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Designing the Human Machine Interface to Address Range Anxiety

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Abstract

It is essential that the interfaces of low carbon vehicles particularly fully Electric Vehicle (EV) support new users while they adjust to a different type of driving experience. Use of EV is not yet widespread and little is known about the user requirements for Human Machine Interfaces. One of the common concerns is driver anxiety about his/her vehicle's ability to cover the distance required. However the problem is one of perception and driver experience in the context of new technologies, EV's limited range and an immature charging infrastructure. Nevertheless eliminating range anxiety for the EV owner is one of a major design challenges for future Low Carbon Vehicle manufacturers. The current study found that drivers who had some experience of driving an EV have less anxiety than those who had never driven an EV. Experienced drivers develop strategies to ensure that they only undertake those journeys that they are confident about having enough range to complete and aware of the factors that could potentially impact on the range. It is clear from users' feedback that estimated range of the vehicle is one of the most critical pieces of information for a driver. Combining this with battery state of charge information can provide the driver with a better understanding of the current range of their EV. However accuracy is a key factor to gain trust in range information. EV drivers need dynamic information on factors that influence available range. There is also a requirement for information that will enable drivers to drive economically. While designing the EV driver information system, designers must overcome the information complexity issue. Concerns were raised that complex information in current EVs could potentially lead to driver distraction and may increase anxiety further. In conclusion providing reliable, relevant and prioritise information can help to minimise range anxiety.

Keywords: Battery charge, EV (Electric Vehicle), energy, navigation, range

1 Introduction

The age of the Electric Vehicle (EV) has started and automotive manufacturers are heavily engaged in development of this new vehicle technology. A number of studies have examined people's willingness to purchase an EV in the near and medium term and it can be argued that EV mass acceptance is imminent. However many challenges remain. This vehicle technology introduces many unfamiliar issues for driver, a good example of which is the lack of engine noise. When starting an EV, the driver does not receive the same auditory or tactile feedback that he/she would from an internal combustion engine. This could lead to confusion over the vehicle's state. Another example includes the vehicle's limited range and how vehicles communicate the effect of driving style on potential range. These unknowns mean it is important to understand the issues related to user interaction with EVs as these will have an impact on driver acceptance of the overall vehicle. Therefore in order to maximise the adoption of EVs it is vital for automotive manufacturers to make the driver's interaction experience, especially with Human Machine Interfaces (HMI), a positive and rewarding part of the overall EV ownership experience. This means understanding the issues users have with current products, and identifying the pertinent design problems that need to be addressed. As such, [1] emphasized the importance of all design beginning with an understanding of intended user's attitudes, needs and requirements. To support this argument, this paper summarises the technical study carried out during the Low Carbon vehicle Technology Project (LCVTP) within the vehicle HMI workstream. The overall objective of the user-centred research was to investigate the behaviour, needs and opinions of Low Carbon Vehicle (LCV) customers in order to understand what 'HMI rules' that any range or charging information should abide by in order to promote confidence in the driver information data. The data from the study was used within TATA Motors European Technical Centre (TMETC) to develop the Range Estimator concept. This was developed to analyse how range can be calculated instantaneously and display this in order to help minimise range anxiety.

In the last five to ten years, the role of technology in vehicles has steadily expanded

beyond the familiar areas of safety and efficiency features, to include entertainment, communication, and information services. The point at which a user interacts with these technologies is known as the Human Machine Interface (HMI); this provides a way for the user to manipulate the vehicle User Interface (UI) and Information system and for the system to indicate the effect of the manipulation. Because of this key position mediating between user and machine, the experience of interacting with the HMI needs to be intuitive and positive, which is why automotive manufacturers and suppliers wish to optimize this aspect of their vehicles [2].

2 Research Questions and Methodologies

To address the main objective of the Low Carbon Vehicle Technology Project (LCVTP) workstream 13, a user centred research method was applied. This was used to investigate in depth the problems drivers experience with EVs and inform the development of next generation of HMI in Low Carbon Vehicles (LCVs). The emphasis was on driver behaviour, driver concerns and related HMI needs. After prioritisation by workstream partners, two themes were chosen to investigate in greater depth. Table 1 shows the two themes along with research questions that were investigated. This paper summarises the findings of research theme 1 related to EV range and Range Anxiety.

