Understanding the Social Practice of EV Workplace Charging

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Abstract
Owning or leasing an electric vehicle (EV) is becoming more common in developed countries. While home charging is the most common choice, workplace charging and its provision by employers has become an important option. For many, it is essential to cope with the limited range of most EVs. Home and work are the two places where vehicles are parked for long periods and so are prime candidates as charging locations. However, workplace charging is often a limited resource. This paper reports on an empirical study of workplace charging at a UK public sector employer. It explores the use of workplace charging (WPC) via spatiotemporal analysis of employees and visitors' charging events over a 3-month period. It provides insights into weekly patterns and daily mechanisms of using shared facilities in a WPC environment. We identify insights that are relevant in the design of workplace-charging infrastructure, identify the design needs, emerging requirements, and highlight potential areas for sociotechnical-interventions.

Author Keywords
Design requirements; electric vehicle; usability; spatiotemporal analysis; workplace charging.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

Transport represents one of the fastest growing sectors of the economy in terms of energy use and environmental impact. Electric vehicles (EVs) as ubicomp transport devices are emerging as a zero carbon alternative to conventional internal combustion engine (ICE) vehicles. The transport sector currently supports a wide range of ubicomp technologies [Elbanhawy et al., 2012; Beeton, 2012]. Research on Intelligent Transport Systems (ITS) covers a wide field, as it comprises combinations of communication, computer and control technology developed and applied in transport to improve efficiency and system performance and facilitate mobility. Innovative technologies can be applied to vehicles as well as transport infrastructure and used by stakeholders embracing transport organisation, information technology (real time information, tracking and vehicle-to-vehicle communication) and passengers to improve service quality and transport management. Large-scale deployment of EVs is anticipated in the near future [Cao et al., 2012; Anable et al., 2011]. EVs offer real potential to make cities smarter [Graham et al., 2012; Elbanhawy, 2014; Beeton, 2014]. Although EVs have the potential to resolve many sustainability issues related to the transport sector, there are also many uncertainties including economic viability, consumer satisfaction and environmental perspectives [Earley & Green-weiskel, 2011].

Setting the Context

EV drivers face three particular challenges compared to drivers using the established fossil fuel infrastructure: i) current battery technology limits range, so depending on the commuted distance drivers may be required to recharge while at work in order to get home without stopping; ii) re-charging takes a significantly longer time than conventional fossil fuel refuelling; iii) the infrastructure for charging is poorly developed compared to the traditional infrastructure, and iv) EV drivers may have to compete for the charge points that are available. In order to overcome some of the barriers and enable a better EV market share, the design process of charging infrastructure needs to be addressed. This includes all non-domestic charging facilities: commercial (off street at shopping mall car parks), on street charging points (CPs), motorway service stations, and workplace charging (WPC) locations. WPC refers to EV charging facility that is provided at or near the user's place of employment [Scott et al., 2010], which is perceived as potential solution to the infrastructure design problem. Although not all users need to charge at work in order to return home, the ability to charge increases flexibility [Calstart, 2013] and fills a critical gap in EV charging infrastructure needs [Scott et al., 2010] It increases the certainty of having access to charge apart from the domestic one, which in turn decreases the EV range anxiety. Because EVs are parked at workplaces for substantial periods over the weekdays, WPC is a promising option only if practical ways can be found to provide the needed infrastructure [National Academy For Science, 2013].

Identifying the Problem

While designing a non-domestic charging service, alongside the business considerations, spatial and behavioural aspects are fundamental. End user feedback and perceptions are derived from the system usability and adoption of the new technology [Elbanhawy, 2014b]. Plugging in the EV engages drivers in an essential new behaviour. Using WPC requires control; the frequency of use and number of employees or visitors affects the individual's charging pattern, which may lessen the market growth. Figure 1, depicts a broad insight into some of the problems and thought patterns observed in our study of WPC.

