectively. The meta analysis will reflect the 10 year-span. The first study as carried out by Meier-Eisenmann et al. (2001). An interview of (n=179) out of 297 EV owners was conducted in the Swiss canton of Ticino, Switzerland. The owners comprised of two wheels (27%) and four wheels EVs. Meier-Eisenmann et al. (2001) reported the behavioural patterns displayed by EVs and their owners, by (monitoring charging systems, questionnaire conducted directly with owners), in their analysis of a pilot scheme. The respondents were asked about the frequency of using EV reserved parking places (9 places). For 3-4 times per week these places are utilised, 4 wheels EV users reported 29% of the users charge their battery while parking.

Antropologerne Ltd. carried out an anthropological field study of (n=50) users within the remit of the Etrans project in Denmark. This study was based on in-depth interviews with consumers (some of whom were EV users). The respondents were asked to comment on the prejudices that people generally had towards EV (Ulk et al., 2009). The study revealed that an EV user could be a complex, unique, contradictory, moveable, social and very different individual with just as many different needs, preferences and circumstances of life.

In 2010, (n= 4,000) drivers in the USA (n=1,000), Japan (n=1,000), China (n=1,000), and Europe (including UK) were asked to share their sentiments on EV and reveal the enablers and barriers to owning alternative mean of transport. The respondents were asked to report on the purchase decision, factors affecting their decision, awareness level of technology and environmental concerns of conventional means of transport and finally the willingness to pay an EV. The survey was designed to capture responses that would provide a clear insight of EV market in each country ranging from an end-user perspective, awareness, and key purchasing considerations.

Unlike other studies, the majority prefer leasing an EV rather than owning one and they believe a battery range of less than 100 miles is unacceptable. Most of the respondents have not heard of EV technology, almost 35% of respondents excluding China sample (60%) were willing to consider the purchase of an EV as soon as it is available otherwise they will wait until it is well established in the market. Fuel savings is the most important favourable factor compared to environmental impact and incentivises. With regard to China, customers were concerned about the capacity, price, universal, and lifetime of the battery. Customers were worried about the convenience of the charging network, and nearly 40% (of China consumers) were not satisfied with the speed, vehicle price, component, and component replacement and maintenance (Li & Sun; Ernst & Young, 2010).

In May 2011, an online survey of (n =696) was conducted (for one month) in Germany. The main aim was to assess intention to purchase and EV use of the various consumer groups: actual EV users (n=92), members of the public interested in becoming potential users (n=244), potential users with no concrete purchase intention (n=352), and consumers who are not literate of EVs (n=285). The survey was assessing: i) the affinity towards EVs and the likelihood of purchase and usage; ii) the perceived advantages and characteristics of EVs; and iii) socio-demographic dimensions (Peters et al., 2011). Findings showed that the driving characteristics, security and vehicle capacity do not influentially affect the consumer evaluation. The study could not observe a significant effect of the infrastructure on the market due to the early stage of market diffusion and having less forecasts and estimates of demand.

5.5.2 2001-2011 meta analysis

In total, six EV user studies were conducted across Europe, the UK, China, Japan and the USA, see (Figure 5-10). Between 2010 and 2011, the USA was surveyed through two studies collecting (m=4,951) responses on market enablers and barriers and EV brands. Ernest & Young (2010) study covering Europe, China, Japan besides the USA (n=1000/ each) reported on acceptance and preferences:

> *"Purchasing behaviours are affected by four factors: i) charge inconvenience, ii) short battery range, iii) cost, and iv) psychological factors." [Ernest & Young, 2010]*

Reporting on range, Conway's survey stated that 77% of (n=1702, USA, 2011) perceive it as a major issue. This confirms the previously analysed consumer study by Lieven et al. (2011), which stated that out of price, range, environment, durability, convenience, and performance, the participants marked price and range as the most important issues for the vehicle use and brand.

Confirming previously analysed consumer studies, Peters et al. (2011) stated that costs, environmental concerns, and ease of use were in favour of EVs. The study described the time between 2009 and 2011 was seen as the phase of preparation of market and technology. Development of costs, range and user acceptance of new systems were the main paradigms of that phase. It witnessed a dramatic change in market penetration. In Germany the number of registered EVs dropped from 2,700 in 2001 to 1400 in 2008.

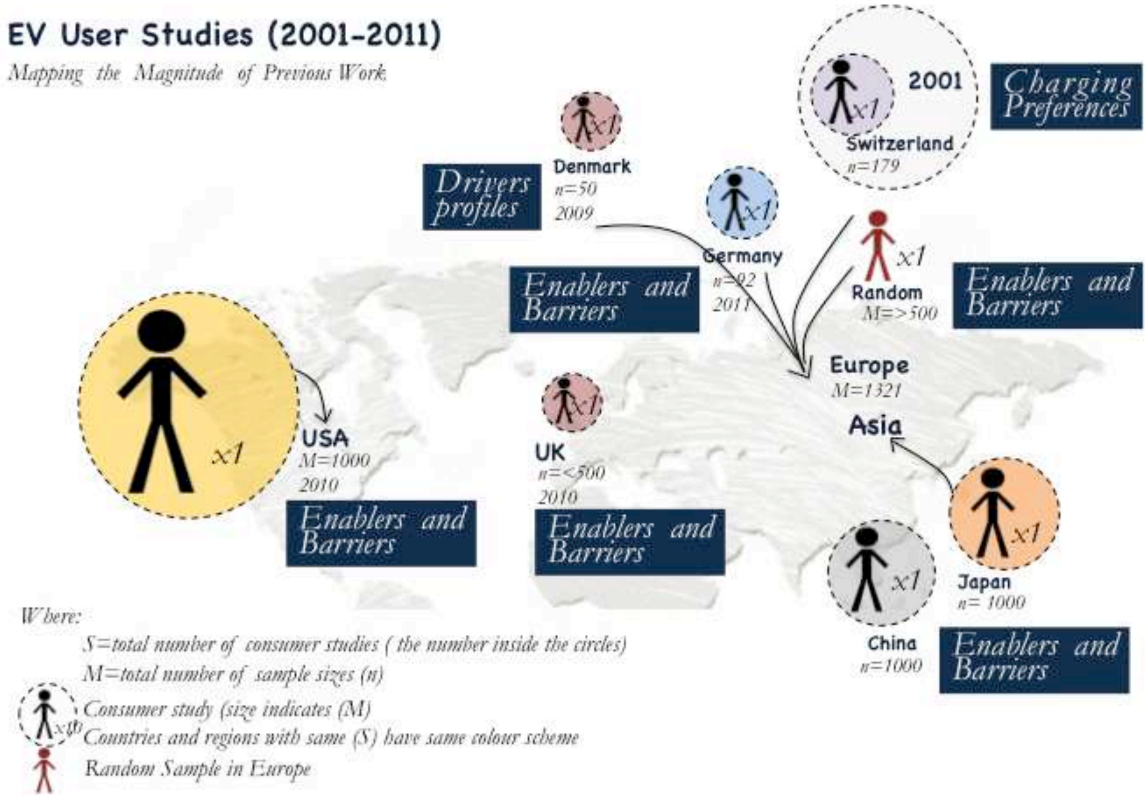


Figure 5-10: Mapping EV user studies 2001-2011

5.5.3 EV user studies (2012)

In February 2012, a survey was conducted (n=1,419) by Clean Technia and was followed by another survey, round 2 when the sample reached (n=2,039) participant (Berman, 2013). Both rounds reported on the importance of factors of EV acquisition. The survey targeted EV buyers (individual California EV owners and drivers), from the year 2012 onwards (n=2,039) out of 2,611; a number of questions regarding their purchase decision, demographic data, and how aware the users were of government initiatives and private companies rebates were posed. The findings showed that schemes and incentives have a profound effect on the EV sales in the USA. The EV users asserted fuel savings hitting 37%, which is a very influential factor of purchase. On the contrary, only about 21% of participants bought EVs for its environmental benefits (DEMorro, Center For Sustainable Energy, 2014).

In March 2012, a California EV driver survey was released within the context of the Clean Vehicle Rebate project (CVRP) (Rebate, 2013). The survey included (n=1,151) EV individuals, which ranks this survey numerically at the top of the large number of such surveys, and the most detailed nationwide survey. The survey covered the following areas: satisfaction with the vehicle, average daily mileage, motivations around and influential factors in the recharging process, the time and rate of recharging, access to a level 2 charger whether at home or in public places, and finally the satisfaction with public RFs (Nicholas et al., 2013). In order to determine how the drivers use their EVs, through a designed web interface, they were asked to place: i) charging places, ii) desired charging locations, and iii) farthest destination from home. Participants were also asked about the lowest SoC attained over the EV lifetime. A total of 80% of the respondents have reached 8% SoC which is approximately 6 miles left. This shows that people are not experiencing the full electric range. With regard to infrastructure, only 10% of respondents have never charged using non-domestic chargers and 40% charge at workplaces.

In 2012, a survey as a part of Bay Area Plug-in EV Readiness project was lunched in California. The act aimed at understanding the EV owners and potential EV drivers. It was targeting EV drivers and city car share users, especially Nissan LEAF owners. City CarShare EV Survey, (n= 443) drivers were included. The survey mainly addressed the before and after purchasing an EV experience and users' preferences, perceptions, changes that occurred to driving patterns and daily life. In addition to questions related to range anxiety, domestic charging, workplace charging, charging timing and time spent charging, as well as barriers and factors affecting market penetration were asked. It included 200 questions covering the following EV readiness elements: parking permitting and building codes, marketing, fleets, connection to grid and renewable energy, training, zoning, RFs (domestic, public and workplace), and incentives for deploying workplace CPs (Sahran; ICF, 2013). A total of 91% of the respondents have access to domestic charging, and their replies to charging preference reflected the importance of charging at home, anonymous participant said:

> *"Genuinely, I see lack of access to a socket or charging station outside one's home as the biggest or second-biggest barrier to the electric vehicle revolution (possibly second to awareness). Who is going to buy an EV if they can't charge at home?" [Bay Area Plug-in project survey, participant, 2010]*

The respondents stated their reasons for driving an EV: i) the personal image, ii) EVs being energy efficient and cheaper in the long run, iii) performance, and iv) significant emissions benefits.

In June 2012, California local employers survey (n=500) was issued to Bay Area Workplaces (ICF, 2013) to access employees who are interested in CPs deployment, to successfully support their employees and fleets. This survey comprises of three studies: EV users (n=443), government authorities (n=103), and fleet managers (n=500). The questions (lasted for two months), and covered the following points: access to parking, company fleet information, parking availability, workplace charging options, average daily mileage and possible incentives. As for the EV users, almost half of the respondents were from 100+ employees' firms. The data collected from the survey indicated that 97% of the participants have on-site parking, 60% of them own, rent, or a combination of own and rent vehicles, and half of them reported having at least one vehicle that travel on average less than 60 miles each day. As for the fleet managers' and government authorities' feedback, the results showed that 21% were considering EVs for fleet replacement or expansion and 22% had EV charging stations currently installed at the workplace. The three key challenges that employers have encountered during the EV charging station installation or operation were: i) cost of the installation, ii) cost of the equipment, and iii) no use of this equipment 13%.

In October 2012, a study was conducted by the United States' Department of Energy through the Clean Cities Community Readiness and Planning for Plug-in Electric Vehicles and Charging Infrastructure Act (Larson, 2012). This survey examined (n=22) participants' feedback on commercial properties and their perception of EV charger installation, reflecting a total of 76 public CPs installed in Oahu. The participants were EV and CPs experts, and the research team was able to leverage in transportation specialists on the state of energy, as well as a national renewable energy laboratory. A 5-minute questionnaire was disseminated to cover five core areas: planning and permitting, installation of EV chargers, cost and payment, managing of the charging station and business aspects. It included non-scientific questions to gain the respondents initial perspective on their specific EV charging.

The survey was followed by a structured-interview to elicit a better understanding of specific lessons learned and to obtain clarity regarding the decision process. It had eight sections, covering: the installation initiative, planning, permitting, installation, cost and payment, managing the CP, business model, and take home notes. The questions overarched influential points of interest: The selection of the type of charger, steps taken to become familiar with the EVs and charging events, the selection bases of choosing a charging facility management company, the administration and permitting charging and parking. Also it included technical questions about the installation process: the length of the conduit, concerns about purchasing and installing the chargers, charging event price decision, payment handling, dealing with technical operational problems, and how to report a problem (Larson, 2012).

Derollepot et al. (2014) reported an on-going survey as a part of EVREST project, EV with range extender as a Sustainable Technology Transitional European research project. The survey was conducted with respondents who had practical experience with EVs. The project was launched in 2012 and it collected responses (n=32) from Germany, France and

Austria. The survey aimed at studying how EVs with a range extender could match the different usage patterns via investigating the needs of the end-users and their charging patterns. The questions addressed the following points: i) the user acceptance relative to the use of alternative mobility solutions to fulfil its longest daily mileage in a year, ii) the proportion of the car use profile that could be achieved in all electric mode by the Extended Range EV (EREV) solution, and iii) the electric range that the EREV solution can offer. As the EREV is a EV with an extended range, this proportion is expected to be high (Derollepot et al., 2014; EVREST, 2012).

5.5.4 2012 meta analysis

In 2012, a total of four studies were conducted in the USA and one study in Europe covering Austria, France and Germany, see (Figure 5-11). Besides range, the use of EV, and charging preferences, the themes of this phase included two new topics, charging infrastructure and workplace practices.

With regard to the vehicle attributes. Sahran (2013) and Consumer Reports National Research Centre (2011) reported on the importance of performance as considered one of the main reasons behind driving an EV. The fuel cost as one of the major contributors was mentioned by Clean Technia and Larson (2012) and was previously discussed in consumer studies by Ernest& Young and Peters et al. (2011).

Three studies addressed the workplace and in particular Bay Area research projects. The first survey of the Bay area focused on the EV users and attempted to explore the employees' charging patterns and preferences of the workplace charging facilities. The responses seconded the wide deployment of the workplace charging facilities and showed the employees willingness to use shared facilities over the weekdays. Positive feedback on the workplace charging has been reported by (Elbanhawy & Price, 2015; Calstart, 2013; Scott et al., 2010).

The second survey addressed the workplace charging from different angle, the employer's perspective. The study aimed to investigate the main barriers to install more charging points. From the employer's perspective, installing workplace CPs in the parking area demonstrates the employer's environmental leadership; however, feasibility studies and data analytics have to be conducted prior to deployment to avoid any waste of investment.

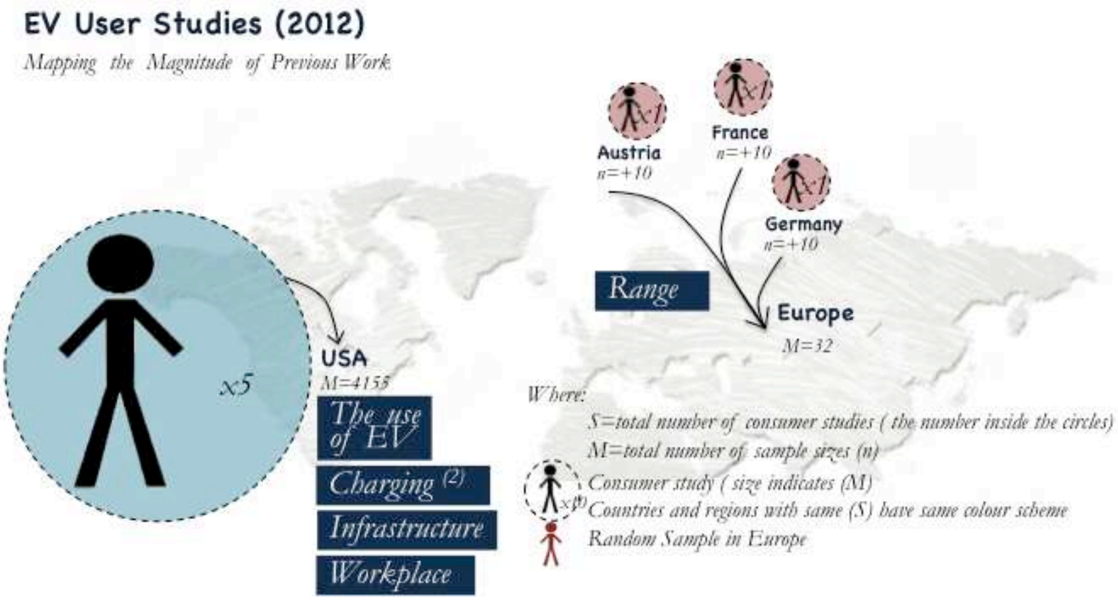


Figure 5-11: Mapping EV user studies 2012

5.5.5 User studies (2013-2014)

In December 2013 a telephone-based interview was conducted in the USA amongst (n=1,004), 501 males, which assessed their driving habits, vehicles' needs and attributes towards EV. In four days, participants were contacted. Those individuals were 18+ years and EV users with access to domestic charging. The study examined the potential for the use of EV and revealed that 42% of households with vehicles could potentially drive (own or lease) an alternative mean of transport and only 25% would go for EV with an effective low range of 60 miles. The survey was testing the level of awareness and reported that the majority of Americans (65%) are aware that EVs are an essential part of the nation's transport future to reduce the oil use and the global warming pollution. The survey had three different criteria: i) charging access, ii) charging type and housing type, ii) passenger needs, iv) weekend and holiday travel, v) average daily driving, vi) average daily driving variance, and vii) concerns regarding EVs (Union, 2013; Huertas, 2013).

In December 2013 a USA nationwide online survey of EV charging habits was carried out by a joint research project between the University of Washington and the MIT by Mackenzi & Keith, (2013). The study aimed at understanding how various factors affect operators' decisions on when and where to charge their EVs, (n=125). The survey consisted of 3 parts: i) Background information about the participants, their vehicles and households. ii) Different situations that the EV drivers may encounter whist driving, where for each situation they are asked whether they would charge their EVs and providing a range of information (price of charge, charger power, expected time to be spent in destination, remaining distance to home, electric range remaining in battery, and distance to nearest recharging facility), and iii) Users' charging patterns, such as information about their EV model, the primary function of driving an EV and the year of purchasing an EV (Mackenzi & Keith, 2013).

In January 2014 an employee-based survey at the USA Office of Facilities and Administrative Services (OFAS) was conducted concerning the feasibility of installing EV charging stations. The study reached (n=265) participants and it aimed at determining the feasibility of installing stations in workplaces (asking about their charging preference and daily mileage) and attempted to forecast potential employees shifting to EV. It was investigating whether investing in workplace CPs would be an incentive for employees to purchase an EV. A 10-item survey was developed to collect employee feedback: i) do you currently own an EV or hybrid car?, if yes, do you use it to commute to work?, and what is its approximate range?, ii) where do you currently park your EV, if any?, iii) do you prefer using workplace CPs?, iv) would you use a slow workplace charger that may take up to eight hours for a full charge?, v) how many miles do you commute from home to the office?. Another question was for potential users: vi) would you consider purchasing an EV, if yes when?, and ii) with more workplace CPs would you be more likely to purchase an EV and drive it to work?. Home-work miles commuted varied between 6 to 20. The majority of respondents didn't have an EV 96%; 41% are considering having an EV. A further 68 % confirmed the importance of workplace charging, access to workplace charging may increase the probability of purchasing a car 64%, and finally 68% of respondents see the fast charger as a first choice for non-domestic charging facility (OFAS, 2014).

In May 2014 an online survey (n=93), by the Technology department of Delft University in the Netherlands, was conducted as a part of Smart EV Charging and House Energy Management project (Delft University, 2014). The findings of this study were not published. The part of the survey relating to EVs comprised of questions about personal information about respondents (gender, age, profession, yearly income, number of household, owning an EV and interested in driving an EV). The survey was investigating the crucial information that needed to be provided by end-user in smart energy management applications. Questions regarding car charging status, real time energy consumption data, accumulative energy consumption data and energy saving suggestions where addressed. The respondents were asked about the preferable notifications they would need to receive such as: the EV is fully charged, the EV is not connected properly or not being charged properly and energy consumption updates. Moreover, they were asked about visualisation and how regularly they want to be updated (consumption and generation of energy). Also which type of data they would prefer (amount of energy, energy cost or money saved by using the application). The participants were asked about their charging patterns. There were choices of charging mode: only charged at night where electricity price is low, set a time when the system should start and finish charging, smart meters). Additional questions were added regarding the system settings, as well as additional functionalities and price (Delft University, 2014).

An online survey was polled in June 2014 on the usage of the public charging stations in Michigan by the Detroit-based market research (Burke, 2014). The survey covered (n=250) EV commuters from the My Driving Power EV club and community. The survey highlighted interesting observations regarding the charging pattern spanning 2 months. The survey outcomes are not predictions or stochastic assumptions; real information about users was collected after the two month-survey time. The survey aimed to report on the following areas: driving during the week (number and type of trips), number of charging events per week, access to public chargers and when, the availability and fee of public chargers, charging preference and willingness to pay. The survey outcomes showed some meaningful insights into the context of EV use. Almost all users (90%) have a domestic charger and the availability of non-domestic CPs is not the problem for the participants, as per an anonymous participant:

> *"It is more about the convenience, distance from locations, or the charger power capacity, it is about a charging pattern based on home and workplace. Also the pricing strategy is critical, all types payment schedules are required."[An anonymous participant in Detroit study, 2014]*

5.5.6 Meta analysis-EV user studies

Four studies were conducted in the USA (m=1,577) forming 85% of 2013-2014 EV user studies, in addition to an unpublished study in the Netherlands, see (Figure 5-12). The USA Office of Facilities and Administrative Services (OFAS) conducted a further study addressing the workplace charging facility. Reporting on Bay Area workplace survey, this study tested the willingness among the users to use the workplace charging especially in case of low charger. Due to the cost of installation, which was also indicated previously in ICF study, the questions that were addressed in OFAS study were very useful. These questions explore the non-domestic charging pattern of the EV user. In the case of workplace studies, responses to such questions shall imply the prospective charging patterns using shared facilities (the overall population is the employees). To conclude this section, there are some remarks on user choices: price, maximum range, environmental impact, performance, durability and convenience are the attributes considered to influence the users choice in addition to social preferences and individual priorities.

Many studies whether consumer or EV user studies focused on the limited range of EV, the following sub section focuses on several range related studies.

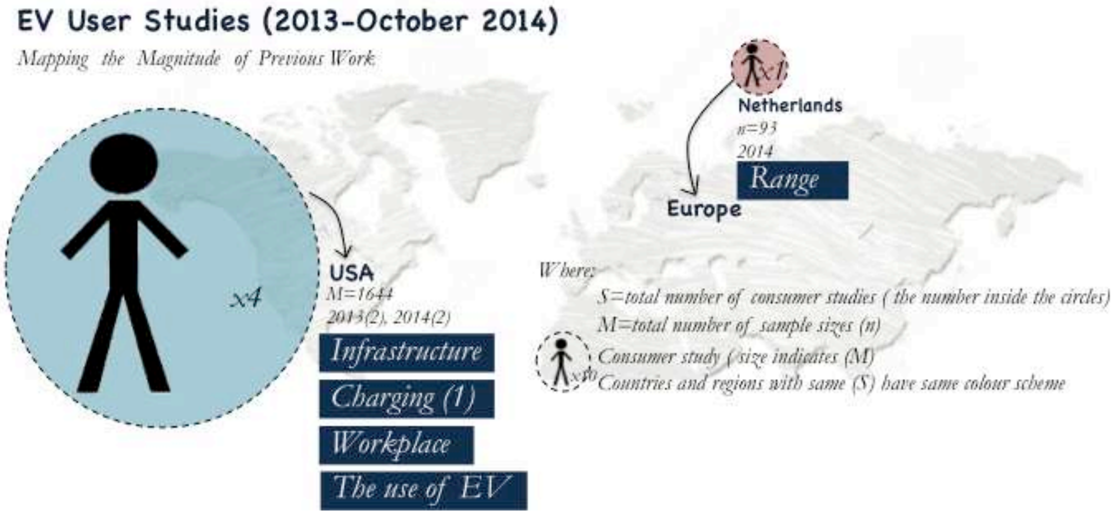


Figure 5-12: Mapping EV user studies 2013-2014

Range location–related studies

Limited range was addressed in 14 studies varied between consumer and EV user, see (Figure 5-13), highlighting the consumer studies in red and the EV user studies in green. Hidrue et al. (2011) attempted to predict the EV diffusion in the market addressing the range as to evaluate the vehicle attributes. Deloitte Ltd. study surveyed the purchase decision and how fundamental is the range to the consumer. For the same objective, Pike, Leiven et al. (2011) and Sahran (2013) addressed EV range in their studies investigating the consumer opinions and preferences and what would motivate them to own/lease an EV.

From a different angle, Bunzeck et al. (2011) conducted V2G project survey asking the consumers on the minimum acceptable range. Ernest& Young, ELVA (2010) asked EV users about the minimum range they accepted or they would have accepted in their EVs. With a different approach, range related questions are addressed in consumer and EV user studies. In the latter, the participants have experienced driving the car and thus the questions relate to the use of EV rather then to predict behaviour. In order to assist Automotive and battery technology providers meet the end user's design needs, Mackenzi & Keith (2013) surveyed the minimum SoC the users ever reached interrogating the accepted range for their daily use.

In brand-perception surveys, the range was addressed to evaluate the user selection criteria as was mentioned by Conway (2012) in the USA study. EVREST project surveyed the impact of the EREV on the users acceptance. A further study reported by Lo (2013) addressed the range in the Chinese market. The outcomes highlighted it as a barrier to purchase. Finally, the range was surveyed by OFAS when asking the staff members on their individual preferences and how the range and the workplace charging fit within their daily routine.

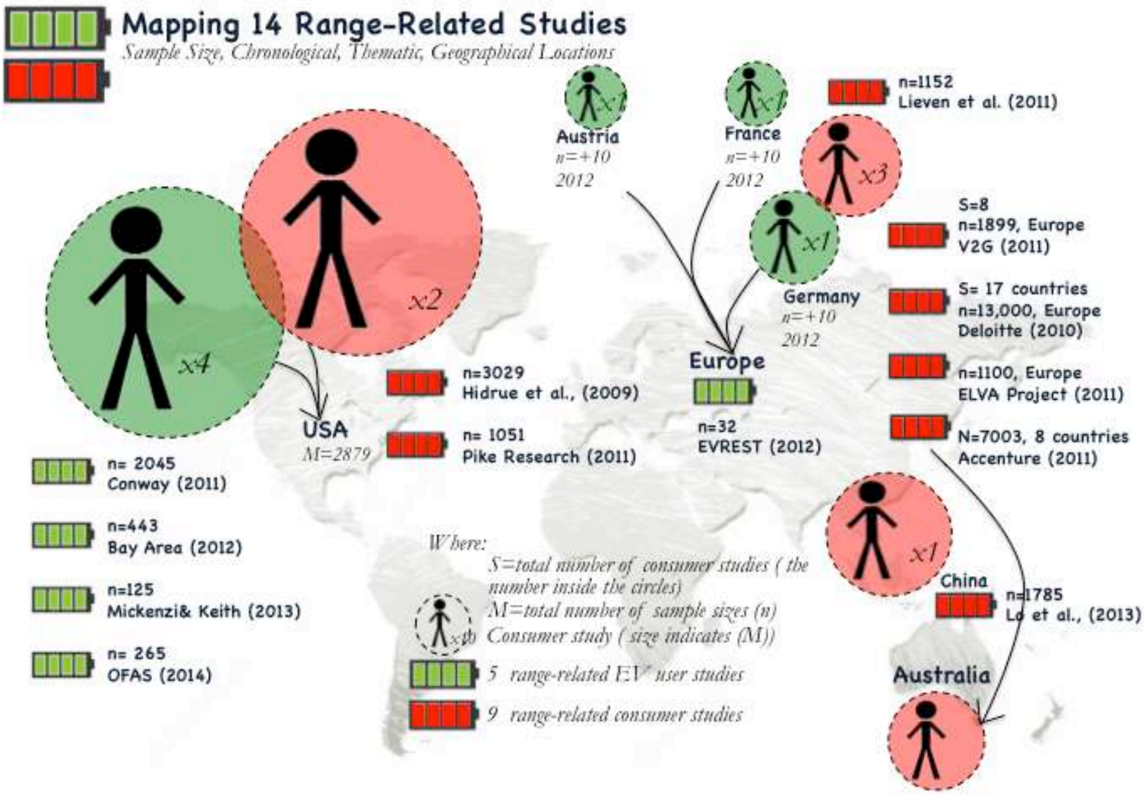


Figure 5-13: Mapping of range-related studies

Commenting on results

A total of 24 studies including nine EV trials were covered in part B. With a 15 EV studies collecting a total of (m=10,849) responses from the , Denmark, Switzerland, Germany, France, Austria, China and Japan were surveyed. As some of these studies cover multiple countries, the total studies were 19 and 13 EV trials. Remarkably, the UK was surveyed only once by Ernest & Young (2010), as per the list of EV user studies included in this review see (Figure 5-14). The USA contributed 28% (14 consumer studies and 11 EV user studies) and the UK by 11% (10 consumer studies and one EV user study) of the overall studies analysed in this chapter.

The studies ranged between (n=22 to n=2,039) including nationwide EV users studies spanning the USA. For non-USA countries, the sample size was approximately (n=165) having the highest (n=1,000) in Japan, Europe, and China. Practical EV experience is needed to develop an accurate conception of mobility needs and validly state preferences for parameters (Derollepot et al., 2014; EVREST, 2012).

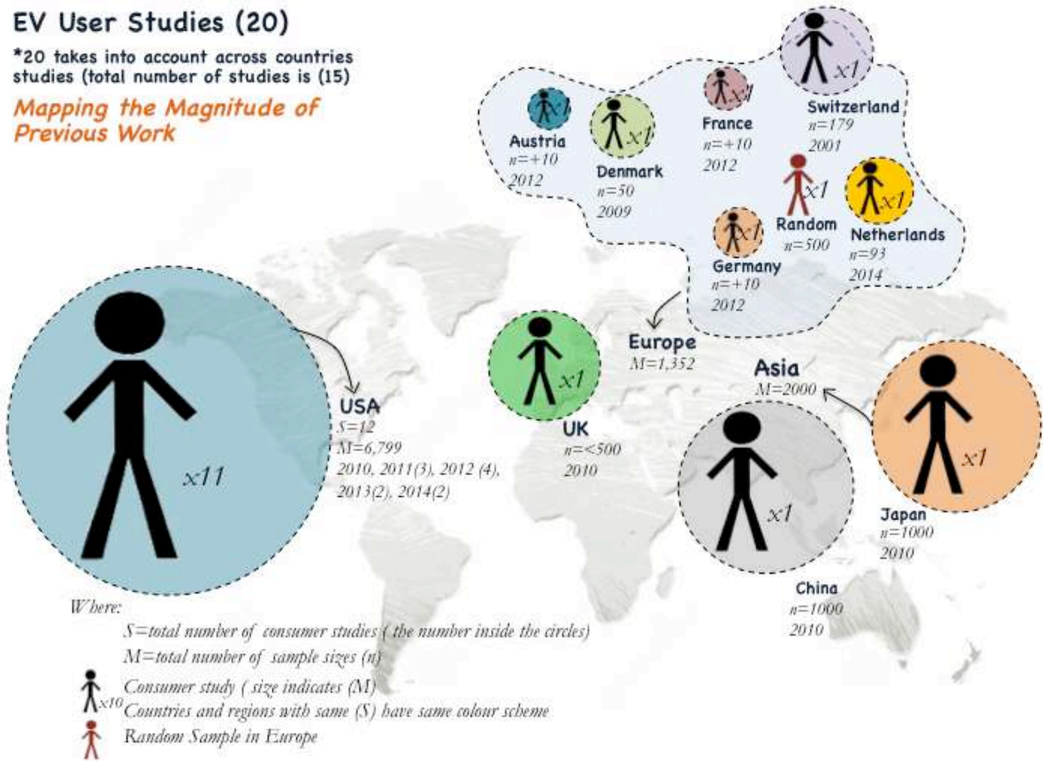


Figure 5-14: An overview of EV user studies (with thematic and sample size filters)

To summarise this section, the themes of previously presented EV user studies are: drivers profiles, enablers and barriers, charging preferences, range, infrastructure, charging, and workplace. The next section presents EV user trials.

5.6 EV Trial: User

As part of an online BMW Mini E trial, UK (n=40), USA (n=450) (Singer, 2010) and Germany (n=65) (Dempster, 2013), a structured questionnaire and interviews were designed by Ultra Low Carbon Vehicles Demonstrator Programme. The trial lasted for 2 years, it reported on drivers' adaption to transition to EVs and charging behaviour, including routines, infrastructure and barriers. The questionnaire was on a scaled-response base; and the participants were asked to complete at home. The interviews compromised of open-ended questions, which yielded rich information and a direct impact on manufacturers' and the government's understanding of key issues. In general, the questions were set in the following order: before using the car (pre-experience questionnaire and interview), during the use (first week, and three-six month trial time questionnaires) and at the end of the trial phase (focus group discussions and pre-post questionnaires). The pre-experience section started with testing the participants' willingness to take part in the trial and their environmental awareness level of carbon emissions of the transport sector. This was followed by examining the participants' behavioural intentions and their typical daily driving patterns (e.g., trip length, type, road network pattern, times of day and working or non-working). In addition to, the anticipated difference in driving patterns that may occur in case of driving an EV. Finally, the survey investigated the drivers' confidence level in using an EV. The pre-experience questions included: i) with what type of transport would you have to go when you have to go on a long journey?, ii) What do you anticipate the biggest differences between an EV and non EV to be?, iii) are you confident in dealing with the differences?, and iv) what will take the longest to get used to?. The pre-experience questionnaire was designed to investigate some different areas: interest in technology, issues of range (anxiety), expectations of driving, charging, general attitude to EV, driving habits, and purchasing preferences. The first week of use questions were focusing on the actual behaviour of users by assigning trained interviewers who are knowledgeable about the key issues. This included: i) has your typical day changed?, ii) has your driving style changed?, in which way?, and iii) have you established a routine?.

Questions about the transition to using and adapting to the EVs were addressed in the pre-final phase of the study (final focus group interview). The discussion aimed at emphasizing their experience, knowledge and opinions developed over the course of the trial while understanding the psychology underlying the adaptability to the EVs limited range. Moreover, they were asked to report on range anxiety and how the confidence level might have changed over time. Four main questions were asked: i) will you be back to conventional vehicle?, ii) during the trial when using non-EVs in between, how did you find the readjustment?, iii) what would have improved your experience in the trial?, and finally iv) what are the most important things to focus on in future development?. The last phase of the survey was the post-trial questionnaires to measure the difference (if any) with the results from the pre-trial questionnaire. It was mainly concerned with the feedback on the range matter and charging pattern. There were three questions referring to mileage: i) how many miles did you expect confidently to drive with a fully charged battery, ii) what might influence the range of the vehicle?, and iii) what range would you consider to be perfectly adequate for your daily use? In addition to a question on the charging times, it was also explored into what length of time users felt appropriate to fully charge the battery? (Burgess & Harris, 2011).

In May 2011, (n=58) out of 85 consumers in the UK were given a direct experience of driving an EV followed by an additional questionnaire to ascertain their perspectives and evaluate their feedback. Participants (44 males and 14 females, both groups at age 35-40 with no prior experience driving an EV) were recruited from Eon workplaces in the UK and provided with the same car model. A large majority of the sample drove regularly on 6 or 7 days in a typical week. The trial was to provide them a 2009 Mitsubishi I MiEV with a full electric range of 100 miles using 16 KWh Lithium b-ion batteries. A predefined route was told, a 10 miles road trip on a public road network. The trial had two sections: the first section was to complete a questionnaire designed to characterise the participants based on their attitudes to car use, public transport, policies and regulations. This was designed based on the defined Personality traits as per Newcastle Personality Assessor (NPA), Extroversion, Neuroticism, Conscientious, Agreeableness, and as per Nettle (2007). Whereas the second section focused on their attitudinal elements regarding the EV, EV performance, owning or leasing an EV, purchase intention, and their perception of the charging infrastructure (current locations, size and pricing strategy). The findings suggested that some consumers might start to consider EV as a first or second car if they had a range of 150 or 100 miles, respectively. They may be willing to pay a modest premium over conventional vehicles, equivalent to around three years' running cost savings. Most would recharge at home overnight (Skippon, 2011).

In August 2011, a study by Nicholas et al, (2013) as a part of the US Department of Energy EV project, reported the results of an online survey of plug in vehicles owners with (n=1,140) respondents, having been asked about the current use of public RFs and needed chargers. The sample included (n=1,092) owners of Nissan LEAF (with a 73 miles range), and (n=24) owners of a Volt (with a 37 miles range) and (n=24) owners of Tesla (with a 244 miles range) took the survey; charging patterns and the SoC were monitored and reported. The participants were all EV owners in California. The project provided free domestic chargers in exchange for participation. The survey was designed to determine how the EV commuters were using their vehicles and identify which locations were (perceived to not being possible) to travel to due to limited range, range anxiety, and what are their location preferences. An interactive Google map interface was used; however, 20% of respondents found it problematic and a complex tool to interact with.

The questions started with: i) current use of the EV and infrastructure to investigate how much of the vehicle range people are using and ii) the lowest SoC attained over the road trips of the EV lifetime. Observations showed that usually the battery capacity is sufficient for the daily use; however, the extremely cautious users take an unnecessary buffer. The following question concerned frequency of use over the week, including the domestic charging while indicating which public one they tend to use and which type of charging (Type 1 or fast charging). The majority reported workplace charging and 35% didn't place any desired chargers on the map. Another question was about the distance they commuted every day to work and based on this EV users were categorised as having a lesser or greater than 73 miles round trip commuting distance. Due to the spatial distribution, study observations and recommendations cannot be generalized; though the study was intended to assist planning authorities and policy makers in California and San Diegeo at a local scale (Nicholas et al., 2013).

SwitchEV (2011) project led by Newcastle University in the North East of England launched an EV trial. For three years, the trial had seen a range of different (n=44) EV users covering over 400,000 miles (SwitchEV, 2013). There were three studies undertaken: pre-trial survey, post-trial questionnaire and fast charging questionnaire. In general, the project aimed at understanding the EV population/predicting the future users by sensing the perceptions of and readiness for and of EVs, and investigating the willingness to pay of the public.

The pre-trial survey covered the following areas: i) personal and demographic data (age, house, own driveway, home insurance, employment), ii) vehicles and journeys (driving licence, vehicle model, number of cars in the household, types of journeys, daily mileage), iii) recharging information (awareness of public RFs), and finally iv) data collection, research and communications related questions and contents. The post-trial included questions on the speed of charging events and how this suits the daily routine, the lowest level of charge of battery a driver had reached, charging timing and duration (due to the routine or the flat battery), and finally the necessity of having access to public RFs. This was followed by a fast charging survey, which addressed the main motivations for using a quick charger, how often they used it, and the money spent whilst waiting for the car to be charged (SwitchEV, 2013). The trial was based on tracking the participants and recording all their charging events. For a period of six months, the drivers reported that they have driven further than the UK national average (product of distance commuted and number of trips). The trial was lunching the idea of smart meters and how this can change the charing behaviour by avoiding peak times.

In 2013, a study was conducted as part of the SmartCEM project, which aimed at implementing an ICT platform for the integration of EV sharing management, EV efficient driving, EV navigation, EV trip management and EV charging station management. The project is currently on going across seven European countries; four pilot studies commenced in 2012 in Barcelona, San Sebastian and Gipuzkoa county, Newcastle and Reggio Emilia where the survey was executed as part of the pilot study. Two questionnaires were designed to test the daily use of alternative means of transport spanning two groups: i) EV users within the four pilot sites (n= 274) and it had four main areas: EV acceptance, smartCEM services acceptance, range anxiety, and willingness to pay. ii) non-EV users to survey their opinion of not using EVs and discover the barriers to uptake (n= 725) (Dell et al., 2014; Fernando & Euskandi, 2014). In addition, an interview-based study was carried out by meeting the hybrid buses drivers (n=4) in San Sebastian and reported by Zubillaga (2013). The interview included questions on: i) conventional and electric bus driving history, ii) perception of driving an electric bus, and iii) the differences, concerns, expectations, problems, and the advantages and benefits of driving an electric bus. Further, the questions addressed the idea of the amount of fuel being saved, the usefulness of an electric bus, the change in habits whilst driving an electric bus, the willingness to drive it as the primary future form of public transport, and the drivers' eagerness to have a privately owned EV.

In Germany, a longitudinal field trip study for private and commercial uses of EVs was conducted by Globisch et al. (2013). It contained a trial of (n=50) out of 58 private EV users. The study included three pilot regions having three online surveys and questionnaires for 14 months. The three surveys assessed: i) consumer expectations of EV prior to the purchase (n=858), ii) first impression of the EV after one to eleven weeks of usage (after the trial) (n=781), and iii) to experience after more than three months of usage (n=690). The surveys comprised of a 6-point-scale ranging from "does not apply at all" until "fully agree" presenting 30 questions. The respondents were asked in seven sections: i) ease of use, ii) range, iii) process of charging, iv) charging infrastructure, v) driving experience, vi) costs, safety and reliability and vii) instrumentation and passenger compartment, environmental friendliness and social environment. A further 75% of the users were males, around 40 years old and highly educated. The trial lasted for seven months, user acceptance and vehicle characteristics. The study confirmed previous research findings (Anable et al. 2011), it indicated that EVs are rated overall very positively in the whole sample for the ease of use. Private users indicated that social influence (Word of Mouth-WoM) is very important for the intention to adopt an EV, which confirms Anable et al.; Peters et al. (2011). Reliability and cost saving and infrastructure were all above median. Range, price and time of charge and parking spaces seemed to be their main obstacles (Globisch et al., 2013).

In 2013, at a community action scale, My Electric Venue project, led by EA Technology, launched an EV trial (n=100), which is comprises 10 neighbours of 10 neighbourhoods. The idea was to have neighbours from the same street or very close participate in an EV trial. The technical trial is for 18 months where the participants tried a new technology, which will monitor and control the electricity used when the car was charged. A result-driven approach is taken in recruiting new participants. Due to data protection, the results were not published. Through this trial, a more realistic analysis of its effect on their local electricity substation was made. As a part of the trial, installation of CPs took place (Piggott; Middleton; Gordon-Bloomfield, 2014; Nowell, 2013).

In Ireland, Energy for Generations launched the Great Electric Drive in 2013 and 2014. The idea was to invite EV active drivers; EV ambassadors, trial 1 (n=21) and trial 2 (n=26), to partake in a one-year trial, each driver participates for a 4-month trial. In order to develop an understanding of charging infrastructure and technology requirements, ESB, in conjunction with EU projects such as TEN-T, Green eMotion, MobiEurope launched a number of trials and surveys to analyse the charging infrastructure and collect data on consumer behaviour and trends. In the first trial, the participants covered approximately 105,000 Kms of pure electric driving in Ireland.

The trial outcomes revealed some meaningful observations with regard to: performance, acceleration, cost savings, and the reason of purchasing an EV. Cost savings were high on the agenda and were cited by 90%. Almost 60% of EV owners drove more than 300km per week and 92% of EV owners were driving their EV at least once a day with 82% driving their EV multiple times a day. In both trials, the ambassadors were able to charge at home or in the workplace. For longer commutes, they used the smart public charging network located across the country (Ecar, 2014).

5.7 EV Trial: User Summary

In total, nine EV trials were conducted through 13 samples across the UK (seven samples), the USA (two samples), Spain, Italy and Germany (two samples), see (Figure 5-15). Total number of EV trials' participants were (m=2268).

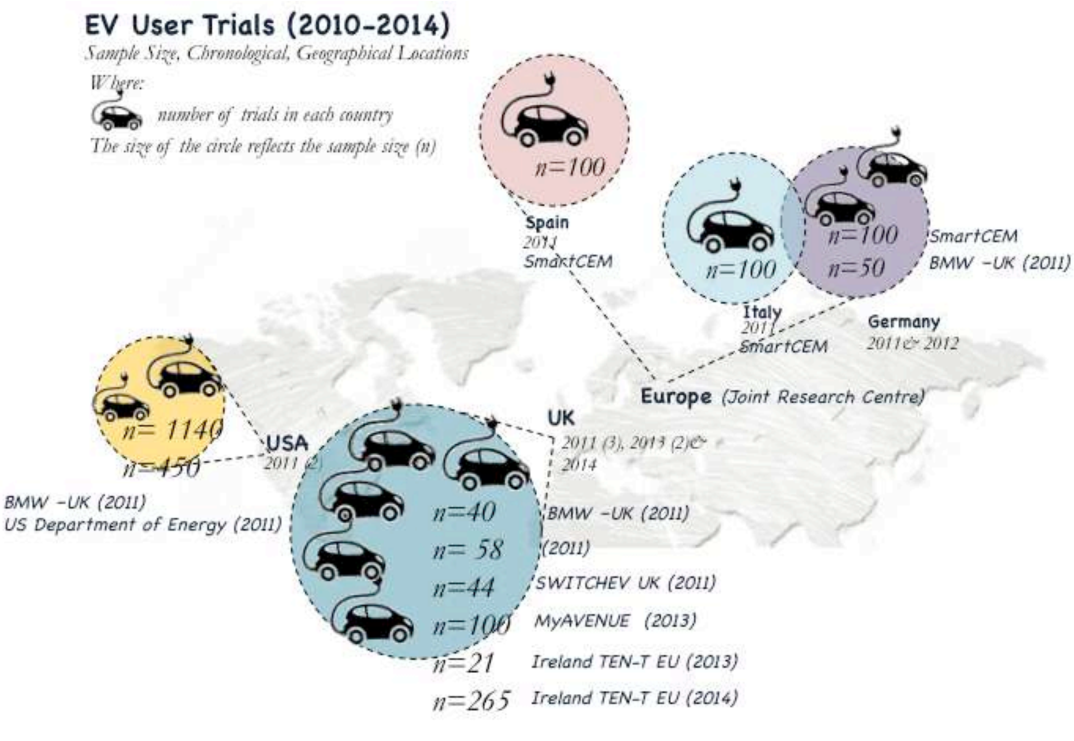


Figure 5-15: Mapping of EV user trials

The conclusion that can be drawn from the EV trials' findings is that the range restrictions and high costs seem to be the most salient barriers to acceptance of EV. Studying EV social practice is fundamental, as consumers cannot anticipate e.g., barriers and easiness. Understanding the e-mobility system is challenging as without experience, or relying on conventional cars to anticipate behaviour or pattern, will not provide the needed insights for planning and designing new infrastructure.

5.8 Chapter Discussion

Results from various surveys have presented a split in opinions between willing to drive an EV and the market barriers and technology adoption. Issues addressed in each study and relevant answers have to be interpreted with caution. Technical, demographical and timeframe considerations should be taken into account. The temporal validity of studies' results and recommendations are very critical. Potential bias involved when conducting an online survey, due to anonymity of the respondents in many cases and especially with surveys, which are opened to self-selection. The majority of the studies were looking into the consumer's willingness to drive an EV and the driver feedback. This includes owning and leasing. In a sense, this may indicate the necessity of understanding the barriers, incentives, and the end-user emerging design needs (car and infrastructure) affecting the diffusion of EV models in the market. The studies were compiled into chronological order, some years were quantitatively and qualitatively rich periods of studies. The years 2011 and 2013 contributed 70% of the reviewed studies. The drop in the published EV studies in the year 2012 may have indicated the market saturation in the year 2011. The year 2014 contributed almost 20% of the studies where 70% of the studies were targeting current users, see (Figure 5-16).

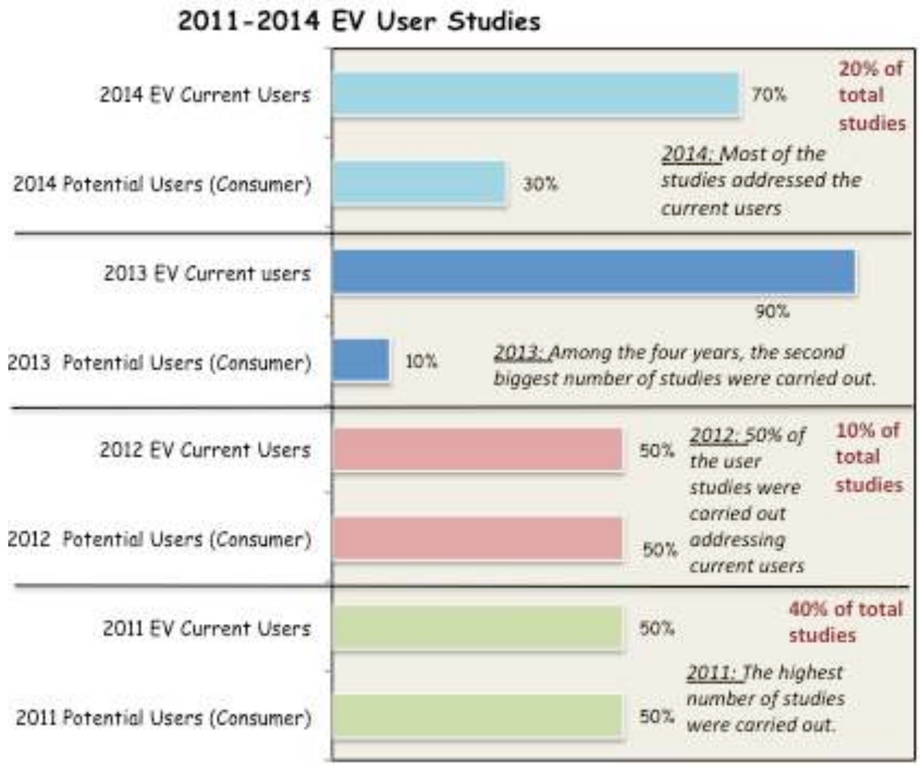


Figure 5-16: 2011-2014 EV user studies overview

The introduction of any new technology such as EVs requires extensive research and pilot projects (Ecar, 2014). Franke et al (2013) indicated that practical EV experience is needed to develop an accurate conception of mobility needs and state preferences for parameters.

5.8.1 EV triability

The analysis revealed that the national travel surveys currently publicly available are not detailed sufficiently to predict EV charging patterns for further assessment. Therefore, either the surveys should be adapted to incorporate new parameters such as driving and parking patterns (on an hourly basis for at least a representative week), trip diaries and vehicle details, or new, more dedicated surveys should be conducted to derive EV charging profile assumptions (Pearre et al., 2010).

Emphasising on EV trials, Golob (1998) stated that survey-based studies without EV trials are often criticised, as respondents are usually not familiar with EVs, thus do not have enough experience to assess such technology. SwitchEV reserch's underscored the finding that the period of EV adaptation requires learning. The UK's Department for Business Enterprises and Regulatory Reform (BERR) published a study on uptake scenarios for EVs. The report stressed on the significance of triability in EV adoption. IET (2011) and Hatton et al., (2009) reported on the resistant to radical or untested technologies indicating triability as a contributor to innovation uptake, saying:

"New EV drivers may be precautious, so triability should be emphasised."
[Hatton et al., 2009]

There are issues and questions arise from early trials, which help facilitate a useful flow of information (IET, 2011). One of which is the change in the daily routine. Significant steps have to be taken by the EV user to accommodate the vehicle into their lives. Neumann et al., (2010) also mentioned the field studies as these studies reveal many facts with regard to driving experience. Application of a longitudinal trials, especially with EV users not consumer, allows drawing valid conclusions about changes in attitudes and behaviour unlike short surveys.

In this chapter, there were 16 trials (consumers 38% and users 62%), see (Figure 5-17). These trials collected (m=6,777) responses. Consumer trials focused on performance and acceptance, driving patterns, EV consumption and charging evaluation, safety implications, forecasting EV diffusion in the market. Whereas, EV user trials focused on driver's adaption to transition to EVs and charging behaviour, attitudes and users' perspectives, perception of current charging network, understanding the daily use of EV in urban context and predicting future users' profiles, users' expectations, understanding purchase intention process, and finally technology acceptance and affordability.

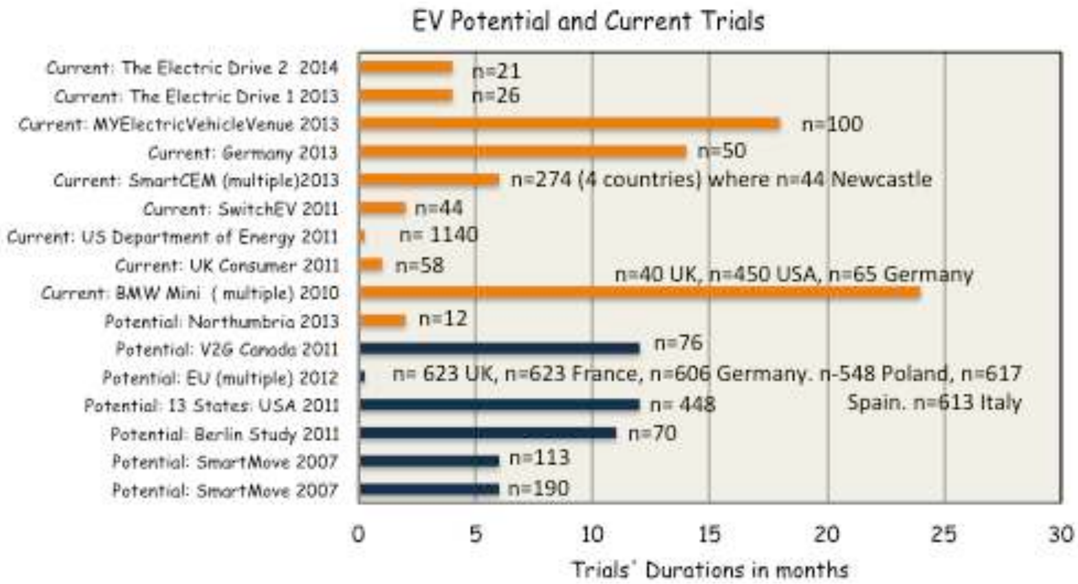


Figure 5-17: Bar chart of the 16 trials of EV potential and EV users

The trials with large sample sizes were: i) carried out for shorter terms, ii) spanning large regions or multiple countries, iii) population or consumer focused. Before driving an EV, the majority of the consumers expected to be constrained by the limited range (Neumann et al., 2010) which shows that anxiety is a pre purchase condition (Raia, 2014). In order to generalize the results a validation with a larger, more focused sample should be selected (Neumann et al., 2010).

5.8.2 EV triability effect on the attitude-behaviour process

The formation of the attitude affects the consistency of the attitudinally behaviour. Individuals express their attitudes toward objects when needed, depends on the activity they are engaged with (Foster, 2001). As Fazio et al (1983) explained attitude-behaviour process, the strength and formation of the attribute moderate such relation. Attitude influences behaviour through several mechanisms. Attitude is knowledge and a self-expression function; it helps organising information and expresses their opinions. Events trigger and motivate the individual to say their opinions (attitude), like an interview or a questionnaire (Foster, 2001). The attitude is postulated to act as a determinant of the attitude to behaviour process. In behavioural experience (direct experience like trials), Fazio et al (1983) suggested that an individual finds behaviour toward an object to be a very indicative reflection of their evaluation. Attitude associability determines how (direct and indirect) experiences differ in the degree to which they prompt attitudinally consistent behaviour. In the EV context, this is reflected in the feedback of consumers having pre-experience driving an EV to build on their perception, see (Figure 5-18). This can be a trial or a several rides from another family member who has an EV or a friend. Previous studies which reported EV trials, reported a more positive perception compared to potential users who didn't have such direct experience (Blythe, 2013; Robinson et al., 2013; Cocron et al.; Browne et al., 2011; Steve; Carroll & Walsh ; Future Transport Systems, 2010);

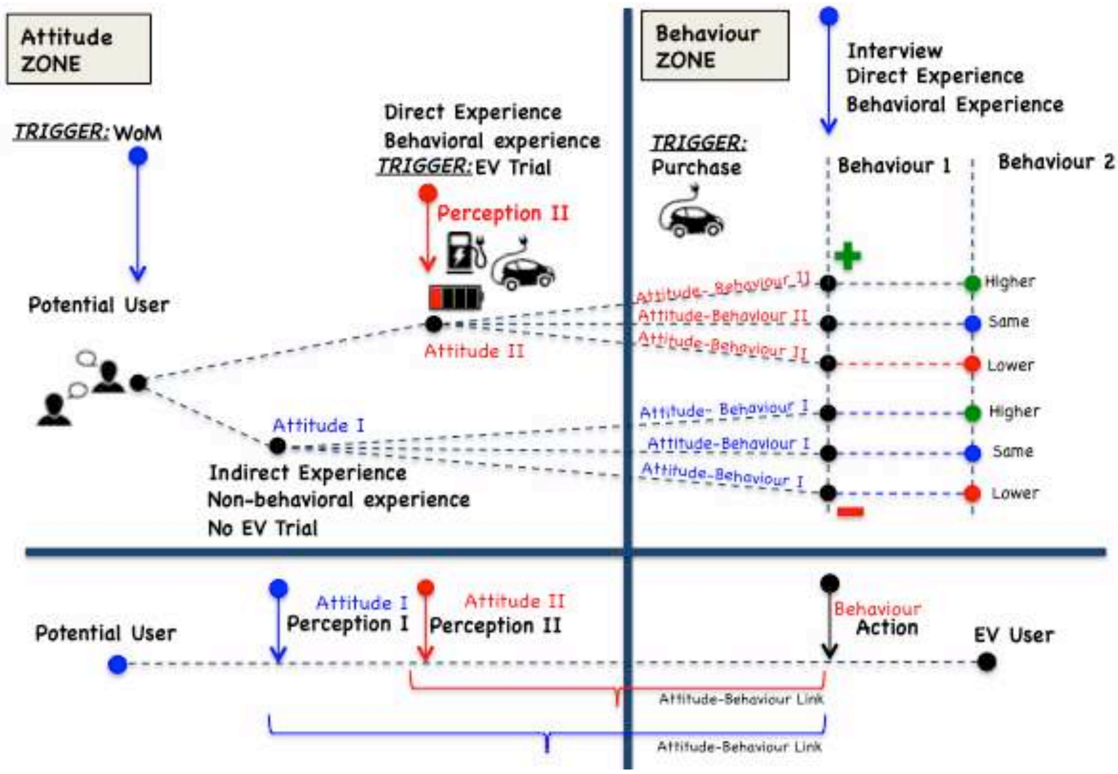


Figure 5-18: Attitude-behaviour diagram-EV use

5.8.3 EV studies comparability

Another challenge regarding the comparability of data from various country surveys concerns the slight differences in methodologies applied (Pasaoglu et al, 2013). Another element of comparability is the best selling or common brand in each country. As per Conway (2012) reporting USA survey in 2011, the 10 brands were surveyed among a long list of attributes in a car-brand perception survey, which did not include Nissan LEAF.

5.9 Concluding Remarks

This chapter provided a thorough review of EV related studies that explored various insights into the e-mobility system of different regions. The chapter addressed one of the thesis objectives, which is to understand the e-mobility system and the main issues associated with the context of EV use.

> *Objective 2: Explore the charging pattern, profiles and personas of EV users, which responds to the diminished range anxiety issue of driving an EV.*

Table 5-1 summarises all consumer and EV user studies and EV trials previously discussed in this chapter. The table displays the studies in a chronological order using filters: sample size, thematic, and geographical location.

Table 5-1: EV user trials- Consumer and EV User studies

	Consumer		Survey/ Interview
	Year	Sample Size	Geographical
1	2005	n= 602	Canada
2	2007	n= 1,100	UK
3	2007	n= 2,373	USA
4	2009	n= 1,974	Turkey
5	2009	n= 3,029	USA
6	2009	n= 809	Portugal
7	2010	n= 200	Hong Kong
8	2010	n= 13,000	17 Countries
9	2010	n= 309,163	USA
10	2010	n= 2,300	USA and UK
11	2010	n= 1,046	USA
12	2010	n= 7,003	13 Countries
13	2011	n= 548	USA
14	2011	n= 1,899	8 Counties
15	2011	n= 8,417	France, Germany, Spain, and UK
16	2011	n= 1,100	Europe
17	2011	n= 2,302	USA
18	2013	n= 1,051	USA
19	2011	n= 1,152	Germany
20	2012	n=1,702	USA
21	2012	n=4,240	UK
22	2012	n= 250	South Korea
23	2012	n= 1,785	China
24	2012	n= 234	9 Countries
25	2013	n= 3,000	USA
26	2013	n=1,084	USA
27	2014	n= 962	UK
28	2014	n= 3,000	Germany and UK
		Consumer	**Trial**
	Year	Sample Size	Geographical
29	2007	n= 113	SmartMove UK
30	2007	n= 190	SmartMove UK
31	2011	n= 448	Atlanta counties USA
32	2011	n= 76	V2G Canada
33	2011	n= 70	Berlin Germany
34	2012	n=c.600each	EU 6 Countries
35	2013	n= 12	Northumbria UK

		EV User	Survey/ Interview
	Year	Sample Size	Geographical
36	2001	n=179	Switzerland
37	2009	n= 50	Denmark
38	2010	n=1,000*4	USA, Europe, China, Japan
39	2011	n=92	Germany
40	2012	n= 2,039	USA
41	2012	n=1,151	USA
42	2012	n= 443	USA
43	2012	n= 500	USA
44	2012	n= 22	USA
45	2012	n= 32	Germany, France, Austria
46	2013	n= 1,004	USA
47	2013	n= 125	USA
48	2014	n= 265	USA
49	2014	n= 93	Netherlands
50	2014	n= 250	USA
		EV User	**Trial**
	Year	Sample Size	Geographical
52	2010	n= 555	3 Countries_Mini BMW
53	2011	n=58	UK
54	2011	n= 1,140	USA
55	2011	n= 44	UK_SwitchEV
56	2013	n=274	3 Countires_SmartCEM
57	2013	n= 50	Germany
58	2013	n=100	UK MYElectricAvenue
59	2013	n= 21	Ireland TEN-T EU
60	2014	n= 26	Ireland TEN-T EU

This chapter explored the variance of studies in terms of sample size, location and targeted sectors. Regardless of the variations and considerations taken into account when analysing the studies, there are some key findings that can be observed.

1. Range is a prior to purchase phenomenon; users found the vehicles normally had enough charge for their intended journey (Lenz, 2014; Mackenzi & Keith; Huertas; Lo, 2013; Conway; Pike; Newman et al.; EVREST, 2012; Peters et al., 2011, Lieven et al.; Bunzeck et al.; Hidrue et al.; Lesemann et al., 2011; Deloitte, 2010).

2. A single prototype does not meet all consumers' EV preferences (e.g., type, price, range) depends on their use of the EV (Lenz, Burke, OFAS, 2014; Dempster, Carley et al., 2013, Axsen & Kurani, Baptista et al., Pike, 2012; Accenture, Lesemann et al, Bunzeck et al, Anable et al, Hidrue et al, Lieven et al., 2011; Peters et al., Vyas et al., 2011; Ernst & Young, Deloitte, Rodriguez, 2010).

3. Trials affect the perception of users as it allowed them direct experience. As per Liven et al. (2011), 82% of the public participants considered owning an EV compared with 56% from a captive test-drive audience. Consumers feel more positive about EVs (especially regarding the range issue) after taking part in the trial (OFAS, 2014; Globisch et al.; Nicholas et al.; Zubillaga, 2013; Skippton & Garwood, Burgess & Harris, 2011; Carroll & Walsh; Smart Move; Pearre et al., 2010). During test drives the EV exceeded the general public's expectations on all monitored performance aspects (Carroll & Walsh, 2010).

4. EV questionnaire and survey-based studies should be designed considering the following observations:

    i) Potential users may indicate the level of awareness of the existing charging network but will not reflect how integrated it is;
    ii) EV users' feedback on the current charging network is fundamental and this will not be obtained without asking particular questions on particular RF;
    iii) Linking age, gender, years of driving an EV to how confident is the EV driver would explore more insights of the social practice;
    iv) More visualisation is needed;
    v) Range matter has to be addressed in a way that the user can express how they feel or react. Stimulating a scenario or visualising the distance and the SoC would be effective;

vi) The SoC is one of the overlooked variables. User studies are the best tool to investigate the SoC (SoC upon arrival at the CP);
vii) Data analytics of user studies it is as important as the design of questionnaire;
viii) Spatial and temporal tools (maps and relating time to SoC) are recommended;
ix) Having a small sample size and detailed questionnaire-based study is more expressive and will provide meaningful observations compared to short surveys disseminated among bigger sample of participants;
x) The Social media is one of the e-mobility mechanisms, analysing it would shed light on the social practice of driving and EV.

Each study was carried out for a reason and was trageting a focus group at a certain time, which is the main pitfall of meta-analysis (Nordelof et al., 2014), the results of studies should be seen in certain context.

As it is discussed in Table 5-1, these studies are more focused and oriented to the end-user. This set of studies tests the charging patterns and attempts to identify the pros and cons of the system use. The self-selection approach is still possible in this set as in studies carried out in large regions meeting every participant is not feasible. Online user interviews are very useful especially in a niche market. Potential obstacles and are summarized below:

i) lack of fast charging infrastructure;
ii) lack of charging stations at destinations at the moment;
iii) lack of education on these topics, more education is needed to raise awareness;
iv) costs of batteries, vehicles, fast charging stations and electricity are cited as concerns;
v) range anxiety is an obstacle for some drivers;
vi) difficulties with multi-family dwelling units. Respondents indicate problems with getting charging stations at rental apartments (ElBanhawy & Nassar; ICF, 2013);
vii) the majority of people are not testing the limits of their EV or they simply have nowhere to travel or to charge (Nicholas et al., 2013).

Understanding the customer's needs, and correctly segmenting vehicle buyers by range needs, appears to be a more cost-effective way to introduce EVs than assuming that all buyers, and all drivers, need currently-expensive large batteries or liquid-fuel range extenders (Pearre et al., 2010). End-user design needs and feedback are essential, as in case of negative feedback, this might be a reason for the fact that only very few consumers are planning to buy an EV (Lieven et al., 2011).

CHAPTER 6. EV USER STUDY

"The North East region has more than enough RFs to make EV a viable transport option."

By Newcastle City Council, Transport Office (2014)

This chapter reports on the EV user studies, it presents an EV user study that was carried out in October 2014. In total, (n=15) structured interviews were conducted with active EV users who have been driving an EV for a minimum of one year. Another (n=5) semi-structured interviews were carried out with smart transport local authorities and an EV service provider, CYC Ltd. The data analysis is carried out in 2 different approaches: i) end-user analysis at a macroscale level investigating the social practice of driving an EV and an end-user study at a mircoscale level, which includes the user study (individual-based), in Chapter 6. Furthermore it covers the service provider's dataset to explore and identify the charging patterns and personas of the EV users, in Chapter 7. The second side is the charging network usage and management. The management is addressed through the local authorities and service provider interviews; whereas, the RF's spatiotemporal analysis is addressed in Chapter 7. It is carried out to interrogate the relationship between the spatial arrangement and the behavioural element of driving an EV (charging pattern), see (Figure 6-1).

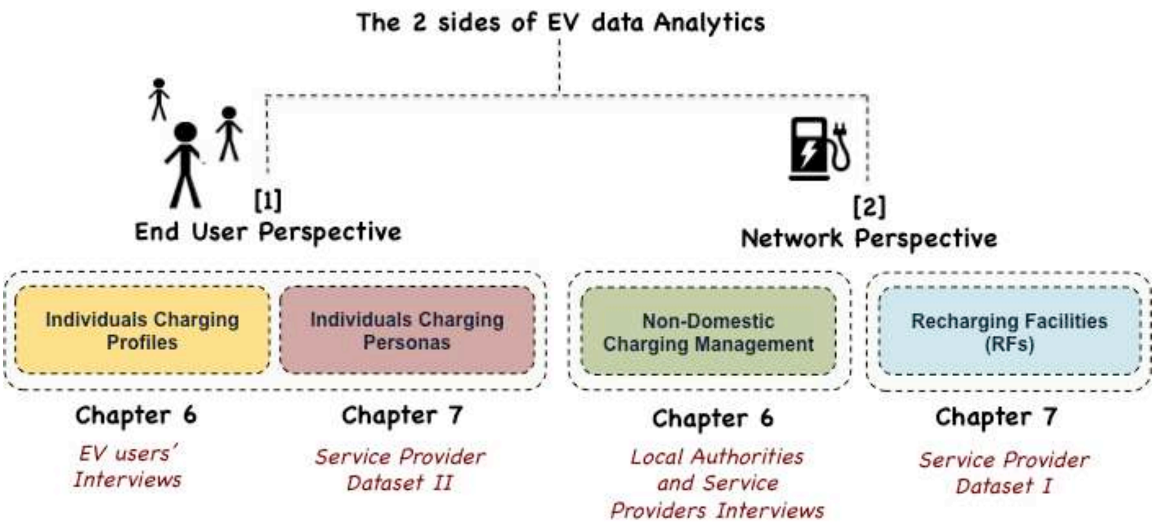


Figure 6-1: The two sides of EV data analytics

6.1 Introduction: The Social Practice of Driving an EV

The current EV users see themselves as a community; they liaise with each other through Social media suggesting indispensable tools and many phone and computer applications that can help the driver to familiarise with the charging network and all related issues to EV use. The Social media is used for posting updates and spreading news of interest for any EV user. The users tend to help other EV users benefit from their experience and share any piece of information that can assist them in their daily trip, see (Figure 6-2). In some other cases, users ask for help and call for owner corporation, see (Figure 6-3). Due to the e-mobility network instability, immature monitoring systems and available database, EV drivers always tend to double-check the information from different sources. This happens if the driver is taking a non-routine journey, which requires further planning. As was explained in Chapter 2 (2.1.2 Actual daily driving needs), this might occur two to three times a month, however, when needed, the EV user would need to make sure where to charge their car.

6.1.1 Social media

In order to deal with the EV technology, the user attempts to find a mean of communication or interaction with other users to gain reassurance. The use of Social media was and is still one of the tools that EV community uses to interact. It plays a major role in sharing knowledge and experiences among users.

The Social mediation evolved by the emergence of EV. Users discuss the social practice especially over Social media (Axsen & Kurani, 2013). Social influence plays a key role in market dynamics (Axsen et al., 2013), if the hurdles the current users are facing are not resolved, this would result in negative Word of Mouth (WoM) that could lessen EV diffusion in the market (Kearney, 2011). Innovative technology adoption is driven by motivation for purchasing and willingness to pay. Learning processes are a critical dynamic in the spread of new technologies (Turrentine et al., 1992). To advance technologic diffusion beyond the early adopters, EV must appeal to the majority of consumers (Cooper, 2014).

Charging network websites

This refers to the national charging network websites and blogs that provide updates for all CPs statuses across the UK. Each service provider e.g., CYC, in the North East of England, Source London, and Chargemaster Places Ltd. covering mainly Midlands and South of England, have their own websites and live maps to show the charging network updates. However, these websites are deemed insufficient for the overall EV population. A user would like to see an overview of the national network (constructional and operating updates) while being categorised by the service provider, socket type, and power. These filters are very fundamental for any EV driver (compatibility and availability).

Twitter

The Social media Twitter has gained popularity among EV users in the UK. More than 10,000 users across the country are using it frequently. The highway agency runs a number of Twitter channels to help the public plan their journey and arrive at their destinations (UKGOV, 2012). In Twitter, there is a hash tag #UKCharge, which started in July 2012. This is one of the very popular UK Social media in the context of EV. Jointly with @ElecHighway updates and tweets, EV users communicate and interact virtually. The @ElecHighway is dedicated for the EV infrastructure and was launched in June 2012 as the first official home of the UK first national motorway network of charge points for EVs. It carries messages around the current state of the working CPs across the UK. In December 2014, there were 1,600 followers and 1,563 updates were sent (Highways Agency, 2012).

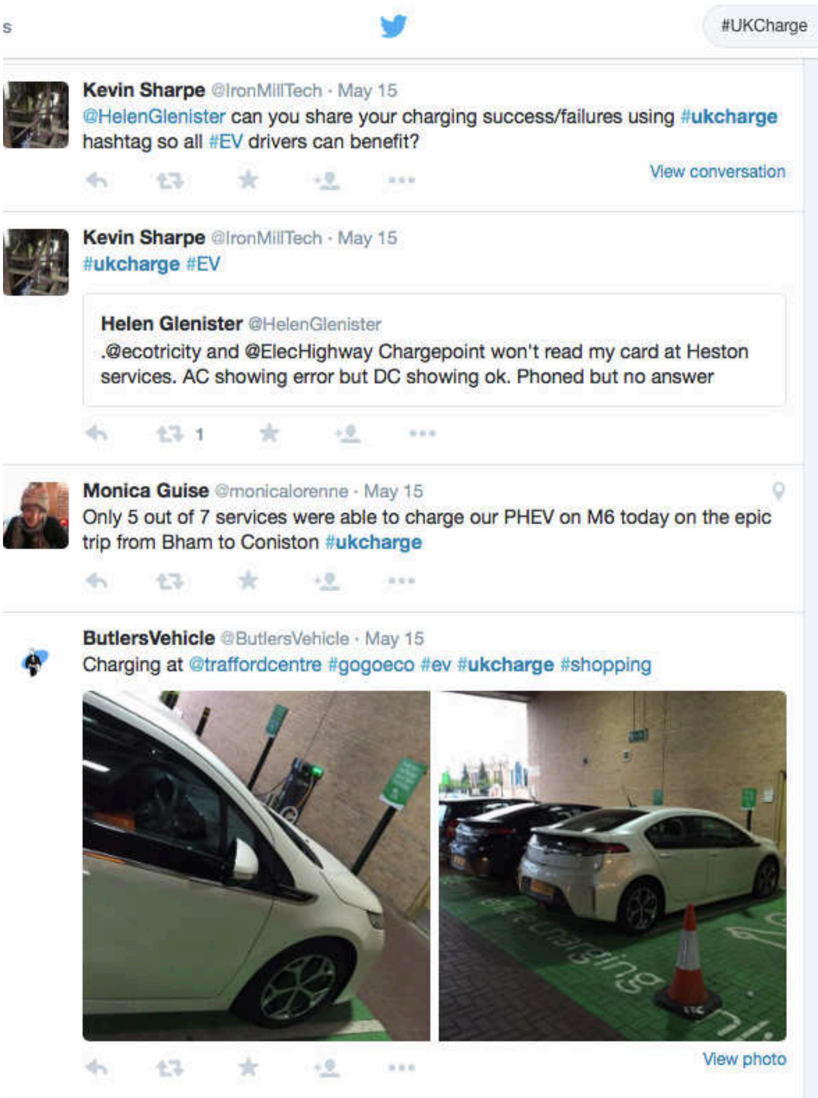


Figure 6-2: Twitter: #UKCharge, pieces of information that can assist other EV users

Figure 6-3: Twitter: #UKCharge, a tweet shows owner cooperation

A longitudinal study on the Twitter website shows the trend of users' reactions towards the EV use. The study analysed #UKCharge tagged tweets for the month of November in consecutive years (2012 to 2014). The number of tweets increased by the years of operations, see (Figure 6-4). In November 2012, there were 58 tweets, in November 2013 the tweets reached 198, and by November 2014 had reached 275 tweets. This incorporation of digital technologies has started to attract discussion in a range of fora. Also, this sheds light on the importance of having an advanced monitoring system that would better notify and communicate between the users and the charging network.

