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Spatiotemporal analysis of the e-mobility system in Newcastle-Gateshead area

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Abstract
The world is witnessing an accelerating expansion of urban areas and intensive urbanization. The robust relation between transport infrastructure and urban planning is reflected in how integrated and reliable any system is within the urban spatial system. Designing an integrated infrastructure to support full electric vehicle (EV) use is a crucial matter, which concerns planning authorities, policy makers, as well as current and potential users. Reducing range anxiety by facilitating access to public refuelling stations (RSs) is designed to overcome one of the main barriers that stops potential users to utilise EVs. The uncertainty of having a reliable and integrated charging infrastructure presents hurdles to, and slows down, the growing trend of smart ecosystems and sustainable urban communities as whole. Strategically locating non-domestic (public) EV charging points will help to pave the way for a better market penetration of EVs and, in space syntax terms, this involves establishing the spatial configurational correlates to successful charging locations. This paper analyses real information about EV usage of the year 2012, in one of these metropolitan areas. A case study of 38 charging points (CPs) with 120 EV users located in the inner urban core (NE1, NE4, and NE8 postcode districts) of a metropolitan area in the North-East England, the city of Newcastle upon Tyne, incorporating space-time analysis of the EV population, is presented. Information about usage and charging patterns has been collected from the main local service provider in the North East of England, Charge Your Car (CYC) Ltd. The primary methodology employed is a clustering analysis. It is conducted as a dimensional analysis technique for data mining and for significant analysis of quantitative datasets. A spatial (consisting of space syntax measures) and temporal analysis of charging patterns is conducted using SPSS and predictive analytics software. The study outcomes provide recommendations and an explorative design theory for the implementation of non-domestic EV charging infrastructure. This paper presents a methodological approach useful for planning authorities, policy makers and commercial agents in evaluating and measuring the degree of usability of the public electric mobility (e-mobility) system.

Keywords
Charging behaviour, clustering analysis, design configuration, electric vehicles, spatial analysis, refuelling stations.
1. Introduction

There is a growing momentum behind owning a low carbon emission vehicle (Robinson et al., 2013; Arup and Cenex, 2008) driving a convention gasoline car is a major polluting factor that degrades our environment. The EV is emerging as an alternative solution to the conventional gasoline vehicles in order to reduce the dependency on gasoline and its environmental burden (Spoelstra, 2014). Even though EVs have existed for some decades, the term is still thought of as a new technology (Hjorthol, 2013). E-mobility offers considerable potential to make progress in a variety of wider environmental, societal and economic objectives (Wee et al., 2012), which accelerates the development of smarter cities (Lozano, 2012). Many strategies have the potential to promote EV deployment (Dong et al., 2014); adding incentives, purchase subsidies, promoting initiatives, wise marketing, and spreading awareness likewise tax exemption, plug-in places and cars, government's subsidies, dedicated parking areas, driving zones, and special lanes strongly boost up the probability of having more EV customers (Wirges & Linder, 2012). However, anticipating the buyer behaviour is a key factor that would positively direct stakeholder towards a maturing market (Lin & Greene, 2011). The usability of EV is an indicator of how reliable is the system (vehicle and infrastructure). The charging infrastructure may refer to the domestic chargers and non-domestic charging points (CPs). The non-domestic option includes publically available CPs excluding the workplace CPs provided by employers in their own parking area.

