A Heuristic Apporach for Investigating the Integration of Electric Mobility Charging Infrastructure in Metropolitan Areas: An Agent-based Modeling Simulation

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Abstract— *This paper discusses devising a methodology for developing a heuristic approach for planning authorities and policy makers to investigate the integration of electric mobility charging infrastructure in metropolitan cities, particularly in the UK. This study is a part of a PhD research project; it presents a part of its overall methodology which will be employed in a smaller-scale pilot project to obtain initial findings. An agent-based modeling and simulation (ABMS) technique is proposed to represent the phenomenon and analyze it. This study covers the development of the model, emphasizing how it would reflect Electric Vehicles (EVs) current users' behaviors and their charging habits. The aim of the PhD research is to examine whether the current electric-mobility charging infrastructure can support current users and whether it can accommodate future potential users or if the planning authorities and policy makers need to forecast and plan for more charging points. This in return shall potentially provide a better accessibility to e-mobility and support its market, partly by better informed locational decision making.*

Keywords- Electric mobility; Agent based modeling simulation-ABMS; Agent attributes; EVs users' behaviors

I. INTRODUCTION

In recent years, the extensive use of conventional transportation means resulted in more negative environmental impacts, with an increasing interest in mitigating this (Michaelis, 1996; Orsato, 2009), as well as to deveop and (re-)design cities to make them more liveable (Breithaupt, 2010). A projected look into the future indicates a higher population growth rate, and increasing urbanization trends (OLEV, 2011; Proost, 2000), with road-based emissions as a clear area of concern (Kutz, 2010; Kousoulidou, et al, 2008; Foresight Intelligent Infrastructure Systems Project (2010; Johanson, 1995; Jansen and Denis, 1999) and potentially geo-political issues of energy security and dependency on oil-exporting countries (Sperling and Cannon, eds, 2010, Strahan, 2012). This persuades governments of many developed countries across the Organization of Economic Co-operation and Development-OECD (IEA, 2011, IEA / OECD, 1993) as well as the EU (European Commission, 2002, 2001; CE Delft et al., 2011) and increasingly in the United States of America at state and federal level (U.S. National Research Council, 2010; California Energy Commission, 2011; Lindquist and Wendt, 2011; Kemp, 2005; Kreith et al, 1999) initiating and accelerating current plans to provide more clean (alternatively fuelled, i.e. non-internal combustion engine or ICE (see IMechE, 2000, Tate et al, 2008; Thomas, 2009; Wiesenthal et al, 2010) and smart and intelligent means of transportation (Bell, 2006) at city, regional and global scales (OECD et al, 2012; Small and Gómez-Ibáñez, 2005), so that despite some false starts not so long ago (Mom, 2004; Anderson and Anderson, 2005; Deventer et al, 2011; Dings, 2009) this time round effective support from the state / public level (Ahman, 2006) and the commercial and technological competition race for capturing market share and commercialised R&D leads (Altenburg, et al 2012; Motavalli, 2011; Pilkington and Dyerson, 2006; Magbusson and Bergruen, 2001) might deliver breakthrough (OLEV, 2011);(Deventer et al., 2011, Sandalow; Serra, 2012); (Cowan and Huélten, eds, 2000); (Wakenfield, 1998);(Sperling, 1994).

It is perceived by many that Electric Vehicles (EVs) are the most efficient way of transport (compared with Internal combustion engine, or ICE, vehicles) with the smallest CO2 footprint at the moment, though the extent of it depends also on the sources of electricity energy source (Logica, 2011);(Barkenbus, 2009) Energy Information Administration, 2009; Electric Power Research Institute, 2007; UCS, 2012; (Institution of Mechanical Engineers, 2000; Boschert, 2006; Lilienthal and Brown, 2007; Lytton, 2010; Thomas, 2011; Carson and Vaitheeswaran, 2007; Chan and Chau, 2001)). From a wider environmental perspective, the life cycle performance of different EV batteries also need to be taken into account (Majeau-Bettez et. al, 2011; Thomas, 2011). There, however, will continue to be commercial, technological and political competition between differently fuelled and powered vehicle (Bakker et al, 2012; Fujimatu, 2011; Thomas, 2009; Cowan, R. and S. Huultén, eds, 2001), and the innovation paths created by the co-evolution of technologies and markets may be highly relevant (Dijk and Yarime, 2010; Tate et al, 2008), including for an electric mobility trajectory (Dijk et al, 2012; Tran et al, 2012), as will political decisions and societal attitudes (Rayner, and Malone, eds, 1998; Sartorius and Zundel, eds, 2005), and conceptual and cognitive frameworks of decision-making by institutions and individuals (Cheng-Weilin et al, 2009).

