INTEGRATING SPACE-SYNTAX AND DISCRETE-EVENT SIMULATION FOR E-MOBILITY ANALYSIS

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ABSTRACT

Modeling and simulation of dynamic systems has been commonly used in the context of transportation, urban planning, and land use as being the basic tool for planners and policy makers. Vehicular movement modeling is one of the most popular models that deal with relevant aspects of urban regions and communities. This paper focuses on a particular mobility system; electric vehicles (EVs) clusters. It presents a study was conducted to simulate EVs population of the inner urban core of Newcastle-Gateshead via a developed 2D simulation model. The novelty of this study is the new approach proposed to simulate EV population in particular vicinity. This is by utilizing hybrid simulation technique (agent based modeling and discrete events) while applying space syntax theory and principles to predict the travel demand pattern of the urban system. The combination of these layers of modeling within the context of electrical mobility has proven successful in portraying the population and showed promising results. It aims at providing guidelines and recommendations to locate preliminary charging points and determine their numbers and capacities, which should be of interest for researchers, planning authorities and policy makers. This paper is a part of an EU project that focuses on simulating a part of the North Sea Region e-mobility system.

Key words: Agents, Electric Vehicles, Discrete events, Simulation, Space Syntax

INTRODUCTION

Modern urban regions and particularly urban centers are the most complex networks constructed by human societies. They involve several layers of complexity and provide a matrix for economic and social evolution for the entire city hence the country (Buhl 2006). Since 1960's, many mathematical, statistical and logical models have been formalized to predict vehicular movement networks and relative applications. There is a reciprocal relationship between transport network and urban changes. Any change/ growth in roads network eventually influences the economic activities which in turn is reflected in the travel demand pattern of the particular location (Lacono, Levinson et al. 2008). For copious applications, configuring the layers of urban space and their inter-relations is a crucial matter for designers and planners. **M**odeling and simulation has been commonly used in the context of transportation, urban planning, and land use as being the basic tool for planners and policy makers. The representation of dense dynamic environments such as populated cities remains as a problem (Tecchia 2001) as they are highly complex entities to be virtually presented using real-world metropolitan data.

On another note, the environmental burden of these communities and particularly the transport sector had left no choice for many developed countries across the Organization of Economic Co-operation and Development (OECD) (IEA 2011) to work towards resilience and sustainability plans and schemes (ElBanhawy, Dalton et al. 2012 A). With the expected population growth rate, and rapid urbanization trend, we are putting tremendous pressure on the world's resources and high demand for land (Foley 2009). 2011 report, (Sousanis 2011) revealed that the number of cars on the world's roads surpassed one billion in 2010 which spurs the debate on what the rapidly-growing car population will mean for the world's economy and environment (Tancer 2011). Syntactically, many developed countries' local authorities, researchers, and policy makers have focused on the low carbon emissions vehicles industry and their market penetration levels considering alternative means of transportation (IMechE 2000) e.g. hybrid, electric, hydrogen/fuel cell vehicles (Herbert 2011). Electrical mobility (e-mobility) has been touted as a potential solution to the problem of increased CO2 and greenhouse gases emissions.

Study Focus

Likewise any publicly or privately operated mean of transport, EV system requires reliable soft infrastructure (regulation, business models, incentives, skills, community engagement) and integrated hard infrastructure (recharging points, smart grids, buildings transport systems) to viably support its operation (Beeton 2011). EV population is an independent complete mobility system that incorporates marketers, operation services, manufactures, batteries and compulsion technologies providers. Furthermore, the end user's perspective and feedback is highly considered so as to know the main enablers and hurdles of the system usability. This paper is part of a research project that aims at simulating EV system in metropolitan areas to investigate how to integrate charging points into urban infrastructure and how the planning authorizes and policy makers decide where to late charging points wherever needed.

Study Approach

The utilization of agent based modeling (ABM) has been widely used in vehicular movement network studies and traffic management analysis. Some hybrid models were developed integrating ABM to portray a specific phenomenon in transport networks Bonabeau, 2002); (Acha, 2011). As an alternative approach to predict the human crowd dynamics and vehicular travel demand models, space syntax analysis was used as the urban layer of several simulation models (Hillier, 1997); (Xinqi at al, 2008). Integration between space syntax and ABM has also shown interesting results in the area of pedestrian crowd flow and vehicular movement models (Penn and Turner, 2001); (Calogero, 2008); (Penn, 2003). The novelty of this piece of work is integrating the existing hybrid simulation technique ABM and discrete event (DE) with space syntax analysis to present EVs population in metropolitan areas. In the following sections of the paper, each in turn shall be discussed ended by a developed prototype tool.