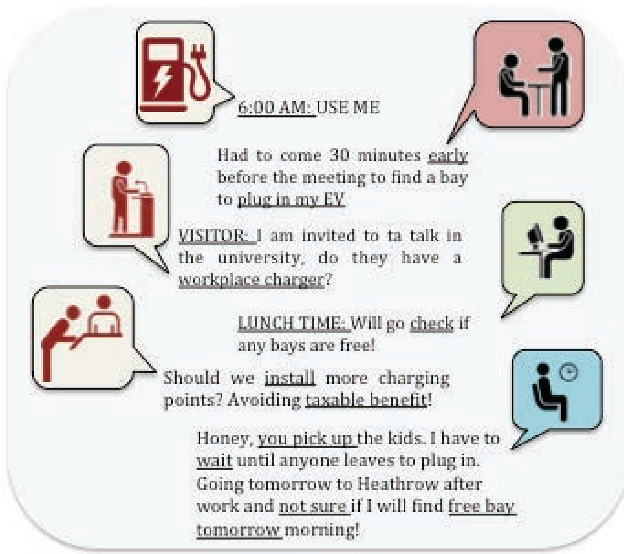

Figure 1: Infographic shows the two ends of the EV system

Prior Work

Since 2012, studies and research projects have tackled EV adoption [Edbue & Long, 2012], range issues, infrastructure, charging loads on electricity grid, and the use of renewable energy to charge the battery [Mal et al., 2012]. What little existing literature there is on WPC practices tends to be published as business cases by utility providers, private companies or as part of national and governmental initiatives and scheme announcements [Calstart, 2013; Scott et al., 2010; Large, 2012]. Other studies report some statistics on anticipated use of the network based on surveys. In one California survey, 37% of EV drivers had access to WPC [Scott et al., 2010]. Two studies reported trials carried out in a workplace environment. As part of the Switch EV project, staff members from Northumbria and Newcastle universities in the North East of England participated by trying to drive an EV for one week [Future Transport Systems, 2010]. The other study was carried out in Shell Technology Centre where 57 members took part in the BEV study utilizing two EVs. The latter was to examine the anticipated social influence and consumer preference for green mobility [SwitchEV, 2011]. These small scale and simulation-based studies suggest that there is a gap in the literature as no one has studied real users over a significant time period. Real world use and monitoring of the system will allow the community's (user and provider) design requirements to emerge. Ethnographic studies and spatiotemporal data analytics that explore and identify the behaviour of EV users rather than their perceptions or attitude will allow actual relevant insights to emerge. Relying on anticipated behaviour or probabilistic scenarios of WPC environment would be misleading due to the special nature this system has compared to public shared charging network and to conventional refuelling infrastructure in the first place. EV users do not have pre-existing preferences for novel attributes that they have not previously experienced [Axsen et al., 2013]. Thus some behaviours are spontaneous and constructed in the moment in the process of facing new technology [Caperello & Kurani, 2012] and allows users to examine technology affordances [Wirdedu, 2008]. The present study addresses two research questions and discusses the emerging Design Requirements and Insights proposed.

Research Question 1:

Employer's perspective: With the slow take-up of EVs, is it viable to invest in WPC? Will it be underused? How to manage the use of non-taxable benefit?

From the employer's perspective, installing a WPC in the parking area demonstrates the employer's environmental leadership. There are emerging initiatives and subsidies by local and private bodies. For example, in February 2013, the UK Secretary of State for Transport subsided up to 75% towards the cost of installing WPC points for public sector bodies [OLEV, 2013] and since then several private sector organisations have followed suit with similar schemes [Axsen et al., 2013]. The present case study covers one UK University, which took up this scheme and installed two CPs in August 2014. Each CP has 2 ports and each port has a capacity of 7 Kw, in two different locations on campus. One CP is in the visitor car park near main reception to accommodate visitors and staff while the other is in a staff car park. Users need an RFID card, which is free for visitors but costs GBP 30 per year for staff.

A Multi Method Approach

Following a multi method approach, we elicited details about EV users' perceptions, social practice, interactions and charging patterns sharing the WPC network. First, a spatiotemporal analysis was carried out investigating the usage of the current CPs from October-December 2014. This was done to exclude system familiarization effects. In total, there are 10 registered users although only 9 are regularly using the system. Second, a structured interview (Interview I) was designed and carried out in January-February 2015 with the staff members (n=9) who are in the EV scheme. In total, 4:07 hours were spent interviewing the 9 participants. Qualitative and quantitative data was collected through open-ended questions. The first user joined in August 2014 and the newest joined in December 2014. Table 1, summarises the EV users profiles and relevant data. This was followed by another semi-structured interview (Interview II) with the EV scheme university administrator (Admin.) to discuss system from an employer perspective.

