Range anxiety in potential electric vehicle users

by:

Jonas Schlüter (s1607057)

supervisors:

Suzanne Vosslamber

Dr. Matthijs Noordzij

Introduction

Potential users of electric vehicles (EVs) are concerned with the limited range of these vehicles compared to vehicles with combustion engines (Egbue & Long, 2012). Franke and Krems (2013) devised a model to explain in which way users handle the limited range and suggested that the design of the display is crucial to cope with it (Franke, Rauh, Günther, Trantow, & Krems, 2016). The aim of the current study was to assess which display features users prioritize to handle limited range resources.

The growing problems of air pollution and global warming obligate a change in the way we use energy (McCollum, Krey, Kolp, Nagai, Rihai, 2014). A major step to face these sustainability challenges would be the transformation of road transport into a system that is reliant on electricity rather than fossil fuels. The usage of battery electric vehicles (BEVs) gives us the opportunity of transportation while causing no emissions at all if the required electricity is generated by using renewable resources. These BEVs are even more energy efficient than fuel cell electric vehicles which are powered by hydrogen (Eaves & Eaves, 2004). This makes BEVs one of the most sustainable forms of transportation. However, there are barriers that hinder electric vehicles from being widely adopted. One of the biggest barriers is the capacity of the battery which leaves the user with limited mobility resources.

Franke and Krems (2013) devised the adaptive control of range resources (ACOR) model. This is a framework that illustrates how the user deals with the limited electric vehicle (EV) range. It is assumed that the user constantly checks for the fit of the available range resources and the range resource needs with the goal to keep a range resource buffer that feels comfortable for the user. This comfortable range is the range of the EV that is utilised without negative experiences such as range anxiety.However, the comfortable range is not as high as the actual technical range of the EV, the range that it can cover under standardized conditions. The range that a user could possibly obtain with a specific EV is based on his skill and precise informative feedback to monitor and control energy consumption, it is called competent range. Usually the user only reaches performant range. This is the average range that the user can usually obtain due to his driving habits and motives. As long as the user experiences no range

anxiety the experience is optimal and we speak of comfortable range (Franke, Rauh, Günther, Trantow, Krems, 2015).

Range anxiety is a term that has always been associated with the limited range and availability of charging opportunities of EVs. Wellings et al. (2011) defined range anxiety as the perceptions and experiences of a driver regarding the fear of not reaching your destination while driving an EV. The range anxiety has been shown to diminish in a few weeks ,after the user becomes familiar with the EV. This is supported by the results of an interview study conducted by Nilsson (2011). Nilsson states that range anxiety only exists due to uncertainty in the EV technology and charging opportunities and that limited range incidents are associated with the ability of the user to manage the EV. While using the EV the user develops trust in the energy feedback system and learns how to use the energy management system of the EV to extend the range. However, it is also possible for the range anxiety to increase. According to Nilsson (2011) users have experienced an increase in range anxiety whenever they could not trust the feedback that was provided by the EV. For example, the EV becomes less trustworthy if it underestimates the required energy for a certain distance as the user will be uncertain whether the estimated energy will be sufficient or if the vehicle breaks down before reaching the destination.

To avoid something like that happening the tank in a vehicle powered by fossil fuel could be enlarged to cover a higher range. This is also possible for BEVs, however, the production of bigger batteries is less cost efficient and (McManus, 2012) has more severe effects on the environment (Yuan, Li, Gou, Dong, 2015). Due to that the BEV would be an unsustainable choice as a bigger battery makes it difficult to compensate the initial resource cost for the production of the battery. In addition to that battery size is also linked with the ecological footprint (McManus, 2012). Thus, simply expanding the BEV battery is not a sustainable solution. Therefore a way must be found to assist the user to efficiently manage the limited range capacities and prevent range anxiety.

Recent research has again highlighted the relevance of the human factors perspective by assessing how display design factors can protect against range anxiety. Franke, Rauh, Günther, Trantow, & Krems (2016) point out that the assistance systems in the display of the EV should aim to enhance the user's ability to manage critical range situations, as successful coping with

these situations decreases feelings of range anxiety (Nilsson, 2011). Nilsson (2011) states that the successful management of range resources and a resulting extension of range in a critical situation increase the users feelings of security and control in similar future situations. According to Franke & Krems (2013) the highest range that the user can obtain is based on individual skill and the energy consumption feedback and management. Therefore, future EV designs should focus on the improvement of display features that assist the user on every skill level to provide fitting energy consumption feedback and enable the user to increasing their range (Franke, Rauh, Günther, Trantow, & Krems 2016).

The design and improvement of displays has always been a core topic for the human factors and engineering approach so that general display design guidelines are available. In the Handbook of Human Factors and Ergonomics Bennett, Nagy and Flach (2012) introduce a problem-driven approach with the main goal to provide the user with a supportive tool for a specific problem-solving task, in this case the management of range resources. According to Bennett, Nagy and Flach (2012), for the display to be an efficient and supportive tool two main two problems must be addressed. The first one is the correspondence problem, it refers to the question: which information should be displayed to meet the tasks and domains demands? In the case of an EV user this would mean: Which information is necessary for the user to effectively manage his range resources? The second one is the coherence problem which is mainly concerned with the extent to which a user can acquire and make sense of the presented information. For example, a clear and salient presentation of consumption relevant factors would make the task of an EV user, to extend the range in a critical range situation, less demanding.

