An Experimental Study on the Influence of Smartphones on the Behaviour of Electric Vehicle Drivers

Masterarbeit

zur Erlangung des akademischen Grades „Master of Science (M.Sc.)” im Studiengang Wirtschaftsingenieur der Fakultät für Elektrotechnik und Informatik, Fakultät für Maschinenbau und der Wirtschaftswissenschaftlichen Fakultät der Leibniz Universität Hannover.

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Hannover, den 30. September 2014

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Appendix i

Own work declaration / Ehrenwörtliche Erklärung

1. Introduction

“The federal government's target is to make Germany the leading market for electric mobility“

— Sigmar Gabriel, German Environment Minister, August 19th, 2009

In times of rising oil prices and the public awareness that fossil combustible material is a limited good the research for alternatives becomes more and more important. Additionally while most likely one single alternative will be the successor to oil the efficient use of that alternative should be considered from the beginning. There is still a spot available for one country to become the leading pioneer for effective and sustainable mobility. Therefore the german government has set itself an ambitious goal: the multiplication of the number of electric vehicles [*e-vehicles*] by 140, from 7114 vehicles in 2013 to one million in the year 2020[1], hereby becoming the leading market for electric mobility [*e-mobility*] in the world[2]. To achieve this goal, e- mobility has to become more accepted and more attractive for the average owner of a car. One way could be by introducing electric cars to potential users by integrating these cars into existing car-sharing models. One of the main problems of electric cars – besides the initial purchase price – is the vigorous limitation of the range achievable with one charge, especially as recharging can easily take up to nine hours[3]. To maximize the achievable range, the efficiency of driving and other parameters relevant for the energy consumption become important. Recent studies mostly concentrate on the influence of external factors and the energy efficiency of the e-vehicle itself, but lacked to analyze the persuability of the driver himself and his driving style. While it is well known that a more offensive driving style results in lower ranges with one tank or charge it is important to determine if and how this alternation of his behavior is possible. Therefore several steps have to be taken and even more factors have to be concerned. To allow the intended manipulation data from different sources has to be collected and analyzed to feed it back to the driver. Since the use of smartphones has reached an all-time high[4,5], this human-machine interface could prove to be the optimal way to feed back the analyzed data. Using this data may allow to influence the behavior of drivers of said e-vehicles as he is able to see what

[1] c.f. FAZ 2013

[2] c.f. BEE-ev 2009

[3] c.f. VW AG 2013b

[4] c.f. Bitkom 2013

[5] c.f. Statista 2013

benefits he himself gains by acting (e.g. driving) more economical and thus achieving a higher electric miles per gallon [*mpg-e*][6,7] value. The widely spread acceptance and availability of smartphones could be used to enable people to use an application [*app*] on their phone or other mobile devices to control certain aspects of their car and learn more about efficient mobility and efficient driving. Such an app also has to consider various aspects to allow the usage within certain limitations such as legal aspects concerning the use of mobile devices while driving a car.

The general question at hand is now if it is possible to influence the behavior of said drivers in a positive way by using smartphone-based applications that act as a trigger mechanism and if so, how this goal can be achieved. The approach used for the determination and examination of the research question is shown later in this thesis. While there are projects working on the extension of the achievable range of e-vehicles using technological approaches, the psychological approach, e.g. the behavior of the person driving and controlling the car and therefore its energy consumption, is another important way to achieve said goal of extended range. As the title “An Experimental Study on the Influence of Smartphones on the Behaviour of Electric Vehicle Drivers” states the goal of the study is to determine if a correlation between the driving style and the possible manipulation of the driver’s behavior with the use of a smartphone application exists. In the following paragraphs the general approach and the methodical commitment for the study of this correlation will be described while the parameters that will be used for the determination of said styles or profiles have to be evaluated by using one of the two available e-cars, that are both the model “e-Up!” made by the German car maker Volkswagen. That particular model is based on the common model “Up!” that is sold with a normal combustion engine. While the research is limited by certain aspects, as described in chapter 3 and 5, the question at hand is if and how an application designed to support energy efficient driving can influence the contestants. Therefore the following separation aspect is considered:

> What effect does the trigger mechanism have on people with different driving styles? The chosen research experiment will show if people describing their own driving style as offensive are more severely influenced in the aspired way then reluctant drivers.