Table 1: Research themes

	Theme	Research Questions
1	Range anxiety and lack of confidence in feedback	Is the occurrence of range anxiety related to familiarity with the vehicle?
		In what way is battery charge information conveyed to the driver? Does the battery charge information meet the drivers expectation and needs
		In what way is range information conveyed to the driver? Do they trust this information? Does the range information meet the drivers expectation and

		needs
2	The charging process	<p>How long does it take customers to fully charge their vehicle, and do they think this is satisfactory?</p> <p>Did customers forget to charge the vehicle at any time?</p> <p>How often do customers use public charging stations, and does this change over time?</p> <p>How can the act of plugging in and setting the vehicle to charge be improved for the customer?</p>

The study was completed in two phases. In phase I current and near-term automotive HMI solutions in Low Carbon Vehicles were benchmarked. Two sources of data were analysed; user blogs published by early adopters including Mini-E trial participants in the USA and data from user trials of LCVs, including, CENEX (Centre of Excellence for electric and fuel cell technologies) Smart Move trial in UK. In phase II, a schedule of questions based on the findings from earlier research were put to the participants of the CABLED (Coventry And Birmingham Low Emissions Demonstration, [including TATA Vista EVs]) programme using self-completion questionnaires and structured interviews (in collaboration with Oxford Brookes University, UK). Data were collected at different points of time – pre-use, one week experience, more than three months experience etc. The results of the responses were analysed in order to find out whether the driver had experienced similar problems to those previously identified and suggest ways in which the vehicle HMI could be improved. Comparisons were made between the responses of participants before they had driven an EV with their responses after they had some experience of doing so.

The data were compared with previously identified issues. The analysis formed the pre-requisites for EV driver information management

experimental HMI design work within the partner organisations including TMETC.

3 Definition of terms

3.1 Range Anxiety and Range

“Range Anxiety” is a term mostly associated with Plug-in EV (PEV) or Fully Electric Vehicle (FEV). Range anxiety has been portrayed as one of the major barriers for full scale adoption of EVs. Some authors argued Range Anxiety as the main factor affecting penetration of EVs on the global market together with long charging times and high purchase price [3]. Range Anxiety is a complex phenomenon and findings are somewhat contradictory [4]. However it is clear from the various findings that the concern is more one of perception and driver experience in the context of EV’s limited range and the underdeveloped charging infrastructure. There are a number of research findings available to support this argument; an example of which is reported in [5]. This research conducted by Columbia School of Engineering and Applied Science analysed the typical user journeys pattern in United States from the year 2009. The research found that 95% of Americans' single journeys were less than 30 miles (48km) while total daily journeys were less than 50 miles (80km) for 98% of drivers. The research also found that average distance covered by drivers was 5.95 miles (9.5km). Table 2 shows the breakdown on daily commuting data [5].

Table 2: Daily commuting data on US user

Journey Type	Daily travel distance
Single journey to/from work	40 miles (64km)
Average total daily urban based journey	36.5 (58.7km)
Average total daily rural based journey	48.6 miles (78.2km)

Therefore it can be argued that even if a user utilises an EV for short journeys he/she some time could use term ‘Range Anxiety’ to relate a future hypothetical negative event or consequence.

Various formal definitions on Range Anxiety exist. In [4] author defined range anxiety as “*Perception of drivers regarding the fear of not reaching your destination when you are in an EV*” while in [6] authors defined it as “*driving with little energy remaining in the battery, sometime dubbed as*

'Range Anxiety'. The associated term *'Range'* is defined by [7], where authors described *'Range'* as the number of miles that an EV can be driven before recharging becomes necessary. Analysing various definitions together with ELVIRE (Electric Vehicle communication to Infrastructure, Road services and Electricity supply) research document, a conclusion can be made of the characteristics for range anxiety. Figure 1 depicts the characteristics.

