The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

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Abstract
The sustainable future for transport lies in a radical shift to low carbon technologies. The electrification of surface transport coupled with an increase in electricity production from renewable sources will play a major role in this transition to low carbon vehicles in the years to come. However, the widespread adoption of electric vehicles is obstructed by a number of barriers, both real and perceived. One such barrier is the importance placed on the provision of public charging infrastructure. This paper, through analysis of soft data and smart telemetry data, investigates the use of public charging infrastructure by 100 participants and over 6000 charging events in the SwitchEV trial. It shows that recharging events that occur at public charging locations could be reduced by up to 93% through the maximisation of energy transfer at non-public locations.

Keywords:
CHARGING, ELECTRIC VEHICLES, TRANSPORTATION, ITS, PUBLIC CHARGING INFRASTRUCTURE

Introduction
The North East of England is host to a pioneering electric vehicle demonstration project designed to collect and analyse data about vehicle diagnostics, driving and recharging behaviour. The Switch-EV trial is one of 8 projects across the UK to have been rewarded funding through the TSB’s (Technology Strategy Board) Ultra Low Carbon Vehicle (ULCV) Demonstrator Programme [1]. The operation of the three year trial sees 44 fully electric vehicles (EV) being fitted with on-board data loggers which capture vehicle data on a second-by-second basis to provide an insight into the driving and recharging behaviour of the
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

trial participants. This information will be used to establish behavioural profiles and to apply those to other early adopters either inside or outside of Switch-EV. The hard data recorded by the on-board loggers is collected in parallel to attitudinal, soft data through focus groups and questionnaires to better understand trial participants’ choices pre- and post-trial. This method of data collection allows for potential perceived barriers in EV adoption to be identified through soft data and either justified or dispelled through analysis of the hard data.

The driving range, both actual and perceived, of an EV has been identified as one of the main barriers to widespread uptake of EV’s. It is because of this perceived lack of range that the general public’s attention is naturally drawn towards a desire for a dense charging infrastructure in their area of daily operation. When considering public infrastructure investment and placement there is a need to find the right balance between expected demand and supply [3].

Switch-EV is in a rather unique position in the TSB ULCV trials as the desired dense public charging infrastructure, installed and managed by Charge Your Car (CYC), is already in place resulting in a ratio of approximately five posts to every one EV. CYC provides trial participants the option of subscribing to the scheme for the price of £100 per year [2]. This subscription gives members access to free use of all public charging location. This paper tests the hypothesis that free inner-city parking encourages the use of public charging infrastructure. Furthermore, public charging infrastructure is located in areas where there is likely to be a high demand for use of the posts for energy and convenience. Many charging posts have therefore been installed near working and leisure areas (shopping, entertainment etc.) as these locations are in areas service by a greater number of daily trips than more rural settings. As a by-product of this spatial design, the usage of the public charging infrastructure is influenced heavily by the operating times of these destinations. Inevitably, in urban areas in the North East, the main usage of CYC infrastructure occurs during the peak time of the day (08:00-19:00) when the carbon content associated with the electricity generation in the UK is at its highest [4].

The aim of this paper is to investigate whether the perceived need for dense public charging infrastructure is justified by analysing whether the energy transferred at public infrastructure is needed in order to complete the trips before and after the charge event. In addition, it will be considered how Intelligent Transport Systems (ITS) can play a role in lessening this dependence on public charging infrastructure through better driver information. This in turn will help contribute to eliminate of one of the barriers to EV uptake as drivers will see that their driving habits can be serviced by fewer public charging infrastructure.

**Methodology**
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

The analysis is based on the drive and recharge events for the first 16 months of the trial collected through data loggers fitted on each of the 44 EVs operating in Switch-EV. In addition to those hard data, focus group and questionnaire responses are used to justify any assumptions.

Vehicle Based Data Collection

The data loggers installed on the trial vehicles enable the collection of real time second-by-second driving and recharging information by connecting to the CAN (Controller Area Network) bus through the vehicles OBD (On-board Diagnostics Port). In addition to the CAN bus the loggers can also record external analogue and digital inputs. These inputs include the GPS and time-stamp as well as a number of analogue inputs from current-clamps which are attached to various electrical systems of the vehicle to measure current flow and battery drain/regeneration. The raw data collected is stored on a remote server in binary format. This information is then parsed through the use of a number of Python scripts to pick out drive and charge events, identified by an ignition or charge indicator. Drive event distances were calculated from GPS time-stamps collected by the data loggers. The charge events which occur chronologically before and after a series of drive events are also derived from the raw data. The time and location of each charge event is recorded along with the duration of the charge and the associated energy transfer.

