

# Real-Time Electric Mobility Simulation in Metropolitan Areas

## ***A case study: Newcastle-Gateshead***

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**Abstract.** *This paper discusses the potential of emerging digital representations of built environments coupled with agent-based modelling (ABM). A new set of urban transportation data is provided as an input which is the electric vehicles (EVs) population of one of the UK metropolitan areas. The study is a part of a PhD research that focuses on investigating computer-aided software to develop a virtual route for electric mobility in the North Sea Region. An overview of agent-based simulation platforms is discussed. Electric mobility system has particular paradigms that differ from conventional urban transport systems; a comparison is presented followed by the recommended approach of integrating the two techniques (visualization and simulation). Finally, the architecture of agents' algorithm within the EVs network is presented through a case study of virtual Newcastle-Gateshead model.*

**Keywords.** *E-mobility; electric vehicles; simulation; agent based modelling; virtual city models.*

## **INTRODUCTION**

This paper discusses mainly two computer-based techniques for real-time electric mobility simulation in urban areas: (1) simulation and (2) visualization. In this context, visualization is the digital representation of urban environments from aerial view maps to the more accurate city plans produced to the 3D virtual city models (VCM) (Horne et al., 2007). In the planning context, the advent of computer aided design (CAD) and three-dimensional (3D) modelling shaped the way in which we can better create and simulate metropolises (Thompson and Horne, 2006). Vehicular simulation is one of the simulation applications that depicts mobility system, analyzes, and studies its characteristic to procure reliable realistic

results (Paruchuri et al., 2002); its output analysis is a very relevant step in simulation approach (Ali et al., 2007) where it is sometimes integrated with other models e.g. energy, air quality, noise, etc. The world now is approaching green and smart urban transport means to reduce caused Co2 and green house gases (GHG) emissions. Low carbon emissions vehicles, electric and hybrid, are considered to be the optimal means of alternative transport that would eventually reduce the emissions hence save the environment (Logica, 2011); (Strahan, 2012). As any other phenomenon, the electric mobility (e-mobility) pattern has to be studied in order to analyze the current state of the users and determine needs

and demand for potential future users. Integrated models that combine e-mobility system with other models, have been simulated before for particular marketing and environmental studies e.g. energy model (Acha et al., 2011), market penetration (Zhou et al., 2011), power grid (Kintner-Meyer et al., 2010), customer choice (Mueller and de Haan, 2009). The paper tries to address the following set of questions:

- What are the common and extraordinary paradigms between conventional and electric mobility systems?
- What are the possible approaches to represent micro-dynamic mobility system?
- Is it viable to utilize 3D city models to simulate/present e-mobility system?

## ENVIRONMENT AND TRANSPORT SECTOR

Transportation and logistics is the engine for economic growth. It is crucial to move goods, people around the countries, and allow accessing employment, services, leisure activities and socialize with wider communities (HMGovernment, 2011). It also allows businesses to expand and create wealth and employment. However, it is, the internal combustion engine vehicles (ICVs) type (Herbert, 2011) considered as a major contributor to GHG, and hence has a considerable carbon / environmental footprint emissions. In recent years, the environmental burden of urban road traffic has been worrying governments and authorities of developed countries (OLEV, 2011). A projected look into the future indicates a higher population growth rate, and increasing urbanization trends where the automobile population is growing at a much faster rate (Garling, 2001). Accordingly, researchers, policy makers, and many governments across the OECD countries (IEA, 2011) have focused on low carbon emissions vehicles industry and market considering alternative means of transportation (IMechE, 2000) e.g. hybrid, electric, hydrogen/fuel cell (Herbert, 2011) because of the expected depletion of fuels (Wee et al., 2012).

## URBAN DATA VISUALIZATION- 2D PLANS TO 3D CITY MODEL

Urban data has been used before within the two different forms of digital representation: two dimensional (2D) and three dimensional (3D) in numerous applications. With a particular attention to 3D, the extensive available urban settlements data nowadays of developed countries has emerged opening new channels for more applications: town planning, architecture, microclimate investigations or telecommunication (Carneiro, 2008). As per a very recent survey was conducted, there are up to 1036 virtual city models worldwide; this indicates the increasing development of digital representation technology (Morton et al., 2012). The representation of geometry and topology of 3D objects memorizes the shape and configuration of the city. The challenge in visualization is to present it in an uncomplicated way while keeping it on an acceptable level of details and density (Thompson and Horne, 2006). Wang (2005) has mentioned that researchers started managing and presenting geographic information using true 3D representation and forms of analysis of the built environment and present the outcomes.

## SIMULATION MODELLING

Simulation modelling has passed through different stages of development to replicate social sciences (Troitzsch, 1997), (Figure 1) shows the present study focus.

Simulation has been widely used in social sciences (Wang, 2005) and the occurrence of its collective phenomena always attached researchers;

For simulating real-time network, simulation solution will better fit due to the occurrence of state changes over time, discrete events and discontinuous equations where by using analytical solutions, the time factor is not considered as outputs functionality depends on the input (Borshchev, 2004).

