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Development of a Mobile Application for Android to Support Energy-Efficient Driving of Electric Vehicles

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1 Introduction

The issue of electric vehicles is more topical than ever before. Big automotive manufacturers are investing a lot of money for the research and development of them. As a consequence, the number of registered electric vehicles has been increasing continuously for the last years as it can be seen in figure 1. Nevertheless, the amount of electric vehicles is low compared to the overall registered cars.

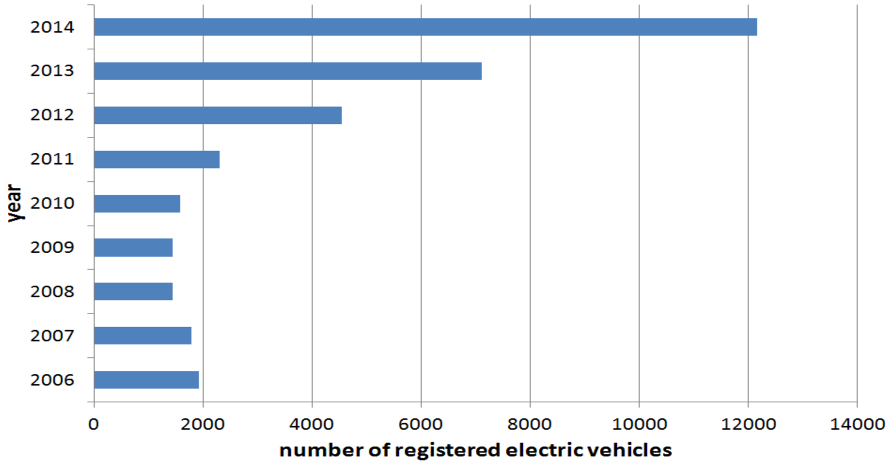

Figure 1: Number of registered electric vehicles in different years in Germany
Source: Statista GmbH 2015.

In this, there are different challenges which have to be mastered regarding electric vehicles. One of the major problems of electric vehicles is the range. Due to the use of a battery system the maximum range is very limited considering the current state of technology. Thus, driving energy-efficiently is essential. That is the reason why tools which are optimising the current driving behaviour are very useful. Hence, investigating more intensively how to drive energy-efficiently helps to optimise the range of electric vehicles which is why different possible factors are analysed within this paper to determine the respective degree of influence. However, as the mere analysis is not useful for the driver of an electric vehicle, this can only be a first step. In a second step all this information is utilised to design a mobile application which allows to evaluate the current driving behaviour and to display this on the screen of the mobile device in real time. Due to this, the driver is able to adapt the driving behaviour continuously. Thus, this paper provides a concept for an energy-efficient driving application on the use case of the Volkswagen (VW) e-up!.
The aim is to elaborate a mobile application to support energy-efficient driving. Therefore, every important influencing factor is considered as far as possible. This is feasible due to a comprehensive analysis of different influencing factors. The elaboration of these factors in combination with measured data is the basis for the following design of the mobile application. The special feature is that the design is not only elaborated on theoretical considerations and calculations but also based on measured data.
In general, the methodology of this paper follows the concept of Hevner et al. (2004) and his seven guidelines for "design science in information systems research". The first guideline demands that something innovative has to be produced. In this paper that is done by the development of the mobile application, which is designed in chapter four. According to the second guideline, the topic has to be relevant. The relevance is explained in chapter one and hence is given. The requirement in guideline three is a well-founded evaluation of the elaborated aspects. The different influencing factors which are explained in chapter two are evaluated in chapter three with base on data collected in test drives. Thus, the evaluation can be seen as well-executed. This guideline is followed by the demand of solving a problem in a better way than before. Within this paper, this is done by developing the mobile application and so supporting the driver of an electric vehicle to drive more energy-efficiently. The fifth guideline deals with the elaborated artefact. It has to be ensured that it is coherent and consistent and besides it has to be determined how well it works. This is mainly done in chapter five in the course of the critical appraisal and the limitations. The penultimate guideline demands a contracted problem space to be able to reach the objective of the research. In this case, the problem deals with energy-efficient driving and its influencing factors and there is a clear definition in the first chapter of what