It is important to note that most research on EVs focuses on early adopters (Franke, Rauh, Günther, Trantow, & Krems, 2016; Nilsson, 2011) as they have a high social status, financial liquidity and are more socially forward. It has been a common practice in these studies that the participants lease an EV themselves. This requires the participants to possess financial resources and the will to do so, which was found in the population of early adopters. The early adopters are also willing to use innovations and were therefore a suitable research population. However the early adopters are a rather small group with 13.5 % of the overall population other parts of the population must follow the example of the early adopters to reach the goal that EVs

are widely adopted. Therefore this study will be conducted on non-early adopters that consider buying an EV. As mentioned earlier the skill and experience of the user determine partially which range he can actually reach (Franke & Krems, 2013). Due to that it can be expected that the less experienced non-early adopters are more concerned with limited range capacities. Additionally the way in which consumption related information needs to be presented to be understandable might differ from what early adopters require, for example litres/100km to monitor consumption instead of kWh/100km. Non-early adopter might also still rely on different information to monitor and manage their consumption. For example a high engine speed, something that is not present anymore in EVs, as an indicator for high consumption. In this way their lack of experience in the domain of EVs could constrain the users understanding of certain energy consumption feedback (Bennett, Nagy and Flach, 2012). So the questions that emerge are: What type of information do non-early adopters require to manage their energy consumption? And how does it have to be presented to ensure understanding of the information?

The system features that the user requires to fulfill his needs, in this case the need for consumption relevant information, to be met are called user requirements (Spath, Hermann, Peissner, Sproll, 2012). Spath, Hermann, Peissner and Sproll (2012) highlight the importance of the collection and analysis of user requirements in the beginning design process of a system. In addition to that they point out that it would be beneficial to the success of the system if user requirements would be prioritized and implemented if given a high priority. However, a method of prioritization was not suggested by Spath and his colleagues in this handbook. Luckily recent work by Beltman, Molderink, Noordzij and Vosslamber (2016) investigated the robustness of a fairly new technique for prioritization, called the Moscow method. The method was deemed robust and fit to prioritize user requirements efficiently by bringing them in a hierarchical order. The refined research questions that take into account the value of requirement prioritization are: Which user requirements do non-early adopters prioritize for managing the range capacities of an EV? Which way to present the relevant information is valued the most by non-early adopters and which less?

Method

Participants

In total 16 participants took part in this study, 9 of them were women, 7 were male. The age of the participants ranged from 20 to 51 years (M=24.2, SD=2.1). Exclusion criteria for the participants were not possessing a valid driver's license, not being able to drive due to impairments or illnesses. A restriction based on demographic characteristics was the minimum age of 17 to be eligible to obtain and hold a driver's license. These exclusion criteria and restrictions ensured a sufficient amount of experience of handling a vehicle in the participants. Furthermore potential participants that owned an EV at the time of or prior to the study were also excluded. This should have ensured that all participants can be regarded non-early adopters. All of the participants have had at least 12 years of education, the majority of participants has obtained a university-entrance diploma. None of them has had immigrant status. Their language preference was german.

The researchers approached friends and acquaintances informally in speech, on the telephone or via text messages. Everybody that has been approached took part in the study, none of the selected themselves into the sample. Ethical approval was obtained through the Ethics Committee of the University of Twente before the interviews took place. The interviews took place at the participant's home address and they did not receive any kind of payment or reward for participating.

One pilot interview has been conducted beforehand. It took place at one of the researcher's home address in a quiet room. The pilot interview resulted in a few changes of the interview template to ensure a more logical order of the questions and to save time. In addition to that the participant came up with a display feature which was not mentioned before.

Materials

A semi-structured face-to-face interview was conducted with all participants. To ensure

consistency across researchers and interviews a template (App. A) has been devised that covers all questions that will be asked and information regarding the procedure of the interview that will be given to the participant. The interview was designed to cover one demographic question, to check for the exclusion criteria, and eight questions that cover the concept of range anxiety. The questions regarding range anxiety aim at the knowledge of participants about the range of EVs, range related problems and factors that influence these as well as assessing their performant and comfortable range, terms that were introduced by Franken & Krems (2013). The major component is a set of 46 questions regarding the features of an EV display. The participants were asked which range related features they would like to have in an EV . In addition to that there are five more questions that should provide a prioritization of the features following the MoSCoW method.In the end there is a display feature checklist on the template to keep track of the features that have been mentioned by the participant and to make it easier for the participant to recall all features for the prioritization procedure. The questions about range related features in the major component of the interview are derived from an earlier study by Neumann & Krems (2016) which investigated a similar topic within another population. Further display features have been derived from displays that are already in existence by BMW, Tesla and other vehicle manufacturers. Others features stem from conventional vehicles but still have relevance when it comes to range and consumption, such as speed and temperature. A fast acceleration and high overall pace result in an increased consumption. Low temperatures decrease the efficiency of the motor. Due to that the EV consumes more energy for the same effect which results in a decreased overall range. Therefore speed and temperature are relevant factors to the consumption and range of the EV. The interviews were recorded using the voice recorder app of the HTC one. The duration of the interviews was approximately 20 to 30 minutes.

Procedure

From the 27th of march until the 10th of may 16 interviews have been conducted by the researchers. At first the introductory information about the procedure and goal of the interview was read to the participant. After that a informed consent was handed out to the participants for

them to sign. During the interview the researcher first covered the demographic question and proceeded with the questions regarding range anxiety. When that part was finished a short explanation has been read to the participant which highlights the importance of range related display features in the following questions. The Participant was asked to think of any range related display features. The given features were ticked off on a separate checklist on the interview scheme to keep track. The participant's answers are followed up by questions regarding the importance of a specific feature, the way it should be presented and how it would prove useful to the participant. At the moment at which the participant can not think of any more features the researcher introduces the features from the checklist that have not been mentioned and continues then with follow up questions. When every feature has been covered the researcher proceeds to the explanation of the MoSCoW prioritization method. If the participant understood the process he was given the checklist and had to sort the features into categories: Must have; Should have; Could have and Won't have. After finishing that task the participant was given time to make comments or ask questions. Then the participant was debriefed and thanked for his participation in the study.

Data analysis

The interviews were structured using an inductive approach which was favoured over an deductive approach because, even though a lot of research on range anxiety and the effect of displays has already been conducted it mostly focused on early-adopters. Different responses and opinions were expected from non early-adopters. Therefore the coding-structure should not be based on responses that early-adopters have given as this would make the analysis less flexible and less receptive for new insights . This means that no predetermined framework has been used to analyze the data as it could have possibly been insensitive for differences between the populations and therefore would have biased the results in a way that less differences between the populations emerged. This was not suitable for the designated research question as we were especially interested in the commonalities and differences between these populations.