Simulation provides solutions whilst considering a set of rules e.g. equations, mathematical equations/from theories (Lombardo and Petri, 2004), flowcharts (Borshchev, 2004) Cellular Automata (CA) (Lombardo and Petri, 2004).

Microscopic simulation provides detailed environment of vehicles movement and facilitates coupling Intelligent Transportation Systems (ITS) (Burgout, 2004).

## Vehicular Simulation

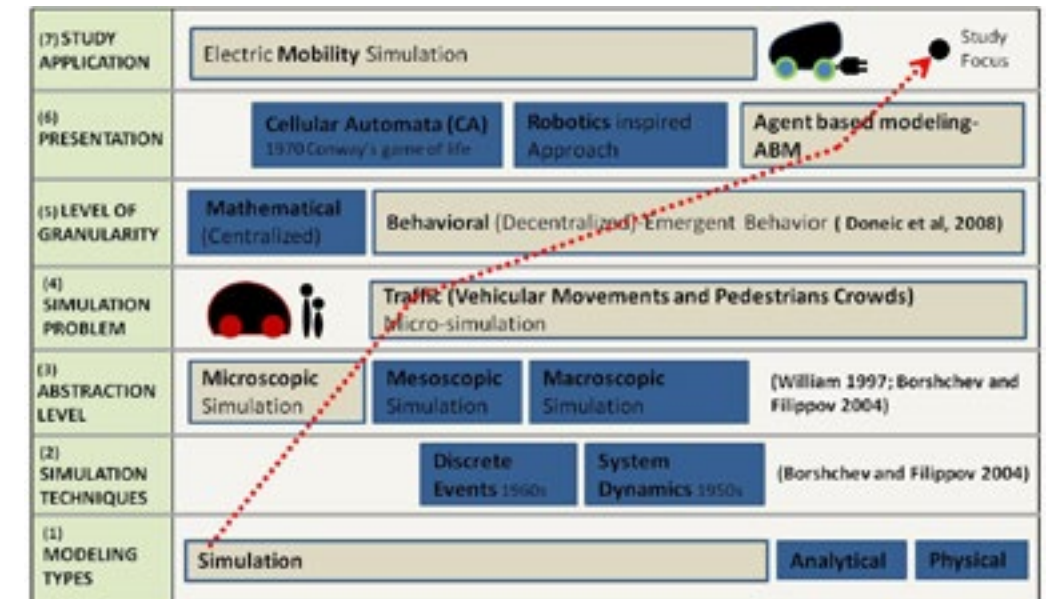
Vehicular simulation as one of the advanced simulation applications that is capable to simulate mobility population, behavioural characteristic, and direct and indirect interactions while allowing a better understanding of astronomical observations (Helbing, 2011). This type of simulation can be achieved via two different approaches; mathematical (centralized) or behavioural (de-centralized) approaches shown in (Figure 1). In centralized approach, car-following laws and scheduling techniques are used which are not generic and can not portray many traffic phenomenon, facets, and behavioural characteristics. On the contrary, de-centralized simulation is more sensible to population behaviour being simulated (Doniec. A, 2008). Hence, the present

study falls under this approach by employing agent based modelling (ABM) to develop a spatial intelligent agents (Narzisi, 2008). Agents in such modeling, maintain preference, act differently (Summala, 2005), be opportunistic and anticipate situations (Björklund and Åberg, 2005).

## Agent based modelling-ABM.

Agents sense and act upon their environment, try to fulfil a set of goals in a complex-dynamic environment (Schelhorn, 1999). They involve both goals and constraints forming and emerging the overall complex network (Frank, 2001). Independent perceptions and individual decisions are taken and virtually presented (Li et al., 2006). Agents work together to find the best solution for a problem (Chen, 2009), learn from their experience and adapt to better suit their environment (North, 2010). (Tables 1 and 2) introduce a collection of simple and intuitive ABM platforms.

Figure 1 Present study area of research- dotted line arrow shows the employed approach to simulate new phenomena



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 behaviour. 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 and 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 1 ABM platforms' techniques, environments, and applications(Railsback et al., 2006); (Luke et al., 2005); (Doniec. A, 2008).

Table 2 ABM platforms pros and cons- (Railsback et al., 2006); (Luke et al., 2005); (Doniec. A, 2008).

Platforms	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 visualization suite, GIS, fast, high complex problems, good functionality of traffic flow, measure of effectiveness (MOE's) reports.	Mathematical models are behind the modelling (check centralized 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 organized, 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

Vehicular simulation using ABM was applied in 1998 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. 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 external centralized process. Doniec et al. (2008) developed a more realistic behavioural model by simulating drivers' behaviour in real simulator depicting their local autonomous behaviours while applying opportunistic and anticipation traits. Our study continues on investigating the appropriate technique to simulate EV population. A hybrid model that combines me-

so-scale (emergent behaviour of infrastructure usage) and micro-scale (related to individual charging behaviour) using decentralized ABM while adding artificial intelligent (AI) rules and learning algorithms to find the system evolution (Lombardo and Petri, 2004).