2. Range and the Refueling Stations (RSs)

The penetration of the EV market is facing technical and social barriers; inadequate RSs, limited range, high purchase price, and immaturity of battery technologies are the main technical issues associated with owning or leasing an EV (ElementEnergyLimited; Propfe et al., 2013). Several factors pertinent to EVs’ range anxiety appear to influence users’ anxiety during driving; known as Electric Vehicle Range Anxiety-EVRA (Rauf et al., 2014; Nilsson, 2011). EVRA basically exists due to the short full-electric range the EVs have (HM Government, 2011). Range anxiety emerged as a concept in the late 1990s and captured a drivers’ concern of not reaching their destination while travelling in an EV (Nilsson, 2011). It describes consumers’ fear that their electric car battery will run out mid-route. Such fear of having insufficient range to reach the destination has been shown to be a significant obstacle to market acceptance of EV (Dong et al., 2014). It will occur more often and irritate the EV driver as a consequence of limited and unreliable On street/Off street RSs. An On street charging, which may refer to as opportunity charging, is the CPs located side the roads; whereas, Off street includes the public and commercial parking areas (ElBanhawy, 2014). As per Golob (1986), the road trips can be categorised in 5 categories, see (Figure 1), non-domestic charging events may occur during home-based trips.

The Preferred Charging Option and Market Penetration

EV owners may desire to charge their EVs while at work in addition to domestic charging (Jewell et al., 2014). Studies show that the vast majority of current users rely on domestic charging (Cattaneo et al., 2014; AVTA, 2014; Keros, 2014; BEES, 2013; Calstart, 2013; Boyce, 2012; Mcdonald, 2012; Housely, 2010). In the UK, recent research claims that around 80% of UK EV drivers rely on domestic charging (50% urban, 70% suburban, and > 95% rural) (Lane et al., 2013; Warburton, 2013; McDonald, 2012). Even though, in order for EVs to gain widespread consumer adoption, it is critical to have an existing integrated charging infrastructure in urban areas (Xu et al., 2013; Chapin et al., 2000). The success of a mass roll out of EV is strongly associated and underpinned by the deployment and the design of the RSs (Namdeo et al., 2013). This includes the inner urban cores and across cities and countries. Having supported routes (down centres and motorways) that have guaranteed reliable charging services is a perquisite for any potential shift to mainstream market (ENEVATE, 2014). The limited range and the scarcity of RSs in convenient locations is a critical issue holding back the diffusion of e-mobility (Eppstein et al., 2011; Hakimi, 1964; Bapna et al., 2002).
The importance of the study

The planning for nondomestic charging network is an existing problem that is gaining more attention particularly in the last three years (Sathaye & Kelley, 2013; Nie & Ghamami, 2013; GE et al., 2012; Shukla et al., 2011). To assist planning authorities and policy makers efficiently in aiding the deployment of RSs, a systematic and constructive approach is needed (Dong et al., 2014) to identify and quantify the elements of selection. A few important strides have been made to tackle this problem particularly, in late 2012 and 2013 (Chen et al, 2013). Some of which are carried out by professional bodies as it forms a real-life business case (Carroll & Walsh, 2013; Logica,AECOM, 2011; Element Energy Ltd, 2009; Klein, 2007). The selection practice of charging locations is complicated process, which associates with different considerations and overlooked attributes. It needs a clear understanding of the system’s mechanisms to evaluate the performance, avoid pitfalls, work on barriers and raise awareness of potential users. The absence of such understanding and planning guidelines is a major impediment to mainstreaming EVs (Namdeo et al. 2013).

The proposition is that by improving the recharging experience, the probability of potential users to shift to EV market and household loyalty to use the EV as their first choice would increase (Kim & Kuby, 2012). In order to achieve this, a reliable accessible monitoring system that reports all the charging events and transactions has to be developed and becoming available, which is very challenging. The problem with the planners and policy makers is that they deal with locating and sizing RSs as static location allocation planning problem (Wirges and Linder, 2012). Designing a new charging network is a product of promising business cases, commercial interests, power distribution, and end user’s charging preference. Installing a CP in a relatively abandoned urban area that is very well connected to the electric power distribution, will not promote the e-mobility system. Behavioural aspects and spatial design qualities have to be considered. Analysing existing RSs is the first step towards a proper designing process (ElBanhawy, 2013), which is main objective of this study.