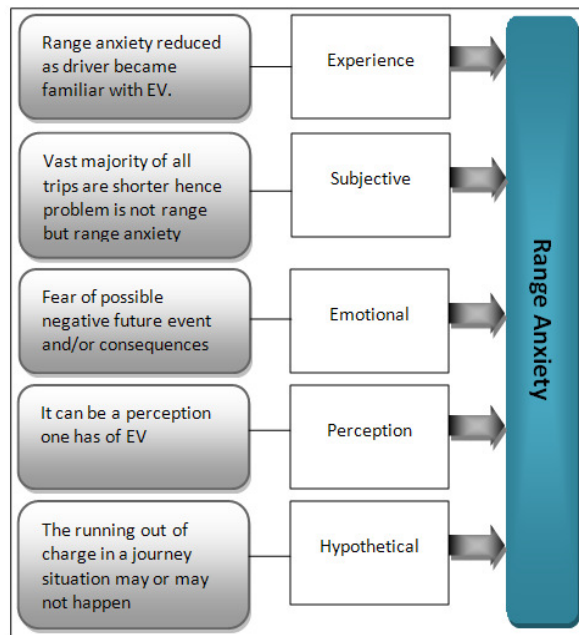


Figure 1: Characteristics of Range Anxiety

4 Findings from LCVTP

4.1 Status on Range Anxiety

The thematic analysis of US Mini E Trials user blogs along with data from [8], [14] and published results from CENEX trials [9], [13] along with responses of participants in CABLED trial [10] confirmed that Range Anxiety reduces with experience. Prior to starting the CABLED trial, 24 drivers were asked in a questionnaire how much they agreed that they felt anxious about the range. After they had some experience of driving an EV they were asked the same questions and their responses are shown in Table 3.

Table 3: Agreement with statement about range anxiety

Responses	Agree	Disagree	Neutral response	Total
Pre-experience	23 96%	0 0%	1 4%	24 100%
Post-experience	18 69%	3 12%	5 19%	26 100%

The results showed that the drivers who had some experience of driving an EV reported less anxiety than those who had never driven an EV. Our finding confirms the earlier findings and conclusions by [11], where a three month study was carried out to see how quickly drivers adapt to an EV. This study found that range anxiety dropped by 35% after the user has some experience with an EV. In our study, out of the 20 drivers who were interviewed, 11 (55%) had felt concerned about the range of their vehicle while they were driving. This anxiety was felt at different stages – with between 5 and 34 miles left. The majority of the participants who had experienced range anxiety thought that this would reduce with experience. The results from both studies showed that over time, drivers develop strategies such as planning their journeys to ensure that they only undertake those that they are confident about having enough range to complete.

4.2 Limiting Range Anxiety

The study found that estimated range of the vehicle is one of the most critical pieces of information for drivers. Combined with Battery State of Charge (SOC), a driver can get an understanding of the current range of an EV. This finding is supported by [12] where the author argued that having information about range of their vehicle and location of charging stations in a vehicle GPS map would help drivers to plan their journeys. This paper also suggests features that would assist a driver who is not experienced with driving an EV. These include prioritising displayed information, adopting a combination of meter-navigation display and providing a two way communication capability with real time information. At present there are number of HMI design strategies adopted by LCV manufacturers in particular with EVs. However several currently available LCVs that we have studied do not provide drivers with information about range. We concluded that development of HMI regarding range information and associated supporting data can be a possible solution for limiting Range Anxiety.

4.3 Range Information

We conducted benchmark studies on several EVs to analyse the efficiency of range information and driving metrics. The data for distance travelled against estimated range (Figure 2) shows that vehicle “A” recalculated estimated range often enough to adequately represent the performance of the vehicle. That is, at any point in time the figure displayed varies no more than 1 mile from the distance travelled, and this was maintained for the duration of the drive. This was compared with vehicle “B” where range information is not displayed but state of charge (SOC) against speed was measured during the drive (Figure 3). In both cases our analysis shows that the range calculation is averaged over the whole journey and shows a downward trend from start to finish. During the journeys, fluctuations in value were observed which suggest that current road conditions and driving behaviour have an immediate effect. The slope of the line shows that in a high energy use scenario the actual range of the vehicle decreases twice as fast as predicted at the start of the drive.