## EV MARKET IN BRIEF

In Europe and with a particular strategic focus on private and non-commercial electric cars, the total number of registered cars can indicate the level of market penetration. In the first half of 2011, the total EVs registrations were 5,222 (JATO, 2011) which depicts the EV niche market that is in a real need of expansion and creation of conditions for growth for the mass adoption (Graham-Rowe, 2012). The market is hampered by many factors e.g. cost, range, capacity, visual appeal (Graham-Rowe, 2012) speed, and lack of recharging infrastructure integration (Garling, 2001); (Hatton et al., 2009). The higher upfront

price of EV compared to conventional car is one of the considerable barriers by potential users (Garling, 2001); nevertheless, the degree of urban geography, market maturity and infrastructure have their effects on market growth (JATO, 2011) as well. However, the roll out of intelligent infrastructure, creation of innovative service models and changes in consumer behaviour are all positive transformations that indicate that it is a growing market (Beeton, 2011) with a positive effect on climate change (Herbert, 2011)

Several factors pertinent to EVs' battery range appear to influence users' anxiety during driving; known as Electric Vehicle Range Anxiety- EVRA (Nilsen, 2011). It is believed that this anxiety hinders 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, 2011). Therefore, it can be said that providing accessible and high visible

Paradigms	Conventional (non EV) Mobility	E-Mobility
Problem class	Congestion, 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 CO <sub>2</sub> , increase market uptake
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	Simulations were conducted with different structure: A- Layers: (1) Physical layer (2) Mental layer (3) Feedback layer (4) Condition layer B- Layers: (1) Reference layer (2) Route feature layer (3) Event layer C-Cellular Automata: (1) Estate (fixed) (2) Agent (non-fixed) D-Classes: (1) Environment(2) Agents	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)

Table 3 Conventional (non-EV) mobility and e-mobility comparison: (Arampatzis et al., 2004);(MVA, 2011); (Burghout, 2004);(Hall, 1997);(Benenson and Torrens, 2003);(Bazzan, 2005);(Ali et al., 2007);(Jiang, 2000);(Ali and Moulin, 2007B);(Fellendorf, 2010);(Chiu et al., 2005);(Lombardo and Petri, 2004);(Balmer et al., 2008);(Narzisi, 2008);(Element Energy Ltd, 2009);(Arampatzis et al., 2004);(Bell et al., 2000);(Paruchuri et al., 2002);(Doniec. A, 2008);(Bishop and Gimblett, 2000);(Acha et al., 2011);(Wang, 2005)

Interactions	More direct interaction with agents	More interaction with the environment
Route Choice	Travel time, distance, and cost	Travel time, distance, and battery state
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
Routes Type	Real-time path searching-routes/ sub-routes	
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 battery, charging time, parking lots. Speed, gap, lanes, and brake are N/A.
Behaviour	Vehicles traits/flow in traffic (route)	Charging behaviour (profile)
Key Components	Roads, intersections, traffic lights, pedestrians, vehicle's speed and size	Vehicles and battery type and capacity, no. of users, charging points
Emerging GIS Visualization	Possible, works as repository of the data and user interface Required for better presentation	
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

charging network (hard and soft infrastructure (Beeton, 2011) generates interest amongst consumers and encourages uptake (Element Energy Ltd, 2009). Towards developing a unified ecosystems and smart cities, investigating and predicting the consumers' response is a significant challenge EV marketers are facing (Beeton, 2011); (Strahan, 2012)

In vehicular simulation (Valverde and Sol'e, 2002) and particularly in the context of EVs, it is very interesting to study and analyse emergent behaviour. This behaviour is a collective macro-scale behaviour

coming from the bottom-up (Crooks et al., 2008) and resulting of agents' coordination (Morton, 2011);(Bonabeau, 2002)(Li et al., 2006). EV patterns or clusters have different nature from normal vehicular patterns. To simulate such pattern, we need to understand its nature and parameters so that we can set the right configuration and have reliable simulation outcomes. A wide range of applications and research studies have focused on the conventional mode of transport and traffic management using micro-scale simulation to present a specific phe-

nomenon. Whereas, little literature was dedicated to EV population and particularly those are focusing on planning and policy making area. An overview of the main paradigms of e-mobility system has to be declared and studied to better understand the system hence better develop the simulation environment and agents' architecture. The following (Table 3) is considered as one of the main steps of the process of simulating EV population. It summarizes the paradigms of conventional mobility and the extraordinary paradigms of EV mobility systems and it is followed by authors' observations.