In recent publications, (ElBanhawy, Dalton et al. 2012 A) explained the overall methodology of the research and the main paradigms of EVs population (ElBanhawy, Dalton et al. 2012 B). This paper follows the series of these publications presenting the new approach of modeling and explaining how a conceptual model for simulating EVs' drivers in metropolitan area can be developed and operated.

EVs MARKET AND MOVEMENT MODELNG

Electric Vehicles (EVs) market is hampered by many factors (DfT 2011) which in return affect EV market penetration level e.g. cost, range, capacity, visual appeal speed, and lack of recharging infrastructure (Graham-Rowe 2012); (Garling 2001). Urban geography, market maturity and infrastructure have their effects on the market growth (JATO 2011). Furthermore, EV anxiety range- EVRA (Nilsson 2011) is considered to be also one of the main hurdles. EVRA basically exists due to the short full-electric range the EVs have (HMGovernment 2011). Full-electric range is the maximum distance a vehicle could travel without a need of charge (Eppstein 2011).This anxiety is significantly linked to how integrated and reliable is the charging infrastructure. Locating and estimating the demand for these charging points requires (1) a detailed analysis of the urban context, (2) deep understanding of the driving and charging patterns and behaviors, and how these two factors interrelate in metropolitan areas.

E-mobility is a sub set of the conventional mobility data. It is a small part of a large group which shares common paradigms e.g. roads network layer, some of the agents' behaviors and traits, goals scale, visualization and GIS purposes. Whereas, it has other unique features and parameters e.g. battery state, charging preferences, number of destinations and parking areas, that exist. Depending upon the applications and end users' drives, the simulation set up is formulated. In some applications, vehicle type is not an influential factor, EV and non EV will be typically replicated. Network and controlling rules will be applied to both like the case of traffic management/ impact analysis (ElBanhawy, Dalton et al. 2012 B). Whereas, other applications pertinent to air quality and noise, the vehicle type is affecting the simulation outcomes hence, the EV would be recognized (Hodges and Bell 2011).

HYBRID SIMULATION TECHNIQUES

The concept of this study is to embed metropolitan area's vehicular movements into hybrid simulation while incorporating space syntax analysis (Batty, Dodge et al. 2000).To decide which simulation technique to be employed in the model, we need to understand the potential techniques and the different possibilities to integrate more than one method as inadequate representation of the detailed population structure can lead to spurious results. There are mainly three simulation techniques: (1) Agent-based Modeling (ABM), (2) Discrete Events (DE), and (3) System Dynamic (SD). The latter is used in the area of engineering design process. DE mainly revolves around the concept of entities, resources and block charts where queuing, waiting, servicing, and processing events occur while the system changes instantaneously in response to certain events (Maria 1997). This type of modeling roots to 1960s and it is used to portray entities flow and resource sharing which is useful in problems like services, manufacturing, logistics, business processes, etc. In DE, entities can be people, products, documents, calls, tasks, etc.(Borshchev 2004).

ABM is a decentralized approach of portraying emergent behavior of a crowd. In comparison to SD and DE, no global system behavior would be defined though an emergent behavior of a particular number of population/crowd can be depicted. This is based on individual autonomous heterogynous agents and which is why it is called the bottom-up approach (Li, Sim et al. 2006). Agents work to find solutions (Chen 2009), learn from their experience and adapt to better suit the environment (North 2010). In former publication, the ABM was the proposed technique to portray the EVs drivers' behavior and charging patterns (ElBanhawy, Dalton et al. 2012 B).This was due to several reasons one of which is the interdependences problem. Using ABM does not require knowing a lot about the level of interaction/effects/dependencies/global sequence at an aggregate level. By having enough knowledge about individual participants performance, the phenomenon can be depicted (Borshchev 2004). A hybrid model is proposed as it might better serve the present problem due to the fact that the main paradigms of the model are being a large-group simulation of active objects that has timing, sequential events, and individual behaviors.