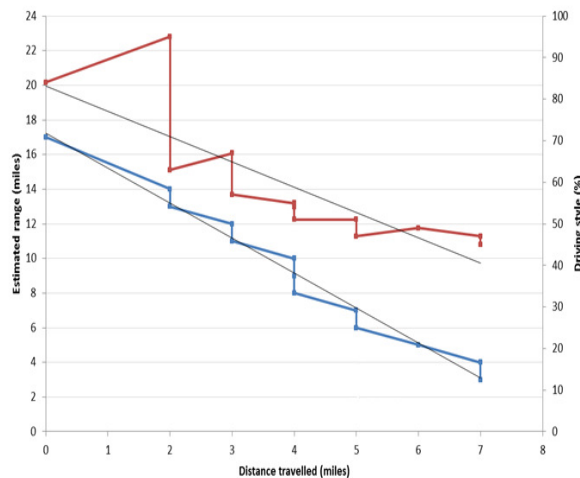


Figure 2: Range reduction analysis vehicle “A”

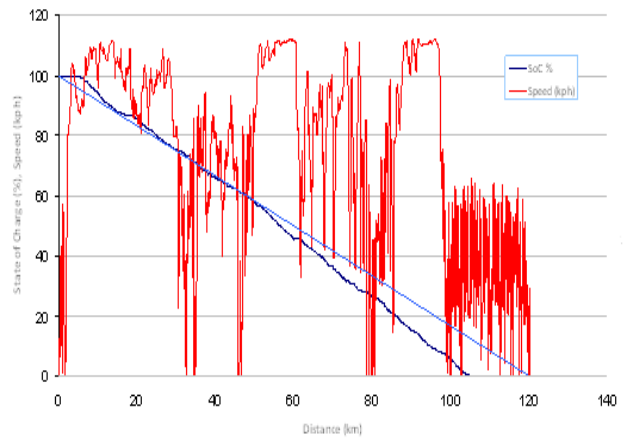


Figure 3: Range reduction analysis vehicle “B”

We observed that the majority of drivers in trials wanted an estimated range figure and felt this would be useful. Drivers whose vehicles did not provide a range figure inferred this from the SOC. After they had some experience of driving their vehicles, 26 drivers were asked about the confidence in range information in their vehicles. The results were split with 58% saying they trusted the vehicle’s range information while 35% said they have no trust in the vehicle’s range information. 7% provided no opinion. The responses are shown in Figure 4.

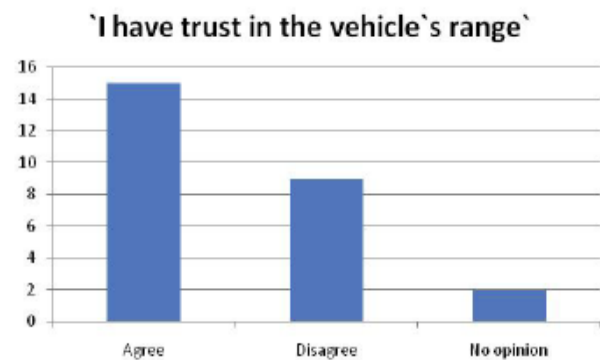


Figure 4: Participants opinion on range information

The results suggest that a single figure for the number of miles or kilometres that can be covered before recharging becomes necessary is an insufficient indicator of range. There was also requirement to provide the driver with information about driving speed, outside temperature and other factors that affect the range. The majority of participants thought that providing range information remotely would be helpful and some suggested key fob device could be used to facilitate this feature. Results from the participants

also confirmed that users wanted range to be visible at all times and not require drivers to search for it.

4.4 EV User driving behaviour

Information related to users driving patterns was collected during the CABLED trial. Each vehicle was fitted with data logger to collect speed and acceleration data. The aim was to develop an EV drive cycle characterizing typical driving behaviour (Note: Tata Vista Electric Vehicles in West Midlands region were used for this development). The standard drive cycles most commonly used around the world were explored and compared to the frequency of speed and acceleration distribution plots against CABLED EV (Tata Vista) average data (The average data represents driving behaviour of all vehicles as part of CABLED trial over period of 5 months). Visual comparison of the CABLED data and selected Standard Driver Cycles lead to a preliminary conclusion, that LA 92 and WLTP Drive cycles were the closes match as shown in Figure 5 and 6. From the comparison data we observed a driving style which represents an economical driving speed amongst users.