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Overall, the three major reasons for engaging with Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles PHEVs (Bradley, Frank, 2009; Saucedo et al, 2010.) are 1) to try and realize the potential of reducing Greenhouse Gases - GHG and CO2 emissions (for measuring and quantifying this for EVs, see Suresh, et al, 2010), which is in part predicated on de-carbonising the electricity generation and input (Royal Academy of Engineering, 2010; UCS, 2012), as well as the overall lifecycle environmental footprint, depending on manufacturing inputs and recycling (DeLuchi, 1989; Thomas, 2011); 2) a public health dimension with regard to urban air pollution levels and respiratory diseases (Woodcock, 2009; Brady and O'Mahoney, 2011; Proost, 2000; Proost and Van Dender, 1988); 3) and also to create and grow the new 'green - low carbon - industries' (KPMG AG, 2010; Beeton, 2011, 2012; Barlag, 2011; Draper et al, 2008; EuPD Research / DTCI, 2011). 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), including at aggregate city level (see CATCH project, 2012).

The significance of EVs as an alternative transport technology is initially driven from two crucial rationales: environmental impacts of conventional means of transport and the opportunity of having smart transport, which is linked to ICT and traffic demand and flow (congestion) management, which in turn could reduce environmental impacts (Kudoh, 2001) though electric cars will never become a full substitute for public transport, due mainly to land take and the inefficient use of infrastructure (Van Wee, 2012). These rationales these are discussed below.

1) Environmental Impact of Transportation

Transportation and logistics is the engine for economic growth, moving goods and people around the countries, and allowing people to access employment, services, leisure activities and socialize with wider communities (HM Government, 2011; HM Treasur, 2010, 2009), as well as allowing businesses to expand and create wealth and employment.

However, it is considered as a major contributor to greenhouse gas emissions (DfT, 2011; Arup and Cenex, 2008), and hence has a considerable carbon / environmental footprint emissions as is shown in Figure 1. The extensive use of conventional means of transportations has resulted negative impact to the environment (OLEV, 2011). Between years 2004-2010, road-transport in UK contributed by more than 66.6% to the climate change and 68% from the overall energy consumption (DfT, 2011). This reflects the urgent need of a smooth transitional mobility system by having alternative clean and smart means in addition to overcoming the switching barriers.

Transport is a vital spine for societies to deliver logistics solutions and enable mobility. Internationally and across Europe, we have a range of technology opportunities and strategies available for the smart and sustainable transportation modes in the 21st century (Eberle and Heimolt, 2010; Kreith et al 1999). Depending on which modes and fuels we will choose, and from which source and how they are generated (Kampman and De Buck, 2011), this has consequences and benefits for reducing the negative environmental impact of transport modes; see TOSCA 2012 project results for scenarios (Schäfer, 2011).

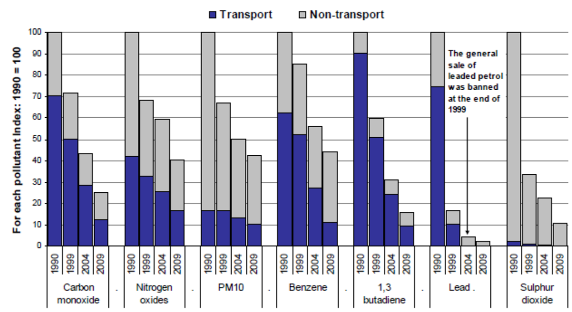

Figure 1. UK greenhouse gas emissions, 1990-2009 (DfT, 2011).

2) The opportunity of having smart transport

The transport sector is already well imbued with ICT and other smart technology (e.g. GPS). It can be considered as a platform for exporting and commercializing services and Information and Communications Technology- ICT and hence business growth (Beeton, 2012). Therefore, EVs connect with the national and regional economic growth agendas with not just a focus on manufacturing but also associated technologies and also the application and integration of telematics, and intelligent transport solutions as part and parcel of EV Ecosystems; something that itself may be commercialized and hence be internationally tradable (Beeton, 2011).

B. The rearech project as part of an Interreg IVB North Sea Region Programme

In the context of urgent challenges presented by carbon reduction targets and air quality goals, EV industry is seen by developed and developing countries to be a viable solution (Morton et al, 2011). These proactive countries have launched initiatives and programs to support the Electric EV market. One such programme is an EU funded project led by the University of Hamburg of Applied Science and has stakeholders and partners (with sub-partners) from Sweden, The Netherlands, UK, Belgium, Denmark, Germany and Norway. The project is called North Sea Region Electric Mobility Network (E-Mobility NSR), and was launched in April 2011 (Figure 2). It aims to create favourable conditions to promote e-mobility within the North Sea region, defining current technological and end-users' barriers, and supporting the market, and assist the common development of e-mobility in the North Sea Region. Transnational support structures in the shape of a network and virtual routes are envisaged as part of the project (Borgqvist, 2012), striving towards improving accessibility and the wide use of e-mobility in the North Sea Region countries. It has seven work packages, one of which focuses on developing a transitional "plan" of - or development and implementation manual / guide for - e-mobility (NSR E-mobility, 2011).

This paper represents the research methodology employed in the related work package of the e-Mobility NSR. It represents a heuristic approach for investigating the integration of EV charging infrastructure in metropolitan areas using agent-based modeling and simulation ABMS technique.

Figure 2. E-mobility proposed North Sea region route

C. Study questions

This overall study discusses the following set of questions:

- Does the current EV charging infrastructure support for its current users?
- Is there a need for an expanded EV charging infrastructure beyond 2012?
- If so, where should the additional infrastructure be placed, based on which criteria ?