User	ID	EV	G	ToP	D	WPC	S
EV1	AA-AB01	2 LEAF	M	42m	3m	home	No
EV2	AC-02	LEAF 2nd hand	M	14m	6m	2-3	Yes
EV3	AD-03	LEAF	F	43m	8m	2-3	Yes
EV4	AE-AF-04	LEAF	M	18m	4m	4	Yes
EV5	AG-05	LEAF	M	7m	5m	0-1	No
EV6	AH-06	LEAF	M	3m	6m	3	Yes
EV7	AI-07	LEAF	M	6m	30m	4	Yes
EV8	AJ-08	LEAF	F	4m	27m	1-2	Yes
EV9	AK-09	Zoe	F	6m	8.5m	1-2	Yes
EV10	AL-10	Zoe	F	1m	3m	2	Yes

Table 1: Participants personal and EV related information. Where G is gender, ToP is the time of purchase in months (e.g., 14 m means the user bought his car 14 months ago from the day of the interview), D is distance commute in miles from home to work, WPC is their weekly charging pattern at workplace, and S is whether the user drops off the kids at school in the morning. EV1 and EV4 have double characters IDs as the two users share the EV with their spouses.

Insight 1: WPC Managing and Data Retrieval

Interview II explored the management process. In August 2014, the university contracted a utility management company to monitor the WPC. The interviewee talked about the system operation.

> *"Utility regulators retrieve the data every 3 months. We, as the university, do not have direct access to the WPC system API." [Admin, 2014]*

When we asked about the mean of communication employed to notify the users with any updates, he replied:

> *"So far, we did not encounter maintenance or electricity shortage [issues]. I do not know how/when we would notify the users, if any." [Admin, 2014]*

Another operational matter is how the employer should manage membership. In this system they decided that visitors could use the system free of charge but providing free electricity (fuel) to staff would be considered a taxable benefit. To avoid this the administrator stated that an annual membership fee was charged but a pay per use could be introduced in the future. The data retrieved does not classify each port, it provides records for each 2-port charging post, see Table 2.

CP	ID	Date	Start	End	Kwh
1	AC-02	29.12.14	11:34:5	13:24:02	6:44
92	AI-05	12.11.14	15:23:1	20:19:56	8:67

Table 2: *Data extracted from WPC database*

Insight 2: WPC Usability and Related Issues

Via spatiotemporal data analytics (see Table 2) the system usability becomes clearer, it includes various dynamics. There are two key elements we are interested to identify: the Most Frequent Time (M) and the Average Time Spent (A). The first insight was to capture the M the WPC is being used. Once the arrival times are plotted, as show in Figure 3, a collective pattern can be seen. Apart from the three early morning arrivals (made by AE-AF-04), the first batch charges their cars during lunchtime, 12:00PM. The first swap takes place around 2:30 PM, where the lunch-time plugged in users remove their cars for others. The second swap is at 4:30 PM, which is the last major swap of the weekday. This implies that the occupation duration during the busiest periods has a value of A between 2:30-3:30 hours. There are three random charging events showing after midnight. This is due to the different work patterns some staff members have, they need to stay late at night working on campus.

Requirement 1: Design Requirement for Deterring Bay Blocking

Another recurring phenomenon, which does not tend to happen in public CPs due to the cost impact, was to leave their vehicle plugged-in more than the time needed to charge, known as bay blocking. To depict this, the time spent charging can be calculated from the personalised EV interface each user has (which depends on the EV model). The information displayed in this user interface (UI) is fundamental as it justifies the charging patterns and profiles. For most of our users' car model (Nissan Leaf) there is an arbitrary display of 12 cells is in the car UI (see Figure 2 for example of web interface). In the case of a full charge, the 12 cells will apear in green, the last cell from top displays from 12% to 15%, depending on the model. Each following cell displays 8%-5% of the charge, depending on the EV model. We retrieved the historical charging information for users. Figure 4 displays the WPC sessions of user EV4 (AE-AF-04). The graph depicts the times the car was parked; moreover, it highlights the plugged in times. In a poorly designed system, this phenomenon cannot be automatically banned. In the early days of operation, there were no communications or sharing mechanisms. The charging process was purely based on first-come-first-served basis and no updates were shared to exchange real time information.