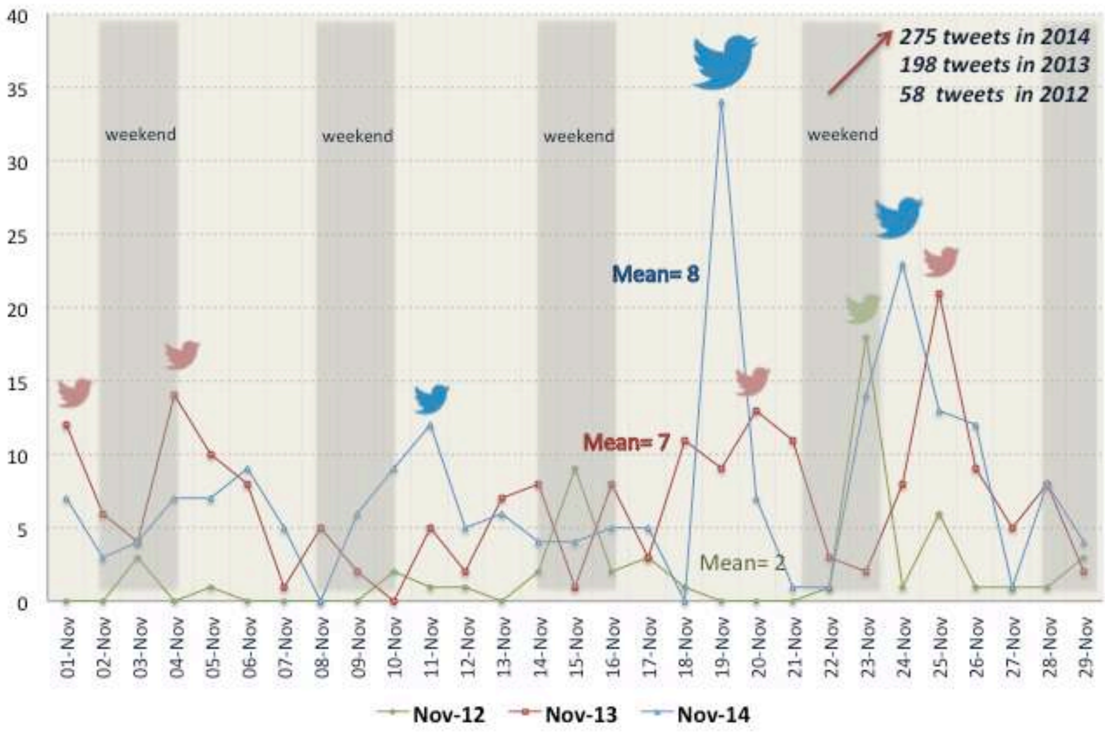


Figure 6-4: Tweets records November 2012-2014

6.1.2 EV forum: LEAFTalk

One of the very successful examples of the community actions is the Nissan unofficial forum. LEAFTalk is an unofficial Nissan LEAF online forum for owners where they share their experience and post updates (Nissan LEAF, 2014a), see (Figure 6-5).

Figure 6-5: LEAF Talk: a proposed application by a user

This forum was launched in March 2011 by Nissan LEAF pioneers who are interested in sharing knowledge and experience of driving an EV in the UK. Via the online discussion system, all registered users may express the views and opinions about individuals on shared posts.

> *"The public sees the importance of installing CPs in the workplaces in the first place. In mall parking areas, leisure activities, major employers like schools, colleges, universities, hospitals, police station."[Anonymous EV Driver I, 2012]*

"The bare minimum is to provide charging services in these relevant areas, City councils are the ideal use of EVs." [Anonymous EV Driver II, 2012]

"If the individual has a routine and usually commutes a short trip in the city road network. If they commute a home-work trip then EV is a sensible choice." [Anonymous EV Driver III, 2012]

An interview was carried out with the LEAFTalk moderator, an active EV user since 2011. The interview (in December 2014) aimed at asking how the forum was started, and how does it work.

"3.5 years ago, I was looking for information before I purchase my old EV, automotive manufactures were misleading, and I found this forum."[LEAF Talk Moderator, 2014]

"There is another popular forum, SpeakEV, launched in 2013 and it is not only for Nissan LEAF users." [LEAF Talk Moderator, 2014]

Lay, (2014), is an IT Officer who emphasised the meaningful observations and insights the forum provides as being the moderator. Lay mentioned the social practice of EV and how is Social media powerful in promoting the market. Through forums, blogs, websites, and user interfaces, users receive live notifications and general updates. Moreover, Lay (2014) was able to clearly identify the potential user profile based on the exposure he receives from the forum.

"EV users are short-distance commuters with more rigid week plans and fairly modest requests." [LEAF Talk Moderator, 2014]
"They think ahead, they do not want to spend money on the long term."[LEAF Talk Moderator, 2014]
"Believe that by driving an EV, they would contribute to lessen the environmental burdens of ICT." [LEAF Talk Moderator, 2014]

6.1.3 EV clubs

Further aspect of the social practice is EV clubs. In the USA, there is an EV club named Eastern Electric vehicle Club (EEVC) in Pennsylvania. This club had 20 EV users in 2013 and they run monthly forums and also they run relay twice a year, see (Figure 6-6). These relays aim at testing the confidence level of users as the club committee tracks the charging events of each participant to measure the minimum SoC, type and location of RF that was used. With a quick interview in June 2013 with the Club Chair, Olive Perry, he said commenting on the club objectives:

"EEVC has a free membership. Likewise other car clubs, these clubs can be used as satisfaction indicator as it reflects the end-user feedback."

Figure 6-6: Shots taken from Eastern Electric Vehicle Club (EEVC) forum-June 2013

6.2 Interview with Local Authorities and Service Providers

As it was discussed in the previous chapter, meeting potential users with no EV experience will explore many aspects of the system; however, design for future RFs should not rely only on this solely (Dimitropoulos et al., 2011). Meeting individuals with an EV experience is more realistic and sensible as it is based on practice not hypothetical or predictive thoughts based on ICE experience. In addition, interviewing e-mobility stakeholders explores other sides of the e-mobility system. EV stakeholders include key persons in the automotive industry like Nissan and Tesla, planning authorities and town-city planners (Newcastle city councils and others), utilities management (CYC), Traffic Management Monitoring Authority (UTMC), pioneer researchers in the area, and more importantly the user. Furthermore, meeting them at a later stage of the research opens channels for a high quality level of validation and verification and examines the research creditability. It is very difficult to get the design requirements from the end-user. Starting with local authorities travel office and town city planner, interviewing Herbert, 2011, helped identify the current EV system mechanism.

> *"There are different RF management companies (e.g., CYC, 2010) and (Source London, 2010) and each of these companies has its own business plan and scheme. There is an emergent system (whitelist Scheme) that allows the driver wherever he lives in (North East and London Central), uses the publically available CPs." [Smart transport Officer, 2011]*

Herbert spoke about the standardisation and regulations that govern the e-mobility system in the UK.

> *"Newcastle City Council has an interest in finding a constructive and rational methodology that can be employed to RF location problem. The locations of the existing RFs were not wisely selected; the process was driven by business models and incentives." [Smart transport Officer, 2011]*

A further two interviews were carried out with the CYC Sales Manager, Prescott and Infrastructure Director, Wardle. The first interview with Prescott, was in 2011 prior to the research where she spoke about the type of data that can be retrieved from the charging network, level of granularity, administrative fees, agreements with other network providers, and some insights into service management and future expansion.

> *"Once the EV driver registers, they can have access to all CYC points whether as a 'pay as you go' option or an upfront administrative fees option, and may have access to other providers in the Whitelist Scheme. The WLS is a consortium agreement that accepts and 174 nalyzing 174 n 174 registrations for various EV utilities management companies in the UK." [CYC Sales Manager, 2011]*

> *"The data availability is a main issue as this data falls under data protection and freedom of information matters." [CYC Sales Manager, 2011]*

Both Herbert and Prescott emphasised the number of CPs that are under used. They were looking for a tool to assess the current system and investigate the factors that affect the poor level of usability.

> *"Actually, this is even more important than planning for the new EV generations. Since Newcastle is saturated with the number of the installed CPs, assessing and analysing the current system is a priority".[Smart transport Officer, 2011]*

A post research interview was carried out with CYC Infrastructure Director, Wordle, 2014, addressing how the present research would help the company management improving their business plans. The interview was a partial validation of the way the variables had been selected, quantified and processed in the model.

"Developing a methodological approach to assist planning authorities and policy makers to better understand, analyse and design RFs." Wardle (2014) conceived public engagement and sending messages to planning authorities are fundamental." [Infrastructure Director, 2014]
"A further 40% of the CPs in Newcastle and Gateshead area are underused." [Infrastructure Director, 2014]

According to the latest update of CYC, the total number of registered drivers in the Newcastle and Gateshead area was 420 (CYC, 2014). Focusing on the NE1, NE4 and NE8 users, there was a noticeable change spanning the last three years. In 2011, the number was 91, and reached 120 in 2012 and in 2013 increased to 425.

"There are over 500 publicly available CPs and 12 fast-charging points (Type 3) in the North East." [Infrastructure Director, 2014]
"Nowadays, households are advised and encouraged to have a home installation of an EV charger. Until August 2014, PodPoint Company supplied and installed domestic chargers free of charge."[Infrastructure Director, 2014]

The fourth and fifth interviews were with the traffic management and monitoring authority in Newcastle, in 2011 and 2014. King (2011) provided an insight of the monitoring system and level of traffic flow (congestion, engineering work, peak times etc.) they reach in providing updates to drivers and local authorities.

"Our unit prime concern is the effect of alternative means of transport in the traffic network. We need more information about the charging pattern and planning tool that will help identify the charging hotspot and the effect on the network."[UTMC Manager, 2011]

The second meeting with King was conducted in 2014. The interview was manily covering the current situation of Newcastle transport system.

"Anticipating charging corridors in the network would be ideal and essential especially when the EV market reached a maturity level and be at a mainstream level." [UTMC Manager, 2014]

"We should be aiming at an integrated system where the cameras capture congestion, engineering works, weather condition, and refueling stations' corridors updates. This is feasible."[UTMC Manager, 2014]

A further interview was conducted with the Spatial Planning South Tyneside Council in 2014. The interview focused on the planning strategies of the urban cores of Newcastle, this interview is reported in Chapter 7.

6.3 Obtaining User's Insight-EV Interview

A questionnaire-based interview was designed to investigate the EV users preferences and their network spatial awareness of the existing charging infrastructure of Newcastle-Gateshead area. The questionnaire was disseminated among (n=15) EV users in October 2014. Each interview takes approximately 35 minutes and consists of 5 sets of questions. The interview responses were analysed using content and clustering analyses. In the following lines, each set of questions is presented, followed by analysis. The second part of the chapter presents the clustering analysis investigating the users profiles and the main predictors that affect the users charging patterns.

A total of 15 participants (7 males and 8 females) at a Newcastle-Gateshead Area were selected. The selected sample covered a wide spectrum of active EV users who may have access to domestic, workplace or public CPs, users' data is provided in Table 6-1.

Table 6-1: EV study: participants' information summary spread sheet

ID	Ownership	Gender	Age	EV drive/year	Average Daily Ms	Living
EV1	Private Car	Male	c. 50	2 years	20 Miles	NE7
EV2	Private Car	Female	c. 30	3 Years	30 Miles	NE21
EV3	Private Car	Male	c. 50	2 years	30 Miles	SR2
EV4	Private Car	Male	c. 50	3 Years	30 Miles	NE25
EV5	Pool Car	Female	c. 30	2 years	30 Miles	DH3
EV6	Pool Car	Male	c. 50	3 Years	20 Miles	NE2
EV7	Pool Car	Female	c. 30	3 Years	10 Miles	NE6
EV8	Pool Car	Female	c. 30	3 Years	10 Miles	NE2
EV9	Pool Car	Male	c. 40	3 Years	40 Miles	NE38
EV10	Private Car	Male	c. 30	3 Years	10 Miles	NE7
EV11	Private Car	Female	c. 40	3 Years	10 Miles	DH1
EV12	Private Car	Female	c. 30	3 Years	20 Miles	NE3
EV13	Pool Car	Female	c. 30	3 Years	20 Miles	NE21
EV14	Private Car	Male	c. 40	1 Year	40 Miles	DL16
EV15	Pool Car	Female	c. 30	1 Year	10 Miles	NE6

The participants have been using the EV Nissan LEAF for at least 12 months and living or working in the inner urban core of Newcastle. The sample size encompasses private users (own their EVs) and fleet users (maybe used for private purpose). The interviews aimed at evaluating the behaviour of EV use (private and fleet, 50% split). The intention of including fleet users is to gain insights into the use of EV from a different angle.

6.4 EV Interview: Participant's Profile, Motivation and EV Use

The first set of questions investigated participant's profiles and purchase intention process. The set contains two questions:

1. *Profile: age, gender, home address and work location?*
2. *What motivated you driving an EV? (Private EV users)*

This section aimed at investigating the attitude toward willingness to use an EV. The first question addressed the participants' profiles, responses were tabulated, see (Table 6-1). Gender and age are basic criteria addressing socio-demographic side of EV and non EV mobility studies. Understanding gender differences is essential to policy, marketing, and EV charging infrastructure deployment to ensure that sustainable mobility is appealing and accessible to all users (Caperello et al., 2014; Franke & Krems, 2013b). Gender has been an influential factor that determines the driving habits. The gender dynamics of consumer tastes in the context of EV was addressed in previous studies (Hjorthol; SwitchEV, 2013). In order to explore the possible nexus between the different dependent variables that affect use of EV, the variables are assessed with respect to the gender. The first variable is the age, see (Table 6-2). The majority of users are senior males and young females.

Table 6-2: EV participants' age versus gender (n=15)

Drivers	Male	Female
c. 30	7%	47%
c. 40	13%	7%
c. 50	27%	0%

The second question addressed the decision of electric driving (particularity owning an EV referring to private users). Usually the main intention to purchase is a replacement of an old car or shifting to car as a primary form of mobility (Rolim et al., 2014). The participants (n=15) responded to this question differently. Motivations ranged between the environmental concerns of conventional means of transport 40%, the habit of being a technology geek 8%, long-term based financial calculations 30%, the self-satisfaction of being early adopters 12% or a risk taker (Social image) 10%. Based on the content of the responses, a flowchart was developed, see (Figure 6-7). The users indicated their opinions about purchase intention process.

> *"I had an accident and my car was a total loss. I had a road trip with my friend who has an EV, and guess what, the very next day I decided my next car is NissanLEAF."[EV 2, F, c.30]*

"I am happy to use an EV but still will not buy my own."[EV 6, M, c.50]

"I would recommend the EV for those who commute short distances to work." [EV 12, F, c.30]

"I am very passionate about it. I work for a service provider and I can see a very positive future of charging points deployment." [EV 12, M, c.40]

The purchase decision takes time and passes through phases. Based on the interviewers' responses to this question and to the following "Access to charge" question, a flowchart was drawn to illustrate the process, see milestones in (Figure 6-7), and the process may end up purchasing a conventional car. One of the key factors is to have access to charging (domestic) and workplace.

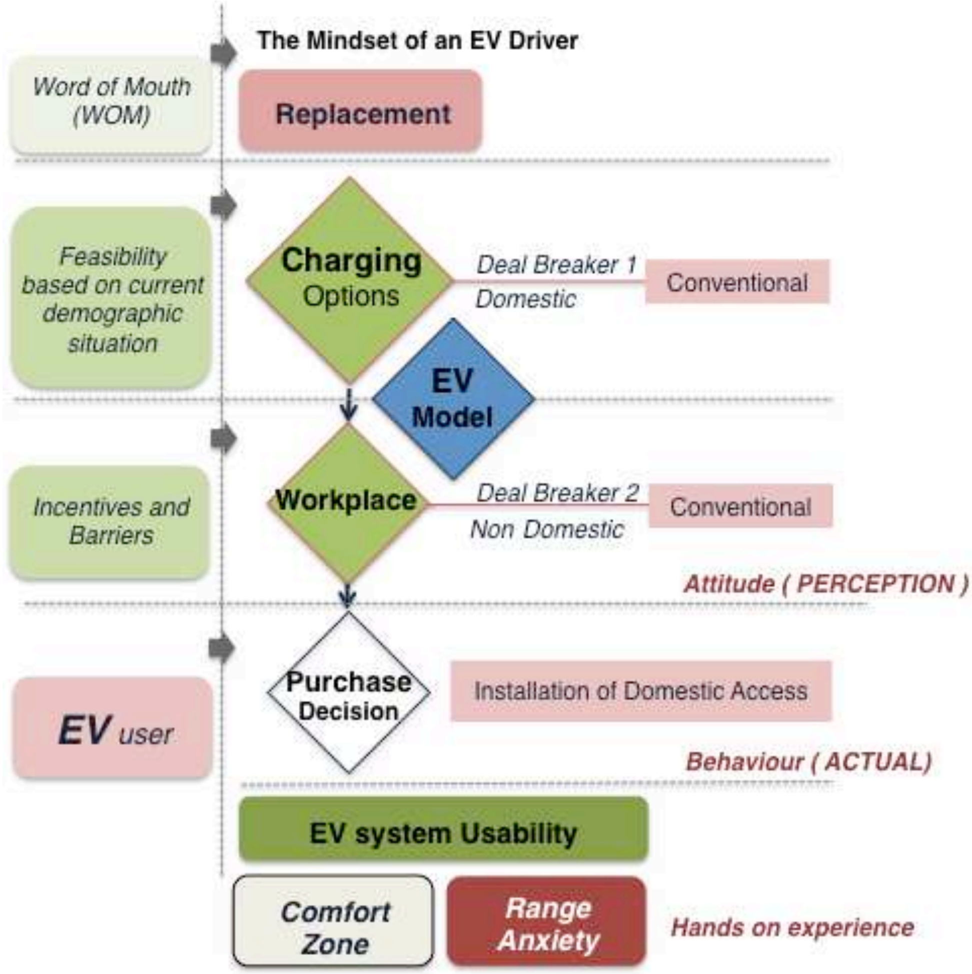


Figure 6-7: EV purchase intention process flowchart

6.5 EV Interview: Access to Charge, Workplace and Charging Frequency

The second set of questions addressed charging preferences and daily trips. The set contains five questions:

3. *Do you have access to domestic charging? Workplace charging? If you do not have access to domestic charging, would you still consider having an EV?*

4. *What is the average of your daily destinations? (Number of destinations you reach- number of trips) Example: 2 destinations (xxxx and yyyy)*

5. *How many times (in days) you drive your EV/ week?*

6. *How many times you charge your EV/ week?*

7. *What is the usual SOC that you arrive to a charging point? Example: 20 miles left OR 10% of the battery charge left.*

The third question is associated with the purchase intention and process. As shown in Figure 6-7, the first milestone of the process arises with the exploration phase of a possible available domestic charging facility. This was reflected on the third question responses as: all private users had full access to domestic chargers. The private users indicated the importance of domestic which proves the previous studies' outcome (Rolim et al., 2014; Skippton & Garwood, 2011; Anable et al., 2011). All private users responded that they would not have contemplated buying an EV if there was no access to a domestic charging. However, this is not the case for all EV users, fleet users have a different opinion.

> *"I do not worry too much about the non domestic charging, I do the daily trip planning briefly on my head as there are only 3 or four destinations."[EV 1,M, c.50]*
>
> *"My wife always asks me if I charged my car though she never voluntarily plug it in when both at home".[EV4, M, c.50]*
>
> *"I drive my EV for everyday use. This does not mean I can only rely on domestic charging." [EV11, F, c.40]*
>
> *"I am a fleet user, I never charged at home."[EV13, F, c.30]*

The second milestone of the purchase intention process is the workplace charging which was reflected by the respondents' feedback. Recently, workplace charging has gained more attention by the stakeholders and the end-users. After checking the domestic access, the selection of the EV model takes place. By this the attitude phase finishes and the use of EV starts where the driving and charging behaviour commences (Turrentine & Lentz, 2011;Turrentine et al., 1992).

> *"I live 3 miles away from work, I do not have kids at school, and Nissan Office is next my Office, so why to worry? However, if any of these parameters change, I have no idea what to do." [EV2, F, c.30]*

> *"I used to charge at home until I know that I may charge at work and even cheaper. Now my domestic charger is the workplace one."[EV14, M, c.40]*

The fourth, fifth and sixth questions addressed the number of destinations per day and the use and charge frequency of the EV over the week. The 15 responses were analysed and a visualisation of the driver's diary was created, see (Figure 6-8). The average of weekday-daily destination rate is two (work+ school (drop-Off /pickup)); however, the school is on the way home, which does not consume more than two to four miles extra to the road trip, see (Figure 6-8).

The workplace charging practice has a different nature than public charging network. Employers as public or private bodies, promote an environmental image by providing CPs (workplace CPs) and offers EVs to their employees. This refers to two other types of cars: i) fleet for work use only and ii) fleet for work and private use. The first type is the case of fleet users interviewed. Furthermore, community interest groups like public access car clubs, started to include EVs in their fleet (CoWheels, 2011; Fleet Drive Electric, 2008). Car sharing is becoming more and more common. The UK is the largest European carpool representing 12.1% of the total EU fleet.

Charging facilities shared by staff members and visitors requires an internal communication platform. EV4 is a participant who has access to workplace charging facility. There, the EV users communicate with each other to manage the shared charging facilities via internal system.

> *"We have a mailing list, once I reach work and I need to charge, I look for the empty bay and send a note to the mailing list notifying them and also I do the same once I am done."[EV14, M, c.40]*

The fifth question addressed the weekly charging frequency. The main differences arose between the private and the fleet users, see (Table 6-3). The private users tend to charge from five to seven times a week (domestic + workplace). Fleet users charge only at workplace with a different frequency depending on the number of users charging the car and their locations.

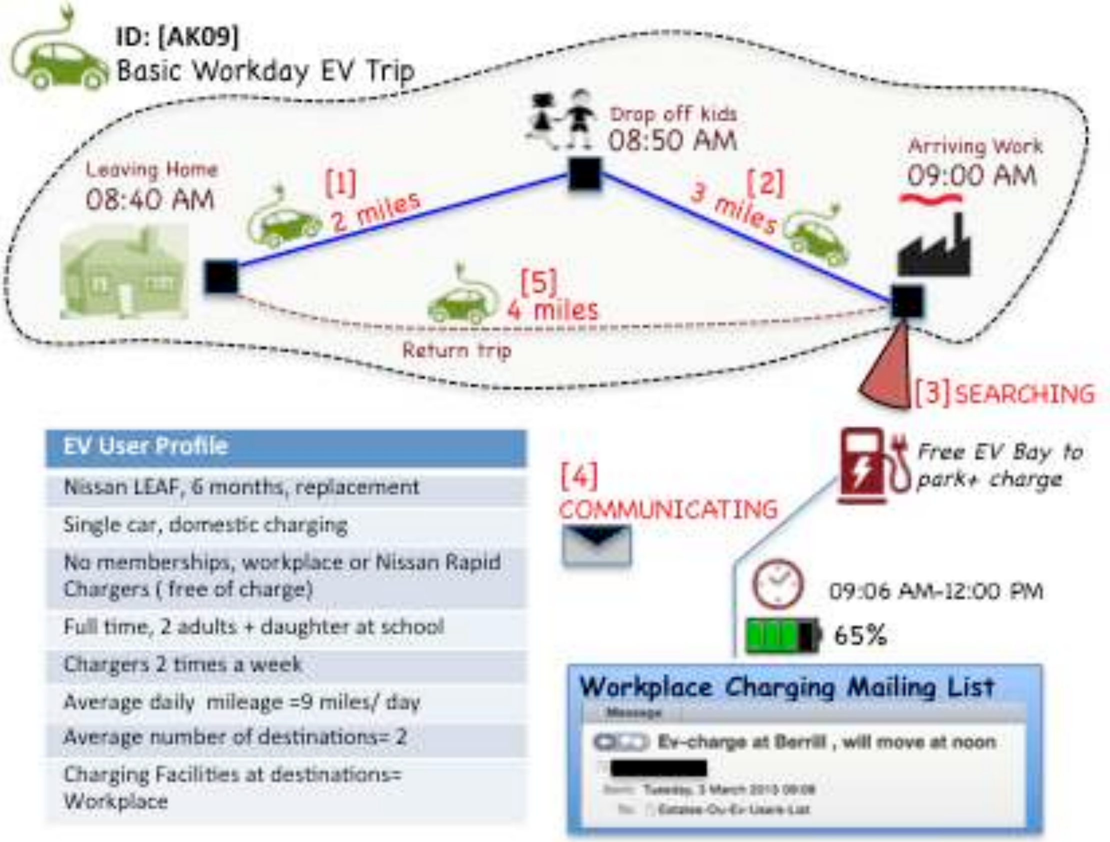


Figure 6-8: Participant EV4 dairy visualisation and profile

The gender had an effect on participants' responses to SOC related question. The seventh question regarded the usual SoC on arrival, see (Table 6-4). The private use of the EV affects the SoC and the frequency of charge at the workplace. By visualising the responses, see (Figure 6-9), a comparison between EV fleet and private use of EV is depicted in terms of (access to charge, number of charges per week, and weekend/weekday use of EV),

Table 6-3: EV participants' charging frequency versus ownership (n=15)

Charge/W	Private	Fleet
2	0%	10 %
3	5%	20%
4	0%	0%
5	15%	10%
6	0%	0%
7	30%	10%

Table 6-4: EV participants' SoC versus gender (n=15)

SoC	Male	Female
Below 20%	7%	0%
20%	7%	20%
30%	20%	13%
50%	13%	20%

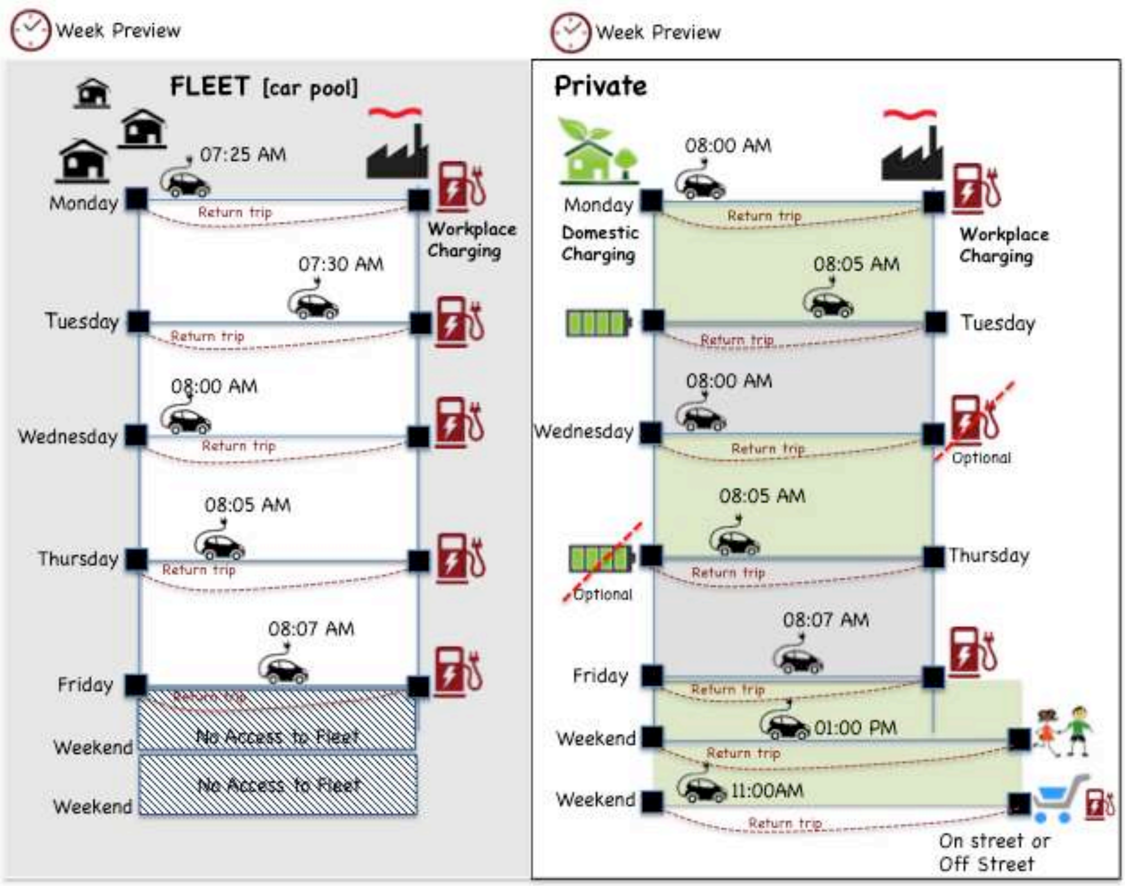


Figure 6-9: Visualisation of fleet versus private EV users

6.6 EV Interview: Participants' Charging Patterns

The third set of questions addressed charging patterns as follows:

8. *Do you commute across postal zones in NE to reach your work? (please specify the first part of your work address) Example: I live NE4 and commute to work in NE33)*

9. *How can you describe your driving comfort zone? (time, mileage, or area). Example: After commuting "XX" miles, I start to feel worried about my state of charge (Attitude)*

10. *What is the minimum SoC you can tolerate?*

The eight question aimed at identifying the daily-mileage commuted by EV users by counting the number of the postal zones the participants drive through from home (origin) to work (destination). The responses to this question are included in the clustering analysis, which is discussed later in this chapter. The ninth question is more attitude-oriented, asking the respondents about their range personal preferences. From this perspective, the higher the percentage the individual indicates, the more conservative they are in using their cars (less confident). A further 7% (males) of respondents reported a wide comfort zone driving an EV. This means tolerating a very low battery (one to two cells charged out of 12 or below 20% SoC). No occurrence of female respondents expanded their comfort zone to the same extent. The smaller the comfort zone (closer to the origin), the more the female drivers occur. At a small comfort zone circle (equivalent to 50% charged or more), 20% was female and 13% were males, see (Table 6-5).

Table 6-5: EV participants' charging behaviour versus gender (n=15)

SoC % left (the min the user tolerates)	Comfort Zone	Male	Female
Below 20%	(1-2 cells)/12 cells	27%	13%
20%	(3-4 cells)/12 cells	13%	13%
30%	(5-6 cells)/12 cells	0%	20%
50%	(7-9 cells)/12 cells	7%	7%

The respondents indicated that they would experience severe anxiety by reaching this stage, but it is not on an everyday basis or even weekly. For example, see (Figure 6-10), a trip to the airport will not consume the whole battery. The respondents reported that this only happens when:

> *"I have been driving my car for 3 years now, I usually reach 15% charge on my third day on a raw not charging, this happens when I arrive at the workplace to charge. Yes, I do have anxiety by then, but manageable because I know where to charge."[EV4, M, c.50]*
> *"Below 20%? This never happened to me and I will make sure it does not happen. I will be scared to death."[EV8, F, c.30]*
>
> *"my anxiety sometimes differs. It depends on where I am and how familiar I am with the vicinity (charging points/ nearby home charger at friends or family."[EV11, F, c.40]*
>
> *"Being down to 20% SoC is not in my favour. This may take place only if I have strictly necessary trip and will prefer finding alternative charging solutions."[EV11, F, c.40]*
>
> *"I do not see this possible, having said my routine and charging accessibility. But yes, I will be having a severe anxiety."[EV12, F, c.30]*
>
> *"It happened once before I installed my domestic charger, and I promised myself it will never happen again. I can not even foresee this as I do not use my car that spontaneously, yet."[EV14, M, c.40]*

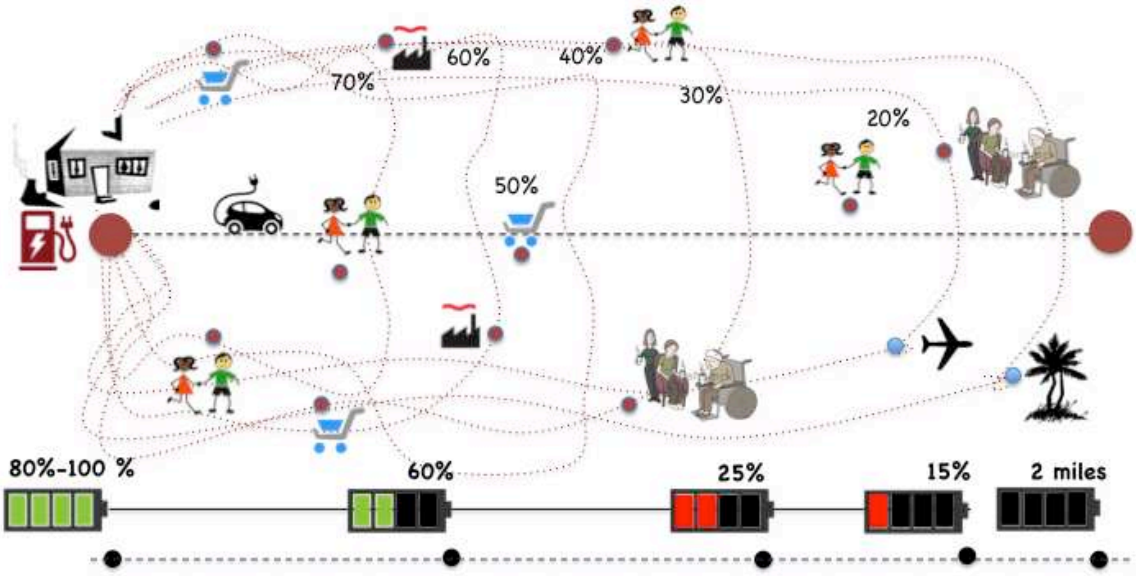


Figure 6-10: State of charge associated with daily commuted trips

The responses can be visualised in a word cloud showing the most frequent words, see (Figure 6-11). Charging (35%), RFs (20%), range and purchase intention (10%), and EV users and driving (5%) are the most frequent words mentioned in the respondents' feedback to interview questions.

Figure 6-11: Interview topics' cloud

The tenth question addressed the charging behaviour. The respondent was asked to indicate the minimum SoC ever reached. On the contrary, the lower the percentages the respondents indicated, the more confident they are. This question is addressing their everyday patterns as what is the lowest state they reached spanning their driving experience. This question is different to the usual SoC when arriving at a CP. The latter would indicate when the user tends to charge (whenever possible or when needed). Fleet users didn't reach a low charge due to charging accessibility and limited distances commuted. Additionally, females (13%) indicated that it was under very special circumstances that they reached this level.

> *"I didn't charge on Monday at the workplace, I went to pick a friend from Newcastle Airport on Tuesday and was having a meeting outside my company premises on Wednesday. On my way back home after the meeting I was a little bit worried as it was my first time seeing the counter reading 20% charged!"[EV 2, F, c.30]*

The results showed how different the perception and the actual values can be with regard to minimum SoC, see (Table 6-6).

Table 6-6: Participants' records of comfort zone and minimum SoC (n=15)

Participants	**Perception** Attitude: what is my comfort zone? In SoC	**Action** Behaviour: what is my minimum SoC you reached?	**Status**	**Gender**
EV1	20%	45%		
EV2	45%	25%	Stepping out the comfort zone	FEMALE
EV3	60%	70%		
EV4	24%	15%	Stepping out the comfort zone	MALE
EV5	35%	50%		
EV6	5%	40%	Inconsistency	MALE
EV7	40%	40%		
EV8	50%	60%		
EV9	5%	60%	Inconsistency	MALE
EV10	70%	30%	Inconsistency	MALE
EV11	20%	30%		
EV12	20%	20%		
EV13	5%	20%		
EV14	10%	10%		
EV15	5%	50%	Inconsistency	FEMALE

An inconsistency is observed when analysing the interviews. The records of some respondents, who indicated a tolerance to an expanded comfort zone, were inconsistent in terms of minimum SoC, see (Table 6-6). A further 60% of users have indicated a conservative experienced SoC compared to their indicated comfort zone values. However, two cases (EV2 and EV4) reported that they experienced RA as the minimum SoCs they reached were below their comfort zone values. The users justified that these two cases happened under special circumstances. Out of 15 users, 26% (3 males and 1 female) have inconsistency in their attitude-behaviour process. Although it is based on direct experience (as being active users for more than one year), those users experienced different minimum SoCs than the tolerable values they indicated. This does not mean that the SoC Perception and Action percentages should have been identical. Users at the point of the interview may not have had the chance to experience full electric range although they were willing to. However, the inconsistency, which is referred to, pertains specific cases (EV6, EV9, EV10 and EV15), where the two values showed a significant difference.

6.7 EV Interview: Participants' Perceptions

The fourth set of questions explored the travel demand, flexibility of and willingness to spend time charging an EV over the course of a journey.

11. *In which road trip you usually charge your car? (maybe multiple)*
12. *EV Range: Does the confidence level improve by practice?*
13. *How much time are you willing to spend to charge your battery during a working day?*
14. *Is there any time of the day at which you regularly struggle to find an empty charging point?*

The eleventh question aimed at identifying (timing/ road trip) of the non-domestic charging events made by the participants. The respondents were asked to identify in which trip purpose the charging event likely occurs, see (Figure 6-12). As for the non-domestic CPs', 90% of respondents charge in the morning on their way to work or at noontime at the workplace.

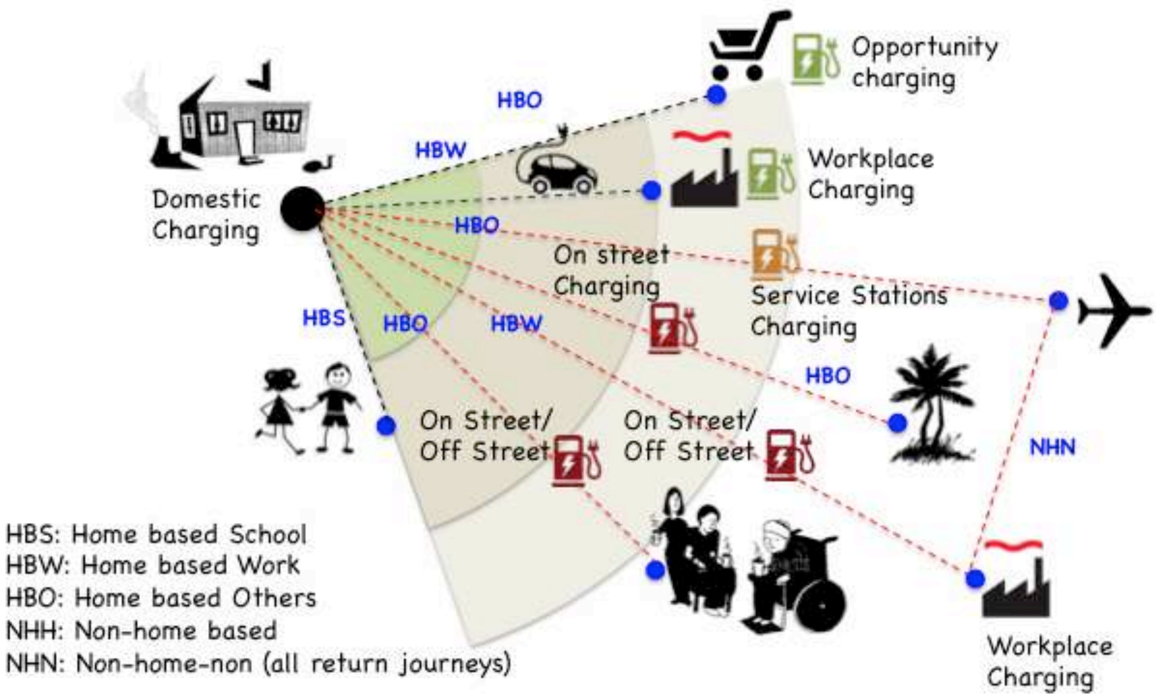


Figure 6-12: Types of trips and the charging event

The twelfth question ascertained the relationship between the years of driving an EV and the user's confidence of driving an EV. The majority of the participants have been driving an EV for 3 years (females and males). Only two participants (male and female) had been driving for one year, see (Table 6-7).

Table 6-7: EV participants experience versus gender (n=15)

Drivers	Male	Female
Newly Joined	14%	13%
Experienced	29%	13%
Early Adapters	57%	75%

The thirteenth and fourteenth questions were designed to identify the anticipated peak time of charging using the non-domestic network (to be included in the clustering analysis).

6.8 EV Interview: Future Investment

The fifth set of questions concluded the interview by interrogating the participant's perception on the current network and individual feedback on possible future investment. The set contains three map-based questions:

15. Is the current recharging network in Newcastle sufficient? See (Figure 6-13).

16. Mark your preferred CPs in NE1, NE4 and NE8, see (Figure 6-13).

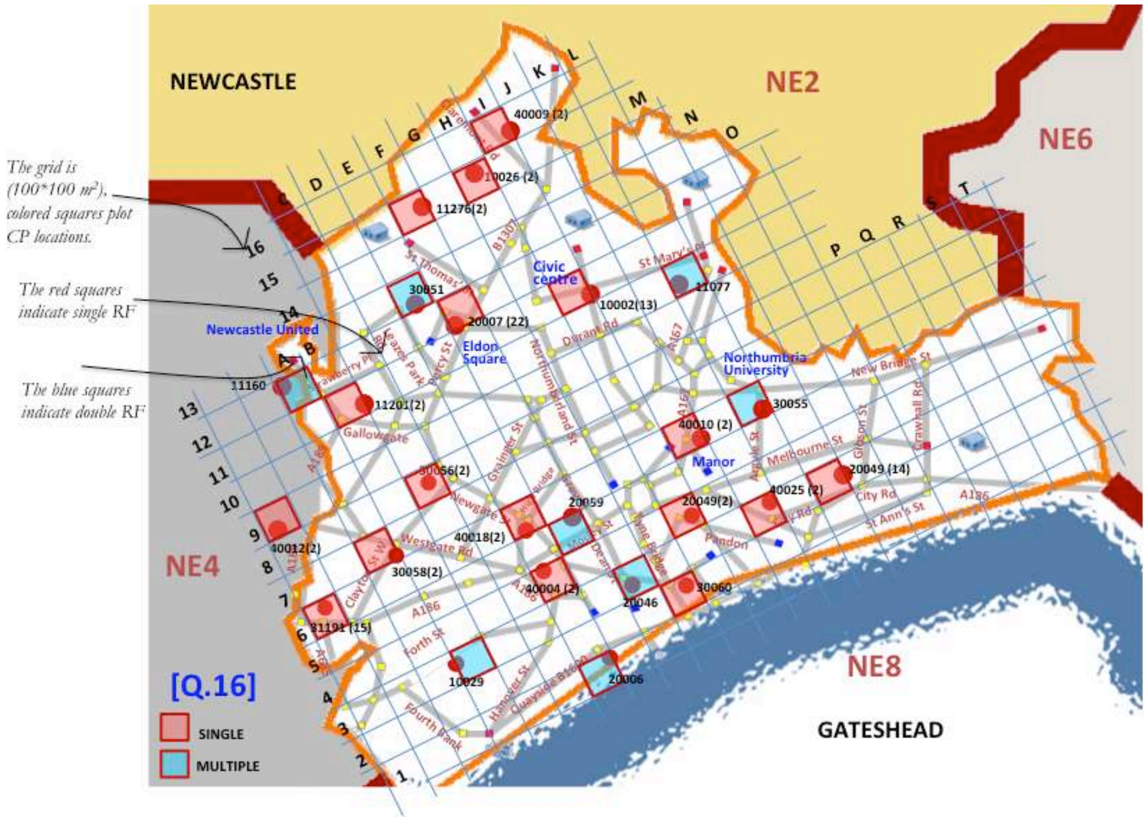


Figure 6-13: Interview map: respondents were asked to identify the preferred RFs

17. *Do you think the current RFs are sufficient? Do the service provider and planning authorities need to activate extra/ deactivate points in special areas? The respondents were asked to indicate (A) for Activate and (D) for Deactivate, see (Figure 6-14).*

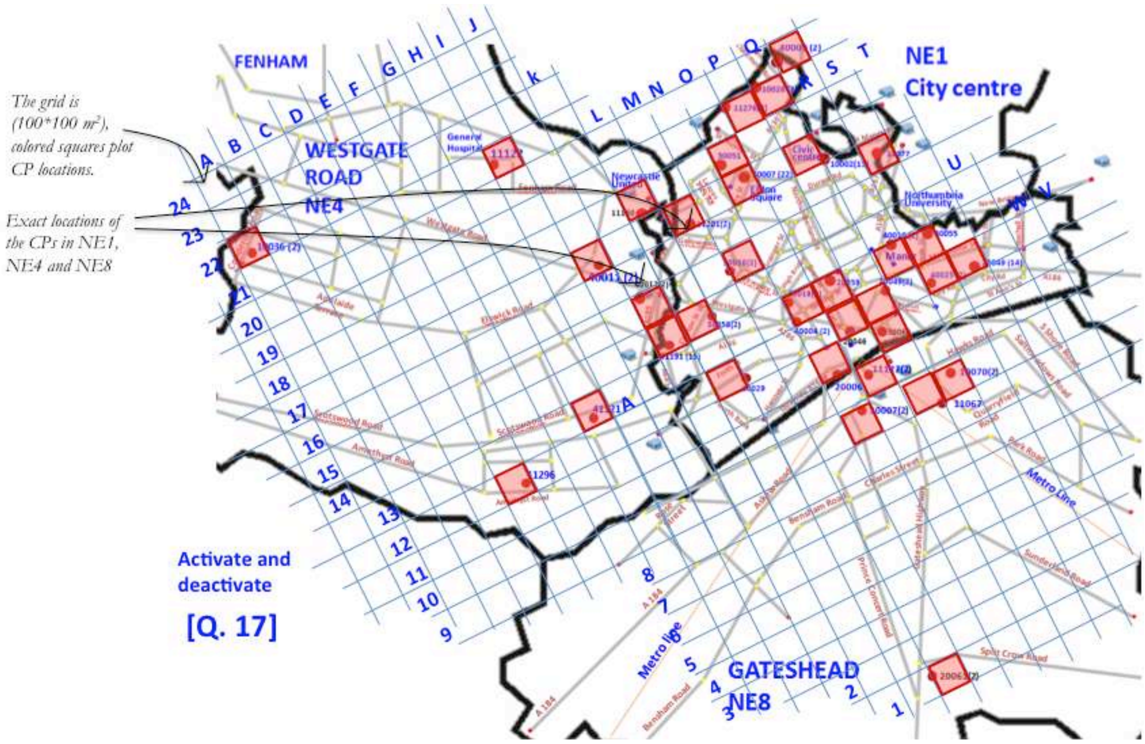


Figure 6-14: Interview map: respondents were asked to mark (activate and deactivate) the RFs

The responses were gathered and tabulated to highlight the end-user's feedback and perception of the current network. The respondents were asked to identify the other locations they think required investment (mentioning in writing the places which need CPs) and to write messages to the stakeholders (service providers in particular).

6.9 A Synopsis of the Context of EV Use

The selected users are young and older adults who have fair knowledge of e-mobility. The outcome of the interview followed the trend already found in other studies. This study yielded insights into the users' attitudes towards driving an EV. The aim of the study was to assess users' satisfactions and adoption to EV technology. A sub-set of the issues addressed through the interviews was presented, which covered: i) workload and ii) range-battery scale. The interview was conducted with the participants to address aspects such as driving behaviour, mobility patterns, and charging routines. From a statistical point of view, interviewing 15 users is not significant. However, the sample size and variety compared to the overall population is an indicator. From the interviews, the elements that affect the Range Anxiety (RA) occurrence can be summarised and displayed in Table 6-8.

Table 6-8: Synopsis of the context of EV use

Factors	In the context of EV use	
Gender	**EV Male Driver**	**EV female drivers**
	Male EV drivers are more confident and are risk-takers. They always take control on charging the car at home and ready to expand their journeys to practice some of the full electric range. This element is very critical because the driver's attitude is different than the behaviour. The minimum SoC that a driver reached still not below the 20% which reflects that the full electric range hasn't been experienced before by respondents.	The female drivers tend to be more conservative with the driving comfort zone.
Driving Experience	**Less one year**	**More then a year**
	Newly started driving an EV. Not that adventurous and this maybe because i) no chance, ii) less confident, iii) couldn't support the route (using non-domestic), iv) secondary car for short distant trips only.	Experienced driver. Some of them tried low SoC and shared their experience (negative). Others yet didn't try long journies for i) fleet car, ii) secondary car for short distant trips only, iii) only rely on domestic charger hence only short distances.
Temperature	**Summer**	**Winter**
	The temperature affects the time spent to charge the car and this is very significant in Rapid Charger case. This phenomenon is not significant in 3.3 & 6.6 kw Chargers. It is measurebale but significant.	Using Rapid Charge: In winter it may take double the time needed to charge the same amount of electricty. Considering also the SoC. Drivers often adapt their driving style to consume less power (driving at lower speed, switching Off heating).
Charge	**Domestic**	**Non-Domestic**
	Domestic access is a mandatory to all privately owned EV users. Fleet users rely on workplace charging access and have the car in case of used for perosnal use as a second car.	The charging capacity of the charger affects the time needed to charge. EV users are full time employees. A rapid charger would allow them to charge up to 40% of their battery capacity in 15 minutes which is equivalent to 30-40 miles. A daily routine would range between 8-15 miles a day and some cases 40 miles.
Time of day	**Peak and Off Peak**	
	When it is congested, the amount of energy consumed waiting (especially in winter using the heater) affects the normal energy usage.	
Purpose of the trip	**Urgent**	**Flexible**
	HBW, drop offs and pick ups are urgent journies. I) these trips are within the comfort zone of the EV driver , ii) daily routine, iii) planned and known, and iv) the prime reason of purchase (short trips), hence EV tends to be used heavily.	The trip may be re-scheduled or commutied using conventional car.

6.10 EV Study Clustering Analysis

The second part of the chapter discusses the clustering model. The clustering analytical method was previously discussed in Chapter 4 (4.4.2 Clustering analysis as a research tool). A TwoStep analysis was conducted to categorise the (n=15) users into different groups based on the recorded attributes. Due to the mix of categorical (gender, locations, CPs) and contentious (state of charge, age, years of driving) data types, the TwoStep method was chosen instead of the other two approaches: the hierarchical and k-means. The TwoStep generates a report with some graphs and figures showing the cluster quality, see (Figure 6-15), size, structure, see (Figure 6-16), and influential variables, see (Figure 6-17). The clustering process took several iterations until the most coherent structure was reached. The decision is made based on the cluster quality, a reasonable number of clusters, and the ratio of clusters' sizes to each other (the biggest to the smallest). The quality should not be poor, and the ratio should not exceed three. As for the predictors (the influential factors affecting the clusters formation), willingness to spend time charging scored the first non-polar attribute that affected the clusters membership formation. The second most influential non-polar predictor was the number of charges/week. The third-ranked predictor was the number of destinations/day, see (Figure 6-17).

Model Summary

Algorithm	TwoStep
Inputs	11
Clusters	3

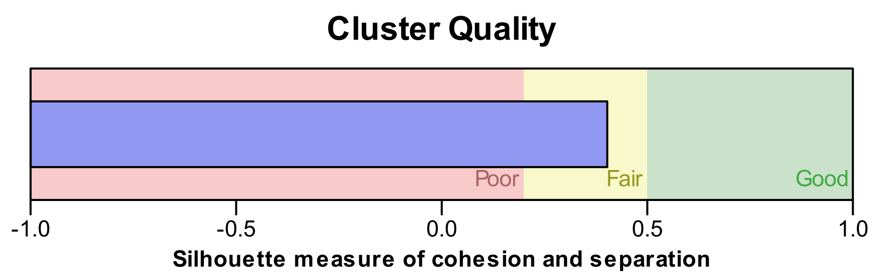


Figure 6-15: Clustering quality bar

Frequency of use/ week, willingness to spend time charging, domestic or non domestic, and willingness to use On Street were the points of assessment and evaluation of the formation of the clusters membership.

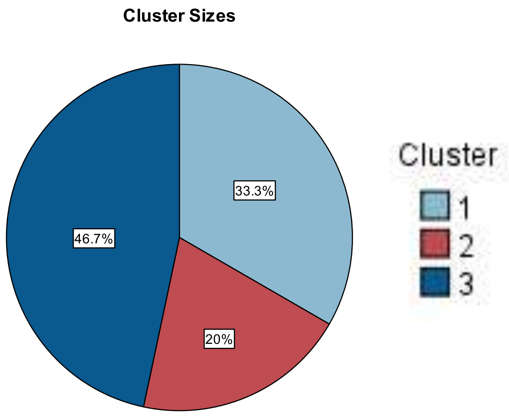


Figure 6-16: Clustering formation

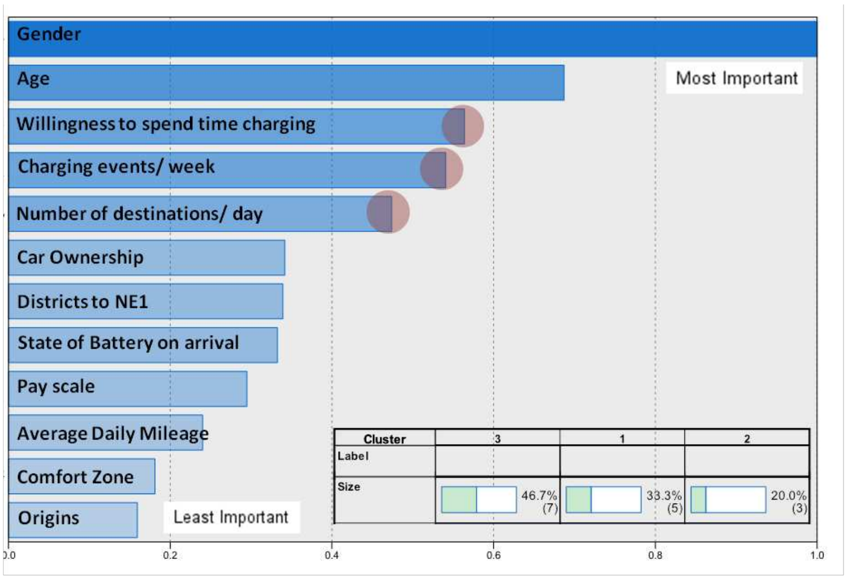


Figure 6-17: Clustering predictors

Spatiotemporal analysis of charging patterns was conducted using SPSS Statistics 21 (SPSS, 2012). The model output reflected the traits of the participants and managed to form a heterogeneous three clusters. The first group was termed, "The Risk Takers", see (Figure 6-18). It is the second biggest cluster, and contains individuals in the age group of 50-59 years old who had been driving their own EV now for more than three years. The majority were males who usually commute around 30 miles a day. They preferred the On Street CPs (such as the Grey street one, CP #20059). The number of destinations was two and they lived two miles away from the city centre. This group can tolerate up to 30% left in their batteries. Users of this group are the lucky few who have access to CPs; however, they can tolerate low charge with a high confidence levels of getting back home safely. The records showed that they charge 5 times a week, however, they drive around the city and reach the CP with only 30% charged. Those individuals are not happy and willing to spend more time charging; however, they see that investment in RFs is necessary. Compared to other groups, this group considered themselves as risk takers, they tolerate that their SoC being pulled down to 5% and then they start to worry about finding a CP. The majority of this group lived and worked outside the study area, commuting and passing through every day.

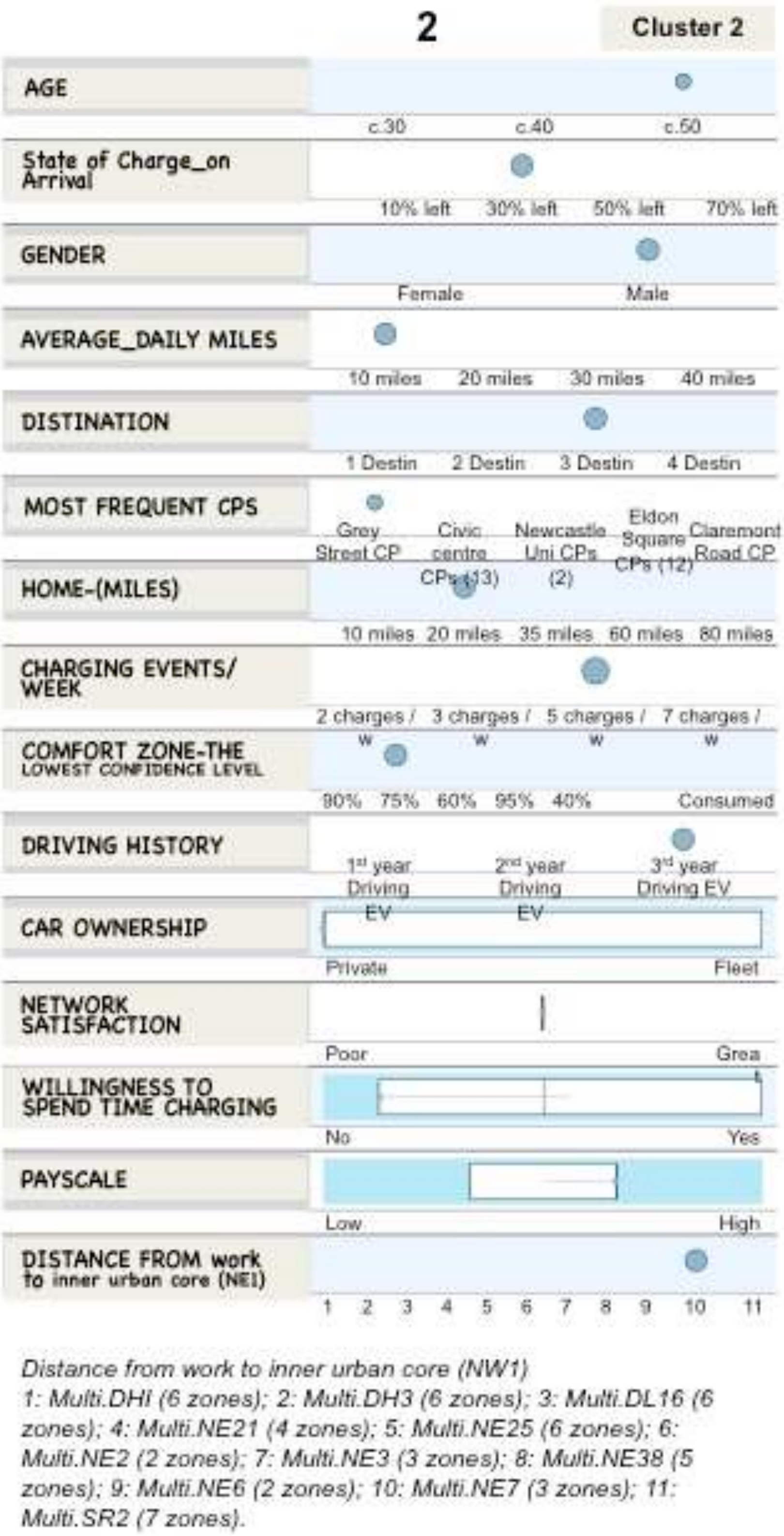


Figure 6-18: Cluster 1: "The Risk Takers"-SPSS

The second group was termed "The Old School", see (Figure 6-19). The cluster contains individuals in the age group 50-59 who had been driving their own EV for 3 years. The majority were males and they tend to commute around 10 miles a day, two destinations a day and they live 2 miles away from the city centre. It is suggested that this group has low confidence levels. They charged seven times a week and their SoC is always relatively high when they arrive at the CP, 70% charged. Those individuals are willing to spend more time charging their batteries within the day.

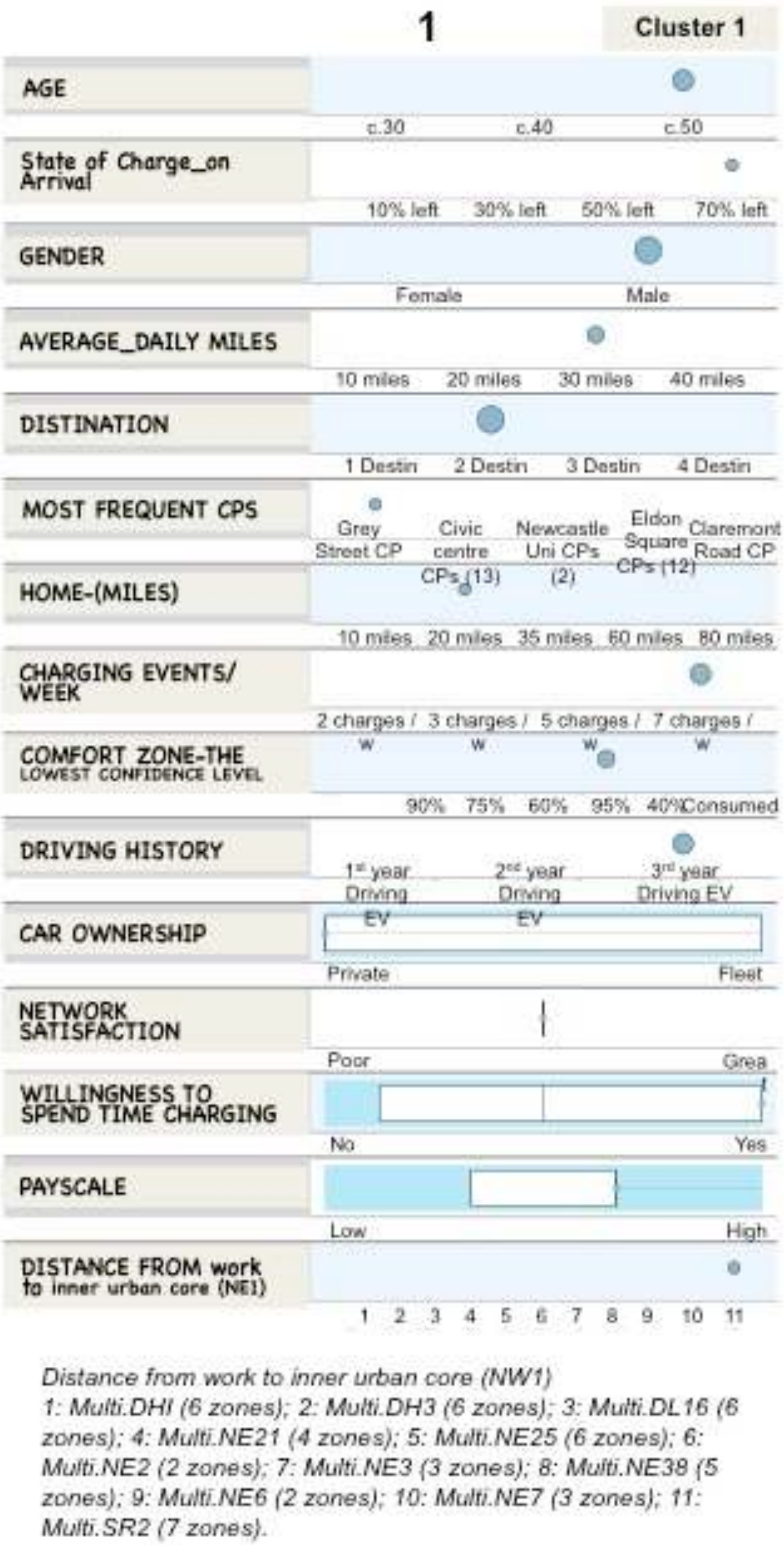


Figure 6-19: Cluster 2: “The Old School”-SPSS

The third group was termed “The Opportunists”, see (Figure 6-20). The cluster contains individuals in the age group 30-39 who have been driving an EV for three years. They do not own an EV; they go for the work-provided EV car pool option. The drivers of this group are females who commute 10 miles a day on average. The number of destinations was two and they live two miles away from the city centre. The car they use is usually charged at the workplace. This reflects the seven charges a week and explains why the state of charge when arriving at the CP is relatively high, 50% full of charge. Those individuals were not willing to spend more time in charging their batteries within the day.

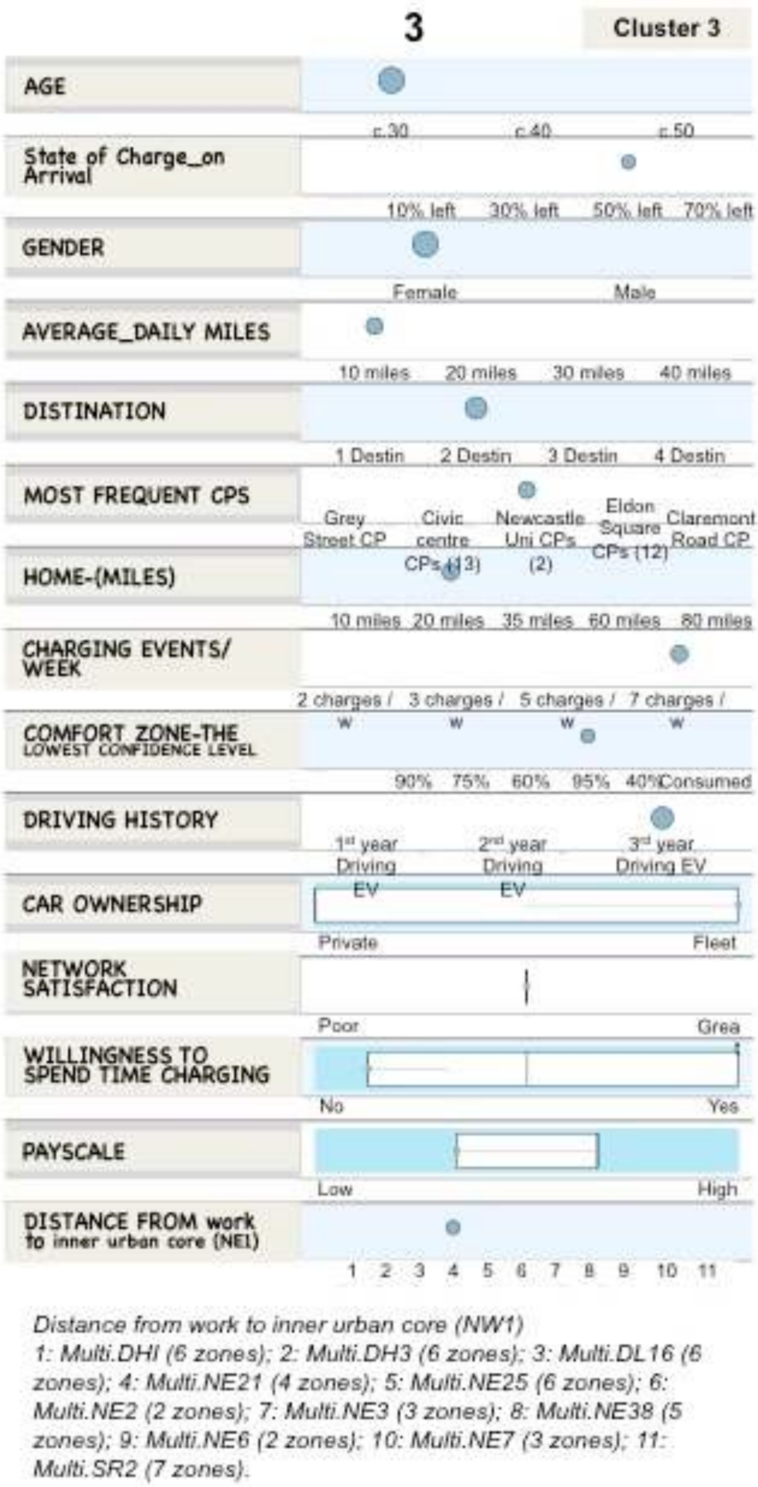


Figure 6-20: Cluster 3: “The Opportunists”-SPSS

6.11 Commenting the EV Study's Clustering Results

The EV user study presented a new way of investigating the users charging patterns, spatial awareness, and their network recognition. With the clustering analysis, the users' profiles were created and formed into groups with shared characteristics. These clusters may help the stakeholders to elicit the picture of the current system's users and work on satisfying their needs and demand. Each of the three-formed clusters has different paradigms. The Risk Takers are psychologically ready to deal with RA. They are willing to invest on infrastructure; however, they are not willing to spend time on charging especially the On Street option unless it is a quick charger. This means that the investment in slow chargers (types 1 and 2) is not in their favour or at least not to their preference, and may result in them not using slow chargers.

The Old School cluster has an issue with the driving pattern. It seemed that they do not expand their comfort zone. This zone is not metric measured; it is about the lowest state of charge at which they are confident to drive their cars. They can only consume up to 30% of their battery and within the comfort zone. They do not go further than their home, workplace or the zones within which they know they have access to charging. This group is cautious and conservative and do not tend to practise the full electric range.

The third group is The Opportunists, which included those individuals who are the majority of current users. This cluster supports workplace CPs. The Opportunists are aware of the environmental burden of conventional means of transport, they were happy to take initiatives; however, they cannot afford owning a private EV. The way they contribute to the EV market is by car pooling, using employers fleet and charge at workplace (Axsen et al., Calstart, Zhang et al., 2013).

6.12 Messages to The Planning Authorities and Policy Makers

The e-mobility is associated with socio-technical and psycho-temporal dimensions. It is observed that for private EV users, the main differences between driving an EV and a gasoline vehicle are related to the fact that:

- i) they are modest in their car requirements;
- ii) short distance commuters
- iii) most of their journeys are known and planned ahead (less spontaneous),
- iv) generally they use vehicles for short periods of time.

One of the main aspects to take into consideration when analysing EV user studies is to identify the main paradigms of the sample size. Although the sample size and variety compared to the overall population is indicative, the results of this study must be interpreted with caution. To measure the consumer's feedback in the different aspects of the context of EV use, user studies' conclusions are subject to change. To an extent, the outcome represents a sector of EV population. Nevertheless, the market is at the niche state:

i) more charging infrastructure is being deployed;
ii) EV technology is rapidly evolving
iii) influential demographic changes are foreseen;
iv) consumers' level of acceptance of EV technology improves.

6.12.1 Recommendation based on clusters

The interview aimed at investigating the users' charging patterns, profiles, each sub-set of questions focused on a particular facet of the e-mobility system of Newcastle-Gateshead area. The interview questions interrogated the driving confidence issue, RA, and the associated variables with the use of EV in its urban context. These variables were included in a clustering model which generated three main clusters of EV users.

The clusters' assessment is articulated in Table 6-9. It presents the evaluation criteria of the three EV users clusters in relation to the size of each group. The assessment shows the imbalanced state of the e-mobility system of Newcastle-Gateshead area. As per the sample size, only 30% of the users were happy to practise the full range of the EV and had high confidence level, the risk takers (this confirms the outcome of previous EV user studies presented in Chapter 5). Those users were not willing to spend time charging, which means they require quick charge (50-250 kw) and may relate to the TOP UP persona (using On Street). Another suggestion is that they are the LUCKY CHAGRE persona (using Off Street), in the case of using slow chargers. The Opportunists cluster forms over 50% of the sample size and this might be an explanation of the e-mobility low market penetration level. This group contributes mainly to The Superb and Beyond Charging personas. They use the non-domestic CPs; however, they tend not to use the publically available CPs as most of their charging events are made at workplace.

Table 6-9: EV participants' clusters assessment table

Assessment	the Risk Takers	the Old School	the Opportunistic
Sample size %	**30%**	**15%**	**55%**
Frequency of use/ week	80 %	100 %	100 %
Average time Spent willingness to spend time	Low	High	N/A
Domestic or non domestic	Domestic and On Street	Domestic, workplace, and Off Street	Workplace
Willingness to use On street	Yes but quick charge Only	Yes	They do not own EVs

This leaves only 15% of the sample size, the Old School cluster which uses the charging network relatively more than others. They are willing to spend time charging and invest in installing more CPs. This group is widely spread (the LUCKY CHARGE, the GOOD ENOUGH and the SUPERB) and they are using both On and Off Street CPs alongside the workplace, if any.

6.12.2 Concluding remarks

This chapter thoroughly covered the social practice of EV users through interviewing stakeholders, users and analysing their responses. In Chapter 5, the meta analysis provided insights into the previous consumer and user studies. Both Chapters 5 and 6 addressed the second research question:

RQ2: How useful are the user studies in the contact of EV use?

Responses showed that exceptions to daily routines require more planning effort; however, it is still manageable. Users form an interest in EVs based on their existing lifestyles and they adapt whenever necessary. This study provides insights into the context of EV use, some meaningful observations can be attained:

i) shapes the interview design process in away that can depict the social and psychological aspects of the EV use. This in turn could facilitate stakeholders in understanding the end-user perspectives;

v) highlights the importance of EV trial as it positively affects the perceptions of potential EV users;

vi) identifies the potential user profile and conveys a clear message to them with regard to RA. RA does not an everyday worry, it may happen occasionally;

vii) experience of driving an EV is associated with various aspects and elements that need to be incorporated when designing new models and planning for charging network.

CHAPTER 7. MODEL I: SERVICE PROVIDER DATA ANALYTICS

"Happens every time... Some Newbie keeps hanging the Plug on cable support @ElecHighway maybe more signs? #UKcharge."

By Dr David Beeton, Managing Director of Urban Foresight (2012)

This chapter presents spatiotemporal analysis of the e-mobility system of the Newcastle-Gateshead area. The chapter takes a data driven approach and is divided into two parts: RF-oriented analysis and user-oriented analysis. It studies the service provider (CYC) datasets I and II in addition to other spatial attributes, see (Figure 7-1). In part A, a clustering model is presented as it integrates the design configuration parameters, with site location features, and users' charging patterns. Part B analyses dataset II and creates five charging personas which are associated with charging spectra and profiles.

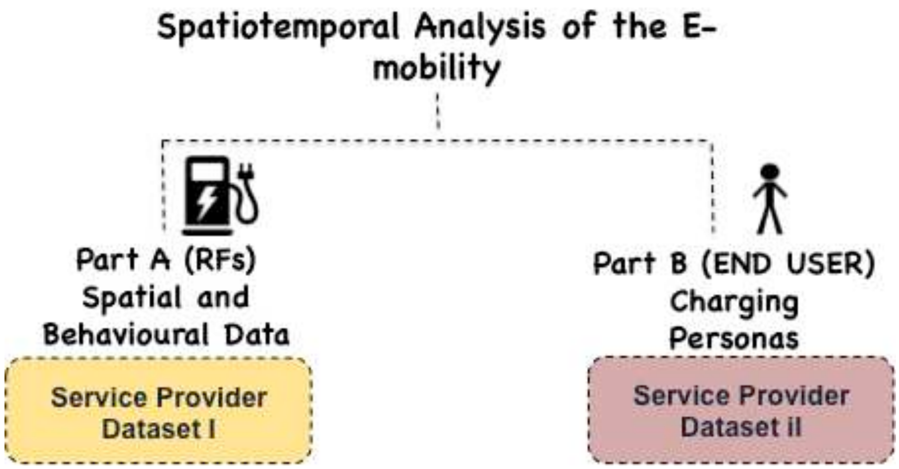


Figure 7-1: Chapter structure-parts A and B

7.1 Part A: Spatial and Behavioural Data

The first section of this part introduces the datasets provided by Charge Your Car Ltd. (CYC). This is followed by definitions and ways of quantifying four spatial and three behavioural variables. This chapter explores a list of some of the overlooked urban context-related attributes in the EV literature as this list was neither quantified nor analysed in the RF's design process. These variables are the input for the clustering model presented by the end of part A, see (Figure 7-2).

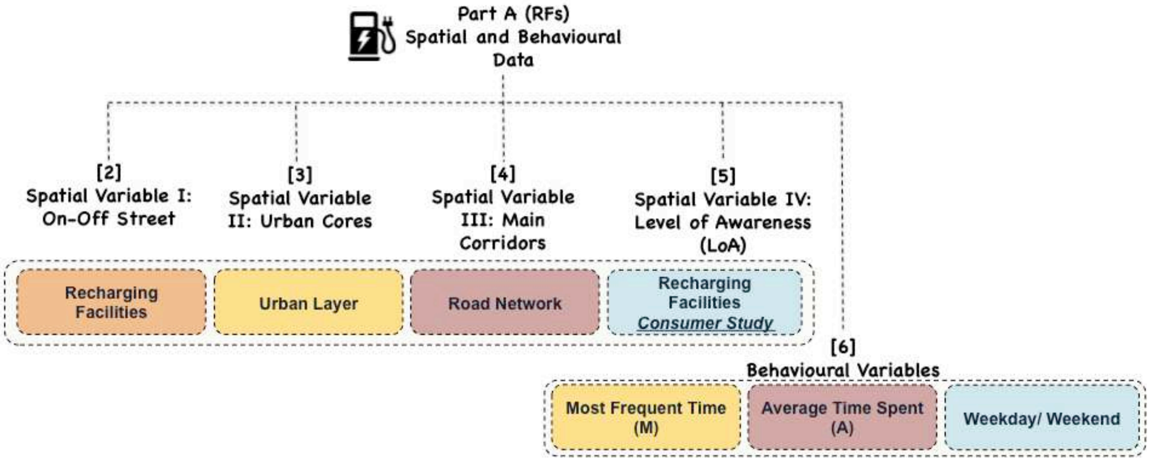


Figure 7-2: Spatial and behavioural data diagram

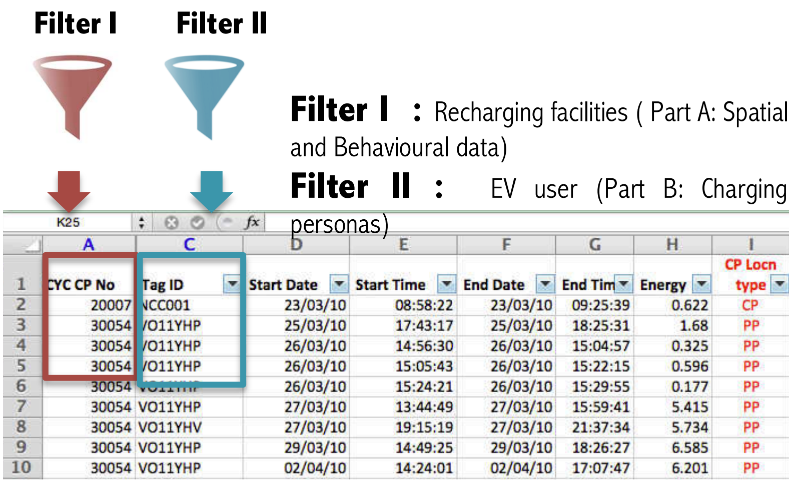
The CYC database has records of all the active and inactive CPs. The data is shown in Table 7-1. The table provides a full description about the posts: charger type, site name, street name, postcode, number of charging posts, power (3 or 7 kw), single or multiple outlets, date of installation and post ID.