D. Study framwork

Addressing these questions requires a decision to be taken. A decision by policy makers and planning authorities is on whether to allocate a budget for more investments in this sector. Accordingly, an infrastructure gaps analysis needs to be conducted giving an insight of the current state, identifying infrastructure gaps, critical routes, different EV clusters and business models in the North Sea region coming up with guidelines and recommendations for the upcoming EV adopters.

To carry out this type of analysis, a theoretical framework is planned. We need to tackle (1) data collection phase which includes soft and hard infrastructure information. This includes interviewing policy makers, governmental authorities, and cars' manufacturers to conclude up-to-date technology targets, business models, incentives and subsidies ; on the other hand, meeting early adaptors to depict a clear image of their charging schedules and behaviors. This is to provide a preliminary reliable database of usage information to start the supply and demand analysis.

Subsequently, we shall start (2) the data analysis phase which counts on the amount and quality of collected data. Finally, (3) conclude outcomes and recommendations for decision makers to put national and regional plans ahead. Practically, this theoretical/conceptual framework will not be employed due to the potential hindrances to conduct it. In figure 3, the flowchart depicts the framework while emphasizing the barriers and the proposed alternative solution to overcome them.

The need of simulation is perceived to be fundamental to pursue the research aims and objectives. This technique enables capturing dynamic effects and real-time interactions (Xi, 2010) between the consumers and the infrastructure. In the next part of the paper, the approach is explained in detail showing the agents' algorithms and definition.

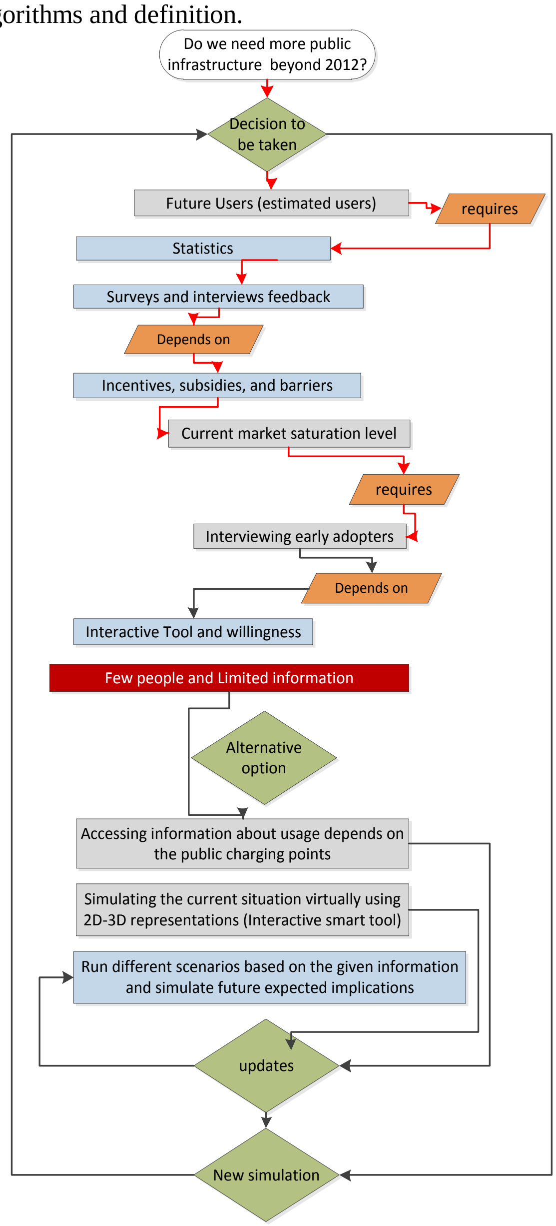

Figure 3. Reseach framwork flowchart showing barreirs and solutions

E. Pervious applications of the ABMS methodology.

The use of integrated ABMS in the area of social sciences that involves behavior of human beings has been analytically corroborated in many literatures (Chen, 2012). Pedestrian and wayfinding simulation is one of the more popular studies that shows physical interactions and congestions among people and the spatial environment regardless the main aim of the simulation (Xi, 2010).

Also, ABMS has been used to simulate various mobility patterns such as transportation, logistics, medicine, entertainment etc. (Wang, 2004). Road traffic is one application that simulates the moves of road users (behavior) on a roads network and employ ABMS to generate realistic traffic environment (Doniec, 2008). Previous studies employed the ABMS in real-time problems and social and spatial interaction-decisions problems (Chen, 2009). Moreover, it was used to integrate between a simulated EV-system environment and energy and power flow studies (Acha, 2011) where it was applied to conventional vehicles movement and traffic management researches integrating air-quality and noise analysis by the Transport Operations Research Group-TORG (Galatioto, 2011). ABMS was also applied to city models investigating geo-spatial and urban topographies phenomena by (Crooks, Castle, & Batty, 2008).This is in addition to wide range of simulation purposes (Borshchev, 2004).