The specific method of analysis that was used in this research is thematic content

analysis. It is based on the grounded theory approach. At first each of the recorded interviews was transcribed into text documents which were then added to an Atlas.ti project. After reading through all the transcribed interviews codes have been determined that summarize the meaningful fragments of the interview into a couple words. It is important to note that in Atlas multiple codes per fragment are possible and the corresponding fragments can be viewed in the code manager. This simplifies axial coding, a process in which overlapping and co-occurring codes are reviewed and merged into broader codes that contain more variation. This resulted in a set of 17 codes. Using the code group manager in Atlas the codes were gathered in 2 code groups. The groups that emerged are “Content of displayed information” and “Presentation of information”.

The next step is to devise user requirements based on the codes. The motivation behind each of these requirements will be explained in the results section. In addition to that Table 1 and 2 show the design implications that can be drawn from the requirements as well as their prioritization. To order the codes according to their priority the MoScoW method was used. It is the goal to obtain a hierarchical order with four steps: “Must haves”, “Should haves”, “Could haves”, Won’t haves. Must have requirements are crucial to the functionality of a system and can not be missed out on without endangering the systems success. The requirements that should be implemented exceed the bare minimum and add to a wider adaption of the system. Less important but still beneficial requirements are labelled Could haves. Won’t have requirements are only rarely beneficial and can be regarded as unimportant. They will likely be neglected in the design.

In order to obtain the total moscow score the total amount of quotes per requirement is calculated with the code manager and displayed in Table 3. Then the amount of quotes is split into four steps Must have >=34, Should have<=33, Could have<= 22 and Won't have <= 11.

Following that step the each requirement is scored respectively to the strength of the expressions that participants make about them. This is displayed in Table 4. If a participant has made strong expressions about a requirement it gets the score 2. Weaker expressions are scored with a 1 and if requirements are seen as unimportant the score is a 0. Occasionally not all requirements have been investigated equally thoroughly during the interviews. Therefore some

participants have not made any expressions about certain requirements. Due to that there is no information available which is marked with N/A. The following cut-off score is used: <=0,8 “won’t have”, <=1.2 ”Could have”, <=1,6 “Should have”, <=2 “Must have”

Results

The participants mentioned a variety of display features that they would require in an EV. Participants were not only concerned with the content of displayed information but often judged its importance and accessibility based on the way it is presented. Therefore their requirements are split in two interrelated categories: content of displayed information and presentation of information. Further below the motivation behind each requirement will be elaborated. Based on the two scores for amount of expressions (AoE) and the strength of a participant's expressions (SoE) the total Moscow score is calculated. AoE and SoE are handled with equal weighting, added up and then divided by 2: (AoE*1+SoE*1)/2=Total cut-off score.

Content of displayed information

Remaining range

The remaining range was mentioned most often as users want to know if they can reach the desired destination because they were bothered about the limited range capacities of an EV compared to a combustion motor-powered vehicle. Novice users experience range anxiety in the first weeks of usage which declines over time. They heightened importance of this requirement for EVs has been highlighted by the respondents and it was frequently one of the first things that came to their mind when being asked which features they require. Participants expressed that information about remaining range is required to consider if stops at charging stations along the way are needed. Having knowledge of the remaining range provides the participants with a sense of security and control over the situation:

“Remaining range is very important, that for me is one of the most important things. It gives you

security if you know how far you can go. Because, as i said, there is a chance that you break down." (T 1)

Speed

Also the speed of the vehicle was one of the things that participants came up with first, as they view it as crucial to be able to monitor their pace when driving a vehicle. Participants reported that this would enable them to drive more consistently by avoiding quick acceleration, an immoderate pace and frequent braking a considerable amount of energy can be saved. This gives users a sense of control as he can adjust his pace to improve his remaining range, especially if the consumption would also be displayed. Another, maybe even more influential factor that makes this information so valuable to users is that they require it to obey speed restrictions: "Well, if the consumption is shown in the display i would know how to reduce it with my pace, but actually it is most important to be able to stick to the speed restrictions." (T1)

"That is a must have, also to obey the speed restrictions. It would help me little with the range if only the speed would be displayed, but in combination with how far i can go very much." (T3)

Warning system

Participants require a warning system for multiple situations.A fraction of the participants that could be described as more experienced drivers wanted a warning when the outside temperature drops below zero as this may cause the road to be slippery.

"In the winter I think it is important to see if the temperature drops below three degrees and that combined with a signal would be best." (T15)

Every participant wanted to be warned when they are running low on fuel because they fear that they are not always paying attention to the remaining range.

"A warning system is also very important, you do not want break down because you could miss things while focusing on driving... because you are not watching the battery status the whole time, that can go wrong ."(T8)

If the remaining range drops critically low many participants want to be warned at a point where

they can still reach the next charger. They would appreciate the opportunity to be guided to the closest available charger at this point, the feature that will be explained next.
“Mhmm, it would make sense to be warned so early that i can still get to the next charger.” (T5)

Closest charger

As mentioned above participants want to know if they can still reach a specific charger in situations where they are low on battery. The majority of users is concerned with the availability of charging opportunities and want those in the the proximity to be displayed.
“Something to see where the next chargers are would be nice. Although one would plan that before the trip. But because there are not so many chargers i would think it is practical to know where the next one is.” (T1)
An overview of all the closer chargers on a map could be a big organizational help to the participants especially when they are unfamiliar with the region. This enables them to plan the time of their breaks ahead and ensure that they do not run too low on battery.
“It would be cool to have the chargers on a map so you as a EV-driver can have a look at it if you are somewhere unfamiliar.”