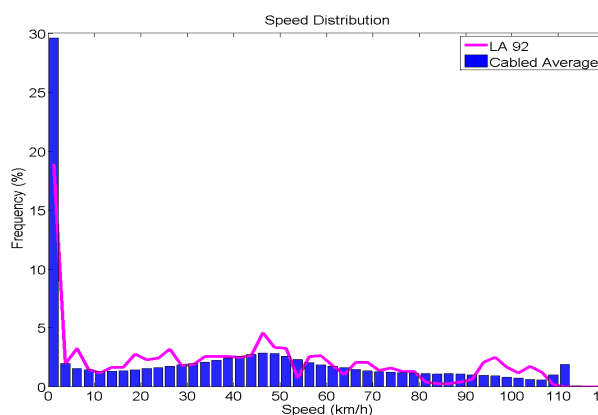


Figure 5: Speed distribution comparison 1

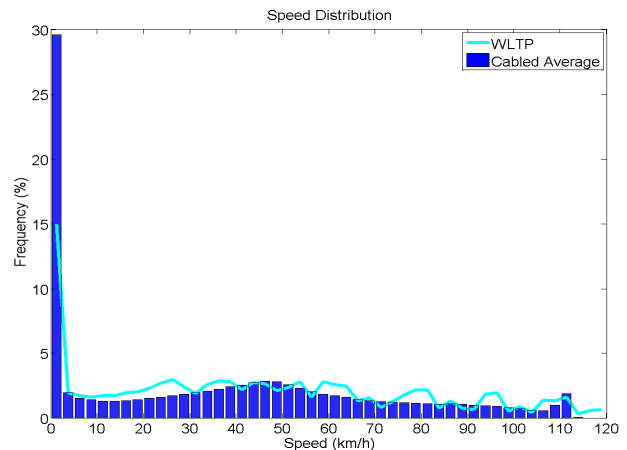


Figure 6: Speed distribution comparison 2

The results from questionnaire survey showed that drivers were aware of the factors that could potentially impact on the range of the vehicle even before taking part in the trial. This was evident from pre-trial questionnaires where 54% of the drivers said that they were aware of factors that could influence the range. Factors that were identified by users include extreme outside temperature (cited by 77% respondents), driving style, use of the heater and air conditioning system of the vehicle.

The questionnaire survey results also identified a clear requirement for information that will enable drivers to drive more economically. 77% of the drivers responded strongly (Figure 7) in favour of receiving guidance on how to driver economically once they had experienced driving an EV. The reason may be to adapt to the limited range of the EV and cope with range anxiety.

'It is important for me to understand how my driving behaviour can maximise economy'

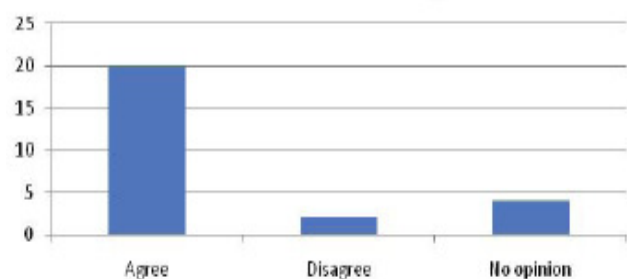


Figure 7: Driver response on maximise economy

[Sample Size = 26]

4.5 Complexity in information system

Three types of EVs were used during HMI evaluation and benchmark study. HMI feedback forms were given to users who drove benchmarked vehicles. Users were selected based on level of EV technology interest and understanding (low interest with good understanding, high interest with low understanding and high interest with good understanding). Figure 8 shows a sample of HMI feedback form that was used to obtain the user evaluation data.

Analysis of user feedback from the benchmark study identified some concerns about the EV driver information system. Users felt overwhelmed by the variety of information. Some concerns were raised that this could potentially lead to driver distraction from the primary tasks of driving and may increase anxiety further. One possible solution could be to implement a priority management of driver information which is not evident in many EVs. This will help to reduce driver fatigue and reduce anxiety during driving. Feedback data also showed that there is evidence of information duplication between the vehicle centre display, instrument cluster and secondary information display (in case of some EVs). Majority of the users did not understand the importance of many of the information that was presented in the displays. The overall impression is that the HMI appears to be complex and require upfront learning before system can be used which some users felt is rare in most vehicles today. Therefore the concern here is that Low Carbon Vehicle manufacturers may find it difficult to establish the appeal to users for various HMI information features. We concluded that EV drivers prefer to have relevant, prioritised and easy to understand information on the vehicle display. It is however important to point out that there are some areas in current Electric Vehicle's HMI that were well developed and expectations were met.