II. CURRENT STATE EVS MARKET

A. EVs European market subsidies, market uptake and consumers' interpretation

This study as part of the research project, strategically focused on both private and commercial electric cars. The total number of registered electric cars can indicate the market penetration. In Europe, in the first half of 2011, the total EVs registrations were 5,222 (JATO, 2011).This implies a niche market that is in a real need of expansion and creation of conditions for growth for the mass adoption of EVs when 'early adopters' may not represent 'mainstream consumers' (Graham-Rowe et al., 2012; Kurani et al, 2008; Gould and Golob, 2000).

Yet, the change of EV market's paradigm and symptoms is intensifying competition between stakeholders (Eppstein et al, 2011); and depends on different policy frameworks (Karplus et al, 2010). In most of the European countries and mainly those which are considered to be the earliest adopters of EVs operating different EVs' schemes, incentives and subsidies are there to support the market. These countries like Germany, Sweden, UK, The Netherlands, France, Spain, Norway, Denmark, Ireland, and Switzerland (AEA, 2009). As a proof of concept, in the UK, Norway, Denmark, Netherlands, all EVs are exempt from car (and van) registration tax in UK (OLEV, 2011). In the UK and Sweden, EV car owners get a subsidy of £5000 and 10,000SEK respectively (VMAL, 2010). Attention is also given to fleet EV solutions (MEC Intelligence, 2011).

This gives us an insight of the current European EV market which indicates the several factors that affect the market maturity (JATO, 2011). As a niche market compromised by early adopters, it is expected to have a low level of maturity (Beeton, 2011). These are different factors affecting the level of penetration and maturity of the EV market. The higher upfront price of EV compared to conventional car is one of the considered factors by potential users (Garling and Thøgersen, 2001; Lemoine and Kammen, 2009; Lieven et al, 2011); nevertheless, the degree of urban geography, market maturity and charging infrastructure have their effects on sales and market growth (JATO, 2011) as well.

From this point, we can roughly gather and conclude the six distinct aspects that radically affect the EVs competitive positioning in the market which range from private and public stakeholders, national and regional businesses, polices and regulations, and social and media influences as summarised below:

Key factors affecting EVs market penetration are:

- Policy makers and Vehicles manufacturers (investments influencing PHVE adoption
- Media and social networks (psychological and social factors)
- Size, performance, brand (with the proviso that they must stay within budget)
- Governmental regulation and incentives
- Technological awareness and communication
- vehicle purchasing decision (vehicles' heuristically perceived benefits against rational financial consideration)
- Planning authorities' (infrastructure) decision strategies.

Media influence is considered to be one of the key influences on how powerfully and effectively it swiftly conducts and circulates pervasive views and feedbacks within certain vicinities and metropolitan particularly potential leverage points of EVs (CATCH, 2012; Lane, 2000), but also at a national level overall with regard to potential purchase customers (Lane and Banks, 2010). In other terms, it is the barrel that endorses conventional means of transportations consumers' own perceptions and switching barriers and EVs business reputation and technological parameters. Also, behavioural aspects of usage, especially with regard to battery charging, will make a difference to charging and battery degradation cost to consumers over time (Lutz, 2012).

B. *Electric Vehicle Range Anxiety- EVRA*

Several factors pertinent to EVs' battery range appear to influence users' anxiety during driving the car which is known as the Electric Vehicle Range Anxiety- EVRA (Nilsson, 2011). It is believed that this anxiety does hinder the EV market expansion (DfT, 2011) . EVRA basically exists due to the short full-electric range the EVs have (HM Government, 2011). Full-electric range is the maximum distance a vehicle could travel without a need of charge (Eppstein et al, 2011). Therefore, it can be said that providing better charging infrastructure for EV users is one of the vital factors for market penetration. It has a direct relation with the EVRA and the social networking which in return affect the market growth. There are two types of infrastructure for EV; hard and soft infrastructures. Hard infrastructure consists of the charging points, smart grid, spatial environment factors including transportation pattern; whereas, the soft infrastructure covers the regulations, standards, schemes, business models and degree of community engagement (Beeton, 2011).

This level of anxiety is changeable and varies as it has a direct relation with two factors: (1) potential users awareness and knowledge about EV market and (2) its infrastructure. The second point is whether the infrastructure is integrated and reliable or not which is the main aim of this study. These two factors are the way that will develop the EV market from a niche market to a mass adoption which will have its positive commercial and business consequences and effects.

Researchers, investors, and public sectors have to endeavor to investigate the charging infrastructure gaps and users' needs in order to develop a transitional electric mobility plan within the active and operating countries in the North Sea region. Early adopters and targeted sectors tend to be within the European Union countries which are taking the environmental concerns on the top of their priorities in new developments, investments, and products. Nevertheless, these countries promptly reacted to the international call by the European Union to reduce the Co2 and GHG emission by the year 2020 and 2050 by 20% and 80% compared to 1999 respectively (AECOM, 2011).

III. Transport Sector Technologies and EVs' Networking

A. *Transport secter can support more technologies.*

The transport sector is an emerging market as endures a wide range of technologies and development. It enables vehicle-based, battery, charging types and charging supply chain technologies (Bongardt, 2011) which impact the long-term future strategies for EVs. Particularity battery technology and charging types (introducing fast charging), are evolving very rapidly to meet desired energy savings threshold, ranges, and speeds (European Commission, 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, 2011).