This led to a number of problems of charging positions being blocked. Figure 5 is a snapshot of a conversation between one of the users (participants) and the Estates department. The absence of a smart mediation that works inline with the EV technology and lack of coordination led to disappointment and negatively imaged practice.

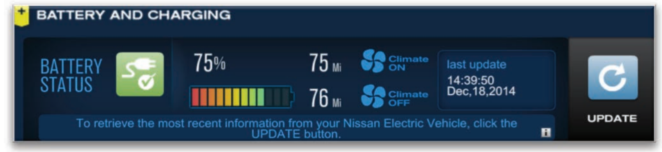

Figure 2: Nissan LEAF user interface snapshot

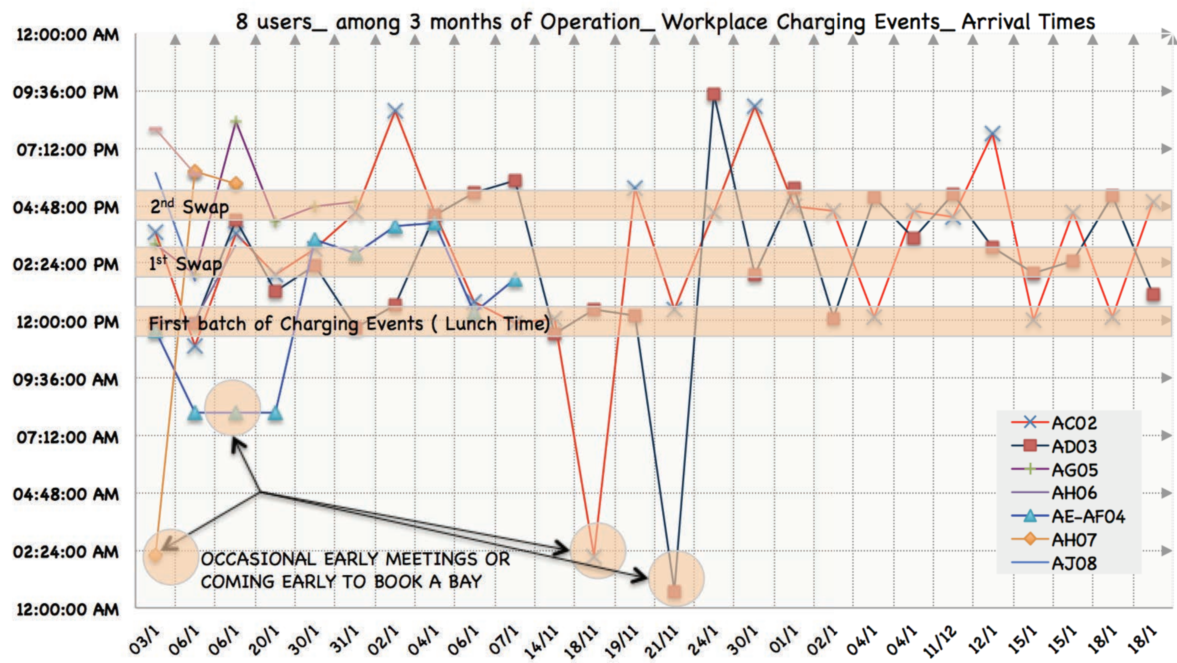

Figure 3: Charging events (time of arrival) of the 9 users in November 2014- January 2015