Instantaneous Consumption

To drive more efficiently and reduce the energy consumption of the car the users need a way to keep track of the instantaneous consumption of the car. A display of this enables the user to analyze and evaluate their current driving style and adapt it to extend range.
“That is also quite important, because I can see if I consume more than normal and also make assumptions how far i can still get. If i drive like this i get that far. Especially when you notice that you are running low on battery, so that you can drive more energy efficient.” (T4)
However this informations should already be taken into account when calculating the remaining range, according to the participants. Therefore most participants do not view it as essential to be visible in the display when they already have the remaining range.
“Yes, the instantaneous consumption is relatively important, because as i said i would find it cool if the car could show me how far i can still get, on the basis of this data. Therefore it would be rather smart to have the information but only if it would be processed into remaining range.”

Charge status

Whether they are planning their next trip or the brakes to recharge, the participants need to know how much charge they have left and how long it is going to recharge. This provides them with a way to plan their trip and consider stops along the way. Most participants like a presentation that resembles the one in a regular vehicle as well as percentages similar to the battery status on a mobile phone as they are familiar with it. Most participants mentioned the time it takes to charge negatively together with this requirement, but that is what makes this feature so important. Because different charging systems take a different amount of time to recharge the EV battery it would be helpful to know how much of the battery needs to be refilled and how long it takes when you leave it to charge.

"This would be very important, otherwise you do not know for how long you have to sit there. It would upset me or disturb me. And especially when I am in a hurry and I know i can not wait any longer, but i already have 60%, that is enough for me. Then i could get going." (T2)

"At a normal gas station you know you are ready when no more fits in. But EVs take way longer. Therefore i like this feature, the charge status in percent or maybe the remaining time until it is charged, so i know if i can go shopping in the meantime." (T7)

Additionally a few participants mentioned the idea of a mobile phone app that provides live updates on your charging status as they find the time that it takes to charge an EV irritating and do not want to spend the time in the car.

Odometer

Even if just a couple of times a year the users still want to know how many kilometers they already drove with the car in total. This information is only crucial for users in special occasions, for example if they have a leasing contract or want to sell the car. Most participants report to want an Odometer because they had one in their old car and are used to it and appreciate the function to count the kilometers on a single trip. It could still be potentially of use to a participant with more experience that knows how much of the battery is used for a specific amount of kilometers. This would provide an additional way to monitor the remaining range.

“I would like to have one like in my normal car. The total amount, and so that i can reset it to zero when I have charged to see how much i have been driving since the last stop. At some point you have experience, then you know how far you can drive if it is freshly charged. Then you got the Odometer as an extra indication for how far you will approximately get.” (T2)

Availability of charger

The charging duration of EV’s still can not compete with that of combustion motor vehicles. Due to that waiting times at the charging station are significantly longer. Therefore the participants reported to welcome an indication of the availability of the charging stations in the proximity. Knowing which chargers are actually free would simplify the process of choosing a charging station and safe time.

“...charging stations are pretty rare, if i am in the city and need to recharge it would be good to know if the intended charger is available. If there is somebody already who needs another two hours I do not need to drive there.” (T 15)

Most of the participants viewed this feature as quite useful but others as more crucial. There are also a few participants who are not concerned with waiting times at the charger.

“I like that, really useful. Then you can see if the next one is free, this one not, so you would drive to the next. If that one is then just occupied you might have to wait, but usually it would save time.” (T 13)

“I think that is not so important. If you drive to a gas station it is not relevant if it is occupied or not. You must expect that you might have to wait. This expectation will be the same with EVs.” (T 12)

Temperature

The temperature outside of the car is interesting to the participants who know that low temperatures reduce the efficiency of the engine and thus the remaining range. There is occasional overlap between the temperature and the warning system in the code scheme. This points to a rather small portion of the participants that deem temperature as highly important if

the roads get slippery due to frost. According to those participants, temperatures below zero should therefore definitely be indicated by a warning signal to ensure security of the user, as mentioned earlier. A constant display of the outside temperature is deemed rather unimportant by most of the participants.

“It is important to know the temperature to know the influence it has on the car and the range. But I find it also important to be able to see if it is under zero degrees, because it could be dangerous then with slickness and ice. (T 1)”

Average consumption

This feature enables the participants to monitor their usual consumption. Most participants agree that it can be valuable to know your average consumption because they can draw conclusions on their consumption pattern in the long run. However it is mostly considered an information that does not need to be present on the display while they drive and it would suffice to be able to access it elsewhere to avoid clutter.

“The average consumption would be interesting to see but that should not be on the main display, otherwise you are drowned in numbers. Maybe it would be nice if it could be seen when you arrive. You do not look at that while you drive, it is enough to know the instantaneous consumption. I do not really think that you need it directly but if you could see in later on in a menu that would be useful.” (T 1)

Past consumption

A reliable estimate of the consumption on already travelled routes could be helpful to plan for the user with the remaining battery and range in mind. To most users this is another interesting tool to monitor their own driving style and consumption and that it might help to promote a more efficient driving style.

“That is quite exciting. If you are ecologically aware you could try to improve to consume less every time. If you can not remind yourself in any other way this feature is great. But it is more an extra, I do not think that you need it.” (T 1)

Some participants expressed doubts about the reliability of the estimate because of changing external influences.

“That is not really informative, because the current ride can completely differ from the earlier one. For example, a traffic jam, if I drive the same route later I will be faster and consume more. It is a good information but can differ from what you actually have to expect.” (T 15)

Regenerative braking

A part of the participants reported that it could be interesting to get this information and some said it would make them happy to know that they regained energy, but argued that they would not likely adapt their driving style due to this. The majority of participants pointed out that an indication of the regained energy does not give them any way to extend their range. Therefore it is rather a gimmick with little use and most participants deem it as not required in the display. “Does it have any use to see that? Because I would not brake more often to regain energy. It is irrelevant for me.” (T 17)

Table 1

An overview of the user requirements that regard the content of displayed information. They are in a hierarchical order from the most to the least important requirement.

