EVS26
Los Angeles, California, May 6-9, 2012

Ultra Low Carbon Vehicle Demonstrator Programme – Post-Experience Usage Patterns, Driver Attitudes and Behavioural Change

Andrew Everett[1], Chris Walsh[2] Steve Carroll[2], Mark Burgess[3] Margret Harris[3]

[1] *Technology Strategy Board, North Star Avenue, Swindon, SN2 IUE, andrew.everett@tsb.gov.uk*
[2] *Cenex, Centre of Excellence for low carbon and fuel cell technologies, Holywell Park, Loughborough University, Loughborough, LE11 3TU, chris.walsh@cenex.co.uk*
[3]*Dept of Psychology, Oxford Brookes University, Oxford, OX3 3BP, mark.burgess@brookes.ac.uk*

Abstract

The UK's Technology Strategy Board, with central and regional government support, has funded the world's largest multi-site demonstration trial of ultra-low carbon passenger cars. 349 cars have been deployed, supported by the installation of approximately 500 electrical charging points. The trial will help the UK Government, vehicle manufacturers and energy suppliers understand how people use these cars and how they feel about them.

Eight project teams each comprising at least one vehicle manufacturer, an energy supplier, a local authority, infrastructure provider and a university have gained funding. The trial includes two separate research activities:

1. Usage patterns – including time and duration of journeys, energy used and charging location.
2. User perception – questionnaires and interviews with users before, during and after the trial to help understand their feelings about the car and if they have adapted to use it.

The first 65 cars were handed over to users on 13th December 2009. By December 2011, 349 vehicles from 19 manufacturers had been deployed over a mix of private domestic, company pool or fleet vehicles. The vehicles have undertaken over 180,000 trips covering over 1,000,000 miles. The vehicle models include the plug-in electric Tata Indica, Mercedes Smart ForTwo, Nissan Leaf, Ford Transit Connect; BMW Mini-E, Mitsubishi i-MiEV, Allied conversions of the Peugeot Tepee MPVs; the hydrogen fuelled Microcab; and performance electric sports cars including the Delta E4 Coupe and the Ecotricity conversion of the Lotus Exige. The fleet also includes plug-in versions of the diesel hybrid Land Rover Range-E and the petrol hybrid Toyota Prius. This paper provides details of the programme and results of the research to date, focusing especially on vehicle usage and perception data from the first three months of vehicle trials.

Keywords: BEV (battery electric vehicle), charging, passenger car

1 Ultra Low Carbon Vehicles in the UK

The United Kingdom's Technology Strategy Board (TSB) stimulates technology-enabled innovation in areas which offer the greatest scope for boosting UK growth and productivity. Using a challenge-led innovation approach, the TSB sees the societal, economic and environmental challenges of the future not as threats, but rather as opportunities for innovative solutions that enhance quality of life and increase wealth.

One such challenge is transport greenhouse gas emissions, which represent 21% of UK domestic emissions [1]. In response the TSB's Low Carbon Vehicles Innovation Platform was launched in September 2007. The Innovation Platform aims to promote low carbon vehicle research, development and demonstration in the UK to deliver:

- Carbon reduction in domestic and international vehicle markets
- Accelerated introduction of low carbon vehicle technology and vehicles (compared to a purely market driven process)
- A UK automotive sector benefiting from growing demand for low carbon vehicles

The Ultra Low Carbon Vehicle Demonstrator (ULVCD) programme is a headline project within the innovation platform where £25 million has been allocated to highly innovative, industry-led collaborative research projects in the field of ultra low carbon vehicle [2] development and demonstration. With industry matching the public sector funding the total programme investment is over £50 million. Using a competition approach the programme is focused on encouraging the development of industry-led consortia that can bring significant numbers of vehicles onto roads quickly.

With plug-in electric and hybrid electric vehicles from manufacturers such as Ford, BMW, Jaguar Land Rover, Allied Vehicles, Mercedes-Benz, Toyota, Mitsubishi and Nissan, 349 new innovative cars have been deployed in eight locations around the UK, supported by four energy suppliers, five universities, and three regional development agencies, the trial is the world's largest multi region trial of ultra low carbon vehicles.

Since its launch in January 2009 the ULCVD programme has focused on the collection of analytical research data to aid UK understanding on integrating vehicles with the lowest carbon footprint into the national fleet.

The trial includes two separate research activities conducted by Cenex and Oxford Brookes University respectively:

Cenex is the UK's centre of excellence for low carbon and fuel cell vehicles. Founded in 2005 by UK central government, Cenex works with technology providers, vehicle operators, government and academia to stimulate the market for low carbon vehicles, provide market opportunity to the UK automotive industry and help achieve UK greenhouse gas reduction targets. Cenex runs a number of programmes for UK government focused on low carbon vehicle deployment, and has an in-depth understanding of the behaviour and benefits of low carbon vehicles in the field. This knowledge has been gained through extensive testing and analysis of over 500 operational vehicles utilising a wide range of alternative powertrains and fuels.