Data about EV users is collected by CYC for each active post. If in one RF there are multiple points, each one generates separate usage records, (CYC CP ID). The CYC dataset is analysed using two filters. For part A, the data is sorted by CPs and all the analysis is network-oriented; whereas, for part B, the data is sorted by the EV user, see (Figure 7-3). In both filters, the time of the day and the time needed to charge/ energy used are recorded. As the user may charge overnight, or after midnight, the end date is also recorded, alongside the amount of energy consumed and the CP's ID.

Data was first received in 2012, recording the system operation starting from the second half (H2) of 2010, until the first half (H1) of 2012. The second wave was in 2013, to include H2 of 2012 and H1 of 2013. The last update was in May 2014, giving a full set of data for both users and CPs either active (in operation) and not. In addition, a list of registered users' homes was provided to integrate the postal district of the user home to the their charging profile (e.g., user tag ID: NX11DVK, lives in NE1).

Table 7-1: NE PIP standard CPs in Newcastle and Gateshead council areas

Charger Type	Partner / Host	Locations	Post Code	Qty Points	Qty Posts	7kW	3kW	Mixed	Outlets	Make	Date Commissioned/Install	Location No
Std	**Newcastle City Council**	Collingwood Street	NE1 1HE	2	2	2			Single	Elektrobay	30/11/10	40004, 40005
Std	**Newcastle City Council**	Dean Street	NE1 1PG	1	1	1			Single	Elektrobay	30/11/10	20046
Std	**Newcastle City Council**	Bigg Market	NE1 1UG	2	2	1	1		Single	Elektrobay	03/03/11	40018, 40019
Std	**Newcastle City Council**	City Road	NE1 2AF	2	2	1	1		Single	Elektrobay	23/02/11	40025, 40026
Std	**Newcastle City Council**	Quayside Car Park	NE1 2AQ	12	6	12			Double	Elektrobay	12/07/13	31207, 31208, 31209, 31210, 31211, 31212, 31213, 31214, 31215, 31216, 31217, 31218
Std	**Newcastle City Council**	Quayside Car Park 7th Floor	NE1 2AQ	2	2	2			Single	Elektrobay	18/07/12	20049, 30050
Std	**Newcastle City Council**	Melbourne Street	NE1 2LA	2	2	2			Single	Elektrobay	23/02/11	40010, 40022
Std	**Newcastle City Council**	Swing Bridge	NE1 3RQ	1	1	1			Single	Elektrobay	30/11/10	20006
Std	**Newcastle City Council**	Akenside Hill	NE1 3UG	1	1	1			Single	Elektrobay	30/11/10	30060
Std	**Eversheds**	Central Square, Newcastle Upon Tyne	NE1 3XX	1	1	1			Single	Elektrobay	21/02/12	10029



	A	C	D	E	F	G	H	I
1	CYC CP No	Tag ID	Start Date	Start Time	End Date	End Tim	Energy	CP Locn type
2	20007	NCC001	23/03/10	08:58:22	23/03/10	09:25:39	0.622	CP
3	30054	VO11YHP	25/03/10	17:43:17	25/03/10	18:25:31	1.68	PP
4	30054	VO11YHP	26/03/10	14:56:30	26/03/10	15:04:57	0.325	PP
5	30054	VO11YHP	26/03/10	15:05:43	26/03/10	15:22:15	0.596	PP
6	30054	[illegible]	26/03/10	15:24:21	26/03/10	15:29:55	0.177	PP
7	30054	VO11YHP	27/03/10	13:44:49	27/03/10	15:59:41	5.415	PP
8	30054	VO11YHV	27/03/10	19:15:19	27/03/10	21:37:34	5.734	PP
9	30054	VO11YHP	29/03/10	14:49:25	29/03/10	18:26:27	6.585	PP
10	30054	VO11YHP	02/04/10	14:24:01	02/04/10	17:07:47	6.201	PP

Figure 7-3: Screenshot of datasets (different filters to apply) in addition to years of operation

7.2 Spatial Variable I: On and Off Street

In order to interrogate the importance of accessibility, the first variable is the On-Off Street charging options. In this thesis, this variable is referred to as:

> *"A location-based value which identifies the CP measure of accessibility within the charging network. It is a dummy variable, e.g., if a CP is Off Street, it will take one for being an Off Street and a value of zero for not being an On Street CP."*

By disregarding all other RF's design measures and only focusing on its accessibility, the difference in the use of On and Off Street options is clear. The dataset contains 38 CPs (18 are Off Street). As per the charging events' records (charging event is each time the EV driver plugs in their car in a non-domestic CP), the Off Street CPs form 66.6% of the total charging events. Figure 7-4 shows the relationship between the CP's accessibility and times it has been in use (charging events).

This suggests that investors and local authorities should direct their investment to install Off street CPs as this should generate more profit. However, with the current state of the charging network (rapid chargers are not widely spread) this will lead to:

i) users will rely more on domestic charging which potentially will add more loads to the grid;
ii) users will need to dedicate more time for charging and amend their routine to use the Off street CPs;
iii) users who work for employers that do not provide workplace charging facilities may not have convenient access to non-domestic CPs;

iv) garage orphans might not have a daily (weekdays only) access in case there is no workplace option;

v) the targeted sector will be narrowed down to those who live close to commercial areas or have workplace charging access. By this, more limitations and barriers are added that hurdle and lessen the market penetration.

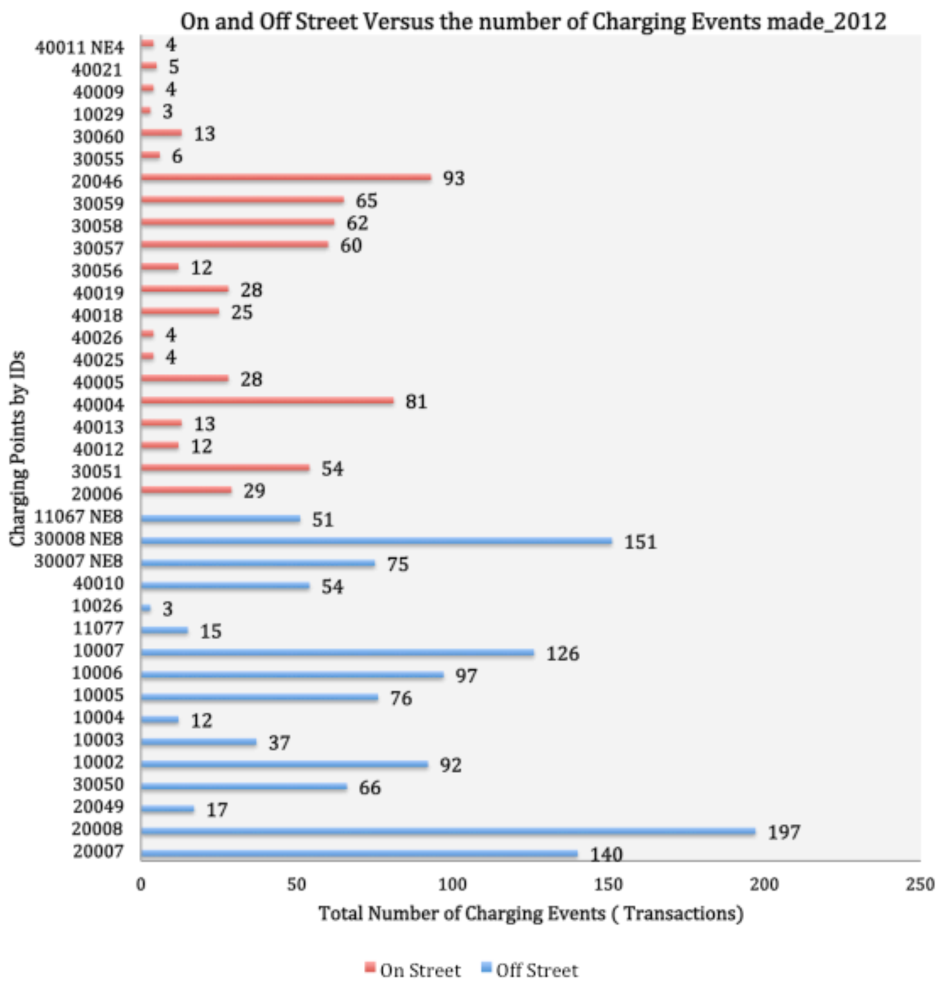


Figure 7-4: On and Off Street CPs and the number of transactions_2012

Accessibility is also associated with the number of CPs in one site. Some On Street CPs score higher values compared to Off Street, for example CP #20046, #40004 are higher than #30050, #10005, and #30007, see (Figure 7-4). Accordingly, the RFs are categorised into four categories depending on the power supply and the number of the CPs in each site, see (Table 7-2). There are 13 RFs with multiple (double) CPs and 25 single post RFs. The installation of 7 KW power is most common. Figure 7-5 illustrates the 38 RFs of Newcastle-Gateshead area, urban core; RFs with doubled CPs are highlighted in yellow and single ones are highlighted in blue.

Table 7-2: Doubled and single CPs

Category	Multiple RF	Single RF	Ratio
Number of CPs in NE1, NE4 and NE8	13 CPs	12 CPs	
7 kw	9	8	65%
3 kw	4	4	35%

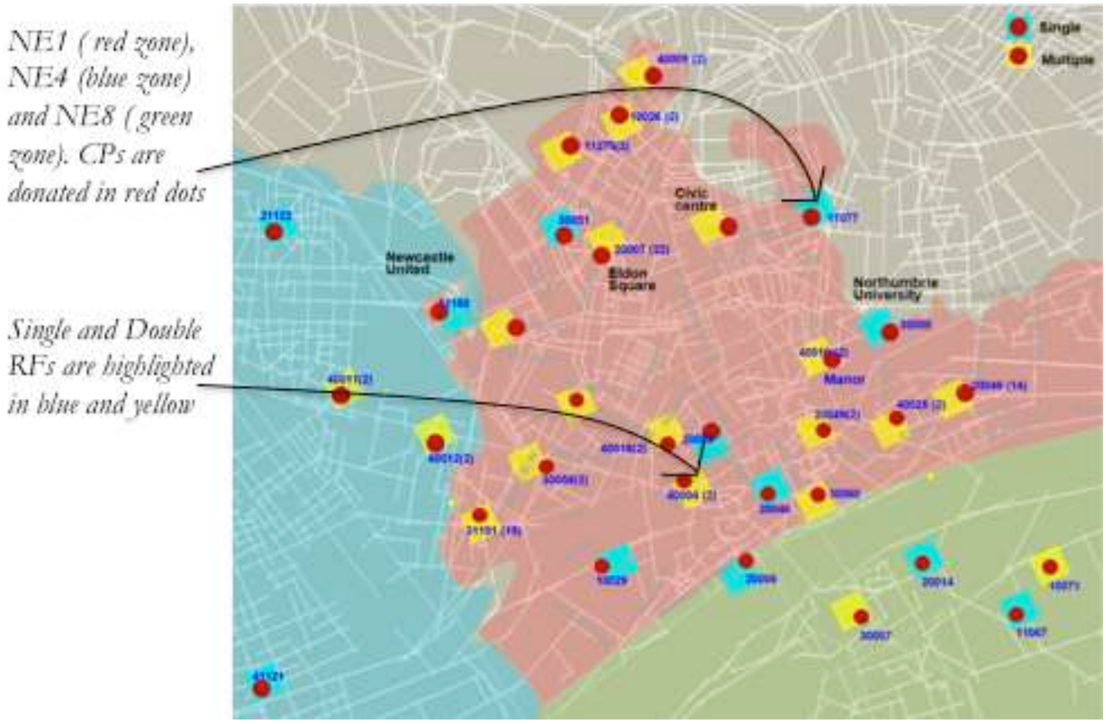


Figure 7-5: Locations of single and multiple CPs

7.3 Spatial Variables II and III: Urban Cores and Main Corridors

The second two variables are related to urban morphology and vehicular mobility in cities. Urban core areas, districts and zones are defined by urban policies, spatial planning reports and demographic records generated by the Government. The main corridors and arteries of vehicular mobility form the city structure and shape its urban expansion and development.

The metric distance from the nearest urban core is the second variable where the urban core is the:

> *"area that is defined by urban form, density, commercial area and travel behavior. This area is functionally more suburban and has high transit (work trip)." [Cox, 2014]*

The second variable is the traffic count of the nearest main corridor(s) to the CP. The traffic count is the Average Weekday Traffic (AWT) which is the average 24-hour traffic volume occurring on weekdays at a specific location for less than a year (in this thesis, the traffic count was collected from network main corridors for September, October and November 2014 avoiding holidays).

Each corridor is split into several links; real time cameras are located in main arteries covering links and major corridors (each link is covered by two cameras at both ends). To calculate the number of trips originated from a zone/ point (e.g., A) or headed to another zone/ point (e.g., B), the overall is included in the calculation (including all exists and entries), see (Figure 7-6).

Figure 7-6: The way of calculating variable III, main corridors

Prior to analyse these variables, the basic definitions of urban areas, systems and environment with the associated characteristics are discussed in the following section.

7.3.1 Newcastle Urban Layer- strategic design polices

Under the Planning and Compulsory Purchase Act 2004 and the North East Regional Spatial Strategy, the documentation of Core Strategy and Urban Core Plan (CSUCP) for Gateshead and Newcastle upon Tyne 2010-2030 was drafted (NG, 2011). Major amendments have taken place since the Consultations Drafts were published in 2011. This plan is part of the Local Development Frameworks (LDFs) of Newcastle and Gateshead; the two councils decided to jointly work on it due to the geographical and demographic integration of the two urban areas. Gateshead and Newcastle City Councils are therefore producing the core strategy development plan and the urban core area action plan for the two Boroughs. Transport sector is an influential sector affecting the development of ecosystems. Transport policy is drafted within the core strategy (NCC, 2013). The enhancement and delivery of an integrated transport network is one of the main goals for the councils in order to support the desired sustainable development and economic growth. Ensuring development is the main theme as smart sustainable transport modes generate significant movement. Newcastle and Gateshead are at the forefront of delivering investment of smart transport via initiatives such as PIP project (DfT, 2013a), hybrid buses, and domestic charging government grants (FLO, 2014). Figure 7-7 shows the three spatial characteristics: urban core, neighbourhood area and rural and village area. Two main spots identify the urban centres, Newcastle City Centre and Gateshead Centre.

Economic development

Successful economic development planning is based on a solid analytical framework that accurately describes the local economic context and identifies the areas for development including the special needs groups, availability of local resources and community assessment (Leigh & Blakely, 2013). Focusing on Newcastle, initiatives are taking place to unlock the city centre growth (Newcastle Gateshead Accelerated Development Zone (ADZ).

In 2012, a move was taken by Newcastle city council to kick-start economy across the North East. Such commitment made by the government is to foster the business rate income by initiating an infrastructure programme, securing mega investments, and creating more than 13,000 additional jobs. This highlights the upcoming years of Newcastle, where more urbanisation, economic development, road network and infrastructure and smart initiatives are taking place. It implies a prosperous era is ahead, which flourishes the way to smart cities and communities' establishment.

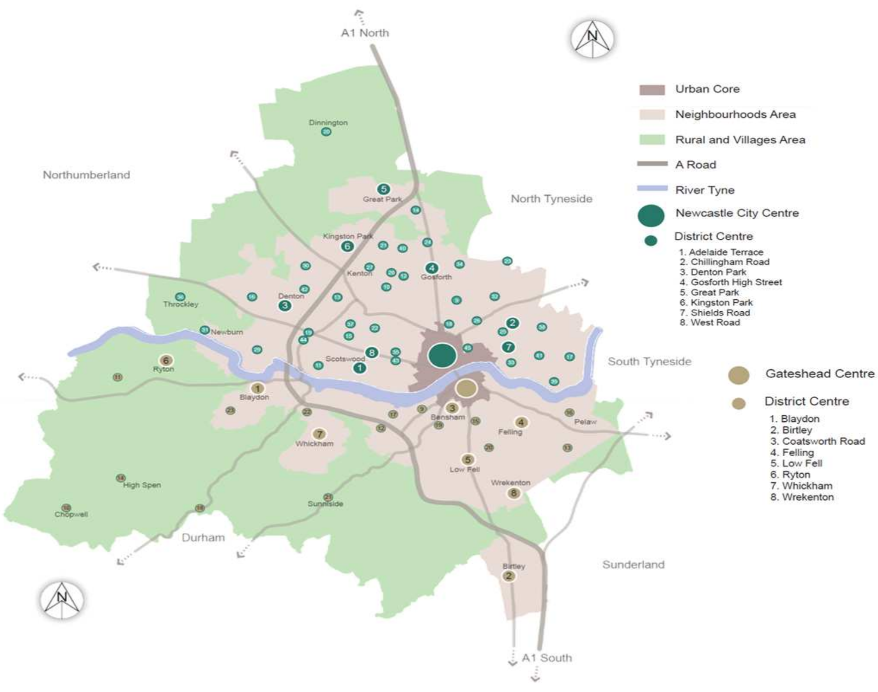


Figure 7-7: Gateshead and Newcastle areas (source: Core Development plan, 2013)

Assigning traffic count values

There are nine main arteries pass through the inner urban core of the Newcastle-Gateshead area and eight urban cores in NE1, NE4 and NE8, see (Figure 7-8). All data related to traffic count and real time O-D calculations are collected by the Unit of Traffic Monitoring in Newcastle (UTMC). The first step was to apply a grid to the urban layer that is relevant to the main transport corridors distribution. The sides of the grid are equal to the distance between the two closest parallel corridors in the network.

Figure 7-8 maps the main corridors of Great North Road (first main corridors are indicated with red arrows, second main with blue arrows). The westbound, Westgate Road, links NE1 to NE4, and Great North Road links it to NE2 alongside three other secondary roads, which are Ponteland Road, Coast Road and New Bridge Street, Eastbound. Looking at the Gateshead area, three main arteries are feeding the postal zone: Bensham Road, Durham Road, Southbound, and Bolden Lane.

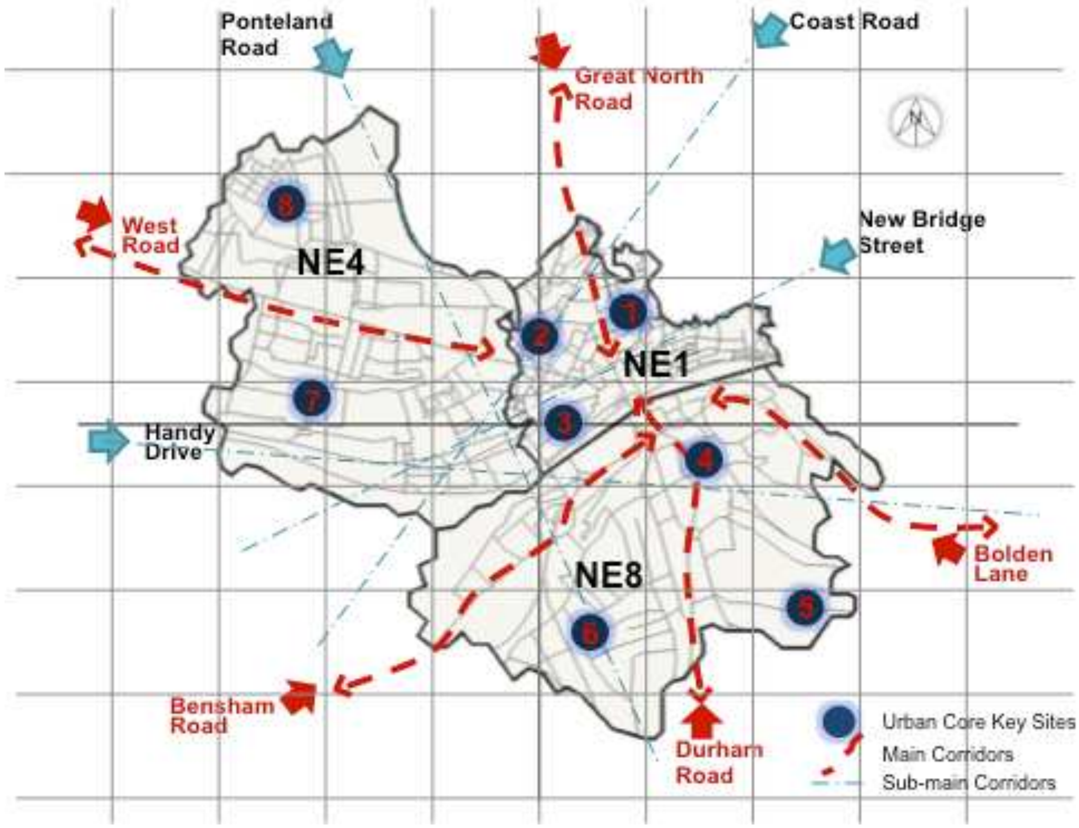


Figure 7-8: Main corridors and urban cores (sources: Edina and Development Core plan, 2013)

The traffic counts of all the RFs included in each zone will be the same. For example, Great North Road feeds three zones which contain CPs 20007, 20008, 30056 and 30086. This means that the value (traffic count) of these RFs, is the same. A zone with its RFs can be located between two main corridors; the traffic flow will be based on the sum of the two feeders, see (Figure 7-8), NE2 has two feeders Great North Road and Coast Road and all RFs located in this zone will be having the same traffic count. Finally, for each CP, the traffic flow of the main arteries feeding its district or urban zone was calculated, see (Table 7-3).

Table 7-3: Main feeders and traffic counts

Origin	Charging Points at destination	Main Feeder	Total expected number of cars at destinations
NE6	20059,40025, 40026, 40018, 40019	New Bridge Street	23652
NE2 and NE3	- 40009 and 40008 - 10026 - 20007 and 20008 - 30051	Great North Road	12663

Mapping the prosperous EV population

Data is collected from urban policies, spatial planning reports and demographic records generated by the government in order to identify the urban centres (highlighted in blue circles in Figure 7-8).

Across NE1, NE4 and NE8, there are eight urban cores, which are different in size and demographic profiles, see (Figure 7-9). Some of these cores are prospective urban areas as per the Development Core plan. The urban cores' selection criteria were:

i) Where the potential users live as per the survey;
ii) The nearest to the main arteries and high traffic road, a more central and busy area with numerous trips (high TTWAs) (Office of National Statistics, 2013);
iii) A residential area where its inhabitants own the household and are moderate social class (technology literate and can afford owning an EV), (Office of National Statistics, 2013);
iv) 30's and 40's age profiles who are interested in owning an EV (Office of National Statistics, 2013).

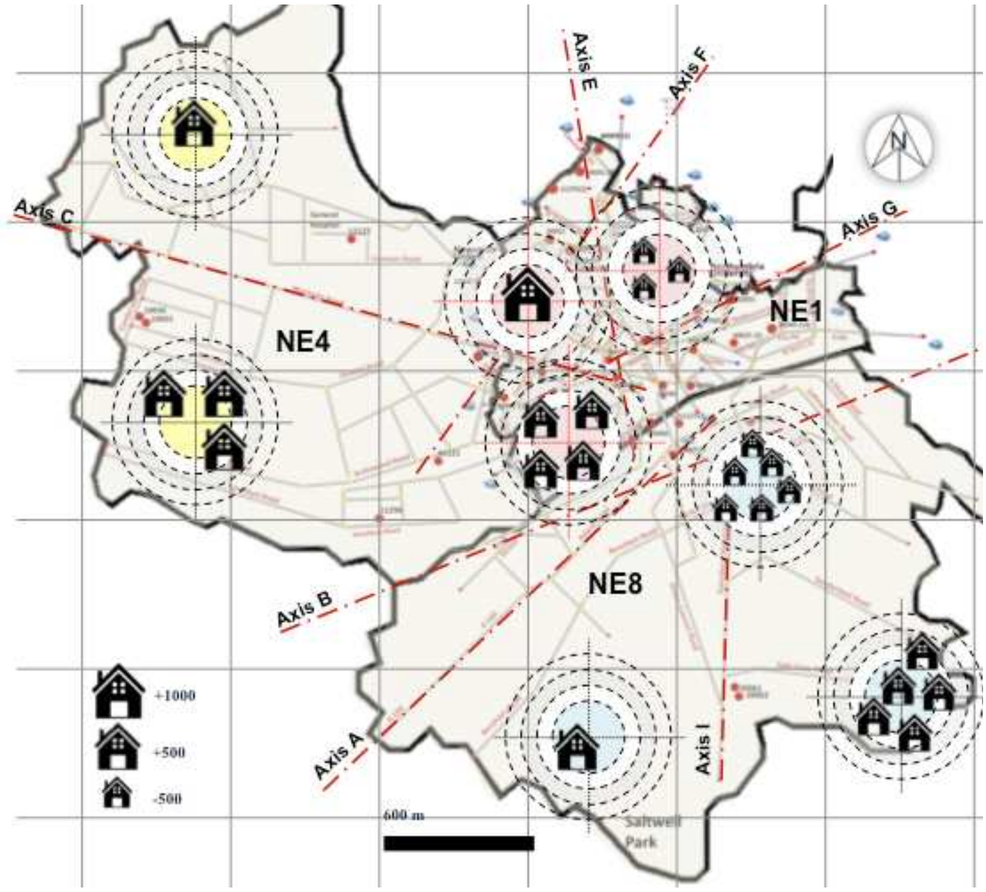


Figure 7-9: Demographics (source: Edina and Development Core plan, 2013)

The development of the charging network is a prolonged process, it has to be phased in order to achieve the interim goals, monitor the progress, revisit and revise development plans. Distance from the centre variable is the value of:

> *"choosing the minimum number of urban cores and calculating the distances between the nearest core to the CP."*

The definition of urban area by planning authorities

In order to calculate variable I, an interview was conducted with the one of the planning authorities in Newcastle, Spatial Planning South Tyneside Council. A semi-structured interview was carried out with Telford-Cooke, addressing the way the urban cores are identified and distances are measured.

> *"English spatial town planning takes a more strategic approach by looking into areas rather than points. We, as a local planning authority and town planning team, study and analyse urban areas considering at zones and districts scale."[Planning Analyst, 2014]*

Subjectively, authorities carry out the design process and update the core strategies and developments every five years. Telford-Cooke, continued saying:

> *"Urban planning lacks evidence of defining the means of measurement. There is no objective rationale behind identifying locations in urban fabrics; therefore, the LoD is the urban boundaries and zones." [Planning Analyst, 2014]*

Cores are identified by demographic data, commercial areas, and distribution of retail areas. In order to measure distances between two zones/districts, there is no standard methodology to calculate the points of measurements.

> *"There is not a right or wrong way to identify the core' coordinates; however, it has to be justified and maintained consistent for calculation throughout the our reports." [Planning Analyst, 2014]*

The residential urban zones' boundary is administratively identified at wards level. For each CP, there will be a value that measures the distance to the nearest residential area, (Distance from centre). Telford-Cooke further explained a possible way to measure distances and identify stating:

> *"Points of measurement (zones' centroids) are used to calculate the distance to the main corridors." [Planning Analyst, 2014]*

Figure 7-10 visualises the urban centres in relation to the main corridors and illustrates the metric distance between these centres and the nearest main corridor. Once the urban centre is identified, (Office of National Statistics, 2013; NG, 2014; 2011), the bounding shape was drawn using AutoCAD and the geometric shape centroid was calculated.

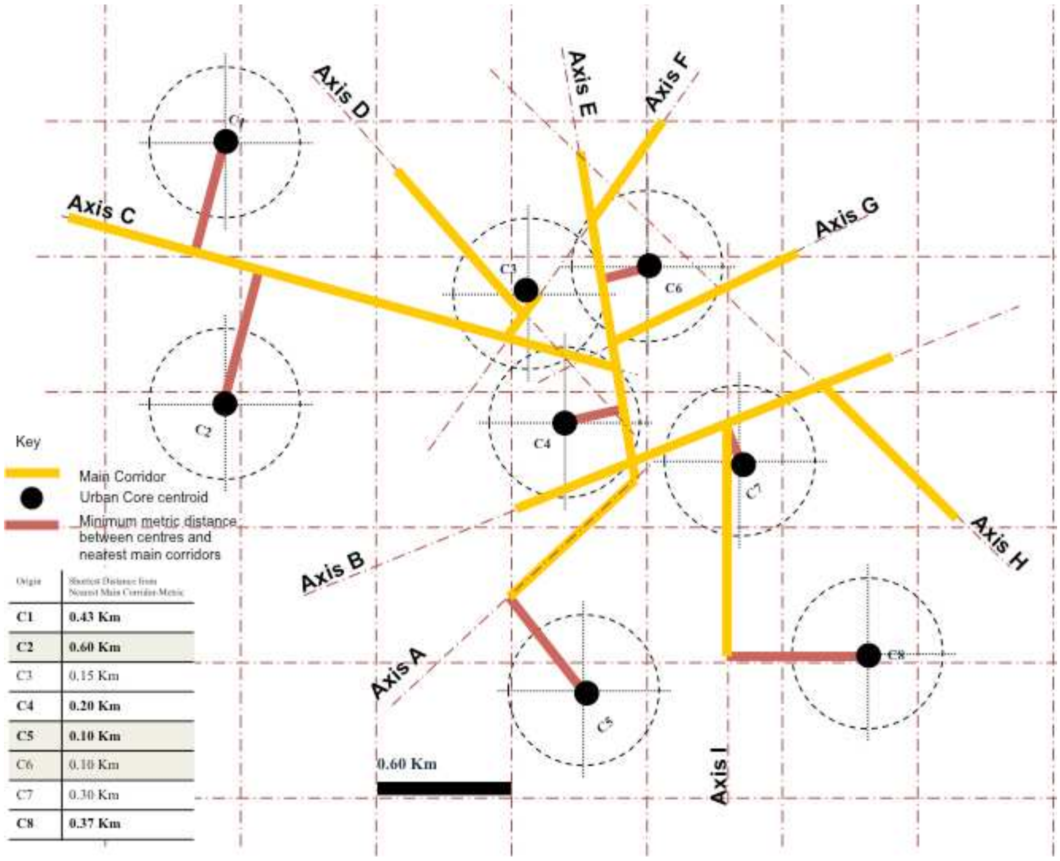


Figure 7-10: Urban centres and main corridors centrelines

Graph visualisation for spatial relation adjacency

The idea of visualising the relation between the CPs and the nearest urban centre stems from the graph theory (Euler, 1936). The use of graph a visualisation tool is useful to depict the spatial relationships in urban environment, boundaries and spaces via links and nodes. Kruger (1979) has subdivided the urban system into two main stands: channel network and built form units. The channel network is based on the transport geography and planning. Following Kurger (1979), urban system and its associated relationships between the urban areas were denoted by Bransley & Barr, (1997); Donnay et al. (2005) and graphically visualised using remote sensed imagery in different types of the built environment. This was the introduction of mathematical tools into the realm of urban morphology, and in particular the graph and set theory. The graph theory was illustrated by Kruger (1979) and applied in practice by (Hillier & Hanson, 1984) introducing the space syntax body of work.

Urban Core membership Calculation

After identifying the urban cores of the study area, the formation of membership takes place. The urban core attribute can be defined as:

"the topological distance from the neighbouring urban core(s) where high traffic, high probability that EV users are commuting from/to these areas. Linking this attributes with the charging patterns of the users and the spatial features of the CPs allows spatiotemporal analysis to take place."[Elbanhawy et al., 2014]

Measuring urban core attribute considers the natural boundaries in the urban layer, see (Figure 7-11). In some cases, the natural boundaries and network govern are stronger than the metric distance rule. Figure 7-12 visualises the CPs into clusters (each cluster is linked to the corresponding topological centroid). For example, a CP like 10026, in terms of metric distance is closer to C3d to C6dd. However, there is a main road (Coast Road), which passes in between 10026 and C3d. This means that if it was to predict the number of users charging their cars in this CP, one should consider those in C6dd not C3d.

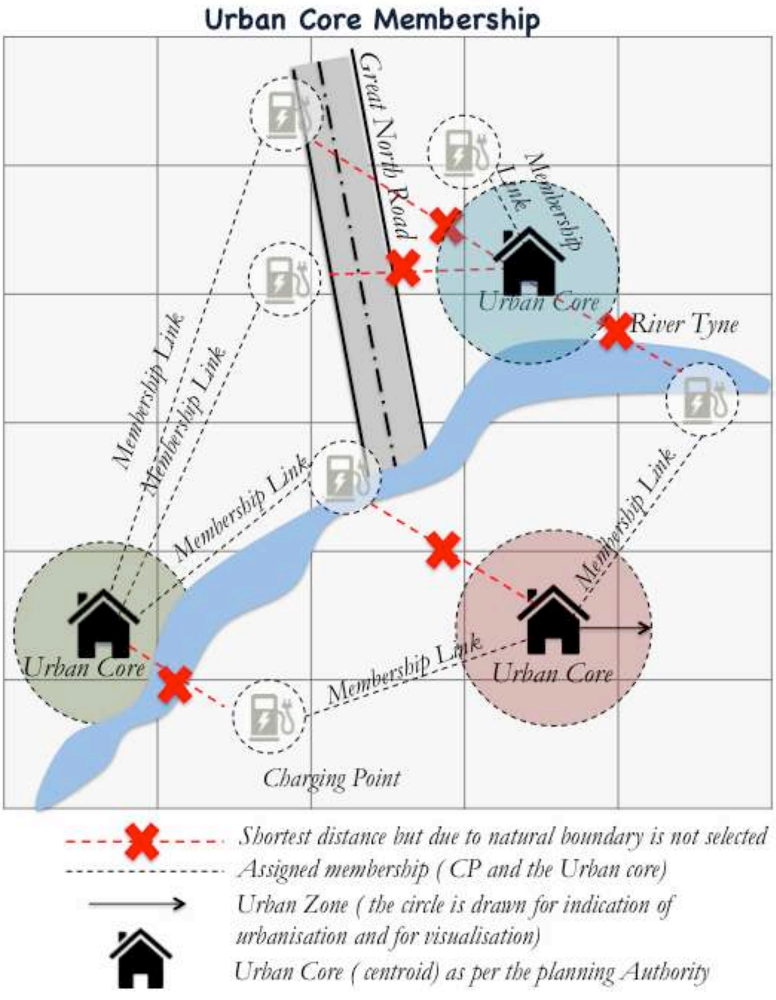


Figure 7-11: Measurement of urban core membership

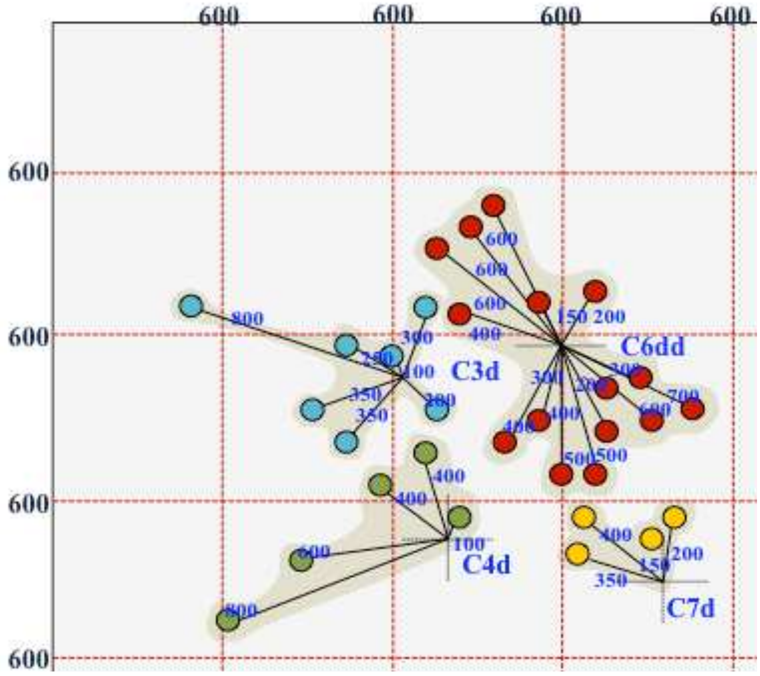


Figure 7-12: Metric distance to nearest urban centroid- metric distance- shortest path

7.3.2 Distance from centre

Figure 7-13 illustrates the final representation of the urban areas and travel demand. CPs are the small blue circles, urban centroids are denoted in black squares with an indicative dotted circle (visualising an urban area), perpendicular lines from the centroids to the nearest arteries, and the dotted red lines measuring the distance to the CPs.

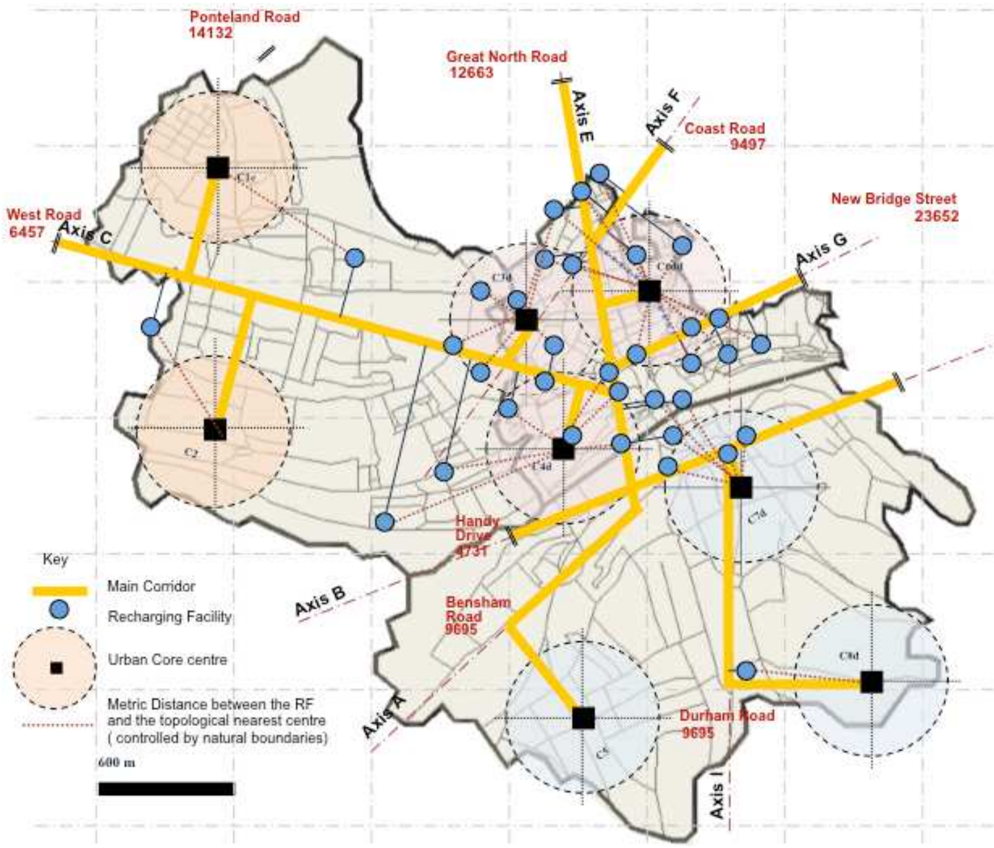


Figure 7-13: Distances to main roads and cores

Variables II and III of CPs are documented in (Table 7-3). Variable III was calculated based on a survey-based study. The next section presents the survey and the quantification of variable IV: public awareness of RFs.

7.4 Spatial Variable IV: Level of Awareness Attribute

EV passenger acceptance depends on knowledge about car's specifications, capabilities, benefit of smart transport, and how these cars can fit in their daily life. It also depends on the raised awareness about the available charging network and how accessible is the On street/ Off street charging service. The attitude of car drivers towards EVs was investigated through a visual survey. This variable is to test the spatial awareness of the existing available (means active and ready to be used anytime) RFs in NE1, NE4 and NE8. Level of awareness (LoA) value indicates how aware the public is with the existence of the EV infrastructure network. It tests the spatial recognition of potential users. In order to calculate the (LoA) variable, the following steps were taken.

The first step was to develop a method to test the LoA. A map-based survey was designed to quantify the LoA and justify the user preference of the network. The survey addressed consumers (potential users who are willing to consider the EV as a form of transport) about remembering any of the RFs, the selection criteria was as listed in (Table 7-4).

Table 7-4: Survey sample size selection criteria

	Selection criteria of sample size
1	Individuals who can recognise the publically available charging points;
2	Car passengers commuting on a daily basis to NE1, NE4 or NE8;
3	Individuals who are environmentally aware and technology literate;
4	Individuals who are financially able to afford owning an EV;
5	Work or study in the city centre (NE1, NE4 and NE8);
6	Commuting, working, or living in NE1;
7	Males and females with no age limitation.

7.4.1 Map-based EV survey

The survey was conducted in March, April and May 2014 time and the time allowed to complete the survey was four minutes. It consisted of six questions; two questions for every postal zone (NE1, NE4 and NE8). The first task was designed to test the respondents' memory (visual memory, unaided awareness (M)). Without any guide provided to the respondents, they were asked to mark the areas of CPs. There was an error margin; a correct answer would be if the respondent marks a neighbouring cell of each side of the correct cell.

1. *Without identifying the CP's locations, mark the squares wherever you can memorise a CP in NE1 (Figure 7-14). [same question for NE4& NE8]*

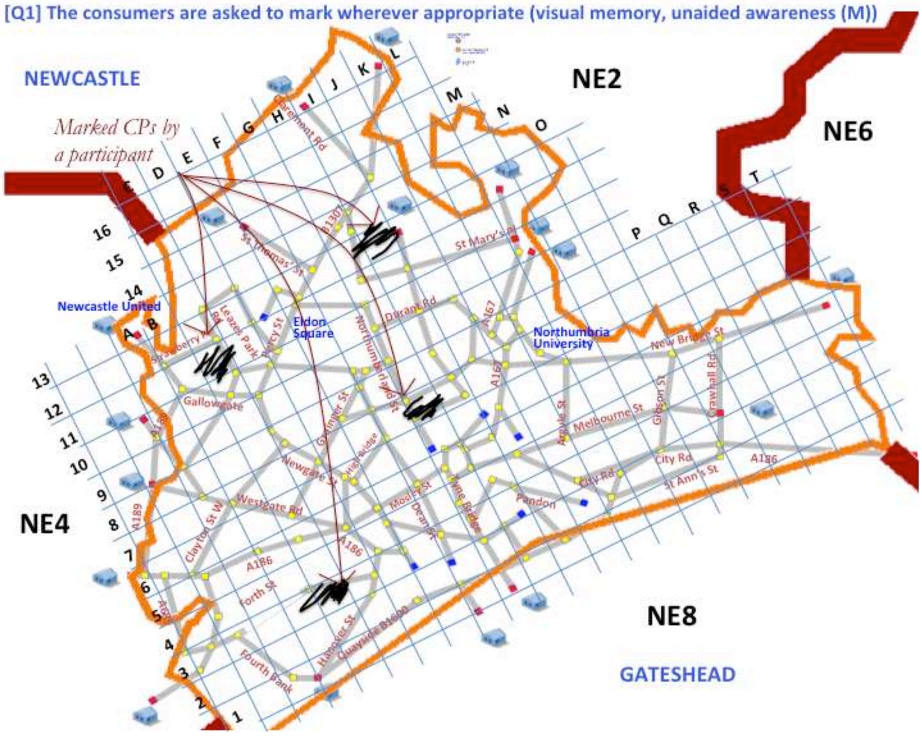


Figure 7-14: A snapshot of LoA survey (testing M)

As for the second task (spatial recognition, aided awareness (R)) the CPs locations were highlighted and the respondents were asked to mark the CPs they are aware of.

2. *Mark the squares wherever you can remember a CP in NE1 (Figure 7-15). [same question for NE4& NE8]*

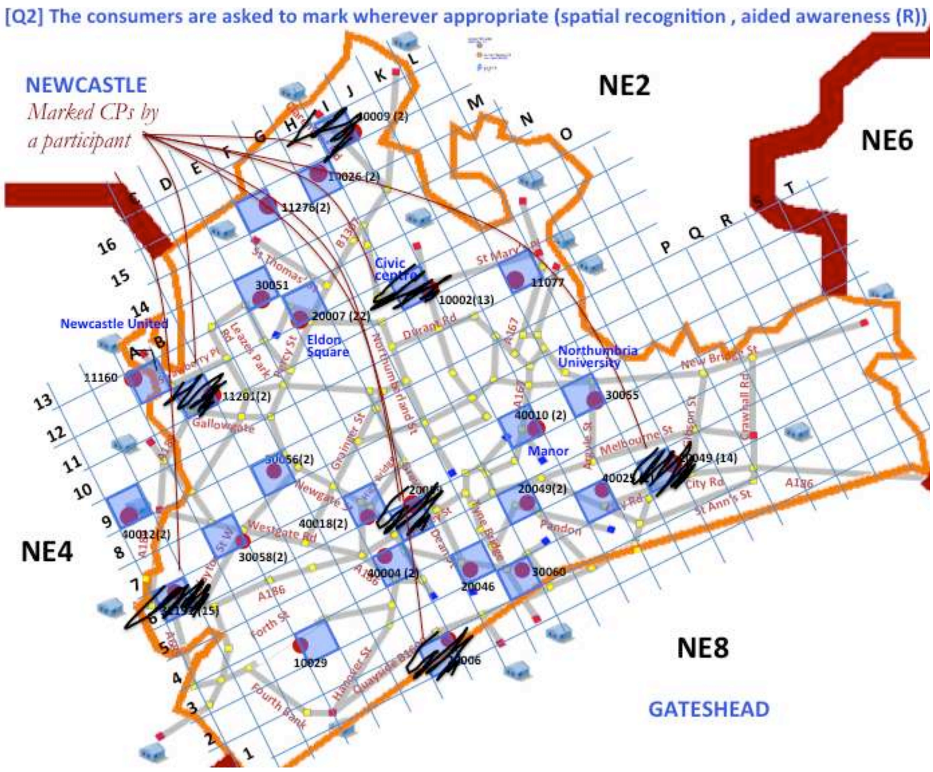


Figure 7-15: A snapshot of LoA survey (testing M)

7.4.2 Quantification of LoA

A total of (n=45) surveys were collected. For each RF, there were three values: Recognized (R), remembered after seeing the exact locations (M), or a complete dismiss of the RFs (blank), see (Figure 7-16).

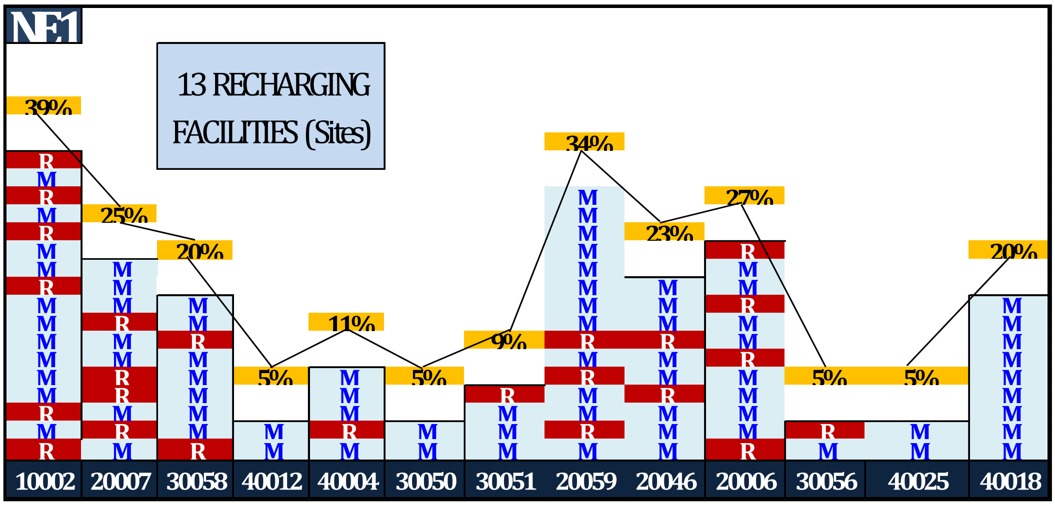


Figure 7-16: Responses projection all zones-quantifying the scores

The LoA value was calculated for each CP (38 CPs) as per (Equation 7-1):

Equation 7-1: LoA calculation

$$(LoA)^{Potential} = \beta\ (M^{Potential}) + \alpha\ (R^{Potential})$$

Where

$\alpha^{Potential}$:is the sum of M and R- potential users.

α, β :weighing coefficients, β is 0.8 and α is 0.2

Figure 7-17 illustrates the LoA score of each site where the CPs with high scores are highlighted in red. The LoA attribute is an index and identified as:

> *"the value of how aware are the participants of the current charging facilities. It is the summation of the times the participants highlight a CP that they acknowledge, spatial recognition. This attribute will be used as a value to investigate the correlation between RF's usage and spatial awareness. "*

The four sites named: Eldon Square (Off Street), Civic Centre (Off Street), Northumbria University (Off Street), and Grey Street (On Street), see (Table 7-5).

Table 7-5: Highest four CPs of LoA and transactions of 2012

	Charging Point	Transactions	Most Frequent Time	LoA
1	20008 (4)	197	Morning	25
2	20059	62	Morning	34
3	10002 (5)	92	Afternoon	39
4	30055	6	Afternoon	34

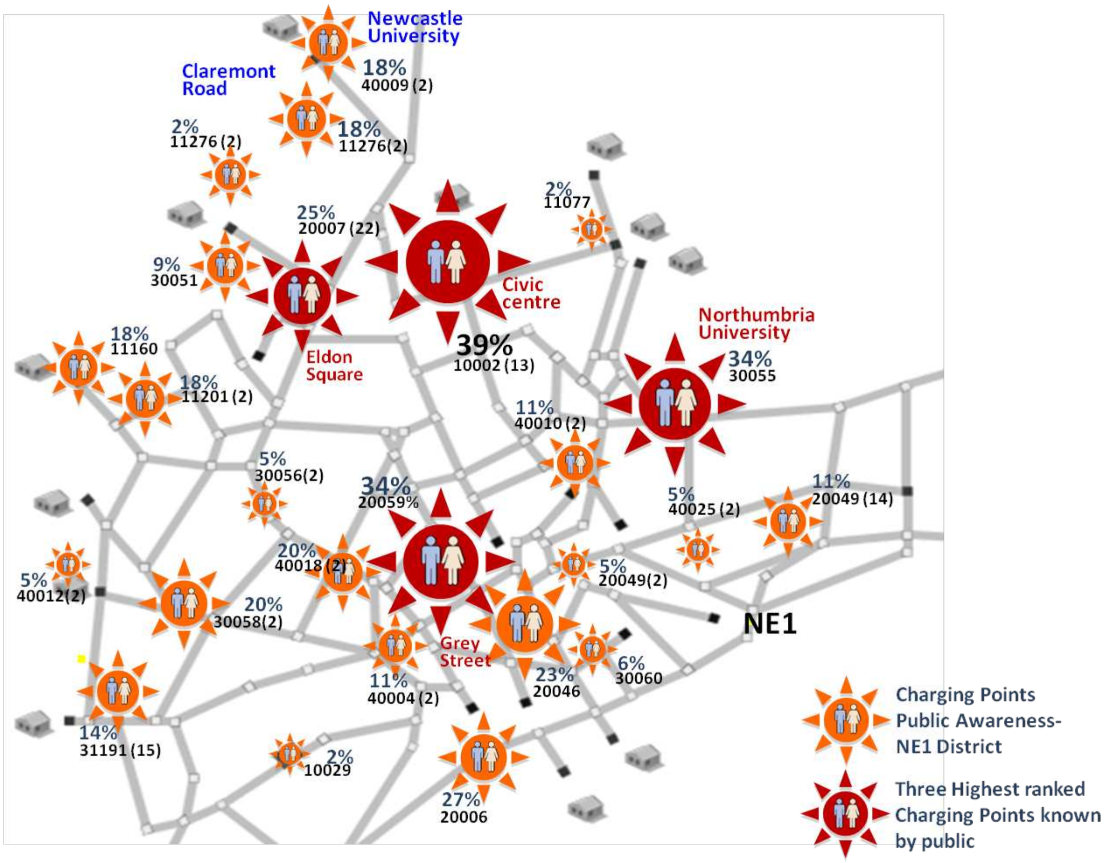


Figure 7-17: Visualising the records

Table 7-5 displayed the LoA with the total charging events made in 2012. From the values, CP #20008, #20059, #10002 have high values of transactions which reflects a possible positive correlation between the LoA and the use of CPs. CP #30055 has a relative small number of transactions however this is due to it was newly installed in year 2012. With an exception of #20059, the high LoA sites are located Off Street and in very vital and busy area of the city centre. In particular, the Civic centre car park as it serves as both: workplace and public charging facility.

7.4.3 A summary of spatial variables

Four spatial variables were discussed in previous sections of this chapter, Table 7-6 summaries the spatial attributes. Prior to running the spatiotemporal analysis, it is required to identify fundamental charging pattern-related measures, see (Figure 7-18). These variables are discussed in the next section.

Table 7-6: Spatial attributes: urban context related variables

	Attributes	Explanation/ Measurement Technique
1	Level of Awareness (LoA)	The measurement of the extent to which the potential users aware of the charging network. This is examined through a spatial questionnaire disseminated over 45 potential users. Response is collected and summed up.
2	On / Off Street (O)	This value is dummy. Zero for Off street charging points, and value of 1 for On street charging point.
3	Integration (I)	Space syntax measure, calculated by DepthMap.
4	Connectivit y(C)	Space syntax measure, calculated by DepthMap
5	Traffic Counts (T)	Actual travel demand provided by the Traffic Monitoring Unit in Newcastle (UTMC). The values are for the main corridors feeding the RFs sites
6	Distance from centres (ι)	Metric distance measuring the road length between the charging point and the nearest residential district core.

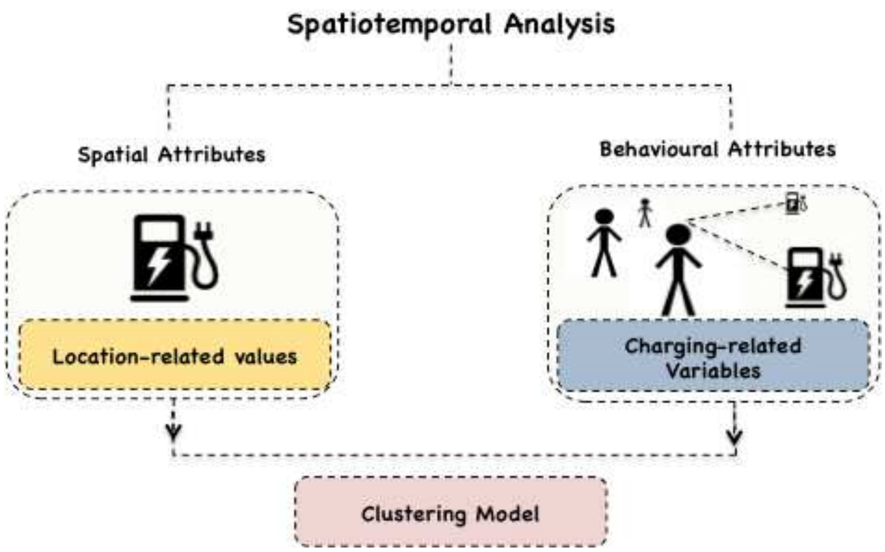


Figure 7-18: Components of e-mobility spatiotemporal analysis

7.4.4 Behavioural variables

This section discusses some charging-related (behavioural) variables. There are four main variables which are used in various analyses throughout this thesis, see (Figure 7-19). The fist behavioural variable measures the time of charging within the day, labelled as Most Frequent Time (M) and it is used to know the busy times of charging. The Average time spent (A) measures the average time spent by drivers charging their cars using the RF.

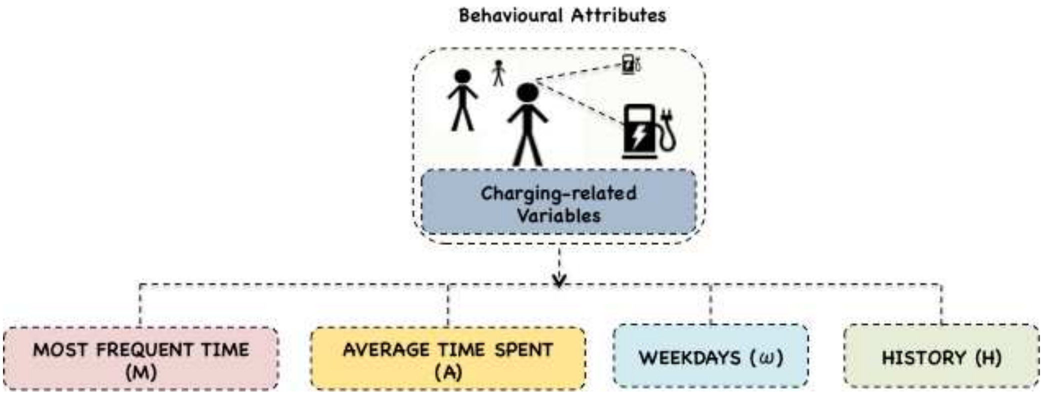


Figure 7-19: Charging-related attributes

M reflects the peak hour/ period where most of the population prefers to replenish their batteries. This is particularly useful when dealing with a big dataset similar to the one used for Newcastle. The first attempt of calculating (M) value is the average time of charging events over a period of time. This is misleading as (M) calculates the most frequent time the users tend to charge their car. To get (M) value, the day is to be devided into four time spans, and then the total number of the charging events took place in each period (morning, afternoon, evening and night) is calculated. Figure 7-20 demontrates the concept as for example, the morning starts from 6 am to 11:59 pm, the afternoon is from 12:00 pm to 5:55 pm, the evening is from 6:00 pm to 11:59 am and the night is from 12:00 am to 5.59 am.

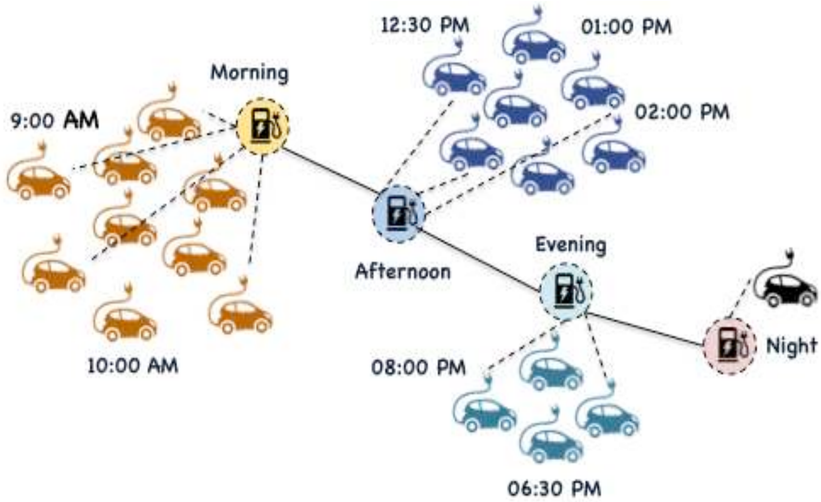


Figure 7-20: A display of most frequent time (M)

As shown in Table 7-7, if the January 2012 (M) is needed. The total number of the monthly charging events, which were made throughout the day, is calculated. In order to calculate the percentage of occurrence, the value of each quarter (e.g., morning 163) is divided by the total number of transactions of this month (e.g., 332). In some analyses, (M) is represented as one value, which is the highest percentage over a timeframe.

Table 7-7: Calculating the most frequent time method

Year 2012	Morning	Afternoon	Evening	Night	Total	%M	%A	%E	%N
Jan	163	138	30	1	332	49%	42%	9%	0%
Feb	160	196	47	2	405	40%	48%	12%	0%
March	143	157	38	2	340	42%	46%	11%	1%

Where M is morning, A is Afternoon, E is Evening, and N is Night.

The calculation can be executed using the following Equation 7-2:

Equation 7-2: Most frequent time (M)

$$(Y)(m)(n) Most\ Frequent\ Time\ (M^x) =$$

$$If\ (Hour\ (\mathrm{HOUR}(\delta) < 6, "NIGHT",$$

$$IF(HOUR(\delta) < 12, "MORNING",$$

$$IF(HOUR(\delta) < 18, \mathrm{AFTERNOON}.$$

$$If(HOUR(\delta) < 24, "EVENING")))$$

Where

Y	is the year
m	is the month
n	is the EV population
X	is the user ID
δ	is the arrival time
x	is the CP

The second variable is the Average Time Spent (A). This variable is calculated as per (Equation 7-3).

Equation 7-3: Average time spent (A)

$$(Y)(m)(n) Average\ time\ spent\ (A^x) = (time\ of\ departure(d) - time\ of\ arrival\ (\delta)$$

The mean value is a correct measure of (A) as it indicates their willingness to spend time charging. However, in the Most Frequent Time, the mean value is misleading. It has to be calculated as the exact timing of the charging sessions.

The third variable is the Weekdays ($\boldsymbol{\omega}$) which calculates the ratio between the number of transactions made during the weekends and the weekdays. It can be calculated as per (Equation 7-4).

Equation 7-4: Weekday-weekend calculation

$$(Y)(m)(n)\%\ Weekday = \sum \text{TEXT}((day\ of\ charge, \text{"}dddd\text{"})/(\beta)days) * 100$$

Where β is the number of days of charging events without repetition

The charging pattern-related variables are identified and quantified, see (Table 7-8). To run the analysis, the variables should be wisely selected as well as the Dependent Variable (DV). The clustering analysis will be based on an equation maximising or minimising the DV (in this case maximize), the Total Energy Used (Λ).

Table 7-8: Behavioural attributes: charging variables

1	History (H)	In months, the total number of months the charging point has been installed and used. (CYC data)
2	No. of users (η)	The total number of EV drivers used the charging point over 2012 (CYC data)
3	Distance from centres (ι)	Metric distance measuring the road length between the charging point and the nearest residential district core.
4	Transactions (τ)	The total number of transactions made by the users in 2012 in each charging point. (point not site)
5	Average time spent (A)	In minutes, the average time spent by drivers charging their cars using RF. (CYC data)
6	Most Frequent Time (M)	Discreet data, showing the most frequent time of the day the drivers tend to charge their cars using a specific charging point. (morning = 1, afternoon =2, evening =3, night =4)
7	Weekdays (ω)	Percentile, the weekday to weekend ratio converted into percentage. This value shows when the RF is being used over the week.
8	Total Energy Used (Λ)	In KW, the total energy spent charging cars by each RF in year 2012. (Dependent variable, Profit indicator)

Table 7-9 concludes the 38 CPs' location-related variables (measures), which include the three configurational values (I, C, and MD), three spatial values, and the history (indicates the years the CP was in operation).

Table 7-9: 38 CP's spatial measures

CP ID	On/ Off Street	Integration	Connectivity	Mean Depth	Distance from Centres	Traffic Counts	Public Awareness	History
20006	2	1.01084	7	11.2234	500	17394	27	25
20007	1	0.81448	2	13.6882	400	12663	25	11
20008	1	0.81448	2	13.6882	400	12663	25	11
20059	2	1.01179	9	11.2138	300	23652	34	22
20049	1	0.91787	5	12.256	400	23652	5	7
30050	1	0.91787	5	12.256	400	23652	5	7
30051	2	0.81271	5	13.7158	300	12663	9	25
40012	2	0.94335	8	11.6065	350	6457	5	22
40013	2	0.94335	8	11.6065	350	6457	5	22
40004	2	1.08422	19	10.5315	400	12663	11	24
40005	2	1.08422	19	10.5315	400	12663	11	24
40025	2	0.97521	3	11.5969	600	23652	5	22
40026	2	0.97521	3	11.5969	600	23652	5	22
40018	2	1.00146	12	11.3192	400	23652	20	21
40019	2	1.00146	12	11.3192	400	23652	20	21
30056	2	1.00569	9	11.2758	200	6457	5	22
30057	2	1.00569	9	11.2758	200	6457	20	22
30058	2	1.03265	10	11.1173	400	20589	20	22
30059	2	1.03265	10	11.1173	400	20589	20	22
10002	1	0.77028	5	14.4163	150	9497	39	22
10003	1	0.77028	5	14.4163	150	9497	39	22
10004	1	0.77028	5	14.4163	150	9497	39	22
10005	1	0.77028	5	14.4163	150	9497	39	22
10006	1	0.77028	5	14.4163	150	9497	39	22
10007	1	0.77028	5	14.4163	150	9497	39	22
20046	2	1.0467	6	10.8732	500	36315	23	25
11077	1	0.95292	3	11.8449	200	9497	2	18
30055	2	1.02234	7	11.1085	300	23652	34	25
30060	2	0.96062	4	11.7579	500	36315	6	25
10026	1	0.74405	4	14.8892	600	12663	18	26
10029	2	0.86686	1	12.9215	100	6457	2	10
40010	1	0.89105	5	12.5978	200	23652	11	22
40009	2	0.84387	5	13.2463	600	12663	18	22
40021	2	0.84387	5	13.2463	600	12663	18	22
40011 NE4	2	1.03356	10	10.9987	350	6457	2	22
30007 NE8	1	1.04996	5	10.8425	350	17394	5	21
30008 NE8	1	1.04996	5	10.8425	350	17394	5	21
11067 NE8	1	0.85383	5	13.1034	150	17394	5	20

7.5 Clustering Analysis and the E-mobility System

After introducing all spatial and behavioural variables, a clustering model was developed to provide a description of what the prototypical shape of an EV recharging infrastructure should be. The use of clustering techniques to group different cases while considering different continuous and categorical variables as it was previously explained in Chapter 4.

This next section presents a RF-oriented study through a clustering model. There are many factors were considered in this analysis; behavioural, technical, spatial configuration, and demographics. Spatial configuration analysis is conducted to ultimately help developing design tools for planning authorities and policy makers. This should benefit the EV stakeholders as it identifies the main influential factors affecting the use of RFs, the main features and can potentially provide guidelines for smart RF network for a more optimized roll out of RFs.

7.6 Spatial Clustering of RFs

The TwoStep clustering method is selected; spatiotemporal analysis of users' charging and driving patterns is executed to NE1, NE4 and NE8. The model is based on analysing 420 users records spanning the year 2012 using the 38 CPs. As it was explained in Chapter 4, the majority of these RFs are located in NE1, having 26 CPs, 4 CPs are in NE4, and 8 CPs are in NE8, see (4.1 Study Area: Background and E-Mobility System, Figure 4-3).

There are some key alterations that can be made to the selection of the variables, the maximum and minimum number of clusters, and the evaluation fields. Clustering analysis involves several procedures as summarized by Milligan (1996): selecting clustering objects and clustering variables, deciding on the type of data, variable standardization, choosing the measure of association, selecting the clustering method, determining the number of clusters and interpretation, validation and replication. This includes a description of administration procedure of data collection, data cleaning and a description of the data set.

In this model, there were 11 as Independent Variables (IV): Level of Awareness, Integration, Connectivity, Distance from Centre, Traffic Counts, On or Off Street, Number of Users, Transactions, Average time spent, Most Frequent Time, Weekdays, and History, see (Figure 7-21).

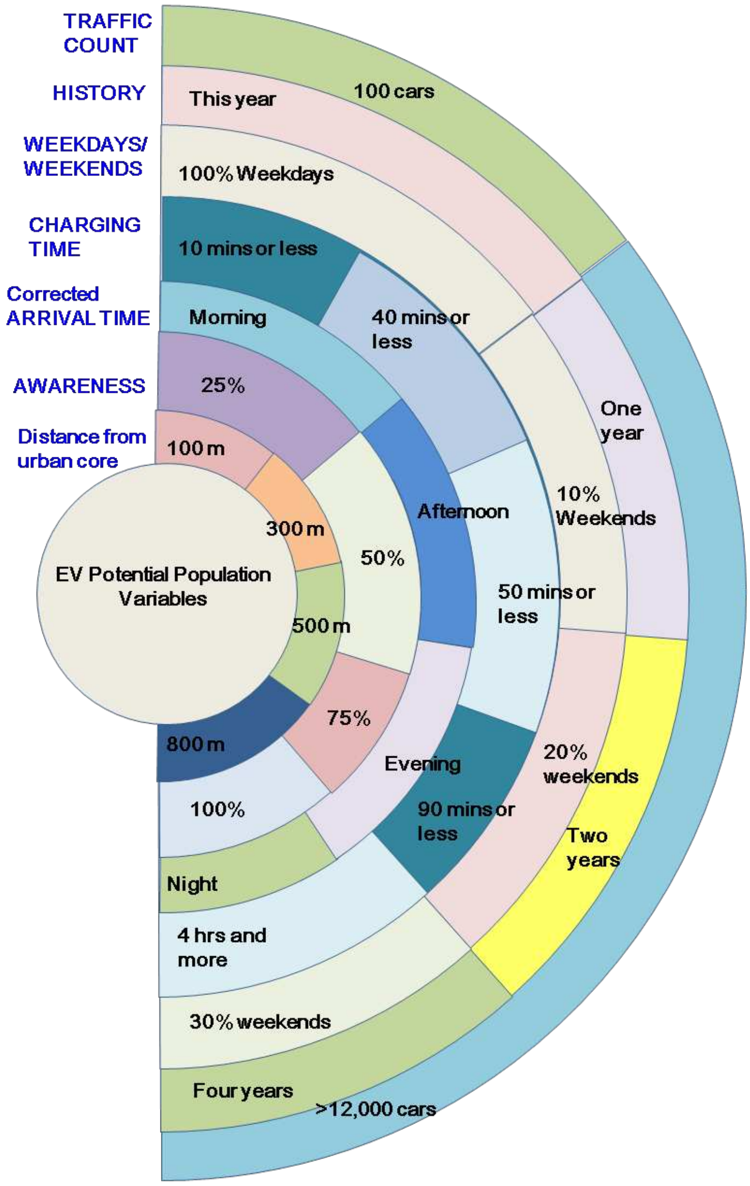


Figure 7-21: Infographic of input data for the clustering modelling

7.7 The RF's Clustering Model

Following the same clustering technique of Chapter 6, a TwoStep clustering model was performed. As for the quality of the clusters membership and formation, the following checks were made, see (Figure 7-22). As per (Figure 7-23), the model contains four clusters with a ratio of 1.5, which is acceptable. The number of inputs (categorical and continues selected variables) is 13. The overall distribution of cluster is balanced as it is indicated in the cluster quality bar, see (Figure 7-22). There is not a dominant influential variable; Level of Awareness, On Street and Off Street, Integration, traffic Counts, and History are the main predictors, see (Figure 7-24).

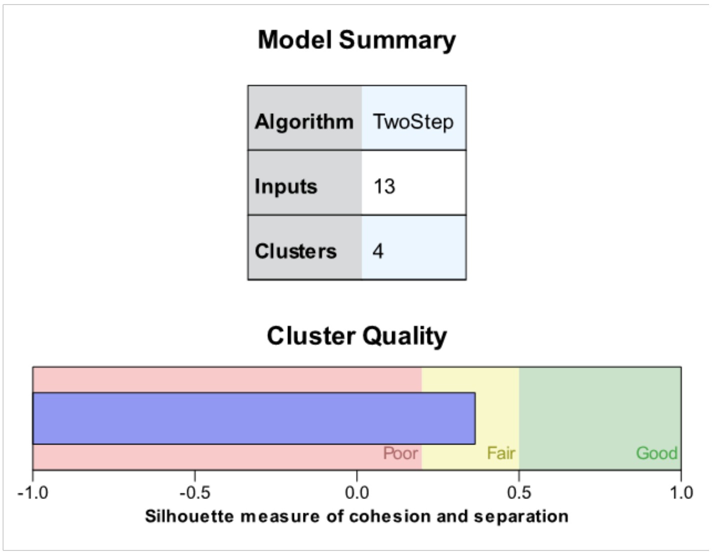


Figure 7-22: Clustering quality

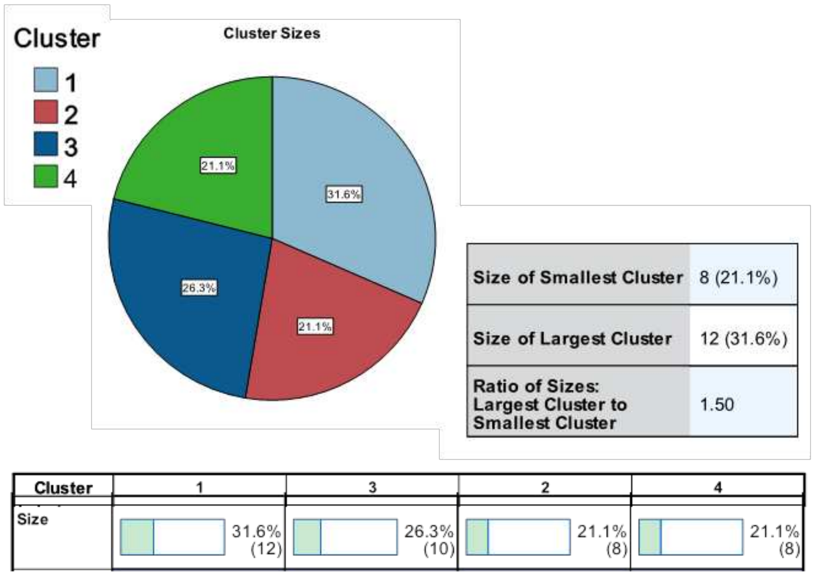


Figure 7-23: Clustering profiles

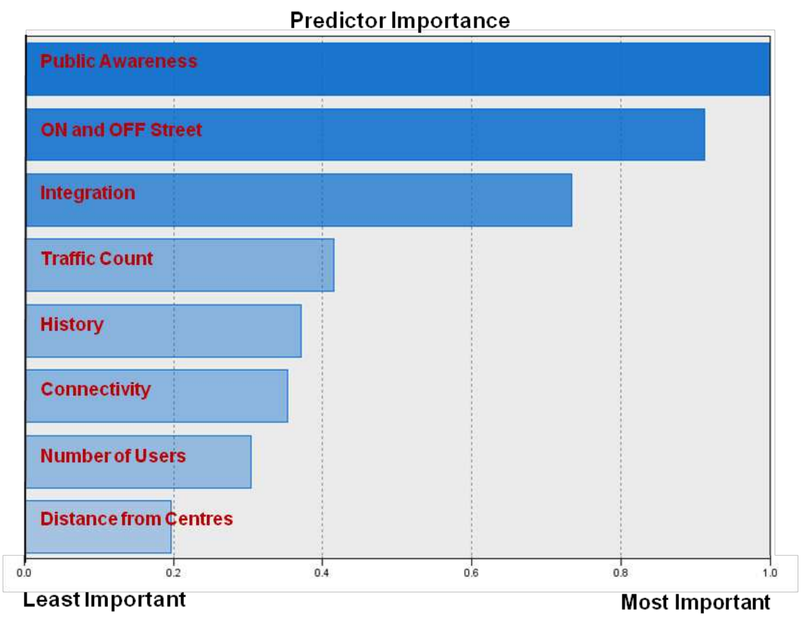


Figure 7-24: Clustering predictors

Four different clusters of RFs have been generated as the outcome of the TwoStep spatial built-in clustering algorithm. Each cluster has main features that identify and configure common RFs usability attributes, recharging static design characteristics and spatial configuration values. The clusters are listed based on the size of the clusters.