As it can be observed from (Table 3), 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 reflects that EV population is a subset of the conventional mobility data. The mutual paradigms are clear and recognized e.g. roads network layer, some of the agents' behaviours and traits, goals scale, visualization and 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. For an example, both EV and non EV can be typically replicated within a conventional mobility simulation where network and controlling rules will be applied to both similarly. Since the vehicle type is not an influential parameter that may affect the simulation results, the EV will not be recognized as a low carbon vehicle in this particular simulation. However, in other applications pertinent to air quality and noise where the vehicle type affects the study, EV would be recognised as it would completely differ in environmental and acoustical statistics (Hodges and Bell, 2011). The present study targets social scientists, policy makers and planning authorities, who are concerned with the EVs hard and soft infrastructure. In this case, the vehicle type is a major influential factor of the simulation as the outcomes of the simulation would assist in the EV urban planning and infrastructure processes. Drivers' charging behaviour should be depicted

and analysed after running different scenarios (number of users, charging points locations..etc); such behavioural characteristic needs distinctive setup. Thus, we can conclude that EV population is a small part of a large group; depends on the application and the end-users' requirements, the simulation setup changes accordingly.

### **INTEGRATING SIMULATION WITH VISUALIZATION FOR E-MOBILITY SYSTEM'S STUDY**

The aim of this study is to investigate the potential integration of simulation and visualization techniques to better represent EV population in metropolitan areas. We are witnessing a long history of the development of simulation, 3D visualization and also geographic information system (GIS) in research and practise. However, the integrative uses of these techniques are still in early stages. For urban environments and transportation systems planning and policy making, the importance of spatial visualization, VCM, lies in its potential for improving the quality of decision-making (Wang, 2005). VCMs help presenting large amount of data, identifying patterns (Ware, 2000) and presenting interdependencies hence better understanding (Helbing et al., 2000). VCM is based on CityGML data format which is a profile of GML3. CityGML implements an interoperable, multi functional, multi-scale and semantic 3D city model. It supports several levels of detail (LoD) as identified by Kolbe et al. (2005) which start from LoD 0, the coarsest level and it contains two and half dimensional digital Terrain (Terrain surface: foremost geographic object and a base of 3D space in VCM (JIN et al., 2005)), to LoD4 which is detailed architectural models including interior and furniture. 2D maps and plans with occasional prospective views and static images presentation technique has been used for urban-planning purpose (Wang, 2005). Planners primarily work on a 2D analytical mode (Pietsch, 2000, Orford et al., 1999). However, for the purpose of the study, a VCM with LoD 2 which presents building textures, networks and infrastructure would perfectly suit.

Towards better spatial planning and micro-dynamic network outputs, the integration of 3D visualization and simulation modelling can represent the dynamics within a realistic visual environment (Figure 2) instead of non-visual approaches such as text and tables (Wang, 2005). In order to represent mobility system, three ways of integrating simulation and visualization techniques can be considered: (1) 2D visualization of ABM simulation, (2) 2D simulation presented in 3D environments (simulation is draped on a 3D Terrain surface) or (3) simulation in a 3D modelling environment.

Since the integration concept has proven its importance and vitality, the guidance in choosing the approach to be employed, is the capability of the simulation platform and how good it would accommodate 3D visualization. Following the evaluation of the platforms presented early this paper, and on the purpose of the present study, the selected platform should be reliable and capable to simulate behavioural characteristics of drivers, give same results with less effort, simplify the simulation environment configuration and provide more flexibility in changing simulation parameters and future situations.

VISSIM platform showed good results in terms of 3D visualization. From literature, it has been utilized before to simulate traffic and it has proven success in merging traffic simulation with 3D modeling (Norden et al., 2009). However, due to the unique nature of EV population as observed from (Table 3), EVs simulation will not require massive traffic and complex network data as an inputs. A more agent-based oriented platform in modeling would get more credits and higher preference. Anylogic is ABM platform in the first instance, 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, state charts options and API (Application Programming interface) would perfectly facilitate modelling EV population with less coding effort. To conclude, integrating simulation outputs with 3D modelling is the recommended approach for simulating EV for urban planning purposes. 2D simu-

lation to be conducted in ABM platform (AnyLogic is recommended for its capabilities), exported, draped in VCM creating spatial dynamic interaction model.

Finally, we can now clearly clarify the five main steps needed to develop the EV Agent (EVA) simulation: (1) understanding the nature of the system, (2) evaluating available platforms and selecting appropriate one for the study focus, (3) developing agent's architecture, (4) simulating the population using appropriate platform, and finally (5) integrating the simulation with VCM. The setup, configuration, and environment of the simulation is a multi criterion decision:

- Simulate micro-dynamic large-group simulation (vehicular movements);
- Fast execution time, stable, interactive and reliable agent based modelling;
- Requires less coding for adding IF THEN simulation rules;
- Has a 2D and can be coupled to realistic 3D visualization solutions (Figure 2);
- Accepts GIS in case of geo-simulation is required;
- Can simulate societal and behavioural models;
- Has an API collects and extracts real-time information, exports to 3D visualization suite (if needed for visualization purposes);