Enabling technologies with charging networks by the utilization of geo-visualization, micro-simulation and allowing the integration with Geographic Information Systems (GIS) applications shall assist EV planning authorities and policy makers. On the other hand, it enables business intelligence software and provides many kinds of mobile applications to assist end-users finding charging points and managing the charge process (Logica, 2011).

B. *Finding your nearest charging points*

Latest and advanced telecommunication and network support allowing users to be informed by their location with ease of use. EV manufacturers, technology providers, who recognize and provide EV charging points' location content data enabling navigation and location-based services, with the coordination of local services providers, covering EV clusters in many areas of US and Europe (C(ar), 2011). Figure 4 depicts the whole cycle of transferred signals. Versatile and handy built-in GPS receiver connected by the service provider via NAVTEQ can be installed in smart phones working as a mobile navigation device assisting EVs' drivers.

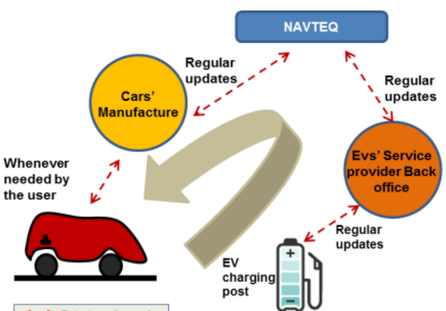

Figure 4. Data transfer digram

It this worth mentioning that one of the successful charging networks is the one provided by Nissan LEAF(LEAF, 2012) for all the points installed and operated by Nissan. Also the EV charging points mapping service provided by the main service provider of the North East of England, Charge your Car (CYC). All of the above systems, in order to let the navigation kit respond to an EV user's inquiry, provide directions to preferable charging points based on heterogeneous attributes.

The transferred signal shows the nearest publically-available charging infrastructure in the inquirer's route while advising them state of the post, parking availability, type of socket/charging and exact postcode (C(ar), 2011). Yet, there are other real-time attributes need to be conveyed like the occupancy state of the charging post showing how long it will take the driver to start charging his vehicle but it is beyond the scope of this study.

C. *It is a growing market – but will it be a mass market ?*

From the literature review initial findings, it is evident that the EV market is set to be a growing market, though not evenly across different countries, and with challenges for both the public and private sector (Frauenhofer IAO / PriceWaterhouseCoopers, 2010); Barlag, 2011; Beeton, 2012; Dings, 2009; Element Energy Limited, 2009; HM Government, 2008 and 2007; E4tech, 2007). With the ever more stringent constraints on environmental concerns and energy resources, EV are likely to attract more and more interest from the consumers and the automotive industry, though battery costs are still a major issue (Deutsche Bank, 2008). Although the market share still insignificant today, it can be predicted that EVs will progressively gain popularity in the market due to environmental and social-economic factors (Gao, 2007). It is not clear, however, which market share (and probably differentially so in different markets / countries, or even regions) EVs and HEVs will take (Caulfield et al., 2010; Smith, 2010). In parallel, success in this market segment depends on EVs becoming price competitive by providing promotional prices or subsidies (Sprei and Bauner, 2011; Coad et al, 2009; Diamond, 2009; Gallagher and Muehlegger, 2008). However, the market pernetration and expansion also depends on the public's understanding of the technology, social attitudes to it (Skippon and Garwood, 2011), and identifiable and communicated benefits on price over use over time returns (Anable et al, 2008; DeLuchi et al,1989), as well as status and environmental values (Heffner et al, 2006 and 2007), both at a micro- and a macro-level (Anable, J. et al, 2006; de Haan, 2009; FOM, 2010; Hayashi, 2001). This approach is already being implemented by many developed countries (Garling and Thøgersen, 2001; and AEA, 2009; Gärtner, 2005). One more relative advantage of the EV market is that the public sector in most countries prominently dominated by large fleet operators (EV20, 2012). These vehicles are typically used for short trips during normal working hours, which makes this market less sensitive to the technical limitations, electric-range problem, of current EVs (Garling and Thøgersen, 2001). The design of product platforms in urban setting for EV and supporting and associated infrastructure, including charging stations, matters a lot (Hatton, 2009), as do the overall infrstraucture development innovation strategy (ENEVATE, 2012; IET, 2012; Lumsden, 2012; Huétink et al, 2005), including the nexus with ICT systems (Hartkopf et al, 2010). Likewise, the development of business models for EV infrastructure is critical to sustain and expand them, with likely shrinking public revenues, investment and subsidies going into to it the medium term at least San Román et al, 2011). There is considerable evidence that EVs have to be introduced carefully, but in a very visable and promoted way, through an experimental approach, supported by demonstrations, trials and user engagement, and flanking research (Graham-Rowe et al, 2012; Technology Strategy Board, 2011; MEC Intelligence, 2011; Hoogma, 2002; Hoogma, 2000; Eberle and v. Heimholt, 2010). There is also space for alternative models to car ownership, such as leasing or car sharing clubs (Cairns, 2011), as well as generally strategies to transform and reduce (including with multimodal integrated transport strategies) the role of automobility in society (Geels et al, eds, 2011), and with local innovations and implementation critical (CARE-North, 2012; Pérez Montañez, 2011; Rausch, 2012; Kneeshaw, S. / EVUE, 2010; Kaufmann-Hayoz and Gutscher, 2001).