The first cluster, The Comfy, forms the biggest cluster and it contains eight RFs with a total of 11 CPs, see (Figure 7-25), This cluster has a very high Integration and Connectivity values meaning that these CPs are spatially connected within the road network. In the space syntax literature, Connectivity measures the number of immediate neighbours that are directly connected to a space (space here is the line that represents the road with the CP) (Hillier & Hanson, 1984). These 11 CPs identification numbers (IDs), according to CYC identification system, are 20006, 20059, 30051, 40004, 40005, 40018, 40019, 30058, 30059, 20046, 30055, and 30060.

This cluster contains On Street CPs, and they are being used by the inhabitants and visitors during the noon / lunchtime period, mainly on weekdays (10% on the weekend). This implies that the charging session does not happen before going to work and probably this is not the first destination of the day. It is worth mentioning that the CPs of this cluster are highly recognised by the public and users (LoA value). The profit is generated due to the high number of users. This means that users tend to use the CPs more often but for shorter time of charge (time of the charging event). This highlights a crucial matter; many charging events with less time spent might generate more profit than fewer charging events with longer time spent, which makes more sense. People tend to rely on domestic charging due to the unwillingness to spend time charging in public points especially the On street. However, it is convenient and manageable to stop for a shorter period of time to charge during their daily road trips. This implies that drivers, who are used to charge their cars using The Comfy, are technology literate and aware that a 10 minutes charge would be sufficient to secure a journey back home.

The second cluster is “The Loser” CPs, see (Figure 7-26). This group forms the second biggest cluster, containing six FRs with a total of 10 CPs (40012, 40013, 40025, 40026, 30056, 30057, 10029, 40009, 40021, and 40011). These sites are On Street and have been active for almost two years. RFs of this cluster have significant features:

i) poor parametric design which resulted in having under-used RFs;
ii) the six sites of this cluster are not recognised by the public (high value of LoA);
iii) the sites are relatively distant from urban cores and very few drivers use these RFs, which negatively affect the profitability.

Two main observations can be stated; this cluster is not accessible (low Integration value) and has poor marketing (LoA). Marketing plays a major role in EV market, which is clearly reflected in this cluster.

Figure 7-25: Cluster 1- "The Comfy"-SPSS

Figure 7-26: Cluster 2-"The Loser"-SPSS

The third group is the "The Settled" CPs, see (Figure 7-27). This cluster has eight CPs (20007, 20008, 10002, 10003, 10005,10006, 10007, and 10008) located across two sites. This cluster contains the least number of RFs as at one site there are six CPs. This cluster has a different nature in comparison to the previous two clusters. The RFs are located Off Street; however, with a very high value of (LoA), and have been installed for almost two years. The RFs of this cluster have low Integration values, Connectivity values, and are not located close to residential areas. Users charge their cars in The Settled RFs are only used over the weekdays and usually in the afternoon. Users that tend to charge using any of the RFs of this cluster, are not willing to spend time charging. In other words, users charge for almost less than 10 minutes, which may take place in two cases:

i) very low SoC when arriving the CP: the time is spent to replenish the battery with enough power to take them home.

ii) moderate SoC while depending more on domestic charging: the time is spent to replenish the battery with a few kilowatts (opportunity charging, see Chapter 1: 1.3.4 E-mobility infrastructure).

Figure 7-27: Cluster 3-"The Settled"-SPSS

The fourth group is the "The Selective" CPs, see (Figure 7-28). This group has the same size of the third one, it contains 8 CPs (20049, 30050, 10026, 30007, 30008, 11067, 11077, and 40010). The CPs in this cluster are Off street, recently installed, and users are not aware of their locations (very low LoA value). EV commuters who use these sites (20% of the times is weekends), charge their cars in the morning and tend to spend ample time charging.

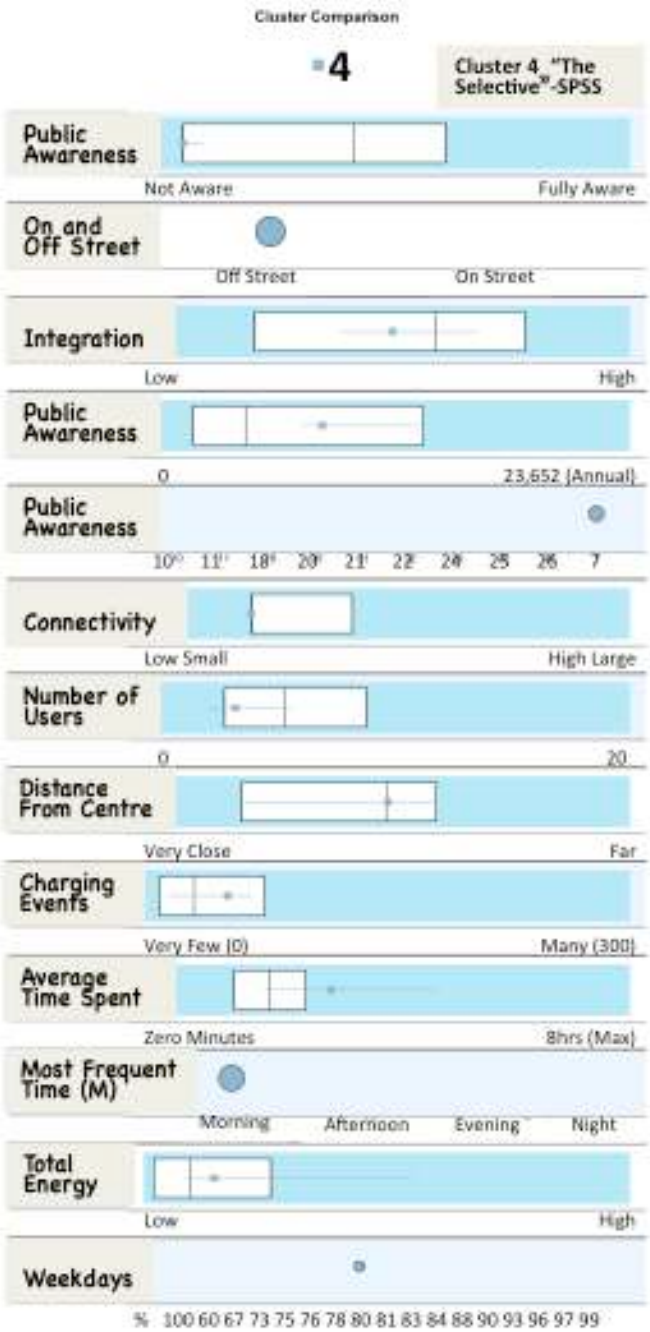


Figure 7-28: Cluster 4-"The Selective"-SPSS

7.8 Clustering Discussion

A spatiotemporal model was developed to cluster the charging network by identifying the main features of the most utilised RFs. This is to show the best setup for both On Street and Off street options. This relation between the variables and the total energy used can be observed from the formation membership of the clusters and the graphs show the quality, separation and distribution. The cluster quality bar displayed in (Figure 7-22), reflected a fair and close to good quality of cluster in terms of cohesion and separation. The quality might have been better with a higher number of cases and a variety of variables. As shown in (Figure 7-24), LoA, On and Off Street and Integration are the most influential predictors forming the different EV clusters.

7.8.1 Designing for the On Street

Among the four clusters, the first one, “The Comfy” is the chosen one to be replicated when designing and planning for On street RFs. Under the process of assisting in the planning of future EV system, this model recommends to expand the EV systems with a nature of The Comfy cluster. This cluster setup meets the business needs of the EV system as it hits the highest number of transactions made by the enormous number of users in an On street CPs. It is an overused accessible facility with a significant value of integration, connectivity and high number of users, which reflects suitability, accessibility and ease of reach within the road network. This indicates that drivers feel comfortable charging their cars in On Street charging location. It is worth mentioning that The Comfy is perfectly designed to accommodate charging services especially for the fast charging option. As a part of the recommendations for planning authorities and policy makers, quick chargers are to be located in The Comfy areas. Nevertheless, The Loser cluster needs to be deactivated from the current systems and to be avoided in new network design.

7.8.2 Designing for the Off Street

In case of planning for Off Street, there are two clusters to choose from: “the Settled “and “the Selective”. The first thought will be to select “The Settled” for replication of Off street CPs. However, it is very important to analyse the outcomes of the clustering analysis in relation to the site location of the RF. In some cases, like this cluster, the interpretation of the analysis might be misleading. There are other factors affecting the use of six CPs out of the eight CPs of the cluster, they are workplace CPs. Due to the use of Civic Centre carpark by the employees, high records of transactions are made (as explained in this chapter, 7.4.2: Quantification of LoA).

The second site is a shopping centre car park, Eldon Square, which again justifies the use. This pulls the options down to The Selective. It is an accessible Off Street facility with reasonable values of integration and connectivity, and users tend to have long charging periods (four to six hours), which reflects suitability. The number of users is considered small compared to the number of transactions. This means that selective people prefer to charge their cars particularly in The Selective and are willing to spend time charging in early time of the day. The selective is in use during the weekends as well (20% of the transactions are made in the weekends). The locations of this cluster seem very famous and preferred placed for parking. This cluster does not represent a majority, only eight out of 38

CPs, are in this cluster which justifies the poor level of the whole network usability. Planning authorities need to understand the features of The Selective and maximize the investment in installing CPs with a similar nature to it.

7.9 Part B: End-User Charging Personas

In Chapter 6, the users profiles were identified based on the EV user study that was carried out. In part A of this chapter, the RFs were clustered into four clusters: the Comfy, the Loser, the Settled, and the Misplaced. In this chapter, the charging personas based on empirical data are created, see (Figure 7-29).

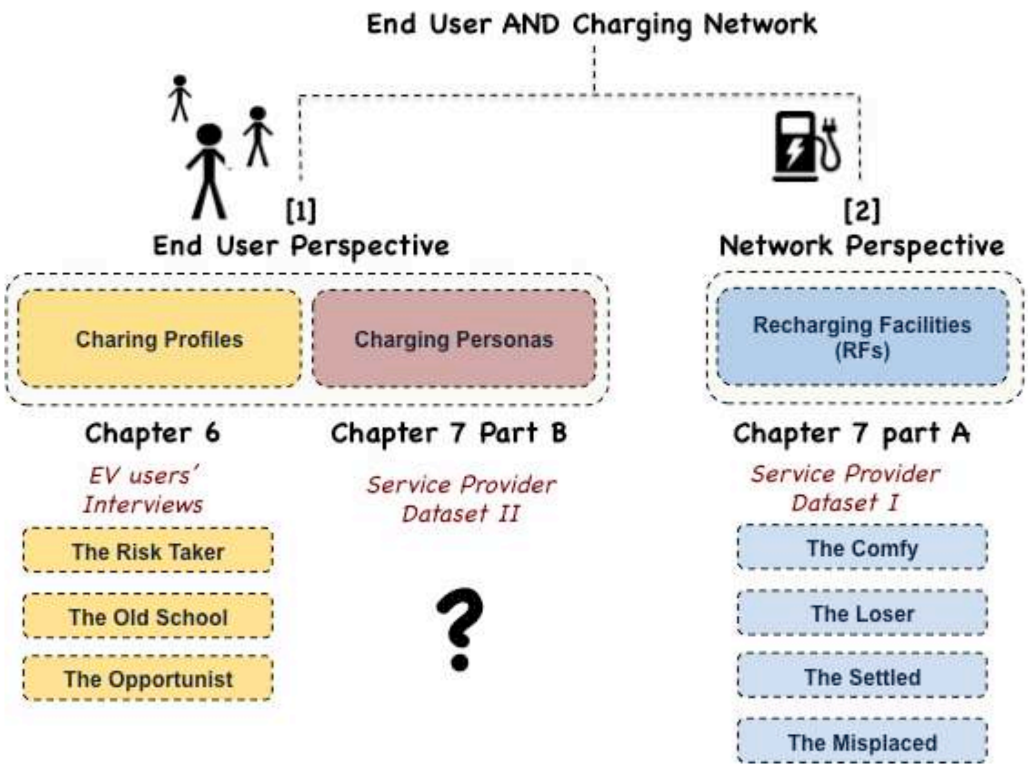


Figure 7-29: Network and EV user perspective matrix (prior to charging personas)

Cooper (1999) created and defined Persona as:

> *"a user-centred design method which sets up fictitious characters to represent the different user types within a targeted demographic group that might use a site or product."*

A persona is a collection of realistic representative information. In this thesis, the target group is the EV users and the persona as a user-centred design method is employed to characterise the charging spectrums among the group. Charging personas can be defined as:

> *"EV users have non-linear charging patterns that change on weekly and monthly basis. A charging persona is the charging pattern of a user after tracking their charging records (location and timing) for a period of time not less than 6 months. Charging personas are associated with demographic and socio technical elements."*

The charging personas are function of the charging-related attributes identified in part A of this chapter. A charging preference can be described as (Elbanhawy et al., 2014):

> *"Individual's usual charging pattern that is convenient in terms of time, price, and location. The EV user demands an easy way to publically charge their car in addition to the domestic charging. Depends on the individual routine and mobility demand, and other socio economic and demographic reasons, the EV owner uses the car in a way that it suits their lifestyle."*

To classify the different charging preferences of EV users, CYC dataset II is analysed in a way that serves the research objective. From the definition of charging personas, the attributes Most Frequent Time (M) and Average Time Spent (A) are essential.

7.9.1 Charging spectra

Prior to integrating the charging measures M and A in an attempt to classify the charging preference; the charging practice has to be identified. The charging practice can be defined as:

> *"The common practice of EV drivers using non-domestic charging network where the users charge their cars to commute not a matter of opportunity charging. A creation of charging spectrum that has different patterns. Each spectrum stems from: the desired road trip, initial SoC (as charging rate differs), confidence level and level of awareness, SoC in relation to the distance to be commuted, charger capacity and the willingness to spend time charging. There are five charging spectra (practices)."*

The dataset has been analysed based on the five charging practices, which stem from the current research, see (Figure 7-30).

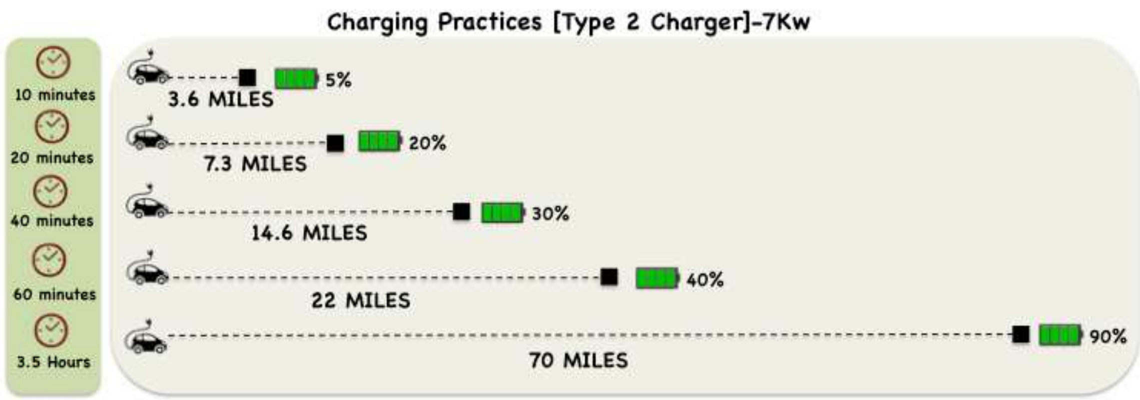


Figure 7-30: EV charging spectra- type 2

The first charging practice is a10 minute-charge, which will top up the battery with enough charge to at least commute around 4 miles in case of using Type 2 charger (in case of Rapid charger, more miles and higher probability to occur in the charging spectrum). Based on the literature and the EV user study, short-distance commuters may stop to charge their car for 10 minutes. The second charging practice is a 20 minute-charge which would be enough to replenish the battery almost 20% charge (differs based on the initial SoC before charging, refer to (Chapter 2, Section 2.3.2: Actual Daily Driving Needs). The third charging practice is a 40-minute charge, which would allow the commuter to drive another 15 miles. The fourth and the fifth charging practices are for those who are willing to spend time charging (one hour up to three hours and a half). The fifth practice is when the drive gets a full charge or 90% charge (it is advised by battery technology provider to charge the battery only up to 90% for a better battery lifestyle).

7.9.2 The charging trend

To interrogate the possible charging preferences, the first step is to look for a charging trend that reflects the EV population. An insufficient group of EV users charging their cars in a discrete pattern does not assist the understanding of the charging patterns of current users. For example, a significant group of EV users tend to charge usually at the afternoon, for 15 minutes using a particular rapid charger in the city centre, will indicate a emergent behaviour, see (Figure 7-31).

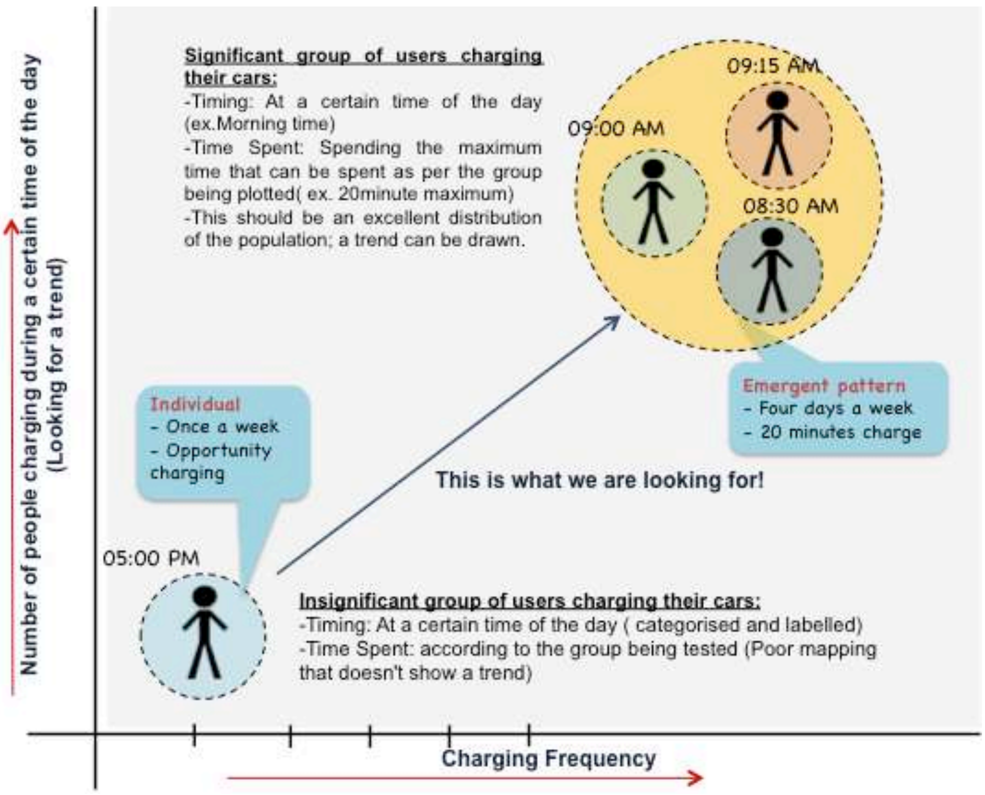


Figure 7-31: Visualising hypothetical EV charging trend

7.9.3 Forming User Charging Personas (UCP)

Following this line of thought, the analysis is carried out by designing a matrix of four data arrangements, see (Figure 7-32), creating five user charging personas. The four data arrangements are:

i) Most frequent time value;
ii) Cumulative value of all monthly charging events;
iii) Average time spent sorted by charging spectrum (charging practice);
iv) Percentage of the overall EV population.

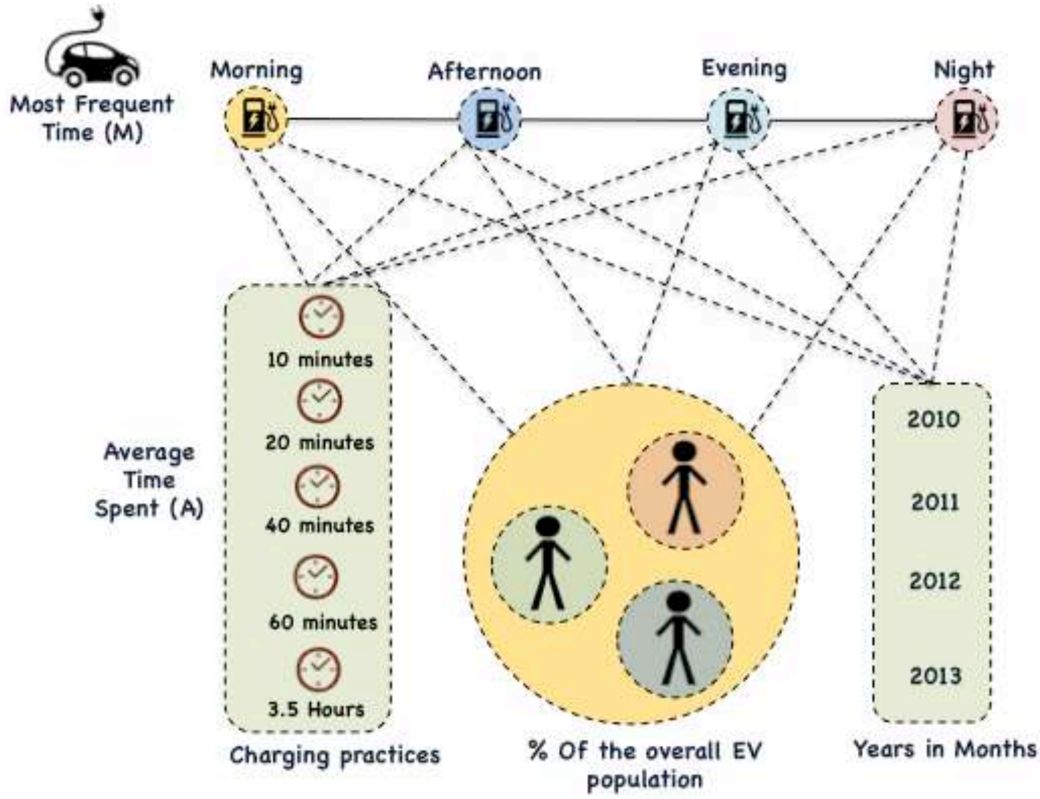


Figure 7-32: EV charging personas formation data matrix

By applying the matrix to the three and half years of operation charging records (service provider dataset Filter II) is administered in a spatiotemporal data analytics (secondary X axis chart) at these five levels of practices. The five personas are presented and discussed, see (Figure 7-33) for hypothetical data representation of the charts.

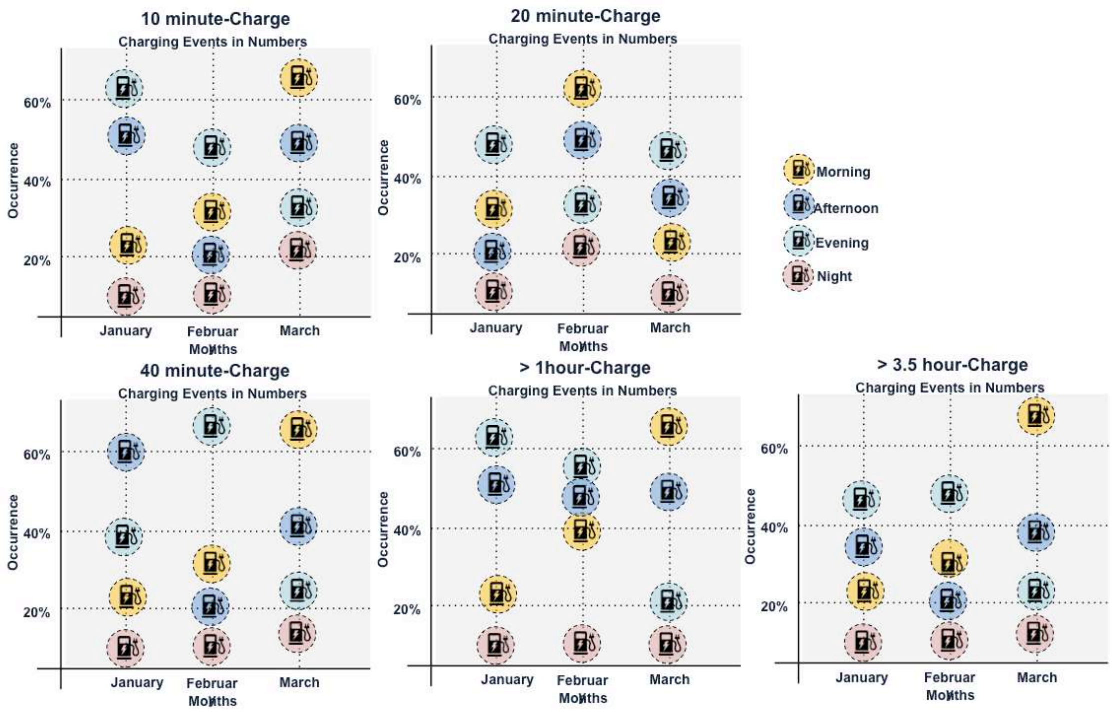


Figure 7-33: Explanatory-cumulative data representation_ (M) and charging spectra (2 Xs graphs)

The personas are based on Nissan LEAF model battery capacity and consumption rate. Equation 7-5 calculates the charging persona membership based on M and A values.

Equation 7-5: Calculating charging persona membership

$$
\begin{aligned}
&User\ Charging\ Persona(UCP) \\
&\qquad = INDEX\ (\{BeyondCharging, Superb, TheLuckyYou, GoodEnough, TheTop\}, \\
&\qquad\qquad MATCH\left((time\ of\ departure\ (d)\right. \\
&\qquad = -Time\ of\ arrical\ (\delta)), \mathrm{TIME}\ (0, \{600,180,60,40,20\}, 0), -1\left.\right))
\end{aligned}
$$

Where the time is in minute

The five personas are presented in five different graphs similar to Figure 7-33. The first persona is “The Top Up” contains those drivers who are willing to spend up to 20 minutes charging their cars over the daily road trip, see (Figure 34). This can be down to 10 minutes, which is sufficient to replenish their batteries and go home safely. A high percentage, 91%, of this group charges their car for 10 minutes only. This reflects the reliance on domestic and workplace options. Almost half of the users charge their cars for 10-minute in the evenings, which means after work and probably on their way home. The other half is equally distributed over the mornings and the afternoons.

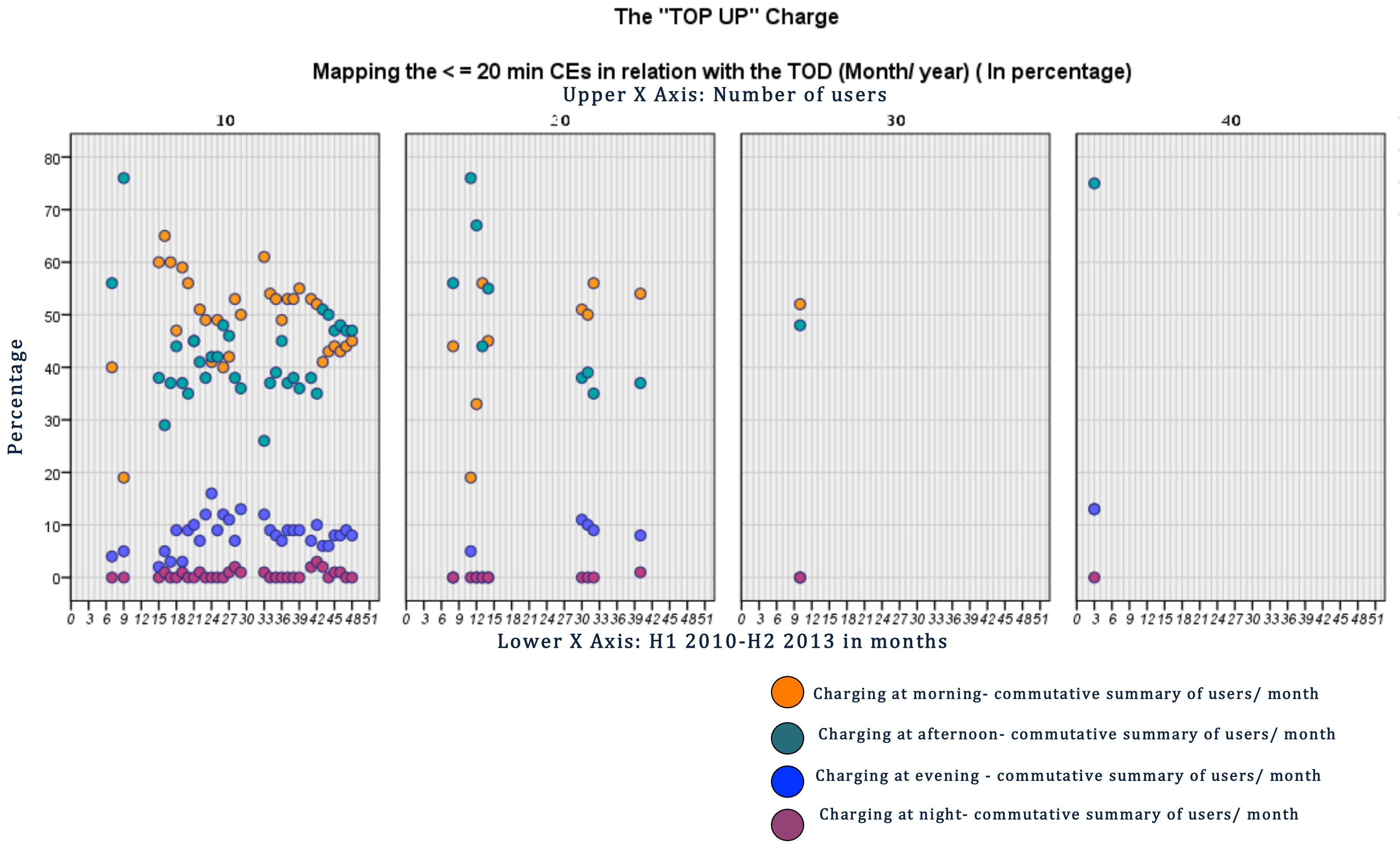


Figure 7-34: First persona: The Top Up

The second persona is “The Lucky Charge” and contains those drivers who are willing to spend up to 40 minutes charging their cars throughout their daily road trips, see (Figure 7-35). The analysis showed that the majority of transactions made by this group are ranging between 10 and 19 transactions per month. These records were scored throughout the 3.5 years. This means that this persona barely contributes to the overall charging events. Those users charge their cars in the mornings and the afternoons; in particular in the mornings.

The third persona is “The Good Enough” and contains those drivers who are willing to spend up to almost an hour charging their cars throughout their daily road trips, see (Figure 7-36). The analysis showed that the majority of transactions made by this group are ranging between 10 and 19 transactions per month. These records were scored throughout the three years. This means that this group barely contributes to the overall charging events. The EV users with this persona are those who charge their cars at mornings, and afternoons and in particular in the morning.

The fourth persona is “The Superb” and contains those drivers who are willing to fully charge their batteries using RFs, see (Figure 7-37). This means that they are so technically oriented and think wisely with respect to electricity. This group does not have a problem with charging. This is due to the high probability of having access to workplace charging (as implied from the charging spectrum), which means that users do not need to worry if they did not charge at home.

They save a lot as they probably do not mainly rely on domestic charging, they plan ahead so that they can have full charge which will guarantee a safe daily trip, and also they will ultimately have the longest life time for their batteries. However, in case of having 3KW CP, this will only replenish 50 percent of the battery capacity. Yet, this is still considered as a high level of dependency and reliance on public charging services. Graphs reflect that the majority of the charging events of this group are more often during the day. Compared to other groups, 50-59 transactions are made monthly. The second highest scores are these charging events that happen between 40-49 times a month and the third ranked scores are over 60 charging events per month.

The fifth persona is “Beyond Charging” and contains those drivers who are using 3KW chargers and/or have the luxury of fully charging their batteries using it, see (Figure 7-38). The charging events of this group are fairly distributed between (20 and 50) charging events monthly. Users tend to charge also in mornings, afternoons while less likely at evenings, as displayed in Table 7-10.

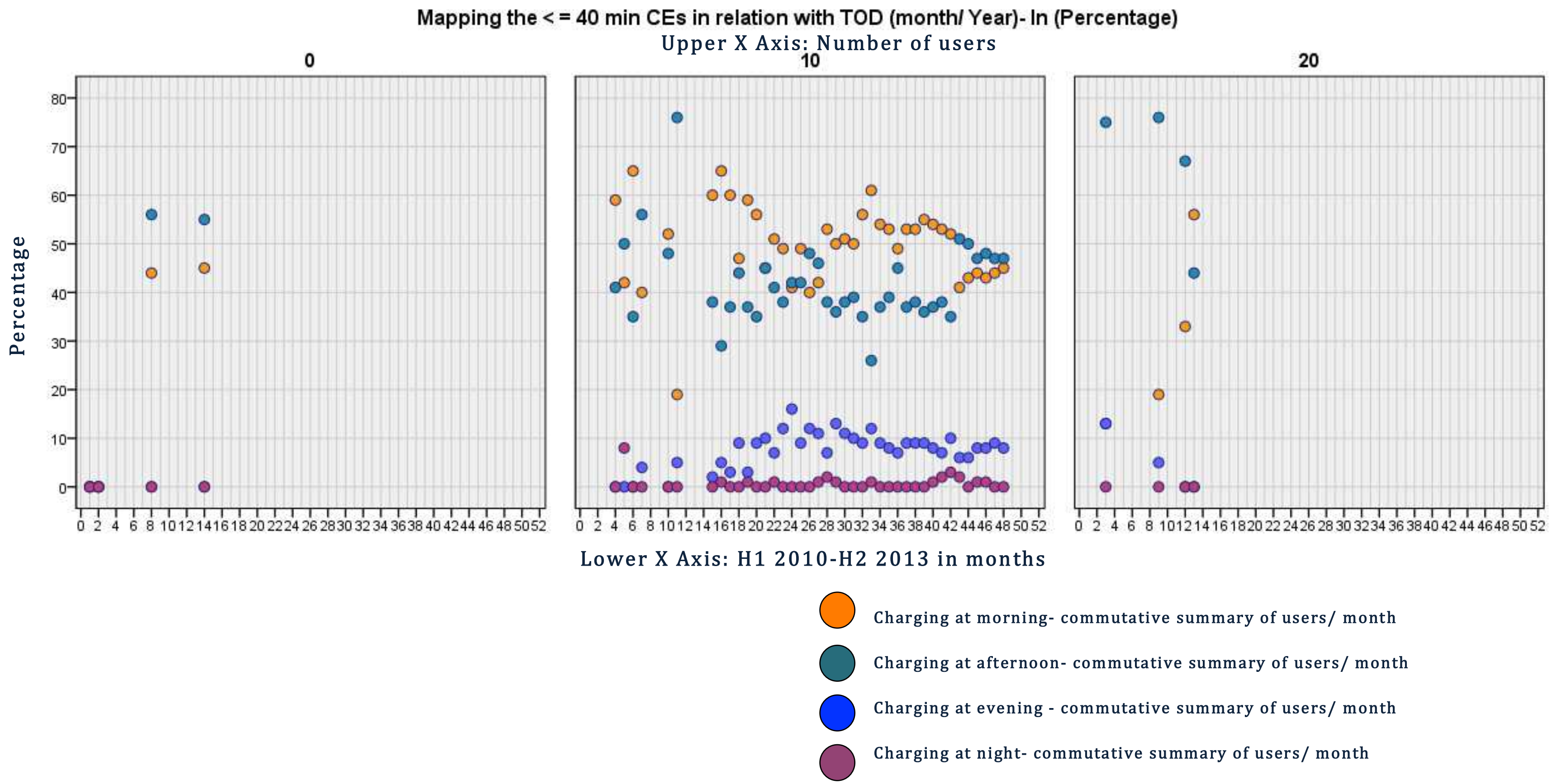


Figure 7-35: Second persona: The Lucky Charge

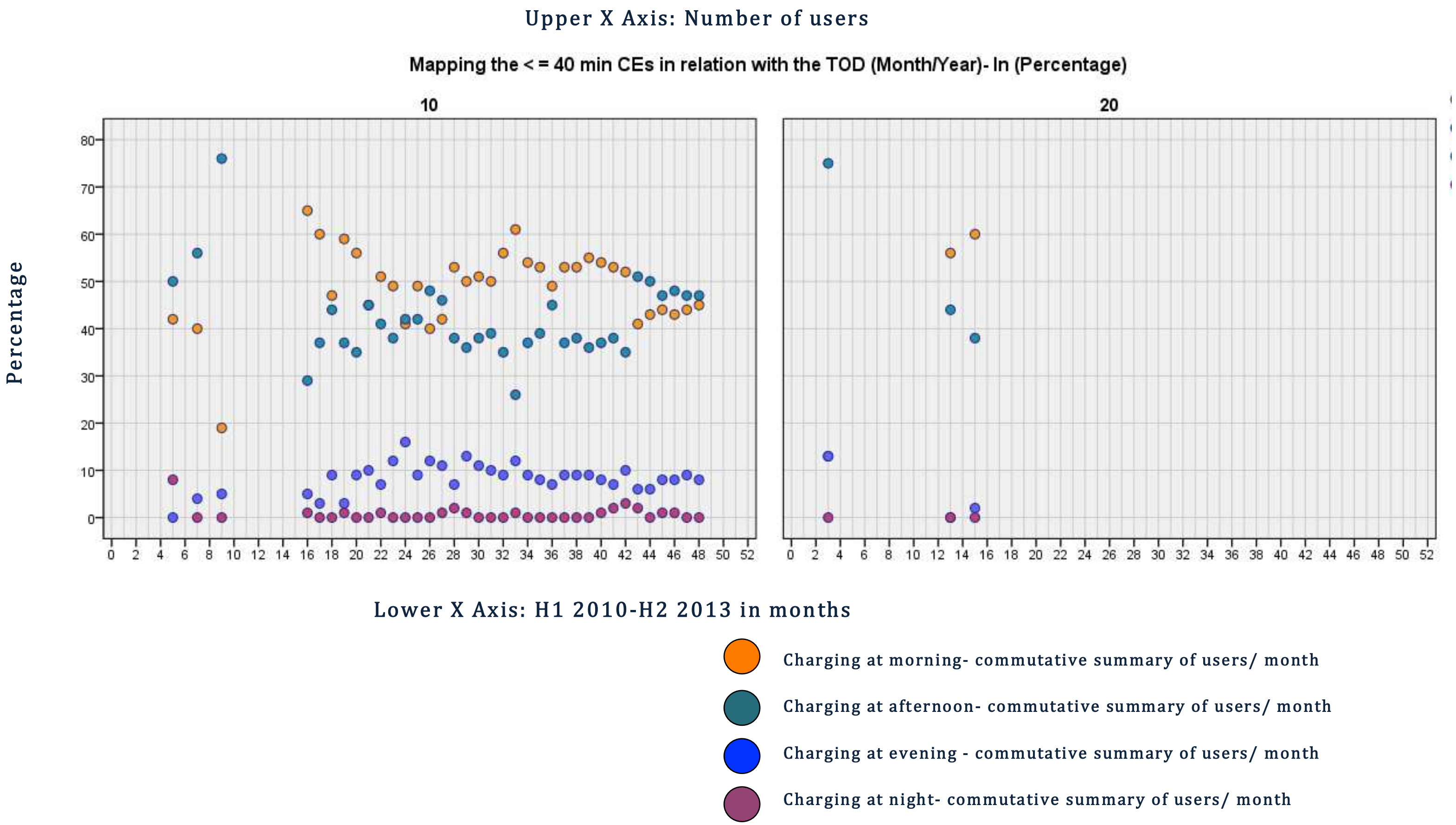


Figure 7-36: Third persona: The Good Enough

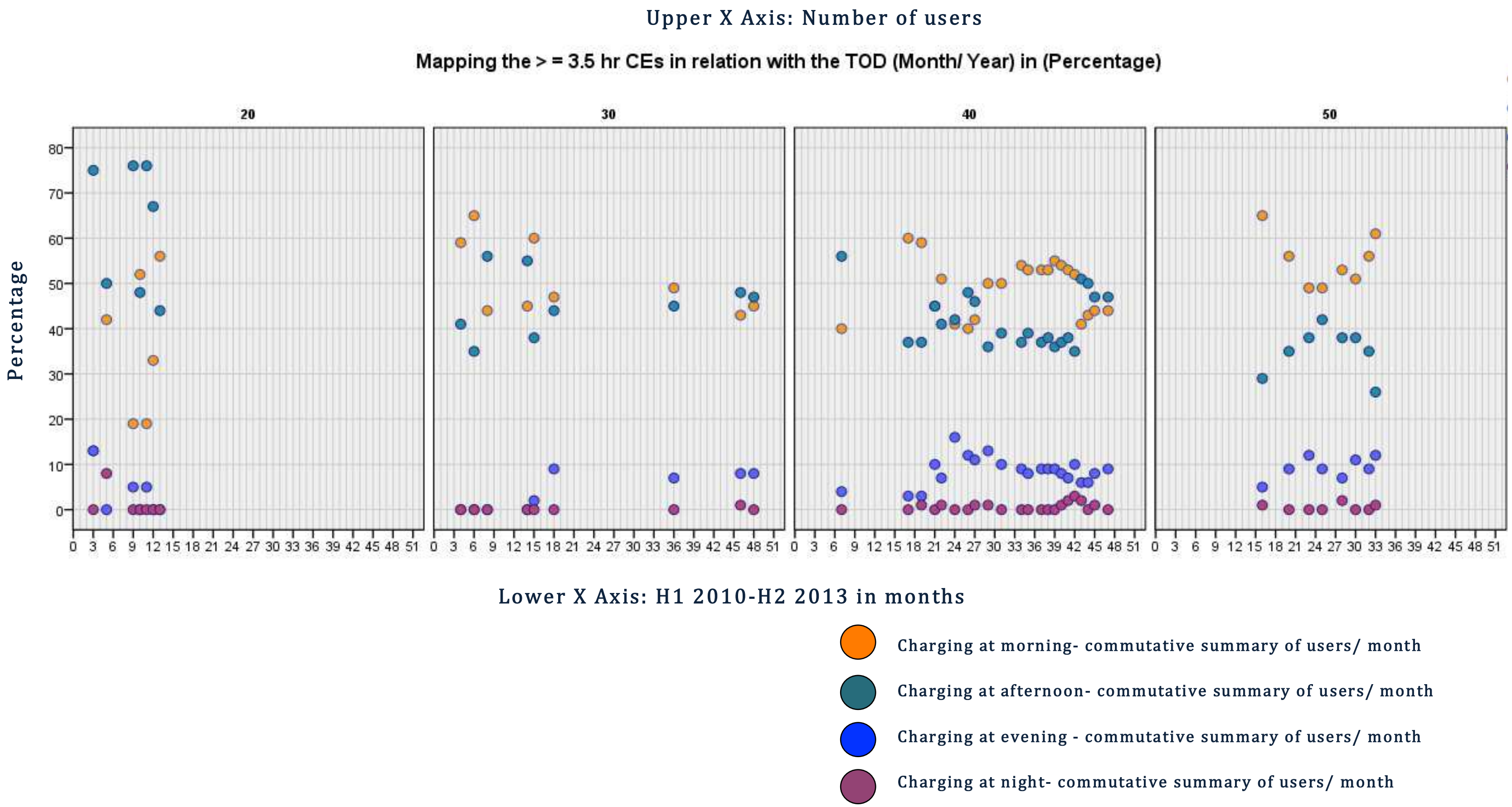


Figure 7-37: Fourth persona: The Superb

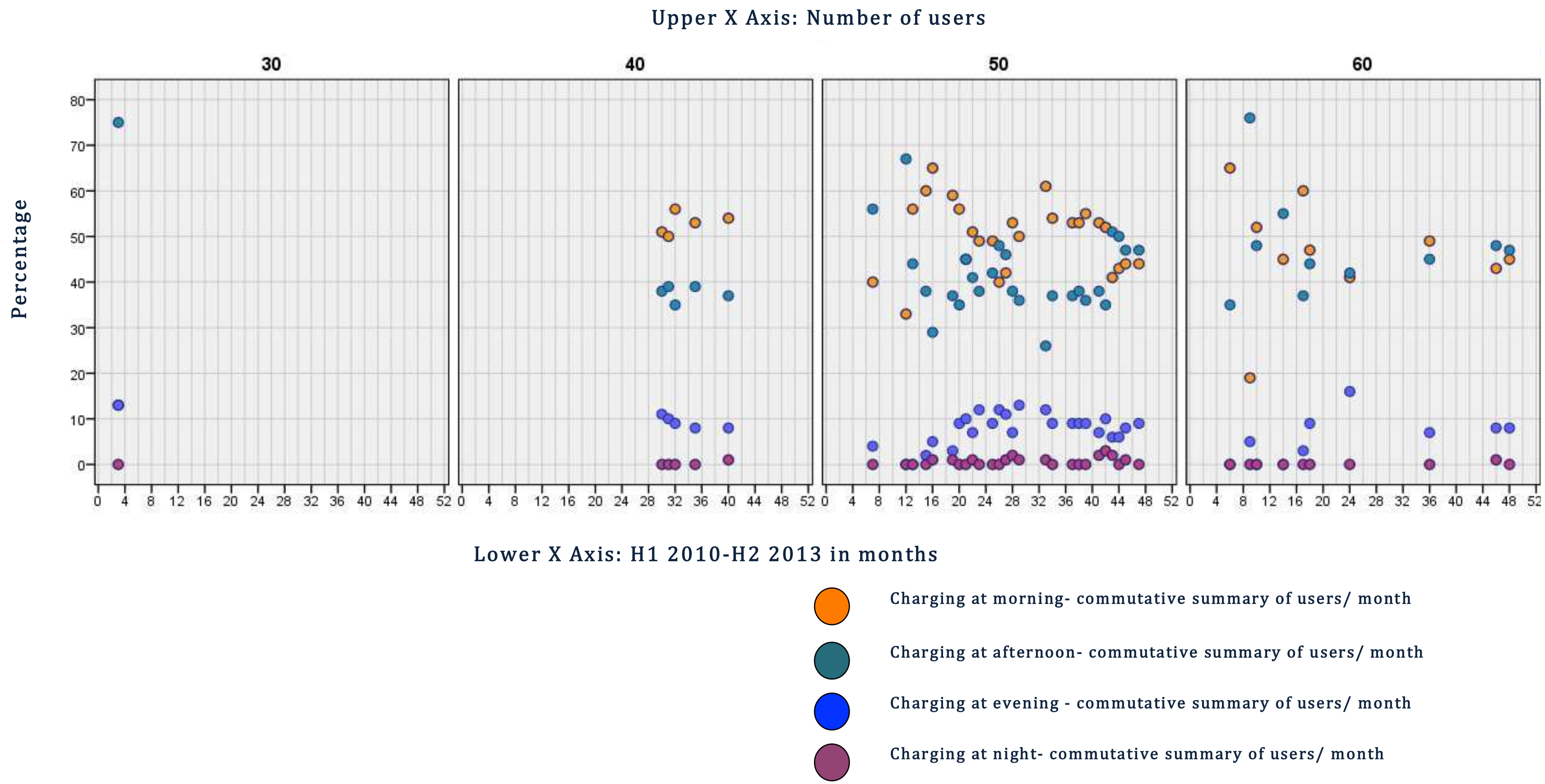


Figure 7-38: Fifth persona: Beyond Charging

Table 7-10: User charging persona matrix

Charger Type	7KW	7KW	7KW	7KW	7KW	3KW
Average Time Spent (A)	>10 Minutes	>20 minutes	>40 minutes	>1 hour	Full Charge < = 3.5 hrs	> 4 hours
Most Frequent Time (M)	Morning	Afternoon	Evening	Night		

7.10 Concluding Remarks

Chapters 6 and 7 addressed two of the research objectives of exploring users' charging patterns and personas.

> *Objective 1: Identify and quantify the spatial and behavioural attributes in order to investigate the correlation between the spatial features of the network and the charging patterns of EV users.*
>
> *Objective 2: Explore the charging pattern, profiles and personas of EV users, which responds to the diminished range anxiety issue of driving an EV.*

This chapter presented two different analyses. The first analysis was RF-oriented. The study was carried to cluster the RFs according to the identified spatial and behavioural elements of e-mobility.

From a planning perspective, the planners and policy makers would need to have a clear indicative description of the RF design characteristics and configuration that provide key design elements as well as guidelines for what to expect to have in terms of the business needs. This chapter interpreted the users' data in a meaningful way. The developed clustering model outcomes provides guidelines and recommendations to the design of On and Off street RFs. It observes that the spatial design attributes are not the only factor that a decision maker should consider while planning for RFs; behavioural and spatial attributes should be incorporated with the analysis alongside the demographic and travel demand measures. Designing RFs is a complex design process that needs integration of sociotechnical and behavioural considerations. These considerations should be based on EV users' feedback and experience, which justifies the importance of the ongoing research.

- Designing for the end-user requires a full understanding of the demand prior any further step;
- Meeting EV users justifies their preference and concerns;
- Time spent charging and arrival time are the two main strands of the behavioural layer.

The second part was about the evolving charging spectra and personas. This part undertook exploratory analysis trying to interpret the current social-behavioural configuration of the EV system by data summarisation, inference, and intuition about EV users charging spectra data. It draws on the drivers' charging behaviour and attempts to cluster their usage patterns via recording the transactions made using the RFs.

To analyse the use of the charging network alongside the charging profiles and preference, a simple infographic was designed to illustrate the matrix of use, see (Figure 7-39). The matrix works as a collective matrix linking between the three layers of the system. From the planning authorities perspective, the design features and configurational design attributes that would:

i) create an integrated system;
ii) maximize the use of the charging network;
iii) generate profits to the government tax revenue in the medium term;
iv) to build a successful business model for utilities management companies.

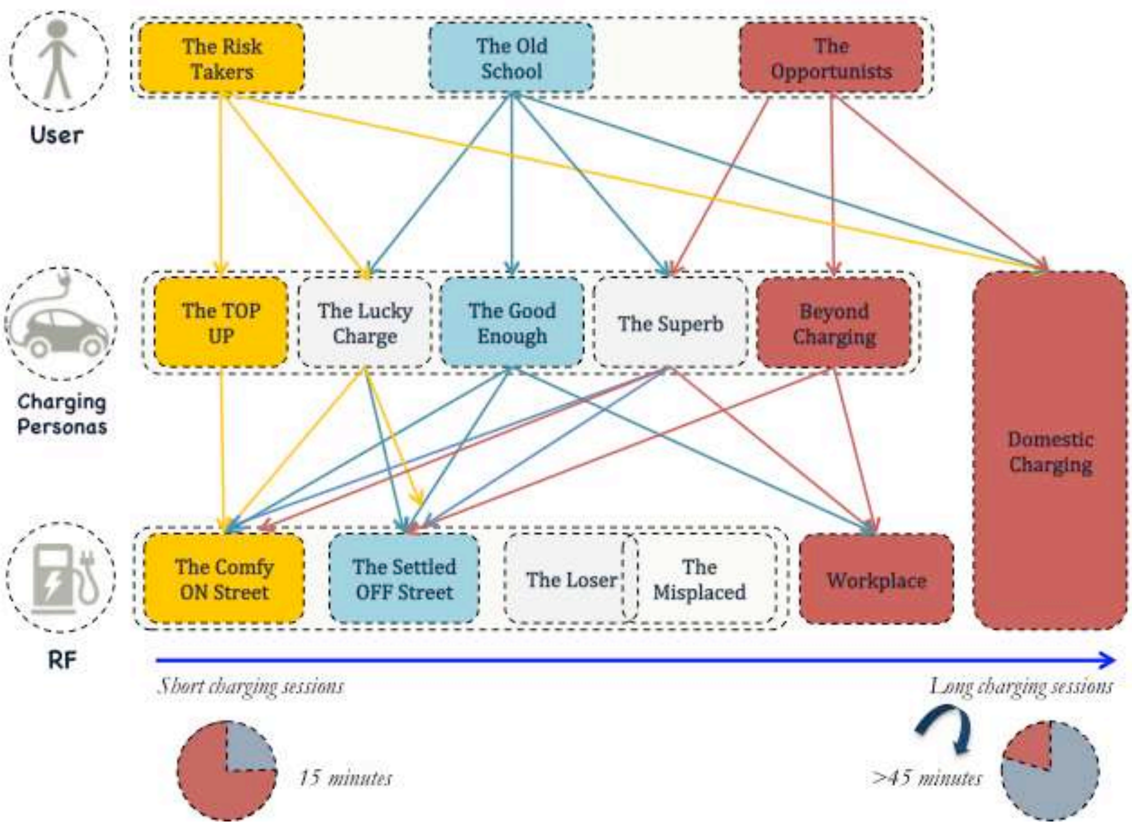


Figure 7-39: The matrix of use

The next chapter introduces the second phase of modelling, Chapter 8: Model ii: E-Mobility main paradigms and platform selection.

CHAPTER 8. MODEL II: E-MOBILITY MAIN PARADIGMS AND PLATFORM SELECTION

"He said that he was going to charge me with theft by taking because I was taking power, electricity from the school."

By John Kamooneh, an EV driver in Atlanta (2015)

Simulation modelling is the fourth employed method in this thesis. Prior to conducting the simulation and in order to tackle the steps of development, an identification of the main paradigms of e-mobility is necessary. The e-mobility system is a subset of conventional modelling; however, the system has unique paradigms that may affect the design and development of the model. In order to simulate the EV population, this chapter provides the main paradigms of the e-mobility simulation model followed by the selection criteria of the simulation platform.

In vehicular simulation (Chen & Wang; Paul, 2009; Turner & Dalton, Banos et al., 2005; Valverde & Sol'e, 2002) and particularly in the context of EVs, it is very stimulating to study and analyse the emergent behaviour. This behaviour is a collective macro-scale behaviour coming from the bottom-up (Batty et al., 2012; Crooks et al., 2008; Li et al., 2006).

Table 8-1 presents a comparative analysis between non-EV and EV simulation modelling. This analysis is one of the prime steps in the process of developing the simulation model.

Table 8-1: Conventional and e-mobility comparison

Paradigms	Conventional (non EV) Mobility	E-Mobility
Problem class	Congestion (queuing theory), traffic management, air quality, noise, and fuel usage, finding solutions to decrease the number of usage	Infrastructure integration, charging habits, energy usage, market penetration (Well-to-wheel studies), EVAR, finding solutions to decrease CO2, increase market uptake congestion is NA as this model is to simulate the behavior of EV drivers finding charging points in the road network (No Queuing theory)
Possible applications	Planning and policy makers, traffic impact assessment, parking and pedestrian studies, sensitivity analysis, traffic safety, forecasting and controlling traffic, optimizing traffic flows	Social and Engineering Sciences, daily dairies (Charging behavioral characteristic), planners and Policy makers, EV and batteries manufacturers, technology providers, renewable energy, R&D.
Solution	ABM, CA, both, or geo-simulation (Not analytical)	ABM for IF THEN rules, complex space-time, and computational tasks of collective agents (Not analytical)
Source of date	Theories, Artificial Intelligence (AI), interviewed and surveyed persons (driving pattern)	Interviewed and surveyed EVs early adopters and market stakeholders in addition to AI, IF then rules, etc.
Aim	Shortest path propagation	Nearest charging point
Market and R& D development	Different platforms, integration of different approaches and applications	Niche market. Little literature focusing on integrating EV simulation with other applications (not urban planning)
Simulation Environment layers/ Classes	Layers: (Balmer et al., 2004) (1) Physical layer, (2) Mental layer, (3) Feedback layer, (4) Condition layer. Layers:(Lombardo and Petri, 2004) (1) Reference layer, (2) Route feature layer, (3) Event layer CA:(Benenson and Torrens, 2003). (1) Estate (fixed), (2) Agent (non-fixed), D- Classes: (Narzisi, 2008). (1) Environnent, (2) Agents (state, parameters)	Layers/Classes: (1) Simulation environment (network, city topology and charging points) (2) Autonomous Agents (vehicles showing battery states) (3) Rules (mathematical, activity based or AI)
Interactions	More direct interaction with agents	More interaction with the environment
Route choice	Travel time, distance, and cost	Travel time, distance, and battery state

Paradigms	Conventional (non EV) Mobility	E-Mobility
Choices and decisions' factors	Time, mode, location	O-D matrix, time granted, full-electric range, charging location/time (initial battery state, and power capacity)
Mobility mode choice	All modes of vehicles - Battery Capacity is N/A	One mode / simulation: e.g., private cars with different batteries capacities
Agents goals	Macro and Micro goals	
Reactive agent's brain (key traits)	Selfish principle in reaching goal, fine-tuned parameters (speed, gap between vehicles, queuing, collision detection, and brake.	Selfish principle in reaching nearest charging within vicinity, check state of charge, charging time, parking lots. Speed, gap, lanes, and brake are N/A.
Behavior	Vehicles traits/flow in traffic (route)	Charging behavior (profile)
Key components	Roads, intersections, traffic lights, pedestrians, vehicle's speed and size	Vehicles and battery type and capacity, no. of users, charging points
GIS- 3D visualization	Example: recreational areas visitors' movement, traffic impact analysis	Gap in the literature - lacks technical depth and temporal detail
ITS strategies integration	Message signs, transit signals priority, corridor alternative analysis, control techniques	Nearest charging point is considered based on location and availability reported by NAVSAT.
Multi agents	Traffic:1- Network (destinations and roads) 2-Vehicles, 3-Control	EV: 1-Network destinations, roads, and parking lots)2-Charging points,3-Vehicles, 4-Batteries, 5-Drivers
Routes of evolution	1-Theories, 2- Knowledge based findings (Activity based approach), 3-Artificial Intelligence (IF then)	Knowledge based findings and IF THEN rules (if required) to apply more rules related to battery state and availability of charging posts

Table 8-1: Comparative Analysis- Non-EV and EV: (Acha et al., MVA, 2011; Fellendorf, 2010; Element Energy Ltd, 2009; Doniec. A, Balmer et al., 2008; Ali et al., 2007; Ali and Moulin, 2007B; Wang, Bazzan, Chiu et al., 2005; Burghout,;Arampatzis et al., Lombardo and Petri, 2004; Benenson and Torrens, 2003; Paruchuri et al., 2002; Bishop and Gimblett; Bell et al., Jiang, 2000, Hall, 1997)

It can be observed from Table 8-1 that the EV population is not entirely a new type of simulation compared to conventional mobility. They have lots of common and mutual parameters; whereas, the first has some unique parameters that signify its simulation nature. This implies that the EV population is a sub set of the conventional mobility data. EV population is a small part of a large group; depends on the application and the end-users' requirements, and the simulation setup changes (ElBanhawy et al., 2012; López-Neri et al., 2010; Robinson, 2007; 2008). The mutual paradigms are clear and recognized e.g. roads network layer, some of the agents' behaviours and traits, goals scale, visualization and Geographical Information System GIS purposes, and the way the ABM is structured. Unique paradigms e.g., battery state, charging preferences, number of destinations, and parking areas exist due to the differences in simulation aims and targets. Figure 8-1 depicts a schematic visualisation of the e-mobility system highlighting the givens and expected outcomes of the simulation.

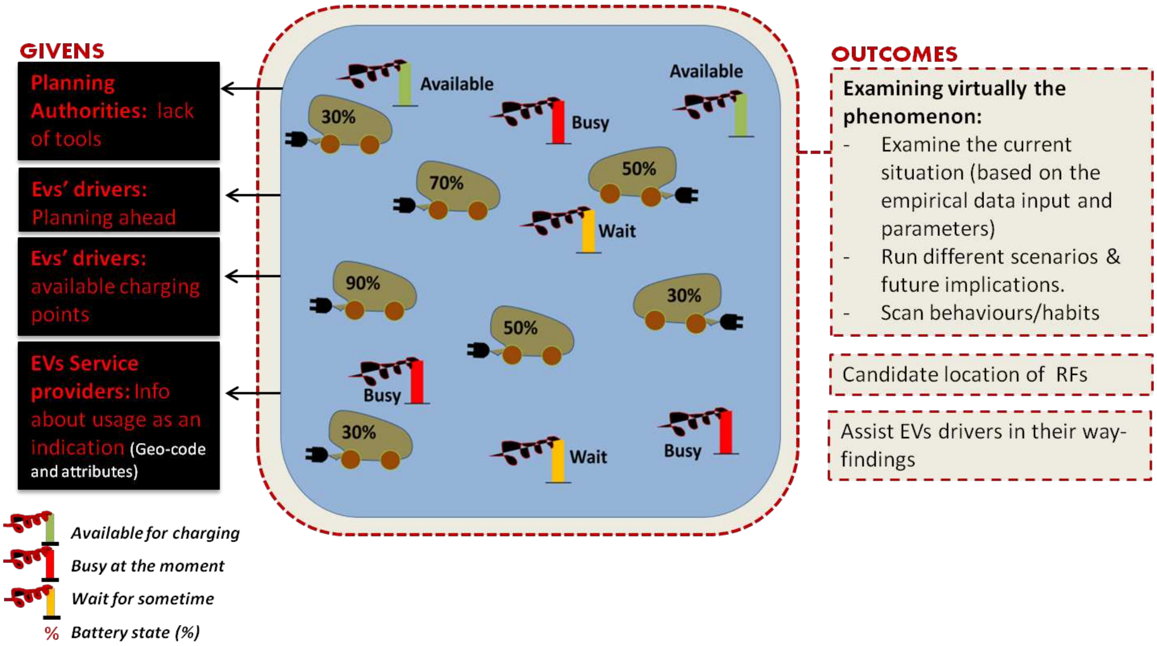


Figure 8-1: Schematic e-mobility system simulation model

For example, both EV and non-EV can be typically replicated within a conventional mobility simulation where the network and controlling rules are applied. Since the vehicle type is not an influential parameter that may affect the simulation results, the EV will not be recognised as a low carbon vehicle in such simulation. However, in other applications pertinent to air quality and noise, the EV is recognised as it would have different environmental and acoustical calculations (Hodges & Bell, 2011). In this context, the main attention is to the charging behaviour. A prototype is chosen, Nissan LEAF (Nissan LEAF, 2014b), using the same vehicle' assumptions and consumption rate in all studies.

The AB technique enables capturing the dynamic effects and real-time interactions (Lee, 2010) between the users and the charging network (ElBanhawy et al., 2012). There, agents (EVs) may execute various behaviours appropriate for the EV system they represent (Bonabeau, 2002). The design process of the agent architecture is a long developing and evolving process. This part of the thesis takes the reader through the development of the agent architecture and computational technicalities of the model.

8.1 The Evaluation of Available Platforms

The simulation model mechanism is introduced in Chapter 9. In order to execute the simulation model, selection criteria have to be established to select the appropriate platform. This process started with outlining the basic essentials the platform requires to run the desired model. Once the requirements are clear, a systematic overview of the current available platform that may support the simulation of e-mobility system is presented. Following the identification of appropriate platform, a filtering process based on the requirements of the research was applied to establish the simulation modelling application that were deemed appropriate for use within the scope of the research.

8.2 Basic Requirement: Vehicular Simulation

This chapter aims at identifying a commercial platform, which is capable of running hybrid models while incorporating both visual and non-visual aspect of the system. This process involves understanding the needs and the requirements of the research and identifying a set of fundamental features in the desired platform to meet those needs. The platform was identified based upon either current capabilities or evidence of future development appropriate for the desired application. The review therefore concentrated on identifying and selecting software from four categories:

i) Vehicular simulation (high level of complexity, see (Figure 8-2)
ii) Individual dynamics (social behavioural simulation);
iii) Visualised 2D simulation and handling 3D modelling if needed;
iv) Built in scripting Capabilities to control entities behaviour based on agents states

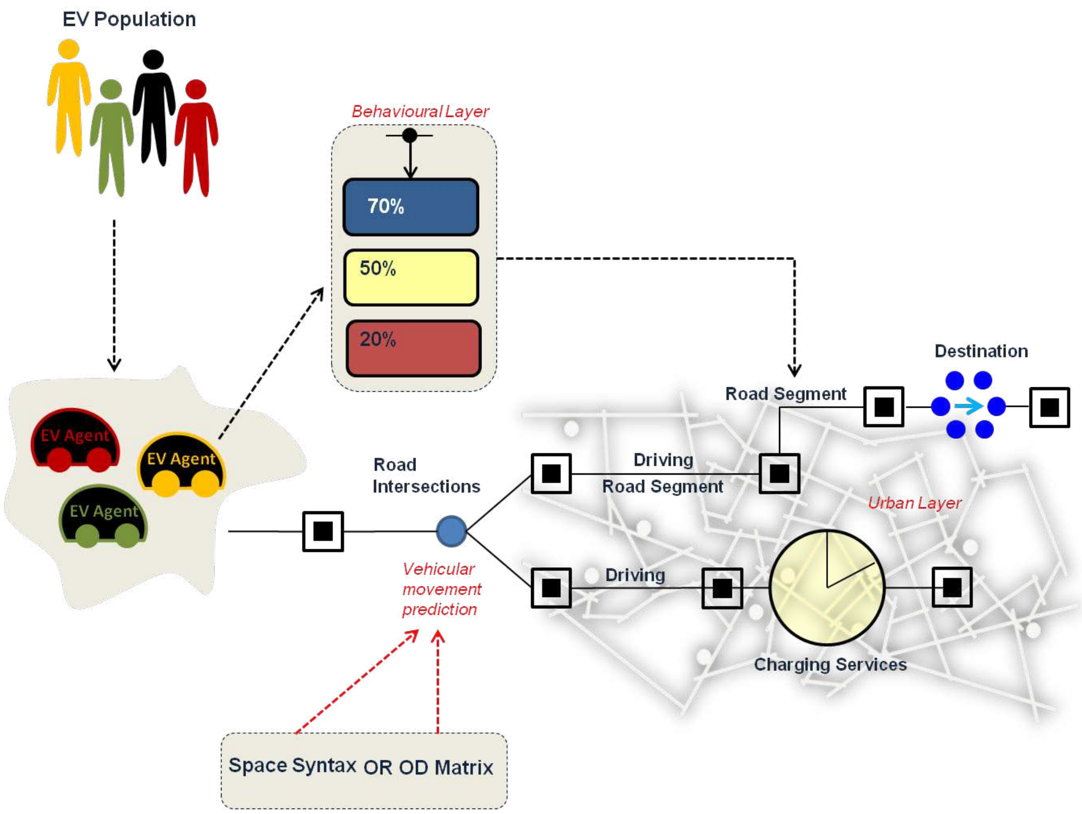


Figure 8-2: Vehicular simulation interactive tool

8.2.1 Is Excel an option?

The social behaviour types of phenomena have lots of interdependencies, time-delayed occurrence, interaction and multiple events. This adds more challenge to model it as it requires regular real-time updates (Chen, 2009). Analytical solutions and MS Excel package can model simple or even complicated environments events; however, they lack the spatial and virtual representation of models. In addition, MS Excel works more with the optimization problems and successfully provides reliable outcomes, which is different in case of using simulation modelling. In simulation, all feasible solutions are texted randomly and several trials and runs are simulated with spatial representation of the environment. Randomness, time delay, independencies, system interaction, complexity, spatial interaction, and individual decision rules (*social force*) are the reasons behind utilizing simulation modelling to solve the present problem (Borshchev, 2013; Lee, 2010; Gilbert & Troitzsch, 1999; Troitzsch, 1997).

8.2.2 Available potential software

Due to the e-mobility system complexity and hybrid techniques being used, the platform should be able to:

i) Import external files .xlsx and .csv files and other formats;

ii) Code editor while simulation is playing, less scripting, more interactive user interface (drag and drop objects and entities);

iii) Fast to learn and to create models, visuals iterations and simulation runs rather than texts and codes;

iv) Show run time errors and compile time errors, with a fast simulation time;

v) It does not require high level of details (LoD) in the creation of the entities; cars can be presented with simple geometric shapes.

Following the identification of the basic requirements, a list of available potential software was established. Table 8-2 summarises the main features of six commercial platforms.

Table 8-2: Platforms main paradigms

Platforms	Simulation Technique	Simulation Environment	Application
MASON	Single process-discrete-event, ABM	Layers: 1-Agents and the schedule, 2- Fields	Intensive computational applications (large group)
VISSIM	Discrete simulation-object oriented programming-OOP	Vehicular model: Blocks: (1) Infrastructure (2) Traffic (Vehicles) (3) Control Pedestrian model: (1) Fixed routes (2) Dynamics routes (3) Dynamic Assignments	Realistic driving and pedestrian behavior. Microscopic and traffic operation
Anylogic	Hybrid (ABM, Discrete event - System Dynamics)	Classes: 1- Environment (main), 2- Agent (People)	Several ABM applications: agents can be: consumers, vehicles, equipment, products, or organizations
Swarm	Agent and individual based modellers	Swarms, collections, actions, schedules, observers	RePast, Ascape and MASOn creator
NetLogo	Discrete time steps- multi-agent programming	Layers: 1- Network- Link segments 2- Nodes (intersection) 3- Control Features	Education purposes, short time simulation, local intersection of agents and grid environment
RePast	Discrete time-OOP, scheduling. Multiple computational agents &personality trait modelling	Environment (main class) and Agents (layers): 1-Properties (Topology) 2-Networks (Transport) 3-Diffusion models (info)	Social network and dynamic models

Table 8-2: ABM Platform techniques, environment, and applications (Lytinen et al., 2006; Revilla et al., 2005; Doniec, 2008).

As it can be observed, all listed software run microscopic simulation and simulate social science phenomena. After checking all of the software, each has an edge on the way the model is processed. The second selection phase was to apply a filtering process to identify software unsuitable for further consideration and those that required further and more detailed study.

i) Filter 1: Agent based modelling
ii) Filter 2: Execution of different simulation techniques
iii) Filter 3: Message based protocol between the agent and the entity
iv) Filter 4: The ease of integrating vehicular movement prediction techniques (Easy Implementation)

8.2.3 Filter 1:Agent Based Modelling (ABM)

In order to execute such model, an ABM platform is needed. Several platforms can be used to simulate ABM. The desired platform needs to incorporate agents' traits. The EV agents sense and act upon the urban environment, they try to fulfil a set of goals (Schelhorn, 1999) in a complex environment like the e-mobility system. There, independent perceptions and individual decisions are taken and virtually presented (Li et al., 2006). These agents reflect how individuals behave (North, 2010; Macal & North, 2009; Chen, 2009) and learn and engage in dynamic strategic interactions (space, time, information exchange (Chen, 2012). The EV agent has dynamic relations with other agents/ simulation environment (*message protocol based*), have a spatial component to their behaviours and interactions (*adhering vehicular movement prediction technique*).

The agent architecture (LoD), real-model-correlation ratio and scale are problem-based decisions, which should be wisely decided. This should enable the ABM building a model that balances between needed complexity and acceptable assumptions (AnyLogic, 2009). There are various possible LoDs to create the agent architecture within the model; a good enough LoD that serves the phenomenon is considered. Although if the model handles only simple architectures (stop-drive, LoD 1), that will not solve the simulation problem. Figure 8-3, illustrates the different levels of complexity with respect to driving behaviour. To run such a model, an interactive platform, which can accommodate LoD 3, is required in order to stimulate the agent architecture, which is explained in Chapter 9.

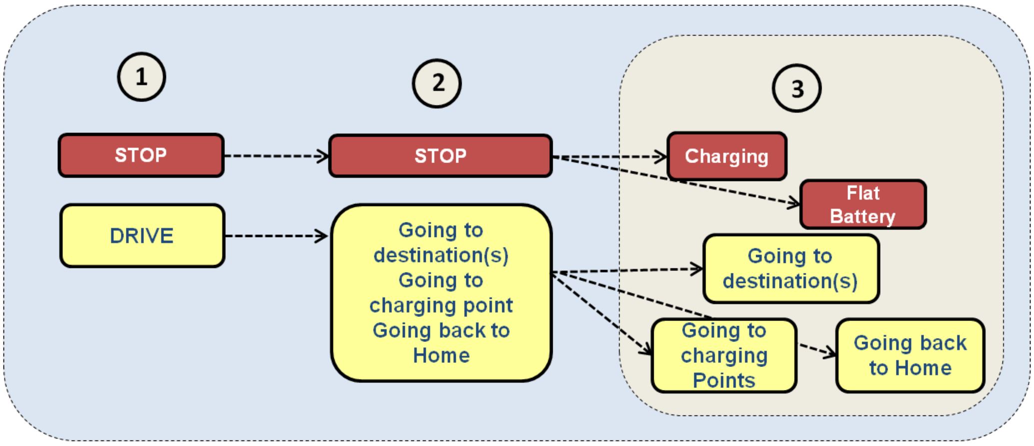


Figure 8-3: Stop- Move- 3 LoDs of ABM statechart

To assess each software for filter 1, a simple model was developed to evaluate the platforms. The model is very basic, it has all the simulation environment elements but simulated as a single agent going around a simple network, see (Figure 8-4).

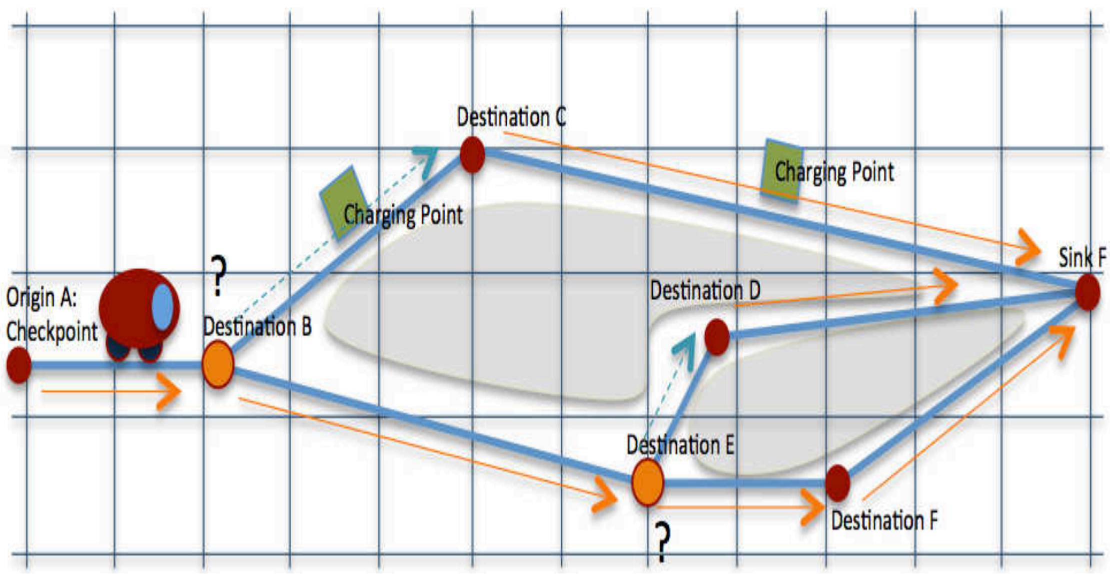


Figure 8-4: ABM key elements

Before proceeding with the second filter, a broad overview of the pros and cons of each platform was needed. Table 8-3 below summarizes a brief comparison of the key issues of the platforms. MASON, VİSSİM and Anylogic are the platforms that can perform 3D representation.

Table 8-3: Platforms pros and cons

Platform	Pros	Cons
MASOn	Fast execution speed, clever, high complex problems, good user interface, generate graphs and charts	3D display only , non-standard and sometimes has confusing terminologies, problems in interface and programming
VISSIM	2D and 3D visualisation suite, GIS, fast, high complex problems, good functionality of traffic flow, measure of effectiveness (MOE's) reports.	Mathematical models are behind the modelling (check centralised approach)
Anylogic	Fast, code writer, drag and drop, GIS, high/ medium complex problems	3D display only, poor visualization, medium complex ABM problems
Swarm	Clever, stable, well organised, clear conceptual basis, clear separation of graphical interfaces and the model.	Medium execution speed, minimum complex problems, incomplete documentation, weak error handling,
NetLogo	Less programming time and error checker	No 3D, no GIS, slow, minimum complex problems, and no reproducibility
RePast	Fast, GIS, high complexity, advanced UI, geographic and network function	No 3D, no built-in method to randomize orders among agents

Table 8-3: ABM platforms pros and cons- (Lytinen et al. 2006; CiOffi-Revilla et al. 2005; Doniec, 2008).