The Focus of the Study

The goal of this study is to undertake exploratory analyses trying to interpret the current socio-behavioural configuration of EV system by data summarization, inference, and intuition about EV
users charging patterns data. It draws on the drivers’ charging behaviour and attempts to cluster their usage patterns through recording the charging events (transactions made) of RSs. This includes: the number of users, the charging event timing, and time spent charging. In addition, some other variables related to spatial awareness and configuration are measured and considered in a proposed spatiotemporal model. Integrating the design-configuration parameters, site-location features, and charging patterns, can obtain meaningful observations, which can potentially assist in the planning process. This article presents a methodological approach for planning authorities and policy makers to evaluate and measure the degree of usability of an existing e-mobility system in Newcastle-Gateshead area. The analysis should identify the main paradigms of the most used charging site (refuelling station), which generates more profit to the government tax revenue in the medium term and helps building successful business models for the management companies and utility providers.

3. Prior Work Related To Planning Problem

Several documentations and reports have been published and released, containing phased plans, initiatives and long-term development of recharging infrastructure (OLEV, 2011). However, these reports do not share how the presented size and location of RSs were determined (Wirges and Linder, 2012). Very recent literature covers previous studies which were conducted to solve the RS deployment. The location problem has been seen differently and each of the proposed solutions is concerned by an aspect; power, emissions, facility management, or comfort zone. Lam et al. (2014) discussed the candidate locations and suggested sizes of RSs in different urban contexts and have tackled the planning problem, following two previous studies. One study was based on the power system factors: power, voltage, and current, capacity, e.g., where the authors adopted particle swarm optimization to compute the solution. A similar study was conducted by Liu et al. (2013) looking into the network losses and degradation in voltage profiles, which might happen as a result of poorly insufficient distribution of CPs in urban networks. Another one was based on circuits topologies and grid while discussing the power architectures and power electronics (Lam et al., 2014). Moreover, an enhanced study was conducted by Lam et al. (2014) using nodes and links method based on the charging stations coverage and the convenience of drivers. Chen et al (2013) revealed a study about proposing solutions for the station location problem, which is a function of identified travel demand, possible parking lots and the time needed for charging. Facility location model aided by a GIS was developed by Xu et al. (2013) to identify locations for and size of the network of charging stations. The study proposed geometric reasoning method for identifying ideal charging location in urban areas. A macroscopic RSs planning model was proposed by He et al. (2013) to maximize social welfare associated with both transport and power networks. A mathematical based model is developed there to locate the charging stations.

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

4. Methodology

Data clustering is a continuous fine-tuned process of grouping sets of data. It is a convenient method for identifying homogeneous groups of objects, called clusters (Mooi & Sarstedt, 2011). The use of clustering techniques to group different observations / cases while considering different continuous
and categorical variables is a valid research tool. It identifies the groups within the data while being able to analyze groups of similar observations instead of individual observations (Caccam & Refran, 2012).

It is finding a group of similar objects sharing many characteristics and qualities, which are unrelated to other objects not belonging to that group aiming at reducing the size of the large data sets. These objects (cases, or observations) (Mooi & Sarstedt, 2011) can be customers, products, employees, users, clients...etc. It is to analyze their behaviour, preference, pattern, usage or any other quantified parameter and classify this into groups (Larson et al., 2005). To group the observations into clusters, many techniques begin with similarities between all pairs of observations (Schaeffer, 2007).

**Clustering Algorithms**

The clustering is based on mathematical tools, which is designed to cluster the data based on similarity and homogeneity. The classification of the data clustering algorithms can be in different shapes. In the present study, we are presenting the classification as per the platform being used, SPSS, a predictive analytics software. SPSS has three techniques with different algorithms: K-means (Partitioning or Flat-Hierarchical) clustering, Hierarchical clustering and TwoStep. The first one works on dividing the data into non-overlapping subsets, see Figure 2. The second one is to divide them into nested clusters organized as a hierarchical tree, see Figure 2.

TwoStep is the selected technique for the research problem; it conducts a hybrid approach, which starts with the hierarchical approach (partitioning) followed by flat hierarchal approach, see (Figure 2). The first is used to determine the number of clusters and profile clusters centres (centroid) that would serve as initial cluster formation in the partitioning one. The second phase would take place to provide more accurate cluster membership (as the K-means clustering needs to identify the number of clusters as a first step). This enables the advantage of the hierarchal methods to complement the partitioning method in being able to refine the results by allowing the switching of the cluster membership.