### **CASE STUDY: NEWCASTLE-GATESHEAD AREA**

The chosen focus area is the inner urban core of one of the UK North East metropolitan areas, Newcastle upon Tyne, was selected as the research pilot study. The simulation input data is based on the real information about EV drivers and their usage which is provided by CYC back office (C(harge) Y(our) C(ar), 2011), EV local service provider for the UK North East region. The selection criterion of the case study is based on meeting two conditions: (1) Active in EV market and (2) leading in the 3D visualization techniques. Newcastle has proven success in providing initiatives and schemes for low carbon emissions vehicles. It is leading the North Sea region in promoting EV market. Since 2009, Built Environ-

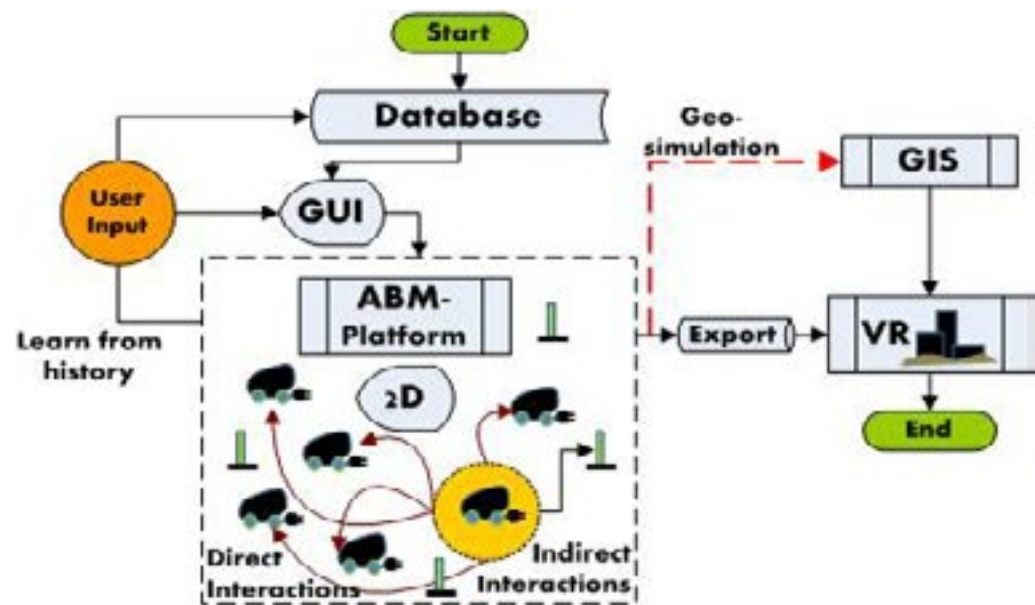


Figure 2 Simulation and visualization diagram showing flow of data.

ment Visualization Centre at the school of the Built and Natural Environment, Northumbria University in collaboration with Newcastle City Council and Gateshead Council has been developing the virtual Newcastle-Gateshead (VNG) to be used for planning and various different applications.

### The Artificial Brain Development of EV Drivers' Agents

The ABM simulates each (EV) battery as an autonomous agent which makes its unique decisions by daily planning (O-D matrix) and finding charging points (Elbanhawy et al., 2012). The following points summarize agent's attributes and model assumptions:

- Simulation path: EV agent starts defining the Origin-Destination(O-D) ;
- Update time-interval: On a daily basis;
- Route Choice/Decisions: Daily basis, and at every destination, the agent chooses its path with new destination(s), checks the EV battery hence charging schedule;

- Battery states: 0%, 30%, 50%, 70%, 90% (depends on domestic charging);
  - No. of possible destinations: 3 destinations /day (based on average miles/ day);
- Charging scenarios: (1) Domestic (2) At work, (3) On and off street (public)(Elbanhawy et al., 2012). The model outcomes will be calibrated by the information about real-world usage provided by CYC. The correlation factor between the simulation and real Newcastle-Gateshead will be monitored. Eventually, more information is to be added and simulated while validating and calibrating the model before trying different states.

### CONCLUSION

This study aims at investigating the paradigms of e-mobility system. An overview showed the common and extraordinary parameters and configurations between conventional and e-mobility systems. E-mobility is quite a distinctive pattern to be simulated by micro-dynamic ABM where an emergent behaviour to be observed as an output. The simulation has

five main stages that start with scanning the market and understanding the EV mobility nature, to selecting appropriate platform, to developing agent's architecture, to developing the simulation modelling, to finally analyzing it and giving recommendations. Recommendations and observations shall depict the current state of the infrastructure network and individual travelling patterns and charging behaviours. For perfectly fitting the purpose, 2D simulation is to be conducted via ABM platform and to be integrated with 3D city model. This would help presenting the phenomenon hence better analyses opportunities for planners and policy makers.

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### REFERENCES

ACHA, S, VANDAM, K, KEIRSTEAD, J and SHAH, N 2011, 'Integrated Modelling Of Agent-Based Electric Vehicles into Optimal Power Flow Studies', 21st International Conference on Electricity Distribution, Frankfurt, Germany.

ALI, W and MOULIN, B 2007, 'GeoSimulation of human behaviors in micro-scale geographic environments: The case of the shopping behavior in a mall', 9th International Conference on GeoComputation, Ireland.