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[6] mpg-e is typically used as the unit of range per energy for electric cars analog to mpg for petrol-powered cars

[7] To convert mpg in l/100km: $\left[x\ mpg * \frac{1,609}{3,785} * {}^{1}/_{100}\right]^{-1} = x\ {}^{l}/_{100km}$

This aspect is of relevance, as more offensive drivers exhibit on average a higher energy consumption per mile than defensive drivers and therefore their benefit from an influenced driving style could be higher than the benefit of already defensive drivers. This would result in a lower energy consumption on average across all drivers, as an offensive driver has a higher impact on the average consumption than a defensive one. Other aspects may be possible but as stated before the selection is limited due to the conditions surrounding the creation of this thesis. The impact of the selection is considered in chapter 5 which presents the limitations of this research and this thesis while suggestions for further research are located in chapter 6.3. The variables for the experiment will be defined according to the selected separation aspects in the corresponding chapter. The definitions for the relevant terms, such as offensive and defensive driving styles, are located in the following chapter. The portrayed objective becomes even more relevant through recent developments. The concepts “MirrorLink” by Google and “CarPlay” by Apple have reached a state where they will be implemented into cars with the next generation or facelift. These concepts allow a deeper integration of smartphones into the cars onboard info- and entertainment systems and enable the driver to access certain functionalities of his mobile device with the built-in controls of the car. In combination with the all-time high of smartphone availability and usage, as described in the following chapter, this allows entirely new ways to reach the driver and offers auspicious new concepts for an energy efficient behavior, especially for the rising electric mobility and thus fortifies the motivation for the initial research question.

To allow the research of the proposed question, various research methods are used. Prior to the methodical commitment, which is given in the third chapter, the following paragraphs display the approach and progress of the thesis, hereby concentrating on the order of the various steps of the research. The creation and execution of an online survey is the first step of the research and will be done in parallel to the planning and the elaboration of the experiment that is then used for the practical examination of the proposed research question. This survey allows a wider range concerning the participants and additionally a statistically more relevant data collection. Therefore the questions asked in the survey concentrate on the personal experiences of the participants with smart devices and e-vehicles and also asks for their expectations in terms of suggestibility through an app. Furthermore, the survey aims at a definition of the various possible driving styles that will then be used in combination with the corresponding definition from chapter 2 throughout the thesis. Chapter 3.2 deals with the methodical aspects of this survey and presents the survey itself as well as an estimation of the validity and reliability of both the individual questions and the survey itself.

The experiment following the survey is divided into various parts as the procedure is more complex than the survey and requires more preparation and planning before the execution. Therefore these parts will be individually described in the upcoming paragraph. An experiment is chosen as the main part of the data acquisition due to several reasons. For one, an experiment allows the generation of data from the real world in real situations, which can then be compared to data generated with other methods, especially the data from the survey. Additionally, an experiment allows the exploration of causal coherences. It also allows the examination of human behavior when the drivers are confronted with different premises in their role as participants. The first step of the preparation of the field study is the lookout for existing applications and therein included the determination of the functions and methods they offer the potential user. This allows the selection of the app that is best suited to fulfill the requirements of the experiment. This concerns especially the legal aspects described earlier in the introduction and later on in the composition of the experiment in chapter 3.3.2 and that are again picked up in the chapter on the limitations of the thesis, chapter 5. Additionally the app is selected after the analysis of its functionality during various test runs. During these test runs also the viable experiment parameters will be defined and put to a test. These parameters include amongst others the driving route that the participants will follow during their drive, the values that will be measured with the data logging device and also the key factors for the post-drive evaluation that are required to allow a comparison of the generated data with the data from the online survey. In addition to the generation of sample data, that is also required for the initial definition of the different driving styles, these test runs show which data from the data logger can be used for the analysis. In this way they help conveying the parameters into a state that is sufficient for the actual experiment procedure. Due to the fact that an experiment that takes place in the real world, in this case on normal roads with real traffic, is exposed to various perturbations, these parameters have to be strictly defined to allow a comparison and ensure the validity of the generated data. These perturbations are the topic in chapter 3.3.2 and also in chapter 5, the chapters on the surroundings and limitations of the research. The completion of these test runs also marks the end of the preparation and the beginning of the execution of the field study. The assignment of the participants to one of the two experiment groups is hereby the first important step of the experiment execution. This randomized assignment ensures that both possible values of the crucial characteristic "driving style" are present in both groups as this presence is required to enable an analysis and comparison as shown in figure 3-2 in chapter 3.3.2. The entire assigning procedure is also described in the same chapter. During the individual drives a data logging device will be present and active to generate the driving data necessary for the analysis of the behavior of the experiment participants. This data generation and collection is the key task of the research, which is then followed by the analysis and comparison of said data. The field study is concluded by a short evaluation that every contestant is asked to take part in. Even though this evaluation is a part of the field study, it is explained as an individual aspect of the research in its own chapter. Chapter 3.4 therefore shows the methodical commitment chosen for this evaluation, presents the evaluation itself and gives a first impression on how the evaluation supports the rest of the research. The following figure shows a compendium of the three steps the approach of the field study consists of and that are portrayed in detail above.