![Figure 2: Significant spatial data clustering algorithms](image_url)
TwoStep
This hybrid method creates clusters based on both continuous and categorical variables which is needed for the present study due to the variety of the data. It has the ability of automatically selecting the number of clusters as well as analysing large data files in an efficient manner (Caccam & Refran, 2012). The clustering algorithm is based on a distance measure that yields the best results if all variables are independent, and it deals with continuous and categorical data set (Mooi and Sarstedt, 2011).

5. Spatial Analysis
The origins of the spatial analysis lie in the development of quantitative and statistical geography in the 1950s (Openshaw, 1991; Berry & Marble, 1968). Spatial analysis often employs methods adapted from conventional analysis to address these problems in which spatial attributes are the most important explanatory variables. In an intelligible network (an urban system with a correlation between connectivity and integration values) (Elkhouly & Penn, 2012), where origins and destinations of movement are evenly distributed, there is a correlation between the spatial configuration and movement flow (Gil et al., 2009; Hillier et al., 1993; Peponis et al., 1989). Other studies explored the relation between the social and economic impact of land use and the accessibility and movement in urban network. There an underlying assumption of much space syntax research that population is relatively homogeneous in terms of its spatial needs and competence (Gil et al., 2009).

Spatial Movement patterns
In this article, the driver movement pattern is modeled. Space syntax derives from a set of analytic measures of configuration that have proven to correlate well with people movement in buildings and urban environments (the spatial configuration and the observed movement) (Penn et al., 1998). Reporting on the correlation between the design features and the spatial behavior of individuals, this study is carried out. The procedure employed by space syntax analysis is to represent and quantify aspects of the built environment (Penn, 2003) and then using these as the independent variables in statistical models of observed behavior patterns. Previous work by Gil et al. (2009) and Larson et al. (2005) employed data reduction technique, clustering analysis, to explore the shoppers’ traces to identify similar strategies to move inside a store. In the current study, spatial attributes alongside other behavioral and spatial variables are the independent variables’ side of the equation and the profit is the independent variable.

Spatial Configurational Attributes
The idea of the configurational modelling revolves around the theory that incorporates the space topological relationships and its relation with the movement (Barros et al., 2007). Configuration modelling in general and space syntax in particular can play a role in the transport studies especially in the early planning stages (Barros et al., 2007). Space syntax approach is used to measure the spatial configuration of an urban system (Long et al., 2007). It provides appropriate tools to describe and quantitatively measure spatial configuration of urban space; the most significant syntactical measures are integration and connectivity (Hillier, 1996; Hillier & Hanson, 1984). Integration, connectivity and mean depth values were calculated for each RS in the study area. A one refuelling station (RS) may contain more than charging point (CP) which will make a repetition but will not be omitted from the calculation to avoid biasness. This study employs space syntax spatial analysis software, Depthmap. Depthmap basically transforms the street pattern into a network graph by disaggregating the network at the intersections.

The Case Study
The case study is the inner urban core of Newcastle-Gateshead area, NE1, NE4 and NE8 postal districts of the Boroughs of Newcastle and Gateshead. The North East of England is considered as
one of the greenest regions that call for sustainable development and implement rigid plans towards resilience concepts. The study area, naming it “The ZONE” presents several express and arterial long roads, which vary in width, speed and capacity. The ZONE is a virtuous experimental area to be syntactically studied; a rich area of trip assignments and movements, which enables the researchers to study the flow of EV population, and the behavioural characteristic of system, reflects on the usage patterns. Particularly, NE1 which covers the city centre of the metropolitan area, contains two universities, schools, shopping and recreational areas, commercial buildings, train station, squares, parks, and partially, most of the busy residential wards of Newcastle area (NE1, 2009). The model is based on analysing 420 users record spanning the year 2012 using the 38 CPs, see figure 3. The majority of these RSs are located in NE1, having 26 charging points in 6 KM sq, where there are 4 charging points in NE4, 14 KM sq., and 8 charging points in NE8, 16 KM sq (see Figure 3).