ALI, W, MOULIN, B, BEDARD, Y, PROULX, M and RIVEST, S 2007, 'Coupling Multiagent Geosimulation and Spatial OLAP for Better Geosimulation Data Analysis', URISA, vol. 19, pp. 23-32.

ARAMPATZIS, G, KIRANOUDIS, CT, SCALOUBACAS, P and ASSIMACOPOULOS, D 2004, 'A GIS-based decision support system for planning urban transportation policies', European Journal of Operational Research, vol. 152, pp. 465-475.

BALMER, M, CETINB, N, NAGELC, K and RANEYB, B 2004, 'Towards truly agent-based traffic and mobility simula-

tions', AAMAS, New-York, USA.

BALMER, M, MEISTER, K, RIESER, M, NAGEL, K and AXHAUSEN, KW 2008, 'Agent-based simulation of travel demand: Structure and computational performance of MATSim-T', 2nd TRB Conference on Innovations of Travel Modeling, Portland, OR, USA.

BAZZAN, A 2005, 'A distributed approach for coordination of traffic signal agents', Autonomous Agents and Multi-Agent Systems, vol. 10, pp. 131-164.

BEETON, D 2011, 'EV ecosystems, Update on Annex XVIII: EV Ecosystems Istanbul, Turkey.

BELL, M, DEAN, C and BLAKE, M 2000, 'Forecasting the pattern of urban growth with PUP: a web-based model interfaced with GIS and 3D animation', Computers, Environment and Urban Systems, vol. 24, pp. 559-581.

BENENSON, I and TORRENS, PM 2003, 'Geographic Automata Systems: A New Paradigm for Integrating GIS and Geographic Simulation', GeoComputation Conference, pp. 24-30.

BISHOP, ID and GIMBLETT, H 2000, 'Management of recreational areas: GIS, autonomous agents, and virtual reality', Environment and Planning B: Planning and Design, vol. 27, pp. 423-435.

BJÖRKLUND, GM and ÅBERG, L 2005, 'Driver behaviour in intersections: Formal and informal traffic rules', Transportation Research Part F: Traffic Psychology and Behaviour, vol. 8, pp. 239-253.

BONABEAU, E 2002, 'Agent-based modeling: methods and techniques for simulating human systems', Proceedings of the National Academy of Sciences of the United States of America, vol. 99, pp. 7280-7287.

BORSHCHEV, A and FILIPPOV, A 2004, 'From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools', The 22nd International Conference of the System Dynamics Society, Oxford, England, pp. 959-966.

BURGHOUT, W 2004, 'Hybrid microscopic-mesoscopic traffic simulation', PhD, Royal Institute of Technology.

C(HARGE) Y(OUR) C(AR) 2011, RE: Interviewing a manager working in Charge your Car.

CARNEIRO, C 2008, 'Communication and visualization of 3D urban spatial data according to user Requirements: Case study of Geneva', The international archives of the photogrammetry, remote sensing and spatial information