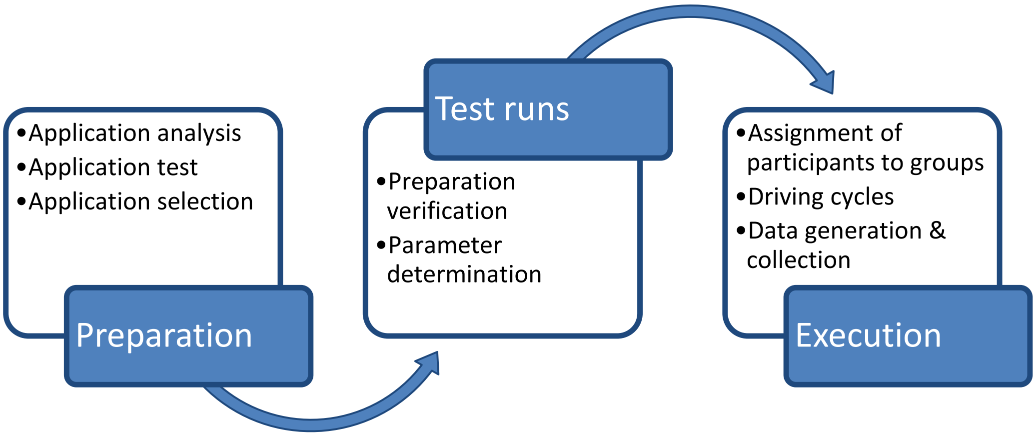

Figure 1-1 Experiment execution sequence[8]

The execution of the field study is followed by the data collection, preparation, analysis and presentation. The analysis of the data hereby includes the comparison of the data from the different research aspects – e.g. the online survey, the experiment itself and also the adjacent evaluation. It furthermore contains the lookout for correlations between the individual research aspects and especially for those between the initial driving style and the suggestibility as the search for this correlation is the primary research aspect. Following this apron, the critical reflection and the analysis of the limitations and surroundings result in an outlook that concludes the research project and answers the initial research question.

[8] As long as not otherwise labeled, all figures are own depictions

matter of course that does not have a huge impact on the driver anymore while an application and therefore something new in the routine task of driving a car still has the chance of changing the driver's behavior. For the experiences of the participants of the experiment during their drives it can be said that they were continuously positive ones that are also superimposable with both the expectations the participants had before their drive and the expectations of the participants of the survey. This once again shows that the interest in the technology is present and the opinion of people who came in contact with it is generally positive, as the e-vehicle often outperforms the expectations. Therefore the accessibility to the technology has to be improved as the public opinion can only improve by altering it in small steps through personal and first-hand experiences.

The comparison of the survey with the experiment and the evaluation shows a high level of compliance for identical questions and aspects. One of the most interesting observations is the correct self-assessment of their own driving style done by the participants. While the general differentiation between offensive and defensive drivers is very complex, the classification of more than three quarters of the participants of the experiment is backed up by the recorded driving data, which is much more than originally anticipated. This high rate allows two things: on the one hand, it supports the definition of the two driving styles that is used within this thesis. On the other hand, the validity and reliability of the corresponding questions from the evaluation are increased. Both data generation methods also back up the described all time high of smart mobile devices and the expectations people have concerning e-vehicles. One exception is the influence of applications, which has been determined to be higher in a real life experiment than anticipated in the theoretical part of the research.

As stated before, these findings, while accurate, are drawn from the data that is generated under the influence of the limitations described in the previous chapter.

6.2 Conclusion

Still, even the influenced data allows the drawing of relevant conclusions, as long as the described limitations are regarded.

For the e-vehicle itself, the e-Up, it can be said that almost all participants are positively surprised about its performance, its driving attributes and especially its noise emissions. The price of the actual car on the other hand remains one of the main negative aspects, as does the limited operating distance. For its intended area of operation as a small city car however, this limited distance would remain sufficient for many participants. These opinions on the car also show the attitude towards e-mobility in general. While many people are interested in the technology for various reasons, whether it is because of personal preferences, the fear of further increasing prices for fossil fuels or the positive characteristics of e-vehicles, most remain skeptical for the time being. This is due to the image of e-mobility just as well as it is due to the described mainly perceived negative aspects, as the buzzwords used the most to describe this type of mobility are "silent", "expensive" and "not finally developed". This skepticism is mostly due to the lack of boundary points with electric cars for the general population. Therefore, the industry should aim at creating these points to improve both the accessibility to these cars and thus the opinion on them and hereby also increase the acceptance and the market opportunities for electric vehicles.