	Must have
	Should have
	Could have
	Won’t have

User Requirements	**Design implications**
Content of displayed information	

Remaining Range	Provide a reliable estimate of the remaining range taking into account all relevant factors.
Speed	Provide information about the pace of the vehicle. Inform the user about violation of the speed limit.
Warning system	Implement warning signal for low battery status and low outside temperature
closest charger	Provide an overview of the charging opportunities in the proximity. If running low on battery indicate which charging opportunities can still be reached

Instantaneous consumption	Provide an estimate of the average consumption, overall and on specific trips.
Charge Status	Provide information about charge status of the car. The way this is presented should be amenable to change by the user.
Odometer	Provide the user with information about the amount of kilometers that the car has been driven, which can be accessed by the user if needed.
Availability of charger	Implement a system that keeps track of whether or not the closest chargers are being used.

Temperature	Provide information about the outside temperature, highlight if frost could occur.
Average consumption	Provide an estimate of the average consumption on 100 km, taking into account the user's individual driving style.
Past consumption	Provide an estimate of the consumption on known routes.
Regenerative braking	Provide an estimate of the amount of energy that has been regained by regenerative braking.

Presentation of information

Adjustable unit of measurement

The unit of measurement was frequently discussed in the interviews. Novice users of EVs are unfamiliar with the unit of measurement for the battery kWh. Therefore they would prefer to be presented with information in percentages and kilometers to get started. The preferred unit of measurement differs dependent on the experience a user has with electric vehicles. The participants mostly agree that for example Kwh as a unit of measurement would be more practical when using an EV and that they would therefore adjust it when they feel experienced enough. Most participants suggested an adjustable unit of measurement so that they can customize their warning notices and information according to their preferences.

“My consumption should preferably be presented in kWh per hundred kilometers to keep it similar to conventional cars. Actually it is not so important in which unit it is presented because it makes no difference as long as you are familiar with it.” (T 4)

“I would say my charge status in percent and remaining range in kilometers, but you could just get used to kWh or convert that to litres.” (T 10)

Visual warning notices

Numerous participants proposed visual warning signals in red color for critical situations regarding fuel or temperature. Participants reported that they would not always be highly focused on the remaining range and required a reminder in case a shortage of remaining range would be looming unnoticed. With red as a signal colour and a sudden onset the visual warning notices are likely to draw the participants attention and direct it to situations that need to be acted upon immediately. Most participants suggested the use of continuous warning notices in steps. Also in this situation the participants vary in their preference for the unit of measurement.

“Maybe with a red button flashing in the display for the last 50km, or the last 5%, 10%, 15% is

shown. So, in steps." (T 6)

Adjustable presentation

The display directly behind the steering wheel does not offer a vast amount of space. Therefore only information that is crucial to the participant should be presented. The participants differed in their view of a crucial information and should therefore be given the opportunity to adjust a certain space of the display to show information that they deem important at that time. As shown earlier the information that participants require alters with respect to the situation, for example the outside temperature is only crucial in the winter.

"I think it is important to see the temperature in the Winter. Around those temperature I watch that constantly. (T 15)"

This code overlaps with many other requirements. Most of them are only required situationally such as the temperature named above or the average consumption.

"My average consumption would be nice to know, but i do not need that on my display the whole time. I would have it in a sub-function where you can have it displayed if interested." (T 5)

Even though they are not always crucial the participants still require a way to obtain this information occasionally without overcrowding the display.

Integrated navigation system

A part of the participants feels distracted if they need to look at the middle console to use their navigation system or monitor the charging stations in the proximity. Therefore they would prefer a navigation system that is integrated in the actual display right behind the steering wheel. According to the participants this would make it easier to focus at the road and switch attention to the information in the display if needed.

It would be cool to have a navigation system directly in the display so i don't have to look to the right. Thereby I would be more concentrated, not distracted. Just more focused on the driving." (T 17)

Surprisingly this requirement was most often mentioned when discussing the closest charger. The majority of participants would welcome an integrated navigation system that shows the charger in the proximity.

Acoustic warning signals

Acoustic signals need to draw the user's attention in a critical situations just as visual signals. In the code scheme both warning signals overlap frequently and acoustic signals are most often mentioned whenever the participant also talks about visual signals.

“As indicator a little charge column should pop up and you should get a reminder sound, so that it gets your attention in any case.” (T 8)

However most of the participants did not mention acoustic signals as often and positively as visual warning signals. In addition to that a small portion of the participants even thinks that these signals are distracting and irritating.

“Well I think sounds are quite unpleasant, they scare you while driving. I would prefer something to flash up.” (T 1)

Table 2

An overview of the user requirements that regard the presentation of information. They are in a hierarchical order from the most to the least important requirement.

	Must have
	Should have
	Could have
	Won’t have

Presentation of information	
Adjustable unit of measurement	Provide the opportunity for the user to set the unit of measurement of his choice in the menu.
Visual warning notices	Give step-like warning notices at intervals chosen by the user with varying colours.
Adjustable presentation	Provide the opportunity for users to decide which information they want to have presented permanently and which one on request.

Integrated navigation system	Implement a navigation system into the display directly behind the steering wheel.
Acoustic warning notices	A mild acoustic signal for critical situations could be implemented as long as it is not too irritating.

Discussion

The goal of the current study was to determine which display features non-early adopters value the most when managing limited range resources of an EV. It was expected that participants would value unfamiliar features less because the effective use of them is constrained by their lack of knowledge in the EV domain and familiar features that they could rely on would be prioritized. Additionally it was proposed that non-early adopters prefer a familiar presentation of the consumption relevant information and value EV specific forms of presentation less because they are incomprehensible and therefore untrustworthy due their lack of experience with this forms of presentation.