IV. PROPOSED HEURISTIC APPORACH

The chosen used tool to conduct the proposed methodology should be well-studied and selected carefully. The justification of such tool should be clear and reasonable as the modeling technique has to be selected to represent social agents interaction via an extensible, transferable and interactive end-user tool (Chen and Wang, 2012). This section starts with the recommended modeling technique and the perceived appropriate platform as per the literatures and previous studies.

A. *Simulation Models vs other solutions*

This study relates to individual dynamic social behavior types of phenomena which has lots of independencies, time-delayed occurrence, and 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 modeling. In simulation, all feasible solutions are texted randomly and several trials and runs are simulated with spatial representation of the environment. Randomness, time delayed, independencies, system interaction, complexity, spatial interaction, and individual decision rules (social force) are the reasons behind utilizing simulation modeling to solve the present problem (AnyLogic, 2009).

After selecting the simulation modeling, the type of simulation should be also decided based on the problem. There are mainly three types of simulation techniques: Discrete Event Simulation (process interaction with agents' behavior), Systems Dynamics (mathematical relationships) and ABMS in addition to other quantitative modeling techniques.

In this research, the ABMS has been selected and this was driven by the following criteria that meet the research problem. (M. Macal, North, M., 2009)

- *Agents behaviors reflect how individuals behave;*
- *Agents learn and engage in dynamic strategic interactions (space, time, information exchange(Chen, 2012));*
- *Agents have dynamic relations with other agents/ simulation environment*
- *Agents have spatial component to their behaviors and interactions;*
- *The past is no predictor of the future because the processes of growth and change are dynamic;*
- *Scaling up to arbitrary levels is important in terms of the number of agents, agents interactions and agent states;*

In ABMS several agents work together to find the best solution for a problem (Chen, 2009). They interact, influence each other and react with the surrounding environment. They have the ability to learn from their experience and adapt their behavior to be better suited to their surrounded environment. (North, 2010).

ABMS is a relatively recent technique which has been widely used to model complex systems that include autonomous, interacting agents (C. Macal, North, M., 2010). Agents are identified computerized units which are autonomous and goal directed (Schelhorn, 1999). Coordinating these agents together with their perceptions and reactions facilitate emergence of the phenomenon to be simulated (Frank, 2001).

The model's level of detailing, real-model-correlation ratio and scale are problem-based decisions which should be wisely decided. This is to enable the ABMS building and simulating a model that balances between needed complexity and acceptable assumptions(AnyLogic, 2009). Model accuracy is one of the key elements of evaluation. The more accurate is the virtual model, the more it is correlated to real model (Wang, 2004). Furthermore, the model should be kept as a flexible interactive tool that supports design, behaviors, system or process changes which eventually represents the desired phenomenon in a better way (Ehlert, 2001).

B. *Anylogic platform*

There are several platforms that can be used to simulate agent based modeling. The more common ones in use are (AnyLogic, Swarm, NetLogo, RePast). (Table 1) below summirizes a breif comparison of the key issues of some platforms showing AnyLogic edge as being capable to support hybrid models that include the three types of simulation techniques (Discrete Event Simulation, Systems Dynamics and ABMS (AnyLogic, 2009).

Table 1. Simulation platforms comparison

	3D capabilities	Simulation type support	Complexity	Programming	Time	Purpose
Swarm	3D	Pure ABM	simple	SCALA-object-oriented language	medium	Cellular Automaton
AnyLogic	3D	Hybrid	Complex+ Library	Code-writer- Drag and Drop + JAVA	Quick	Decision + Rules
NetLogo	3D	Pure ABM	simple	Template based + script	quick for simple problems	Decision + Rules
RePast	3D	Pure ABM	Complex	Hard-coded- JAVA	Slow	Decision + Rules
Vissim AND Legion	3D	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

AnyLogic (AnyLogic, 2009) is one of the tools that was sussessfully utilized in numeruos literature and it supports an ABMS praradigm. AnyLogic is recommneded in litrature due to its ability to rapidly compose industrial-strength agent based models within the same visual environment. It supports ready constructs for defing agent attributes and environmental model with a rich visulaization capabilities. It supports simulating large and complex systems (Borshchev, 2004).

V. Model development and system design

The model proposed in this paper is to be built based on the travel-dairies of EVs' mainstream drivers in the metropolitan city. In figure 5 the simulation environment is portrayed showing the multi-vehicle agents. The ABMS simulates each battery (EV) as an autonomous agent that has, as its unique decision making process, to the planning of its daily trips and determination of the charging schedules. It also models the charging posts with their different state-attributes. Charging posts vary between available, almost available, fully occupied and they are represented as green, yellow and red respectively.