The Psychology Department at Oxford Brookes University (OBU) produces internationally renowned research that informs developments in technology, education, health and social care. In addition to the TSB, the department attracts significant funding awards from bodies including the ESRC, British Academy, Leverhulme Trust, and the Burdett Trust for Nursing. Dr. Mark Burgess and Prof. Margaret Harris' specific expertise in multiple methods of data has led to them designing and analysing the questionnaires and interviews for the current ULCVD programme and enabled them to identify the critical factors underpinning people's transition from having a conventional combustion engine powered car to adopting new transport technology in the form of having an ULCV. The two main research activities taking place during the ULCVD programme are detailed below.

Research activity 1: A study into the ultra low carbon vehicles usage patterns relating to journeys and charging. Data and analysis from the trial, captured electronically from the vehicles and charging posts, will provide an understanding of real world operation, support infrastructure development and inform market development for ultra low carbon vehicles.

Research activity 2: A study of user perceptions. OBU's main aims in this part of the research are: to gain an understanding of the motivations and expectations of drivers taking part in the trials in order to see how these impact on their use of the vehicle; to determine how expectations and attitudes change with day-to-day experience of driving an ultra low carbon vehicle; to compare anticipated and actual barriers to vehicle use. These analyses of data allow a detailed picture of changing experience and evolving expectations to emerge.

To December 2011 the ULCVD programme has accumulated the following operational statistics.

- 8 consortia running projects, including 19 vehicle manufacturers
- 349 vehicles (mix of fully electric, hybrid and fuel cell vehicles)
- Over 180,000 trips covering over 1,000,000 miles
- Over 30,000 charging events recording over 200 MWh of electricity use

2 Overview of Data Collection Methodology

Since the launch of the first vehicles in December 2009, the trial has seen 349 vehicles on the road with users selected to represent a broad range of operating requirements.

For the purpose of this paper, the analysis performed by Cenex and Oxford Brookes University focuses on the first three months of data collected from each consortium. The EV users have been divided into two separate groups, private drivers (PD) and fleet drivers (FD). PDs were typical early adopters who had chosen to pay for their participation. In addition, compared to their fleet Driver (FDs) counterparts, the PDs had a greater amount of time to prepare for and research the car they would drive in the trial. For their part, the FDs did not pay for their participation and were a mix of early adopters (especially those who were able to take the vehicle home as if it was their own) and of non-typical early adopters (especially those who were pooled car drivers and were unable to take the EV home overnight) and often did not elect to participate in the same way as private drivers.

Engineering Data [Cenex]: The objective data are captured electronically by data loggers on-board the vehicles, in some cases this is supported by data from electricity Smart meters. The data being collected and analysed by Cenex includes; journey time and distance, energy used per journey, charging time and duration, charging location, ambient temperature, and the amount of energy transferred during individual charging events. Patterns in usage relating to both journeys and charging are studied, with the objective of understanding real world requirements and limitations.

Psychological Data [Oxford Brookes University]: In this trial, data are collected through the use of questionnaires (at pre-trial and 3 months into the trial) and interviews (at pre-trial and 1 week into the trial). Together these methods allow a detailed picture of changing experience and evolving expectations to emerge. We draw on all phases of data collection in this presentation. Questionnaire items are scored on a 5-point scale whereby 1 = Strongly Disagree; 2 = Disagree; 3 = Neither Agree nor Disagree; 4 = Agree; 5 = Strongly Agree. In the following analyses we present the percentage of drivers that agree with each statement (e.g., 89% agreement), the mean value of drivers' responses on the 5-point scale (e.g., M = 4.30) and the standard deviation, or measure of spread around the mean on the 5-point scale (e.g., SD = 0.72).

3 Analysis of Journey Patterns

3.1 Journey Length and Frequency

Figure 1 below shows the distribution of journey distances. The average trip distance was 6.0 miles (9.7 km) which compares to a UK average trip distance of 7.0 miles (11.3 km) [3]. Typically FDs operate the vehicles within a local area for defined tasks, whereas PDs have more flexibility to explore greater individual journey lengths. This was reflected in the data where FDs achieved a lower individual journey mileage of 5.4 miles (8.7 km) compared with 6.3 miles (10.1 km) for PDs. The chart below shows FDs dominated the low mileage journeys whereas PDs undertook a greater number of high mileage journeys. 63.2% of journeys were below 5 miles and 99% of journeys were below 40 miles. The maximum journey length was 100.1 miles.