has to be covered by this paper. The last guideline formulated refers to the results. They have to be presented and communicated clearly what is done in chapter six within the conclusion and the outlook. A theoretical background is given in the chapter after the introduction. In this chapter factors that influence the maximum range of an electric vehicle are elaborated. Within this chapter, there is differentiated between factors which are changing during the journey and those who are depending on the respective vehicle. The third chapter contains the statistical analysis of selected influencing factors which is done through data raised during test drives. In the following chapter a mobile application to support energy-efficient driving is designed. Finally, the paper ends with a critical appraisal and the description of limitations. Moreover a conclusion and an outlook are given.

2 Factors That Influence the Maximum Range of an Electric Vehicle

To maximise the range of an electric vehicle and consequently driving energy-efficiently there are different factors which have more or less impact on energy-efficient driving. These factors can be distinguished in two different categories. In the first category are the factors which are changing during the journey, the dynamic influencing factors. These factors are explained and analysed in chapter 2.1. In chapter 2.2 are those factors which depend on the respective vehicle, the static influencing factors.

2.1 Dynamic Influencing Factors

The recuperation is one of the biggest advantages in comparison to conventional vehicles with a combustion engine. The frequency and efficiency of recuperation has a decisive influence on the maximum range. The special feature of an electric motor is that it can be used as motor or as generator (Wildemann 2012). The converted electrical energy is stored in the battery and can be used for following driving processes. The current speed of the electric vehicle also plays a very important role regarding the maximum range. To be able to maintain a certain speed, different resistances have to be overcome. As a consequence it can be said that an increase of the speed results in a decrease of the maximum range. Thus, there is no optimum speed where the motor efficiency has its maximum or the range has an optimum. Because of that it is very useful that the maximum possible speed is limited. Another advantage is that the heat development in the battery system which rises with a higher speed is also limited due to the speed limit (Donhauser 2015).
Physically, the acceleration is the time derivation of the velocity. Thus, the acceleration is the temporal change of the speed. This is why different resistances have to be overcome to be able to accelerate and so to increase the speed. These resistances are the same as in case of the speed. Because of this, there is more energy needed to accelerate than in case of driving with a constant speed. Because of that it is recommendable only to accelerate as much as it is necessary and only as long as it is necessary. The optimum acceleration would be zero because to be able to accelerate it is always necessary to use additional energy. That would not be application-oriented though.
It is possible that the respective electric vehicle has different driving modes to reach energy-efficient driving. In case of the VW e-up! "ECO+" is the most economic one and so it should be used as often as possible. The air resistance is another important factor regarding energy-efficient driving and the maximum range of an electric vehicle. In general, an increase of the speed leads to a higher aerodynamic drag force. To overcome this force more energy is needed. In turn, this decreases the maximum range significantly. With the following formula 1 it is possible to calculate the aerodynamic drag force.

$$F_d = \frac{1}{2} * A * c_d * \rho * v^2 \qquad (1)$$

An important influencing factor on the aerodynamic drag force is the speed. As the other factors are constant or can be assumed to be constant, the speed is the only influencing factor which is changing dynamically. As it can be seen in the formula, the speed has a quadratic impact on the aerodynamic drag force.
The factor of the gradient contains the influence of driving uphill and downhill. The gradient influences the maximum range and by that the optimum behaviour to drive energy-efficiently. Another influencing factor regarding the maximum range is the road surface. Depending on the road surface the optimum braking and acceleration behaviour does change. This is because the friction between tyre and road surface is different. The outdoor temperature is also an influencing factor for energy-efficient driving of electric vehicles. Cold reduces the efficiency of the electric vehicle significantly (Schoblick 2013). So the range of the car is clearly lower when the temperatures are lower. Not only cold can

The figure 9 shows the call logic of the individual pages which are presented above. Additionally, it is always possible to use the back button of the mobile device. When pressing this button the page which is activated is always the main menu independent from the current page. Because of the fact that this is always the same, this is not part of the figure 9.