8.2.4 Filter 2: execution of different simulation techniques

The second filter was to have the capability of simualting diferent techniques (Discrete Event and Systems Dynamics) and also execute hybrid models (ABM and DE). MASON has been removed from the list as it only performs 3D modelling and provides level of detailing that is not needed for the desired system. Table 8-4 articulates the main paradigms and capabilities.

Table 8-4 : Main paradigms and capabilities

Platforms	Simulation	Complexity	Programming	Time	Purpose
Swarn	Pure ABM	Simple	SCALA-object-oriented language	Medium	Cellular Automaton
AnyLogic	Hybrid	Complex+ Library	Code-writer-Drag and Drop + Java	Quick	Decision + Rules
NetLogo	Pure ABM	Simple	Template based + script	Quick for simple problems	Education
RePast	Pure ABM	Complex	Hard-coded-Java	Slow	Decision + Rules
VISSIM	Deterministic micro simulation	Depends on the LoD	C-Code (embedded Controls Developer) Drag and Drop + property configurations} AND C++	Depends on the LoD	Visual Simulation

8.2.5 Filter 3: message based protocol (agent and entity)

The third filter was to ensure that the platform can accommodate sending messages between the agents and the entities (*as default agents send to each other*). Simulating a hybrid model requires a message-based protocol to connect between the AB and DE. Regardless of which is embedding which, the agent is inside the entity or the other way around, this protocol is mandatory. A list of the instances of exchanging messages can be summarised as follows:

i) an entity sends message to agent: updates while the entity passes by CP;
ii) the agent sends message to the entity with the state of the battery (in case it is approaching a critical zone, it needs to be charged);
iii) the agent sends coordinates (Origin X, Origin Y);
iv) the agent sends coordinates one entering the critical battery zone (X1, Y1);
v) the agent sends coordinates exiting the critical battery zone (X2, X2);
vi) the agent checks the nearest CP (distance To X charging, Y charging).

8.2.6 Filter 4: ability of integrating movement prediction techniques

The fourth filter is the most important one assesses the easiness of executing the model. Effort and time needed to design, run, amend, and retrieve the results. After understanding the main paradigms of EV systems, the simulation model should contribute to a more integrated approach to analyse and design the EV charging network. In other words, the selected platform should be reliable and capable to simulate behavioural characteristics of drivers, display the same results with less effort; it should simplify the simulation environment configuration and the visualisation of integrated techniques for a better assessment, see (Figure 8-5), and provide more flexibility in changing simulation parameters and future situations.

In order to decide which one can perform the model, the simulation objectives have to be clear. The desrire is to model an interactive and flexible tool that supports design, behaviour, system changes which eventually represents the desired phenomenon in a better way (Ehlert, 2001).

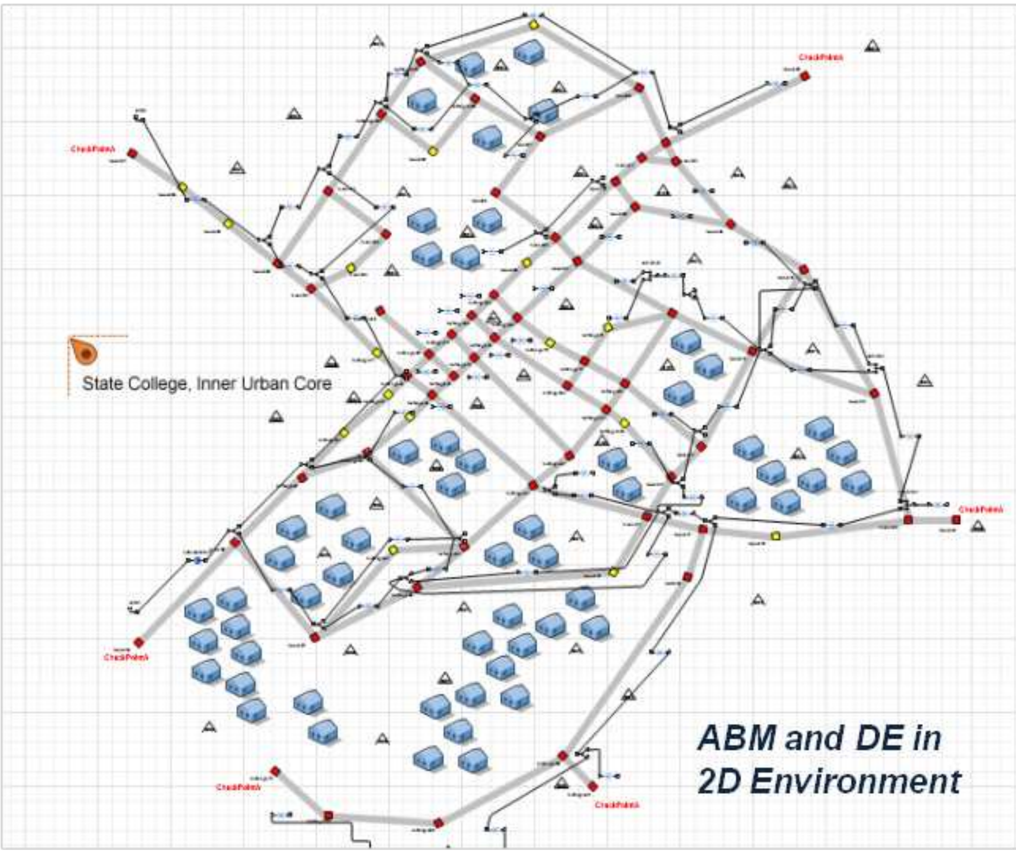


Figure 8-5: Example of integrated visualisation and simulation environment

8.2.7 The decision

The final filtering processes eliminated Swarm, NetLogo, Repast, and MASSON, VISSIM platform showed positive results in terms of 3D visualization, see (Table 8-5). Previous literature has shown that it has been utilised to simulate traffic and it has been successful in merging traffic simulation with 3D modelling (Nomden et al., 2009). However, due to the unique nature of EV population, EVs simulation will not require massive traffic and complex network data as an input, refer to the previously discussed main paradigms of EV simulation earlier this chapter.

A more AB oriented platform in modelling would get more credits and higher preference. Anylogic is ABM platform in the first example, accommodates hybrid problems (if needed), requires less coding (code writer) and has an interactive simulation environment, which facilitates having IF THEN rules and AI algorithms via Java coding. Built-in logic, statecharts options and API (Application Programming interface) would perfectly facilitate modelling EV population with less coding effort.

Table 8-5: Summary of platform selection result

Platform	Swarm	Anlogic	NetLogo	Repast	Masson	Vissim
Fliter 1	Yes	Yes	Yes	Yes	Yes	Yes
Filter 2	No	Yes	No	Yes	Yes	Yes
Filiter 3	No	Yes	No	No	Yes	Yes
Filter 4	No	Yes	No	No	No	Yes

8.3 Concluding Remarks

This chapter presented the main paragims of the e-mobility system and discussed the relavent platform that may simulate the EV population. It addressed the third research question:

> *RQ3: What are the main paradigms of e-mobility compared to conventional transport?*

AnyLogic 6 platform has been chosen among the rest of the collection due to its capability of merging between ABM and DE forming hybrid models in a large group simulation. It has been sussessfully utilized in numeruos literature. It is recoagnized as a rapid, compose industrial-strength ABM and DE within the same visual environment with a friendly user interface. It supports ready constructs for defining agent attributes and environmental model with a rich visulaization capabilities (Borshchev 2004). The selected platform can:

- Produce hybrid models (ABM and DE);
- Simulate micro-dynamic large-group simulation (vehicular movements);
- Have a fast execution time, stable, interactive and reliable agent based modelling;
- Require less coding for adding IF THEN simulation rules;
- Simulate 2D and can be coupled to realistic 3D visualization solutions, see (Figure 8-6);
- Simulate societal and behavioural models;
- API collects and accepts GIS in case, if needed, see (Figure 8-6)

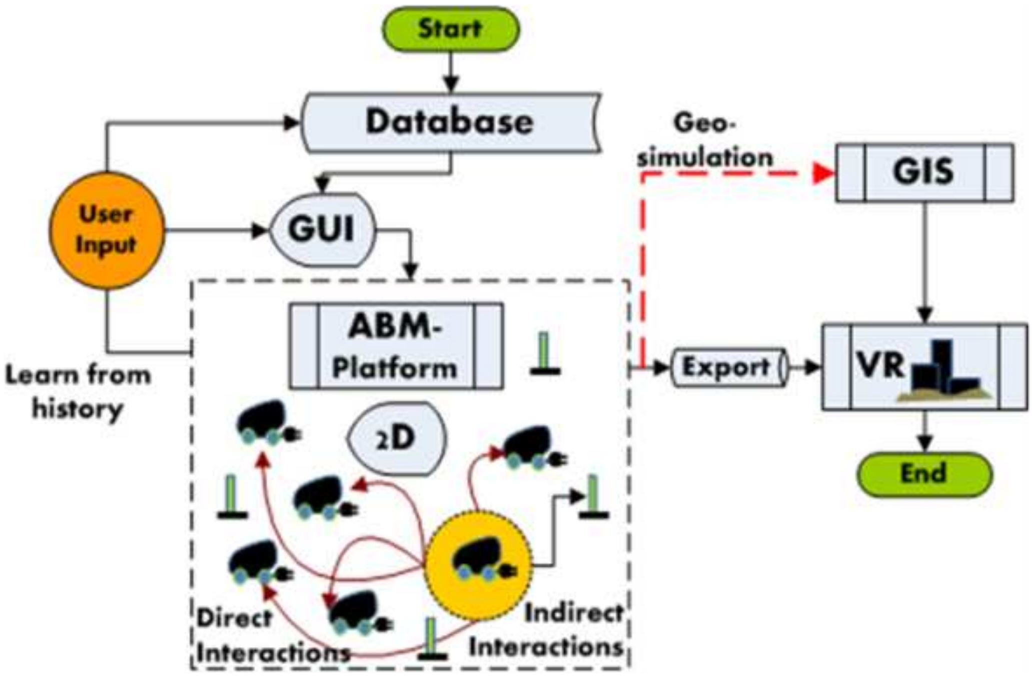


Figure 8-6: Simulation and visualization diagram showing flow of data

The next chapter presents the agent architecture and the application of employing Anylogic to simulate e-mobility.

CHAPTER 9. MODEL III: E-MOBILITY AGENT ARCHITECTURE AND COMPUTATION

"I really miss stopping for gas and then feeling the need to buy junk food because I stopped. Losing a lot of weight not stopping at gas stations to fill up on gas and junk food."

By an anonymous EV driver, Tesla Owner (2013)

This chapter builds on the previous chapter and discusses the application of using simulation modelling in e-mobility context. The chapter is divided into two parts. Part A presents the agent architecture of e-mobility simulation modelling. The development of the agent architecture comprised three models. Part B presents the simulation theory of two simulation mechanisms (paragons) with all related computational and technical assumptions. Comparisons are made between the two paragons to identify the use and main features of each, see (Figure 9-1).

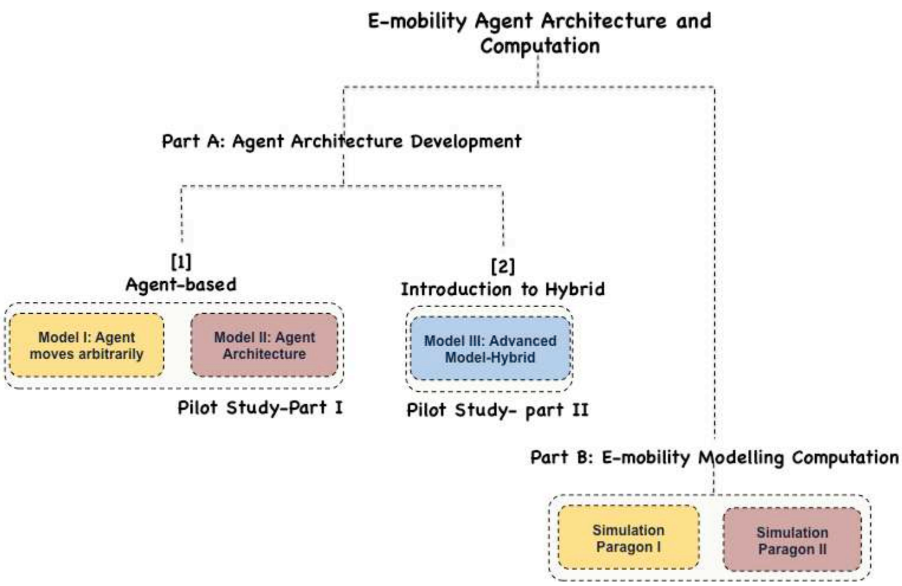


Figure 9-1: Chapter structure

9.1 Model I: The Agent Moves Arbitrarily - First Agent Architecture

The first model is a very simple and primitive architecture. The EV (battery) is represented as anonymous agent. Agents are denoted by oval shapes (car) and there is no defined path, which the agents may take. The population (number of agents) is a hypothetical number of EV users; the simulation environment is a square shape (6 * 6 km ^{2}). All agents follow the same statechart, see (Figure 9-2). The statechart links the car movement to the battery SOC. The initial state of the agent (charged-highlighted in yellow) is a static phase (at origin-the origins are randomly distributed) and the battery is charged (80%- as per the literature as the majority of users depend on domestic charge). The second state (semi charged-highlighted in red) is when the agent starts to move arbitrary in the simulation (square shape). Eventually, (simulation time corresponds to real time), the cars run out of charge (flat rate, driving in the city centre, Nissan LEAF consumption) (Nissan, 2010). The transitions (driving and approaching CP) are associated with the battery consumption rate. The transition from semi charged to (recharged- highlighted in green) is triggered by timeout (timeout that is equal to the time needed to charge- approximately three hours and a half for a full charge battery).

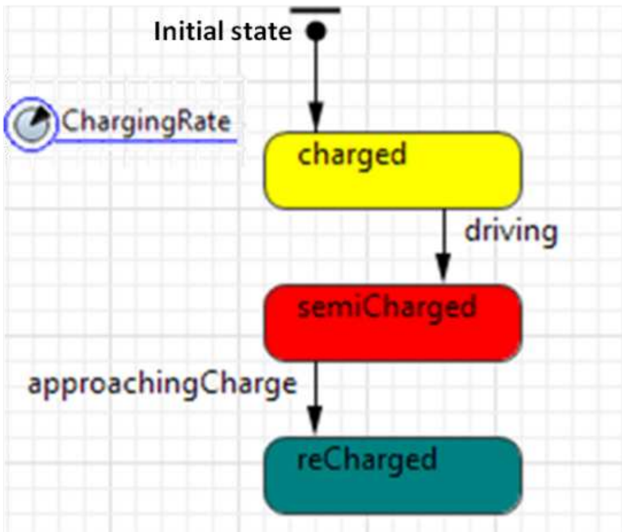


Figure 9-2: EV Statechart- model I

This model was employed to perform the AB technique to simulate an EV population. The first advantage is that it explores the use of the statechart to imitate and stimulate the different states of battery. This model denoted the car with its battery as an embedded entity. The car changes its color and is triggered to move from a state to another based on a condition (time out). The drawback of this model is its capability to simulate the charging infrastructure and its urban context. Simulating the environment in AB modeling is essential (Haase et al., 2010). The model only represented the *car* the statechart is very basic with a very low level of correlation to the real EV charging and driving pattern and with no path for the agent to go around the network. The agents were like a crowd in a space, see (Figure 9-3), which does not represent the urban network.

Consequently, this model (*incorporating system dynamics flowchart*) was applied to simulate the EV adoption and market penetration level incorporating the power of social networking and word of mouth (WoM) (Westbrook, 1987). Agents were the users (not the cars) and the model aimed at stimulating the EV market dynamics and how, when, and the number of the potential users who are considering the EV as an option for their new car, see (Figure 9-4).

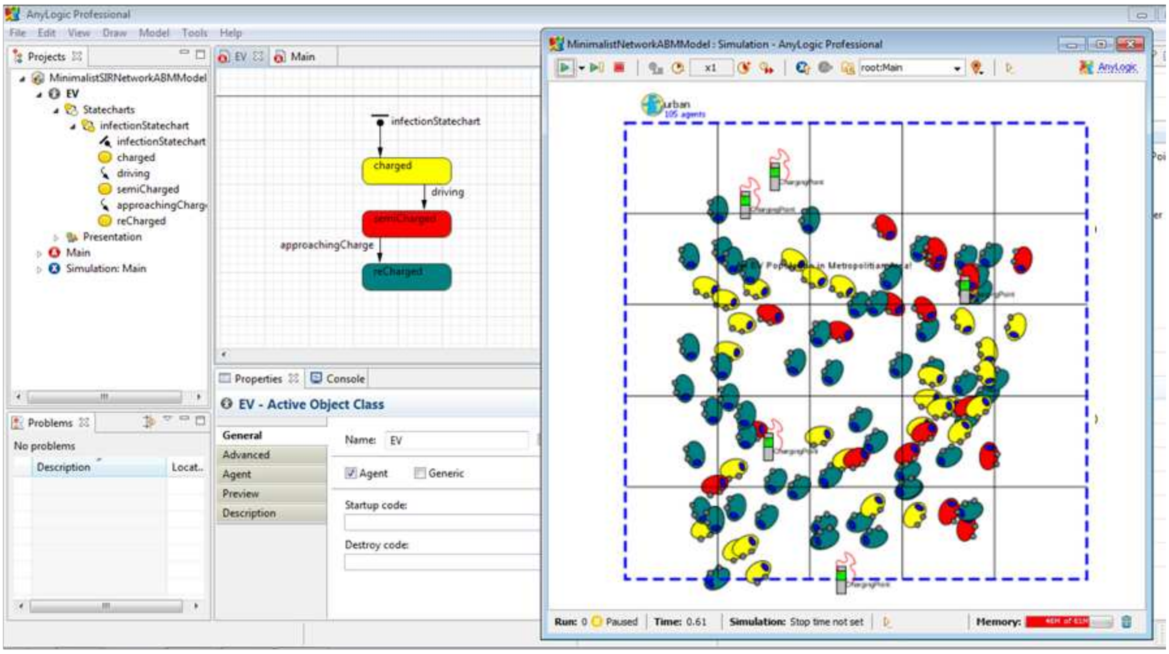


Figure 9-3: Agent architecture and 2D representation-Anylogic- arbitrary agents

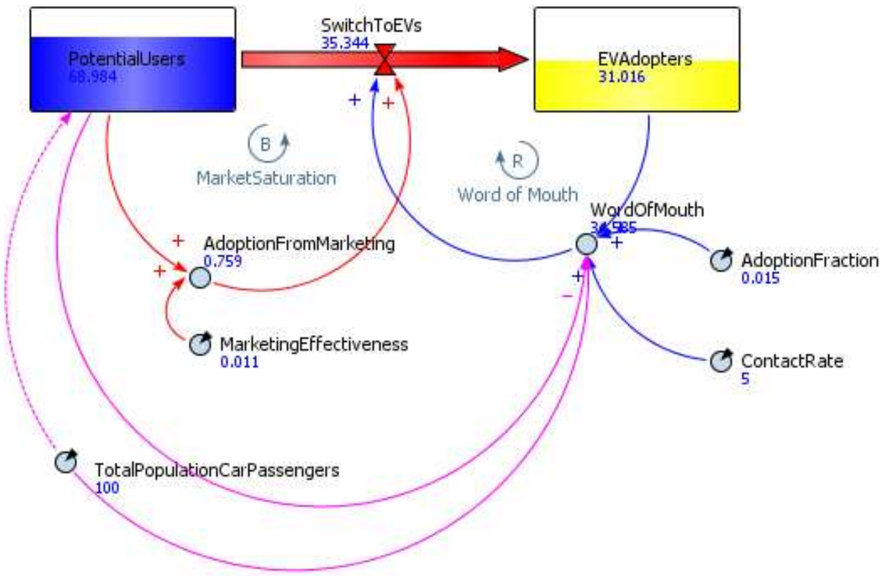


Figure 9-4: EV market penetration

9.2 Model II: Agent Architecture (Pilot study I)

The second model was executed with an advanced statechart, see (Figure 9-5). One of the main corridors linking NE4 to NE1 (Westgate road) was visually represented as the road network in the model (a path to agents to follow). This agent design stemmed from the first statechart with more details of the EV driver's travel dairy, see (Figure 9-2). The agents take a defined path and go around the network, which is also presented as a continuous line. The mechanisms underlying the AB modelling is that each agent has attributes (Helbing & Balietti, 2011; Helbing et al., 2000). The first attribute is the simulation path. The simulation path of each car starts by identifying the start point (the agent's home - origin) and the desired destination (s) within its route. The second one is the update time-interval, which will be on a daily basis in this simulation. This model was executed to conduct the research pilot study.

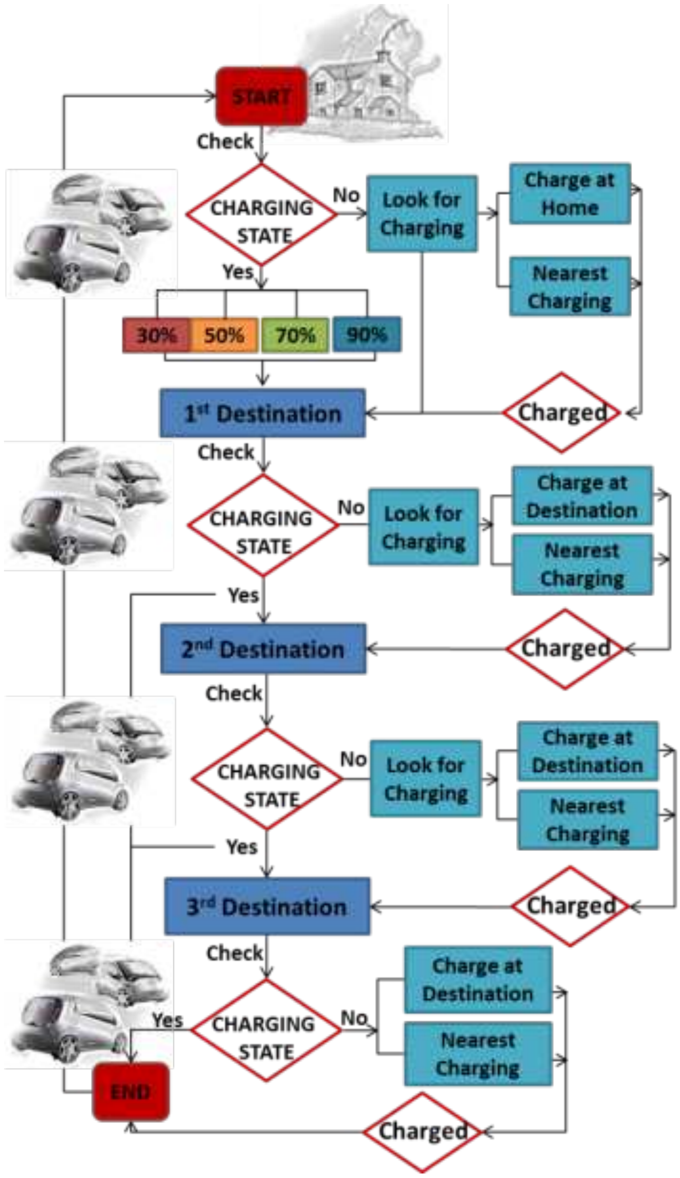


Figure 9-5: Agent architecture diagram (statechart) - in theory

The 2D representation shows that the agents are originated from the starting point (*the green box on the very left*) and all the cars are heading to the city centre, line 1 (*Mosley Street*). There are two ways to choose from; a physical random number generator, two dice (Ingalls, 2002) was applied in this intersecting point (*transition from the square to line 2 (Melbourne Street) and line 3 (Akenside Hill*). The cars sink (sink is when the agent exists the system as per the AnyLogic platform description) once they reach the end of the second line of their journey. The development of the model offers significant improvements over the initial model. These improvements are: the path, the charging station, the statechart, the charging time and the computation of passing by a CP and deciding whether to charge or not.

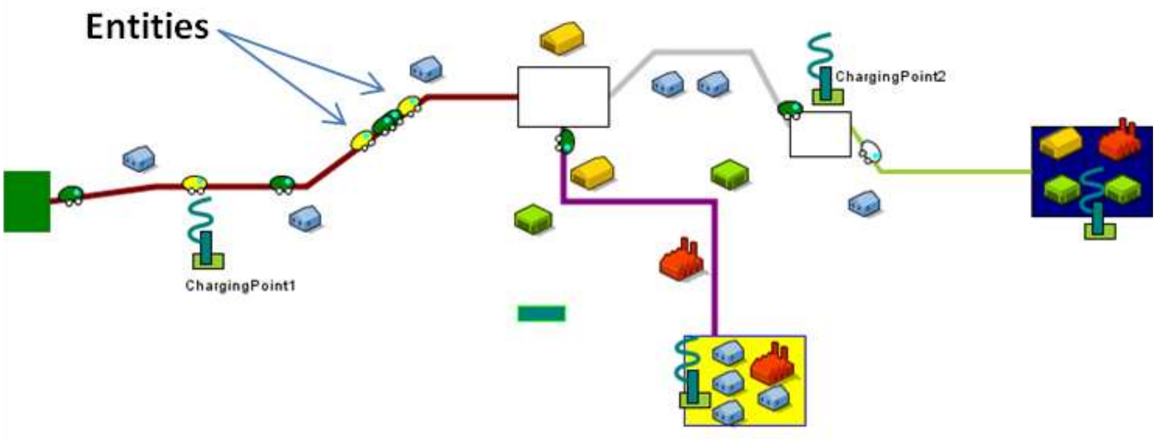


Figure 9-6: EVs and the defined path_ model II

Alongside the development of the architecture, the model in Anylogic (Coensys, 2011) was executed. With the creation of each agent-architecture, there were several versions of Anylogic model. Due to computation and programming implications, the developed model was less complex then (simpler version of) the theoretical agent architecture. In this section, both agent architecture (*input data-real world*) is explained and the relevant modification (*input parameters- in simulation environment*) for each development, see (Figure 9-7).

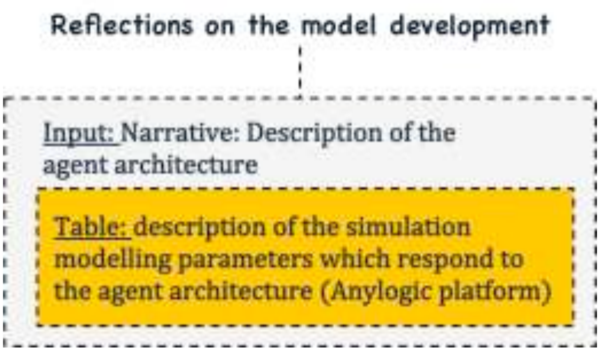


Figure 9-7: EVs and the defined path_ model II

9.2.1 The creation of the agents-input and parameter

The simulation time is weekdays (iteration time). Every day, the agent starts from the same checkpoint (origin). A checkpoint can be defined as:

> *"A point p (x, y) in the simulation model where the agent originates. It causes the first occurrence of the agent in the simulation. A checkpoint represents an agent (EV) starting point (e.g., beginning of a street, road, or destination) not the exact coordinates of the EV user in real world."*

The agent takes the defined path while the destinations are different based on where the probability directs the agent (intersection probabilistic output whether to line 2 or line 3) new destination(s) from its start point/ home (*origin*). The simulation model development is displayed in Table 9-1.

Table 9-1: Creation of the agent- simulation environment

1 Checkpoint	The first appearance of the EV is the checkpoint, which represents the source of generating agents. All the entities are originated from different points beyond the checkpoint (1) as every trip maker lives/ coming different district/ ward, see (Figure 9-8). The difference in charging state reflects this assumption. This is reflected by having a normal distribution of the randomness of batteries states. The state of the battery varies between (70%-30%) charged. The more the entity moves within the network, the consumed the agent state (battery) will be. At each intersection (yellow highlighted squares), the agent decides where to go based on the governing rule at this point (probability).

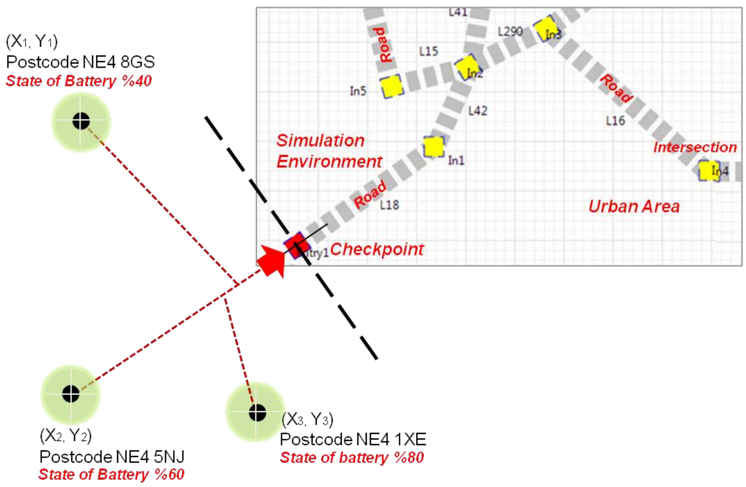


Figure 9-8: A snapshot of what happens behind the checkpoint in the model

9.2.2 The statechart-input and parameter

The statechart of this model is slightly advanced in comparison to the previous statecharts. It incorporated the SoC, consumption rate and the charging events. In this model, the transition between the states is associated with the charging activities (see added parameters to calculate consumption rate and SoC). This was due to denoting the CPs in the simulation environment, see (Figure 9-6). The first decision it takes is to check the state of the EV battery and based on this decision the charging behaviour/schedule is planned for a single trip. This process happens every time the agent reaches a new destination until it ends up it daily-route by going back home, see (Figure 9-5). The simulation model development is displayed in (Table 9-2).

Table 9-2: Statechart-simulation environment

1	Agent Statechart	The corresponding statechart to this model has three main states. (OkToDrive, highlighted in yellow) is the initial state of the agent when the battery is being checked and it is OK to drive. The transition to (need charge, highlighted in red) is based on the consumption rate; the transition is trigged by condition. The state of (need charge, highlighted in red) has two possible transitions, whether to die (flat battery) or to get charged and move to the next state (charged, highlighted in magenta), see (Figure 9-9). The agent does not check the initial SoC as the minimum allowable SoC the agent could have is set to be 30%. This corresponds to the fact that 80% of EV users depend on domestic charging or at least they won't be in a situation that they are home with a flat battery and no access to power.

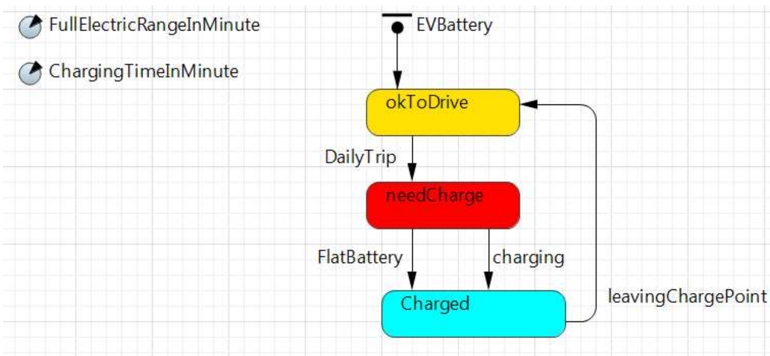


Figure 9-9: Model II-statechart

9.2.3 Charging computation statement-input and parameter

The charging events are presented as a service (with time and location). The charging stations are presented as a shape; once the agent passes through it, an IF STATEMENT is executed. As per the condition indicates the decision of whether to stop to charge or to go ahead in the network depends on the agent's state of the battery. The simulation model development is displayed in (Table 9-3).

Table 9-3: Charging-simulation environment

3	Agent Architecture	Figure 9-10 illustrates how the charging event is computationally executed within the model. The agent (car) may stop for charging or ignore it and continue. As it was previously explained in Chapter 8, Anylogic is Java code based.

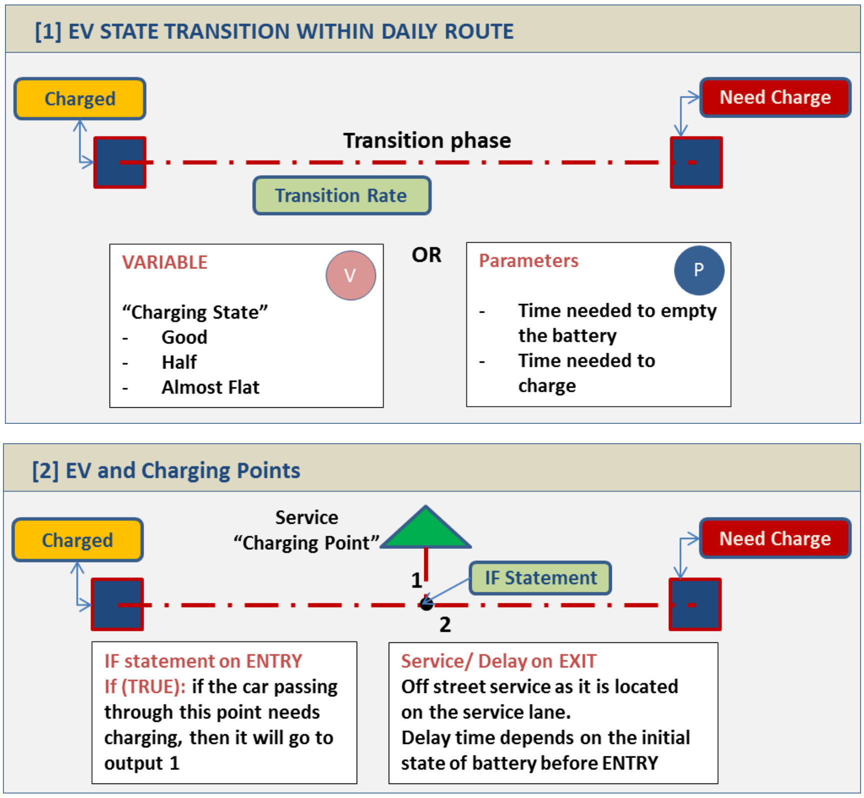


Figure 9-10:Charging statement

9.2.4 Number of destinations-input and parameter

As an initial assumption, possible number of destinations the EV can reach is limited to three destinations /day (excluding return journey). This is calculated based on the average miles per day the EV users usually drive (as per the EV user study presented in Chapter 6). The simulation model development is displayed in (Table 9-4).

Table 9-4: Destinations- simulation environment

2	Agent Architecture	Each agent goes to one destination from the four optional ones in the model. This is based on a probability in each intersection based on Space syntax configurational analysis. Hence, no decisions are taken expect once the agent passes by CP

An understanding of what is going inside the agent's brain is important and how agents respond to the system and other elements in the simulation environment. These elements can be events, situations that need decisions to be taken by it, or other surrounding agents.

9.2.5 Inside the agent's "brain"

Model assumptions and setup are based on what happens inside the EV agent's mind. Each heterogeneous agent considers some variables and parameters, see (Figure 9-11). Starting with the battery, the agent needs to be aware of how the state of charge mechanism works. The battery states are assumed ranging between five possible percentages: 0%, 30%, 50%, 70% and 90% charge, which relates to whether the agent has recently charged their vehicle at home.

These percentages can be changed. Possible number of destinations the car can drive was limited to three destinations /day in addition to the returning home trip. This is due to the following reasons: i) based on the average miles per day the users can drive in the simulated urban context (Mcdonald; Beeton, 2012), ii) the outcomes of a recent EV trials (e.g., SwitchEV, 2011); and iii) EV user study and stakeholders interviews. Homes (garage orphans) were selected randomly around the Westgate road and West road west bond. There are three charging scenarios as per the real EV population: i) charging at home domestic charging), ii) workplace charging, and iii) On-Off Street charging.

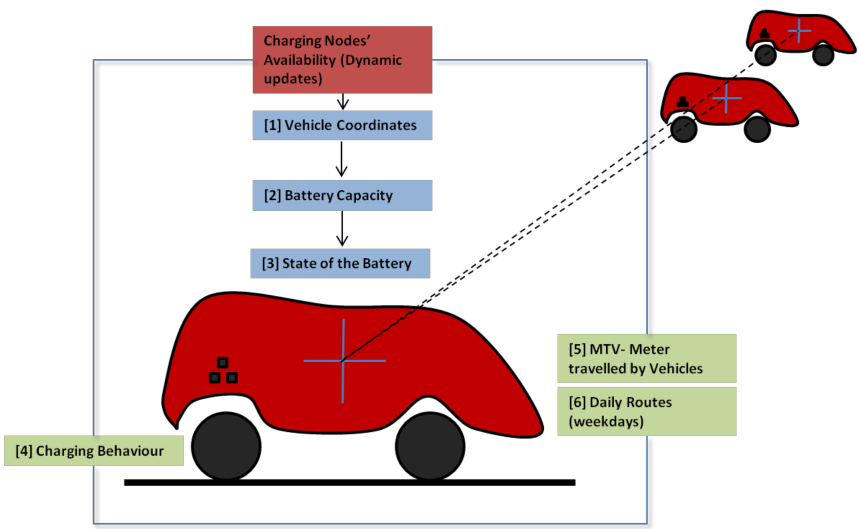


Figure 9-11: Inside the agent "brain"

What is my state of charge?

Each autonomous agent interacts directly with other agents and indirectly with the simulation environment (Chen et al., 2009). In this scenario, the direct interaction is performed between the EVs where the indirect one is between the single agent (EV) and the CPs, routes, and destination(s). The latter interaction affects the agent's behaviour and reaction in return. This process is a continuous process that happens in each iteration; it is called the simulation framework as displayed, see (Figure 9-12). The agent perception and reaction processes are displayed in (Figure 9-13). The simulation model development is displayed in (Table 9-5).

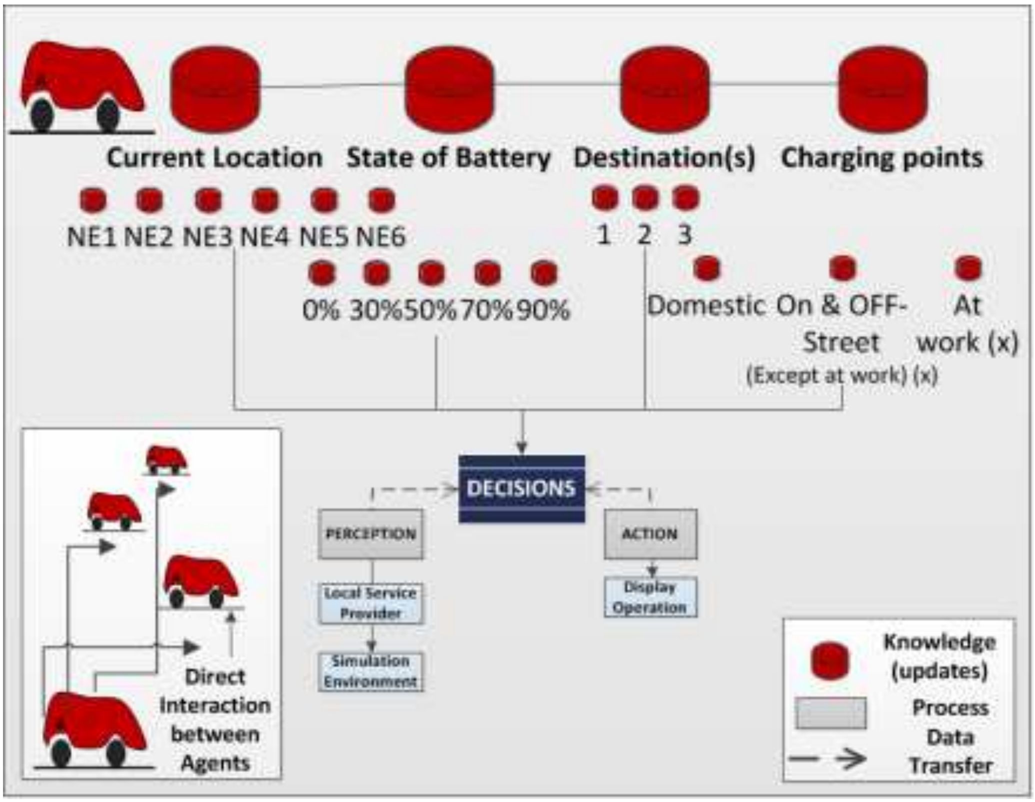


Figure 9-12: Agents framework

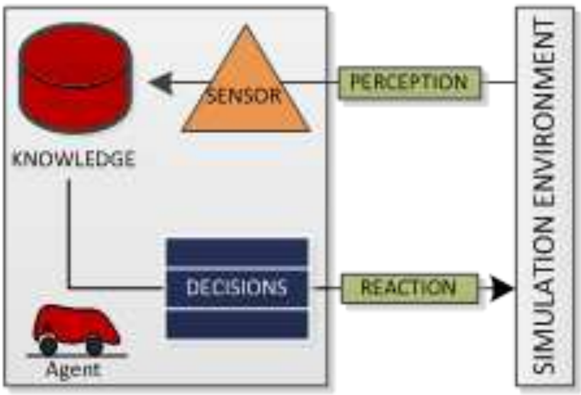


Figure 9-13: Agent definition

Table 9-5: State of the battery- simulation environment

5	Assumptions	Charging states vary between 30% and 70% with a minimal state of 20% (needs urgently to be charged). The agent starts its day with a state. The probability follows uniform distribution.

Who killed the agent's battery?

The agents need to familiarise themselves with the consumption rate. This parameter is linked to the statechart. The battery rate of consumption is based on the chosen EV (Nissan LEAF) and the mode of driving. Based on third-party test drives carried out in the US, reviewers have found that the range available from a single charge can vary up to 40% in real-world situations; reports vary from about 100 kilometres (62 miles) to almost 222 kilometres (138 miles) (Garrett; Nissan 2010). The full electric range of an EV depends on many factors. It depends on the battery type, load, traffic conditions, weather (i.e. wind, atmospheric density), and accessory use.

In addition, the weight and type of vehicle, and the performance demands of the driver (driving style), also have an impact just as they do on the range of traditional vehicles. Based on the rate of consumption, the battery state will change from fully charged to half charged to flat which is the primary concern that counts when examining and scanning individual charging behaviour. Nissan LEAF has been taken as a sample as per the following calculations, see (Table 9-6) (*highlighted in orange*). Nissan tested the LEAF under several scenarios to estimate real-world range figures, and highlighted two scenarios: a worst case of 76 kilometres (47 miles) and a best case of 222 kilometres (138 miles). The following table summarizes the results under each scenario tested using EPA's L4 test cycle and presents EPA rating as a reference.

Table 9-6: Summary of the Nissan's results using EPA L4 test cycle

Driving condition	**Speed**		**Temperature**		**Total Drive Duration**	**Range**		**Air conditioner**
	mph	**km/h**	**°F**	**°C**		**mile**	**km**	
Cruising (ideal condition)	38	61	68	20	3 hr. 38 min	138	222	Off
City traffic	**24**	**39**	**77**	**25**	**4 hr. 23 min**	**105**	**169**	**Off**
Highway	55	89	95	35	1 hr. 16 min	70	110	In use
Winter, stop-and-go traffic	15	24	14	−10	4 hr. 08 min	62	100	Heater on
Heavy stop-and-go traffic	6	10	86	30	7 hr. 50 min	47	76	In use

Sources: (Congress, Energy, Fueleconomy, 2012)

Accordingly, the following assumptions are applied. Vehicle type: Nissan LEAF, 24 kWh battery pack. All electric Range: Nissan LEAF: 109 Mile-175 KM. Time needed to charge: fast charging: eight hours at 220V. It reaches 80 % charge in 30 minutes using rapid charging. Rate: The battery starts with 100% charged and last for 4.24 hours. This means that 1% of the battery is consumed after 2.55 minutes. A flat rate is considered. Hence, the model rate is 2.55.

9.2.6 Making good use of the pilot study

The pilot study allowed the exploration of utilising computer software to depict at a microscale level, the charging pattern of an EV driver. At this stage, it was not expected that the pilot study would simulate the EV system; however, it opened further discussions. It covered most of the assumptions and the setup needed to simulate the system at a small scale and less complicated and correlated to the real system. In order to accomplish a well-studied simulation model, the first model should start with the basic elements and simplest form of interactions and notation. Settings and model configuration are assumed less complicated in the initial runs of simulations. Statechart can reach a sophisticated level of details, see (Figure (9-14). Once the basic features of the system are captured, and then a simple statechart can stimulate the real world behaviour. The success of a model is not measured by the complexity of the statechart. It is measured by how indicative and interactive the statechart is. Every occurring event, rate, variable, condition that is associated with the EV has to be identified and executed in the model. The development of the agent architecture is not about the different states the agent alternate between, it is about the transition, time and condition of transition, dependencies, and the simulation time. Exploring all these aspects of the system is fundamental and a prerequisite to any further development. It is worth mentioning that the theory and mathematics behind the model is more important than the application. Application can differ based on the platform, individuals, and capabilities; whereas, the theory should remain the same.

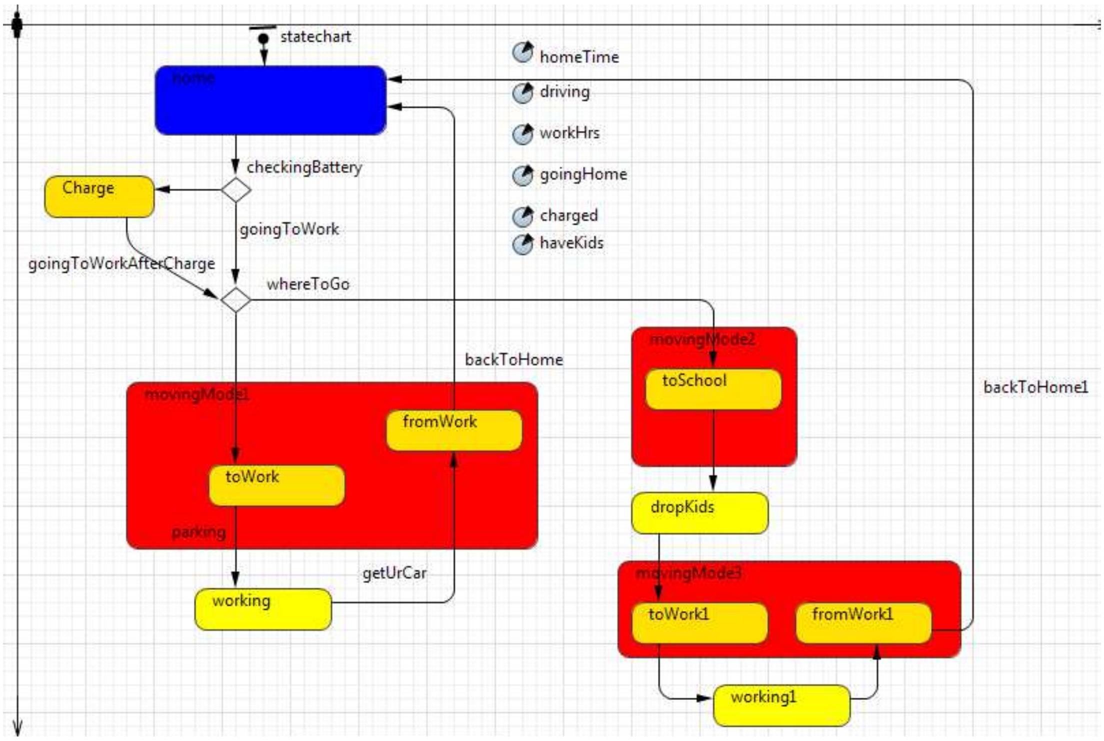


Figure 9-14: Detailed scenario of an EV driver-daily routine

There were some limitations with this model. Cars cannot return home, once they reach the second destination, they sink which is not realistic. The roads are one way so it did not represent the real world network. In addition, there were two critical issues in terms of the agents' capabilities to react, live, and represent an individual. There was a technical problem with the link between the individual agent's attribute and the shape (oval). The transition between the states used to happen to all entities at the same time, which is not the case with real EV population (emergent behaviour all at once). Another master problem was the link between the individual agent's attribute and the car movement. Movement of the agents required predefined paths with accruing events and decision points. E-mobility attributes are difficult to model correctly with these constraints. The statechart was advanced to accommodate more attributes; a hybrid model was processed to simulate the EV system via ABM and DE simulation techniques. The hybrid model is explained in the next section.

9.3 Model III: Advanced Model (Pilot Study II-The Hybrid Model)

Following pilot study I, and studying the agent architecture, the hybrid model was designed to overcome the obstacles of the use of AB modelling solely to simulate the EV system. This model considered the second major milestone in the model development, which was executed, in the inner urban core of NE1 at a bigger scale and with a more advanced architecture and simulation techniques. Integrating discrete event (DE) and space syntax attributes added an edge to the model and its accountability. The deployment of DE was to set the network and all related events within the EVs drivers' daily routes and AB modelling was to portray the emergent behaviour of EVs population.

9.3.1 Hybrid model-statechart

In this model, the entity is the car and the battery is the agent generated inside the entity; the entity is the key element of discrete event technique (Ingalls, 2002). Each EV has a different state of charge that it starts the route with (blue colour with different percentages that range between 30%-70%). It moves to Yellow to red to grey, see (Figure 9-15). The first transition is based on (Time out) condition when the consumption rate goes from the initial state until any values, which is higher than 20%. Starting of 20% the state is changed to the second condition, which is the red colour, and with the same consumption rate, it will turn to grey where it is fully flat. This transition between SOC is linked to time and distance in the simulation. The CPs are presented as services with a delay time that various between (1, 1.5, 0.5) triangular distribution.

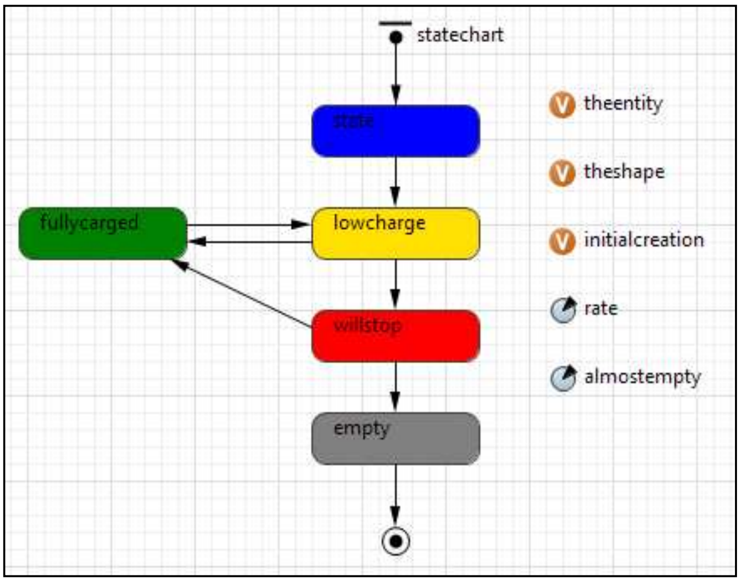


Figure 9-15: Model III- agent statechart

The Java script for that is

```
theentity = new EntityClass(uniform(30,70), this);
initialcreation = time();
theshape = oval;
get_Main().enter.take(theentity);
get_Main().NumberOfAllCars ++;
theentity.setShape(theshape);
theshape.setFillColor(blue);
```

After setting the rate of consumption:

Changing from Blue to yellow: (theentity.initialcharge -almostempty)/rate;
Changing from yellow to red: (almostempty-20)/rate;
changing from red to grey: (20)/rate;

9.3.2 Hybrid model reflections

Having such a hybrid model, where the creation of the entity corresponds to the agent creation enables the model to simulate realistically the EV population. The event of entity creation happens once the EV comes out of the source (origin) going through a path (route) and encounters some events (roads intersection, CPs), see (Figure 9-16). The creation of agents facilitates the messaging protocol. Same as the previous model, the agent has the ability of checking its battery state. In addition to this, the agent may request a service (charging) via sending messages/updates (the battery is almost flat, and needs charging). This messaging protocol happens between the agent and DE system (environment elements).

The product of this model managed to solve the problem of having more than one checkpoint, and that the agent can reach the destination and return to home (maybe in different path) and they do not sink, see (Figure 9-16). It solved the collision detection problem (computational problem of detecting the intersection of two or more objects) and each route represents a road whether one or two ways (the agent will not bump into each other) and an agent can overtake another agent. Also, by the time the last model was executed, the road network was denoted as per the analysis of space syntax. In previous models, upon comparison, the road segments in Anylogic were not that detailed as in Depthmap. In this model, the road segments in Anylogic corresponded to Depthmap segments.

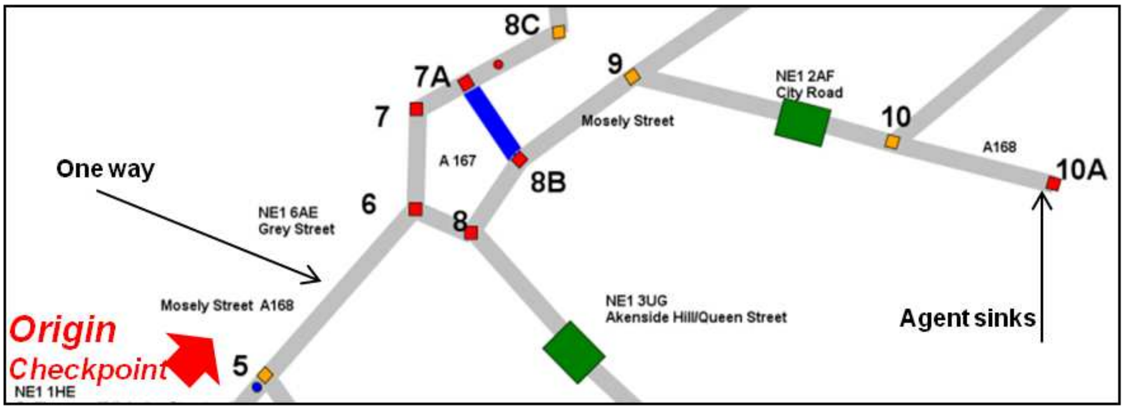


Figure 9-16: Initial version snapshot-hybrid model

This is in addition to the spatial analysis attitudes. The early versions of the hybrid model, (ASA) (Turner et al., 2007; Turner 2005; 2001) values were used to govern the vehicle movement predication in each intersection. Eventually, integration values were used as per the high correlation the integration has with the vehicular movement. This model was built based on some assumptions: the number of EVs in the model (sample size), the model time was set in (days, hours, minutes), the time needed to charge in the CPs was calculated and scaled (real time to simulation time ratio), and finally the time intervals between the creation of the each entity, the traffic flow.

9.3.3 The missing commands in pilot study II

Although, the agent architecture was improved, there were still some limitations in this model. It was difficult to ascertain where the gaps are. The cars were generated and the state of the battery was corresponding to the consumption rate. Moreover, the transitions between the states were smooth and connected to the identified parameters and variables, see (Figure 9-17). A counter was executed to count the number of cars that run out of battery within the network. The counter spots the cars, which entered the anxiety zone (20% or less) and those who became flat (0%) charged.

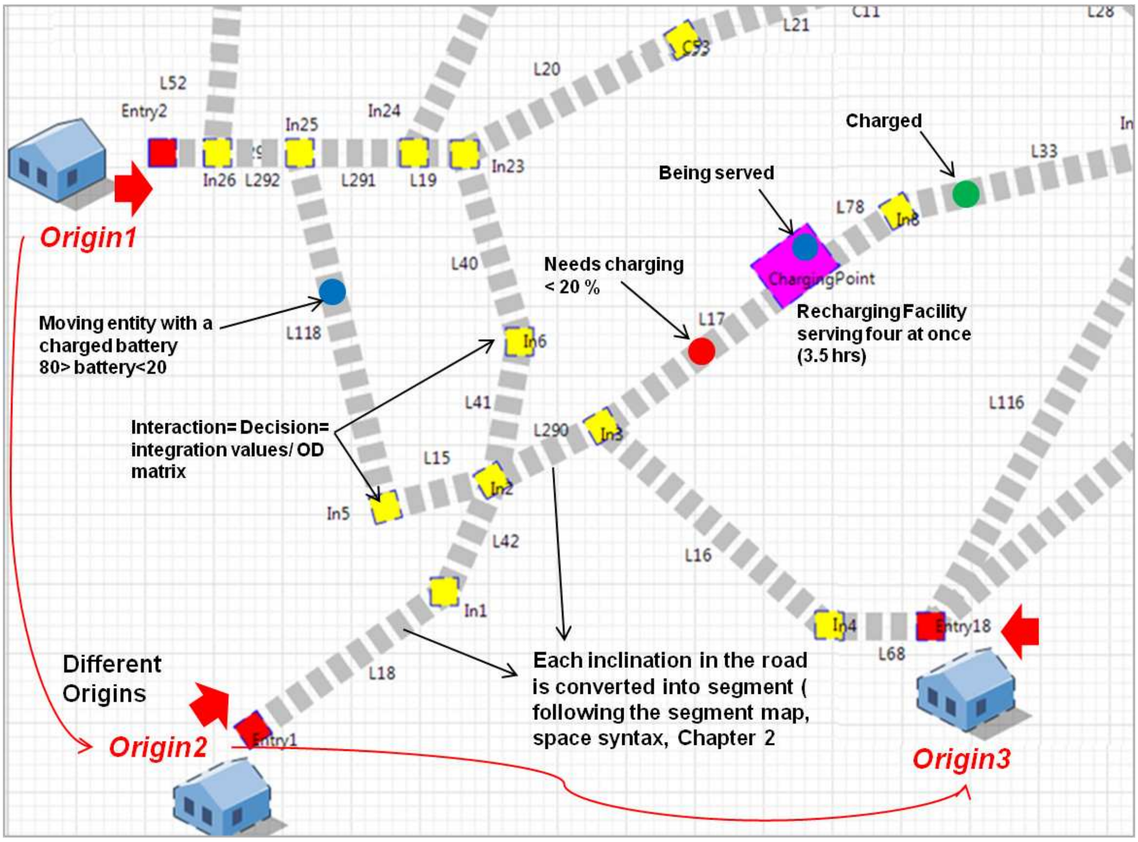


Figure 9-17: Advanced model snapshot - hybrid model

Improvements took place in the subsequent version explained in the following section.

9.4 Simulation Environment and Interactions

The development of the model is a learning process; based on observations from the pilot studies, amend the model, try different setup, run the model, analyse, observe and so forth. The execution of the previous three models developed an understanding of the nature of the system and the way to simulate it. Overarching all the drawbacks and limitations of the models, the detailed computation side of the EV system is addressed. Requirements have to

be conveyed in a language that the computer software understands. The intermediate link between the developer problem and the platform is the algorithms, the logic, and the architecture of the whole system. This means the system has to be split into sub-elements where each of the element's logic/ algorithms is designed. The system has mainly three classes, the *environment*, *CPs* and the *EVs.*
Via the model constructs, programming language and the logic behind the model, four key elements are clear:

i) Depicting the individual charging behaviour;
ii) Decent messaging protocol between the simulation elements (direct interaction);
iii) Indirect interaction with the environment;
iv) Vehicular movement prediction.

9.4.1 Computation fundamentals

The coding and constructs of an e-mobility simulation model are complex. The EV class is constructed depending on the characteristics and the model's level of abstraction the model aims to stimulate. State based behaviour with all related transitions is used to model the EV driver behaviour. Throughout the simulation, the EV passes through different phases; each of which has a different state and a way to trigger the transition between each of them. In general, the simulation data can be summarized as: input, output, and state trajectories, and their transition functions which all support rigorous model development (Sarjoughian et al., 2005). The states construct and the transitions' means and conditions should be clear to enable the software imitating the real case model in the virtual environment.

9.4.2 Roads network

The road network is the simulation environment which comprises all other elements. Entities with their embedded agents are moving around the road network. The representation of roads should meet two criteria: Reflect the real roads' travel cost and all the calculated attributes are legible to all other elements to be perceived so that the interaction can take place. The overlaping of the road network represented in connectors and collectors and outputs, and the visual representation is by ployline (grey) and the red squares, see (Figure 9-18). All events and controls occur in the road network while the individual characteristics of the agents with regard to states and transitions take place in another class, the Agent class. The travel cost between a pair of segments, is measured by the shortest path approach (Murrain, 2013). Roads-centerline map of the system is processed utilizing AutoCAD software from which a road segment map can be generated.

Segmental map is where the road network is divided into a segment at every connection point with other axis (Barros et al., 2007). A list of road segment integration attibutes is used to predict the vehicular movement within the network and assessing probabilities at each interaction.

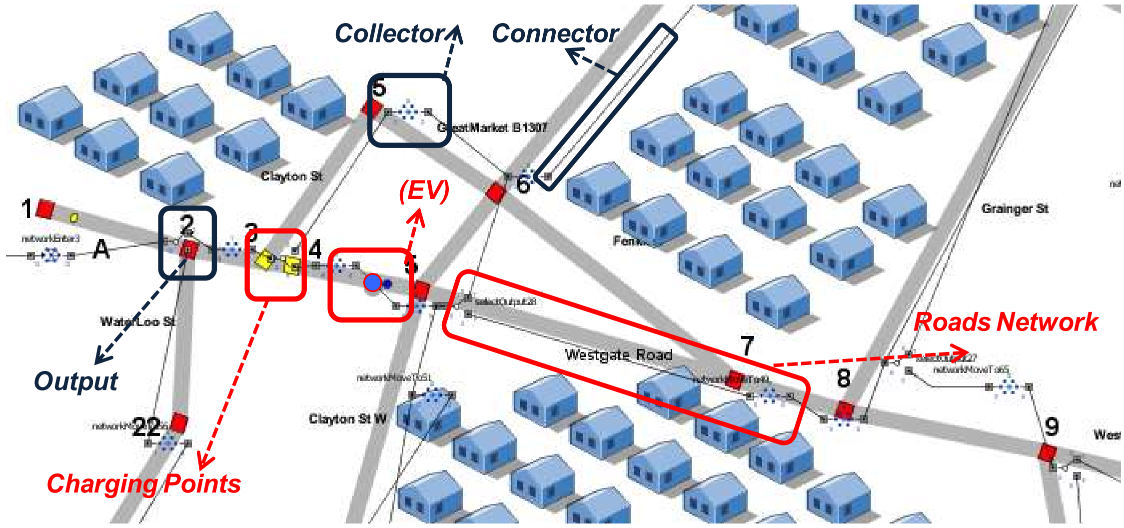


Figure 9-18: Representation of key elements-Anylogic

9.4.3 Mapping of translation- interaction trajectories

The messages (events) exchanged between the battery (agent) and the vehicle (entity) can be arbitrarily complex, it depends on the platform capabilities, message mapping, translation and the used programming language. In a situation like the agent needs to send a command to the vehicle (entity) regarding adjusting the speed. The command must be mapped into the input event of the entity hence the entity can receive and process the input event. Once the entity is tasked, it follows logic.

The agent has the ability of checking its battery state and requesting a service (charging) via sending messages/updates (the battery is almost flat, and needs charging). This messaging protocol happens between the agent and DE system (environment elements). Once the agent requests a service, this associates moving from one state to another e.g., fully charged to need charging. Until this service is tackled, the system receives a message that an entity is in the flow (queue) and needs to be serviced. Eventually, and based on a sequence and specified rate, the service is conducted, hence the entity receives the requested service, updates the agent, the agent moves from the current state to another (need charging to fully charged) and so on. The importance of having a hybrid model appears when the agent's state changes depending on a DE and visa versa which requires a messaging protocol between the entity/system and the agent.

9.4.4 Messaging protocol

The messages and interactions have to be syntactically and semantically well defined. A well defined interaction protocol; the message information needs to be discarded. This depends on the message mapping type. In the model there are two main messaging protocols.

i) messages between the developer and the platform, which is a Java coding based. An object oriented programming (using drag and drop option) to construct the model entities, conditions, variables and properties;

ii) common language that both vehicle and battery will exchange in order to communicate. The messaging properties (e.g., input, output, timing, conditions, and flow of information (one-way or two way)) have to be clear.

The message protocol might be a single or a double way of exchange, it all depends if the entity sends any feedback or updates to the agent. The entity should have a receiver, which understands the order, handles it and performs it. A data transfer scheme is generated within the hybrid model to accommodate all the event-messages mapping in between the agent based modelling, the entity and the network (discrete event). Message mapping is pre-specified by the platform code writer. The messages are expressed in two distinct modelling formalisms, which can have simple (e.g., a string) or complex structures (e.g., a list of objects). The data translation can be arbitrarily simple since the generalized vehicle-entity- network- message structures can be specialized to meet the domain specific needs.

9.4.5 What is next?

The development of the model passed through several trials, each trail showed a new design direction. Researchers are interested in building models of dynamic complex systems for either understanding the emergent behavioural or evaluating various design strategies (Ingalls, 2002).

Several techniques are available and identifying the model's objectives provides the necessary flexibility to the solution (Raffo & Kellner, 2000). In this thesis, there are two objectives:

i) analysing the existing system;
ii) designing for further models.

Table 9-7 proposes a comparison between the two applications in two different contexts of e-mobility.

Table 9-7: Existing versus greenfield urban context

Matter	**Analysing existing EV Systems**	**Designing for future models**
Objective	Analyse	Design
Location of the charging points	Simulation Input: Given	Simulation Output: A simulation model can predict the critical zones in the network
Number of the charging points	Simulation Input: Given	Simulation Output: A simulation model can predict the number of the critical zones and the needed charging points in each
Type of data	Empirical Analysis based	Secondary data
Simulation techniques	Hybrid model	
Possible Agent models and simulation	**Agent:** Critical Zone **Simulation:** Simulation model is designed with no charging points. The zones that tend to have stopped cars are marked, less computation needed (*First Paragon*); OR **Agent:** Finding the nearest (real) **Simulation:** Simulation model is designed with the existing charging points. The highly used charging points with the agents, the zones that need more charging points; elsewhere, can be deactivated (*Second Paragon-real*)	**Agent:** Critical Zone **Simulation:** Simulation model is designed with no charging points. The zones that tend to have stopped cars are marked, less computation needed (*First Paragon*); OR **Agent:** Finding the nearest (un-real) **Simulation:** Hypothetical location of charging points in the network and trying different scenarios and compare the results. The less number of charging points that will have the least number of stopped cars is the selected one (*Second Paragon-unreal*).
Validation	Real system records	Historic data (probabilistic) OR executing the two paragons and conduct comparative analysis, *the overlapped zones*

9.4.6 The Simulation paragons

According to Table 9-8, there will be two paragons. A paragon is the mechanism of how the agent will behave in the simulation environment. The way the paragons are explained differs from the three models previously discussed in this chapter. The urban system is denoted as nodes. The simulation environment is a coordinate system, all of the calculation is based on the coordinates of these nodes and metric distance measurement.

9.4.7 First paragon: Critical Battery Zone plotter (CBZ-plotter)

This model can be used for exisitng and new developments as explained in the comparison table. The rationale behind developing CBZ is to allow the agents to move within the network non-deterministically until their batteries die, see (Table 9-8). The agent in this paragon passes through two phases: comfort zone and ciritical zone (anxiecty range).

Table 9-8: First Paragon: CBZ-Plotter

	Agents model (CRITICAL ZOOE) The network is charging points free. Stakeholders will use this model to assist them finding the optimal location for the charging points or identify the charging hotspot (activate or deactivate), see (Figure 9-19). The software to plot the origin X, Y, the starting point of the anxiety range (X1, Y1) and the end point (X2,Y2) CODE NEEDED; Battery Critical zones (RED ZONES) to be identified and highlighted; Plotting the average critical zones of the vehicles originating checkpoint

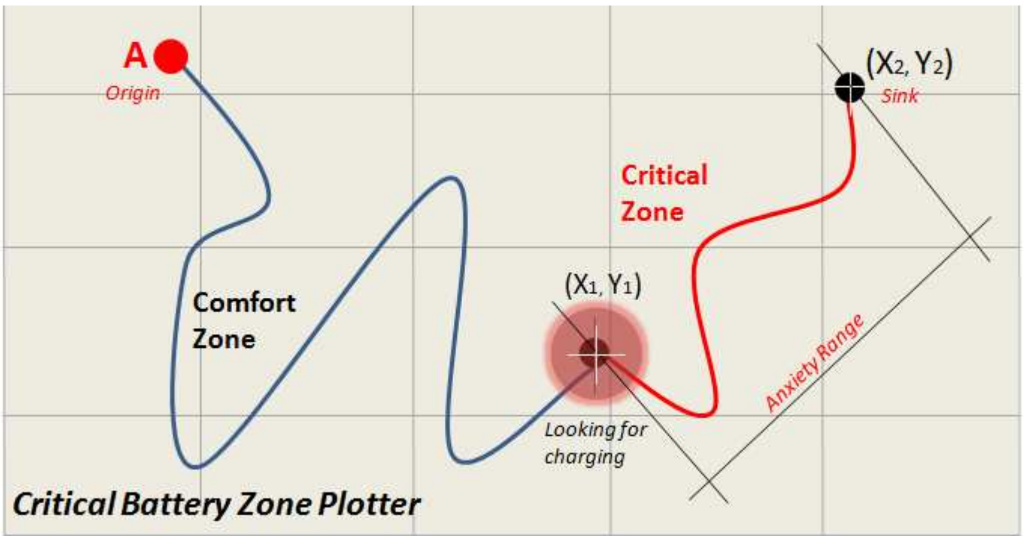


Figure 9-19: CBZ plotter- theoretical representation

The setup emulates the road network of the metropolitan area. The driving pattern is to be synchronised as a city centre driving mode and all agents are to be the same vehicle model (Nissan LEAF) with the same battery capacity, electricity consumption rate, and range mileage. The existing CPs will be removed temporarily. The only controller is the logic of movement.

The logic can be based on traffic-counts analysis, traditional way of predicting vehicular movement in traffic models and/or spatial configuration models of prediction. While going through the network, the agents encounter some events, respond, and take actions, see (Figure 9-20). The red dots represent the checkpoints, A, B, C, D and E. Agents start from these points with a certain flow rate, which depends on the real traffic information. For example, Point A generates 5% of the EV population while point C generates 10% as commuters coming from the eastern border of the study area are more so than those coming from the western side, and so on. The entity leaves the checkpoint plotting the coordinates (X origin, Y origin) and start to move while consuming the electric battery it has with a constant consumption rate. The entity, with its embedded agent.

Journey over time

The journey over space passes through 4 phases:

i) entering the simulation territory;
ii) driving safe;
iii) approaching critical battery state;
iv) running on empty reaching a flat battery state.

The first phase starts when the entity leaves the origin, which is somewhere beyond the checkpoint. This continues until it enters the simulation network and lasts until the battery consumes a certain amount of charge. The initial state of the battery when it passes through the checkpoint reflects two real facts: distances commuted from the origin until the checkpoint and the probability of having access to domestic charging. The second phase is to drive the car in a 'safe mode' with a high confidence not worrying about the charging state. This phase in the simulation context is called the Driving Safe Zone (DSZ), a time unit measures the zone. DSZ is the zone in which the driver moves within the road network with their EV targeting destination(s) while giving no attention to the state of the battery and not worrying about finding a charging service. This is the optimal mode of driving where the EV owners are enjoying the privilege of their choice.

The more the driver uses the EV, the higher their confidence level. Based on the feedback, average drivers start to think about charging having EVRA (Nilsson, 2011) when the battery reaches 35-30% SoC. Once this range of state reaches the third, which is approaching the critical battery mode, this phase is called as the Critical Battery Zone (CBZ). This phase is a short transitional phase as it falls between (30-20%) when the driver gradually starts giving attention to the battery and starts looking for street/Off street charging services and the path turns to red, see (Figure 9-20).

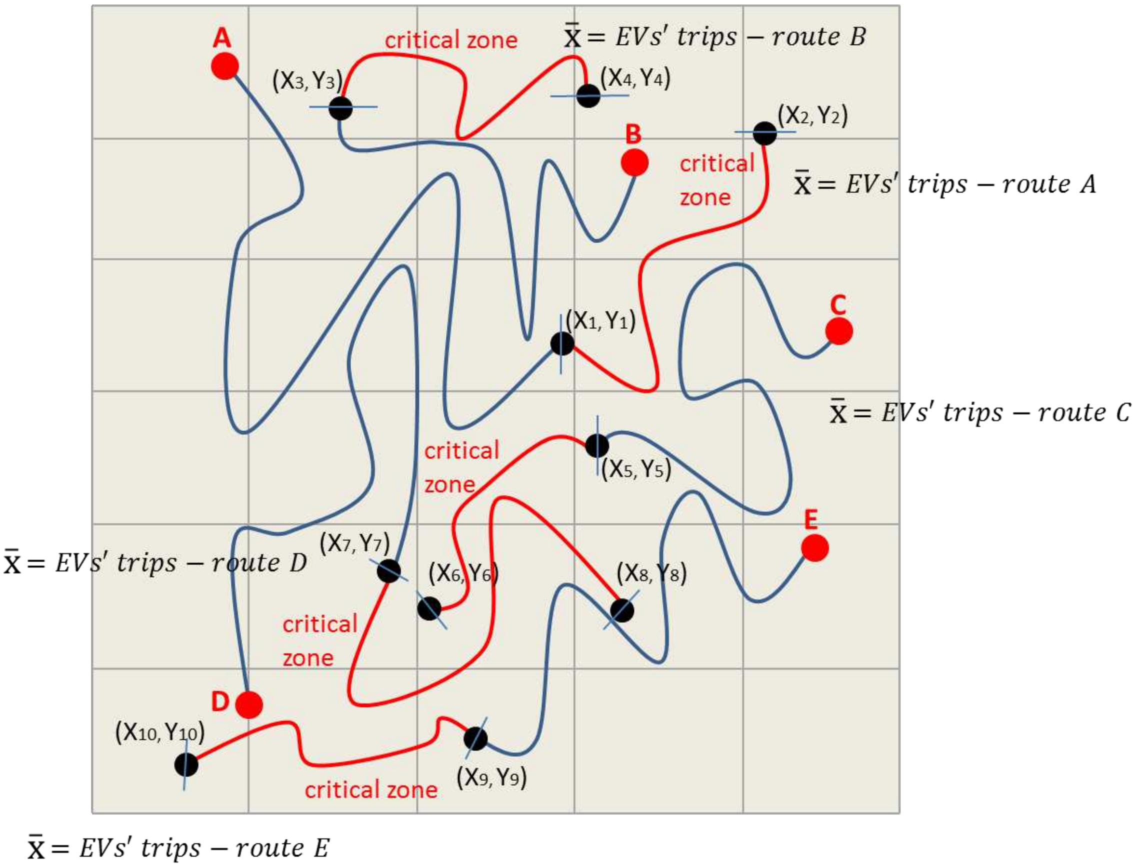


Figure 9-20: Node mobility

With more focus on two of the checkpoints in the simulation, checkpoints A and B, see (Figure 9-21), the DSZ is denoted as a blue path. The end of this path is the beginning the fourth phase, CBZ. This phase is when the EV driver is diagnosed with the EVRA and the driving factor is to replenish the battery redirecting themselves to the nearest CP. The starting point of this fourth and last phase is marked and the programme plots its coordinates (X1, Y1) and (X3, Y3) in the two denoted routes. Once the entity enters this phase the path turns into a red path as the vehicle is running on near-empty battery starting at (20%) charged. The entity keeps moving on the network until it dies and finally sinks. The coordinates of where the entity has stopped, are plotted as to mark the end of the journey, (X2, Y2) and (X4, Y4).