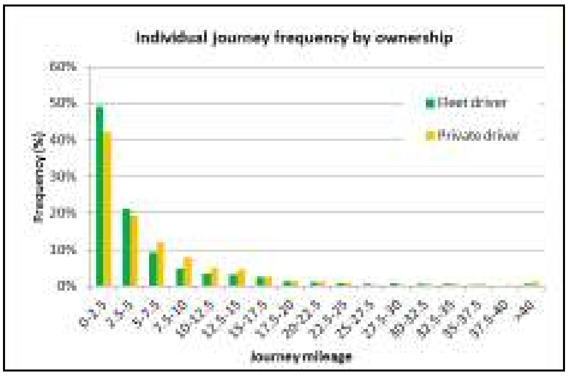


Figure 1 - Journey length frequency

Analysis of journey length statistics showed that there was no significant individual journey length or daily mileage behaviour changes over the first three months of vehicle usage. Here it can be concluded that EV use was well planned in advance or EV use did not significantly disturb normal journey patterns for the vehicle users. This supports OBU research where users reported adapting to the vehicle capabilities quickly (sometimes within week one). Figure 2 below shows FDs achieved a slightly higher daily mileage rate of 25.5 miles compared to PDs who achieved 24.0 miles.

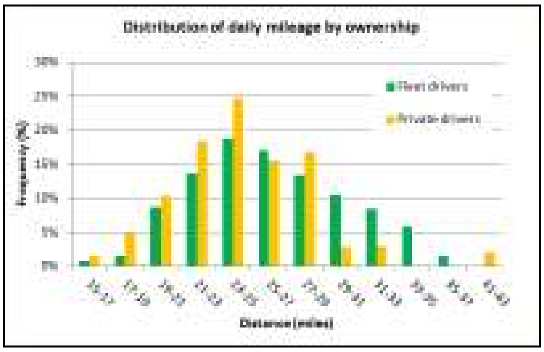


Figure 2 - Daily mileage distribution

3.2 Journey Start Time Analysis

Figure 3 shows the distribution of journey start times. PDs increased their evening use of the vehicles from month one to month three. FDs' journey start times did not change significantly throughout the analysis time period. Low usage variation would be synonymous with a well utilised and integrated EV as they are most suited to fleets with regular and predictable usage patterns. The distribution of journey start times for FDs was slightly skewed towards using the vehicles at earlier times of day with 85% of FD journeys commenced between 07:00 and 19:00, compared with 78% of PDs.

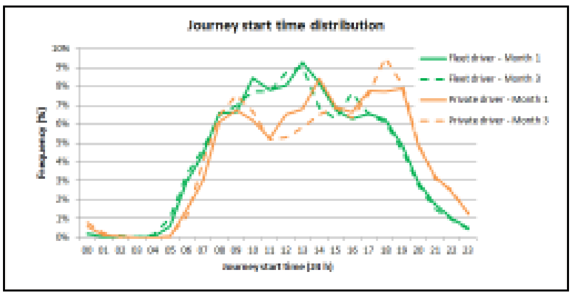


Figure 3 - Journey start time distribution

3.3 Adaptation to EVs in the ULCVD Trial

One of the overlooked aspects of managing a successful transition from a normal internal combustion vehicle to an electric vehicle is the degree to which an individual's deeply entrenched driving behaviour and preconceptions regarding EVs are challenged. Drivers adapt well-learned psycho-motor skills fundamental to driving, learn to process new information from unfamiliar displays, adopt a new style of regenerative braking, power their car differently, learn to assess available range and learn how different driving styles influence range.

3.4 Learning to use the EV

Despite the initial challenges in making the transition from internal combustion engine cars to EVs, both PDs and FDs felt that they would find it relatively easy to learn how to use their new EV. Pre-measures indicated that 89% (M = 4.23, SD = 0.71) of PDs and 90% (M = 4.21, SD = 0.78) of FDs expected it to be easy to learn how to use their EV. Despite this high initial expectation of it being easy to learn how to use the cars, at the 3 month assessment point these figures had increased even further to 100% (M = 4.69, SD = 0.48) of PDs and 98% of FDs (M = 4.68, SD = 0.59). The differences between the pre-experience and post experience measures are statistically significant for both PDs and FDs, meaning that the *actual experience* of learning how to use the vehicle was even more straightforward than the drivers had anticipated prior to the trial.

It is entirely possible that drivers would feel that it was easy *to learn* how to use the car but still find it *more difficult to drive than their normal car*. However, our data shows this not to be the case. Once again, pre-measures showed both PDs and FDs to anticipate that the EV would be as easy to use as their usual car with 77% (M = 3.90, SD = 0.86) of PDs and 80% of FDs (M = 3.80, SD = 0.91) expecting their EV to be as easy to drive as their normal car. Similar to the previous results, this proportion increased for both PDs (95% agreement, M = 4.52, 0.65) and FDs (92% agreement, M = 4.44, SD = 0.86) at the 3 month point of data collection, showing that the EVs in the trial were no more difficult to use than the car the participants usually drove. These data speak to the ease of transition from an internal combustion vehicle (ICV) and adaptation to an EV, an adaptation was even evident in the 1 week interviews:

> It's been really surprising actually. I'd thought it would take a bit more getting used

> to, but apart from little quirks of the car, that you know wouldn't be any different if you were in a different model to your normal car, it's been quite an easy sort of relaxed transition actually.