In DE, entities in the flow are abided by some rules and they encounter some events. In a case like EVs simulation, these entities are the EV agents where we can depict the charging behavior and driving pattern of each driver. Hence, in such system, entities enter the system (the road network), use their batteries (each one starts with different state depends), enter service (charging points), queuing and delays occur (depends on the battery state, power, and availability), then the entities exit the service (finish charging), drive around the system heading to difference destination(s).

Having such hybrid model, where the creation of the entity corresponds to the agent creation enables the model to realistically simulate EVs 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, charging points). The creation of agents facilitates messaging protocol. The agent has the ability of checking its battery state and requesting a service (charging) via sending messages/ updates (the battery is almost flat, needs charging).This messaging protocol happens between the agent and DE system (environment elements). Once the agent requests a service, this associates moving from state to another (fully charged to need charging). Till this service is tackled, the system receives a message that an entity in the flow (queue) and needs to get serviced. Eventually, and based on a sequence and specified rate, the service is conducted, hence the entity gets 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/or visa verse which requires a link/messaging protocol between the entity/system and the agent, hence the present study incorporates this technique. Accordingly, the platform used has been selected among many intuitive and simple available simulation tools. The selected commercial platform is AnyLogic; it is cable to support hybrid models, simulate micro-dynamic large-group simulation, requires less coding for adding IF THEN rules; and simulates societal and behavioral models.

SPACE SYNTAX

In last decades, space syntax has been known as an alternative computational language that is used to spatially pattern the modern cites and analyze the topological relationships of settlement spaces (Hillier and Hanson 1984); (Hillier 1994). Different shapes of relations and levels of interactions between spaces each other and or with society, have superbly shaped the space syntax notion and its principles in analyzing the spatial patterns of cities (Jiang and Claramunt, 2002). Within a given built environment (system) and with its segmental representation of roads network, the virtue of space syntax theories and techniques can be used to quantify the properties of the space arrangement and measure its level of integration, accessibility and connectivity and depth. (Hillier and Hanson, 1984). Figures (3a and b) represent the connectivity and depth graph of the study area, explained later this paper.

Space syntax analysis considers on urban environment as an interconnected space; everywhere is linked to everywhere else (nodes/ points not regions) and there are always choices of routes from any one space to any other space (Hillier and Hanson 1984). The characteristics of the path system can be obtained by analyzing the shortest paths between all pairs of nodes. In transportation and land use context, the spatial configuration of simulation objects is a crucial issue due to the observed correlation between graph-based configurational measures of street networks, represented as lines, and vehicular and pedestrians navigational choices, observed movement, and flow patterns (Hillier and Iida 2005). It is observed that this correlation could strongly provide great insights on understanding cities and visualizing its impact within the field of urban studies, urban planning and urban economics (Law, Chiaradia et al. 2012).

Angular Segment Analysis – ASA

Many studies were conducted on the human movement behavior with respect to angularity. (Kim and Jaepil Choi 2009);(Golledge 1995) pointed out that individuals tend to minimize angular deviation from a straight line to destination as human tend to make the least physical effort. Turner pointed out that ease of directional change can be varied as turning angle, and proposed Angular Segment Analysis methodology that applied the shortest angular path based on angular depth to segmented axial map (Turner 2001) As defined by (Turner and Dalton 2005), ASA is the shortest angular path about each pair of origin-destination segments within the network. Recent related research reveals that ASA methodology shows more remarkable predictability for the actual movement pattern than existing traditional space syntax methodology (Turner 2007).

CONCEPTUAL MODEL

The development of the model is a prolonged phase and has passed through several trials; each trail has guided the authors and showed a better direction. Early this paper, modeling layers have been explained, this section reciprocates by showing how these layers are developed in the pilot study. The study covers most of the technical and behavioral assumptions and the set-up needed to simulate the EVs population in metropolitan areas though in a small scale and less complicated and correlated to real-world system. It studies the concept along with the procedures needed to build the simulation model.

The inner urban core of Newcastle-Gateshead area with a total square area of 500KM, is the selected study area as highlighted in figure (8). Newcastle city is one of the greenest cities of the UK (Jha 2009). The Northeast is to become the UK's electric car capital, with plans to install up to 1,000 charging points around Newcastle and Gateshead over the next two years. Local authorities and universities have been active in the context of low carbon emissions vehicles research and development with a proven successful in providing initiatives and schemes and participating in green/smart programs. The simulation input data is based on the information about EVs' drivers and their usage which is provided by CYC back office (CYC 2011), the EVs local service provider for the UK North East region.