Supporting the first hypothesis, regenerative braking and past consumption are both classified as a won't have. Most participants were unfamiliar with those two features and

reported that they could be a gimmick at best but do not have any real use to them. Also three of the four identified must have features, speed.warning system and remaining range are well known to the participants and resemble their usual vehicles. However the closest charger, an unfamiliar feature tailored for EVs, is also considered a must have. This finding does not sit well with the hypotheses. Supporting the second hypotheses, adjustable unit of measurement is the only identified must have requirement. This underpins the assumption that a presentation of the information in a familiar and therefore comprehensible way is preferred. It is important to note that, most participants stated that they would still switch to an EV-specific presentation when they have gotten used to it as it is more suitable. Participants value an adjustable presentation of range relevant information which can be altered accordingly to their needs.

The label must have for an unfamiliar requirement like the closest charger might appear less surprising in the light of work by Nilsson (2011) who found that range anxiety was predominantly caused by uncertainty regarding the available range and availability of chargers. Even though this feature is tailored for the use in an EV, it actually just is a refined version of a navigation system with a map upgrade for chargers. As it also provides a solution for the uncertainty regarding charging possibilities, and would thereby reduce range anxiety according to Nilsson (2011), it is understandable that the participants value it so much.

In earlier research the importance of a reliable and concise estimate of the remaining range has been highlighted (Franke, Rauh, Günther, Trantow, & Krems, 2016; Nilsson, 2011). Even though earlier research focused on early adopters the importance of the remaining range feature holds true for the in the non-early adopter population of the current study. The value of the remaining range to early adopters as well as non-early adopters can be explained if we look at how Franke and Krems (2013) propose a user manages range resources. Their ACOR model assumes that the user is constantly checking the fit of remaining range and his range goal to maintain a comfortable buffer. Hence the value of remaining range to any EV user, it is a crucial thing to consider when range resources have to be managed. An integrated navigation system would provide the second crucial information for that consideration.

Furthermore the correspondence and coherence problem mentioned by Bennett, Nagy and Flach (2012) can be clearly seen in the two categories content and presentation of

information. The required information to manage range resources does not shift significantly if a user would acquire more experience in the EV domain. However he could use more fitting and reliable forms of presentation for the EV domain, such as kWh as a unit of measurement. A positive effect of experience on the capability to manage range capacities is supported by Franke and Krems (2013).

The strength of the current study is that it provides new insights about EV display design in a non-early adopter population, which has not been studied in the EV domain before. Unfortunately the user requirements and design implications for the presentation of information are only applicable to the non-early adopter population of this study. This means that the findings are not generalizable to populations that differ from the non-early adopters in their lack of experience in the EV domain. The findings regarding the content of information however, are in line with the results of prior studies in early adopter populations. Future studies that incorporate early adopters and non-early adopters could determine if the lack of experience has an influence on their choice of preferred presentation. The current study offers insight into the prioritization of content information and the preferred presentation of that information and addresses potential underlying factors such as experience. Thereby It is the first step towards optimized EV displays for inexperienced users.

Literature

Bennett, K. B., Nagy, A. L., & Flach, J. M. (2012). Visual Displays. In Handbook of Human Factors and Ergonomics (pp. 1177–1208). John Wiley & Sons, Inc. https://doi.org/10.1002/9781118131350.ch42

Eaves S., Eaves J. (2004). A cost comparison of fuel-cell and battery electric vehicles. Journal of Power Sources, 130, 208–212. doi:10.1016/j.jpowsour.2003.12.016

Egbue O., Long S. (2012). Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Energy Policy, 48, 717–729.

doi:10.1016 /j.enpol.2012.06.009

Franke T., Krems J. F. (2013). Interacting with limited mobility resources: Psychological range levels in electric vehicle use. Transport Research Part A: Policy Practice, 48, 109–122. doi:10.1016/j.tra.2012.10.010

Franke, T., Rauh, N., Günther, M., Trantow, M., & Krems, J. F. (2015) The range comfort zone of electric vehicle users - Concept and assessment. IET Intelligent Transport Systems. http://dx.doi.org/10.1049/iet-its.2014.0169

Franke, T., Rauh, N., Günther, M., Trantow, M., & Krems, J. F. (2016). Which factors can protect against range stress in everyday usage of battery electric vehicles? toward enhancing sustainability of electric mobility systems. Human Factors: The Journal of Human Factors and Ergonomics Society, 58(1), 13-26. doi:10.1177/0018720815614702

McCollum D., Krey V., Kolp P., Nagai Y., Riahi K. (2014). Transport electrification: A key element for energy system transformation and climate stabilization. Climatic Change, 123,

651–664. doi:10.1007/s10584-013-0969

McManus M. C. (2012). Environmental consequences of the use of batteries in low carbon systems: The impact of battery production. Applied Energy, 93, 288–295. doi:10.1016/j.apenergy.2011.12.062

Nilsson M. (2011). Electric vehicles—An interview study investigating the phenomenon of range

anxiety.Retrieved from http://cordis.europa.eu/docs/projects/cnect/5/249105/080/deliverables/001-AninterviewstudyinvestigatingthephenomenonofrangeanxietyELVIRE21.pdf

Spath D., Hermann F., Peissner M., Sproll S. (2012). User requirements collection and analysis. In Salvendy G. (Ed.), Handbook of human factors and ergonomics (4th ed., pp. 1615–1642). New York, NY: Wiley. doi:10.1002/9781118131350

Yuan X., Li L., Gou H., Dong T. (2015). Energy and environmental impact of battery electric vehicle range in China. Applied Energy, 157, 75–84. doi:10.1016/j.apenergy.2015.08.001

Beltman S., Suzanne M.Vosslamber, Albert Molderink, Matthijs L. Noordzij

Toward the Design of an Energy Consumption Feedback System *Ergonomics in Design* Vol 24, Issue 3, pp. 9 - 16 doi:10.1177/1064804615611283

Appendix A

Interviescheme A1

Interview Scheme-Range Anxiety in Prospective Electric Vehicle Users

Interview Schema- Reichweitenangst bei potentiellen Nutzern von elektrischen Autos

In the interview we will ask you about your thoughts, opinions and expectations regarding a user interface/display in an electric vehicle. We are especially interested in the concept of *range anxiety* and how a display can influence it.
I would like to tell you some things before we start the interview. Your personal data and the data will be treated anonymously. You are free to end the interview at any given time or not to answer a particular question. The whole interview will be recorded.