Interviews at only 1 week post-pick-up indicate that drivers adapted well to the regenerative braking system, and how quickly to take one's foot off the accelerator in order to stop smoothly at any given required distance:

> I love driving that car, it's easy to drive. The braking system I think is fantastic, and I find it a lot easier that way to slow down; gracefully so to speak. It's a pleasure to drive and I find it easy to drive

3.5 EVs Satisfying Daily Driving Needs

In interviews, both PDs and FDs also highlighted the importance of EVs being able to be integrated into the drivers' lives rather than the drivers having to alter their lives in order to incorporate limitations and idiosyncracies of EVs. Our questionnaires assessed the degree to which participants felt the EVs could satisfy their daily needs. Pre-measures indicated that 84% (M = 4.05, SD = 0.83) of PDs and 75% of FDs (M = 3.81, SD = 1.16) expected their EV to satisfy their daily needs. While the proportion of PDs who felt their EV actually satisfied their daily needs remained stable at 3 months at 82% (M = 4.11, 1.06), the proportion of FDs dropped to 63% (M = 3.38, SD = 1.35). The differences between PDs and FDs are significant at both pre-trial and 3 month post-trial points. In addition, the drop in FDs' responses from pre-trial to 3 month post-trial is also statistically significant.

3.6 Degree To Which Journeys Need More Forward Planning

Concern for having to plan journeys more carefully was evident at the pre-trial phase for both PDs (81%, M = 3.99, SD = 0.95) and FDs (88%, M = 4.12, SD = 0.83). At the 3 month stage of having driven the vehicle PDs' opinion had remained stable (76% agreement, M = 3.91, SD = 1.17) but FDs had become significantly more positive about the degree to which they had to plan their journeys (85%, M = 3.86, SD = 0.90).

> In terms of the practicalities, the only real thing that you have to do is bigger journey planning, you really do need to think about where you're going and plan things in advance so that you know you've got enough charge in the car to be able to use it. Not come into it an hour before you need to go out and find you haven't got enough charge to get there.

> I do plan ahead so there's been a number of occasions where I've tried to, you know, I do think about, I'm definitely thinking all the time, 'when can I use it, when can I use it'.

> Well the main difference is having to think more isn't it? I mean really I have to think every day and even the night before I have to think more of what I'm doing before I know where I'm going or yeah, what I'm likely, where I'm likely to go, you know distance wise really and am I going to be able to charge.

3.7 Concerns about Reaching One's Destination Successfully

One of the classic sources of anxiety facing drivers is the limited range of EVs. At pre-trial, 75% of PDs (M = 3.74, SD = 1.10) and 88% of FDs (M = 4.36, SD = 0.81) said they would be more concerned about reaching their destination with an EV than they would with their normal car. After 3 months, 65% of PDs (M = 3.62, SD = 1.20) and 89% of FDs (M = 4.21, SD = 0.99) felt the same way. We can see that drivers adapt well to the vehicle, but that this does not diminish their concern regarding range. Interviews show that drivers quickly become knowledgeable about the types of trips they can take and make successfully, but the lack of charging opportunities means that considerations of range continue to play a role in the everyday thinking of EV drivers. So, does this mean that they don't feel they will make it to their destination?

3.8 Will My EV Actually Get Me To My Destination Successfully?

Drivers of both groups have relatively high expectations regarding the likelihood of reaching their destination reliably with 83% of PDs (M = 4.00, SD = 0.75) and 70% of FDs (M = 3.68, SD = 1.05) believing they would make their destination. This opinion increased slightly by the 3 month period with 86% of PDs (M = 4.15, SD = 1.09) and 79% of FDs (M = 3.96, SD = 1.17) believing that they will make their destinations successfully:

> Getting more and more confident and impressed with it. My feeling is now I can

probably get 80 miles from my normal driving pattern based on the journey, the maximum I've actually done is 60 miles and I had 25% charge left after doing 60 which makes me think I would get 78 – 80 miles or something like that, which is quite good to know.

So, overall, drivers have to plan more carefully, are *concerned about* reaching their destination, but realise that they will make it (and we haven't had hoards of people not making it to their destination).