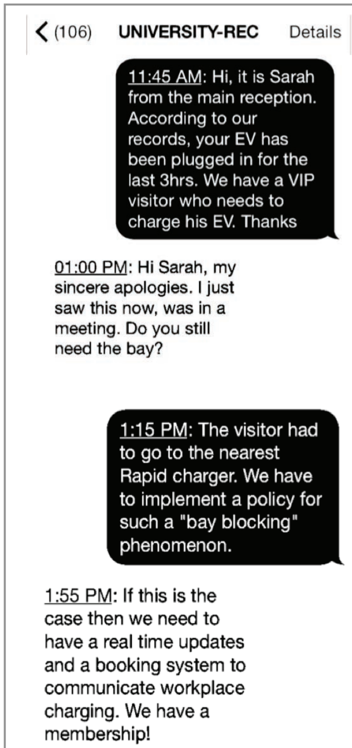

Figure 5: Communication failure between users and provider

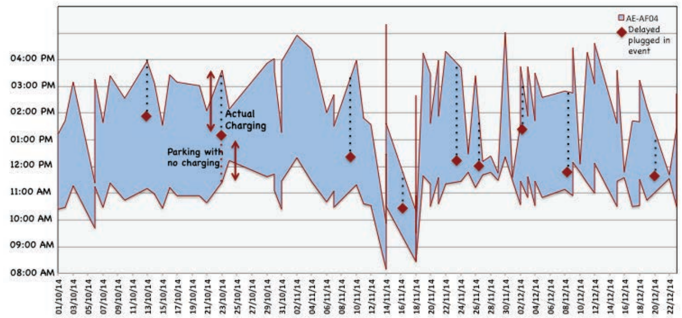

Figure 4: Charging versus plugged in time of EV4. The arrows indicate the plug in events, which show the bay blocking.

Research Question 2:

End user's perspective: EV drivers need to have some element of certainty and planning in the system (need to know they can charge during the day). What are the design criteria for real-time information and planning system?

Requirement 2: Understanding the End user's Mindset

Through Interview I, the (n=10) users were asked to answer 20 questions which varied between qualitative and quantitative addressing questions related to their motivations of purchasing an EV, charging and driving patterns for work-based trips, WPC practice, use feedback, communication system and design recommendations. Attention was given to their insights and feedback on the WPC practice. Users stated different motivations and rationales behind purchasing an EV and selecting the EV model. The social influence plays a main role in the adoption and usability of EVs (Axsen et al., 2013).

The motivations varied between environmental concerns, the habit of being a technology geek, long-term based financial calculations, the self-satisfaction of being an early adopters or a risk taker. The interviews showed the two main predictors of the purchase decision: domestic and WPC access. With no hesitation, the users said:

> *"Having access to domestic charging is compulsory; otherwise, owing an EV would not have been possible."[AG-07]*
> *"I am waiting for my domestic charger to be installed next month, I only rely on the WPC for now." [AL-10]*
> *"Some EV users rely mainly on workplaces, yet domestic charging is essential for non-work, weekends, and long journeys." [AE-AF04]*

Insight 3: The Emergance of the Messaging Protocol

Weeks after establishing the charging network and having more users joining the EV scheme, the users realised that the lack of communication between all the users was a barrier to efficient sharing of the resource. They created a simple means of communication to facilitate the charging process on campus. They agreed among themselves that when anyone started or stopped charging they would send a notification message to the mailing list. Figure 6 shows an example of a 1-line email to the mailing list with a subject line of the form:

EV [ON | OFF] Charge – [Location]- [estimated completion time] – [Number of spaces free].

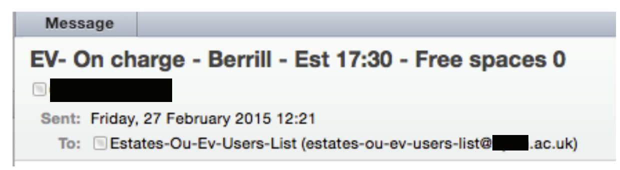

Figure 6: Emailing other EV users (created by the community)

Requirement 3: Real Time Information and Booking System

WPC is a cheaper, more accessible (known population and can be reached) and convenient (vehicles are parked typically for at least 8 hours during the day) option compared to public charging. Through interviews, the EV users commented on the ad-hoc email list solution they had created.