Assigning Charging Locations to Logger Data

The coordinates of each recharge event is cross-referenced against a list of known charging locations. The observed recharging events are assigned to one of the following location classifications:

- Home Based
- Work Based
- Public Charging Infrastructure (CYC managed)
- Fast Charger
- Other

‘Other’ locations are locations at which there is available charging infrastructure, but it is not managed through the CYC scheme. An example of an ‘Other’ location would be a post installed at a supermarket which is owned and maintained for by that supermarket.

Identifying Driving Delay After a Charge
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

Using the time-stamp from the data loggers during observed recharging events and the subsequent driving event, it is possible to identify any time delay between the termination of a charge sequence (for example at 100% battery capacity) and the subsequent drive event. It is assumed that any instance where a delay is recorded represents a scenario in which the battery has reached full capacity and the post has stopped supplying charge. This assumption is made because, under public infrastructure usage guidelines supplied by CYC, it is required that vehicles be plugged in when at a charging bay.

Maximising Energy Transfer at Non-Public Charging Locations

The purpose of this analysis is to show how the maximisation of energy transfer at locations other than public charging infrastructure (Home, Work etc.) can reduce the number of observed public recharging events of each vehicle and still perform all observed driving events. It is important to note the assumptions made in the analysis; outlined below:

- Only observed charging locations are used;
- At an observed location other than a public charging post, the potential maximum energy transfer is calculated by utilising the time from the end of the observed charging event to the next observed driving event (or until 100% battery capacity is achieved);
- The rate of energy transfer during this extended, synthetic period of charge will be based upon the rate of energy transfer in the original observed recharge event;
- The State of Charge (SoC) of the battery is allowed to drop to 20% before a charge at a public charge post is deemed necessary;
- If a public charging event is needed, the maximum energy transfer possible is assumed (as in non-public recharging events); and
- Approximations of range are derived from battery SoC and manufacturers range specifications.

Figure 1 shows a simplified flowchart example of how the analysis is carried out applying the assumptions outlined previously.
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

Figure 1 – Example of Synthesised Scenario Maximising Non-Public Recharge Events

The flow chart shown in figure 1 follows one EV as an example. The SoC of the vehicle is known from the very first observed recharging event in the trial period and thus the approximate range (km) associated with that SoC and battery capacity is known. The subsequent drive event distances, as they have been observed, are then added until the next observed charge event. In this first instance, all logger information used is known to be true. Upon the occurrence of the second observed recharging event, the analysis begins to maximise the non-public recharging events and unavoidable (based upon the distances of subsequent drive events) public charging events to create a ‘Synthetic SoC’ to determine whether or not the public charging events can be missed.

Results

Soft Data: The Perceived Need for Public Charging Infrastructure

Before the Switch-EV trial, each participant was asked how important they thought it was to
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

have access to a public charging post in a pre-trial questionnaire. The results are shown in Figure 2.

![Figure 2 – Pre-trial Questionnaire Results Showing Perceived Importance of Public Charging Infrastructure](image)

Of the 30 responses, 52% thought it was ‘Very Important’ whilst a further 20% thought it was ‘Quite Important’. This suggests that having dense and highly visible public charging infrastructure in place will help persuade the general public that the operation of an EV as a replacement for a standard Internal Combustion Engine (ICE) is practical.

During the trial period, focus groups were held to help assess any changes in participants’ attitudes and perceptions towards their EV usage, after having had time to get used to the day to day operational and logistical aspects of the vehicle. When asked about their recharging habits it became clear that the participants charged as ‘often as they could’. Asked if this behaviour was driven by receiving free energy and parking participants responded that it was and if they actually had to pay for parking they may consider changing their recharging behaviour. Further to the economic savings associated with free parking, convenience was also suggested to be one of the motivations behind recharging as frequently as possible given the charging points are in ‘good locations’ with very little competition for spaces.

**Current Use of Public Charging Infrastructure**

Using the location information from the data logger events, it can be seen that recharge events at public locations account for over 30% of all observed recharging events as shown in Figure 3. The composition of the trial participants in SwitchEV is weighted more heavily towards
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

pool cars users from a number of organisations. Due to the design of pool car use and employees being mindful that the car is likely to be used by someone else that day, it is not surprising that Work based charging is the most common location observed.