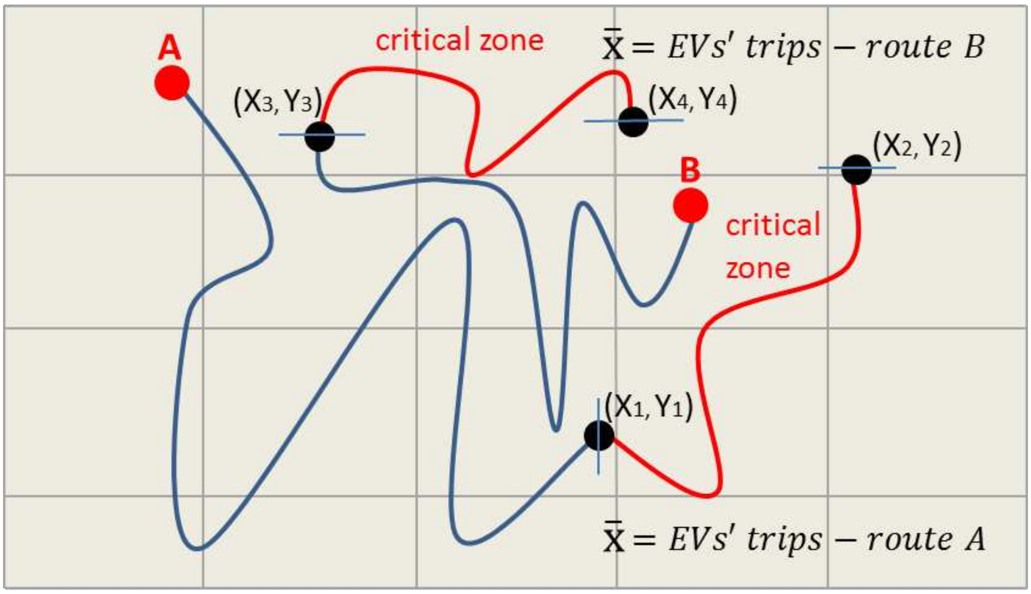


Figure 9-21: Node mobility and simulation layers of checklists A and B

Calculations

Linking the representation of the entities' movements to simulation's occurring events, decisions needed, cynical assumptions need to take place. The following set of Equations 9-1 to 9-4 explains the mathematics behind the simulation. The simulation is built on the following constructs:

i) the agents take different routes based on the vehicular movement predication technique (ASA);
ii) the routs start from several checkpoints;
iii) the EVs are generated from each checkpoint (the average value of all the entities generated from each checkpoint);
iv) the EVs are generated with different SoC following normal distribution (30%-70%);
v) the number of entities (EVs) generated from the checkpoint are calculated;
vi) the areas within which the vehicles reach critical battery are located.

Anxiety Range: the anxiety range shall start when any of the entities reaches the half average of the expected daily mileage is commuted. In the UK, the average mileage is 10 miles, and the EVRA starts when the agent reaches a SoC of (5 miles). The model is adjusted based on the urban context.

Equation 9-1: Critical zone calculation

EVRA shall start at 20 miles.

$$Anxiety\ Range\ starting\ Point = \left(\frac{Average\ daily\ mileage\ (t)}{2}\right) from\ the\ routs\ Origin$$

Equation 9-2: Calculating the range of anxiety

$$Anxiety\ Range = The\ Average\ of\ \frac{X + X'}{2}$$

X=Average of EV' s Single trip to Day's Destination(s) (Source A)
X'=Average of EV^' s Single trip back home(s) (Source A)

Hence, programmatically, the starting point of the CBZ and plot it as (X1, Y1) can be calculated as follows:

Equation 9-3: Calculating driving safe (DS) zone

Average EVs' Driving Safe (DS) of Route A=Distance between source and the Anxiety range starting point (X origin, X1 origin, Y1)

Equation 9-4: Critical battery route calculation

Average EVs^' critical battery zone (CBZ) of Route A=Distance between (X1, X2, Y1, Y2)

Where X2 and Y2 is the point at which the car completes the average daily mileage

From these equations, the CPs candidate locations are allocated at any of points' coordinates within CBZs.

Agent architecture, decisions and phases- agents model (CRITICAL ZONE)

The statechart demonstrated in (Figure 9-23), is the visual construct that allows us to define event and time-driven behaviour of various objects. The statechart is being used in agent based modelling simulation as it depicts the movement of the agent within the simulation environment. States are like nodes, which have concentrated history of the agent, and keeps a record of the reactions to external events at a certain time and condition. States are connected via transitions. Transitions are the sets of actions to take place while entering or existing states. The transition between states is atomic and instantaneous and is being triggered by a condition, timeout, or a message arrival. In the first case of the simulation is that the agent does not know where the CPs are. The CPs are not even plotted in the network. The main aim of running such a model is to try to identify the most common areas in which the majority of the vehicles reach the critical battery zone.

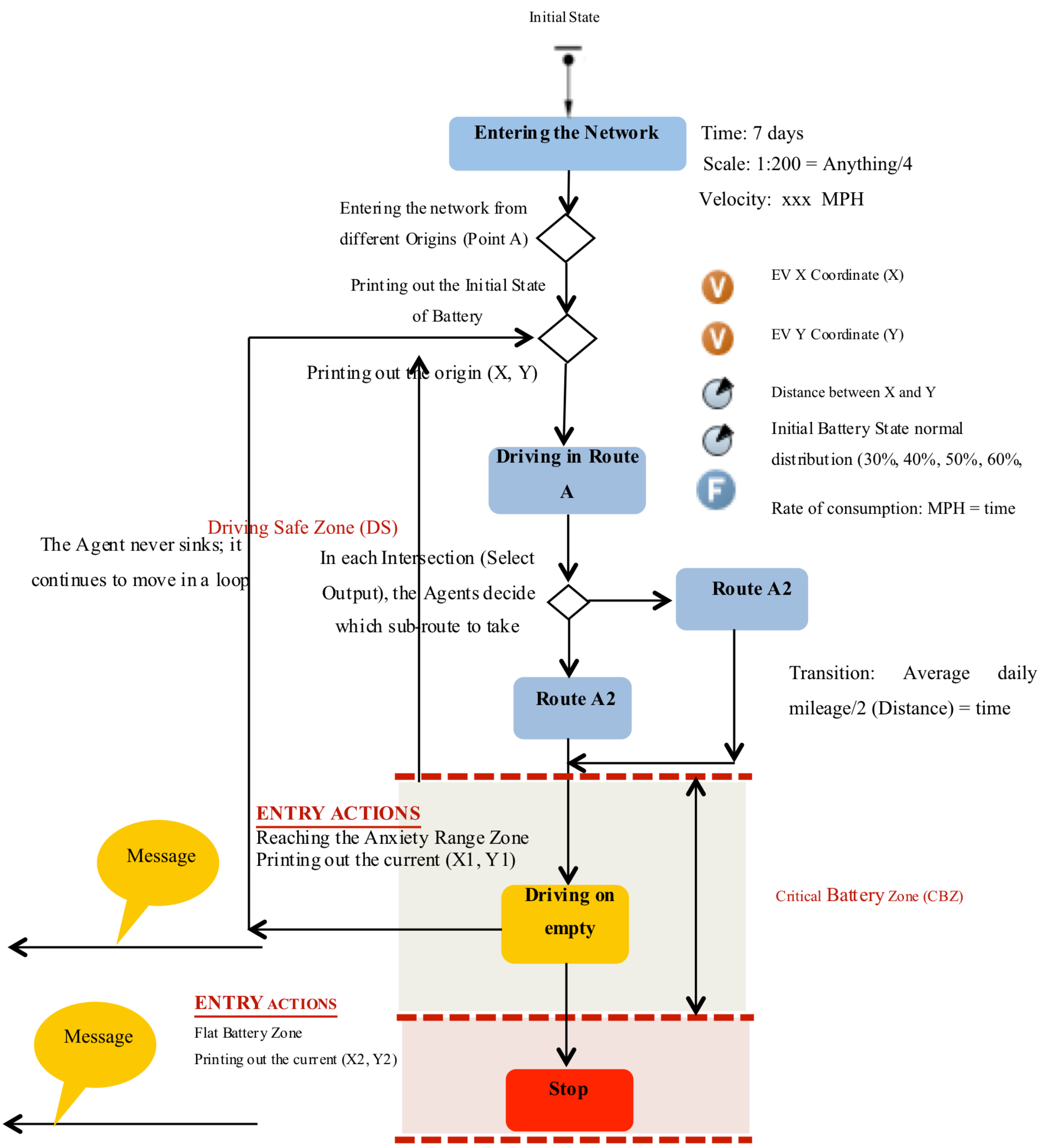
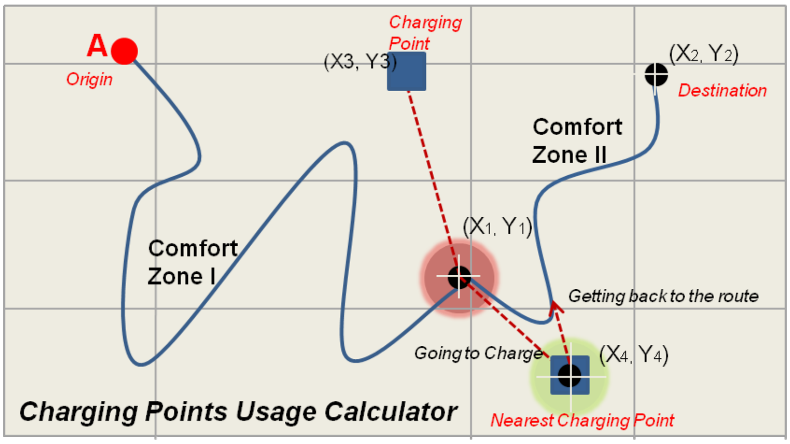


Figure 9-22: Agent architecture-first paragon

9.4.8 Second paragon: CPs usage calculator (CPU-calculator)

In the second paragon, the set up is different as the CPs are located in the simulation environment. This can be based on real distribution or a hypothetical model. The locations of the CPs will affect the model outcome as it counts the usage of the charging network in the simulation environment. This model can be applied to different EV urban systems. The agent in this paragon is always in the comfort zone phase, comfort zone I. The critical zone does not exist; however, the starting point does occur when the driver realises that he needs to look for a CP. Once this happens, the agent's objective changes and the route will change if needed looking for the nearest CP. Once the agent charges their car, it is back again into the comfort zone, comfort zone II, see (Table 9-9).

Table 9-9: Second paragon: charging points usage calculator (CPU Calculator)

Agents model (FINDING THE NEAREST) CPs are located and pre-identified for the agents (X, Y); Once the anxiety starts (X1, Y1), the agent starts to direct itself to the nearest CP CODE NEEDED; Number of used CPs to be calculated, go to (X3, Y3) or (X4, Y4). Finding the nearest CP + taking the shortest path to find the nearest CP, see (Figure 9-23).  Figure 9-23: CPU calculator-theoretical representation

Agent architecture-agent model (FINDING THE NEAREST)

In this model, there are two layers explained in, see (Figure 9-24). Behaviour 1: the EV driver is the shortest path to the destination (algorithm) Behaviour 2: the EV driver is to find the nearest CPs.

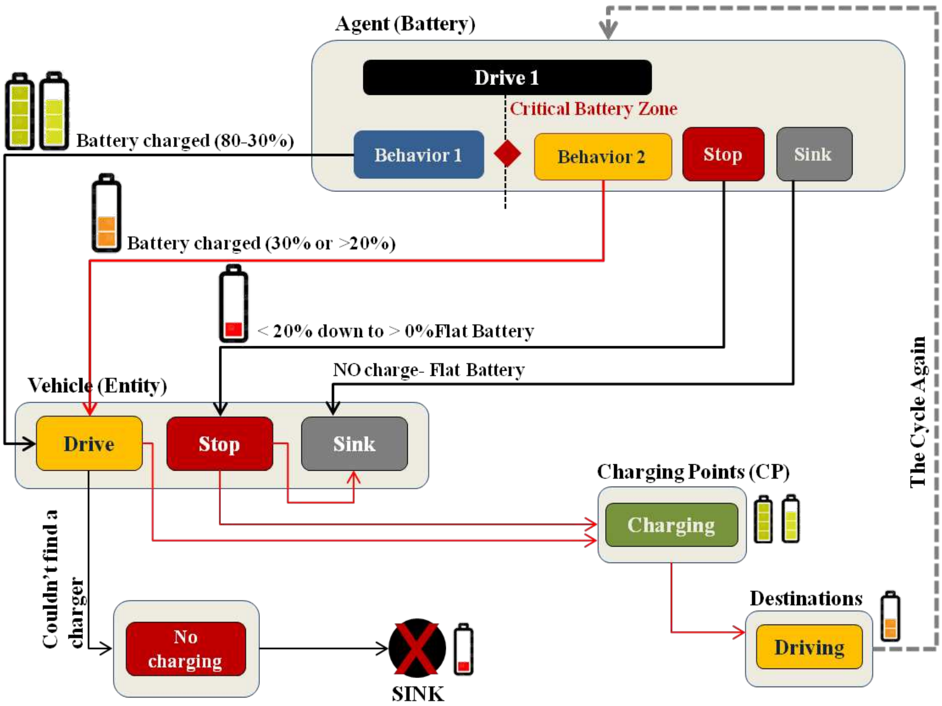


Figure 9-24: The charging diagram

Computational statements

The complexity of the model computation depends on the model objective. The simulation of EV may encounter IF STATEMENT, which is executed through Nested Condition Loop, which is defined as:

> *"a conditional statements where the loop repeats a group of statements for a fixed number of iterations." [Mathworks, 2014]*

Actions associated with events, transitions, process flowchart, agents and controls, etc. are composed into Java code statement in Anylogic. The second condition is embedded into the first loop, as shown in (Figure 9-25), the red bracket within the enclosed within the blue loop.

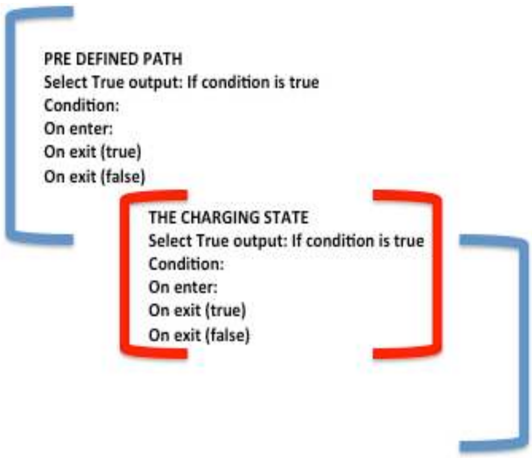


Figure 9-25: Nested loop

Once the agent hits the second condition (state of the battery), this condition will start driving the path and once the condition is over (car is charged) the agent returns to the first condition, blue bracket. The agents experience three main commands:

- get and print coordinates;
- measure the distance between the current location and the nearest CP;
- measure the distance between the nearest available CPs, see (Figure 9-26).

The main programming commands related to the EV agent are displayed in Figure 9-26. The first command is used in the two paragons (Critical zone and Finding the Nearest) as it plots the coordinates of the agent, and checks the battery. This can be used to identify the spot of the agent at any location within the road network. This means that the road network is a coordinate system that can read and get the coordinates of the agents. The second command is executed in the agent model (Finding the Nearest) where it has to do with the

CPs locations and coordinates. The same applies to the third command; an advanced command to be added to the model that checks the nearby CPs and directs the agent to the nearest available CP.

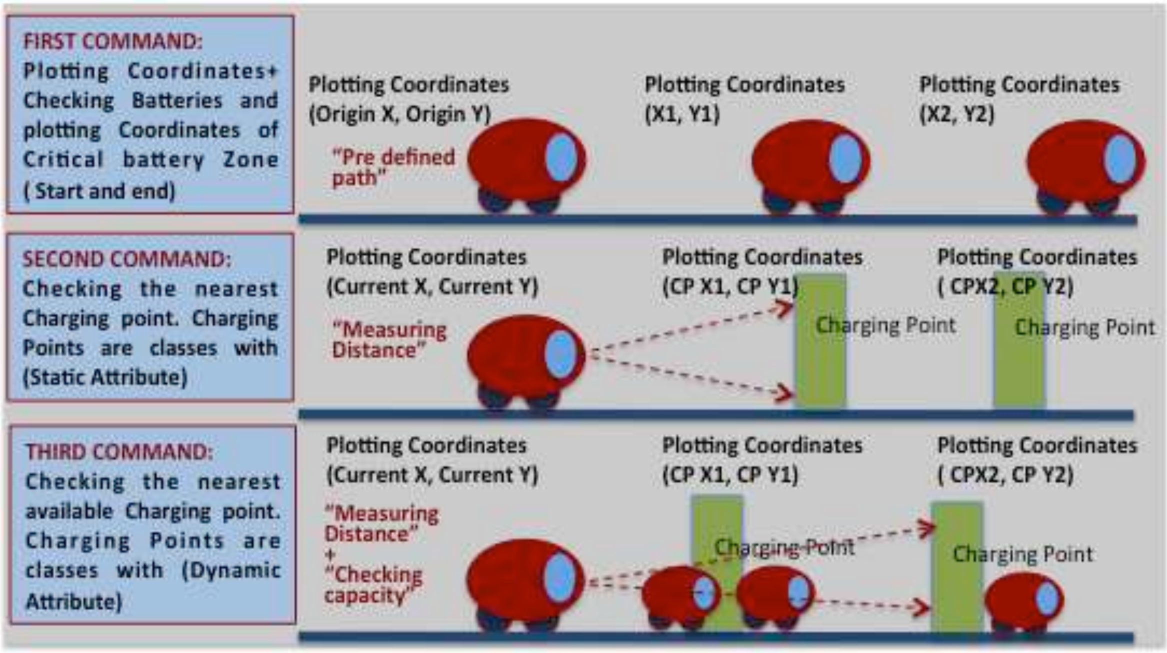


Figure 9-26: Programming command-simulation

Agent architecture-agent model (FINDING THE NEAREST)

The agent architecture of this paragon is rich of messages and interactions with the surrounding environment. In the implementation phase, the EV agent's statechart has four states and the agent alternates depending upon the transition conditions and timing, see (Figure 9-27). The CPs are classes; however, they are not agents (no need to be agent, static object that can send and receive messages to EV agents).

Anylogic visualisation capabilities have shown successful in depicting the system in a 2D format while incorporating vehicular movement prediction techniques and constructing the hybrid model.

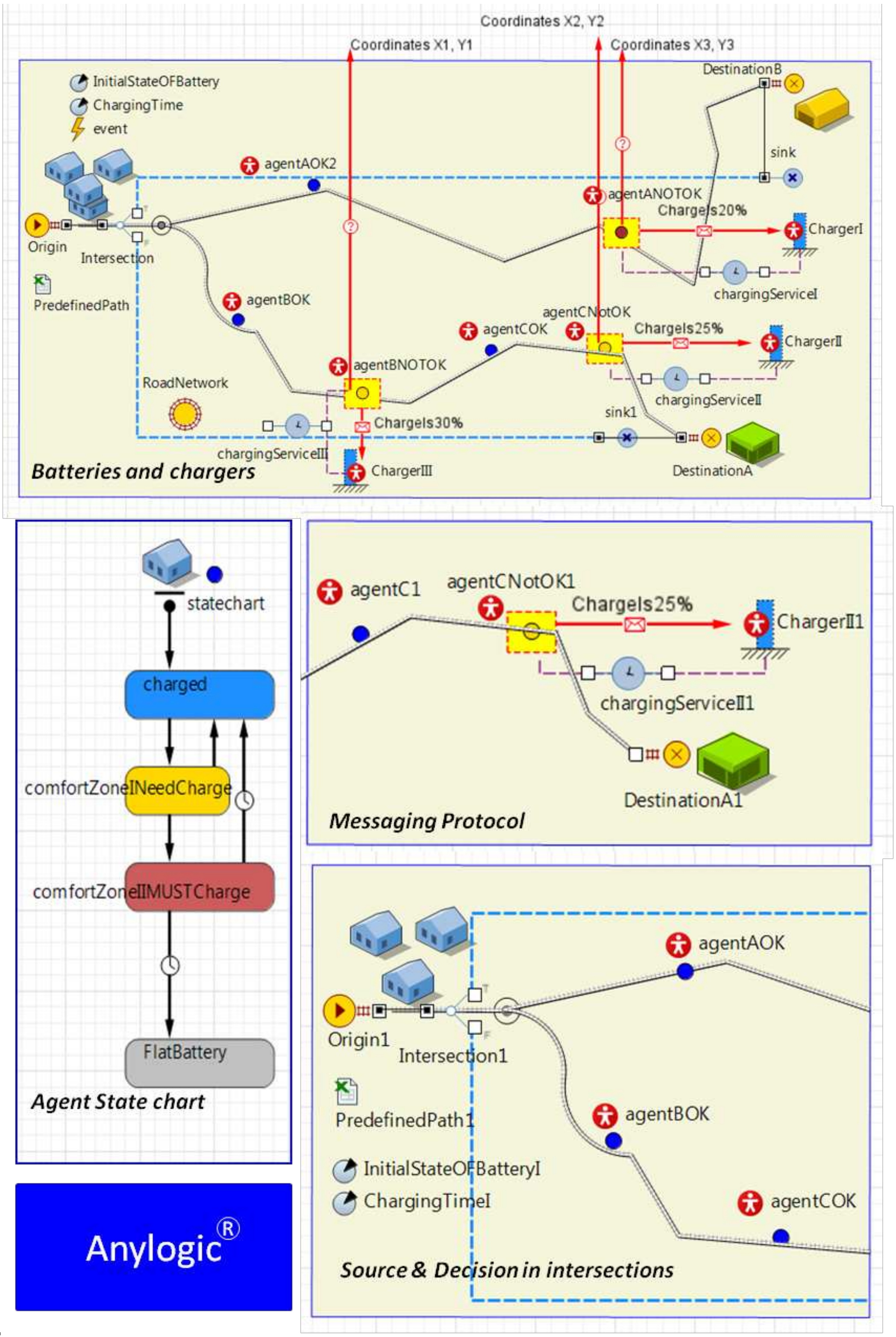


Figure 9-27: Model execution_Anylogic

9.5 Simulation Paragons Comparison

A comparison between the two models would summarise the main paradigms and the extraordinary points of each model, see (Table 9-10). The models generated using Anylogic, the main paradigm of each model and the comparison between them will help the research outcome.

Table 9-10: Simulation paragons

Models	Model 1: critical battery zone plotter	Model 2: charging points' usage calculator.
Population	The population is the electric vehicles only not the whole car passenger population in the metropolitan area.	
Travel cost (Road segments)	Travel cost is reflected on the allowable velocity of road network. The levels of congestion follow the A-F grades. Traffic counts, streets capacities and volumes are measured and considered	
Dominating Layers	The agent alternates between 2 layers urban layer and the behavior layer (DS). In the latter the agent keeps moving till it reaches an end of the network or till it stops (flat battery).	The agent alternates between 2 layers urban layers and the behavior layer (DS). In the latter the agent keeps moving till it reaches an end of the network; however, once it reaches the CBZ, it starts to redirect itself to the nearest charging point to charge. In case it didn't find, the vehicle will stop and sink (flat battery).
Road Network Representation	The network as the 2-way road is denoted as a one streak. The entities' trajectories do not intersect. Only in the charging station (depends on the queuing capacity).	
Simulation technique	Multi method simulation modeling	Multi method simulation modeling +shortest path algorithms
Environment/Elements	The goal of the agent is to find its destination	The goal of the agent is to find its destination
Agents Aim	The goal does not change among the simulation (one behavior).	The goal changes during the simulation depending on the zones (two behaviors).
Source of Date	Defining the starting points, define routes (X, Y), defining the charging points (X, Y) the distance between the start point and all other charging points.	
Classes	The electric vehicles: entity is the EV, the battery is an agent. The environment is the main class in which the road network exists. The road network which runs the discrete event modeling is a main class.	The electric vehicles: entity is the vehicles, the battery is an agent. The environment is the main class in which the road network does exist. The charging points are identified and mapped out as objects in the network (subclasses).
Updates	Locations to be plotted and sent as an update message: (1) checkpoints, (2) the beginning of the CBZ, (3) end of CBZ.	Locations to be plotted and sent as an update message: (1) checkpoints, (2) the beginning of the CBZ, (3) locations of charging points (highlighting the nearest one to the agent).

Models	Model 1: critical battery zone plotter	Model 2: charging points' usage calculator.
Interactions	Indirect interaction with the environment. No direct interaction between the agents (batteries). The entities are not interacting.	The agents interact with the CPs (classes) and determine the shortest path to the nearest CP (Static Attribute). At a later stage, Dynamic attributes (availability of the point) to be added.
Route Choice	Decisions being taken in each intersection based on the urban layer. The network is opened, as the every point is an origin and a destination. There is a possible route that an agent can move within the network from the very first till the very end.	Decisions being taken in each intersection based on the urban layer. The network is opened, as the every point is an origin and a destination. There is a possible route that an agent can move within the network from the very first till the very end. However, the charging state is the driver once the entity reaches the CBZ.
Routes Type/ rules	1. Configurational model and 2. Traffic counts. Both are applied alternately to the intersections (decision making points) in the network. (Probabilities and if statements).	
Choices /Decisions' Factors	Indeterminate points. The agent effortlessly moves within the network.	
Mobility Modes	Driving mode: Speed of the agent: Driving (based on the road capacity) Flat battery mode (stopped).	Driving mode: Speed of the agent: Driving (based on the road capacity). Charging mode: stopped at the charging point.
Agent's brain-key Traits	Autonomous, heterogeneous, reactive, observing, receiving and sending messages and mapping out, absorbing and anticipating. The agent maintains its preference (adjusting speed and direction), and opportunistic.	Autonomous, heterogeneous, reactive, observing, receiving and sending messages, mapping out, looking for the nearest charging point, taking the shortest path to reach the nearest charging points (calculated by the charging points-sub class themselves).
Main variables	EV population, consumption rate, vehicular movement prediction.	EV population, consumption rate, vehicular movement prediction, location of the CPs.
Layers	Urban Layer + behavior layer (DS)	Urban Layer + behavior layer (DS)+ behavior layer (CBZ)
Key components	Identifying the critical zones	Finding the nearest charging point
Interactions	Indirect interactions only	Direct and Indirect Interactions

9.6 Discussion

To thoroughly and systematically study the charging behaviour of the EVs' users, is very important to simulate the real aim system in a virtual environment. This virtual environment with all its elements, characteristics, interactions, massaging and the network protocol. The multi-model simulation is better served the nature of study problem as being a large-group simulation of active objects that has timing, sequential events, and individual behaviours. The main aim is to simulate this protocol and evaluate its performance. The preposition has been validated in two paragons. The relevance of the proposed model has been highlighted by comparing the two paragons and identifying the main paradigms of each.

This chapter has covered several key theories related to the simulation of EVs in metropolitan areas. The depiction of charging behaviour was achieved by deploying AB modelling technique to have a heterogeneous and anonymous agents moving within the road network. The development of the agent and associated modelling characteristics had two main strands: Critical Zone and Finding the nearest agents' models. In the first paragon, the agents do not know where the CPs are. The CPs are not even plotted in the network. The main aim of running such a model is to try to identify the most common areas in which the majority of the vehicles reach the Critical Battery Zone (CBZ).

The second paragon was to have the same setup; however, the CPs were denoted in the simulation as classes. Each class has its own attributes. Each paragon has a different visual output as the first paragon implies the critical battery zones in the road network (gaps in the network). Moreover, it can be used to identify the unnecessary charging service zones in the network hence point out the wasted investments. The second paragon illustrates the usage values of the CPs, Charging Point Usage (CPU). The overlap between the two layouts provides prospective guidelines for policy makers, palling authorities and all EV stakeholders in general.

9.7 Concluding Remarks

This chapter addressed the two of the research objectives and the fourth research question by providing a thorugh reivew of the diferent stages of developing the e-mobility agent achitecture. The chapter presented an integrated model that combines hybrid simulation techniques and configurational analysis.

> *Objective 3: Design an agent architecture that corresponds to the EV system dynamics and messaging protocol between the users themselves and the built environment.*
>
> *Objective 4: Exploit a hybrid-modelling technique to simulate the EV system (urban and behavioural layers).*
>
> *RQ4: Is it possible to depict the social practice and the system's mechanisms in a simulation model? And if yes, what is the recommended modelling technique?*

Simulation improves the understanding of a system's behaviour to evaluate strategies for its operation. The visual depiction of a behavioural layer of system is a crucial matter to analyse the system. The creation of the EV agent architecture is a prolonged process with several changes. ABM can depict the behavioural layer of the system while having occurring events. The E-mobility Simulation Model:

i) Integration values are to be used in EV simulation to predict vehicular movement;
ii) The hybrid model is the way that the urban layer with all occurring events, static and dynamic elements as well as the behaviour layer of the EV can be denoted and simulated;
iii) The theory behind the model has to be very clear prior to application;
iv) The math behind the simulation can be improved and amended along the way of simulation;
v) A simple start is the key; developing a complex model needs to start with elementary level as it is the appropriate guaranteed way;
vi) The model should be set as an interactive tool to support regular updates and changes.

CHAPTER 10. DESIGN I: STATISTICALLY SIGNIFICANT SPATIAL AND BEHAVIORIAL ATTRIBUTES

"Electric vehicles are often sold with the label 'they are not for everyone'.

By The Institution of Engineering and Technology, IET (2011)

This chapter presents the correlation and regression analysis of the e-mobility system, see (Figure 10-1). After exploring various variables and attributes in previous chapters, interrogating the relation between each one of them is fundamental. What is more important is associating these variables with profit. From stakeholders' perspective, charging network should be a profitable business, investors need to reduce the risk of a wasted investment. Profitability is a product of behavioural, demographic, commercial, technical and socio-economic attributes.

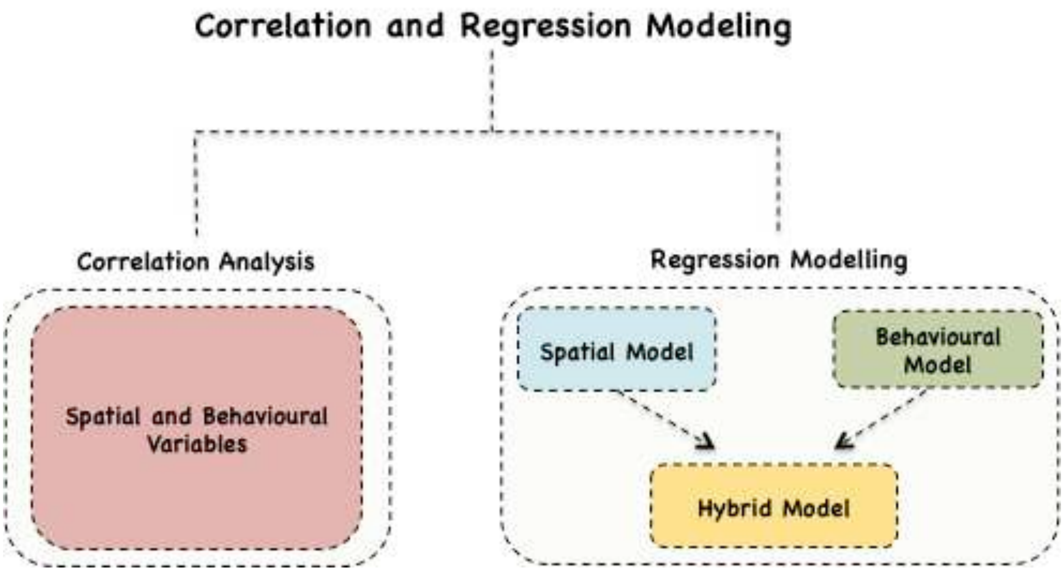


Figure 10-1: Chapter structure

10.1 Correlation Analysis

Correlation analysis is carried out to determine the most significant relationships between the variables (the value of one variable changes when the value of another variable changes). The correlation analysis reflects the dynamic quality of the relationship between the variables to ascertain whether variables tend to move and respond in the same or opposite directions when they change, Table 10-1 summarises the 12 variables.

Table 10-1: Attributes and variables for correlation and regression

	Attributes	Explanation/ Measurement Technique
1	Level of Awareness (LoA)	Measures to what extent are the potential users aware of the charging network. This is examined through a spatial questionnaire for which responses are collected.
2	On / Off Street (O)	This value is a dummy variable. Zero for Off street charging points, and value of 1 for on street charging point.
3	Integration (I)/ Connectivity (C)	Space syntax measures, calculated by DepthMap.
4	Traffic Counts (T)	Actual travel demand provided by the Traffic Monitoring Unit in Newcastle (UTMC). The values are for the main corridors feeding the RFs
5	History (H)	In months, the total number of months the charging point have been installed and used. (CYC data)
6	No. of users (η)	Total number of EV drivers used the charging point over 2012 (CYC data)
7	Distance from centres (ι)	Metric distance measuring the road length between the charging point and the nearest residential district core.
8	Transactions (τ)	The total number of transactions made by the users in 2012 in each charging point. (charging point not recharging facility (site))
9	Average time spent (A)	In minutes, the average time spent by drivers charging their cars using RF. (CYC data)
10	Most Frequent Time (M)	Discreet data, showing the most frequent time of the day the drivers tend to charge their cars using a specific charging point. (Morning = 1, Afternoon =2, Evening =3, Night =4)
11	Total Energy Used (Λ)	In KW, the total energy spent charging cars by each RF in year 2012. (Dependent variable, Profit indicator)
12	Weekdays (ω)	Weekday to weekend ratio converted into percentage. This value shows when the RF is being used over the week.

The correlation coefficient is the numerical index, reflecting the relationship between each pair of variables. In this chapter, the bivariate correlation (for two variables) is addressed where the value of the descriptive statistic ranges between -1 and +1. The absolute value reflects the strength -0.70 is stronger than +0.50. Eyeball method to interpret the value of a correlation coefficient (r) (Salkind, 2011). Eyeball is the is the most common and readily available method of initial data assessment as it:

> *"Using a many data points as possible. Judging the forecast is by drawing a single line that visually indicates the approximate trend of the data." [Jayaratne &Levy, 1979]*

The computational formula for the simple Pearson Product-Moment (Galton, 1877) correlation coefficient between two variables would follow Equation (10-1). Therefore the correlation between Average Time Spent (A) and Most Frequent Time (M) will be addressed. The analysis is conducted using SPSS Statistics 21, Table 10-2 displays the correlation matrix of 15 variables including Connectivity, MD, and users personas.

Equation 10-1: Calculating Pearson Product-Moment method

$$r_{AM=} \frac{n\sum AM - \sum A \sum M}{\sqrt{[n \sum A^2 - (\sum A)\ ^2]\ [n \sum M^2 - (\sum M)^2}}$$

Where

$r_{AM=}$ time	is the correlation coefficient between the average time spent and Most frequent time
n =	is the size of the sample, here is 38 charging points that have been examined
A=	is the individual score on the A variable
M=	is the individual score on the M variable
AM=	is the product of each A score times its corresponding M score
A^2 =	is the individual A score, squared
M^2 =	is the individual A score, squared

Table 10-2: Correlation matrix

Correlations

		AverageTimeSpent	Users_Profiles	MostFrequentTime	ONandOFF	Number_of_users	Public_Awareness	Integration	Connectivity	MeanDepth	DistanceFromCenters	TrafficAccount	Weekdays	Transactions	KM	Total_Energy_Used
AverageTimeSpent	Pearson Correlation	1	.801**	-.363*	-.382*	.071	-.101	.074	-.106	-.071	-.205	-.092	-.095	.149	.183	.294
	Sig. (2-tailed)		.000	.025	.018	.670	.548	.657	.526	.673	.217	.581	.570	.372	.273	.073
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Users_Profiles	Pearson Correlation	.801**	1	-.342*	-.440**	.130	-.124	.081	-.017	-.078	-.229	-.137	-.200	.224	.362*	.405*
	Sig. (2-tailed)	.000		.035	.006	.435	.458	.627	.921	.641	.166	.414	.228	.177	.026	.012
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
MostFrequentTime	Pearson Correlation	-.363*	-.342*	1	.009	.048	.169	-.139	.052	.158	-.106	-.107	-.299	-.179	-.068	-.300
	Sig. (2-tailed)	.025	.035		.957	.774	.311	.405	.757	.345	.528	.523	.068	.282	.686	.067
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
ONandOFF	Pearson Correlation	-.382*	-.440**	.009	1	-.005	-.259	.594**	.476**	-.613**	.417**	.178	-.110	-.282	-.100	-.362*
	Sig. (2-tailed)	.018	.006	.957		.978	.116	.000	.003	.000	.009	.284	.512	.086	.552	.026
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Number_of_users	Pearson Correlation	.071	.130	.048	-.005	1	.201	.056	.202	-.035	.051	.094	-.273	.501**	.116	.483**
	Sig. (2-tailed)	.670	.435	.774	.978		.227	.738	.224	.832	.760	.574	.097	.001	.488	.002
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Public_Awareness	Pearson Correlation	-.101	-.124	.169	-.259	.201	1	-.457**	-.039	.510**	-.303	-.098	.254	.390*	-.418**	.176
	Sig. (2-tailed)	.548	.458	.311	.116	.227		.004	.817	.001	.065	.559	.124	.016	.009	.290
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Integration	Pearson Correlation	.074	.081	-.139	.594**	.056	-.457**	1	.601**	-.993**	.311	.388*	-.194	-.036	.208	.029
	Sig. (2-tailed)	.657	.627	.405	.000	.738	.004		.000	.000	.058	.016	.244	.830	.209	.863
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Connectivity	Pearson Correlation	-.106	-.017	.052	.476**	.202	-.039	.601**	1	-.563**	.066	-.018	-.201	-.031	.002	-.070
	Sig. (2-tailed)	.526	.921	.757	.003	.224	.817	.000		.000	.692	.917	.226	.855	.988	.677
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
MeanDepth	Pearson Correlation	-.071	-.078	.158	-.613**	-.035	.510**	-.993**	-.563**	1	-.317	-.383*	.212	.065	-.227	-.007
	Sig. (2-tailed)	.673	.641	.345	.000	.832	.001	.000	.000		.053	.018	.201	.700	.170	.966
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
DistanceFromCenters	Pearson Correlation	-.205	-.229	-.106	.417**	.051	-.303	.311	.066	-.317	1	.472**	-.027	-.193	.194	-.081
	Sig. (2-tailed)	.217	.166	.528	.009	.760	.065	.058	.692	.053		.003	.872	.247	.244	.628
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
TrafficAccount	Pearson Correlation	-.092	-.137	-.107	.178	.094	-.098	.388*	-.018	-.383*	.472**	1	.090	.086	.067	.074
	Sig. (2-tailed)	.581	.414	.523	.284	.574	.559	.016	.917	.018	.003		.589	.607	.690	.659
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Weekdays	Pearson Correlation	-.095	-.200	-.299	-.110	-.273	.254	-.194	-.201	.212	-.027	.090	1	-.086	-.274	-.053
	Sig. (2-tailed)	.570	.228	.068	.512	.097	.124	.244	.226	.201	.872	.589				
	N	38	38	38	38	38	38	38	38	38	38	38	38			
Transactions	Pearson Correlation	.149	.224	-.179	-.282	.501**	.390*	-.036	-.031	.065	-.193	.086	-.086			
	Sig. (2-tailed)	.372	.177	.282	.086	.001	.016	.830	.855	.700	.247	.607	.608		.756	.000
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
KM	Pearson Correlation	.183	.362*	-.068	-.100	.116	-.418**	.208	.002	-.227	.194	.067	-.274	.052	1	.344*
	Sig. (2-tailed)	.273	.026	.686	.552	.488	.009	.209	.988	.170	.244	.690	.096	.756		.034
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Total_Energy_Used	Pearson Correlation	.294	.405*	-.300	-.362*	.483**	.176	.029	-.070	-.007	-.081	.074	-.053	.896**	.344*	1
	Sig. (2-tailed)	.073	.012	.067	.026	.002	.290	.863	.677	.966	.628	.659	.753	.000	.034	
	N	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

10.2 Notes for Planners, Policy Makers and Regulators

Table 10-3 illustrates the relationships of the variables in a legible way. The e-mobility system readiness and understanding the effects of its variables is what would interest planners, policy makers and regulators and understand.

Table 10-3: Variables correlation insights

Correlations	Average time Spent	Most Frequent Time	On and OFF	Number of users	Number of Transactions	Level of Awareness	Spatial Analysis	Distance from centres	Traffic Counts	Weekend/ Weekdays	User Persona	History
Average time Spent (in minutes)		-ve	-ve								+ve	
Most Frequent Time *(Morning, afternoon, evening and night)*	+ve											
On and OFF *(On is 1 and OFF is)*	-ve	+ve					+ve	+ve			-ve	+ve
Number of users					++ve							
Number of Transactions				++ ve		+ve						
Level of Awareness *(%)*					+ve		++ve					
Spatial Analysis *(Integration connectivity and Mean Depth)*												
Distance from centres *(Metric)*			++ve						++ve			
Traffic Counts *(OD metric)*							+ve	++ve				
Weekend/ Weekdays *(ratio)*												
Users Personas*(1-5) 1 is the top up and 5 is beyond charging)*	++ve		++ve									
History (*years of the CP operation*)												

To determine exactly how much of the variance in one variable can be accounted for by the variance in another variable, the Coefficient of Determination is computed by squaring the correlation coefficient (r). The inverse of this value is the amount of unexplained variance (Coefficient of nondetermination).

Starting with the variables that have a positive or direct correlations, Average Time Spent (A) has a very strong positive relationship with the User Charging Personas (UCP): The Top Up (value of 1), The Lucky Charge, The Good Enough, The Superb and Beyond Charging (value of 5). The correlation analysis suggests that 64% of the variance in the users persona can be explained by the variance in the A. This means that ($r_{AUsers\ Personas}$ = 0.801) and ($r_{AUsers\ Personas}$ = 64%) of the variance in A can be explained by the variance in CUP. On the contrary, A has a negative correlation with the Most Frequent Time (M) and On and Off Street (O). M has a negative relationship with the A. In numbers, this means, the more the time the user spends charging, the earlier they will arrive the CP. This means, (r_{AM}= 0.36) and (r^2_{AM} =13%) of variance in time they arrive M is explained by the time they spent charging A. This indicates a weak relationship.

O has a moderate negative relationship with A., see (Figure 10-2). This is a special case as in On and Off Street, it is a dummy variable where On Street is the value of 1 and Off Street is the value of 0. Therefore, a negative relationship means users tend to spend more time charging when they are using an Off Street CP. This means that, (r_{AO}= 0.39) and (r^2_{AO}=15.2%) of variance in time they arrive (M) is explained by the variance in the location of the CP (O).

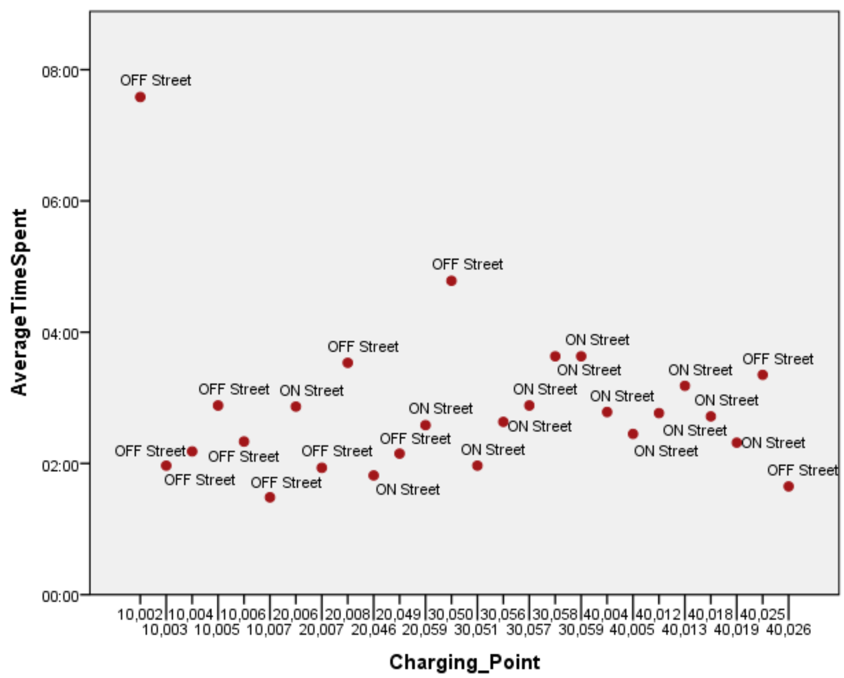


Figure 10-2: On-Off Street and Average Time Spent (A)

On and Off Street (O) has additional significant relationships. It has (r = -.440) with the user persona, which almost implies the same relation of O and A. It means users tend to stay longer when charging their cars in parking lots or at the workplace. This means that ($r^2_{UsersPersonasO}$= 19.4%) of the variance in the user charging persona is explained by the location of the CP whether On or Off Street. This relationship is quite similar to the one previous, the difference is justified as the formation of the user charging persona is a product of A and M.

O has a strong positive (direct) relationship with the spatial configuration attributes, and a strong one with Integration, 0.594, and a moderate one with Connectivity, 0.476. By considering the more important one of them, both the Integration value can be observed that (r^2_{IO} =34%) of the variance in the integration value of the street that has a CP, is explained by whether the CP is On or Off street. This is further clarified in the following section.

10.2.1 Correlation: note 1

Back to the definition of Integration value, main streets would have more integration values than secondary streets or alleys. Accordingly, an On Street CP would have a higher integration value as the Off Street CP will be in car parks. It has a moderate positive relation with Distance from Centres (ɩ). This can interpreted as the more the CP is away from Urban Centres, the more the probability it is an Off Street CP. This has to do with town and city planning and the location of the main parking lots with respect to the urban cores. Hence, this coefficient means here that Off Street CPs positively correlate to ɩ with a value of 0.417 at a level of confidence of 0.05. This means that ($r_{ɩO}$ = 0.417) and ($r^2_{ɩO}$ =16.8%) of the variance in number of transactions is explained by the location of the CP as being On or Off Street.

A further relation is O with the History (H). A moderate positive relation, a value of 0.387, correlates the On-Off Street design parameter of a CP to the years it has been installed. This means that historic CPs are Off Street; whereas, the newly installed CPs tend to be On Street. Consequently, it can observed that (r^2_{OH} =14.4%) the variance in installing a CP On or Off Street is explained by the time it has been installed. This relationship has a value of 0.387 at a level of 0.1.

Further relationships are the ones that the LoA has with spatial attribute, Integration (I) and the number of transactions (η). LoA has a moderate direct relationship with I. (r_{PI} = 0.457) and (r^2_{PI} = 20.25%) of the variance in the level of awareness explains by the integration value of the street that has the CP. This relationship is self-explanatory. The main corridors of mobility have higher integration values and are more visible to people to recognise. Hence, the Integration is positively correlated to LoA. The second relationship is the LoA with the number of transactions (r_{Pt} = 0.390) and (r^2_{Pt} =15.21%) of the variance in transactions made in a CP this can be explained by how aware the users are of it. This is another simple and justified relationship. The more the CP is popular and known by users, the more it will be used. In other words, the variance in the usability of the CP is justified by 15.21% due to being recognised by users.

The last variable is the Total Energy Used (Λ). This variable positively correlates with all variables as explained before. This is because of the direct relationship of all the other attributes in conjunction with the total energy spent by a user charging their cars. The most frequent time as indicated above (most frequent time and the time spent), the number of users, and the number of transactions. This leaves the On Street one in a negative relation, though this is due to the dummy variable, which strongly accept the hypothesis that Off Street CPs generate more profit.

10.2.2 Correlation: note 2

A meaningful observation, can be obtained from the relationship between (Λ) and both (n) and (τ). The total Energy has a moderate direct relationship (0.483)++ with the number of users at a significance level 0.01, and has a very strong direct relationship with the total number of transactions (0.896)++ at a significance level of 0.01. This implies that the more (n) and (τ), the higher the profit; however, the profit does not significantly correlate to the (A). This means that the profit is more sensitive to the transactions made (same user or multiple) throughout the day.

Therefore, a CP with a high number of transactions indicates that the charging sessions were relatively short. This is because the longer the charging session, the smaller the number of charging events (transactions) being made throughout the day. It can be observed that a CP that is being used more frequently (even for short charging sessions, by The Top Up or The Good Enough, see charging personas, Chapter 7), will generate more profit compared to another CP is being used by the same or a higher number of users but for longer charging sessions and less number of transactions.

10.3 Lessons Learnt From E-Mobility Data Analytics

Data analysis has highlighted three major issues, which have to be interpreted with caution.

10.3.1 Single and multiple CPs records in analysis

The number of CPs in each RF may cause biasness. For example, if one RF has two CPs # 20007 and 20008, each CP has its own records of transactions (charging events), η, A, and M, see (Table 10-4). A clarification should be made whether the values are for each CP or both 20007 and 20008. This is to avoid misleading comparison between multiple RFs and single RF, see (Table 10-5). As it is shown in the average value of CP# 20006 transactions will give a wrong indication, see (Table 10-6). To avoid this, each CP is to be listed separately, and some attributes will be repeated, see (Table 10-4). For example, all spatial design parameters and some charging attributes will remain the same for the CPs of the same RF. This is acceptable as it will not affect the ability to predict.

Table 10-4: Separating multiple points

	Transactions			Users			Average Time Spent		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
20006	34	29	39	15	16	19	01:28	02:52	02:14
20007	93	141	159	23	23	33	02:11	01:56	01:49
20008	100	198	240	20	26	37	01:55	03:32	02:20

Table 10-5: Taking the average

	Transactions		Users				Average Time Spent		
	2011	2012	2011	2012	2013	2013	2011	2012	2013
20006	34	29	15	16	8	12	01:28	02:52	02:14
20007-20008	193	339	43	49	70	993	02:03	02:44	02:04

Table 10-6: Summing up

	Transactions		Users				Average Time Spent		
	2011	2012	2011	2012	2013	2013	2011	2012	2013
20006	34	29	15	16	8	12	01:28	02:52	02:14
20007-20008	97	170	22	25	35	199	02:03	02:44	02:04

10.3.2 Users' volume to charging events ratio

One of the major issues is the difference between the number of transactions and the number of users. These two variables are directly correlated, but reciprocal. A high number of transactions does not necessarily coincide with a high number users. For example, and as illustrated in Figure 10-3 in the year 2011, CP# 30058 had 26 transactions made by 14 users, whereas CP # 40004 made 44 transactions made by 11 users and in the year 2012, CP #30058 had 62 transactions made by 20 users where 10002 had 74 transactions made by 8 users.

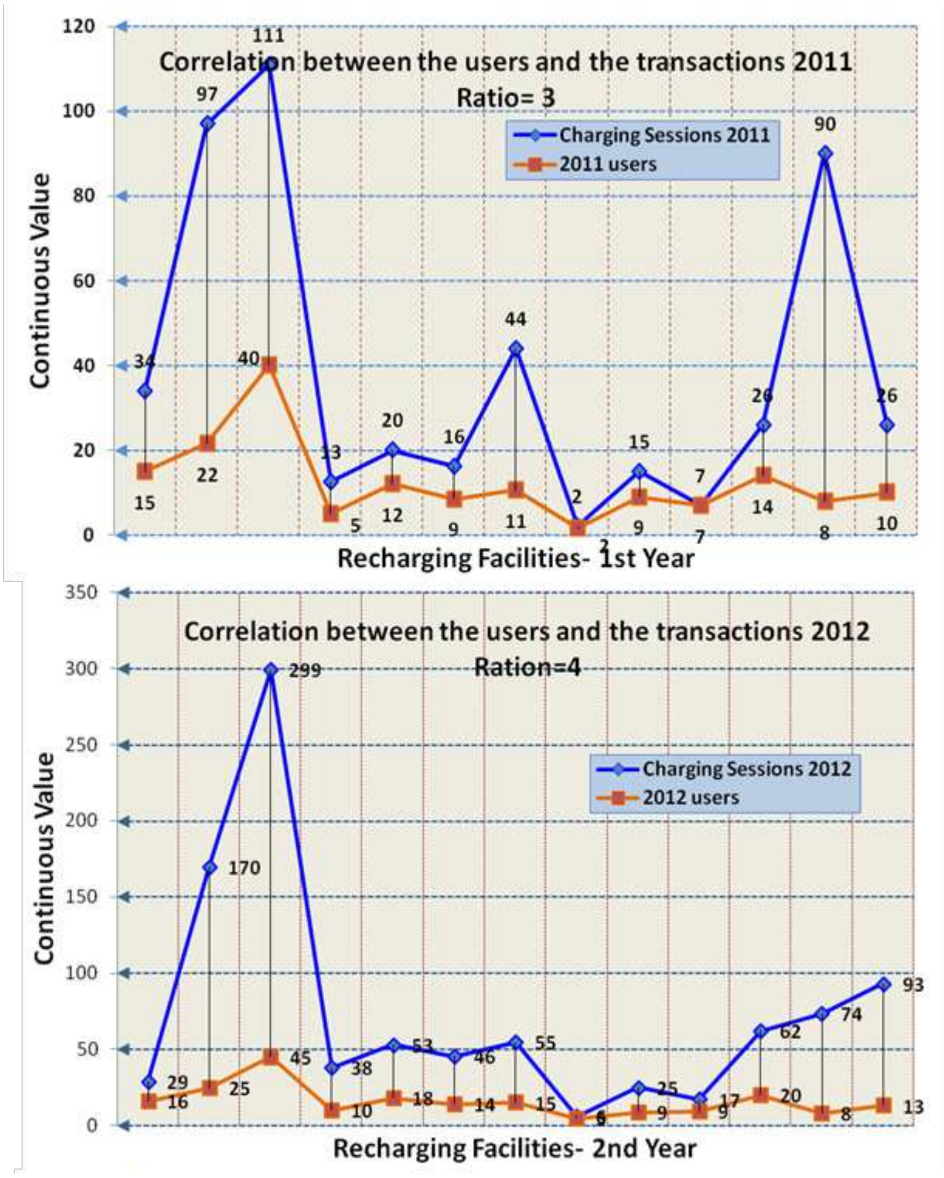


Figure 10-3: Users-charging events ratio-years

10.3.3 Avoiding multicollinearity

In regression analysis, a problem is referred to as a Multicollinearity this is when two or more independent variables in the multiple regression model are highly correlated, meaning that one can be linearly predicted from the others. This makes it more difficult to determine which Independent Variable (IV) is actually producing the effect on the Dependent Variable (DV). Predictors that are highly collinear (linearly related) can cause problems in estimating the regression coefficients, as the estimate of the explanatory variable impact on the dependent variable while controlling for the others tends to be less precise (Iastate, 2004).

To avoid this problem, the following variables will not be included:

- Charging profiles and reliability index as both are computed from other variables. The first is a product of the average time spent and most frequent time where the second is a product of the energy used.
- Connectivity is excluded due to the high correlation with the integration value in the case of Newcastle-Gateshead area.
- Mean Depth (MD)

The year 2012 can be considered the most stable year of operation where the majority of the CPs were activated, more users joined the market, and a noticeable charging pattern can be drawn. A regression analysis is carried out for the year 2012 records. This is to investigate the effect and the interaction between the different variables of the system.

10.4 Hypothesis Development

This chapter aims at interrogating the relationship between the design features and spatial configuration attributes of the RF and the charging patterns and behavioural parameters of EV drivers. The Hypothesis deals with the sample, and can be generalised across the large population. The sample is the EV population of the Newcastle and Gateshead area charging their cars in NE1, NE4 and NE8.

10.4.1 Why to investigate this relationship?

The depiction of the real world population and the system has to denote and stimulate at a high level of correlation. In case of having a system used by human beings like the EV system, depicting the behaviour layer should not be overlooked. An imperative question that needs investigation is the correlation between design parameters of the charging network and the charging behaviour. This illuminates the thesis research question:

> *RQ1: What are the influential spatial and behavioural attributes affecting the design and the use of e-mobility charging network?*

In order to address this question, first the hypothesis has to be clear, which is testing the whether or not the spatial form of the urban context affects the e-mobility system use. Spatial form has been acknowledged in the past as a primary independent variable with respect to vehicular mobility; however, relatively recent research started to explain the spatial analysis of social behaviour and patterns. Attention was devoted mainly to the movement and human behaviour in buildings (Gil et al., 2009; Chittaro & Ieronutti, 2004;

Peponis et al., 2004, 2003) and in spaces (Hillier, 2007; Hillier & Stutz, 2005; Turner, 2003; Batty, 2001). This line of thinking suggests there are two possible viable options:

iii) Non directional stating that there is a clear relationship between the design and the charging behaviour; however, neither the direction nor the strength are known. a non directional research hypothesis is proposed by stating the relationship between the design and the charging behaviour referring to the previous analytically collaborated similar studies in the urban environment (Paul, 2011; 2009; Gil et al., 2009; Nkwenti, 2008; Jiang; Nkwenti; 2008; Hillier & Iida, 2005; Batty, 2001; Mottram et al, 1999; Penn et al., 1998; Hillier et al., 1993) and investigate the strength of the relationship.

iv) A null hypothesis: since the e-mobility is a complex system with unique characteristics compared to conventional mobility system, the null hypothesis is suggested. In fact, there is a lack of evidence or theories corroborating the effect of the RF's design features and qualities on the charging patterns in urban contexts. Referring to previous research and studies carried out in this area, little work has been conducted on the role of the social factor.

Due to the difference between main paradigms of the EV system and conventional mobility systems, a null hypothesis is proposed. The preposition is that there is no relationship between the usability (the profit of a CP) and the design features, spatial configuration attributes of the RF in its urban context, the charging pattern and behavioural parameters of the EV drivers. Where H_0 is the null hypothesis and β_1 *(the design and spatial configuration*) and β_2 (*charging patterns*) are the estimates of the overall EV population estimates of the IVs. If this hypothesis is true, this means that the relation between the profit and spatial and behavioural attributes is false. This is to be tested via the sample estimates b_1 and b_2, see (Equation 10-2).

Equation 10-2: Hypothesis development

$$H_0 : \beta_1 = \beta_2 = 0$$
$$H_a : \beta_1 \neq 0, \beta_2 \neq 0$$

10.4.2 Two models or a hybrid model

The design process of the EV charging infrastructure is very similar to the petrol stations location problem. Both cannot be dealt with as facility or location allocation problem. Location allocation problem can be purely based on spatial and metric tabulated in the optimization model, this approach is extraneous to RF's location problem. An integrated model that accounts for a multi-parameter complex system is required which can link between the two sets of *predictors*. In this chapter, a multi linear regression model is developed to study the relationship between the dependent variable (the Total Energy Used (Λ) and several explanatory variables.

10.4.3 Multiple regression models

Several trials were attempted, it was considered to separate the two sets of variables and design a standalone model for each. Using SPSS Statistics 21 software to perform the regression, the results are shown in (Tables 10-7, 8, 9, and 10).

Table 10-7: Model 1 (spatial) summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.939a	.283	.171	354.722106

a. Predictors: (Constant), OnandOff, Public_Awareness, DistanceFromCenters, TrafficAccount, Integration.
b. Dependent Variable: Total_Energy_Used

Table 10-8: Model 1 (spatial) ANOVA a

Model		Sum of Squares	df	Mean Square	F	Sig. From F table
1	Regression	1586825.006	5	317365.001	2.522	.049b
	Residual	4026488.725	32	125827.773		
	Total	5613313.731	37			

Table 10-9: Model 2 (charging-related) summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
2	.939a	.882	.854	148.797715

a. Predictors: (Constant), History, Weekdays, AverageTimeSpent, Transactions, MostFrequentTime, Number_of_users, Public_Awareness
b. Dependent Variable: Total_Energy_Used

Table 10-10: Model 2 (charging-related) ANOVA a

Model		Sum of Squares	df	Mean Square	F	Sig. From F table
2	Regression	4949090.929	7	707012.990	31.933	.000b
	Residual	664222.802	30	22140.760		
	Total	5613313.731	37			

Insight I

By looking into the two models, some observations can be made. Reviewing Table 10-7 the first model explains about 28% of the variation in Y (the total energy spent), according to the R^2. Under the panel headed ANOVA, the F statistics, equal to 2.522 (more then 2) and the associated significance F, which can be used to perform a test of overall significance. By reviewing Table 10-9, the first model explains about 88 % of the variation in Y (the total energy spent), according to the R^2. Under the panel titled ANOVA, the F statistics, equal to 31.933 and the associated significance F, which can be used to perform a test of overall significance. However, this is not enough; and the coefficients need to be reviewed and whether they are statistically significant for a prediction, see (Table 10-11 and Table 10-12).

Table 10-11: Coefficients_(Spatial) Model 1

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1364.684	734.850		-1.857	.073
	OnandOff	-500.635	157.230	-.643	-3.184	.003
	Public_Awareness	8.458	5.301	.281	1.596	.120
	DistanceFromCenters	.345	.496	.134	.697	.491
	TrafficAccount	-.002	.009	-.047	-.255	.801
	Integration	1876.220	804.389	.516	2.332	.026

Table 10-12: Coefficients_(charging related) Model 2

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	23.515	347.027		.068	.946
	Number_of_users	4.160	4.977	.064	.836	.410
	AverageTimeSpent	.008	.005	.112	1.599	.120
	MostFrequentTime	-30.188	49.638	-.049	-.608	.548
	Weekdays	2.225	2.648	.068	.840	.407
	Transactions	5.583	.542	.884	10.308	.000
	Public_Awareness	-4.594	2.578	-.153	-1.782	.085
	History	-9.799	5.713	-.121	-1.715	.097

On the first model, out of the 12 variables in total, the coefficients to the On and Off Street and Integration are the only two significant coefficients, .003 and .026. In the second model, only the coefficient to Transactions is statistically significant, .000.
Although the two models are capable to predict and can be used to explain the variance of a RFs profit, the separation did not support the integration of the spatial and behavioural variables in the one model. To resolve this matter, some alterations were made. Some *predictors* had to be removed and/or swapped, as the total number of variables is relatively large compared to the 38 observations.

This model is developed to predict and explain the variance in the design process of the RFs and the following points had to be considered:

- *The obtained relationships from the correlation analysis;*
- *The availability of the data (number of transactions will not be possible to get when planning for a Greenfield area);*
- *The necessity of integrating the variables;*
- *The degree of freedom of each model (the higher the better);*
- *The significance of the coefficients (a higher R^2 with insignificant coefficient does not make the model any better), and;*
- *The number of variables in the model.*

Consequently, a hybrid model is designed. The designed model does not couple the two sets; however, it runs each set separately, and then generates a hybrid model at the end with a modified R^2 and adjusted R^2. The two sets of variables were merged, and after trying different combinations and sets of variables, the variables that are the most relevant and likely to affect the DV were finally selected. The final list contains 7 variables in total in addition to the IV.

Insight II

To run the model, the variables are to be classified into behavioural and spatial elements. Behavioural attributes are the ones related to charging patterns; whereas, the spatial ones are the urban context related variables. After conducting several trials trying to mix and match all the variables and see which set up provides better results, the following composition was selected, see (Table 10-13).

Table 10-13: The two sets of attributes

	Charging Behavioural Attributes	Urban Context Related Attributes
1	No. of users (η)	On / Off Street (O)
2	Average time spent (A)	Integration (I)
3	Most Frequent Time (M)	Connectivity (C)
4	Level of Awareness (LoA)	

10.5 Regression Analysis

There are 12 input factors (predictors) with 38 observations. This means that each of the 7 factors is tested at 38 levels. The results will have a random error. The random error indicates that there is a percentage of variance, which is undefined and cannot be explained by the factors. The model is testing how powerful the equation is in representing the relation. The equation is judged by the residuals analysis as the more the random error occurs, the lower the correlation. Accordingly, the weaker is the relationship between the DV and the IVs.

The method being used is ENTER (using SPSS Statistics 21), see (Table 10-14). This means all of the variables are entered at the same time whereas other methods like stepwise, remove, backward or forward involved some sort of wise step regression.

Table 10-14: Variables entered/removed a

Model	Variables Entered	Variables Removed	Method
1	MostFrequentTime, Number_of_users, Public_Awareness, AverageTimeSpent[b]	.	Enter
2	Connectivity, OnandOff, Integration[b]	.	Enter

a. Dependent Variable: Total_Energy_Used
b. All requested variables entered.

10.5.1 Spatial statistical analysis

A hybrid model is developed in two stages 1a and 1b. Using the data of 38 monthly observations, the models are executed and the results are reported here below. The first model comprises of only spatial parameters (predictors). The Adjusted R square value indicates that the five spatial factors explains 17% of the use of RFs variance, which is very low as over 85% of the factors remain unexplained and make the model less able to predict future values. In a second model, the behavioural parameters are added to the spatial one.

The Adjusted R square increases to 0.871, this is displayed in (Table 10-15) and the model significance is improved, 0.000, displayed in (Table 10-16).

10.5.2 F test of significance

In a multiple regression model, the F test of significance (Kahane, 2008) is used to question whether the model explains the variance of the Dependent Variable (Y). Rewriting the formal hypothesis, H_0:β_1=β_2=0. This null hypothesis means that all of the population parameters to the X variables are truly and jointly equal to zero, meaning that the model as a whole has no ability to explain the behaviour of Y.

The Sig. F in ANOVA in Table 10-16 highlights the probability that H_0 is true, given the sample result for the regression. Accordingly, it can be deduced suggesting that the model has something to say about the behaviour of Y, the total energy used. Therefore, the hypothesis H_0:β_1=β_2=0 at a very high level of confidence can be rejected.

Table 10-15: Model summary c

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.532[a]	.283	.171	354.722106
2	.945[b]	.910	.871	139.670909

a. Predictors: (Constant), MostFrequentTime, Number_of_users, Public_Awareness, AverageTimeSpent
b. Predictors: (Constant), MostFrequentTime, Number_of_users, Public_Awareness, AverageTimeSpent, Connectivity, OnandOff, Integration
c. Dependent Variable: Total Energy Used

Table 10-16: ANOVA a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1586825.006	5	317365.001	2.522	.049[b]
	Residual	4026488.725	32	125827.773		
	Total	5613313.731	37			
2	Regression	5106106.697	11	464191.518	23.795	.000[c]
	Residual	507207.034	26	19507.963		
	Total	5613313.731	**37**			

10.5.3 Model significant coefficients

The model is to explain the variance of the use (profitability). As Table 10-17, the coefficient to the variable, η is positive and has a Sig. value of .001, meaning that it is significantly different from zero at better than the 1% level of significance (or 99% level of confidence). Results suggest that the variables η, M, O and I are significant at the 1% level of significance (or 99% level of confidence), as the four have a Sig. value less than 0.05.

Table 10-17: Coefficients a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	105.451	228.742		.461	.648		
	Public_Awareness	4.525	4.267	.150	1.061	.297	.931	1.075
	AverageTimeSpent	.012	.010	.174	1.178	.247	.857	1.167
	Number_of_users	29.468	9.105	.454	3.237	.003	.949	1.054
	MostFrequentTime	-174.872	91.307	-.284	-1.915	.064	.849	1.178
2	(Constant)	-603.145	634.249		-.951	.349		
	Public_Awareness	6.091	4.482	.202	1.359	.184	.671	1.490
	AverageTimeSpent	-.007	.011	-.097	-.623	.538	.617	1.620
	Number_of_users	30.649	8.342	**.473**	3.674	**.001**	.899	1.112
	MostFrequentTime	-189.335	82.325	**-.308**	-2.300	**.029**	.830	1.204
	OnandOff	-425.639	141.100	**-.547**	-3.017	**.005**	.453	2.208
	Integration	1815.200	755.859	**.499**	2.402	**.023**	.344	2.906
	Connectivity	-18.747	16.463	-.192	-1.139	.264	.525	1.904

a. Dependent Variable: Total_Energy_Used

Given the low t statistic and the large associated Sig. values, the variables, Average time spent and connectivity are not statistically significant in this regression. The variables M and O have a negative coefficient, while (I) has a positive impact on the dependent variable.

Aa histogram of the standardised residual values is displayed in Figure 10-4, which is expected to be close to normally distributed around a mean of zero. In addition to the normal plot of regression standardised displayed in Figure 10-5 where it is expected that the values to be very close to or around the reference line. This indicates very little deviation of the expected values from the observed values.

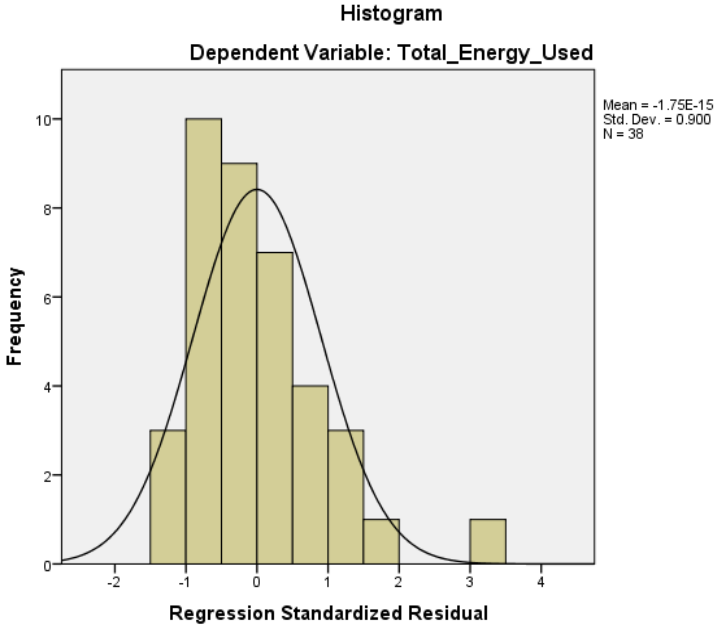


Figure 10-4: Histogram of DV: total enery used

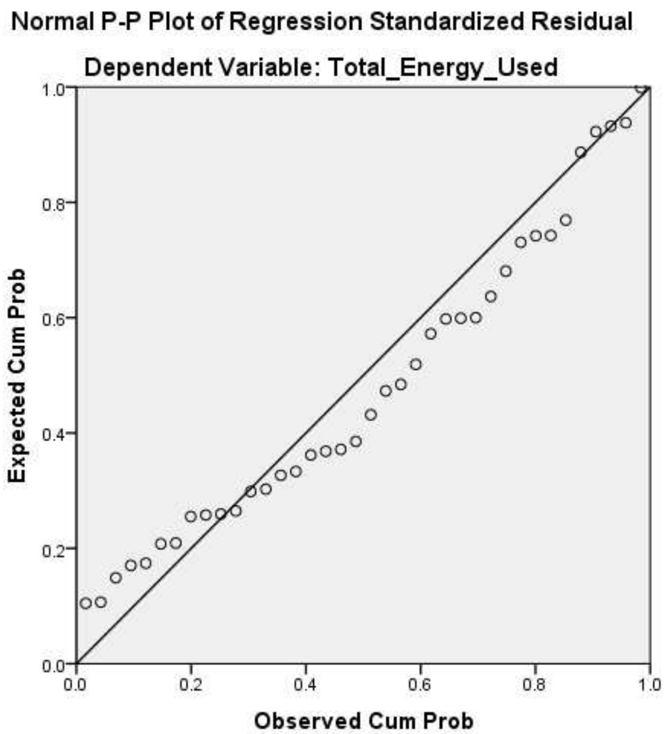


Figure 10-5: Regression standardised residual plot

10.6 Results Interpretations

Through a linear regression approach, was developed a hybrid model that coupled the independent behavioural and spatial variables to explore the relation to the total energy consumed by the CPs. There are some meaningful interpretations and important outcomes. The coupling process of the variables is fundamental for model validity and reliability.

Decoupling behaviour and spatial qualities of a system would lead to maybe higher statistical significance though unrealistic interpretation.

The model is developed to assist in planning future EV charging network based on real experience and empirical analysis. Effects and intersections of all factors should be taken into account. To validate this, the random error value has significantly dropped when the behavioural parameters were added in the second stage. The model explains 45% of the RF's usage variance.

This chapter explored different spatial and charging pattern related variables and proposed a regression model where these variables were coupled in order to identify the most influential factors affecting the use of RFs. Previous research has shown successful in interrogating this relation in different contexts. As a preliminary model, justifying 45% of the variance in a complex system indicates the good selection of variables, validates the success in quantifying and analysing the variables, and outperforms a reliable regression model at a high confidence level.

In return, the model generates a linear equation where the DV is a product of the influential factors that contribute to a utilized and profitable charging network, see (Equation 10-3). Out of the seven factors (predictors), there are four most influential variables affecting the EV system usability. The equation is a simple linear regression, as per Equation 10-3:

Equation 10-3: Linear regression (4 independent variables)

$$Y = a + b_1 (X_1) + b_2 (X_2) + b_3 (X_3) - b_4 (X_4)$$

Where

Y is the total energy used
$X_{1\text{-}4}$ are the four independent variables with significant coefficients
$b_{1\text{-}4}$ coefficients to variables

To formulate the final equation with labels and coefficients, by using the standardized coefficients, see (Equation 10-4).

Equation 10-4: E-mobility most influential spatial and charging related attributes

$$f(\mathbf{\Lambda}) = (+.308\ MostFrequentTime(M) + .473\ \text{Number of users}\ (\eta) - .547\ On/off\ Street\ (0) + .499\ Integration)$$

10.7 Concluding Remarks

The spatial structure of a street network does not work independently of urban and behavioural layers of the given EV system. The statistical model revealed that the measures of design configuration and spatial qualities, behaviour layer, demographic and travel demand attributes are most strongly associated with charging events of EVs when planning for future EV integrated charging network. Therefore it can be suggested that the analysis presented here rejects the null hypothesis that design configuration values do not correlate to charging preference. Location-related values explain 30% of the variance of total energy consumed of the RFs of the network while adding behaviour-related values raises it to 44%.

The chapter shows that these measures: On street and Off street location, LoA, distance from urban centroids, traffic counts of the nearest corridor (s), and integration values are likely to capture only 17% of the EV recharging facilities occupation and usability which is quite a reasonable ratio for a pilot study. Whereas, the charging pattern-related attributes: contribute to 84% and coupling the two categories explains 87% of the system use.

Off Street charging sites increase the likelihood of public charging being used when it is located in the workplace. On Street with high integration values, close to main corridors, distant from urban cores tend to have a high frequency of short charges over the weekdays. Importantly, the results presented here also underscore the significance of the spatial structure of road networks. This chapter has provided an equation that can apply to design a charging network in a similar urban context, within which 45% of its use can be explained based on four identified variables. These variables can be estimated, measured and inserted into the formulated equation.

CHAPTER 11. DESIGN II: FORCASTING THE DEMAND

"Honey, I charged the car. I have just checked #UKCharge, Heathrow Charging Point is working."

By Jef Lay, LEAF Talk Forum Moderator, UK (2015)

This chapter presents the last phase of designing the e-mobility section. It discusses means to forecast the demand in the e-mobility systems based on analysing the current system of the Newcastle-Gateshead area. The chapter is divided into two parts, see (Figure 11-1), Part A discusses the current EV users' charging patterns and personas through a Time Series analysis. The Time series model proposes a method to forecast the charging patterns in e-mobility systems. Part B addresses the assessment and planning assistance tool, an integrated simulation model that is used for the location allocation problem of the RFs.

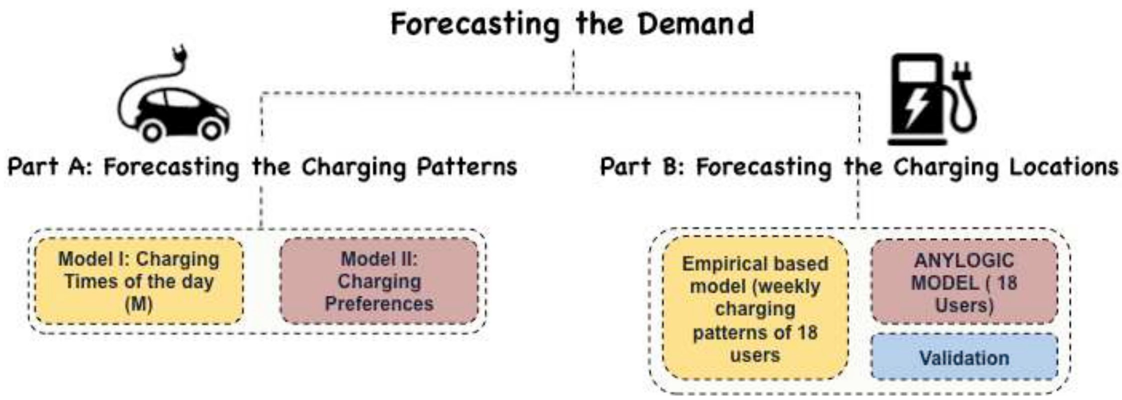


Figure 11-1: Chapter structure

11.1 Part A: Forecasting the Charging Patterns

Part A explores the emergent behaviour of charging throughout the 3-year operation and forecasts the charging pattern of the given area. The e-mobility system of the Newcastle-Gateshead area has been in operation since the second half of the year 2010 and growing. In this part, there are two main variables: Users Personas and the Most Frequent Time (M).