A. *Agent's Attributes (algorithims)*

An Agent's attributes, which are the mechanisms underlying ABMS, need to be developed and assigned to run the simulation (Helbing, 2011); nevertheless, the model should be set as an interactive tool to support regular updates and changes. The first attribute is the simulation path. The simulation path of each autonomous agent (EV) starts by identifying the start point (the agent's home) and the desired dictation(s) within its route. The second one is the update time-interval which is will be on a daily basis in our simulation. Figure 6 depicts a single agent's movement algorithm which is the state diagram of the agent.

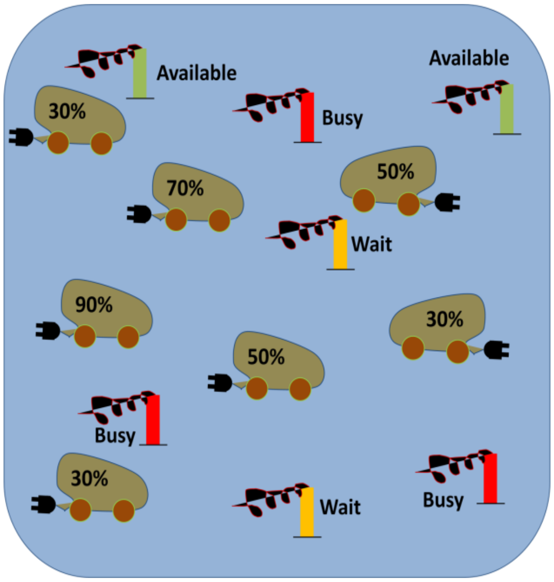

Figure 5. Simulation Environment overview

Figure 6.

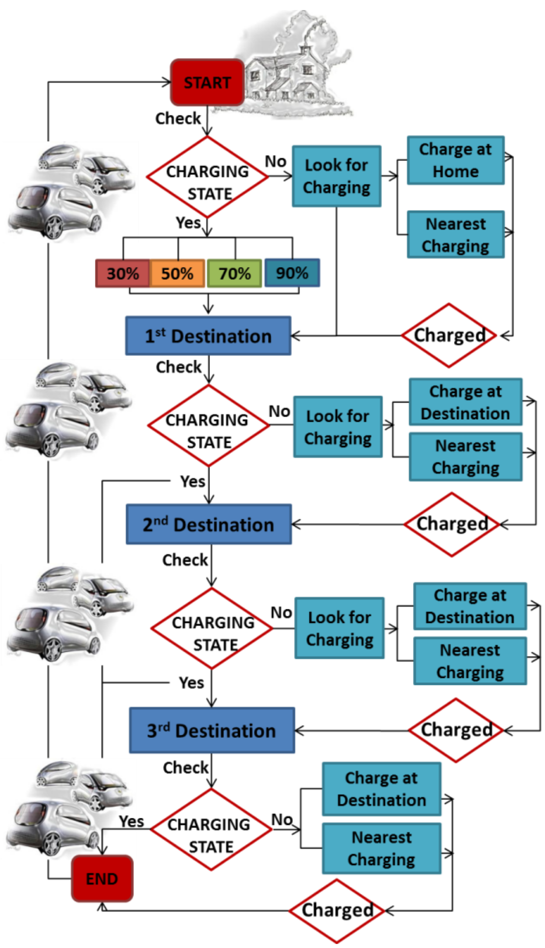

Figure 7. Agent movement algorthim (State digram)

Every day within the iteration timeframe, the agent starts new path with new destination(s) from its start point. The first decision it takes is to check the state of the EV battery and based on this decision the charging behavior / schedule is planned ahead for a single trip. This process happens every time the agent reaches a new destination till it ends up its daily-route by going back home.

Agents automatically direct themselves to the nearest charging points in terms of location and availability counting on personal and external factors which is the anticipated information required for the agent's decision.

B. *Simulation Assumptions and Agent definition*

To present the methodology and for the sake of this simulation, some settings and options are assumed to have a less- complex simulation which can still well represents the phenomenon. The change of these assumptions would give different scenarios but will not change the methodology framework.

The battery states are assumed ranging between 5 possible options for instance: 0%, 30%, 50%, 70% and 90% charge, which basically relates to whether the agent has recently charged their vehicle at home. The percentages can be changed. Possible number of destinations the car can drive is limited to three destinations /day in addition to returning home trip. This is calculated based on the average miles per day the users can drive in the simulated urban context. Homes are selected and limited to the basic demographic-usage information provided by the local service provider of the desired vicinity. The following charging scenarios are also assumed: (1) charging at home (domestic charging), (2) charging at work, (3) on-street charging (publically available charging). Figure 7 prescribes the definition of each agent.

According to a survey of EVs' users in the North East of UK, done by Plugged-in Places program in 2012, most of the current users tend to use domestic charging as it is more convenient for consumers and also delivers energy benefits especially when it is at the night-time, off-peak (McDonald, 2012).This study focuses on the public and non-domestic available charging points.

The proposed algorithm in this paper is preliminary as it shows the overall picture of the agent system design; other factors regarding the iteration time, number of agents, charging schedules, charging types are to be considered in further phases of the research.