5 Critical Appraisal and Limitations

When thinking about electric vehicles, the range is a decisive factor. That is why elaborating how to drive energy-efficiently is a very essential field of research. Within this paper many different influencing factors are considered with the objective to transfer the knowledge gained in this way into a mobile application that supports energy-efficient driving of electric vehicles. But not only theoretical reflections are the basis for the mobile application but also practically measured data. Because of this, the compiled possible design in this paper for such a mobile application can be seen as well-founded. Nevertheless, it is inevitable to simplify or neglect facts to reach the objective explained in the introduction of this paper.

An analysis of different factors which are influencing the optimum driving behaviour is made. As it is not possible to consider every single influencing factor when designing the mobile application, limitations have to be made. On the one hand these limitations concern the impossibility of quantifying the respective influencing factor. For example, this applies for the air resistance. In the theory it is possible to calculate the air resistance. But to transfer this into the magnitude of influence on the optimum driving behaviour is highly complex. The same is valid for the gradient. Although in theory it is possible to determine the current gradient, there is no possibility to define the magnitude of influence within this paper. The reason is that there are no test drives made with different gradients, which is why it is not possible to take this into account when designing the mobile application. In case of the road surface, the temperature and the wind at the particular time and place are also very difficult to quantify and determine the influence on the range of the electric vehicle. Additionally, there is the problem that it is neither possible to determine these factors permanently during the journey when the driver uses the mobile application. On the other hand there are some influencing factors which are changing very slowly which is why they can be assumed to be constant. This applies for the tyre pressure and the age of the battery. Nonetheless this can be seen as a limitation. Another influencing factor which is not implemented in the concept of the mobile application is the weight of passengers. The reason is that there are not made test drives with different numbers of passengers. Because of this it is assumed that there is only the driver of the electric vehicle inside the car without any passengers. In addition to this, it has to be said that it is possible that there are additional influencing factors, depending on the electric vehicle and the current driving situation, which are not analysed within this paper.

Apart from the theoretical analysis there are also some limitations with respect to the measured data. One point is that the number of test drives could be larger to ensure that the evaluation is correct. Furthermore, some of the values had to be measured manually and not with the integrated on-board system. Additionally, it is important to mention that some simplifications are made. Regarding the acceleration there are only calculated average values. This means that it is neglected that the value of acceleration may vary, for instance, during speeding up from 0 km/h to 50 km/h. Furthermore, it is assumed that the degree of efficiency which is calculated once can be used for other test drives to calculate different values. Another limitation is that the analysis is made for journeys in the city. This means that there is no analysis when driving faster than 50 km/h.

6 Conclusion and Outlook

Because of the fact that electric vehicles become more and more popular, it is of importance to consider the topic of the limited range. Due to the current state of the art the range of electric vehicles is relatively small in comparison to vehicles with a combustion engine. Additionally, there is the problem that recharging the battery can take a lot of time. Because of this, especially in case of electric vehicles, energy-efficient driving is very important.

This paper is picking up on this point and elaborates a possibility to support energy-efficient driving of electric vehicles. That is the reason why the objective of this paper was to design a mobile application which is supporting such a driving behaviour. This concept is influenced by a theoretical and a practical part. The theoretical part is the analysis of different influencing factors which affect the optimum driving behaviour. On the one hand factors which are changing dynamically are analysed. With respect to this, one of the most relevant factors regarding electric vehicles appears to be the opportunity of recuperation. Depending on the driving behaviour the driver is able to recover a certain amount of energy. On the other hand influencing factors which are not dynamic but depend on the used electric vehicle are scrutinised. One of these influencing factors is the age of the battery which can be a decisive point regarding the range.