Urban Layer

ASA is utilized and applied to the study area. The entry direction of the flow/ vehicles is important as this will count for the entire calculations. It starts with drawing the road centerline map of Newcastle urban core streets which is the approximate skeleton of urban network (Jiang 1998), figure (1). All streets are drawn as segments; each should be connected to the other by intersection angle. Calculating the segment depth via angular analysis can be done following (Iida and Hillier's (2005) convention. Intersection angles between segments vary between 0-180 degrees, which are assigned to values from 0-2, respectively. Figure (2) demonstrates the way calculating the depth of 3 segments presenting a part of roads network that starts from A and ends with E.

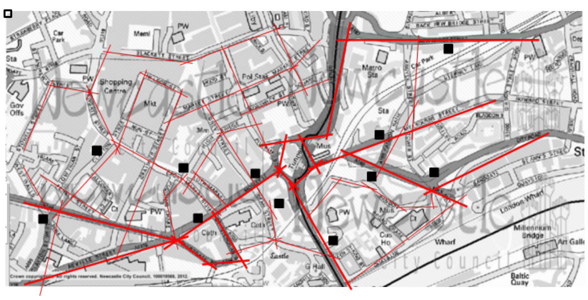

Figure 1: Axial map of the inner urban core of Newcastle

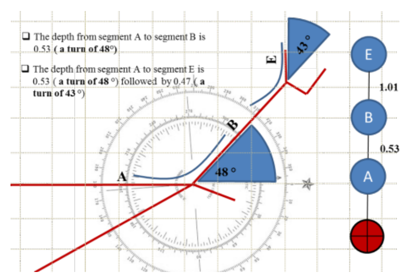

Figure2: ASA calculation technique

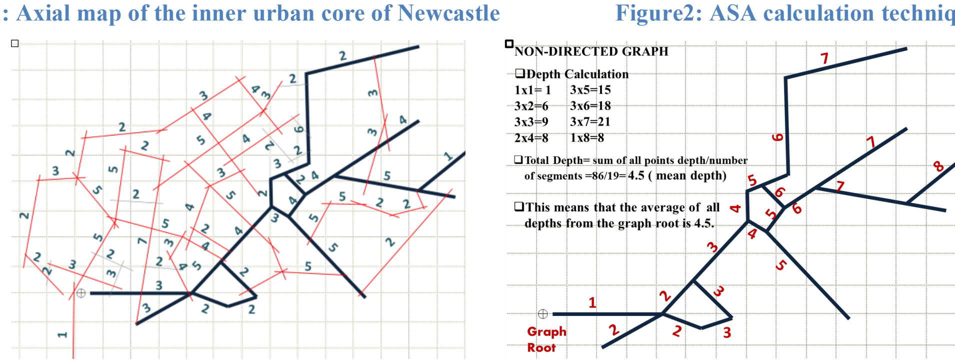

Figure 3a and b: Connectivity and depth maps of the study area

Newcastle Inner urban core segment map with angular mean depth of each segment from the graph root is calculated with active charging points located; figure (4). These values are used to predict the vehicular movement within the simulation due to the proven correlation between ASA and predicted movements. By using these values, the vehicle tends to take the less angular depth cumulatively in its trip. So once the agent reaches an intersection, it has to decide which way to go, figure (5). In the model, the authors pre-calculated the shortest routes, total mean depth, which reflects the angular mean depth values for all possible routes (holistic approach). Another approach might be taken which makes the computation more difficult when this task is left to the agent to calculate in each intersection within the simulation the angular depth and shortest route.

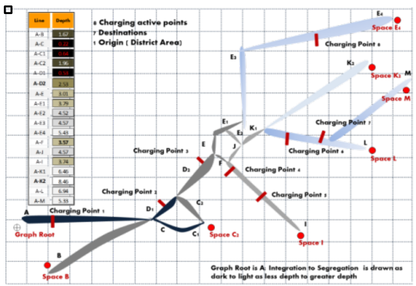

Figure 4: schematic Map showing the ASA of all streets

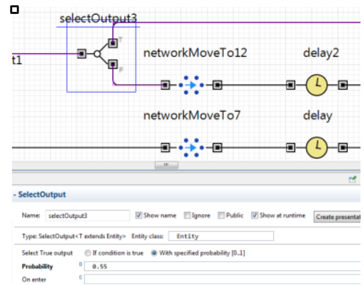

Figure 5: Intersection point and ASA

Via coupling simulation mode with configurational analysis techniques, the knowledge of possible urban patterns can be exploited; hence the movement can be predicted. Numerous urban and planning studies and analysis can be conducted employing such integrated model (Hillier 1994).