Figure 3: Study area with the existing refuelling stations

For each charging point, spatiotemporal analysis is carried out. The measured attributes are: design configuration values (Integration, Connectivity and Meandepth, see Figure 4), demographic data, traffic count, and level of awareness data. Traffic data was provided by local authority (Beasley, 2012) and level of awareness was measured by a survey, which is beyond the scope of this study (Elbanhawy, 2014). Some values are converted into dummy values for higher accuracy and validation purposes. The data forms thirteen factors. Hence, the model inputs include 38 observations analysed among thirteen levels. The clusters membership is formed based on the predictors, see (Figure 8). The iterations ran until the back algorithm came out with the optimal quality of the clusters. (Table 1) summarises the final list of factors considered for this study starting with the most influential predictor.
Pre-Clustering

There are some key alterations that can be made to the selection of the variables, the display, and the maximum and minimum number of clusters, as well as the evaluations fields. Cluster analysis involves several procedures as summarized by Milligan (1996): selecting clustering objects and clustering variables, deciding on the type of data, variable standardization, choosing the measure of association, selecting the clustering method, determining the number of clusters and interpretation, validation, and replication. This includes a description of administration procedure of data collection, data cleaning and a description of the data set. In this model, there were 12 variables included as independent variables: Public awareness, Integration, connectivity, distance from centre, traffic counts, On or Off street, No. of users, transactions, average time spent, most frequent time, weekdays, and history, see (Figure 7).

Table 1: Model Variables and ways of measurement

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Explanation/ Measurement Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Public Awareness</td>
<td>Is the measurement of to what extent are the potential users aware of the charging network. This is examined through a spatial questionnaire disseminated over 45 potential users. Response is collected and summed up.</td>
</tr>
<tr>
<td>2 On / Off Street</td>
<td>This value is dummy. Zero for Off street charging points, and value of 1 for ON street charging point.</td>
</tr>
<tr>
<td>3 Integration</td>
<td>Space Syntax measure, calculated by DepthMap.</td>
</tr>
<tr>
<td>4 Traffic Counts</td>
<td>Actual travel demand provided by the Traffic Monitoring Unit in Newcastle (UTM) (values of main corridors feeding the RSs sites)</td>
</tr>
<tr>
<td>5 History</td>
<td>In months, the total number of months the charging point has been installed and used. (CYC data)</td>
</tr>
<tr>
<td>6 Connectivity</td>
<td>Space Syntax measure, calculated by DepthMap</td>
</tr>
<tr>
<td>7 No.of users</td>
<td>The total number of EV drivers used the charging point over 2012</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>8</td>
<td>Distance from centres (ι)</td>
</tr>
<tr>
<td></td>
<td>Metric distance measuring the road length between the charging point and the nearest residential district core.</td>
</tr>
<tr>
<td>9</td>
<td>Transactions (t)</td>
</tr>
<tr>
<td></td>
<td>The total number of transactions made by the users in 2012/ CP</td>
</tr>
<tr>
<td>10</td>
<td>Average time spent (A)</td>
</tr>
<tr>
<td></td>
<td>In minutes, the average time spent by drivers charging their cars using RS. (CYC data)</td>
</tr>
<tr>
<td>11</td>
<td>Most Frequent Time (M)</td>
</tr>
<tr>
<td></td>
<td>Discreet data, showing the most frequent time of the day the drivers tend to charge their cars using a specific charging point. (morning = 1, Afternoon = 2 and Evening = 3)</td>
</tr>
<tr>
<td>12</td>
<td>Total Energy Used (A)</td>
</tr>
<tr>
<td></td>
<td>In KW, the total energy spent charging cars by each RS in year 2012. (Dependent variable, Profit indicator)</td>
</tr>
<tr>
<td>13</td>
<td>Weekdays (ω)</td>
</tr>
<tr>
<td></td>
<td>Percentile, the weekday to weekend ratio. This value shows when the RS is being used over the week.</td>
</tr>
</tbody>
</table>