HMI Feedback Form
Please leave this document in the folder provided in the car

1. Do you have experience driving EVs?	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
2a. Is this the first time you've experienced this vehicle?	<input checked="" type="checkbox"/> Yes, go to Q.2b	<input type="checkbox"/> No, go to Q.3.
2b. What were your first impressions about the driver interfaces in the Nissan Leaf? (when referring to a control/display please be clear as to its location and appearance) <i>Over complex. Lower displayed gave impression of having more functionality than it had.</i>		
3. When you were using the Leaf, what did you like / find useful / find easy to use? (when referring to a control/display please be clear as to its location and appearance) <i>Speed in good London cruise control logical to use</i>		
4. When you were using the Leaf, what did you dislike / find difficult to use or understand? (when referring to a control/display please be clear as to its location and appearance) <i>Moving between BS and D not immediately intuitive. Centre display not intuitive</i>		
5. If you charged the vehicle / disconnected the charger, describe your experience... <i>N/A</i>		
6. Do you have any other comments you'd like to make about the user interfaces / controls in the Nissan Leaf? <i>General feeling that you need to read the owner's manual - which is rare for most cars today.</i>		

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Figure 8: Sample of HMI feedback

5 Limitation of the study

Most of the data was collected from participants who had a positive attitude towards LCVs especially on EV usage. It was observed that they had adapted their driving behaviour with known limitations in order to use their vehicle effectively. Therefore it is not clear whether the general public will be prepared to make these behaviour changes when EVs will be widely available. It is also accepted that there is insufficient data available to understand the user perception and user requirements for all forms of LCV's HMI design. Therefore an understanding of how driver information and user interface systems within EVs can be improved or possibly custom-configured to appeal to a potentially very wide range of end users is limited. It is however acknowledged that this will be critical to the widespread adoption of EV technologies within various markets. There are number of research questions and issues which require further studies. Potential issues include the method for driver information priority, HMI on battery discharge rate and its impact on range reduction and range anxiety, HMI solutions to

minimize range panic (Range panic is a scenario where, if user plans a journey based on initial range indication but notices a rapid or abrupt range reduction after start of the journey while there are no charging facility nearby and vehicle assistance features are not provided. Thus continuation of the journey becomes difficult. This scenario could lead to user panic).

6 Experimental Development

The results of the LCVTP were used to create functional requirements for the Range Estimator application on EV Driver Information concept development within TATA Motors European Technical Centre (TMETC). The main purpose of the Range estimator was to provide driving range information to the driver (how many km/miles can be driven) in a prototype environment. This was a potential method for Range Anxiety analysis. Application for the system includes HMI on driving range, eco range and range panic assistance. Driving range calculation uses past information regarding the driver's driving behaviour or future information on driver request. In both cases driver driving style is logged within the vehicle's driver information system memory. In cases where a driver does not select a destination prior to a journey then stored past information is used to calculate the driving range. If the driver selects a destination then received data from navigation GPS is used. In the concept architecture the accuracy of range was determined by two concrete scenarios:-, knowledge about the energy source (status of the battery), and knowledge about the consumption of the energy (status of the energy load cycle). Both scenarios are handled by two dynamic models; a) energy model, and b) driving load cycle model. The goals of these models were to work out functions regarding available energy that a vehicle has for a driving cycle and actual energy consumption due to driver driving behaviour. The calculated functions were used to estimate driving range. Figure 9 shows the overview of 'Range Estimator' concept system. In cases where driving history data is not available (normally during virgin state of the vehicle), estimated values are used during the TATA VISTA EV prototype validation phase.

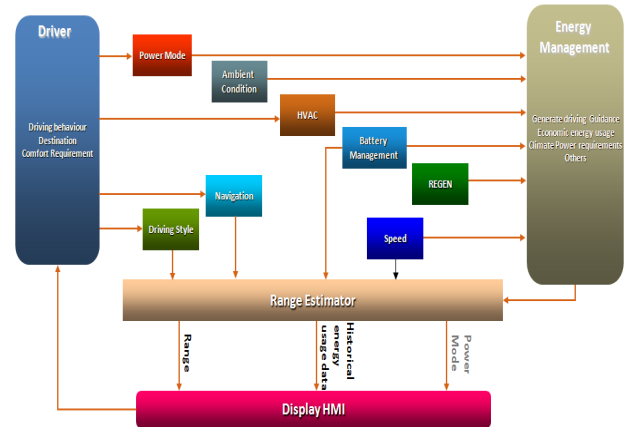


Figure 9: Overview of Range Estimator concept

Actual range was calculated after compensating for error due to auxiliary load such as climate control, lighting, and vehicle Infotainment system along with navigation GPS data. Figure 10 shows function blocks that were used for estimated range calculation.