![Figure 3 – Observed Recharge Events by Location](image)

This information suggests that public charging infrastructure is being used regularly (>30%), however that does not mean that it is being used solely for charge. As highlighted in the soft data review section of this paper, public charging infrastructure has additional benefits such as prime city centre location parking which could be increasing the number of recharge events that take place at public charging locations.

If recharging events at public locations are coupled with the next chronologically observed charging location for each vehicle, we see that the next most common recharging location (60% of the time) is also public as shown in Figure 4.

![Figure 4 – The Next Observed Recharge Location After A Public Recharge](image)
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

This information suggests that home based recharging, which is generally accepted to be the most favourable in terms of reducing carbon content from electricity production when occurring ‘off-peak’ (19:00 – 08:00), is not being used in favour of public charging infrastructure. The fact that public recharging events are second only to work based charges in volume suggests that those trial participants without a dedicated work charge point are using CYC as a proxy.

Results of Driving Delay Analysis

Analysis shows that in 37% of cases, there is a delay of greater than 15 minutes from the end of energy transfer and the user driving away. Of this 37%, the average time delay is shown to be 3 hours and 37 minutes (03:37:00); that is to say on average the EV users reach 100% battery capacity 3 hours and 37 minutes before they return to their vehicle to make the next drive event.

Impact of Maximising Charge at Non-CYC Locations

The results of the analysis show that 93% of observed recharge events occurring at known public infrastructure locations could be removed by maximising the energy transferred at non-public locations. If 93% of public charging events were removed, 98% of the total kilometres travelled in the study could still be undertaken. Figure 5 below shows the comparative charging profiles before and after the minimisation of public charging infrastructure has taken place.

![Figure 5 – Charging Profiles](image)
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

**Conclusions and Future Role of ITS**

The analysis presented in this paper has shown that the provision of dense public charging infrastructure is important in helping to facilitate the uptake of electric vehicles. There certainly is a need for some form of public charging infrastructure to be in place, 7% of the observed recharging events at public locations were shown to be necessary even in a ‘best case’ scenario, however the importance of such infrastructure in terms of the day-to-day operation of EV’s is perhaps over emphasised.

This is where ITS can play a significant role in modifying EV user recharging behaviour through the supply of better information. The immediate area for improvement would be to try and reduce the number of instances (37%) in which the post has stop supplying charge but the vehicle is still plugged in. The supply of a remote form of communication such as a text message from a central server could alert the driver to the fact that their charge is complete. This information, coupled with parking enforcement, could be used to cut down the number of instances where the main motivation for using the charging posts is for parking. The reduction of such instances would then increase the availability of the post in question, thus making it possible to provide the same level of service with fewer posts.

A more complex system could use the known drive event information for each EV user to predict how much charge is a necessity then tailor the period of recharge at a public location accordingly. For example, smart navigation could be used in conjunction with public charging locations. Upon starting a charge, the driver plots out the known journeys for the next day(s). The smart navigation system takes into account known driver behaviour, such as acceleration aggression etc., which will have an impact on battery efficiency. This information is then coupled with traditional navigation elements along with EV specific navigation information such as the effects of topography and average speed on battery efficiency along a chosen route [5]. The post will know that out of necessity a certain amount of energy needs to be transferred in addition to a supplementary safety net amount. The transfer of only energy which is deemed a necessity will again help to cut down the amount of time each vehicle requires at a public charging location, thus increasing availability within the trial area.

While the above examples provide a method of reducing the amount of time each car spends at a public location, they will also help to maximise the recharge events at non-public infrastructure. Recharge events occurring at non-public locations are in turn more likely to be modified in terms of the times at which they occur. Through the use of smart metering incentives can be used to shift the time of energy transfer to an overnight, ‘off-peak’ scenario which would in turn reduce the carbon content associated with the generation of electricity. In conclusion, the introduction of smart infrastructure and related ITS technologies could help address the EV adoption barrier associated with the perception that large amounts of public charging infrastructure needs to be in place and visible before mass uptake of EV’s can occur.
The use of ITS in understanding EV public charging behaviour to inform future smart charging infrastructure

If this is accomplished, savings can be made on the cost of installing unnecessary public charging posts along with maximising non-public recharge events at ‘off-peak’ times.

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**References**

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