3.9 Differences Between Private and Fleet Drivers

For the most part the results for PDs and FDs are consistent. There are some interesting differences and we feel these can be explained in part by the initial motivational profile we identified in our report for EVS25 and in part by the greater variety of roles required for fleet vehicles compared to private vehicles. While FDs adapted well to the EV, significantly more PDs (84% agreement, M = 3.99, SD = 0.73) than FDs (71% agreement, M = 3.28, SD = 1.25) see EVs as practical. In the words of Fleet Drivers, the Fleet EV has to be fit for purpose and those purposes are varied:

> I think first and foremost [the EV] has got to be efficient, it's got to be safe; it's got to be fit for purpose and it's got to portray the right image

> It has to be fit for purpose and that will change depending on what that purpose is

We also know that a greater proportion of PDs (78%, M = 4.11, SD = 0.83) than FDs (57%, M = 3.29, SD = 0.95) felt they received sufficient training to use their EV effectively. Interviews with Fleet Managers reveal a variety of training procedures, which could perhaps be standardised for even greater Fleet adaptation. One driver tells of the level of his training:

> (Laughs) All I got told was 'Have you been trained on these new cars?' and I went 'No'; 'Well, there's the keys, there's the logbook, there's someone going to take you downstairs'.

4 Charging Analysis

4.1 Energy Transferred

The change in battery state of charge (SoC) is used to quantify the energy transferred during charging events. Using SoC data allows vehicles with different battery capacities to be collectively assessed. Figure 4 below shows that over the first three months of EV ownership charging became less frequent, with more energy transferred per single charge as users became more confident in the range of the vehicles and more aware of their own journey habits. From month 1 to 3 the average charge transferred per charging event increased from 26.9% to 30.3% respectively.

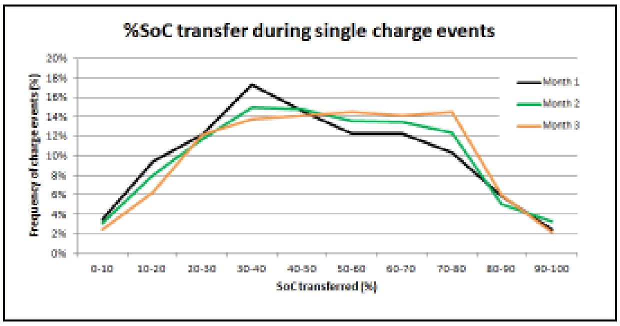


Figure 4 - Frequency distribution of charge energy transferred

Although the journey data analysis in section 3 shows there was little change in journey mileages with ownership length, users appeared to be slower to adapt their charging habits to less frequent and longer charges.

4.2 Charging Time Frequency

Figure 5 shows the most popular time of charge commencement is between 11pm and midnight which accounted for 15% of all charging events. From month one to three, PDs and FDs reduced their day time charging events by 9% and 23% respectively.

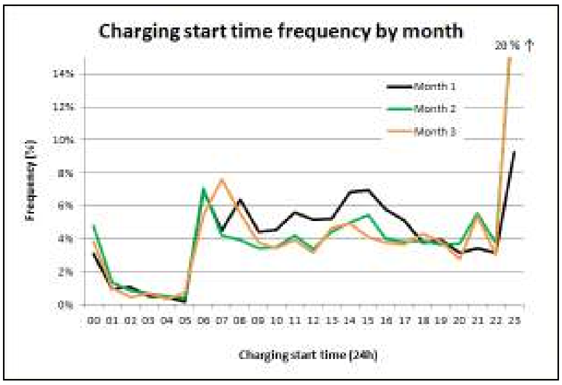


Figure 5 - Charging start time frequency by month

Figure 6 shows the charging start time frequency split by ownership. The PDs undertook a larger percentage of late evening charging with 34% of users opting to charge between 9pm and 1am. This coincides with UK off-peak electricity tariffs, which commonly apply from 9pm until 7am. 37% of all trial charging events coincided with off-peak tariffs. A peak also occured between 6am and 7am where PDs that have access to work place charging plug in on arrival. 73% of FDs put their vehicle on charge between the hours of 7am and 7pm compared with 46% of PDs. Interestingly, there was no significant demand peak from PDs in the early evening. Here it appears that the application of smart metering technology at domestic properties has achieved its goal of moving the demand peak of electric vehicles to off-peak tariffs times.