The precise observation of these influencing factors is one important corner stone for the mobile application. The other corner stone is the analysis of measured data. These measured data are collected during test drives with a VW e-up!. Thus, many different influencing factors which also may interact are considered at least indirectly due to the measurements. It is possible to analyse and evaluate the data based on different calculations. One example for such a calculation is the determination of the degree of efficiency of the recuperation depending on different influencing factors. As calculated, a value of 58 % is realistic for this degree of efficiency. Another essential point regards the range of 160 km, reached when driving in conformity with the NEDC. It is elaborated that the net energy consumption must not exceed a value of 11.6875 kWh/100 km to be able to cover this range. As analysed, this net energy consumption can reached realistically when not accelerating too strong. In connection with this, another result of the analysis of the measured data is that a maximum acceleration intensity of 20 % is sufficient to remain part of the flow of traffic.

Based on these different elaborations it is possible to design the mobile application. As there are two important parts of the concept, this is divided into the inner structure of the mobile application and the graphical user interface. The inner structure shows the general design of how incoming data are processed. In this, one aspect regards the current speed. As there is a speed limit of 130 km/h implemented in the VW e-up! it is helpful to control the current speed. Another point concerns the current acceleration. Because of the fact that an acceleration intensity of 20 % is sufficient, the current acceleration has to be checked. Furthermore, it is essential to analyse the current braking force. It is recommended in this paper to use the highest recuperation level B. Thus, the current negative acceleration is compared to the negative acceleration of -1.05 m/s^2.This value occurs in case of using the engine brake and also the recuperation level B. As the application is based on measured data buffers are implemented. On the contrary, the graphical user interface treats the external appearance of the mobile application. So, the previous analysis results in a mobile application with the objective to support the user to drive an electric vehicle in an energy-efficient way. But as it is not possible to consider every single influencing factor and each partial result of the analysis of the measured data, it is followed by a critical appraisal and limitations.

Although there are some limitations, recommendations for action are elaborated within this paper. The probably most important point refers to the acceleration, the positive one as well as the nega-tive one. In case of increasing the speed it is recommendable to accelerate moderately. Furthermore, it is important only to accelerate if it is necessary because a positive acceleration means the use of extra energy. The other possibility is to reduce the speed. Therefore, it is recommendable to select the highest recuperation level, B, of the VW e-up! to recuperate as much energy as possible. In addition to careful acceleration behaviour, it is sensible to use additional energy consumers as sparingly as possible to maximise the range.

With basis on the limitations made in chapter 5, it is possible to develop ideas of how to expand the mobile application and in general of further research. On the one hand this could be done by a detailed market analysis. By elaborating carefully which aspects are no part of such a mobile application yet, it would be possible to reach more users which are interested in electric vehicles. Furthermore, maybe there are more influencing factors which can occur depending on the particular driving situation. As in this paper only influencing factors which occur in nearly each case are considered, there might be additional ones which only occur because of specific reasons. To underpin this it could be useful to make more test drives. This is also a useful way to improve the reliability of the data further.

In case of expanding the mobile application, the colour scale to evaluate the current driving behaviour could be expanded. This means that apart from the two extremes green and red which are standing for driving very energy-efficiently and not driving energy-efficiently at all, there could be different shades between these two extremes to give a more detailed feedback. Nevertheless, the user should not be confused by too much information. Furthermore, the mobile application could be expanded regarding the type of electric vehicle. In this paper there only analysed the driving behaviour when driving with the VW e-up!. Including more types of electric vehicles would increase the potential number of users.The same effect can be reached by offering the mobile application for different operating systems.

In summary, this paper is a good starting point for further research and is a comprehensive basis for thinking about energy-efficient driving of electric vehicles. This paper and the within elaborated mobile application to support energy-efficient driving of electric vehicles can be seen as an important contribution in the field of analysing the optimum driving behaviour to maximise the range of electric vehicles.