- sciences, Geographical Information Systems Laboratory (LASIG), Ecole Polytechnique Fédérale de Lausanne (EPFL) CH-1015, Lausanne, Switzerland, pp. 6.
- CHEN, Y and WANG, B 2009,'Towards Participatory Design of Multi-agent Approach to Transport Demands',*IJCSI International Journal of Computer Science Issues*, vol. 4, no. 1, pp. 49-56.
- CHIU, DKW, LEE, O and LEUNG, HF2005, 'A Multi-Modal Agent Based Mobile Route Advisory System for Public Transport Network', In: PRESS, I. C. S., ed. 37th Hawaiian International Conference on System Science, Big Island, Hawaii, CDRom, 10.
- CROOKS, A, CASTLE, C and BATTY, M 2008,'Key challenges in agent-based modelling for geo-spatial simulation', *Computers, Environment and Urban Systems*, vol. 32, pp. 417-430.
- DFT 2011, Transport energy and environment statistics, UK: DfT. Retrieved online: <http://www.dft.gov.uk/statistics/releases/transport-energy-and-environment-statistics-2011/>
- DONIEC, AMP 2008,'A behavioral multi agent model for road traffic simulation', *Engineering Applications of Artificial Intelligence*, vol. 21, pp. 1443-1454.
- ELBANHAWY, EY, DALTON, R, THOMPSON, EM and KOTTER, R 2012, 'A Heuristic Approach for Investigating the Integration of Electric Mobility Charging Infrastructure in Metropolitan Areas: An Agent-based Modeling Simulation', 2nd International symposium on Environment Friendly Energies and Applications- EFEANewcastle upon Tyne, UK, pp. 74-87.
- ELEMENT ENERGY LTD 2009,'Strategies for the uptake of electric vehicles and associated infrastructure implications', In: CHANGE, T. C. O. C. (ed.), Cambridge, UK.
- EPPSTEIN, M, GROVER, DAVID K, MARSHALL, JEFFREY S, RIZZO, DONNA, M 2011,'An agent-based model to study market penetration of plug-in hybrid electric vehicles', *Energy Policy*, vol. 39, pp. 3789-3802.
- FELLENDORF, M, VORTISCH, P 2010,'Microscopic Traffic Flow Simulator VISSIM', In: SCIENCE, I. S. I. O. R. M. (ed.), *Fundamentals of Traffic Simulation*, LLC: Springer Science+Business Media.
- FRANK, ODI 2001, 'Agent -based simulation of Human way-finding', Germany.
- GARLING, A and THØGERSEN, J 2001, 'Marketing of electric Vehicles', *Business Strategy and the Environment*, vol. 10, pp. 53-65.
- GRAHAM-ROWE, E, GARDNER, B, ABRAHAM, C, SKIPPON, S, DITTMAR, H, HUTCHINS, R, STANNARD, J 2012,'Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations', *Transportation Research Part A: Policy and Practice*, vol. 46, pp. 140-153.
- HALL, F 1997,'Traffic Stream Characteristics', In: GARTNER, N, MESSER, CJ,RATHI, AK (ed) *Traffic Flow Theory*, Oak Ridge National Laboratory.
- HATTON, CE, BEELLA, SK, BREZET, JC and WIJNIA, YC2009, 'Charging stations for urban settings: the design of a product platform for electric vehicle infrastructure in dutch cities', *EVS24 International battery, Hybrid and Fuel Cell Electric Vehicle Symposium*, Stavanger, Norway.
- HELBING, D and BALIETTI, S 2011,'How to Do Agent-Based Simulations in the Future: From Modeling Social Mechanisms to Emergent Phenomena and Interactive Systems Design', *Santafe Institute working papers*, paper #11-06-024.
- HELBING, DI, FARKAS, I and VICSEK, T 2000,'Simulating dynamical features of escape panic', *Nature*, vol. 407, pp. 487-490.
- HERBERT, S 2011, EV Updates, In: NEWCASTLE CITY COUNCIL, STO (ed), Newcastle upon Tyne: Newcastle City Council.
- HMGVERNMENT 2011,'The Carbon Plan: Delivering our low carbon future'.
- HODGES, N and BELL, M,'A Pervasive Network for Environmental and Traffic Monitoring', *UTMC Conference – Workshop Session 2 – Novel Traffic Management Techniques*, Newcastle upon Tyne, UK. Leicester City Council and Newcastle University, Transport Operations Research Group (TORG), pp. 34-50.
- HORNE, M, THOMPSON, EM and PODEVYN, M2007, 'An Overview of Virtual City Modelling: Emerging Organisational Issues', *10th International Conference on Computers in Urban Planning and Urban Planning Management ( CUPUM07)*, Iguassu, Falls, Brazil, pp. 1-16.
- IEA 2011, Technology Roadmap, Electric and plug-in hybrid electric vehicles, France: IEA- International Energy Agency.
- IMECHE 2000,'Alternatively Fuelled Vehicles', Professional Engineering Publications for the ImechE, Institution of Mechanical Engineers, Institute of Road Transport Engineers, Energy Saving Trust; Institution of Electrical Engineers.
- JATO 2011, Incentives Fail to Simulate European electric Vehicles Sales.
- JIANG, B2000, 'Agent-based approach to modelling urban and environmental systems within GIS', In: FORER P, YAAHJ, ed, 9th Int. Symposium on Spatial Data Handling, Beijing.
- JIN, B, BIAN, F, ZUO, X and WANG, F 2005,'Study on Visualization of Virtual City Model Based on Internet', *Geo-spatial information Science*, vol. 8, pp. 115-120.
- KINTNER-MEYER, M, NGUYEN, TB, JIN, C, BALDUCCI, P and SECREST, T 2010,'Impact Assessment of Plug-in Hybrid Vehicles on the U.S. Power Grid', *The 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exhibition*, Shenzhen, China.
- KOLBE, T, GROGER, G and PLUMER, L2005, 'CityGML – Interoperable Access to 3D City Models', In: VERLAG, S, ed, *International Symposium on Geo-information for Disaster Management*, Delft, pp. 21-23.
- LI, Z, SIM, CH and LOW, MYH2006, 'A Survey of Emergent Behavior and Its Impacts in Agent-based Systems', *IEEE International Conference on Industrial Informatics*, pp. 1295-1300.
- LOGICA 2011, Logica annual report 2011, Shaping a sustainable future, Europe: Logica.
- LOMBARDO, S and PETRI, M 2004, Multi Agent System: three behavioural frameworks integrated into a GIS.
- LUKE, S, CIOFFI-REVILLA, C, PANAIT, L, SULLIVAN, K and BALAN, G 2005,'MASON: A Multi-Agent Simulation Environment', *Simulation Modelling Practice and Theory*, vol. 81, pp. 1-7.
- MORTON, C, SCHUITEMA, G, and ANABLE, J 2011, Electric Vehicles: Will Consumers get charged up? *Open University, Milton Keynes*, 1-13.
- MORTON, PJ, HORNE, M, DALTON, R and THOMPSON, EM 2012,'Virtual City Models: Avoidance of Obsolescence', *Education and research in Computer Aided Architectural Design in Europe- eCAADe*, Prague, Czech Republic.
- MUELLER, MG and DE HAAN, P 2009,'How much do incentives affect car purchase? Agent-based microsimulation of consumer choice of new cars—Part I: Model structure, simulation of bounded rationality, and model validation', *Energy Policy*, vol. 37, pp. 1072-1082.
- MVA, S 2011,'Traffic Micro Simulation-VISSIM', Mumbai, India: Transportation, Planning and Research Consultants.
- NARZISI, G 2008, Agent-Based Modelling in RePast. USA: Courant Institute of Mathematical Sciences.
- NILSSON, M 2011, ELVIRA, Electric Vehicle: The phenomenon of range anxiety, Sweden: Lindholmen Science Park.
- NOMDEN, H, GREENWOOD, D, HORNE, M, MUIZELAAR, T and THOMPSON, EM 2009,'Traffic Simulation in 3D World', *Interdisciplinary Studies in the Built and Virtual Environment*, pp. 26-37.
- NORTH, CMMMJ 2010, *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation*, Oxford Press.
- NSR 2011, E-Mobility NSR-North Sea Region Electric Mobility Network (E-Mobility NSR) , [Online]. Germany: Intregg Project. Available: <http://www.northsearegion.eu/ivb/home/>; and project website <http://e-mobility-nsr.eu/> [Accessed November 2011].
- OLEV 2011, Making the connection- The Plug-In Vehicle Infrastructure Strategy, United kingdom: Office of Low emissions vehicles (OLEV).
- ORFORD, S, HARRIS, R and DORLING, D 1999,'Geography: Information Visualization in the Social Sciences: A State-of-the-Art Review', *Social Science Computer Review Fall*, vol. 17, pp. 289-304.
- PARUCHURI, P, PULLALAREVU, AR and KARLPALEM, K2002, 'Multi agent simulation of unorganized traffic', *The First International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS)*, Bologna, Italy, pp. 176–183.
- PIETSCH, SM 2000,'Computer Visualization in the Design Control of Urban Environment: A Literature Review', *Environment and Planning B: Planning and Design*, vol. 27, pp. 521-536.
- RAILSBACK, S, LYTIMEN, S and JACKSON, S 2006,'Agent-based simulation Platforms: Review and Development Recommendation', *The Society for Modelling and Simulation International*, vol. 82, pp.609-623.
- Schelhorn, T, O'Sullivan, D, Haklay, M, Thurstain-Goodwin, M