Each autonomous agent interacts directly with other agents and indirectly with the simulation environment (Chen, 2012). In this case, the direct interaction is performed between the EVs where the indirect one is between the single agent (EV) and the charging points, routes, and destination(s). The latter interaction affects the agent's behavior and reaction in return. This process is a continuous process that happens within the simulation runs; it is called the simulation/ agent's framework as displayed in the figure 8.

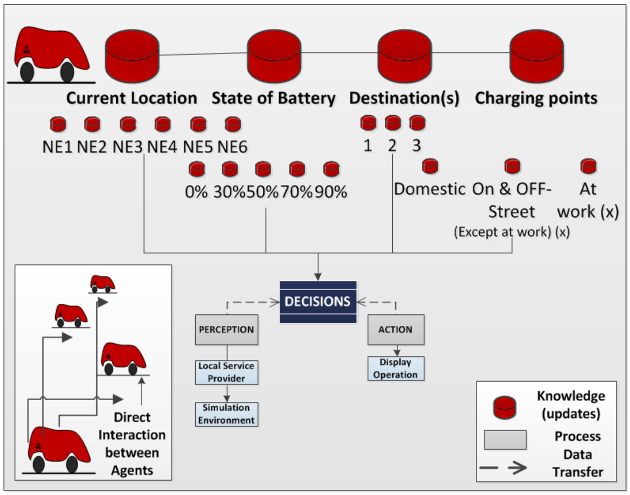

Figure 8. Agent definition digram

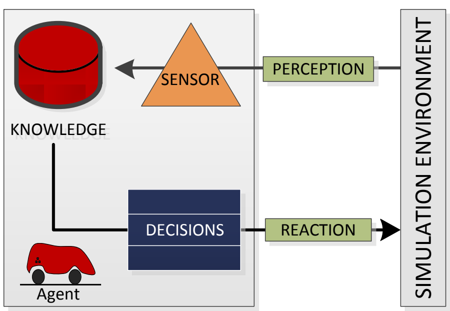

Figure 9. Agent's framework

VI. Simulation and Performance Evaluaiton

Once the first phase of the simulation is developed which is called as the pre-model phase (Schelhorn, 1999), the data simulated is compared to the real case of a metropolitan area. The performance measure is the usage of charging points distribution. This happens by screening and identifying the charging points that are over-used, mid-level, and under-used.

This comparison is based on the observations and reactions of the EVs' real and virtual drivers. This is to ensure the accuracy/quality of the digital representation and how well it portrays the real users' information (phenomena) (Acha, 2011).

As shown in figure 9, the more accurate the inputs, the more reliably the phenomenon is simulated whereas the better correlation between the real and virtual models, the higher accuracy and reliability are the results and analysis.

The next step is to run the model via AnyLogic by plotting the preliminary data provided by the local service provider, run different iterations while changing agents attributes and other factors, analyze the results, and come up with recommendations and headlines.

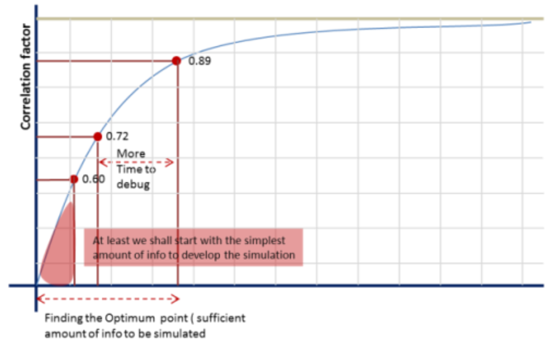

Figure 10. Theoritical corelation graph between real and vertual model simulaiton

VII. Conclusion

This paper has presented an overview of a heuristic approach to investigate a social-economic phenomenon. A methodology to investigate the gaps in the EV charging infrastructure is proposed to investigate whether it supports current users and whether it can accommodate more future users. The ABMS technique has been the employed in former literature in several areas due to its capabilities to study numerous iterations of different design with the combinations of different components and different topology configurations (Gao, 2007). In this research project, the ABMS is applied to new data which is the e-mobility system and spatial environment.

The proposed agents' state diagram (algorithm) realizes the idea using collaborative assignments throughout the iteration timeline. ABMS is a promising mechanism that can be used to develop a decision support tool to improve EV networks planning processes. With more correlation between the real and virtual model, more analysis can be conducted.

Finally, this approach is presented to assist planning authorities and policy makers taking decisions related to the EV sector. It is generic, it can be adopted with any mobility system/cluster to determine or investigate different phenomena.

VIII. Next Steps

The next step of this research which is beyond the paper's scope is to develop the model by using AnyLogic utilizing 3D City models to simulate the above phenomena for a metropolitan area in the North East of UK. The North East is a very active EV region that has launched several initiatives and programmers relate to EV technologies, infrastructure, and schemes. It was one of the eight regions which were funded by the UK government to launch plugged-in-places program in November 2009 (OLEV, 2011). The inner urban core of Newcastle upon Tyne is to be simulated for the PhD research. Information about usage is to be provided by the local service provider, and triangulated by Tyne and Wear local authorities.

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