Simulation Assumptions

Simulation modeling is an evolving process; it doesn't all being created at once. It starts with a simplified model with a less detailed set up, intuitive assumptions, and more limitations, and the more the model is developed, the more mature, detailed, high level of abstraction the simulation model reaches (Borshchev 2004). Assumptions and variables, table (1), are studied and tried. The model is an interactive tool; it can accommodate variations to provide different scenarios.

Table (1): Pilot study assumptions

Assumptions	Pilot Study
Battery State	The agent starts its day with a state. The battery states are assumed ranging between 5 possible options for instance: 30%, 50%, 70% and 90% charge following uniform distribution approach. This basically relates to whether the agent has recently charged their vehicle using domestic charging. Once the EV battery reaches 20%, the minimal state, eventually the agent has to stop for charging otherwise the car will stop.
Charging Points	Charging points are presented as services with a delay time that various between (1, 1.5, 0.5) triangular distribution which presents the different states the charging post can perform (available, almost available, fully occupied), depending on the demand which reflects the time needed for charging.
Simulation Measure	The model counts the number of stopped vehicles in the system. 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 number turns into grey yet not calculating where they stopped in the road network.

The possible charging scenarios as per the real EVs population are (1) charging at home (domestic charging), (2) on-street charging (publicly available charging), (3) charging at work. In this model, the first two scenarios are portrayed.

The full electric range of an EV depends on many factors e.g. the battery type, load, traffic conditions, weather, the weight and type of vehicle, the performance demands of the driver (driving style) and mode of driving.

Based on the rate of consumption, the battery state will change from fully charged to half charged to flat. Nissan LEAF (Nissan 2010), 24 kWh battery pack, in city traffic pattern has been taken as a reference in the model. The following assumptions were considered:

- All electric range: 105 Mile-169 KM/ Speed 24 mph or 39 km/h.
- Time needed to charge: 8 hours at 220V.
- The battery starts with 100% charged and lasts for 4.24 hrs. This means that 1% of the battery is consumed after 2.55 min. A flat rate is considered. Hence the model rate is 2.55

Developing the Agent Architecture

The model is built based on the travel-dairies of the North East EVs' drivers who live /work within Newcastle. The model's update time-interval is a daily-based update (24 hours) which is the required rate needed to examine the system.

Agent's attributes/algorithms are the mechanisms underlying ABM; they are developed and pre-assigned (Helbing 2011).They are mainly related to O-D matrix and the decisions to be taken within the route, table (2). The simulation path is the chosen route within the DE environment. Operating agent architecture passes through stages; the pilot study performs the first step; whereas, the final model includes more complicated configurations. Table (2) depicts the state of both models.

Table (2): Final model Vs Pilot study assumptions

Assumptions	Model (future work)	Pilot Study (present study)
Agents Behaviour (Origin)	On a daily basis, agent starts new path with new destination(s) from its origin. Homes are selected and limited to the basic demographic-usage information provided by CYC.	All agents are generated from one source as all are coming from same district (Flow direction). Four possible destinations (1) Akenside Hill Queen Street, (2)New Bridge Street,(3)Melbourne Street,(4) City Road A185
Agents Behaviour (Destinations)	Possible number of destinations is calculated based on the daily average mileage of UK drivers (41.9 Mile/day) (Aduk 2000). It is limited to 4 destinations /day including home trip.	Each agent goes to ONLY one of the destinations. This is based on a probability in each intersection based on ASA as presented in figure (5)
Agents Behaviour (Decisions)	The first decision the agent takes is to check the state of the EV battery hence the charging schedule is planned ahead. This process happens every time the agent reaches a new destination.	The agent decides to charge or ignore and continue based on its battery state in case it passes by a charging point on its way. Depends on the percentage of charge it will stop to charge or it will

AnyLogic Model

In the agent model part of Anylogic, a state chart is used to design the agent architecture where all the above-mentioned attributes and definitions have to be built in. Sschematics and network diagrams of the EV system were developed. Sources and sinks indicate Origins and Destinations matrix (O-D matrix). Each EV follows the state chart which transfers it from a state to another based on some orders and decisions taken when certain events happen (DE) via adding IF statement in some cases; figure (6). Each EV has different state of battery that it starts the route with *(blue color with different percentages that range between 30%-70%)*. Transition happens between states via *(Time out)* condition; based on the consumption rate. It moves to yellow (driving) to red (needs urgent charging) to grey (flat battery) figure (7).