11.1.1 RFs occupation and frequency of use

When referring to the RF occupation, there are two terms:

- the number of users heading to a CP: a value which indicates the total number of EV users taking particular route to charge at a particular CP. This value will indicate the number of from/to the CP in the road network (transactions);

- the total time the CP is occupied (plugin time). The time interval between the charging events is calculated throughout the day. To calculate the occupation rate, three shifts of M are used (morning, afternoon, and evening) as the night shift, which starts at midnight and finishes at 5:59 AM is excluded.

Planning authorities and policy makers are interested in both values of occupation as quantifying these values will an impact on the traffic network (congestion in corridors). The e-mobility system in the Newcastle-Gateshead area has been evolving, Table 11-1 shows the differences between 2011, 2012 and 2913 NE1, NE4 and NE8.

Table 11-1: The evolution of Newcastle-Gateshead e-mobility system

Evolution	2011	2012	2013
EV Population	75	169	250
Time spent (Occupation)	20417 hrs	41634 hrs	77313 hrs
Transactions	1391	2788	4127
Total Energy Used	97,224.11	244,940.91	422,312.75
Recharging Facilities	25	9	5
Growth Rate (Users)		44%	67%
Growth Rate (Transactions)		50%	34%

From CYC database, which contains more than 12,000 charging events and covers over 30 CPs and 300 users, the data was sorted by years. Monthly transactions were counted into the four time/day categories: morning, afternoon, evening, and night. The time series model is developed using SPSS. The model is covering 8 halves starting January 2010 to have a cumulative of 48 months, which is shown in Figure 11-2, illustrates how the data is sorted as an input for SPSS.

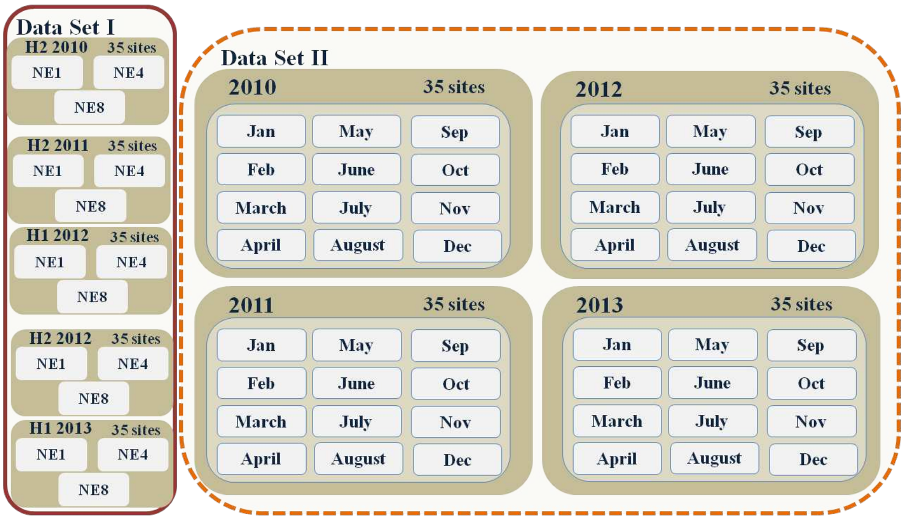


Figure 11-2: CYC dataset structure year/ month (by RF)

11.1.2 Occupation time categories

Prior to developing the time series model, it is always recommended to examine the data by mapping it and checking it for any seasonal effect. The seasonal decomposition procedure can be used to discover any systematic seasonal variations in the data. By using the seasonal Decomposition command in SPSS, which can examine the seasonal factor as the effect of each period on the overall trend. A sequence graph can be created to graphically represent the data while reflecting any seasonality, see (Figure 11-3).

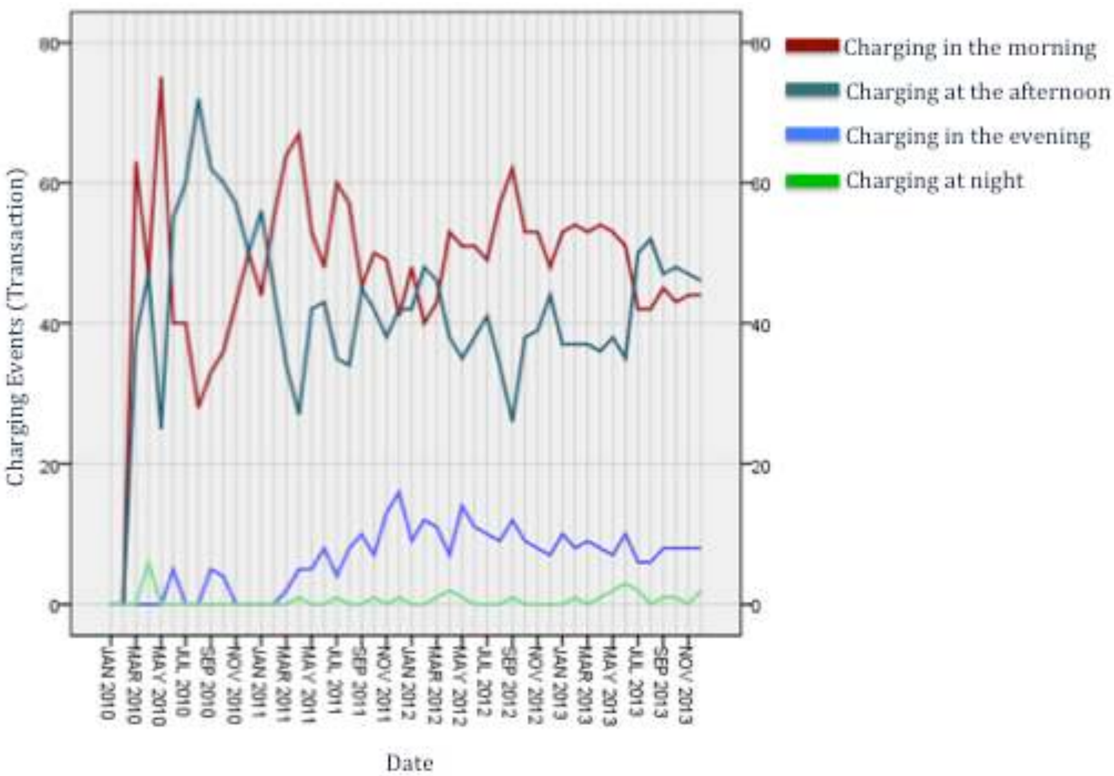


Figure 11-3: Charging pattern /day- occupation over the day

Figure 11-3 shows a gap between the morning and afternoon categories and the evening and overnight categories. This reflects the gap in the number of users charging their cars in each category. Users tend to charge in the morning and afternoon more than charging their cars during the evening time. Night has almost a zero occurrence, which is expected given that users usually charge their cars overnight using domestic chargers.

The data is graphically represent by a sequence graph, thus allowing the identification of any seasonality, Figure 11-3 values on the Y axis represent the percentage of the total charging events occurring in each category (morning, afternoon evening and night). For example, in April 2011, 1% of the total number of EV drivers used the RFs to charge their vehicles overnight, 5% charged during the evening shift, 27% charged in the afternoon, and 67 % charged during the morning shift.

The series exhibits a number of peaks, but they do not appear to be equally spaced. This output suggests that if the series has a periodic component, it also has fluctuations that are not periodic, which is the typical case for real-time series. As shown in Figure 11-3, besides the small-scale fluctuations, the significant peaks appear to be separated: April, August and December of the year 2010, April, August, and November of the year 2011, May and September of the year 2012, and June of the year 2013. This reflects typical highs in three seasons over the years; December holiday, school holidays and spring holiday seasons. The time series has an annual period; hence, seasonality is a prominent feature of this set of data.

11.1.3 Time series model and the seasonality effect method

The Time Series model is employed and it is useful to remove the variation element from a the model (*seasonal adjustment*) in order to estimate the trend for prediction purposes (Ruddock, 1995). Dealing with seasonality, analysing the actual time series data and finding a trend is the initial step for predicting the future values. Moving Average (MV) is a widely used indicator in statistical analysis that helps to smooth out the values by filtering the noise from random seasonality (fluctuations).

The Autoregressive Integrated Moving Average (ARIMA) method is employed to accurately forecast values while dealing with the seasonal variation. The four M categories are plotted separately to show the seasonality and the trend line using MA in Figure 11-4 and the automaticly generated Table 11-2.

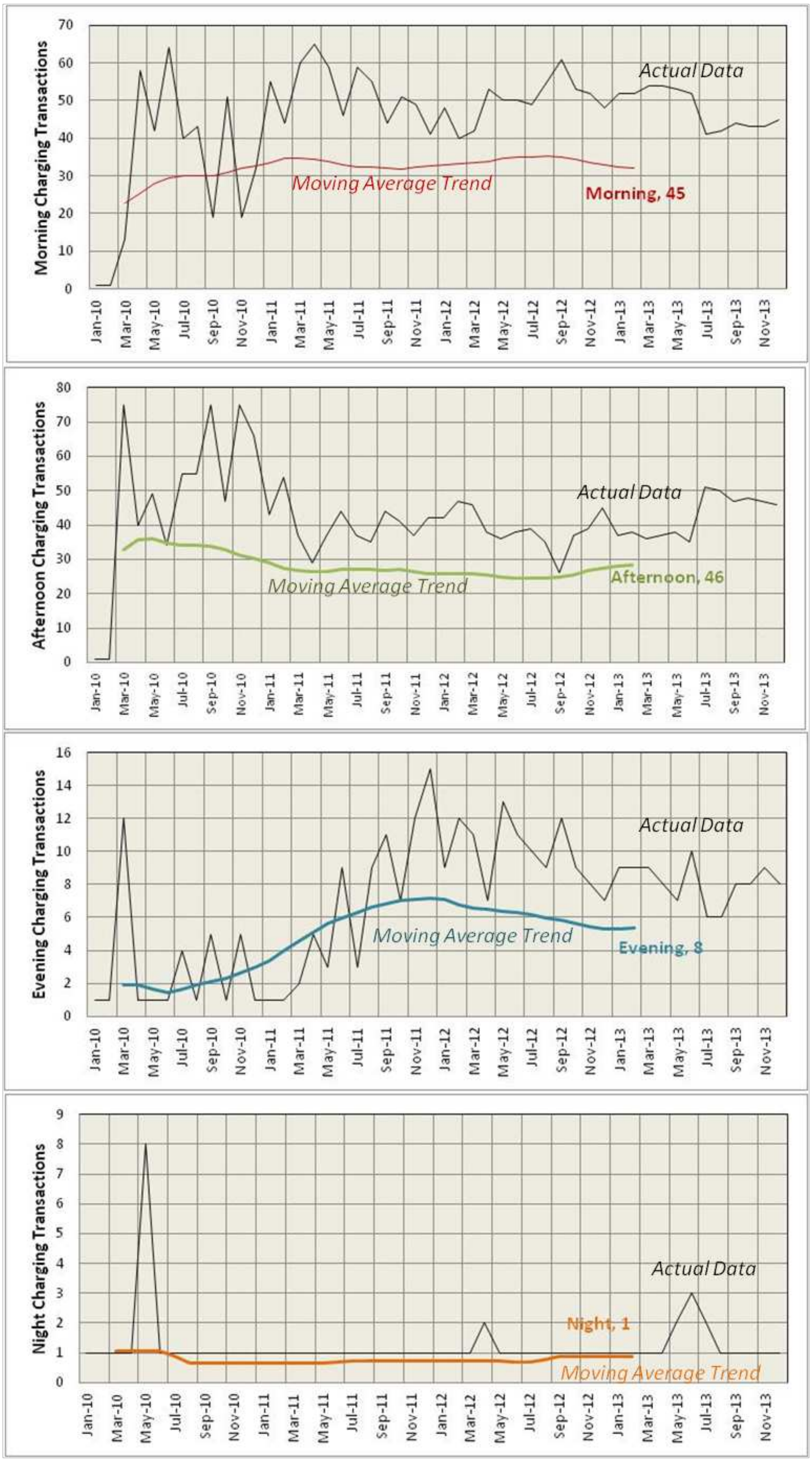


Figure 11-4: Monthly charging sessions in the four periods of the day

Table 11-2: The Autoregressive Integrated Moving Average (ARIMA) values

Month	Mornin g	Aftern oon	Total 12 Months	Total 12 Month s	Mornin g Centre d Total	Afternoo n Centred Total	Mornin g Trend	Aftern oon Trend
Sep-11	44	44	572	485	1154	968	32.06	26.89
Oct-11	51	41	572	485	1144	970	31.78	26.94
Nov-11	49	37	589	467	1161	952	32.25	26.44
Dec-11	41	42	591	463	1180	930	32.78	25.83
Jan-12	48	42	594	465	1185	928	32.92	25.78
Feb-12	40	47	601	468	1195	933	33.19	25.92
Mar-12	42	46	605	463	1206	931	33.50	25.86
Apr-12	53	38	617	454	1222	917	33.94	25.47

11.1.4 Plotting users personas

The five users' charging personas can also be represented graphically, see (Figure 11-5). By plotting the occurrence of the five personas in the system, various separated significant peaks appeared. The graph shows the difference in charging patterns throughout the years of operation, which is the estimation period. All values are based on the data provided as an input. For example, a high peak in February 2013, in the Top Up persona, does not mean a low one in the lucky Charge. The graph shows significant peaks and troughs in the first year of operation, 2011 and a few seasonal changes in December 2011 and 2012 holidays.

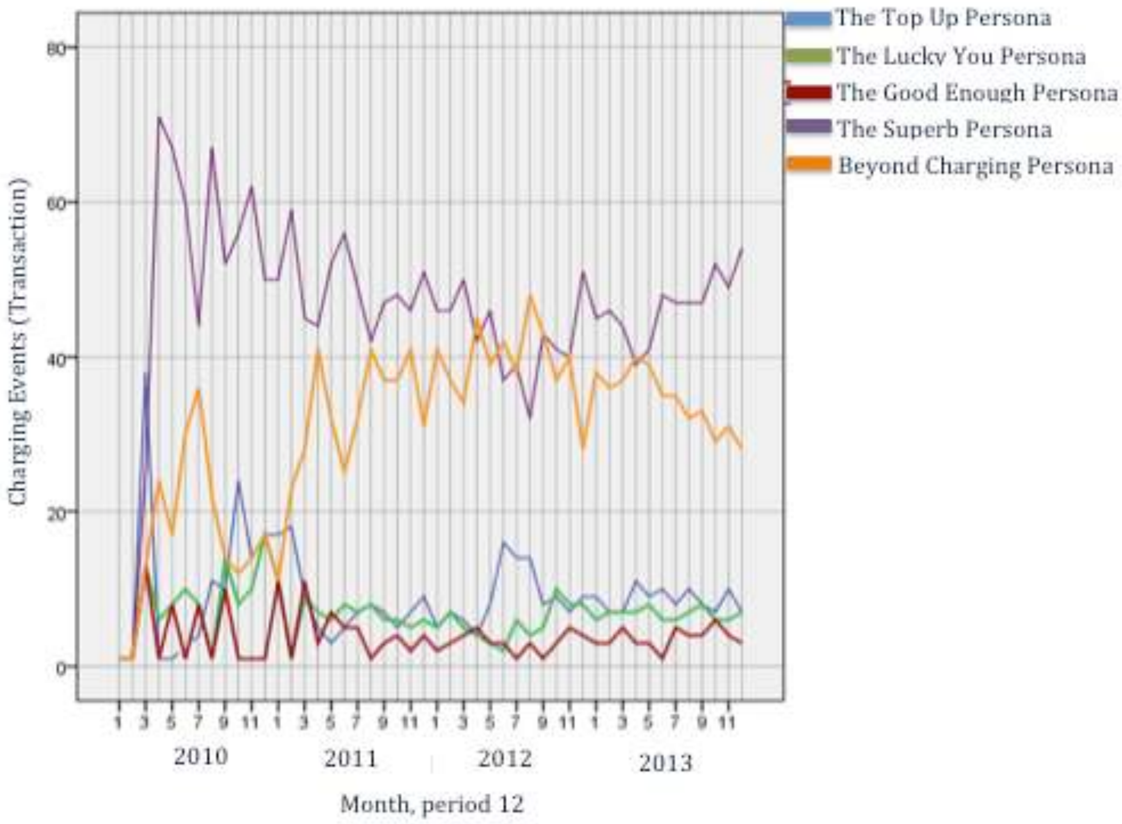


Figure 11-5: Charging personas (all years)

Estimation and validation periods

The model consists of two main periods:

- Estimation/observation/ historical period: the estimation period defines the set of cases used to determine the model. To set the estimation period, select Based on time or case range. This period should not have any missing value, all displayed values/ variables are nominal. The true estimation period is the period left after eliminating any contiguous missing values of the variable occurring at the beginning or end of the specified estimation period.

- Forecast Period: is the period that begins at the first case after the estimation period. The length of this period depends on the research objective with respect to the length of the estimation period for accuracy and results credibility.

Goodness of fit statistics

Prior to tackling the forecasting process, a check of goodness is to be applied to the model in order to test its credibility in forecasting. This is done by using the estimated values to build a validation model or Fit Values graph which is:

> *"It is a way to test how well the model is able to predict (in this case is to predict the charging preferences."*

The representation of the observed values (estimation period values) and the fit ones should indicate the model's predictive ability. By forcing the model to make predictions for the points that are already known (the points in the validation period), it can be clear how well the model can in forecasting.

In this section, one IV is chosen for prediction. In order to test the model creditability, the charging patterns of the morning shift (6AM to 12PM) is selected, see (Figure 11-6). The graph shows good agreement with the observed values (highlighted in red). This indicates that the model has satisfactory predictive ability.

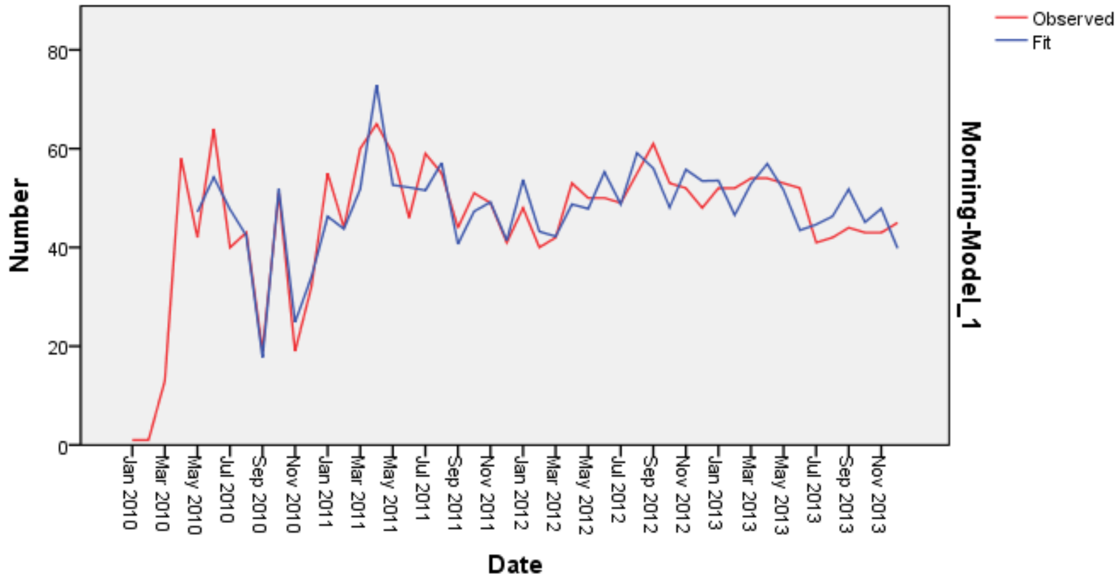


Figure 11-6: Goodness of fitness

11.1.5 The predictive models I and II

Predicting the behaviour elements of the EV system in the proceeding years of operation can provide useful information and help planning authorities to understand the system and design it for future users. For example, if the majority of people seem to charge in the *morning* and for short charge *(The Top Up)*, this in return would have implication on the Traffic Management Systems (TMS). Enhancing the uptake by the government polices and initiatives and with having more cars in the network, the impact of the EV will be influential and the e-mobility within the network would be considered as an independent travel demand. The travel demand magnitude is affected by the several factors, which influence the commuters' decision. Adding another factor, which in this case is the charging events and the desire to find a RF within the network in a relatively short time compared to conventional cars, shall have its effect on the system as a whole.

A prediction of the time of charging over the day, Most Frequent Time (M) and the Average time spent (A) would shape the main charging pattern paradigms. The prediction period is for the year 2014 and it is based on the active data for the years 2010, 2011, 2012, and 2013, using SPSS Statistics 21 software.

The first model illustrates the four different shifts within the day. The estimation values are plotted in a time series model, see (Figure 11-7). The model captures the observed data of the longitudinal study and the forecasted values for the year 2014. The values presented in both periods are the total percentage of the charging events that occurred in each month.

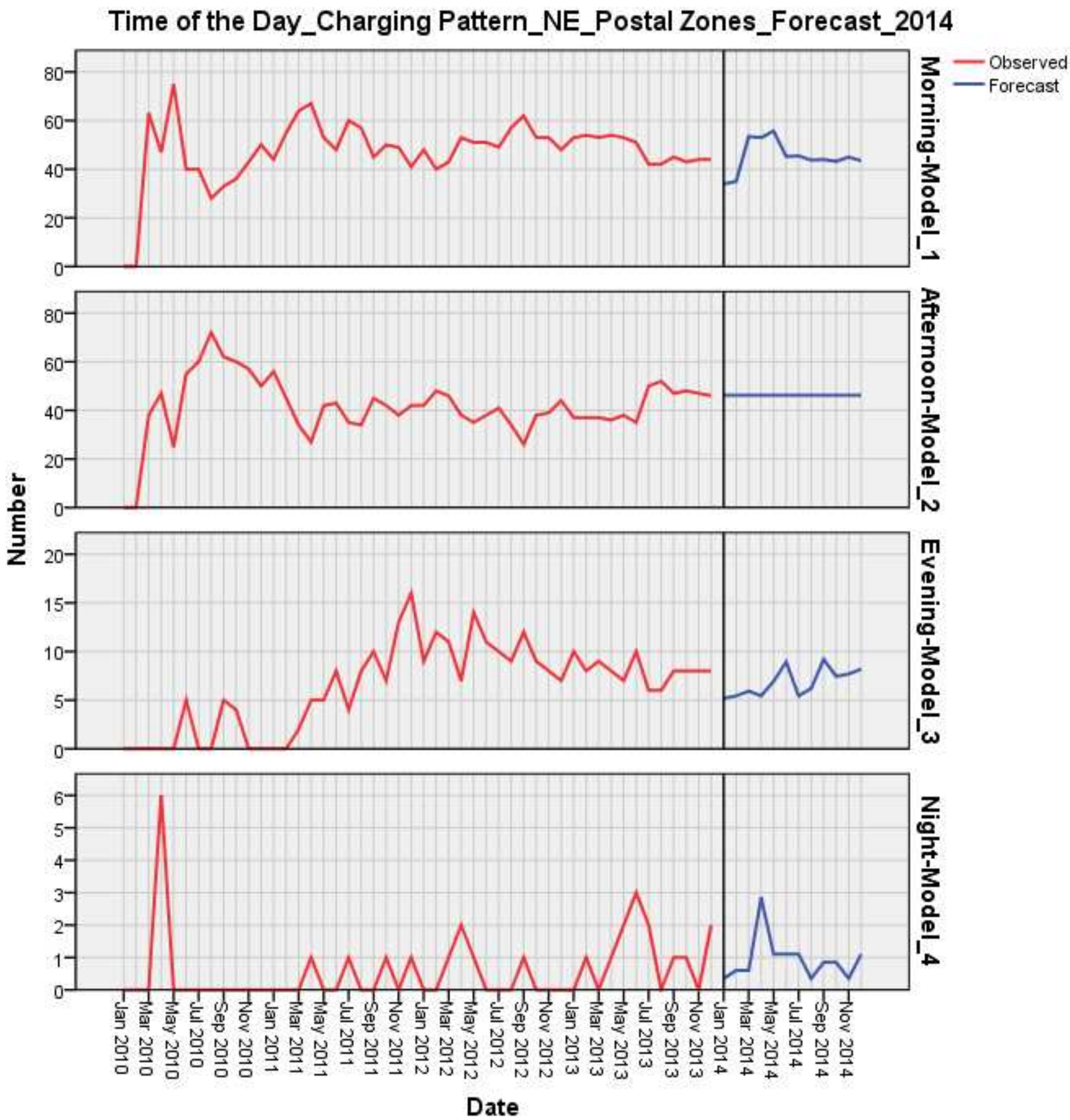


Figure 11-7: Model I: Illustrating the four charging patterns in 2014

The second model, see (Figure 11-8) presents the five EV charging personas, predicts the percentage of occurrence showing seasonality.

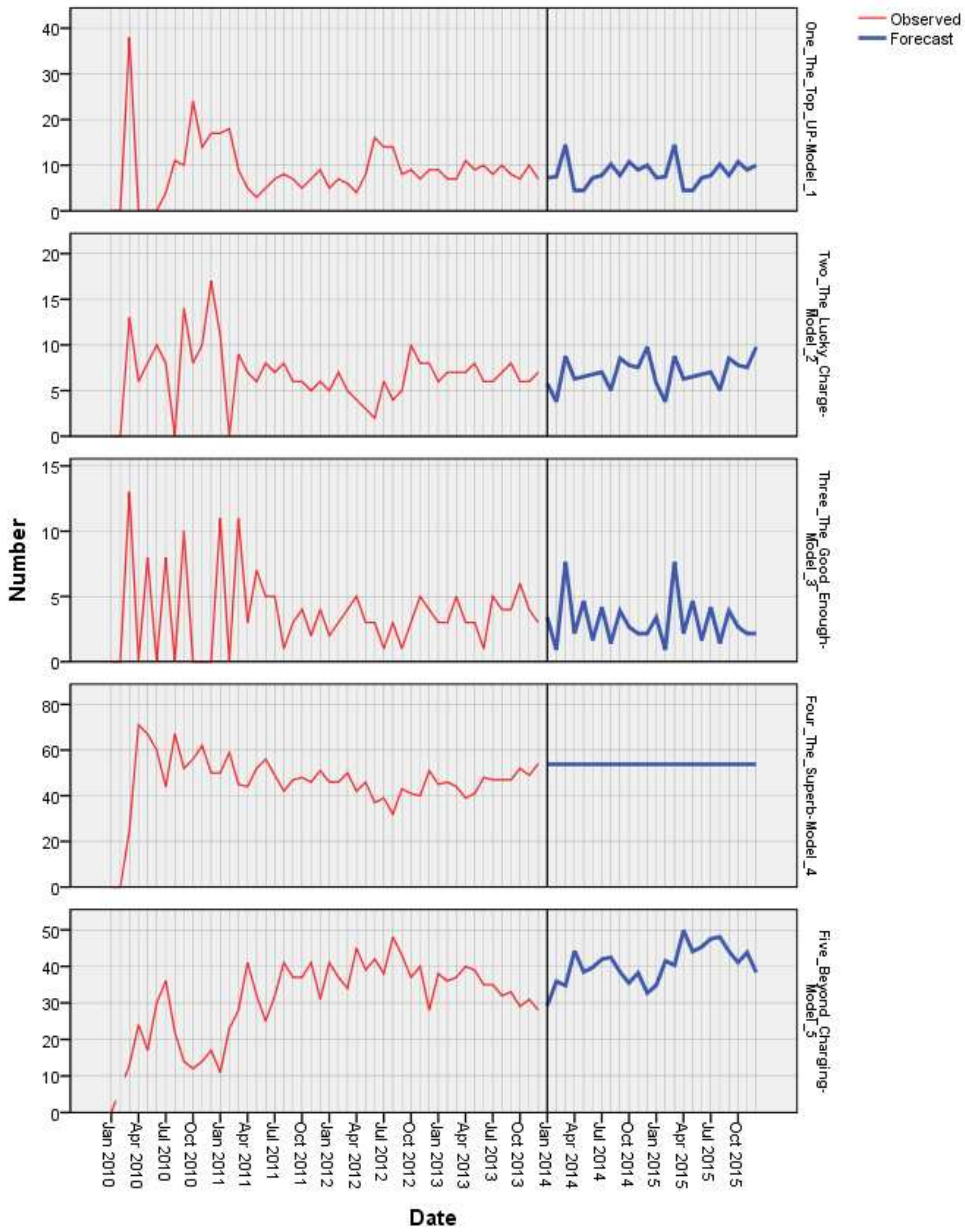


Figure 11-8: Model II: Illustrating the five behavioural charging personas in 2014

11.2 Model Statistics

The descriptive analysis is conducted for the two models providing information and goodness of fit statistics for each estimated model. Initially, see (Tables 11-3 and 11-4), there are no independent variables (predictors) then the model might be exponential smoothing method. The critical value is the Stationary R – squared.

The Model Fit offers an estimate of the proportion of the total variation in the series that is explained by the model, Ordinary R- Squared. Larger values of the stationary R-Squared (up to 1) indicate a better fit. A value of 0.7 - 0.8 more or less means that the model excels in explaining the observed variation in the data series.

Table 11-3: Model fit I: model statistics

Model	Number of predictors	Model Fit statistics	Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	*Statistics*	*DF*	*Sig.*	
Charging at Morning-Model_1	0	.748	8.318	16	.939	0
Charging at AfterNoon-Model_2	0	.009	23.348	17	.138	0
Charging at Evening-Model_3	0	.739	24.753	16	.074	0
Charging at Night-Model_4	0	.784	9.749	16	.879	0

Table 11-4: Model fit II: model statistics

Model	Number of predictors	Model Fit statistics			Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	*R-squared*	*MAPE*	*Statistics*	*DF*	*Sig.*	
Top Up-Model_1	0	.845	.103	44.762	10.524	16	.838	0
The Lucky Charge-Model_2	0	.831	.228	34.053	34.301	16	.005	0
The Good Enough-Model_3	0	.880	.287	57.892	56.765	16	.000	0
The Superb-Model_4	0	-.010	.335	14.611	6.977	17	.984	0
Beyond Charging-Model_5	0	.704	.733	16.561	40.505	15	.000	0

The Ljung-Box statistic, may refer to the modified Box-Pierce statistic, provides an indication of whether the model is correctly specified. A correctly specified model is:

> *"a model that all its variables that affect the response are included. As per Ljung-Box statistic, a significance value less than 0.05 implies a structure in the observed series, which is not accounted for by the model."*

In model I, the values (0.939 is the highest). A value of 0.939 means that the model does an excellent job of explaining the observed variation in the series. This value is not significant, so we can be confident that the model is correctly specified. In model II, the values reached 0.948 which is not signigicant and it ensures that the model is correctly specified.

11.3 Charging Forecasting Discussion

To be able to identify and classify charging profiles helps in understanding the nature of the system. The five charging personas formation is a function of time/behaviour related elements. The peaks and toughs, see (Figure 11-5) showed seasonality with large gaps between the values. The charging pattern is non linear and it is not only affected by the time of the day or the available time that can be spent in charging, but also by the month of the year.

11.3.1 First 22 months of operation years 2010-2011

In the first 22 months of operation, the frequency plot detected that the most frequent time the early adopters used to charge their cars using RFs was in the mornings scoring 50% and more, above average. Only during the summer time, July 2010 and 2011, were there troughs. The cumulative energy in kWh consumed to replenish the cars in the mornings was 5996.463 out of 10546.802 kWh, representing 56% of the total energy spent in the 22 months. The Afternoon shifts were where the most frequent charging events taking place in the July and December Holiday, scoring 3482.416 out of 10546.802 kWh, representing 33% of the total energy spent in the 22 months. This actually reflects the accuracy of the active data due to normal change in driving pattern during the holidays. With respect to the charging profiles, the five profiles were fluctuating; "The Superb" profile was the most dominant profile throughout this period of time, representing 55% and more. The fifth cluster, "Beyond Charging" came second with quite a big 20% difference gap. The first cluster, "The Top Up", was significantly high compared to its occurrence in the following years, yet still it was below 20%. It reached a high percentile during the troughs in "The Superb", where the total kWh consumed to replenish the cars was 3646.278 out of 10546.802 kWh, representing 34% of the total energy spent in year 2012. Overall, this means that the occupation of the RFs was mainly by long charging events (three hours and a half), which were taking place (car parks and especially at the workplace) replenishing a full charge of Nissan LEAF battery. Furthermore, the short insignificant charging events occurrence, indicates the reliance on domestic charging access.

11.3.2 Third year of operation, year 2012

By the early part of the third year of operation, an alternation happened between the morning and the afternoon shifts. The most frequent time started to shift toward the Afternoon. This implies a market penetration. The first year of operation and the morning time charging events indicate the use of workplace CPs more often. This means that users were used to locating the workplace charger available and hence there was no need to wait until the Afternoon. The shift that took place indicates that more users and often more charging events are taking place on a particular RF.

The cumulative energy in kWh consumed to replenish the cars in the mornings was 11,782 out of 20,937 kWh, and in the afternoons it was 6,625 out of 20,937 kWh. With respect to the charging profiles, the long charging events were still scoring the first and second startling occurrence; however, in 2012, both profiles were evenly contributing to the use of RFs, 40% each. This indicates more utilization of the Off Street CPs (ID: #10002 (multiple CPs, Newcastle Civic centre car park, #20007 Eldon Square Shopping mall, #11077 Northumbria University, #20049 and #30055, Quayside car park, #11067 King George VI car park, 30007 and 30008 Old Town Hall in Gateshead, and #20014 Sage Car Park). This indicates that the occupation of the RFs was mainly by long charging events (three hours and a half up until seven hours).

11.3.3 Fourth year of operation, year 2013

By the beginning of the fourth year of operation, the charging patterns seemed to be more settled and fairly distributed among the mornings and the Afternoons with an occurrence of the evenings and night charging events. The more distributed the charging events, the more reliable the infrastructure. The cumulative energy in kWh consumed to replenish the cars in the Mornings was 26,098 out of 46,428 kWh, and in the Afternoons it was 16,247 out of 46,428 kWh. With respect to the charging profiles, the relatively short charging event started to take place. Yet the long charges form the majority. "The Good Enough" formed a stable percentile, 10% of the charging events throughout the year, with a total energy of 6,69 out of 46,428 kWh. This is the second startling occurrence of the short charging events spanning the years of operation with an upward trend. This reflects an expansion, better market penetration, awareness and better use of RFs especially the On Street ones.

11.4 Reflection on the Predictive Model(s)

As per the forecasting analysis, there are some observations about the charging patterns:

i) RFs are expected to be occupied over the Mornings of year 2014, especially in the months of February, March, April and May;

ii) Afternoons have constant representation values that suspect a steady use;

iii) Poor representation of the Evenings and especially the Night patterns. This may indicate that the market is growing and the reliance of the On Street RFs is increasing;

iv) "The Top Up" is not much replicated in the year 2014, this indicates a very low level of awareness; technical awareness and knowledge about the system;

v) The highest two preferences "Beyond Charging" and "The Superb" have startling occurrence, which reflects also more reliance on workplace and in return more attention to be given to accessing charging services at the workplace.

The predictive model can also provide an overview of the expected revenue. Figure 11-9 illustrates an upward trend of the predicted total energy used by the end of year 2014 while a trough during Easter, summer and the December holidays.

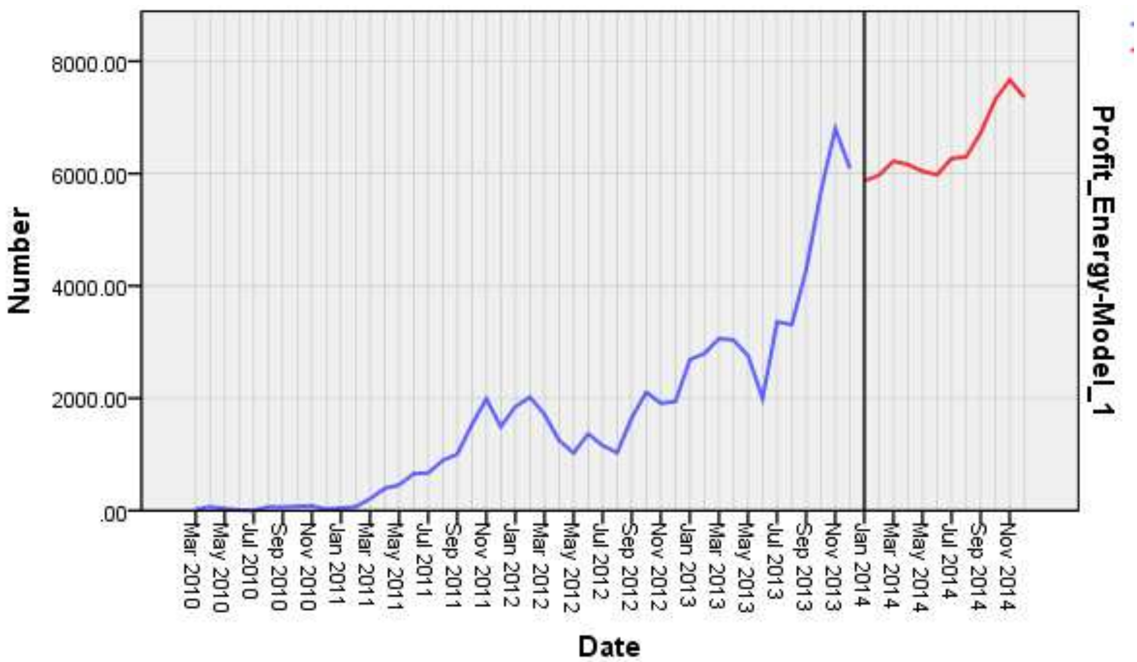


Figure 11-9: Energy/ profit projection in 2014

Part A of this chapter explored the emergent behaviour of the EV users via a Time Series Models, the charging patterns and personas were forecasted. Part B presents the simulation model case study providing as a design assistance tool to assess current e-mobility systems or to be employed to design (forecast the locations of the RFs) for future e-mobility system.

11.5 Messages to Stakeholders (Message I)

To conclude this section, the outcome is to generate an individual profile for each EV user identifying and mapping the pattern and occupation of the used RFs. In addition, forecasting the patterns, which cumulatively (EV population) will provide useful information to planning authorities and policy makers, see (Figure 11-10).

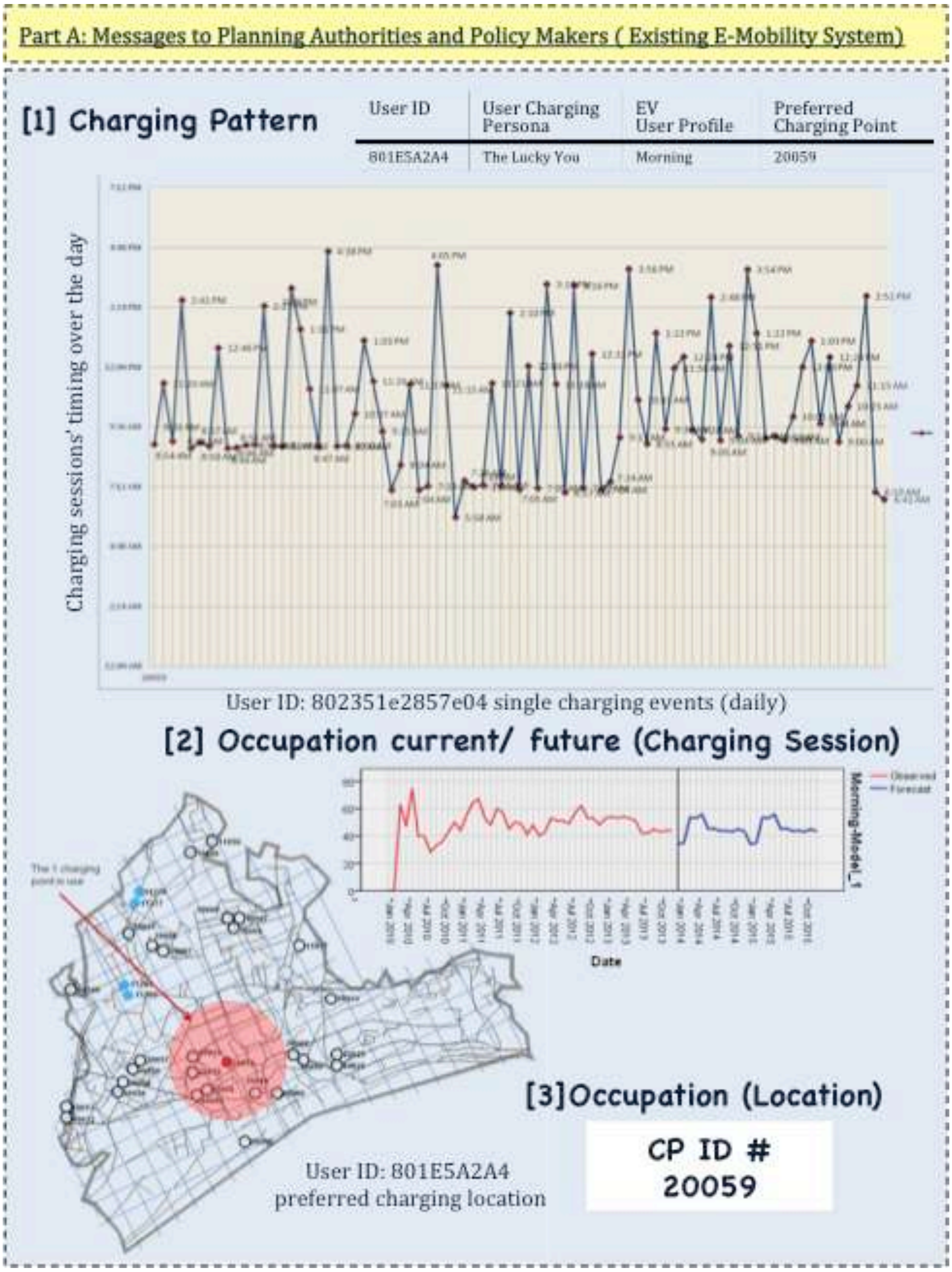


Figure 11-10: Current and forecasted occupation-message to stakeholders

The next section presents the second part of the chapter where the use of simulation model to identify candidate locations of the RFs (assessment and planning purposes).

11.6 Part B: Forecasting RF's Locations

Part B forecasts the candidate locations of the RFs through the research case study employing Anylogic platform. In this section, the usage records are analysed from an end-user perspective. An overview of different levels of analysis is presented. Descriptive analysis is carried out to explore different levels of analysis and investigate which level could be the best indicator to depict individual insights of the charging profiles. This is followed by a case study, which integrates the EV users and presents a simulation model. The case study reports on the use of hybrid modelling and space syntax to simulate selected EV population commuting to and from NE1.

11.6.1 Modelling based on empirical data

After checking CYC dataset, 2012 was considered as the year with the most complete dataset. The year 2011 was the first full year of operation (*the installation started in the mid of 2010*) even though, some points were not yet installed and in 2013, some points were deactivated. Moreover, to avoid seasonality effects likewise Easter, summer, and Christmas vacations, the first half (H1) of 2012 was considered for this analysis.

In H1 of 2012, users (n=97) have used the RFs whereas 20 users only used the charging network once over the six-month period. In addition, some users had records in the first 3 months, and then their IDs did not appear again in the records. There are several suggested reasons for this phenomenon and include:

- Insight I: They sold their EV
- Insight II: They depend only on domestic charge
- Insight III: They have access to private/ employer charging point
- Insight IV: They moved elsewhere or they used other CPs (which are very few) operated by other provider.

This is an example of a low level willingness to use RFs, as they did not return. In this case, those users are excluded from the data set for a better and more accurate interpretation. Moreover, some users joined the system by the second quarter of 2012. If these records are included, this will imply a drop in the first quarter, which is misleading. The drop was not due to the unwillingness to use the RFs, the user at that time was a potential user. Hence, after removing all these cases, (n=18) users were selected; each user has consecutive records among H1 of 2012.

11.6.2 The 18 EV users case study

Prior to running the simulation model, the users data is analysed. Following the user analysis of Chapter 7 (7.10 Part B: End-User Charging Personas), microscale analysis is carried out for the 18 EV users' charging records. The first step is to look at the weekly patterns. The Box and Whisker plot is used to presents the data. It is an exploratory graphic tool that is used to show the visual description of the descriptive data. It displays the variation in the dataset without making any assumptions of the underlying statistical distribution. The degree of dispersion (spread) and skewness in the data and outliers are denoted by the spacing between the different parts of each box.

Charging patterns analysis (monthly)

The first step was to present the six consecutive months starting with January 2012. By plotting the users' charging records, see (Figure 11-11).

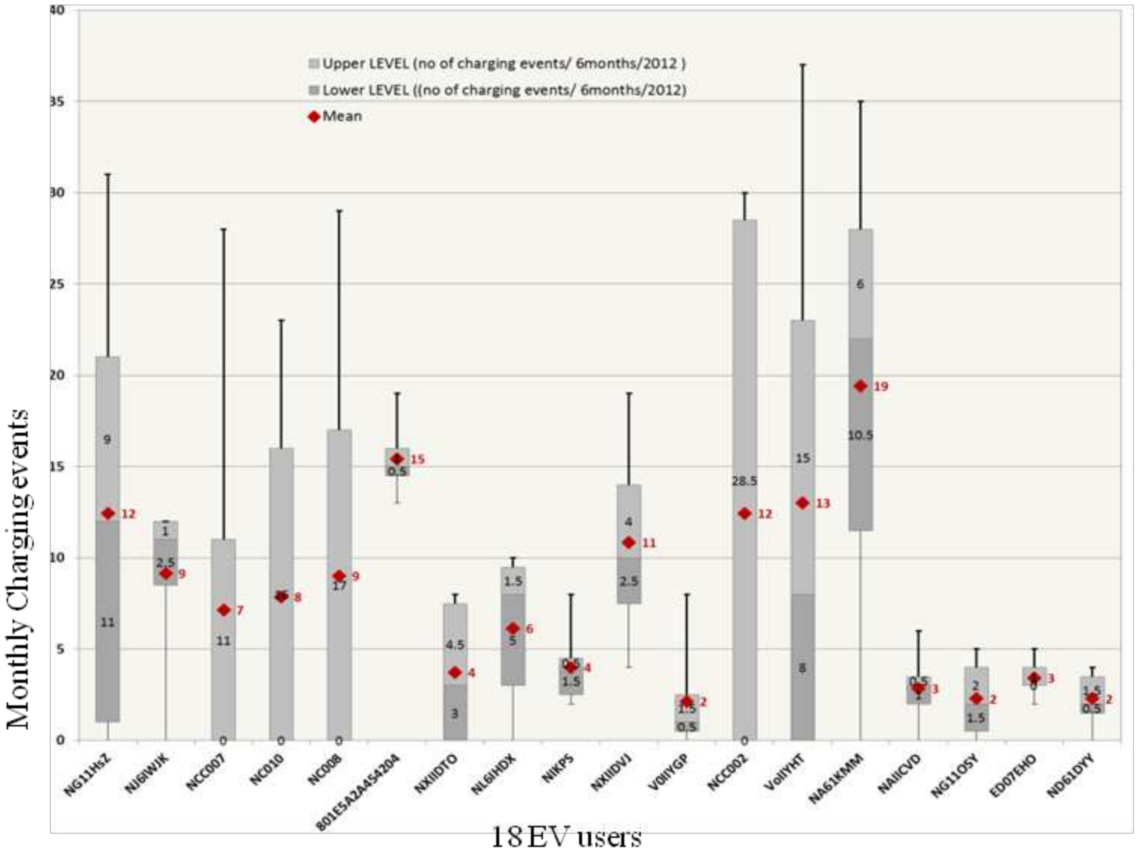


Figure 11-11: 18 EV users monthly charging records_6 months_H1 2012

The monthly charging events provided some insights:

- Insight I: the maximum monthly records done by an individual reached 15 charges per month.
- Insight II: the smallest number was to charge once a month.

This would be useful in the case comparing two sets of data. For instance comparing H1 to H2 to find the maximum and minimum monthly charging events. The total number of transactions for the 18 users was calculated. This was done by taking these records to a higher level of detail and comparing the monthly records of individuals spanning the six months.

Charging patterns analysis (weekly)

The second level is to analyse the weekly patterns of the 18 users. Figure 11-12 displays a box plot the users weekly charge on the X-axis and the records on the Y-axis. Looking into the mean value, the means are approximately the same for many of the users. For example, users IDs # NG11HsZ, NC008, NXIIDVJ, NCC002, and VoIIYGP vary between 11-13 monthly charging events. However, users' records differ in terms of the spread.

- Insight I: The minimum charging events of EV user ID #: NXIIDVJ are seven times and the maximum did not reach 13 times; whereas, EV user ID #: VoIIYHT has spent month(s) with no records at all and in other times the maximum reached 28 times.
- Insight II: This variation in records needs a higher level of detail; the weekly profiles are the next step.
- Insight III: The majority of the users that had around four to five charging events a month, had spent a few week(s) within the same month with no charging records.
- Insight VI: This means if a user has four charging events a month, this does not necessarily mean that they charge their cars using a RF once a week, *once-a-week pattern*.

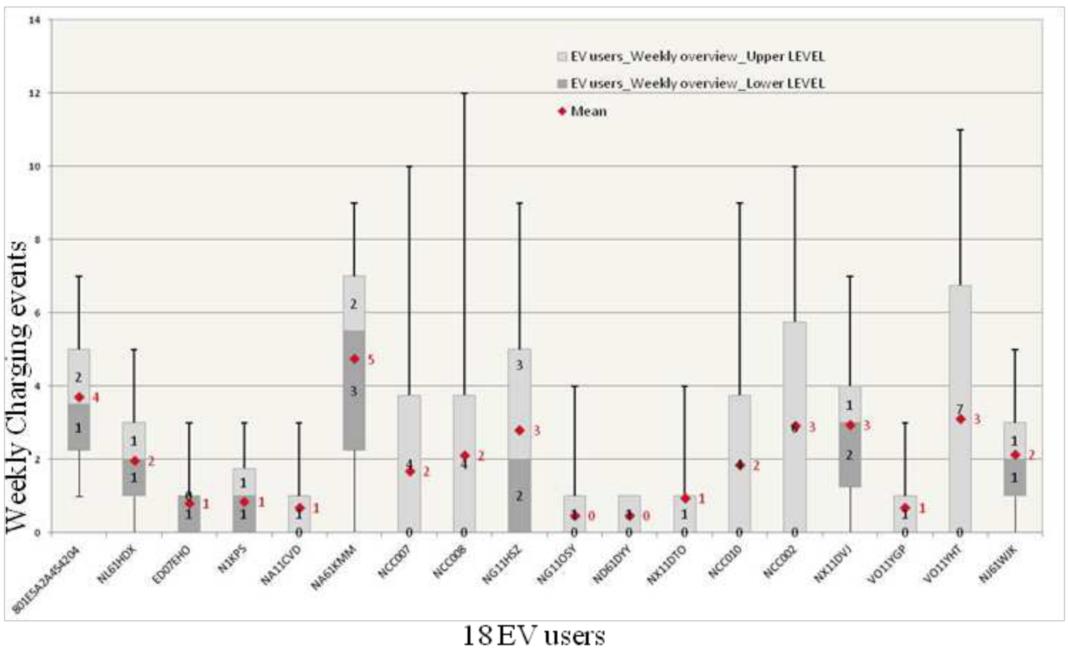


Figure 11-12: 18 EV users weekly charging records_30 weeks_H1 2012

Contrary, the maximum records may be misleading. EV user ID # NA61KMM seemed to charge up to 9 chargers a week in some week(s), which pushes the average to 5 charging events a week, see (Figure 11-13). However, a week-by-week basis analysis showed that this was an exceptional record that happened only twice in 30 consecutive weeks. Such analysis indicates the non-linear charging profiles and patterns of an EV user.

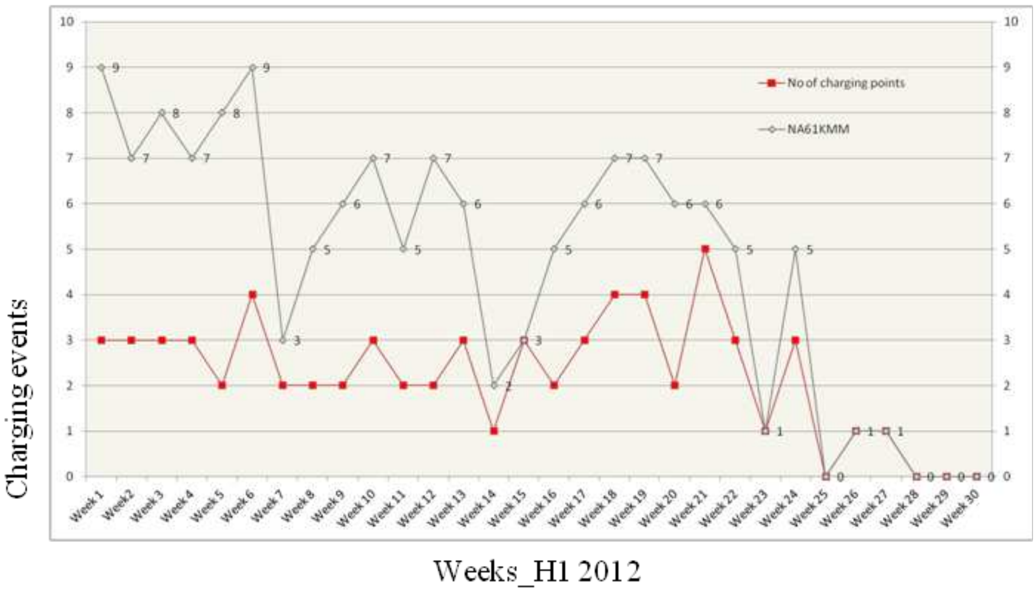


Figure 11-13: Individual charging profile user ID NA61KMM

The weekly overview can show the occurrence of different charging patterns over H1. Another example is user ID # EDO7EHO used the publicly available CPs spanning the H1 of 2012, see (Figure 11-14). In some weeks the user did not use the CPs for the entire week (happened 14 weeks). This means that 47% of the time, the user did not rely on the RFs. In nine weeks out of the 30, the user charged only once a week, which means 30% of the time they merely rely on non-domestic charging.

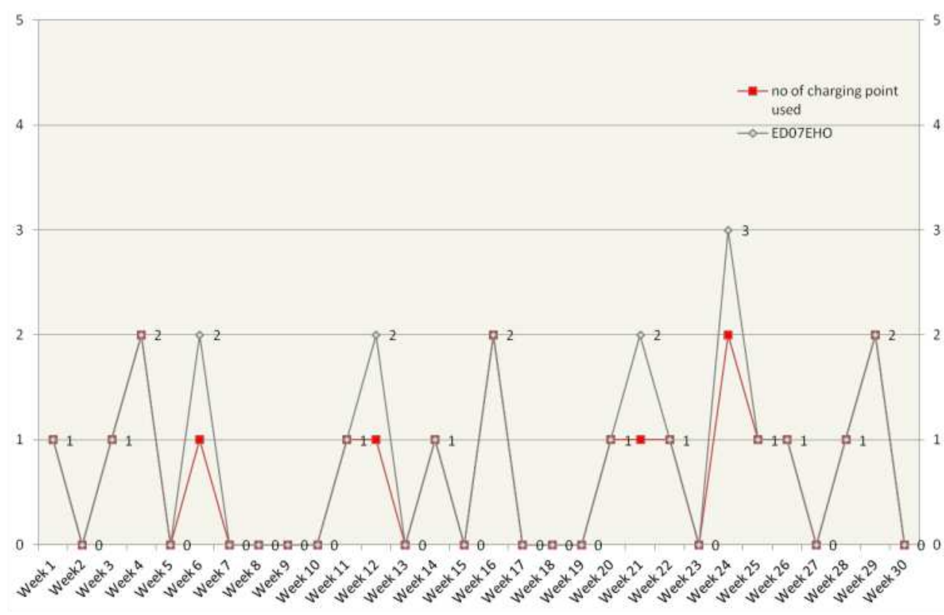


Figure 11-14: Individual charging profile user ID ED07EH0

11.7 The Non-Linearity of an Individual Charging Pattern

It is possible to estimate the EV users charging patterns in terms of the time they usually charge, the time they spent charging and their charging preference (*the CPs they use*). However, it is difficult to depict a weekly pattern or a monthly profile without analysing the data on a weekly basis. Charging profiles of individuals have a tendency to take extreme patterns when it comes to the use of RFs.

- Insight I: An EV user may charge up to seven charges a week using On-Street RFs, while the other three consecutive weeks, charges at home.

If the data is available, a microscale level of analysis explains the user's confidence level, technology acceptance, comfort zone boundaries, and charging behaviour (Morton et al., 2011). A weekly overview can show the occurrence of different charging patterns over H1. There were 540 charging choices in total (*the total number of daily charging events in 30 weeks*):

- 244 charging choices were made not to charge at all (45%);
- 81 charging choices were made to charge once a week (15%);
- 54 charging choices were made to charge twice a week (10%);
- 38 charging choices were made not charge 3 times a week (7%);
- 37 charging choices were made not charge 4 times a week (7%);
- 24 charging choices were made not charge 6 times a week (4%);
- 62 charging choices were made not charge more than 6 times a week (11%).

11.8 Simulation Input Data

Simulation input data is based on CYC users' real information and their usage (CYC, 2014). The roads' hierarchy displayed in the urban layer is as explained in Chapter 4. The population is the (n=18) inhabitants IDs are: NG11HsZ, NJ6IWJK, NCC007, NC010, NC008, 801E5A2A454204, NXIIDTO, NL6IHDX, NIKPS, NXIIDVJ, V0IIYGP, NCC002, VoIIYHT, NA61KMM, NAIICVD, NG11OSY, ED07EHO, and ND61DYY, see (Tables 11-5 and 11-6).

Week (4) in year 2012 is simulated. This week was selected as it showed the highest records of transactions made and the highest number of CPs. Those drivers commute on a regular basis to NE1 and they charge their car at least once a week, see (Figure 11-15), (considering the seasonality effect, Easter and summer vacations) on the charging patterns.

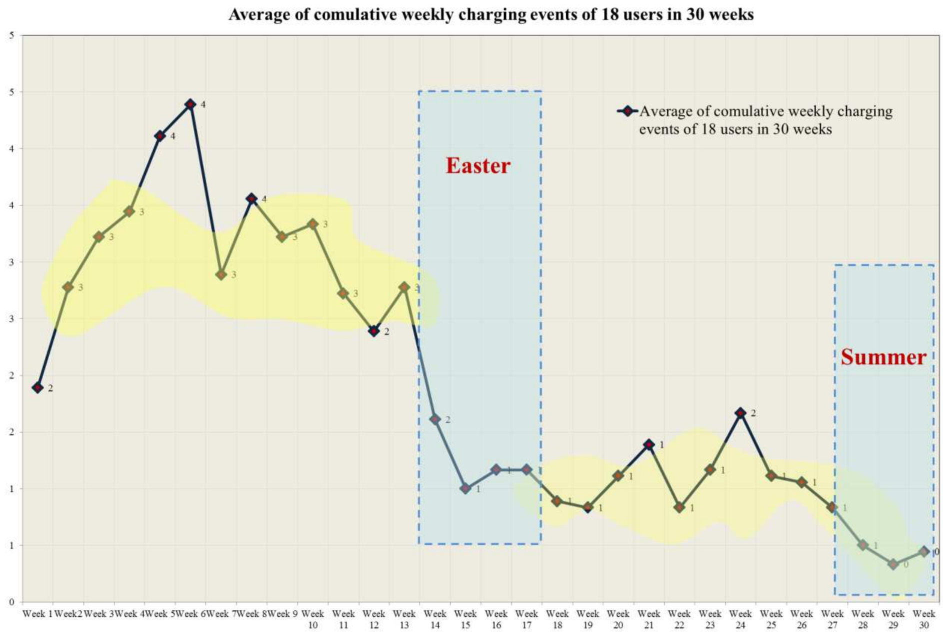


Figure 11-15: Average of cumulative weekly charging events of the 18 users

Table 11-5: Actual charging records of the first 9 users (week 4_2012)

H1 2012 Week (4)	Users 801E5 A2A4	NL61 HDX	ED07 EHO	NIK PS	NA11 CVD	NA61K MM	NCC0 07	NCC0 08	NG11 HSZ
No. Charging Events (Transactions)	6	1	2	2	1	7	4	7	4
No. of Charging Points	1	1	2	2	1	3	1	2	1

Table 11-6: Actual charging records of the second 9 users (week 4_2012)

H1 2012 Week (4)	Users NG11 OSY	ND6I DYY	NXII DTO	NCC0 10	NCC00 2	NA61K MM	NXqq DVJ	VO11Y HT	NJ61W JK
No. Charging Events (Transactions)	1	1	3	1	9	4	1	7	2
No. of Charging Points	1	1	1	1	1	2	1	2	2

11.8.1 Spatial measures- segmental map

To apply the desired syntactic measures, the study area was drawn into a road-centre lines map and a segment map, producing 400 road-segments, see Chapter 4.6.1 Vehicular Movement Prediction, Figure 4-22). Spatial configurational modelling has been applied to the area of study. From a behavioural point of view, this assumption postulates that the number of directional changes on a route, is the primary consideration in path choice, even more so than metric distance and thus it is expected that trip makers prefer routes that involve less turns along the way, rather than shortest routes (Hillier et al., 2007). Some syntactic measures have been calculated using DepthMap software.

For example, and with respect to the NE1 inner core, Westgate road, and Collingwood streets are the most accessible arteries with high values of Connectivity, refer to (Chapter 4 4.5.3 Depth and Connectivity, Figure 4-19).

Figure 11-16 shows the urban spaces and plots of the selected area (59 spaces). The selected area is well studied in Depthmap to get the necessary syntactic measures needed for the purpose of the study. The following step was to convert the segment map (100 segments) into a simple form of network in order to simulate the system, *collective segments*.

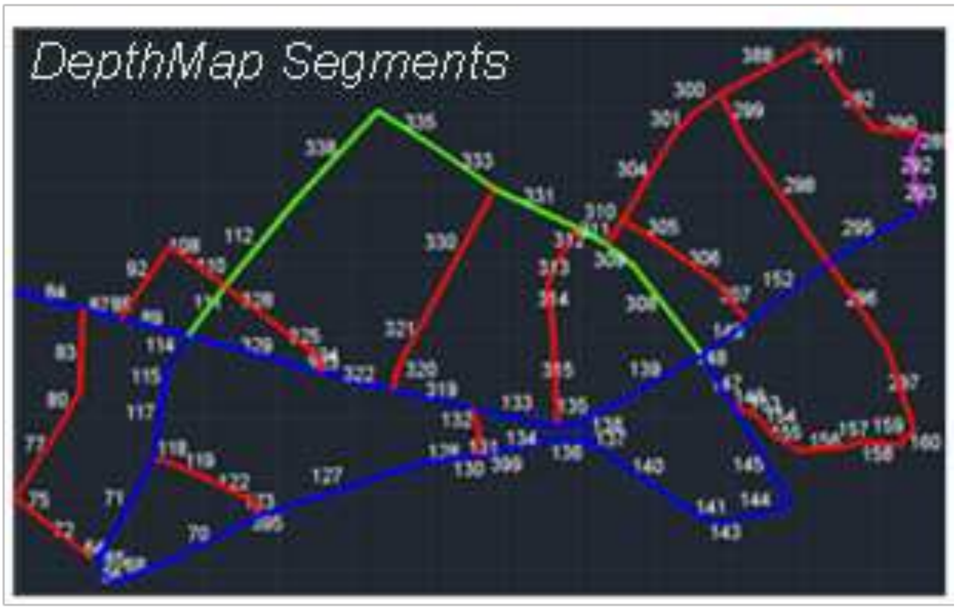


Figure 11-16: DepthMap and AutoCAD_study area

For example, segments spaces Syntax ID (127, 128, and 130) are denoted as AutoCAD ID#11, (Figure 11-15). This process happens to the segments, which do not have any intersection point between them. As segments that have intersection points in between, cannot be merged. The table also shows the average values associated with each segment: connectivity integration, and angular depth. For validation purpose, real traffic information about some major arteries is displayed; traffic counts. The last column shows the road hierarchy which was earlier explained by the speed associated.

From drawings, it can be observed that the area simulated in Anylogic is focusing on the eight main roads of the inner urban core: *Westgate Road, Mosley Road, Akanside Street, Melbourne Road, City Road, A167, NewBridge Street* and *Neville Road*. It is worth noting that the case study boundary was selected with consideration of the CPs. The boundary does not include two (overused) Off Street points, *Civic Centre and Eldon Square, the comfy cluster*. This is to avoid misleading interpretation of the model outcomes or biased results when validation takes place, later this chapter.

11.8.2 Case study simulation main features

This model follows the first simulation paragon: Critical Battery Zone Plotter (CBZ). Commuters go through the road network in a nondeterministic manner consuming the battery and originating from a point and reaching random destinations until the battery dies. The few numbers of CPs located in the selected areas have been removed from the modelling so as to run the model while not considering any point of On and Off street CPs (*There are actual 12 RFs located within the case study boundary)*.

The model depends only on domestic charging and simulate a daily trip of EV driver; a scenario, see (Figure 11-17).

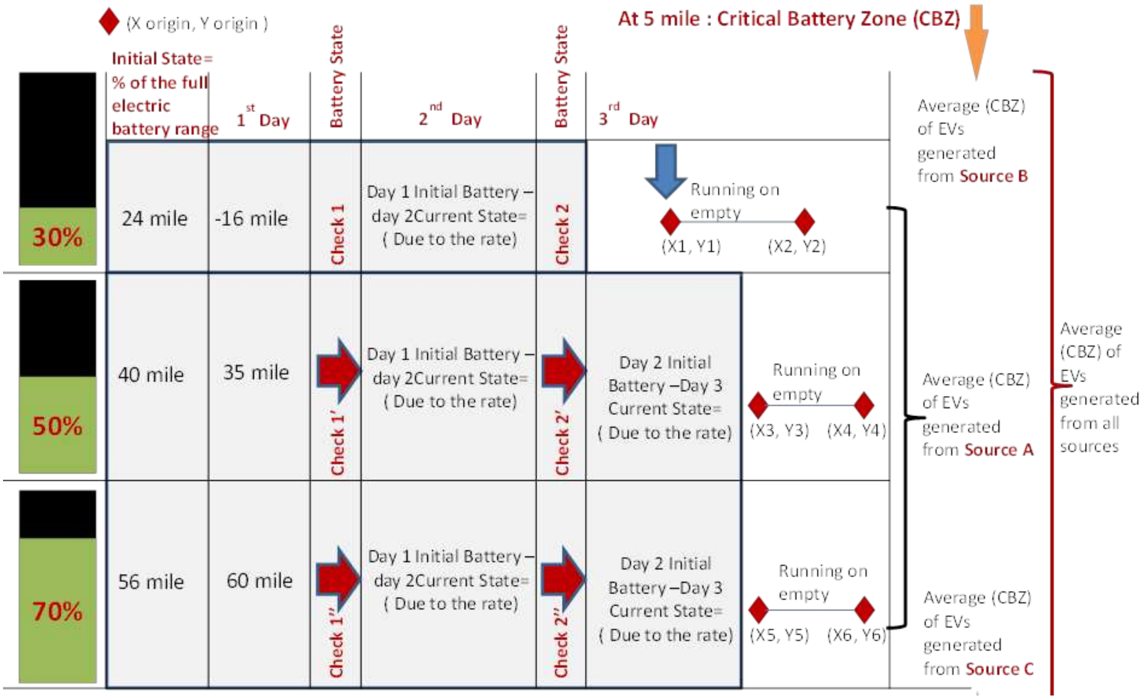


Figure 11-17: Scenarios of EV agents' state of charge

It works at determining the *behaviour layer* of the EVs' drivers when the *critical battery zone* is approached and the driver starts running on almost an empty battery. Several runs are conducted and the number of the stopped cars and the locations of them to be plotted.

All entities (cars) are all originated from different points beyond the checkpoint (1) as every trip maker lives/ coming different district/ ward. Checkpoint (1), is located on the border of the study area at a certain point on Westgate road. The route choice is based on the configurational analysis. The simulation time started on Monday until Thursday with an average of 10 miles a day, applying the flat consumption rate of Nissan LEAF in downtown driving mode, see (Table 11-7).

Table 11-7 : Consumption rate based on Nissan LEAF

Time	Percentage of consumption
One Hour	24%
One Minute	0.40%
Consumption	Time
1% can be consumed in	2.55 mins

Flat battery counter

The model counts for the number of all generated cars and the number of stopped cars (*Critical Battery Zone-CBZ*), see (Figure 11-18). Non-deterministically, the cars will move in the network; CBZ starts once the car state of charge is enough to commute five miles. The model counts for the number of all generated cars and the number of stopped cars (*Critical Battery Zone*). Via an added counter, the number of stopped cars every iteration is calculated and tabulated in the generated summary report.

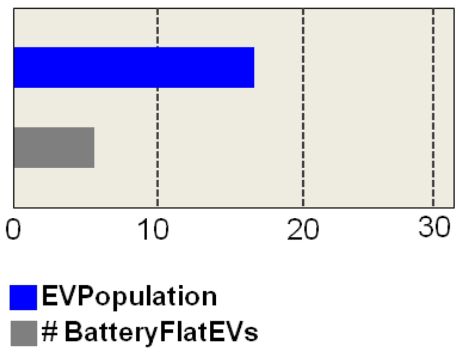


Figure 11-18: Flat battery EV users counter

The model counts the number of stopped vehicles in a chart. Once the vehicle turns into red this means it is in a critical battery state and has to be charged as soon as possible. With the assigned rate, if the vehicle is not charged by that time, it will turn into grey, which means flat battery. The model counts how many numbers turn into grey yet not calculating where they stopped in the road network.

The ABM and DE integrated model

The platform is a Java code based program hence all of the commands are executed whether by adding the class scripts or editing the entities and agents' tabs and statecharts. Figure 11-19 shows the elements of the simulation main environment class.

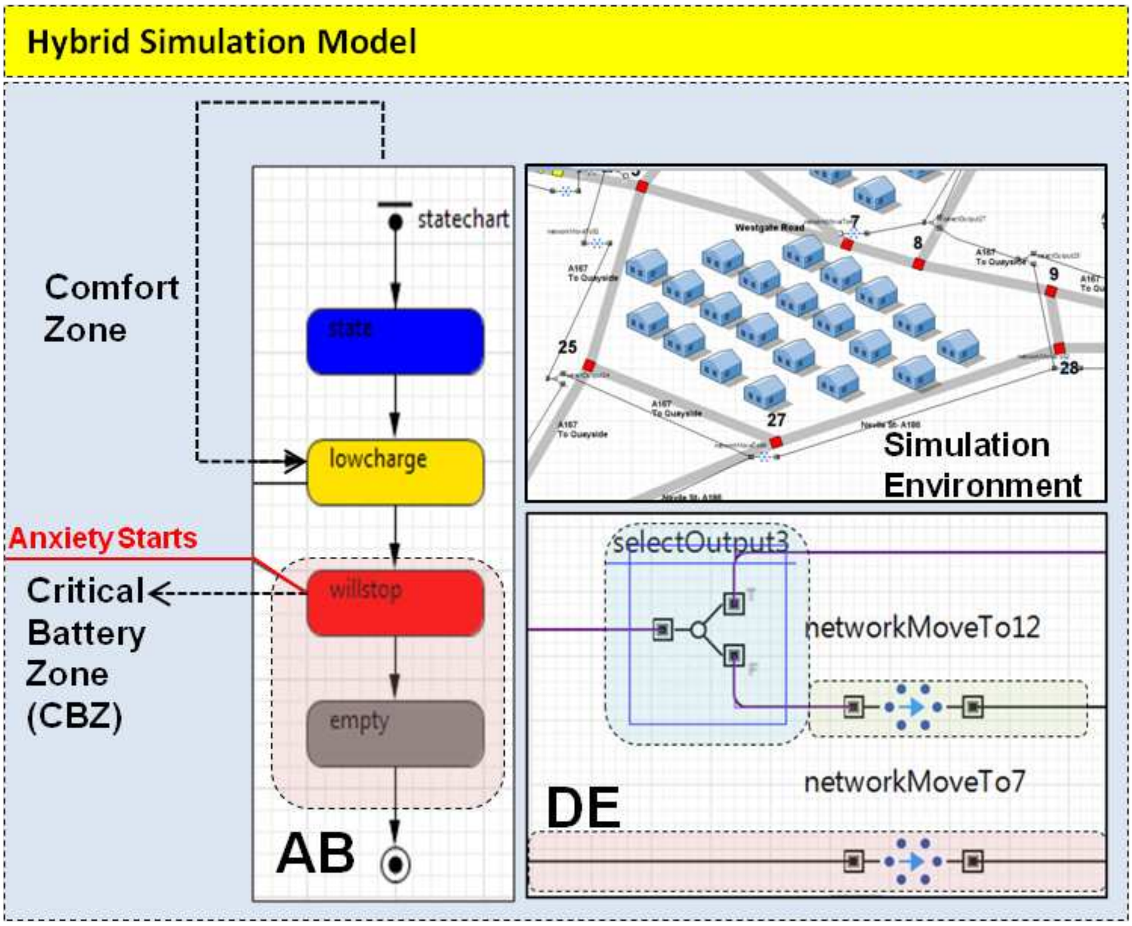


Figure 11-19: ABM and DE hybrid model illustration

11.9 Outcomes

Several runs have been conducted and the number of the stopped cars and the locations of them have been plotted, CBZs. As per this algorithms explained in Chapter 9, CBZs where plotted. An average of 8 cars reaches a flat battery state, which makes them stop and turn into a grey colour. The cut off day (second day, third day, fourth day) was different each iteration, the average of three iterations was calculated to see where the CBZ normally appears. The average occurrence of CBZ happened to be in the highlighted areas, see (Figure 11-20).

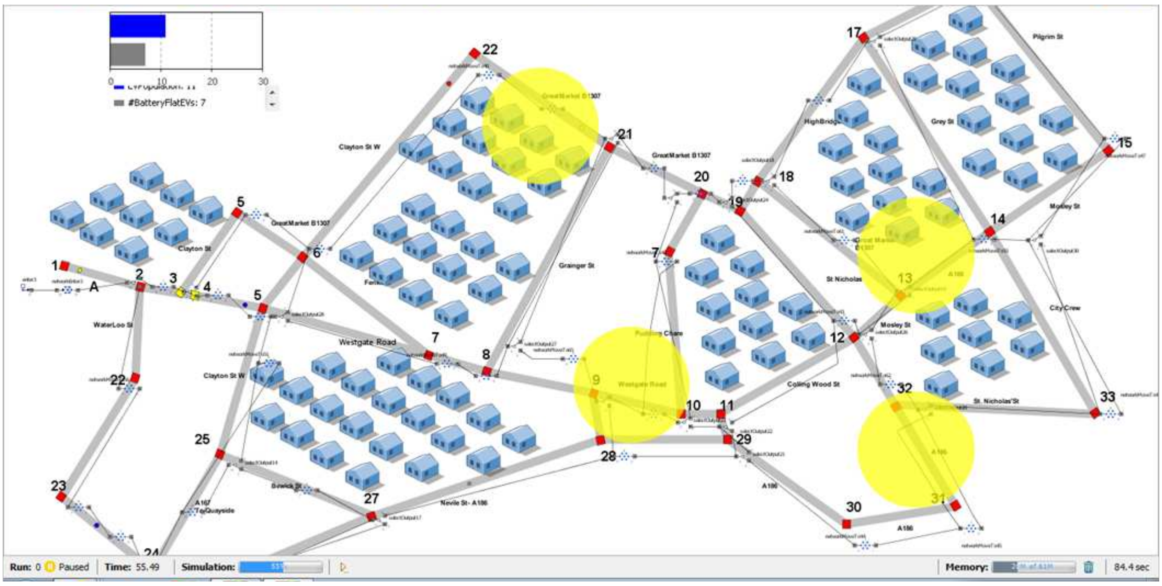


Figure 11-20: Print screen of AnyLogic generated model

11.10 Model Validation: The Complementing Sides of E-mobility

With an ultimate goal of producing an accurate and credible model, validation takes place. Planning authorities and policy makers and whoever concerned with the assessing, analysing and designing of e-mobility system would be rightly concerned with whether the model and its results are correct. The higher the correlation is between the real time and the simulation model, the more accurate and reliable are the results. The main aim is to replicate the method to new urban context. Hence, this model has to be validated.