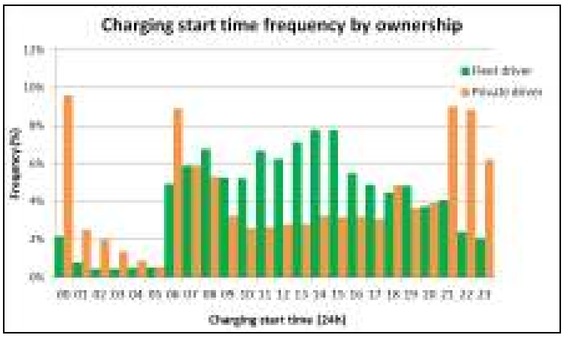


Figure 6 - Charging start time frequency by vehicle ownership

4.3 Drivers' Reports of Difficulty/Ease of Charging

Unsurprisingly, one of the most noteworthy issues in need of thorough investigation is the drivers' anticipation and experience of the charging process. One of the reasons for this being such a pressing concern for individual drivers is that EV drivers need to break an existing well-learned habit (filling up at petrol stations) in order to establish a new habit (becoming accustomed to the mechanics of charging, and also determining when the car needs to be charged). To that end, charging could be viewed as a daunting prospect for those who were about to participate in the trial but had not yet had the chance to charge a vehicle. However, questionnaire data at the pre-experience phase of the trial indicated that drivers did not feel that charging the vehicle would be a difficult task (M = 2.23; SD = 0.98) with only 12% of drivers anticipating any difficulties. It is possible that drivers would alter their opinion after having actually experienced the mechanics of charging an EV. However, if anything, their judgments of difficulty at 3 months are lower than their original anticipations (M = 1.63, SD = 0.88) with only 6% of drivers considering charging to be difficult (Figure 7).

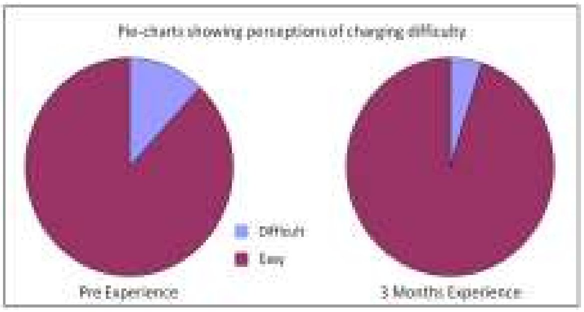


Figure 7 – Pie charts indicating pre-post perceptions of charging difficulty.

Drivers frequently mentioned the simplicity of the charging process during interviews:

> Charging it. It's simple. If you think about the time it takes to go to a petrol station, to open the flap, to put the pump in and all that sort of stuff, you drive it into the garage, you put the lead in and you put it into the socket and that's it. It's as easy as charging your phone or your laptop.

Drivers were more likely to endorse the current charging process as convenient (M = 3.71, SD = 0.92) than inconvenient (71% agreement), but in some interviews suggested that improvements could be made to the system:

> I broke every single nail in the first week. You know, just from a practical standpoint, and I'm not big into long nails, but you know, a man designed that plug. They didn't put a light on it so you could see what you were doing. They could maybe have put something on it to show you that you were actually loaded and ready for charging.

Other participants found the cable heavy and therefore struggled with charging on a physical level. Interestingly, and despite this room for improvement, drivers stated a strong preference for charging their car at home to filling up with petrol at a traditional petrol station (M = 4.20, SD = 0.92; 86% agreement). This is of particular interest as one of the primary limitations that people traditionally associate with EVs concerns the negative effect of the supposed range limitations on drivers' freedom. A considerable number of drivers mentioned the *increased freedom* that charging at home provides to the user. Somewhat surprisingly, this happened as early as the pre-experience phase:

> I just think being able to charge it up at home is an added advantage than having to go to a filling station

And one driver who had completed her EV trial described her first visit to the petrol station with her normal ICV car having charged her EV at home and at work for the previous 6 months:

> It was horrible. I hated it, I hated it. I don't like going to the petrol station anyway, so it's been so convenient to be able to charge up at home, whenever you want, and it's been much more flexible.

4.4 Drivers' Judgements of Time Taken To Charge

In addition to the ease of charging, drivers' most common concern in the pre-experience interviews related to speed of charging. The questionnaire responses go some way to supporting these concerns with only just over half of the drivers (51%) indicating the time taken to charge would suit them (M = 3.51, SD = 0.93). After having used the car for 3 months, more drivers felt that the time taken to charge suited them (68% agreement; M = 3.73, SD = 1.21, Figure 8) but a third of drivers (32%) indicated that the current charging times had limited their usage of their EV at some point during the trial (M = 2.69, SD = 1.32).

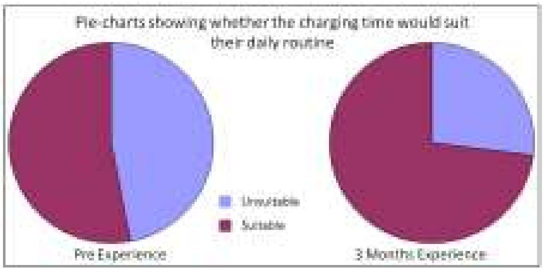


Figure 8 – Pie charts indicating pre-post perceptions of whether charging times suited drivers' daily routine.

Drivers were also asked to give their assessment of a "sufficiently good" and an "exceptionally good" time for the battery to charge fully (i.e., 0% - 100%). At the pre-experience phase of data collection their assessment of a sufficiently good time was 327 minutes (or 5hrs 27mins) and of an exceptionally good time was 150 minutes (2hrs 30mins). At the 3 month point of their experience, drivers' assessment of a sufficiently good time had reduced to 280 minutes (4hrs 40mins) and their assessment of an exceptionally good time had also decreased to 137 minutes (2 hrs 17mins).