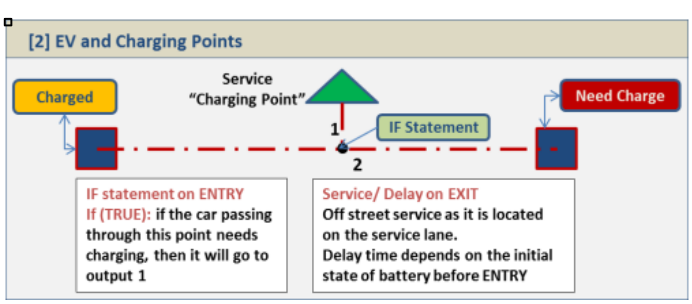

Figure 6: State transition

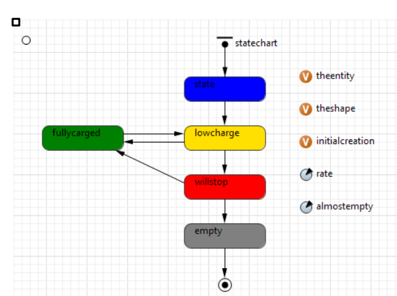

Figure 7: Agent State-Chart

The model consists of two parts: logic diagram and simulation presentation. The logic diagram is the network which is the main environment of simulation. The road network is presented e network works as a DE simulation and the entity is created at the source. Each entity once created, generates an agent with it. This combination provides the DE to simulate the road network system in terms of paths, delay (charging), and destinations (sink) where the agent facilitate having individual attributes which are (battery states), state transition timing, and routes, figure(9) .

Figure 8: Newcastle Upon Tyne-Inner Urban Core (500 KM2) (www.maps.google.co.uk)

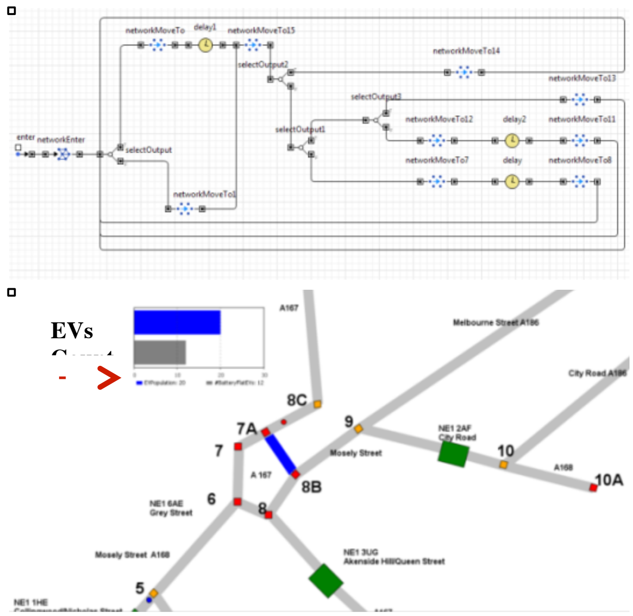

Figure 9: 2 models created by AnyLogic

MODEL INTERIM OUTCOMES/APPLICATIONS

The model shows interesting and promising interim results. With a less-complicated version of simulation, the model reveals a prominent framework for EVs charging infrastructure planning purposes by providing a spatial decision support tool. The simulation of the partial Newcastle EVs system shows the possibility of examining the integration of charging infrastructure. Calculating the number of the stopped vehicles and knowing where they stopped within the system indicates and reflects how integrated is the infrastructure of the study area. By increasing the level of correlation between the real system and the virtual simulation, planners can examine whether the current charging points can accommodate the current demand and future generation or there is a need for new charging points to be located and if yes, then how many and where to be located.