> *"It is a good temporal mean of communication. Surely, it will break down with more users and CPs, it does not scale." [AE-AF04]*
> *"Driving an EV is a joy; however, the system is associated with socio-technical, behavioural needs. The communication between the CPs and us deemed fundamental." [AC-02]*
> *"It opens a channel of communication; however, it is not a platform with real-time updates." [Al-10]*
> *"I do not have a smart phone, I come early after I drop off my kids at school, and charge almost everyday morning." [AG-05]*

Permanent reliance on sending a mail is not scalable. Some barriers may be addressed by providing a controlled WPC system.

Insight 4: Individual Charging Pattern (Academic)

One threat to validity in this case study is the workplace chosen. The academic workplace has a unique charging pattern compared to traditional workplaces. Academic members of the scheme may choose to work from home or go to offsite meetings and use flexible working hours, which adds more variability to the system. The demographic factors are very clear from the EV user's profile as found in Table 1:

1.Most users are local, they commute short distances;

2.Some users charge opportunistically (even though they live close) while others charge because their commute distance requires it.

The case study early adopters have different patterns (as they are more familiar with their car range). Figure 7 and 8 show graphs of users EV2 and EV9; the first shows a pattern (3:30-4:30 PM), preferred charging time for an established member of the scheme; whereas, the second graph shows a new member who doesn't have a trend, yet.

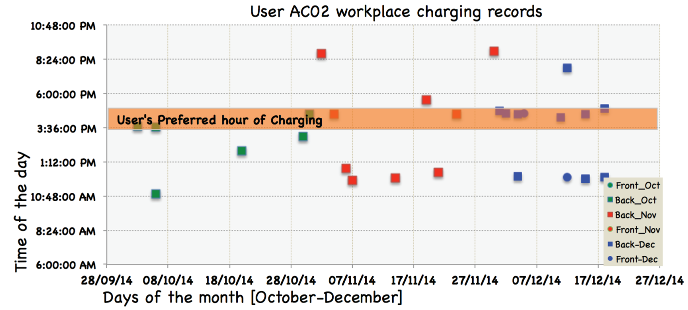

Figure 7: EV user AC-02- charging sessions mapping

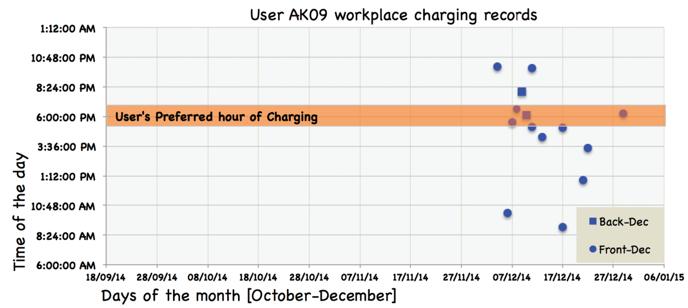

Figure 8: EV user AK-09- charging sessions mapping

Discussion

The paper presented a case study of the weekday-use of a shared charging network in a university campus. Designing for the end–users requires a clear understanding of the emerging design needs, meaningful observations are obtained by analysing the current system. The case study charging network was utilised every consecutive weekday (62 days) and on some days, the records reached 6 charging events. The seasonality effect, often seen in December, was not that influential possibly due to non-standard academic work patterns. By interviewing users and the service provider we created a chain of connections between the insights and requirements.

Conclusion and Future Work

By using a bottom-up approach, this study allowed us to add another dimension, which is the actual dynamics and behaviour of EV drivers in a workplace environment. By having access to all of the charging events and being able to meet every user in the EV scheme, we were able to validate the outcomes. We found that:

i) the data granularity is a major issue that affects the analysis process. To enable data analytics of current systems and predict future demand, a more reliable support platform is needed;

ii) The EV system is complex due to behavioural, technical and demographic aspects. With such advanced technology and different preferences, a user-centric design approach is needed. This paper presented the first step towards outlining the design guidelines of an integrated WPC system. A participatory workshop for both EV users (employees) and provider (Estates department) is proposed to allow engagement and community action;

iii) employers may wish to establish creative policies to govern WPC etiquette. Our future work is to compare this system to another workplace (traditional work pattern, and more users).

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