4.5 Drivers' Accounts of Establishing a Charging Routine

A variety of charging routines were already reported by participants in the 1 week post-experience interviews. In itself this is interesting as it means that even within the first week of participation the widely reported range anxiety had not led everybody to charge at every available opportunity simply in order to manage stress regarding the vehicle's ability to complete journeys. Even at 1 week, some people reported establishing a personal routine relatively quickly (e.g., quote 1 below) while others (quote 2 below) had already developed a flexible approach based upon levels of charge and the distance needed in subsequent trips:

> It's just become habit. As you come in and put the keys on the key rack, so we come in and plug it in. Because we've got the meter on it for cheaper electricity it won't start charging until 9 o'clock. So we just set it up when we come in, then it kicks off at 9 o'clock. So we'll charge it from 9 until 1am. Usually it's full by then, no problem.

> To some extent I've developed a routine in that I try to do it overnight, because it's just convenient since it's sitting there for that long. But it's not too much of a pattern because you're looking at the car at the end

of the day thinking there's 30% [charge] left and that's fine for tomorrow, so it's not a regular "bring it in and charge it every night". You just plug it in and charge it when you know you're going to need that much more the next day. I have charged it a couple of times during the day when I've thought "Phew that's going to be tight for this afternoon; I'll just plug it in for an hour or two". There is a pattern in that it would be charged overnight by preference, but it's not a regular thing.

4.6 Drivers' Judgements of the Importance of Public Charging Infrastructure

In pre-experience interviews, many participants anticipated charging their EVs at home and at work. However, they also underlined the importance of having an extensive supportive public charging infrastructure in order for EVs to be accepted more universally:

> In the future the infrastructure is required and the speed of charging needs improving because in the longer term if these vehicles are going to take off they need to be able to charge very fast, literally within 5 to 10 minutes.
>
> I think they need a universal charging structure where all the annual fees should get scrapped and even if you pay a little bit more for the electricity for the council to get that revenue back, but it needs to be more universal. It needs to be just as easy as pulling into a petrol station. Until charging a vehicle gets that easy it's going to be one of the barriers.

It makes sense that a network of charging sites would reduce potential anxiety regarding drivers scheduling trips and successfully making return journeys. This particular perspective was reinforced in pre-experience questionnaires (Figure 9) by drivers indicating that a public charging infrastructure is essential for people with EVs (M = 4.32, SD = 0.95; 86% agreement).

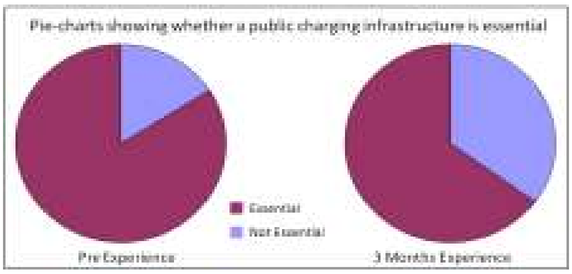


Figure 9 – Pie charts showing drivers' perceptions of charging infrastructure over time.

This might lead us to believe that drivers felt they would be unable to conduct their normal daily trips without such an infrastructure. However, the same pre-experience questionnaires (Figure 10) showed this not to be true, with the overwhelming majority of participants indicating that they could indeed complete their daily trips without public charging facilities (M = 3.94, SD = 0.90; 79% agreement). At the 3 month point the proportion of drivers considering a public charging infrastructure to be essential reduced (M = 3.89, SD = 1.24; 69% agreement), but there was still broad support for such facilities. Having spent 3 months driving their EV though, the proportion of drivers agreeing that they could complete their daily trips without a public charging infrastructure had increased slightly beyond the high level established at the pre-experience phase (M = 4.00, SD = 1.07; 82% agreement).

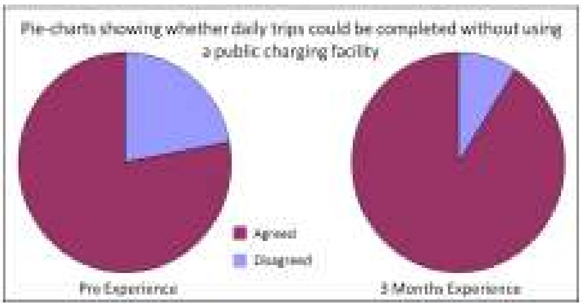


Figure 10 – Pie charts showing drivers' perceptions of ability to complete daily trips over time.