DISCUSSION AND CONCLUSION

Investigating and predicting the consumers' response is a significant challenge EV marketers are facing; however, the roll out of intelligent infrastructure, creation of innovative service models and changes in consumer behavior are all positive transformations and indicators for a better EV market penetration. EV market is on the verge of expansion and maturity. The use of simulation modeling to portray the EV populations in metropolitan areas can potentially assist planning authorities and policy makers to better evaluate the system usability and plan for future stream. In return, this shall support the market as providing accessible and high visible charging network generates interest amongst consumers and encourages uptake. The integrated vehicular model proposed in this paper has allowed us to develop a more realistic simulation of EVs population behavior in metropolitan areas. In the virtue of space syntax theory (urban layer) and hybrid simulation modeling (charging behavioral model), a conceptual model was developed to propose an approach to examine the level of integration and reliability of the existing charging infrastructure. The model shows how these two layers are correlated and strongly linked to portray the phenomenon. Main streets of the inner urban core of Newcastle were modeled along with the active charging points that serve the core area which is a preliminary version of the EVs system showing the overall picture of the agent system design integrated with DE within topological and geometric urban analysis.

Future work

Other factors regarding the iteration time, number of agents, charging schedules and types are to be considered incorporating other variables e.g. number of users and charging points number/ location to study all possible scenarios. Hence, new measures can be deliberated as the time the car waits to get charged in the simulation (queue), no of over-used and under-used charging points and the use of publicly available charging points rather than the domestic and at work

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REFERENCES

Acha, S., Vandam, K., Keirstead, J., & Shah, N. (2011). Integrated Modelling Of Agent-Based Electric Vehicles into Optimal Power Flow Studies . 21st International Conference on Electricity Distribution Frankfurt, 6-9 June 2011.

Batty, M., M. Dodge, et al. (2000). "New Technologies for Urban Designers." CASA, UCL **21**(1467-1298): 59.

Beeton, D. (2011). EV ecosystems. Update on Annex XVIII: EV Ecosystems Istanbul, Turkey, May 2011. UK.

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, 99 Suppl 3, 7.

Borshchev, A., Filippov, A. (2004). From System Dynamics and DE to Practical ABM. 22nd System Dynamics Society, Oxford, England.

Buhl, J. G., J.; Reeves, N.; Sol´e, R.; Valverde, S.; Kuntz, P.; Theraulaz, G. (2006). "Topological patterns in street networks of self-organized urban settlements." THE EUROPEAN PHYSICAL JOURNAL B **49**(4): 513-522.

Calogero, E. Getting from A to B and Back: A Representational Framework for Pedestrian Movement Simulation in a School Environment, The Bartlett School of Graduate Studies, UCL

Chen, Y., Wang, B. (2009). "Towards Participatory Design of Multi-agent Approach to Transport Demands." IJCSI **4**(1).

CYC (2011). Interviewing C. Y. C. Manager. Newcastle upon Tyne.

DfT (2011). Transport energy and environment statistics. . UK: DfT.

ElBanhawy, E. Y., R. Dalton, et al. (2012 B). Real-Time E-Mobility Simulation in Metropolitan Area. eCAADe, Prague.

ElBanhawy, E. Y., R. Dalton, et al. (2012 A). A Heuristic Apporach for Investigating the Integration of E-Mobility Charging Infrastructure. 2nd EFEA 2012, UK.

Eppstein, M., Grover, David K., Marshall, Jeffrey S., Rizzo, Donna M. (2011). "An ABM to study market penetration of plug-in hybrid electric vehicles." Energy Policy **39**(6): 3789-3802.

Foley, J. (2009). The Other Inconvenient Truth: The Crisis in Global Land Use. Yale Enviroment360. USA, Yale School of Forestry & Environmental Studies.

Garling, A., Thøgersen, J. (2001). "marketing of electric Vehicles." Business Strategy and the Environment **10**: 53-65.

Golledge, R. G. (1995). Path Selection and Route Preference in Human Navigation. COSIT. Semmering, Australia, The University of California Transportation Center.

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." Transportation Research **46**(1): 140-153.

Helbing, D., Balietti, S. (2011). "How to Do Agent-Based Simulations in the Future."

Herbert, S. (2011). EV Updates. S. T. O. Newcastle City Council. UK**:** 24.

Hillier, B. (1994). Space is the machine. London, University of Cambridge**:** 355.