In diesem Interview werden wir Sie zu ihren Gedanken, Erwartungen und ihrer Meinung betreffend der Anzeige in einem Elektroauto befragen. Wir sind besonders am Konzept Reichweitenangst interessiert und wie eine Anzeige dies beeinflussen kann. Ich würde ihnen gerne einige Dinge vorab sagen. Ihre Daten und Angaben werden anonymisiert. Sie können das Interview zu jeder Zeit ohne Angabe eines Grundes abbrechen.
Sign Informed Consent

At first we will ask 0.1 to 2.2.2. Secondly we give a short intermezzo to elaborate how the interview will proceed. With the answers to the questions 3 and 3.1 we get to know which display

features the participants can think of. These questions will be followed up until the participant cannot come up with any more features. We keep track of which features the participant has mentioned on a list. If the participant has not mentioned a feature out of the list the corresponding question from 3.2.1 to 3.2.10 will be asked. Questions under the heading Explanation/Evaluation features from 4.1 to 4.10.1 are aimed to provide information about the participants' understanding of the feature and how important they perceive it to be. The goal of question 5 to 5.3 is to get a prioritization of the features by the participant.

Question number ***Frage Nummer***	**Question** ***Frage***	**Purpose/Explanation** ***Grunde/Erklärung***
0.1	How old are you? Wie alt bist du/sind sie?	Personal data
	Demographic	
1	Did you ever consider? Haben sie in *Erwägung gezogen ein Elektroauto zu kaufen?*	General opinion of participant regarding EV's; gives insight in the level of knowledge the participant has
	Range anxiety	
2	What do you know about the range of EV's? *Was denken sie über die Reichweite von Elektroautos?*	General knowledge about EV's range; is the participant aware of range issues? does he/she know about range anxiety
2.1	What do you think how far an EV can go? Wie hoch ist die Reichweite eines Elektroautos?	
2.1.1	Do you think that this is far enough for you?	

	Ist das weit genug für sie?	
2.2	Can you think of anything that might influence the consumption? Können sie an etwas denken, das den Verbrauch beeinflussen könnte	Come to know if the participants is aware of varying consumption and the factors that cause it.
2.2.1	What about environmental factors? Was ist mit Umweltfaktoren/externen Faktoren	If only personal influences have been thought of
2.2.2	How do you think you have an influence on the energy consumption? Haben sie selbst einen Einfluss auf den Verbrauch?	If only environmental influences have been thought of
2.3.1	What do you think how far do you go on average during one trip? Wie weit fahren Sie durchschnittlich auf einer Fahrt	performant range
2.3.2	How much charge would you definitely want to have left when arriving at your destination (next charging possibility) Mit wie viel Ladung würden sie spätestens an ihrem Zielort ankommen wollen.	comfortable range
Intermezzo	So far we have mainly asked you questions concerning what is called ‘range anxiety’. The next part of the interview will focus on the user interface/display. As it has proven effective/ is expected to help the user to	Clarifying what will be next and what was before. Clarifying what is expected from the participant in the second part. If the participant wishes he/she can take a break.

	manage the EV and limited resources more effectively. Bis jetzt haben wir ihnen hauptsächlich Fragen gestellt die das Konzept der reichweitenangst betreffen. Der nächste Teil des Interviews richtet sich auf das Nutzerinterface/Anzeige, Da es sich als effektiv erwiesen haben bei der Optimierung des Verbrauchs.	
	Design display-features and their evaluation	
3	What do you think a display should show you? Was sollte ihnen ein Display zeigen?	Features the participant would like to have included
3.1	Can you explain what you mean by that? Können sie erklären was sie damit meinen?	Clarifying how the participant imagines the features
3.2.1	What about *average consumption*? Was ist mit dem durchschnittlichen Verbrauch?	
3.2.1.1	In which unit would you like to be presented with the information? In welcher Einheit möchten sie diese Information präsentiert haben?	
3.2.1.2	How would this help you? Wie würde Ihnen das helfen?	
3.2.1.3	What do you think how important this	

	feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.2	What about *instantaneous consumption*? Was ist mit dem momentanen Verbrauch?	
3.2.2.1	In which unit would you like to be presented with the information? In welcher Einheit möchten sie diese Information präsentiert haben?	
3.2.2.2	How would this help you? Wie würde Ihnen das helfen?	
3.2.2.3	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.3	What about *charge status*?	
3.2.3.1	In which unit would you like to be presented with the information? In welcher Einheit möchten sie diese Information präsentiert haben?	
3.2.3.2	How would this help you? Wie würde Ihnen das helfen?	
3.2.3.3	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.4	What about *remaining range*?	

	Wie ist es mit verbleibender Reichweite/Ladung?	
3.2.4.1	In which unit would you like to be presented with the information? In welcher Einheit möchten sie diese Information präsentiert haben?	
3.2.4.2	How would this help you? Wie würde Ihnen das helfen?	
3.2.4.3	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.5	What about *past consumption* for a given journey? (For example from home to work) Was ist mit dem Verbrauch auf vorhergehenden Fahrten?	Motion patterns are highly repetitive, being able to know how much resources were need for past journeys might give a source of information which is perceived as more reliable
3.2.5.1	How would this help you? Wie würde Ihnen das helfen?	
3.2.5.2	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.6	What about the amount of energy won by *regenerative braking*? Was ist mit der gewonnenen Energie vom regenerativen Bremsen	

3.2.6.1	How would you like this information to be presented? In welcher Einheit möchten sie diese Information präsentiert haben?	
3.2.6.2	How would this help you? Wie würde Ihnen das helfen?	
3.2.6.3	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.7	What about information about the *closest charging station*? Was ist mit Informationen über die umliegenden Ladestationen.	
3.2.7.1	How would you like this information to be presented? Auf welche Art möchten sie diese Information präsentiert haben?	
3.2.7.2	How would this help you? Wie würde Ihnen das helfen?	
3.2.7.3	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.8	What about *occupational status* of the charging station? Wie ist es mit Verfügbarkeit dieser	