On the one hand these results suggest that extended personal experience of driving an EV gives a driver confidence in being able to pursue their normal transport routine without recourse to supplementary public charging points. We could also say that there is an apparent contradiction between the drivers' assessment of their ability to go about their everyday driving without public charging and their belief that such a system is essential for the success of EVs. However, it is likely that these responses reflect an understanding that the majority of trips can be catered for with a home charger but that the relatively infrequent lengthier trips that people take would only be possible with additional charging en route.

5 Conclusions

The UK hosts the world's largest multi-site ultra low carbon vehicle demonstrator. The programme includes 349 vehicles from 18 different manufactures being demonstrated in eight different locations. The trial commenced in December 2009 and has since completed over 180,000 trips and 1,000,000 miles.

The average journey length was 6 miles, which compares to a UK national average journey length of 7 miles, and the average daily distance travelled was 25 miles. 99% of all journeys were less than 40 miles. Users adapted quickly to the vehicles and journey patters did not significantly alter throughout the first three months of vehicle usage. 63.2% of all journeys were below 5 miles and 99% of journeys were below 40 miles. The maximum journey length was 100.1 miles.

The learning curve for the transition from an ICV to an EV is extremely steep but overall, participants in the current trial met those challenges, often by the point of the 1 week interview. The overriding concern remains range and the associated issue of battery charge. Only a very small minority of drivers experienced any difficulty in adjusting back to driving a conventional vehicle as a result of driving their EV: only 16% of PDs ($M = 2.14$, $SD = 1.10$) and 18% of FDs ($M = 2.06$, $SD = 1.22$) meaning that a driver can easily change between driving an ICV and an EV.

Although users quickly adapted to the range capabilities of the vehicles, they were less quick to adapt their charging behaviour. From month one to three the average charge transferred per charging event increased from 26.9% to 30.3% respectively. Over the same time period PDs and FDs reduced their day time charging events by 9% and 23% respectively, showing that users adopt less frequent longer charges as they become familiar with the EV and their own journey habits.

Although charging requires drivers to learn a completely new habit (involving both mastering the mechanics of the system and establishing a routine for charging), they were optimistic about their charging experiences even prior to participating in the trial. On the whole drivers adapt positively to charging once they get the vehicle (notwithstanding some improvements that could be made to the ease of lifting and fitting the cables for some drivers). As the trial progresses drivers more strongly endorse the existing charging times as suiting their daily routine and are particularly positive about the time and cost saved through charging a vehicle at home (as opposed to filling up with petrol at a gas station). Drivers also believe an extensive network of public charging sites to be essential in their willingness to have an EV (even though their 3 month data show that they recognise public charging sites to be non-essential for everyday use).

The application of smart charging technology at domestic properties achieved its goal of moving the demand peak for PDs of electric vehicles to off-peak tariffs times. 34% of charging occurred between the hours of 9am to 1pm.

Acknowledgments

The authors would like to thank and acknowledge the support of the members of the consortia listed here who have delivered the vehicles and infrastructure for the ULVCD programme: Ford BEV, EEMS Accelerate, Mini-E, Allied Electric Vehicles, Mercedes smart, CABLED, EVADINE and Toyota. We would also like to acknowledge the research assistance of Dr. Louise Bunce, Sarah Mansbridge, Naomi King, and Elisa Lewis.

References

[1] UK Department for Transport, Low Carbon Transport: A Greener Future, published July 2009

[2] Ultra low carbon vehicles are defined as those capable of tail pipe emissions CO_2 below 50g/km.

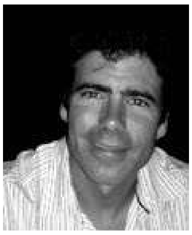
[3] UK Government's Department for Transport, 2009 National Travel Survey, published July 2010

Authors

Andrew Everett BSc, MSc, MBA
With 20 years experience in the automotive industry including senior positions in manufacturing, business planning and programme management Andrew joined the Technology Strategy Board in September 2007 as Lead Technologist in the Low Carbon Vehicle Innovation Platform and was appointed Head of Transport in July 2010.

Chris Walsh BEng, PGCert, MSc
Chris has spent 15 years working to overcome challenges in automotive technology, including powertrain design and analysis at Ricardo and international legislation development with the SMMT. At Cenex, Chris is Head of the Technical Support and Consulting department.

Steve Carroll BEng(hons), MSc
Steve is an experienced project engineer with a background in the automotive, power generation and renewable energy industries. At Cenex Steve provides technical support to the range of Cenex programmes and low carbon vehicle demonstration trials.



Dr. Mark Burgess
Dept of Psychology, Oxford Brookes
Mark focuses on the social psychological challenges thrown up by significant global problems. His research is problem-based, applying a variety of methods, analyses and theoretical perspectives.

Prof. Margaret Harris
Margaret is Head of the Department of Psychology at Oxford Brookes University. She has over 30 years experience of research in psychology using a wide range of methodologies. She has published five books and over 60 articles.