Hillier , B. (1997). Proceedings of the first international sympsuim on space syntax, Univeristy Collelge of London, 1997. Space Syntax Laboratory.

Hillier, B. and J. Hanson (1984). Social Logic of Space, University of Cambridge.

Hillier, B. and S. Iida (2005). Network and psychological effects in urban movement.”. In Spatial Information Theory: COSIT 2005, Springer-Verlag, Berlin.

HMGovernment (2011). The Carbon Plan: Delivering ourlow carbon future.

Hodges, N. and M. Bell (2011). A Pervasive Network for Environmental and Traffic Monitoring. UTMC Conference, UK, Leicester City Council and TORG.

IEA (2011). Technology Roadmap, Electric and plug-in hybrid electric vehiles. France, IEA- International Energy Agency**:** 52.

IMechE (2000). Alternatively Fuelled Vehicles. , IMechE.

JATO (2011). "Incentives Fail to Simulate European electric Vehicles Sales."

Jha, A. (2009). "North-east takes electric car lead." The Guardian(18.40).

Jiang, B. (1998). A Space Syntax Approach to Spatial Cognition in Urban Environments. NSF. Pittsburgh, PA, University of Pittsburgh.

Jiang, B, Claramunt, C. (2002), Intgeration of Space Syntax into GIS: New Prespective for Urban Morphplogy, Blackwell publishers Ltd Vol. 6. no. 3. pp 295-309.

Kim, M. and J. Jaepil Choi (2009). Angular VGA and Cellular VGA. 7th Inter. Space Syntax Symposium, Stockholm: KTH.

Lacono, M., D. Levinson, et al. (2008). "Models of Transportation and Land Use Change: A Guide to theTerritory." Planning Litreture OnlineFirst.

Law, S., A. Chiaradia, et al. (2012). TOWARDS A MULTI-MODAL SPACE SYNTAX ANALYSIS. Eighth Inter. Space Syntax Symposium, Italy.

Li, Z., C. H. Sim, et al. (2006). A Survey of Emergent Behavior and Its Impacts in Agent-based Systems. IEEE International Conference on Industrial Informatics.

Map of the Newcastle Upon Tyne, inner urban core of postal zone NE 1, retrieved on October 10, 2012 from website www.maps.google.co.uk.

Maria, A. (1997). Introduction_to_Modeling_and_Simulation. WinSim, Atlanta.

Nilsson, M. (2011). ELVIRA, Electric Vehicle: The phenomenon of range anxiety. Sweden, Lindholmen Science Park. **1:** 16.

Nissan (2010, 2010-06-26). "Nissan Leaf has 100-mile range--give or take 40 percent. CNET." from http://reviews.cnet.com/8301-13746_7-20008319-48.html.

North, C. M. M. M. J. (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) ,." Retrieved November, 2011, from http://e-mobility-nsr.eu/.

Penn, A. (2003), Space Syntax And Spatial Cognition: Or Why the Axial Line?, "Environment and Behavior", 35: 30-65,

Penn, A and Turenr, A. (2001), Space Syntax Based Agent Simulation, Bartlett School of Graduate Studies, UCL,

Sousanis, J. (2011). World Vehicle Population Tops 1 Billion Units. WARDSAUTO.

Tancer, D. (2011). Number Of Cars Worldwide Surpasses 1 Billion; Can The World Handle This Many Wheels? . The Huffington Post Canada. Canada.

Tecchia, F. L., C.; Conroy, R.; Chrysanthou, Y. (2001). Agent Behaviour Simulator (ABS). GTEC.

Turner, A. (2001). Angular Analysis. 3rd Inter. Symposium on Space Syntax, USA.

Turner, A. (2007). "From axial to road-centre lines." Environment and Planning B **34**: 539–555.

Turner, A. and N. Dalton (2005). A Simplified Route Choice Model Using the Shortest Angular Path Assumption. The 8th Inter. Conference on GeoComputation, USA.

Uboe, J. (2004). "Aggeregation of gravity models for Journeys to work." Environment and Planning A(36): 715-729.

Xinqi, Z., Lu, Z., Meichen, F., Shuqing, W (2008), Extention and Application of Space Syntax-A case study of urban traffic netwrok optimizaing in Bijing, Workshop on Power Electrionis and Intellgient Transporttion System.