The validation process contained two procedures:

- Procedure I: EV empirical data check: comparing the outcomes with the usage records of the existing charging network.

- Procedure II: CYC utility management check: proposing the overall methodological approach (the whole process) to the utility management company, CYC.

As for procedure I, the spotted zones (made by the simulation model) were compared to the actual urban data through four checks, see (Figure 11-21):

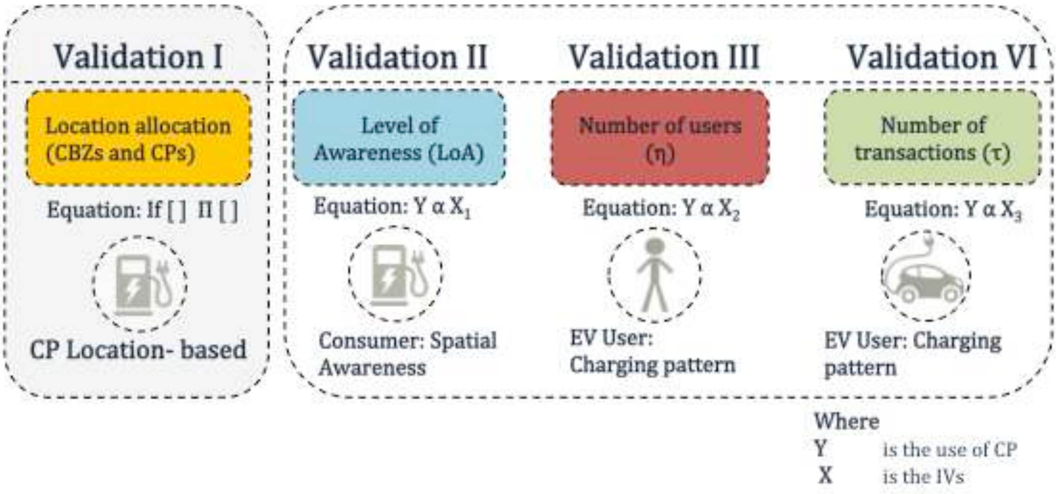


Figure 11-21: Model validation process diagram

11.10.1 Validation I: location allocation (spotted zones and CPs)

The first check was to compare the CBZs with the exact locations of the CPs. This was done by mathematically calculating the coordinates of the CBZ's and the CPs. Figure 11-22 demonstrates the way of calculation.

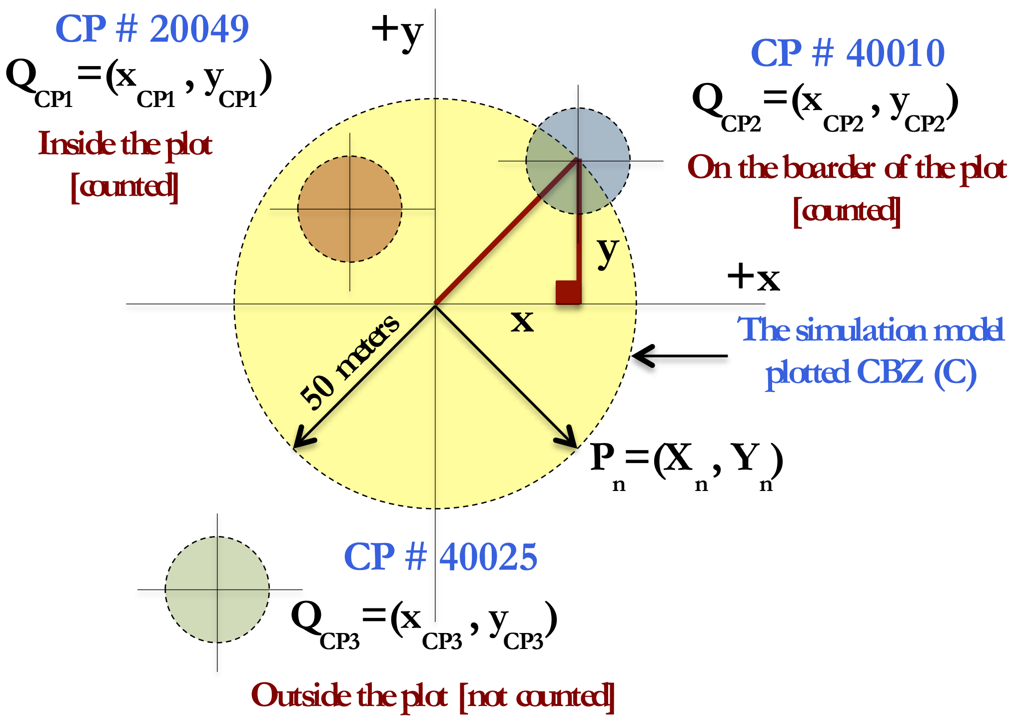
The overlap between CBZ and CP equation follows the null set (empty set) condition. Point Q and Point P should not satisfy the following equation where:

Equation 11-1:The null set condition

$$\textit{The overlap between CBZ and CP } P \cap Q \neq \{\,\} = \emptyset$$

Where
P_m is any point on the circle (CBZ)
Q is the exact coordinates of the actual CP
CP n is Charging Point Number (ID)

This means that if the point Q is intersected with P point, point Q (coordinates of an existing CP) is selected for further analysis. For example, Q_{CP1} and Q_{CP2} in (Figure 11-22), denote CP ID #20049 and 40010. These two CPs intersect with CBZ (C). Whereas, Q_{CP3} which is CP ID #40025, does not satisfy (Equation 11-1). By Euclidean distance, this validation can be achieved as per Equation 11-1.



Where

P_m is any point on the circle (CBZ)

Q is the exact coordinates of the actual CP

CP n is Charging Point Number (ID)

Figure 11-22: The mathematical way of calculating the overlap

Equation 11-2: Location allocation CBZ and exact CPs

$$CP\ Candidate\ Location\ (\ confirmed) = Q(Xcpn, Ycpn) \leq\ P(Xm, Ym)$$

The study area boundary alongside the four spotted CBZs were plotted on NE1 map with the actual location of the CPs. There are 12 RFs fall under the boundary; the other RFs are there for reference. The overlapping indicates the four CBZs in relation to the surrounding eight RFs. The spot diameter is 100 meters as it indicates a zone rather than an exact location. As per Figure 11-23, the CPs IDs: #40010, #40018, #20049, #30050, #30055, #30060, #40004, #40005, #20059, and #20046 are the ones deemed related to the CBZs hence they will be analysed for the validation purposes.

The second, third and fourth validation checks are to compare the spotted zones to charging pattern variables. The second check was to compare the CBZs with the LoA of the nearby 10 CPs. These CPs are distributed into seven RFs, see (Figure 11-23).

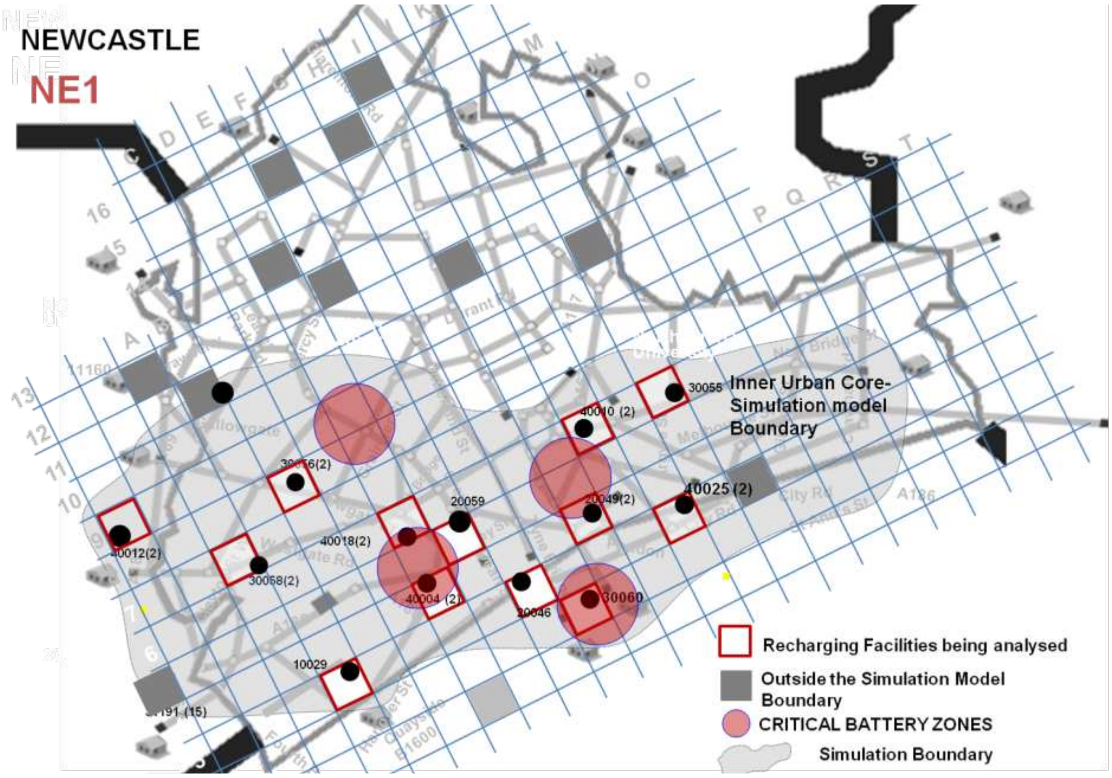


Figure 11-23: Actual CPs_NE1

11.10.2 Validation II: level of awareness (LoA)

The LOA values are mapped in Figure 11-24 having two high values at Northumbria University sit and Grey Street CPs and listed in Table 11-8. As the LoA has proven to be the main predictor of clustering the RFs (statistically modelled in Chapter 10), LoA values are used for validation. It the BCZ was plotted in an area that has or close to a CP, and it happens that this CP has a high LoA value, this zone is validated by the first check. This would imply that the model spotted the area were many EVs tend to stop for charging where there is X CP with high.

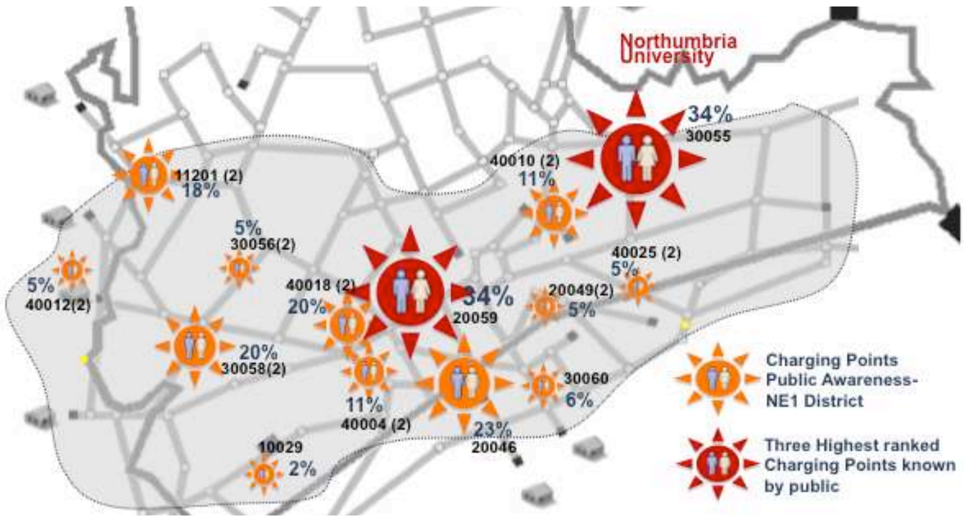


Figure 11-24: Level of Awareness (LoA)

Table 11-8: First Check-Level of Awareness

NE1-inner urban core	**On Street**	Level of Awareness	**Off Street**	Level of Awareness
No change:	Site 3: CP # 40004	11	Site 7: CP # 20049	5
Improvement	Site 3: CP # 40005	11	Site 7: CP # 30050	5
	Site 4: CP # 30060	6	Site 8: CP # 30055*	34
	Site 5: CP # 40010	11		
	Site 5: CP # 40018	11		
	Site 6: CP # 20046	23		
	Site 6: CP # 20059	34		

Table 11-8: Exceptionally, CP 30055 PA is high as it is located in Northumbria University, City Campus East and many of the potential users recognised it.

The validation process aims at investigating the locations of the CBZs in the real network. Match these zones with the urban layer incorporating the actual location of the CPs. A validated model would be a model with indicative CBZs. Each zone identifies a gap in the charging network. If this zone happens to overlap an existing utilised CP, then this model is capable to identify hotspots for charging facilities. On the other hand, if the zone does not overlap with actual CP in the network, then an activation call might be sent to the planning authorities and policy makers to install an extra CP in such zone.

11.10.3 Validation III: number of users (η)

The second and third validation checks are the number of users and number of transactions. These two checks work in line as both values complement each other. If the CBZ overlaps with a CP with a high number of users or number of transactions, it would be considered as a validated zone. It is worth mentioning that any variable that incorporates time is not used for validation as the simulation model is concerned with the frequency of use not the time spent, or arrival time or the total energy used. Accordingly, the total number of users in 2012 was calculated to each of the 12 RFs, see (Figure 11-25).

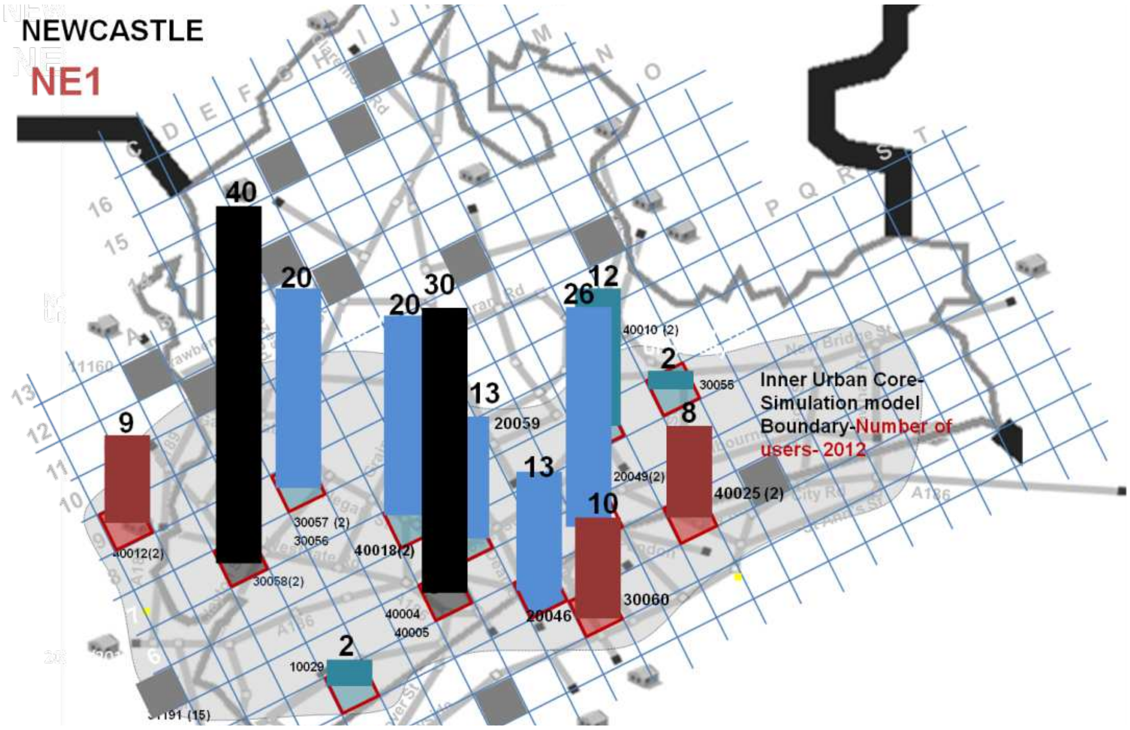


Figure 11-25: Number of users-12 RFs_NE1

11.10.4 Validation IV: number of transactions (τ)

In terms of occupation, CPs #30058, #40004, #40005 and #20049 had the highest scores of the total number of the charging events (τ), see (Figure 11-26).

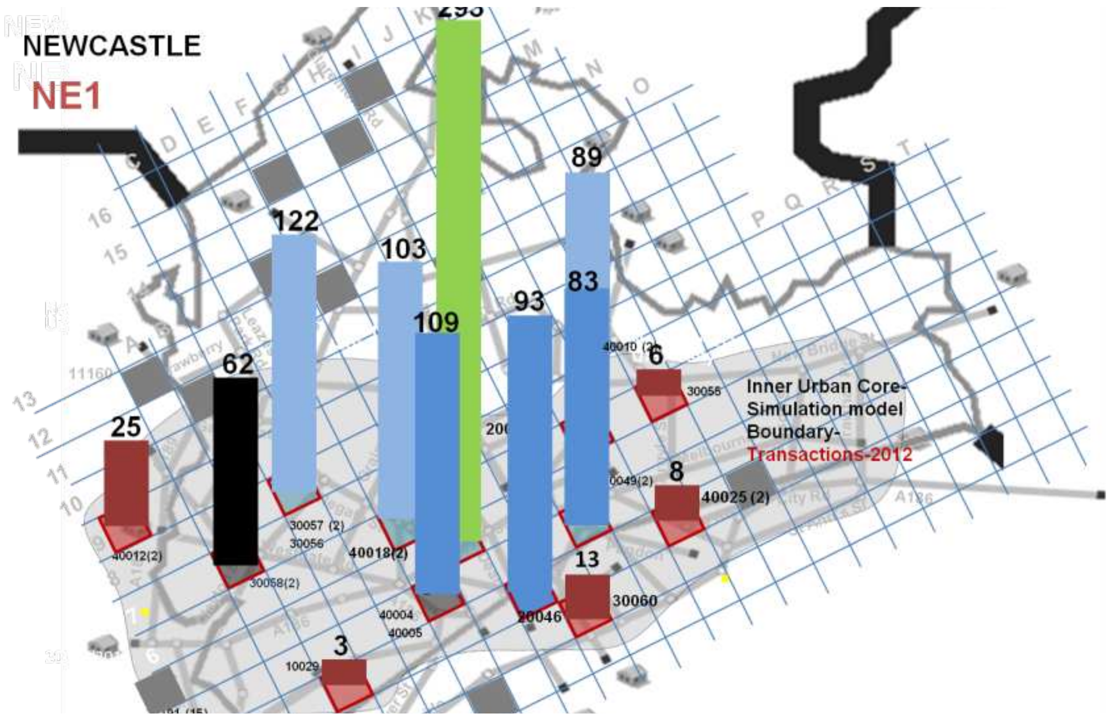


Figure 11-26: Number of users-12 RFs_NE1- CPs #20059, 20046, 20049, 30050, 30056, 30057, 40018, and 40010 had high **τ**

The fourth check is to match the CPs of the spotted CBZ with the cluster profiles generated from the empirical analysis, chapter 7, see (Figure 11-27).

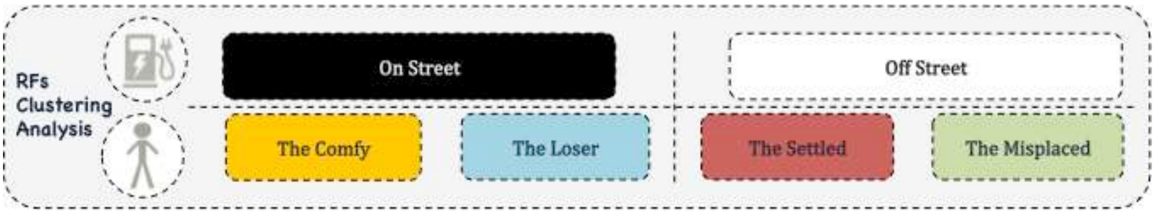


Figure 11-27:E-mobility RF's clusters

The validation was successful as the four checks implied that the CBZ plotted by the model indicate a need of RF in these areas. Out of the 12 RFs, five sites need actions. Table 11-9 shows the CPs with the four checks highlighting in yellow the CPs that need further action.

Table 11-9: Validation matrix

CP	Number of users	Transactions	LoA	Clusters
40010, 40018	**12**	**89**	**11**	***The Comfy***
20049, 30050	**20**	**83**	**5**	***The settled***
30060	10	13	6	*The Comfy*
40004, 40005	**30**	**109**	**11**	***The Comfy***
20059	**13**	**394**	**34**	***The Comfy***
20046	**13**	**93**	**23**	***The Comfy***
30060	10	13	6	*The Comfy*
30055	2	6	34	*The settled*

The model outcome and validation are included in the model proposed generated report to stakeholder, see (Figure 11-27).

11.11 Messages to Stakeholders-Message II

The simulation outcome is summarised in a form of a report, (Figure 11-28), (Table 11-10) and (Table 11-11).

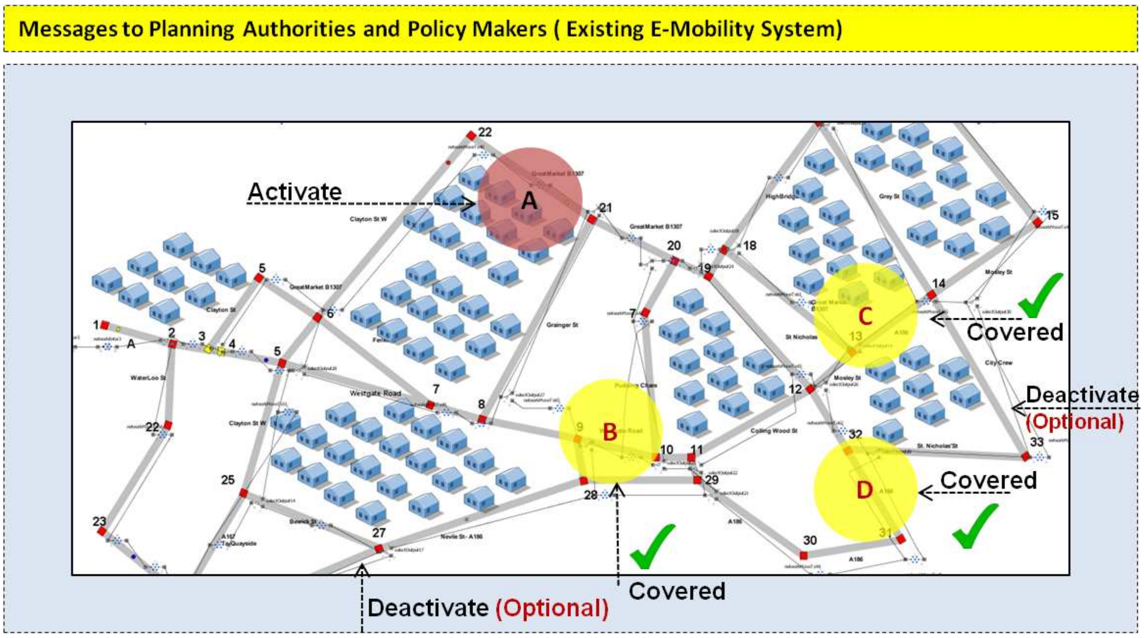


Figure 11-28: Model outcome-activate and deactivate zones visualisation

Table 11-10: Actions to be taken by local authorities (CP owner)

NE1-inner urban core	On Street	Off Street
Activate	**Newgate Street**	N/A
Deactivate	Site 1: CP # 10029 Site 2:CP # 40025* Site 2: CP # 40026*	N/A
No change: Improvement	Site 3: CP# 40004 Site 3: CP #40005 Site 4: CP # 40010 Site 4: CP # 40018 Site 5: CP # 20046 Site 6: CP # 20059	Site 7: CP# 20049 Site 7: CP #30050

As per the spatiotemporal analysis carried out, the activate and deactivate call goes inline with the clustering analysis recommendations, see (Table 11-11).

Table 11-11: Integrating clustering analysis

NE1-inner	On Street	Off Street
Deactivate	Site 1: CP # 10029 *(The Loser)* Site 2:CP # 40025, 10026 *(The Loser)**	
No change: Improvement	Site 3: CP # 40004, 40005 *(The Comfy)* Site 4: CP # 40010, 40018 *(The Comfy)* Site 5: CP # 20046 *(The Comfy)* Site 6: CP # 20059 *(The Comfy)*	Site 7: CP# 20049 *(The Settled)* Site 7: CP #30050 *(The Settled)*

*Table 11-11 *From an optimistic standpoint, 40025 and 20026have other factors that affect their usage. These CPs can kept as long there is no burden as the CBZ was plotted relatively near to them. This argument is supported by the fact that users stop to charge around this RF; however, they do not use this RF.*

11.12 Concluding Remarks

This chapter overarched the various analyses that were carried out throughout the thesis. It addresses one of the most important research questions:

> *RQ5: For planning purposes, how could stakeholders forecast the charging behaviour and locations for a better e-mobility diffusion?*

In part A, a Time Series model was developed integrating users charging personas (UCP) and occupation values of the RFs in order to forecast the charging patterns of the users, see (figure 11-29). Based on the existing e-mobility charging-related measures, the model was capable of forecasting the charging patterns and the timings within which the RFs and the nearby road corridors will be occupied/ congested.

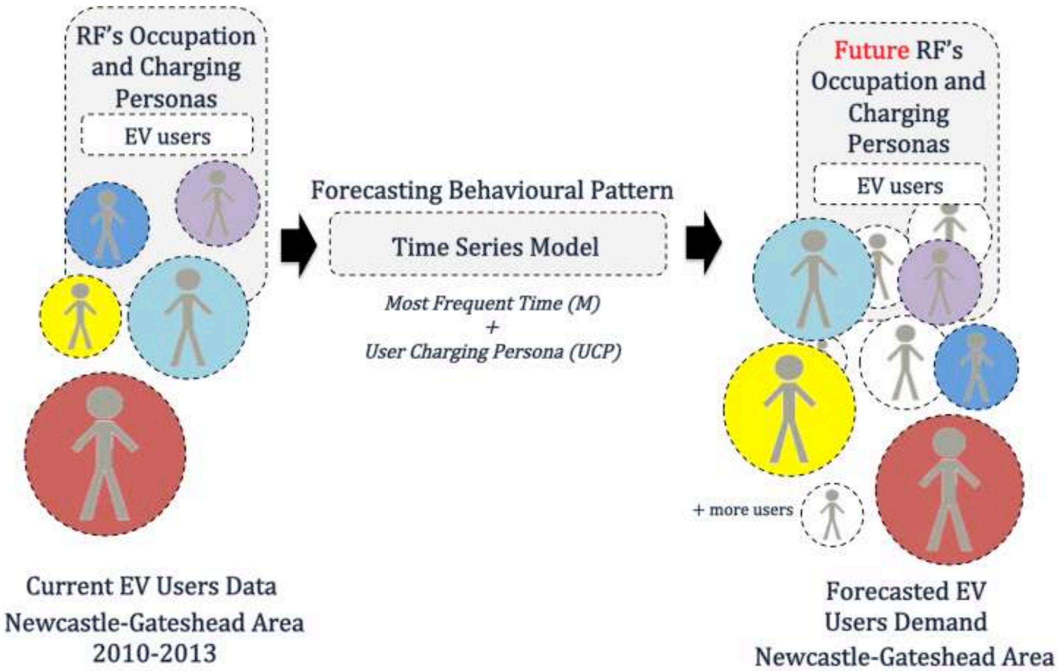


Figure 11-29: Chapter 11 Part A: the RF's occupation and charging persona forecasting diagram

Moreover, it highlighted further application of creating an individual charging datasheet of EV users. This template, see (Figure 11-10) displays the user's charging pattern, charging sessions and preferred charging locations. With more EVs in the network and by the time the EV is at the mainstream level, such information would be viable for urban planners and traffic management and monitoring authorities. The anticipated impact on the grid and the road network would require an enhanced and live updated monitoring system that incorporate users' charging sessions, routes and timings.

Part B presented the final outcome of this thesis by deploying the selected simulation technique integrating spatial configurational modelling to simulate 18 EV users of Newcastle-Gateshead area, see (Figure 11-30). Real information about users was used to validate the model for future replications.

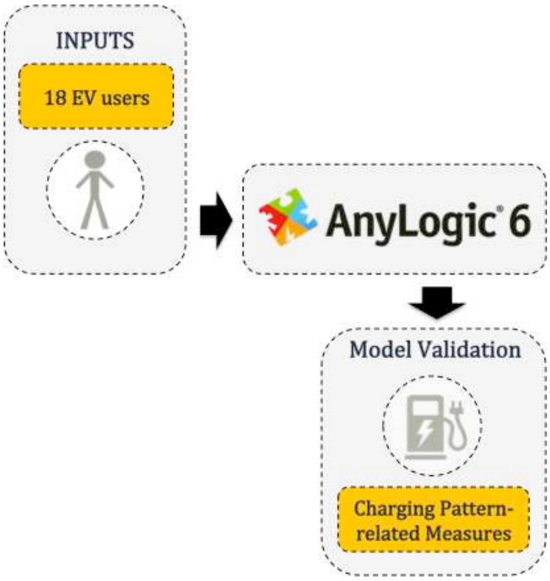


Figure 11-30: Chapter 11 Part B: simulation model with the empirical data of EV users

The next chapter presents the conclusion and future research.

CHAPTER 12. CONCLUSION AND FUTURE RESEARCH

" It's not going to be zero emissions in certain conditions. It's going to be zero emissions."

By Carlos Ghosn, Chief Executive of Renault-Nissan (2015)

This thesis presents an interdisciplinary research study. Each chapter contributes to knowledge as a standalone piece of work. This research provided a thorough analysis to understand and assess the e-mobility system of the Newcastle-Gateshead area addressing five key elements:

i) Meeting EV users;
ii) Accessing the service provider datasets and analysing it;
iii) Identification of the most influential factors affecting the use of RFs
iv) Identifying the mean of RF occupation quantification and forecasting the charging patterns;
v) Forecasting the candidate locations via simulation modelling.

This thesis provided an assessment and planning guide aiming at understanding the spatial and behavioural aspects of EV systems. The thesis objectives were met and addressed in relevant chapters. Within the remit of this thesis, various studies were conducted employing a multi-method approach. The chapters order reflected the development and transition between the three main sections of the thesis, see (Figure 12-1).

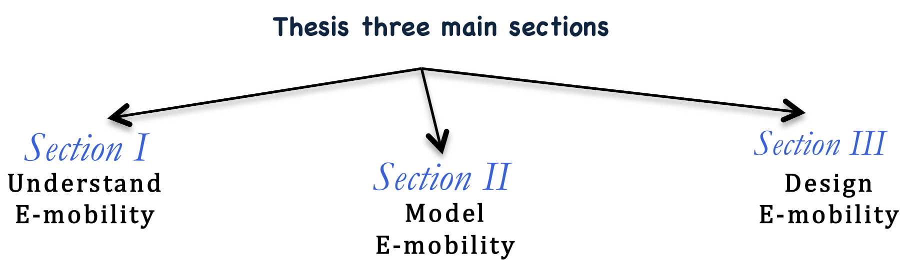


Figure 12-1: Thesis main sections

12.1 Understand, Model, and Design E-Mobility

Each chapter provided a method, approach or explores a new area of application; yet, there were dependencies between the chapters, see (Figure 12-2). Starting with Chapter 5, the meta analysis provided insights into the major issues that concern consumers and EV users. With a chronological order, the analysis highlighted 43 previous survey-based studies and 16 EV trials. Such analysis drove the design of the research EV user study, which was presented in Chapter 6.

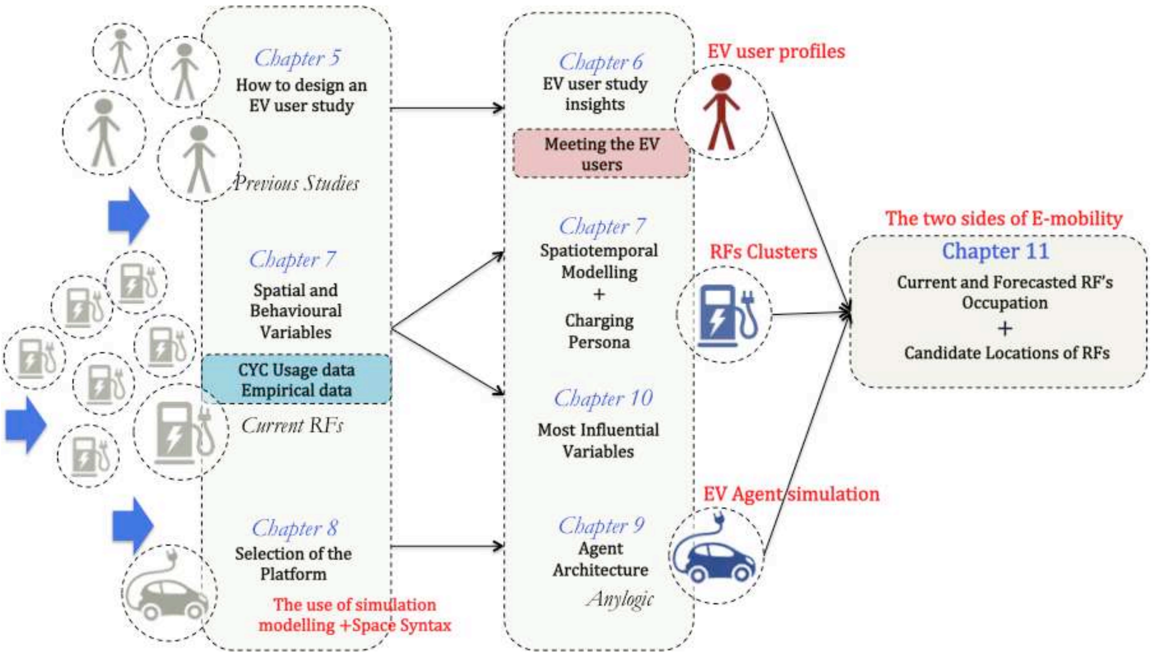


Figure 12-2: The flow of data and transitions between chapters

A further transition was made between Chapter 7 and Chapter 10. The identification and quantifications of spatial and behavioural variables in Chapter 7, was the first step prior to the spatiotemporal analysis. The last transition was between the selection of simulation platform and the development of agent architecture in Chapters 8 and 9.

12.2 A Unified Approach to E-mobility

The remit of this research is to offer valuable information for stakeholders, in particular infrastructure deployment decisions' makers. This thesis investigated a set of different characteristics of the hardscape side of the e-mobility system and its relation to the behavioural layer and social aspects of the system and it was achieved by analysing a current active e-mobility system. Some studies were conducted investigating the charging patterns of the users (Chapters 2 and 5), but to the best of the author's knowledge, the studies were based on hypothetical data or trial data. Conventional mobility system data was used as an input to different mathematical and forecasting models to predict the EV users charging patterns and preferences following the petrol station location allocation problem.

The discussion throughout this thesis can be seen as forming an integrated approach to understand, analyse, and design of e-mobility system and can be displayed with a breakdown of these approaches as follows, see (Figure 12-3).

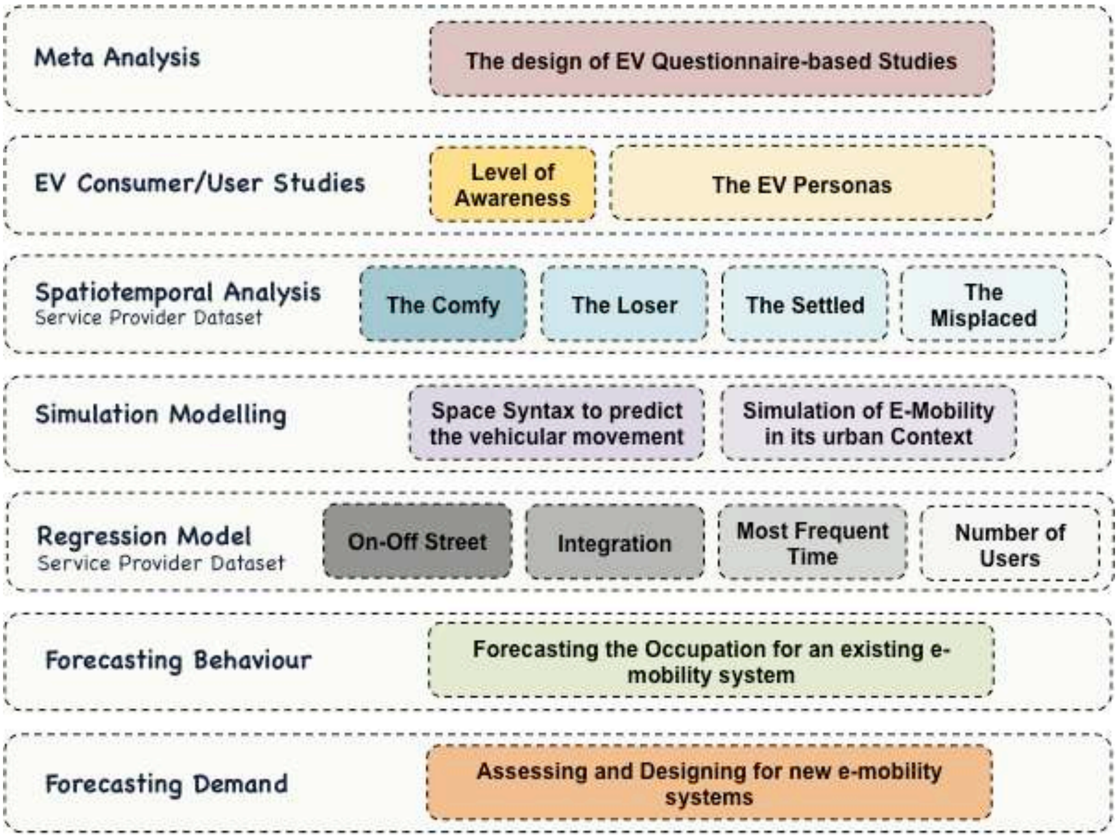


Figure 12-3: The big picture-the research multi methods

The thesis addressed the five research questions as follows:

12.2.1 RQ1: What are the influential spatial and behavioural attributes affecting the design and the use of e-mobility RFs?

With a closer look into the e-mobility system literature, there were some overlooked variables that needed further investigation. The urban context of the e-mobility system was analysed and some spatial attributes and qualities were identified and quantified as per Chapter 7. Via different means of quantifications, intangible parameters were successfully measured. From the end-user's perspective, the charging patterns and the non-linear profiles the EV drivers have, were investigated in Chapter 10. The Average Time Spent

Charging (A) and Most Frequent Time (M) are the main measures of the behavioral layer. As an outcome of the regression analysis, there were mainly four attributes that can be identified as the most influential factors to e-mobility system usability.

- Number of users (η)
- Integration (I)
- Most Frequent Time (M)
- On and Off Street CP

In addition, the integration values were used to predict the vehicular movement of the EV agents in the simulation environment. In return, this depicted the charging patterns of the users. It is an integrated process of analyses and investigations that work together to assess the performance of RFs. Studying these values and understanding the magnitude of each helps in the RF's design process. Figure12-4 shows the integration of the four factors that affect the analysis process of existing system and the design process of the RFs.

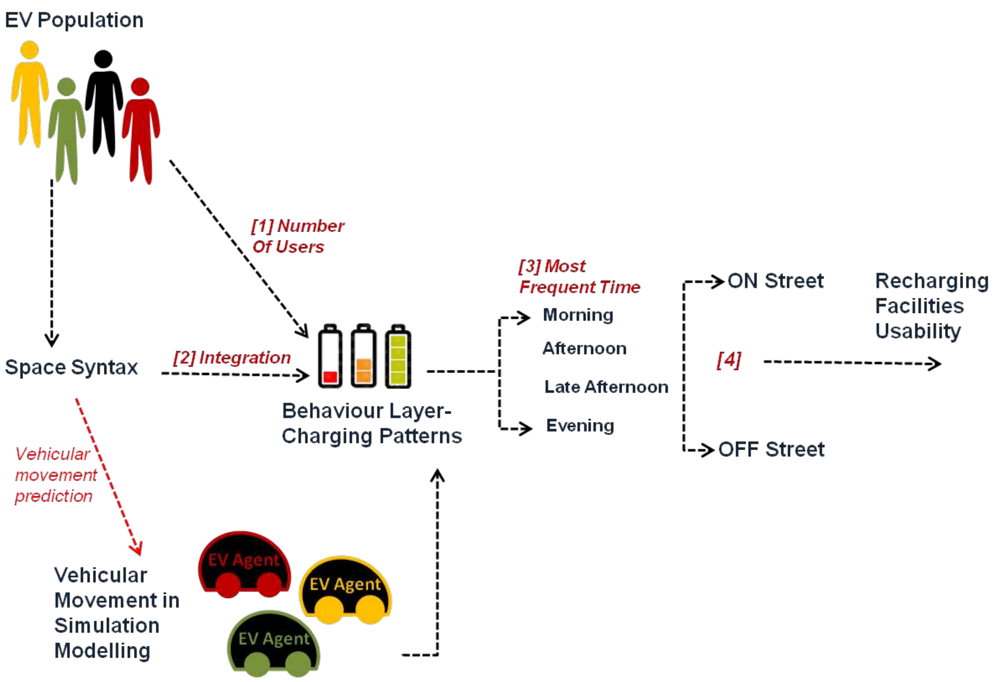


Figure 12-4: Influential factors

12.2.2 RQ2: How useful are the user studies in the context of EV use?

The range-anxiety-syndrome presents hurdles for many potential users to electrify their vehicle use. Even for current users, so far, the EV is still replacing the secondary car in multi-car owning households mainly due to range limitation. Studying EV social practice is fundamental, as consumers cannot anticipate e.g., barriers and easiness. Understanding the e-mobility system is challenging as without experience, or relying on conventional cars to anticipate behaviour or pattern, will not provide the needed insights for planning and designing new infrastructure. In Chapter 5, the meta analysis explored the previous EV studies and provided further explanation of the e-mobility system. This was followed by the research EV user study which provided more insights and identified the EV user possible profiles. EV trials provide an insight of the system characteristics and may be some energy-related assumptions and connection to grid analyses. However, meeting the EV users and conducting an EV user study explains and justifies the social practice of the EV use.

12.2.3 RQ3: What are the main paradigms of e-mobility compared to conventional transport?

Throughout the thesis, the e-mobility system has been introduced and discussed from different angles. In Chapter 1 the alternative means of transport and the immediate actions needed to be taken to promote clean transport were introduced. To simulate this system, the main paradigms of the e-mobility simulation model were discussed. Chapter 8 discussed the system parameters and the level of abstraction required to depict the charging pattern and EV population behavioral characteristics. Denoting the EV system means identifying the key elements of the system, secluding the unnecessary subtle details. As per the research objectives, one of the thesis outcomes is articulating the main paradigms of simulating the e-mobility system.

12.2.4 RQ4: Is it possible to depict the social practice and the system's mechanisms in a simulation model? And if yes, what is the recommended modelling technique?

Simulation improves the understanding of a system's behaviour to evaluate strategies for its operation (Kellner & Raffo, 1997). An integration of ABM approach and vehicular movement prediction technique ASA, was selected to simulate the e-mobility system. Various simulation models are developed to investigate the loads on the gird, battery performance or other environmental related research questions. The ABM with the ability to depict individual pattern and the emergent behaviour, the e-mobility system was simulated. Using Anylogic, an interactive tool was developed and it supports regular updates and changes.

For the first time, the state of the art agent architecture integrated configuration attributes in a DE simulation environment is simulated. The development of this model facilitated the depiction of the behavioural layer ABM while encountering the occurring events of the urban layer DE in the simulation environment. The notion of this model paves the way for a better planning of a fully integrated charging network in metropolitan areas. Based on the simulation objectives, urban context, EV system (*existing or new*), the simulation model will be adjusted and celebrated for replication. The approach emphasises the power of simulation in identifying the gaps of the EVs charging infrastructure. The outcome of the study can be read in two ways depends on the purpose and the current stage of planning:

i) Installation needed: These critical zones are potential locations CPs to support the users (current or future depends on the size EV population was in the iteration).

ii) Revisiting planning: The CPs fall under these areas are to be activated otherwise other points to be deactivated/ or moved to other critical zones as they will not be used and this will save operational and maintenance running cost.

12.2.5 RQ5: For planning purposes, how could stakeholders forecast the charging behaviour and locations for a better e-mobility diffusion?

Clustering analysis alongside the regression analysis emphasised the effect of the spatial analysis on the charging patterns and hence the usability of the charging network. Being an On or Off Street CP is statistically interpreted into a value, this value is one of the main predictors of charging network usage records. Highly used On Street CPs have high integration values as they are mainly located in the main corridors of the city. Moderate Number of Users (η) would be using them; however, for long charging sessions. Analysis showed that the (M) people use these CPs is in the morning.

Whereas highly used Off Street CPs, are recognised by the users due to their accessibility and premium locations (central parking lot-close to amenities), the Integration (I) values are relatively low compared to profitable On Street CPs. Many users tend to use it; however, for a short repetitive transactions. Analysis showed that the most frequent time people use these CPs is in the afternoon.

12.2.6 About designing RFs

There is no confined and rigid definition of the exact locations and sizes of the RFs; there is business need-oriented, behavioural, or technical models. However, there is a link between the EV infrastructure planners, users and its business need which provides an integrated and reliable e-mobility system. This link is the design of an integrated network. The development of an integrated design via spatial clustering approach and end-users' perspective, flourishes the way for a mainstream market where the level of use is increasing as the level of satisfaction is improving.

12.3 Contribution to Knowledge

The construct of the methodological approach is the research contribution to knowledge. Being cross-disciplinary and using different methodologies, this thesis reports on forming a strategy that integrates design features, behavioural and functional characteristics of the e-mobility system in metropolitan areas. This strategy is to understand the e-mobility system and its dynamics rather than providing a formula for replication. The various interpretations of the empirical work and the application of multi method techniques to a new area, e-mobility system, have formed the originality of this piece of work. The way this research was carried out is articulated as guidelines to assist planning authorities and policy makers with the basis of analysing existing EV systems and the design of new recharging facilities. This has resulted into other contributions:

- Creating an agent architecture that corresponds to the EV drivers' charging pattern in a discrete event environment while integrating the model with space syntax to simulate e-mobility system and forecast the charging demand;
- Integrating space syntax analysis, spatial qualities and behavioural attributes to cluster the RFs.
- Forming EV users' profiles that indicate different charging patterns and personas.

To conclude, RFs should be designed to be economically reliable, efficient and meeting the demand. The study aims at assisting planning authority and policy makers by highlighting the main paradigms of the EV system in metropolitan areas. See Appendix A for a detailed documentation of assessment and planning guidelines.

12.4 Future Research

This thesis demonstrated the appropriate approach that can be applied to understand, analyse and design e-mobility system. The use of a multi method approach gave an overview of various analyses and studies (*based on the availability of data*) that can help with:

- Understanding the nature of e-mobility system;
- Analysing an existing system;
- Designing a new system.

Planners and policy makers can evaluate, assess, and revise their system to provide better charging and management services and efficient infrastructure that meet the evolving design needs of the current users and support future demand. Future research is recommended to cover the following areas:

12.4.1 Workplace practice

While home charging is the most common option, workplace-charging and its provision by employers has become an important option and for many it is essential to cope with EV-range limitations. Home and work are the two locations vehicles long periods idle and so are prime candidates as charging locations. However, workplace-charging is often a limited resource and employers and employees have concerns about it which need to be addressed:

i) Communication between EV driver using shared workplace facilities;

ii) The data structure and granularity is a major issue that affects the analysis process and to enable data analytics of current systems and predict future demand, a more reliable support platform is needed.

With such advanced technology and different perspectives and preferences, a user-centric design approach is needed. A participatory workshop for both, user and provider may be proposed to allow engagement and community action. Employers may wish to establish creative policies to govern the workplace charging etiquette.

12.4.2 EV InfraStrategy

One of the next steps is to draft a planning manual that brings together all the work that has been carried out in this thesis. This manual, EV InfraStrategy, should be developed electronically as an interactive assessment support tool to provide the basic essential e-mobility assessment strategies, see (Figure 12-5). A proposed diagram of EV InfraStrategy is illustrated in the following infographic. The information flow, data transfer processes, and dependencies are visualised.

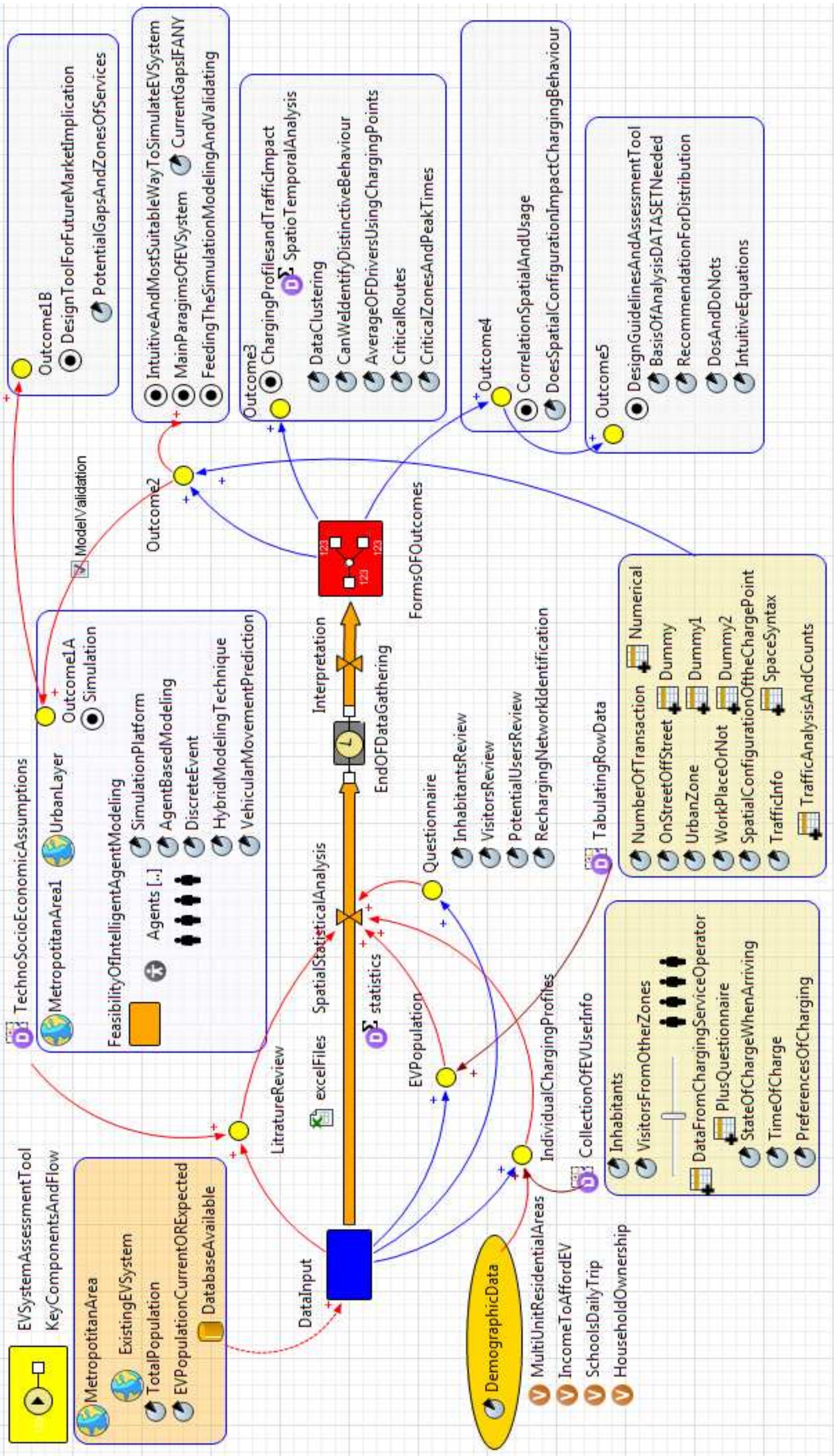


Figure 12-5: EV InfraStrategy snapshot

12.4.3 Simulation model

In a fully integrated model, future research should address new areas for improvement purposes. The road network is a complex system to the EV agents to observe; decisions are driven by the network attributes and charging events. Likewise conventional traffic simulation, the computation of intersections and points of decisions is difficult.

Smart agents

The EV agents need to act and interact more with other EV agents, the charging network and other entities in a shared environment. The EV agents need to be more like deliberative agents. Agents architecture, in terms of agent behaviour, can be whether reactive or delebrative (Bandini, Manzoni, & Vizzari, 2009). Reactive agents are very basic and elementary like the created EV agents in this thesis. In a more developed model, these agents need to be deliberative. So they are capable to select a series of actions (*go to defined destination, but choosing the way to go*) for every possible sequence of perceptions (reaching *an intersection or in case of multiple destinations*). Hence, the EV agents can obtain the mechanism that effectively selects the actions to be carried out. In a highly developed model, (model is to include different types of charging: plug in, battery swapping, fast charging) and maybe cause modifications in their environment (Rao & Georgeff, 1991) (a modification can be in their route taken. So based on the time available for charging, the agent redirects themselves to the type of charging they are after).

Smart movable charger

ElBanhawy & Nassar (2013) outlined the a movable charging unit (MCU) study framework and discussed the study objectives. The MCU was designed to deliver charging services at doors whether by swapping or quick charging option. Following the computational complexity of the ABM discussed in Chapter 9, this solution employs genetic algorithm (GA). The charging utility will pass by the battery, and the battery is replenished, see (Figure 12-6).

Figure 12-6: Movable charging unit plan

The model is a product of the integration of Genetic Algorithms (GAs) with the information about EV users for a given area developing an optimal route for a charging unit. Based on the demand, the model can design having more than MCU to cover all the areas on a timely manner.

Next steps: Scale, scope and urban context related improvements

The planning of the EV recharging infrastructure network is a learning process. There are areas that require further improvement for broader applications and replication. The visual survey that was used to test the level of awareness and the spatial recognition of the system covered only the inner urban core of the city. This was due to the prioritization to start with the city centre aiming at having smart hotspots in cities' cores as explained above. For a better analysis, this questionnaire should cover the entire city. A subcategory has to be added to the analysis s of the charging points as whether the Off Street point is a workplace or a public used one.

Domestic chargers, which are being installed by energy companies, have to be also identified as a charging hotspot and to be added as an attribute to the RFs design features. This includes if it is possible to be shared with neighbour having extra parkway.

Next steps: decoupling matters improvements

There are few decoupling remarks for further research.

- The empirical analysis carried out in this thesis accounted for the inhabitants who are using the charging network for at least 3 consecutive months. Further analysis is needed to investigate the difference between inhabitants and visitors charging patterns. The inhabitants records should be decoupled from visitors usage records;
- On Street charging patterns to be decoupled from Off Street usage records;
- Workplace charging should be decoupled from Off Street charging points due to the different factors causing the use of both.
- Domestic charging should be identified and all relevant charging profiles should be analysed separately.
- Car ownership; decoupling owned cars from on lease cars

12.4.4 Towards smart cities

Creating competitive and economically resilient cities is the way for green ecosystems. A smart city is a place where the data and technology change the way government operates, enable preventive action, incorporate citizens and increase efficiency (Goldsmith & Crawdford, 2014). A green ecosystem where sustainable urban and infrastructure and buildings complement each other. A integrated system that counteracts problems with aging urban infrastructure, improves the power supply through smart grid technology, detects, calculates and communicates optimal transportation routes under congested traffic conditions and deploys ubiquitous sensing devices to facilitate everyday activities in the crowded urban environment (Kortuem, 2014). The idea of smart cities is a strategic device to encompass the growing importance of ICT (Dell et al., 2014). Smart charging is one of the rising technologies (Delft University, 2014); (Sebastion et al., 2014); (Ferreira & Afonso, 2011). Additional communication between the grid, CP and the EV is required. This technology will affect the charging patterns of the users and confine it in a more regular consistent pattern.

In utility network field, the planning process should avoid designing segmented architecture with separate network for separate business. A well-integrated network that supports the inner urban core of cities with the ability to expand to service nearby towns and centres is desirable. Referring to e-mobility charging network, such investment is needed to support the main corridors and arteries that link cities.

Creating a smart transport and infrastructure network is a phased process. Planning authorities design the urban environment and ensure sufficient infrastructure and other basic community services. Major cities are the genesis of smart communities and economies. Cities work as hubs for technologies, smart solutions, and smart communities. This includes all sectors and amenities. Taking Newcastle as an example, the inner urban core is the first step towards a sustainable community with regard to neighboring cities and towns.

The Newcastle-Gateshead area e-mobility system needs strategic planning, which must be considered is model development, market feasibility studies, and economic design of RFs. The distribution of these facilities should be studied well to avoid any waste of investment cost resulting from an under-used CP or unrecognizable facility. Newcastle smart city shall work as a hotspot and hub for satellite towns, distance illustrated in Figure 12-3.

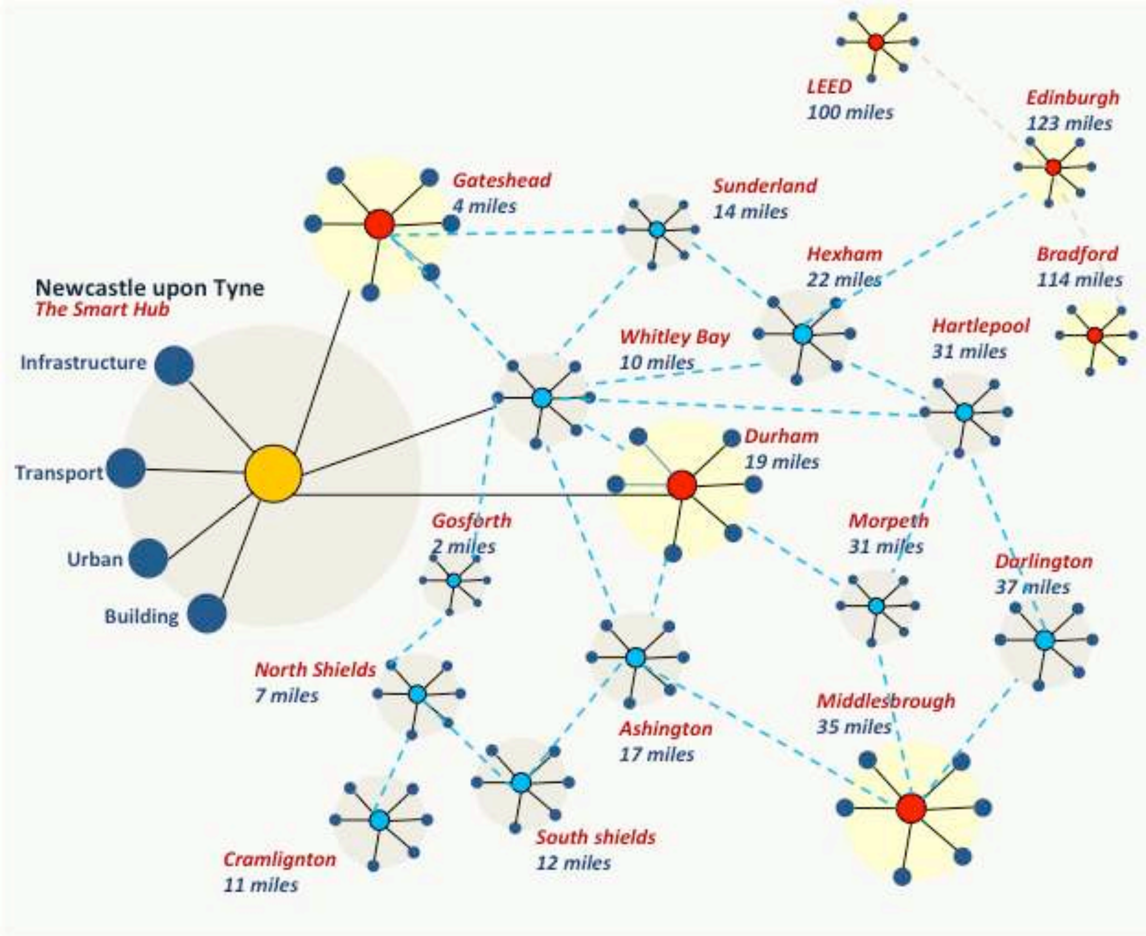


Figure 12-7: The smart hub

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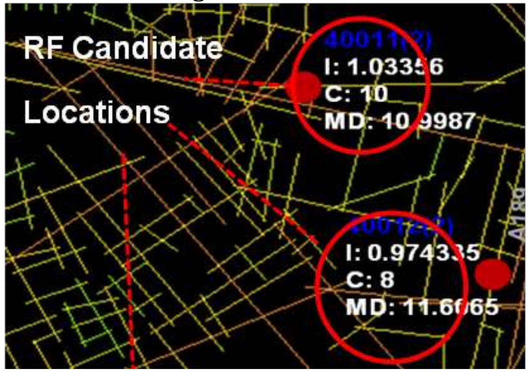
Appendix A: Assessment and Planning Guidelines

Users real information based [empirical]	Potential user information based OR [Secondary]
[1] Spatial Variables	
OFF and ON Street Design configuration values of the existing RFs locations Integration Connectivity Traffic Counts	Traffic Counts Distance from Centers Design configuration values of candidate location to be calculated via DepthMap as indicated in the figure  Figure 1: calculating configurational values
[2] Input Data	
Real information about users	Domestic charging records and patterns. Interviewing current users (*reaching end user is problematic and will take time*)
[3] More variables to be considered	
Traffic Analysis: Congestion Users home address Charging Pattern: Maximum time spent and minimum time spent in each period of time (*Morning, Afternoon, Evening and Night*) Other means of transports (buses)	Traffic Analysis: Congestion Other means of transports (buses)

Users real information based [*empirical*] | **Potential user information based OR [*Secondary*]**

[4] Behavioral Variables

Behavioural Variables

Number of users, Number of transactions, Average time Spent, Most Frequent Time, Total Energy Used, Public Awareness

Taking the same approach of conducting a visual survey (potential users/ questionnaire (users) as indicated in the figure

Figure 2: Spatial survey (identified RF's locations)

Using the same research method

Survey based study: Questioning potential users in the given areas (*taking the same approach of conducting a visual questionnaire*) about their prospective preference in the case of owning an EV.

Public Awareness of potential location of charging points

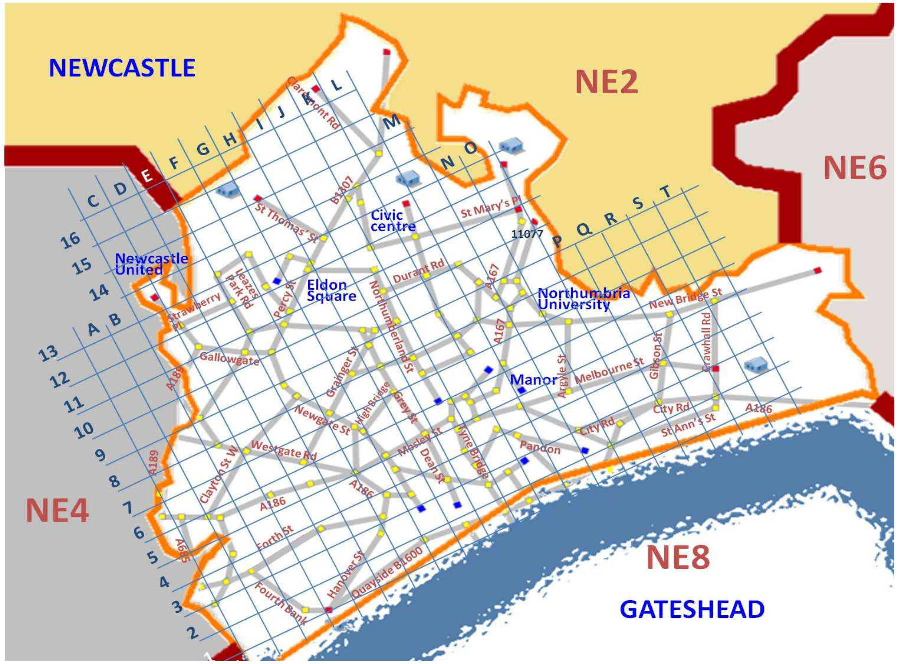


Figure 3: Spatial survey (unidentified RF's locations)

OR Use some records of other alternative means of transport if any (natural gas charging pattern) The use of secondary data (Newcastle)

Users real information based [empirical]	Potential user information based OR [Secondary]

[5] Clustering Analysis

Analysis will be based on both spatial and behavioral attributes as illustrated in the figure.	Analysis will be based on both spatial and behavioral attributes without empirical data of: Average time spent, most frequent time, no. of users and no. of transactions. In this case, secondary data may be used.

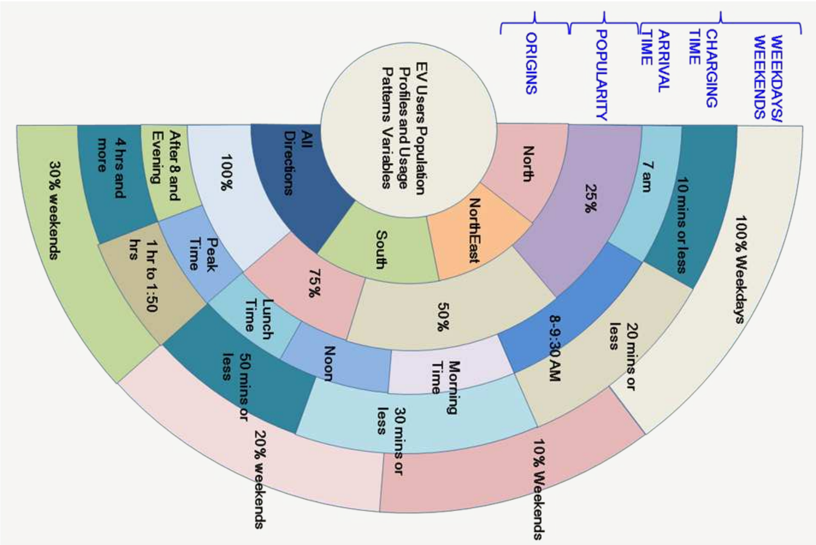


Figure 4: Variables

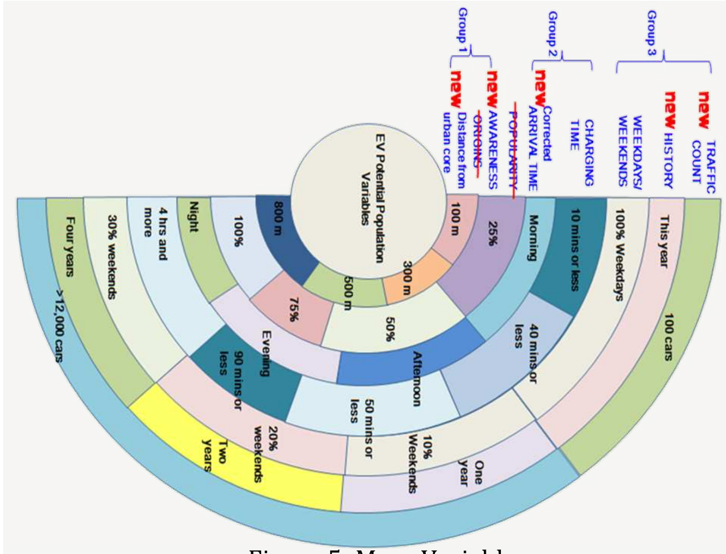


Figure 5: More Variables

[6] Regression Model

Analysis will be based on both spatial and behavioral attributes. Total Energy will be the Dependent variable	Option 1: Execute the second part of the regression model where only the spatial variables are included. OR Option 2: Use both urban context variables (spatial attributes) of the given area and use the secondary data of a similar EV system. **Newcastle (Organic city) records cannot be replicated in State College (Grid based city)*

Users real information based [*empirical*]	Potential user information based OR [*Secondary*]

[7] Simulation Modeling

Refer to chapter 8, the use of Simulation Paragon 1 or 2. This depends on the objective. (1) Activate or Deactivate, and (2) Usage Calculator

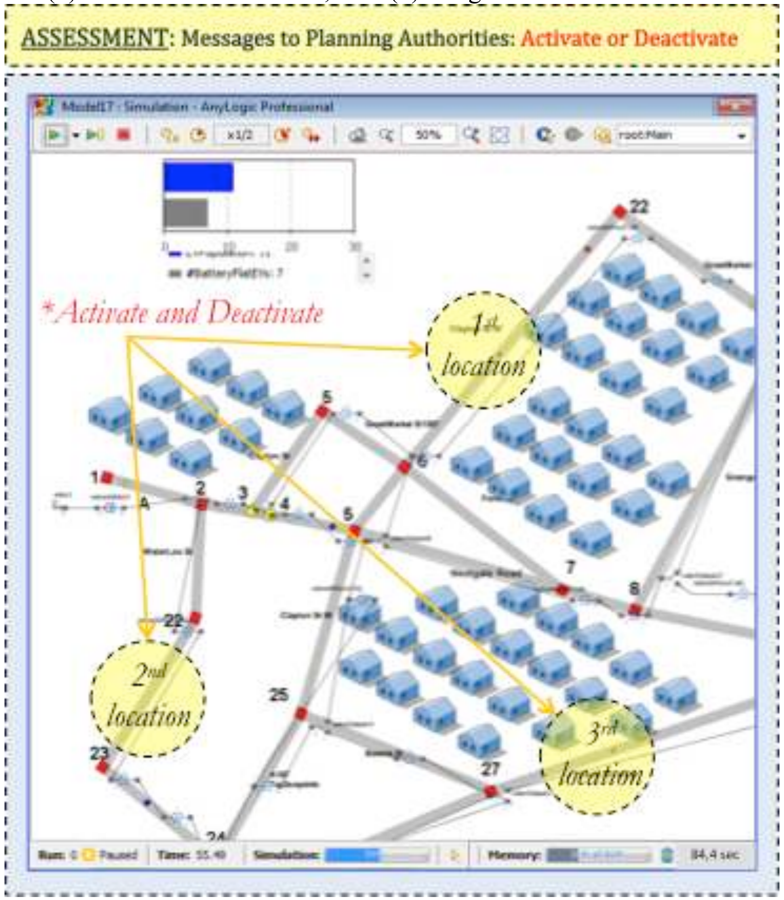


Figure 6: Execution_Anylogic (Activate and Deactivate)

Refer to Chapter 8, the use of Simulation Paragon 1:
Candidate locations (Gaps in the infrastructure)

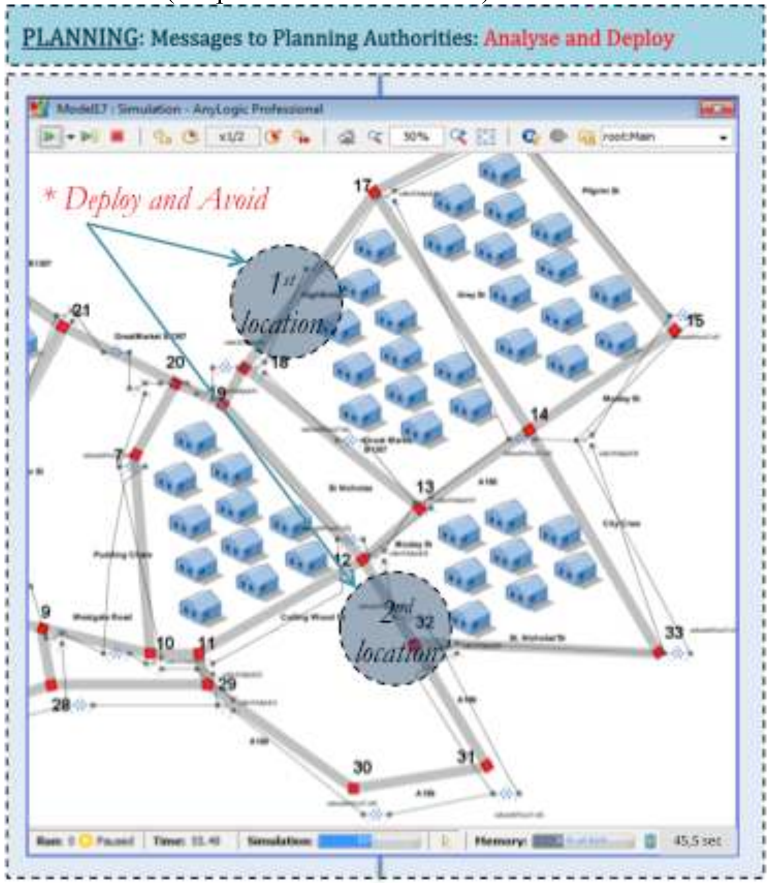


Figure 7: Execution_Anylogic (deploy and avoid)

Users real information based [*empirical*] | **Potential user information based OR [*Secondary*]**

[8] Indications for Stakeholders and Possible Replication

Updates on the Critical Charging Corridors

- As per advised by the Traffic Management, updates on the main corridors of charging would help Traffic planning and management monitor the network and update the system with alternative means of transport impact on the network.

Updates on Charging Points availability

- Users would need updates on the availability of the charging points in their vicinities (*avoid CP# 20009 between 12:00 and 2:00, charge at CP# 20007 from 3:00-5:00 otherwise you pay after 5:00 PM for parking*).

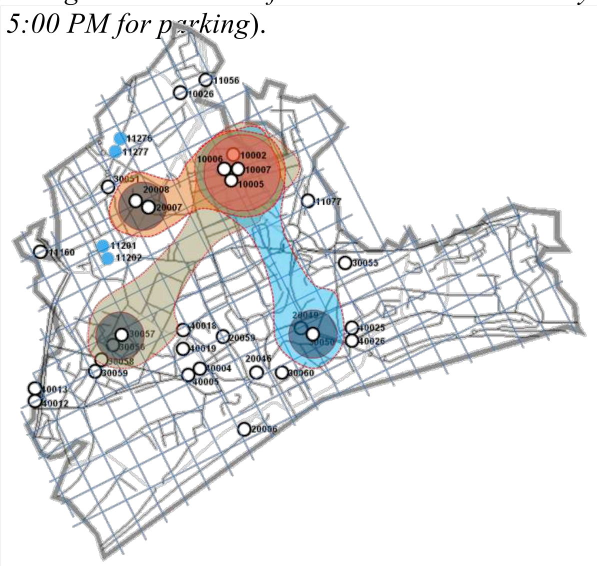


Figure 8: mapping updates for traffic monitoring

Updates on Charging time

- For smart grid records and peak time (smart charging initiative)

After carrying out the simulation model, identifying the urban cores alongside the suggested locations by local authorities and policy makers, these locations are to be mapped.

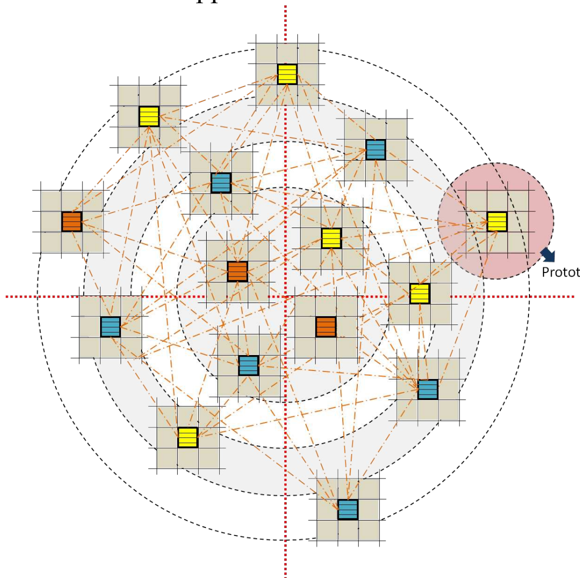


Figure 9: Initial schematic design of RFs location allocation and spatial configurations

Preference is made for OFF Street locations with high values of integration and relatively known by public.
OR ON Street locations with higher values of integration and connectivity, and also with high tendency that public will spatially recognize it.
A prototype is to proposed for each RF as per the following figure.