- 1999, 'STREETS: an agent-based pedestrian model', presented at Computers in Urban Planning and Urban Management, Venice, 8-11 September (online at <http://www.casa.ucl.ac.uk/~david/AnAgent.pdf>)
- STRAHAN, D. 2012. Dump the Pump. NewScientist Journal. UK: Reed Business Information Ltd.
- SUMMALA, H2005, 'Towards understanding driving behaviour and safety efforts', International Workshop on Modelling Driver Behaviour in Automotive Environments, Ispra, Italy, pp. 105-111.
- THOMPSON, EM and HORNE, M2006, 'Diversity in Virtual Reality Landscape Modelling' in: BUHMANN, E, JORGENSEN and STROBL (ed), Trends in Knowledge-Based Landscape Modeling, Anhalt University of Applied Sciences, Heidelberg: Herbert Wichmann Verlag, pp. 128-137.
- TRANNOIS, H, DELEAGE, J and LLEBRUN, A1999, 'A MULTI-AGENT FRAMEWORK FOR CAR TRAFFIC SIMULATION', 3rd International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology PAAM 98, London, England, UC Berkeley Transportation Library, pp. 635-636.
- TROITZSCH, KG1997, 'Social Science Simulation: Origins, Prospects, Purposes' in CONTE, R, RAINER HEGSELMANN and PIETRO TERNA (ed), Simulating Social Phenomena, Berlin, Germany, pp. 41-54.
- VALVERDE, S and SOL'E, RV 2002, 'Self-organized critical traffic in parallel computer networks', Physica A, vol. (312), pp. 636-648.
- WANG, X 2005, 'Integrating GIS, simulation models, and visualization in traffic impact analysis', Computers, Environment and Urban Systems, vol. 29, pp. 471-496.
- WARE, C 2000, Information Visualization: Perception for Design, San Francisco, CA, Morgan Kaufmann.
- WEE, BV, MAAT, K and DE BONT, C 2012, 'Improving Sustainability in Urban Areas: Discussing the Potential for Transforming Conventional Car-based Travel into Electric Mobility', European Planning Studies, vol. 20, pp. 95-110.
- ZHOU, Z, WANG, J and BOTTERUD, A 2011, 'Agent-based Electricity Market Simulation with Plug-in Hybrid Electric Vehicle Penetration', IEEE, pp. 1-2.