6. The Clustering Model

TwoStep clustering technique generates a report with some graphs and figures showing the cluster quality, size, structure, and influential variables, see (Figures 5 and 6). The clustering process took several iterations until we reach the chosen one. The decision is made based on the cluster quality, reasonable number of clusters, and ratio of clusters sizes.

![Figure 5: Clustering profiles](image1)

![Figure 6: Clustering quality](image2)

![Figure 7: Usage profile attributes](image3)

The quality should not be poor, and the ratio should not exceed 3. The model contains 4 clusters with a ratio of 1.5, which is very good, see (Figure 5). The number of inputs (categorical and continues selected variables) is thirteen. The overall distribution of cluster is quite decent and balanced as it is indicated in the cluster quality bar. There is not a dominant influential variable; public awareness, On street and Offstreet, Integration, traffic Counts, and History are the main predictors, see (Figure 8).
7. Model Outcomes

The spatiotemporal model generated four different clusters of RSs. Each cluster has main features that identify and configure common RSs usability attributes, recharging static design characteristics and spatial configuration values. The clusters are organised based on the size of the clusters.

The first cluster, *The Comfy*, see (Figure 9). This cluster forms the biggest cluster, containing 8 refuelling stations (sites) with a total of 11 CPs. This cluster has very high integration and connectivity values, which means that these charging points are spatially connected within the road network. In the space syntax literature, connectivity measures the number of immediate neighbours that are directly connected to a space (space here is the line that represents the road with the CP) (Hillier & Hanson, 1984). These 11 CPs identification numbers (IDs), according to CYC identification system, are 20006, 20059, 30051, 40004, 40005, 40018, 40019, 30058, 30059, 20046, 30055, and 30060.

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

The second cluster is “The Loser” charging points. This group forms the second biggest cluster, containing 6 FRs with a total of 10 CPs (40012, 40013, 40025, 40026, 30056, 30057, 10029, 40009, 40021, and 40011). These sites are On street and have been active for almost 2 years. In the contrary, this cluster, has significant features. It has a poor parametric design that results having an under-used RS. The 6 sites of this cluster are not recognised by the public. The sites are relatively distant from urban cores and very few drivers use these RSs which negatively affect the profitability. Two main observations can be stated; this cluster is not accessible (low integration value) and has poor marketing (public awareness). Marketing plays a major role in EV market, which is clearly reflected in this cluster.

![Figure 8: Clustering Predictors](image-url)
The third group is the “The Settled” charging points. This cluster has 8 CPs (20007, 20008, 10002, 10003, 10005, 10006, 10007, and 10008) located in two sites. This cluster contains the least number of RSs as at one site there are 6 CPs. This cluster has a different nature. The RSs are Off street; however, with a very high value of (Public Awareness), and have been installed for almost 2 years. Low integration and connectivity values and not close to residential areas. Users charge their cars in The Settled only on the weekdays and usually in the afternoon and they are not willing to spend time charging. In other words, users charge for almost less than 10 minutes, which will electrify their batteries with enough power to take them home in case they arrived the charging point with flat state, or they depend more on domestic charging and they are topping up with a few kilowatts.

The fourth group is the “The Selective” charging points, see (Figure 10). This group has the same size of the third one, it contains 8 CPs (20049, 30050, 10026, 30007, 30008, 11067, 11077, and 40010). The CPs in this cluster are Off street, recently installed, and users are not aware of their locations (very low Public Awareness value). EV commuters who use these sites (20% of the times is weekends), charge their cars in the morning and tend to spend ample time charging.