	Ladestationen?	
3.2.8.1	How would you like this information to be presented? In welcher Einheit möchten sie diese Information präsentiert haben?	
3.2.8.2	How would this help you? Wie würde Ihnen das helfen?	
3.2.8.3	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.9	What about a *kilometer counter*? Was ist mit einem Odometer/Kilometerzähler	
3.2.9.1	How would this help you? Wie würde Ihnen das helfen?	
3.2.9.2	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.10	What about the *outside temperature?* *Was ist mit der Außentemperatur?*	
3.2.10.1	How would this help you? Wie würde Ihnen das helfen?	
3.2.10.2	What do you think how important this feature is?	

	Für wie wichtig halten Sie diese Funktion?	
3.2.11	What about the *clock?* Was ist mit der *Uhr?*	
3.2.11.1	How would this help you? Wie würde Ihnen das helfen?	
3.2.11.2	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
3.2.12	What about the *warnings system?* Was ist mit dem Warnungssystem?	
3.2.12.1	How would you like this information to be presented? Wie würden Sie diese Information präsentiert bekommen wollen?	
3.2.12.2	How would this help you? Wie würde Ihnen das helfen?	
3.2.12.3	What do you think how important this feature is? Für wie wichtig halten Sie diese Funktion?	
	Design Display prioritization of features	
4	Which of the above features must be present in an EV? Welches von den oben genannten Features muss in einem Elektroauto vorhanden sein?	

4.1	Which of the above features should be present in an EV? Welches von den oben genannten Features sollte in einem Elektroauto vorhanden sein?	Prioritization of the display features.
4.2	Which of the above features could be present in an EV? Welches von den oben genannten Features könnte in einem Elektroauto vorhanden sein?	
4.3	Which of the features do you think are not that important? Welches von den oben genannten Features ist unwichtig/kann vernachlässigt werden?	

We have reached the end of the interview. We would like to thank you for taking the time to help us with our study. Is there anything you would like to say or do you have any questions left? If you are interested in the outcome of the study we can send it to you later.

Wir haben das Ende des Interviews erreicht. Wir möchten Ihnen an diesem Punkt für Ihre Zeit und Hilfe danken. Gibt es etwas das sie hinzufügen möchten, oder haben Sie Fragen? Falls Sie Interesse haben lassen wir Ihnen gerne die Ergebnisse unserer Studie zukommen.

Display feature checklist

Remaining range (Verbleibende Reichweite)	

Instantaneous consumption (Momentaner Verbrauch)	
Average consumption (Durchschnittlicher Verbrauch)	
Charge status(while charging/)(charge speed) (Ladestatus)	
Past consumption (vorheriger Verbrauch)	
Regenerative braking (regeneratives Bremsen)	
Closest charger (Nächste Ladestation)	
Occupational status charger (Status der Ladestation)	
Outside temperature (Außentemperatur)	
Kilometer counter (Kilometerzähler/Odometer)	
Speed (Geschwindigkeit)	
Clock (Uhr)	
Warnings system (Warnungssystem)	
Additional features mentioned by participant: (Zusätzliche features)	
warnung defekte (ÖL/MOTOR)	
tourenzähler	
motor temp	
navi	

Table 3

This table shows the number of quotes per requirement in total and the corresponding Moscow score

Requirement	Total	Moscow
Unit of Measurement	76	4
Remaining range	37	4
Closest charger	29	3
Visual warning notices	29	3
Speed	24	3
Warning system	24	3
Instantaneous consumption	23	3
Odometer	22	2
Temperature	22	2
Integrated navigation system	18	2
Clock	18	2
Average consumption	17	2
Regenerative braking	17	2
Adjustable presentation	15	2
Charger in use indicator	14	2
Charge status	14	2

Past consumption	12	2
Acoustic warning notices	10	1

Table 4

The following table gives an overview of the strengths of the expressions each participant made regarding specific requirements.

Requirement	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	Average	Moscow
Adjustable Unit of Measurement	1	2	2	1	2	2	1	1	1	1	2	1	1	1	2	1	1.38	3
Remaining range	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4
Closest charger	2	2	2	1	2	2	2	2	2	2	2	1	2	2	2	2	1.88	4
Visual warning notices	2	2	1	2	2	1	1	2	1	1	2	1	2	2	1	1	1.5	3

Speed	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	1.94	4
Warning system	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1.88	4
Instantaneous consumption	1	1	1	1	2	1	1	2	1	1	2	1	1	2	2	1	1.31	2
Odometer	1	2	1	2	2	1	2	2	2	0	1	1	1	2	1	1	1.38	3
Temperature	1	1	1	0	1	1	1	1	1	1	1	1	2	2	1	0	1	2
Integrated navigation system	2	1	2	1	NA	NA	2	2	1	NA	NA	NA	1	1	NA	2	1.5	3
Clock	1	1	1	1	1	1	0	2	1	2	1	0	2	2	0	1	1.06	2
Average consumption	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1.06	2
Regenerative braking	1	0	1	0	0	0	0	0	0	1	1	1	1	0	1	0	0.44	1
Adjustable presentation	2	2	2	1	2	1	2	2	1	NA	2	1	1	1	2	1	1.53	3
Charger availability	2	1	1	1	2	1	2	2	2	1	NA	1	2	2	1	1	1.38	3
Charge status	2	2	1	1	2	1	2	2	0	2	1	0	2	2	1	2	1.44	3
Past	1	0	1	0	0	1	0	1	0	1	1	1	1	1	0	1	0.63	1

consumption

Acoustic warning notices	0	N A	N A	2	2	N A	2	1	N A	1	1	N A	1	1	1	2	1.27	3