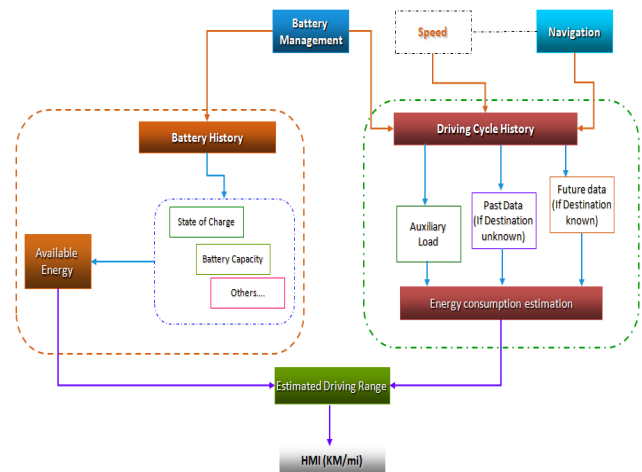


Figure 10: Range Estimator concept function blocks

7 Conclusions

In this paper we have summarised our findings on user issues related to Range Anxiety in EVs. The paper highlighted that driver anxiety about his/her EV's ability to cover the distance required is a common concern and prevalent in inexperienced drivers. This is particularly relevant in the current climate where public charging infrastructure is limited. Lack of trust in currently available EV's range information is identified as a contributing factor towards range anxiety. Hence information on range along with driving guidelines to encourage best use of available vehicle energy

during a drive can be an enabler for limiting Range Anxiety.

Range Anxiety reduces once a user becomes familiar with an EV. There is considerable evidence that experienced EV users initiate driving strategies to reduce their anxiety such as planning their journeys to ensure that there is enough range to complete the journey.

Despite the initial challenges in moving from petrol or diesel engine vehicles to EVs, users felt confident that they would find it easy to learn how to use an EV. This is evident from their driving style which is comparable with an internal combustion-engined vehicle.

In our study data was collected from participants who had positive attitudes towards EV, it is however clear that EVs need to integrate into driver's lives rather than drivers having to alter their lives in order to incorporate limitations of an EV. In this case drivers need to make sense of different types of information when they change from using petrol or diesel vehicles to electric ones. Therefore information that is based on understanding the needs of users can assist drivers to use EVs effectively, maximising usability and satisfaction. In this regard, the TMETC 'Range Estimator' application was designed to put in place effective countermeasures to minimise customer concern on 'Range Anxiety' related issues in future EV programme.

Acknowledgments

The Low Carbon Vehicle Technology Project (LCVTP) is a collaborative research project between leading automotive companies and research partners, revolutionising the way vehicles are powered and manufactured. The project partners include Jaguar Land Rover, TATA Motors European technical Centre Plc, Ricardo, MIRA LTD, ZYTEK, WMG and Coventry University. The project includes 15 automotive technology development work-streams that will deliver technological and socio-economic outputs that will benefit the West Midlands Region. The £19 million project is funded by Advantage West Midlands (AWM) and the European Regional Development Fund (ERDF).

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Terminology

The CABLED Project: The CABLED (Coventry And Birmingham Low Emissions Demonstrator) project, initiated by the Technology Strategy Board and supported by Advantage West Midlands, is a demonstration trial aiming to showcase the ultra-low carbon vehicles in the West Midlands region in of United Kingdom. Amongst 6 vehicle manufacturers in total, Tata's presence in the trial was accomplished through providing 25 Tata Vista Electric Vehicles (28 in total including courtesy vehicles) which have been allocated to members of the public.

CENEX Smart Move trial: The CENEX (Centre of Excellence for low carbon and fuel cell technologies) deployed four electric passenger vehicles in the North East of England, UK with the aim of studying the integration of Electric Vehicles into fleets, accelerating the

adoption of Electric Vehicles in the area and study the efficiency and performance of the vehicles.