8. Discussion

A spatiotemporal model was executed to cluster the charging network by identifying the main features of the most utilised refuelling stations. This is to show the best set up for both Onstreet and Off street options. This relation between the variables and the total energy used can be observed from the formation membership of the clusters and the graphs show the quality, separation and distribution. The cluster quality bar displayed in Figure 6b, reflected a fair and close to good quality of cluster in terms of cohesion and separation. The quality might have been better with a higher number of cases and a variety of variables. As shown in Figure 8, public awareness, On and Offstreet and Integration are the most influential predictors forming the different EV clusters.

Designing for the OnStreet

Among the four clusters, the first one, “The Comfy” is the chosen one to be replicated when designing and planning for On street RSs. Under the process of assisting in the planning of future EV system, this model recommends to maximise the EV system with a nature of The Comfy cluster. This cluster setup meets the business needs of the EV system as it hits the highest number of transactions made by the enormous number of users in an On street CPs.

It is an overused accessible facility with a significant value of integration, connectivity and high number of users, which reflects suitability, accessibility and ease of reach within the road network. This indicates that drivers feel comfortable charging their cars in an On street charging location.

It is worth mentioning that The Comfy is perfectly designed to accommodate charging services especially for fast charging option. As a part of the recommendations for planning authorities and policy makers, quick chargers are to be located in The Comfy areas. Nevertheless, The Loser needs to be deactivated from current systems to avoid in new network design.

Designing for the OffStreet

In case of planning for Off street, we have two clusters to choose from: “the Settled “and “the Selective”. The first thought will be to select “The Settled” for replication of Off street CPs. However, it is very important to analyse the outcomes of the clustering analysis in relation to the site location of the RS. In some cases, like this cluster, the interpretation of the analysis might be tricky and misleading. The CPs of this cluster have low values of integration and connectivity; however, high records of transactions and number of users and are well recognised by the users. This needs an explanation. There are other factors affecting the use of 6 CPs out of the 8 CPs of the cluster, they are workplace CPs. What causes the high records of transactions and users is that it is being used by employees, Civic Centre Car Park. The second site is a shopping centre car park, Eldon Square, which again justifies the use.
This pulls the options down to *The Selective*. It is an accessible Off street facility with reasonable values of integration and connectivity, and users tend to have long charging periods (4-6 hrs), which reflects suitability. The number of users is considered small compared to the number of transactions. This means that selective people prefer to charge their cars particularly in *The Selective* and are willing to spend time charging in early time of the day. *The selective* is in use during the weekends as well (20% of the transactions are made in the weekends). The locations of this cluster seem very famous and preferred placed for parking. This cluster doesn’t represent a majority, only 8 out of 38 CPs, are in this cluster which justifies the poor level of the whole network usability. Planning authorities need to understand the features of *The Selective* and maximize the investment in installing CPs with a similar nature to it.

9. Conclusion

The recharging experience should not be a concern for EV drivers. The use of e-mobility is associated with a range-anxiety-syndrome, presenting hurdles for many potential users to electrify their vehicle use. Even for current users, so far, the EV is still replacing the secondary car in multi-car owning households mainly due to range limitation. This study aimed at interpreting the users’ data in a meaningful way regarding the data observations, and providing guidelines and recommendations with regard to the design and sitting of refueling stations based on this.

![Figure 9: Cluster 1- “The Comfy”-SPSS](image)

![Figure 10: Cluster 4_“The Selective”-SPSS](image)
From a planning perspective, the planners and policy makers would need to have a clear indicative description of the RS design characteristics and configuration that provide key design elements as well as guidelines for what to expect to have in terms of the business needs. This article interpreted the users’ data in a meaningful way. The developed clustering model outcomes provides guidelines and recommendations to the design of On and Offstreet RSs. It observes that the spatial design attributes are not the only factor that a decision maker should consider while planning for RSs; behavioural and spatial attributes should be incorporated with the analysis alongside the demographic and travel demand measures. Designing RSs is a complex design process that needs integration of sociotechnical and behavioural considerations. These considerations should be based on EV users’ feedback and experience, which justifies the importance of the ongoing research.

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