The utilization of a smartphone-based application during the period of the all-time high of smart mobile device distribution shows that the acceptance of smart devices and the data generated by and presented on them is given. Furthermore, people are inclinable to be influenced by this data and are willing to learn from it to gain personal benefits. However, even in this period the market for applications designed to help achieve these benefits is still underdevelopment, if not almost non-existent. While the car and device manufacturers are working on the improved link between these two appliances, the application developers are required to develop this market, create applications aiming at real time data creation, energy efficiency and influencing the driver. The main task hereby remains the determination of the best solution for this kind of app. Some ideas for this are located in the following chapter as recommendations for research and industry. Also the manufacturers are required to work on the public perception, as most people do not know what they can expect from the linkage between the equipment in terms of functionality and benefit. As the research shows, especially the concept of gamification is of importance for the implementation, as it offers the user an additional benefit besides the reduced energy consumption and provokes an alternation in behavior by transferring real life problems into the simulation of a gaming concept and offering incentives to the user for achieving, for example, high scores in this gaming context.

The research itself can be rated as successful, as it was able to answer both the initial research question and also the postpositive supplementary questions. It has also shown that the awareness of fuel economy, energy efficiency and the correlation between driving style and operating distance is present for almost all drivers. Furthermore, the field study presented a point of contact for the drivers to become acquainted with e-mobility and shows that the interest in the general population for e-mobility exists. Still, this interest has to be initially triggered, inter alia with the help of such research experiments.

To conclusively answer the initial research question, if offensive drivers are more severely influenced by the described trigger mechanism than defensive drivers, it must be said that while drivers of both groups are influenced in a positive way in more or less the same extent by the trigger mechanism in terms of an application executed on a smart mobile device, offensive drivers tend to exhibit a higher personal benefit from the use of an application designed to alter their driving style and behavior. Furthermore, the research is able to support the statement that an app can help to save up to ten percent in terms of energy consumption. The generated data therefore also allows the conclusion that smartphones and applications do have a measurable influence on electric vehicle drivers and can help to decrease the mostly perceived negative aspect of e-vehicles, the limited operating distance in comparison to conventional combustion drive trains due to its energy consumption, by changing the driver’s behavior that can be combined with technological advancements in the future. The usage of an application thus is a promising way of optimizing range by minimizing the energy consumption through behavior alternation. Additionally, the decreased use of limited natural resources leads to ecological benefits and improves the subsistence of these resources until renewable energy sources are sufficient enough to solely power e-mobility. The research therefore is able to show that smartphones do have an influence on the behavior of electric vehicle drivers and that the best way to alter their behavior is yet to be determined.

As a final consideration for the conclusion of the research it must be said that e-mobility still has to solve a wide field of problems and overcome a variety of limitations before the goal set by both the industry and the German government can be reached. In this still early phase of the development however Germany possesses the chance to become one of the leading markets for electric mobility.

6.3 Outlook and recommendations

The future growth and increasing importance of alternative mobility concepts and vehicles is probable and, due to the limited natural supply of fossil fuels that lead to increasing prices for conventional mobility, almost indispensable. Therefore e-vehicles exhibit a great potential for a sustained change of the face of mobility, not only in Germany but also worldwide. Due to the described obstacles the technology faces, the increase of market shares of e-vehicles on the entire market for individual mobility will most likely be slower than originally anticipated by industry and government, especially because of the sheer height of the initial cost and also because of the skepticism and lack of experience of the potential customers with e-mobility. Furthermore, the absence of a developed recharging infrastructure is an important limitation for the time being. The market for applications based on mobile smart devices will most likely further increase. The question remains, if apps for energy efficiency and individual mobility will take part in this growth and if their developers are able to create and improve concepts to establish their own niche in this market that also offers the users the personal benefits necessary for success in this market. Some evidence for this development can already be found. BMW as an OEM has a system called “Efficient Dynamics” integrated into both their conventional and their electric cars. When using an economic driving mode of the car, the driver is able to see how much mileage in terms of remaining operating distance he has gained by just using this mode of the car. This system hereby follows the same concept of incentive education and benefit presentation, which will become even more relevant in the future. This also shows the transferability of the findings and results onto both conventional cars and vehicles with a hybrid drive train, as behavior alternation for a decreased energy consumption is also possible for these types of cars. With the utilization of similar systems in cars with different drive trains also allows people to change between mobility concepts with reduced adjustment difficulties as they can expect to find systems they are already used to.

Solution approaches for some of the described limitations are possible, especially for the methodical and technical limitations. Future researches and experiments can use a different user base and, due to the most likely increased number of e-vehicles on the streets in the future, also eliminate the influencing factor of unfamiliarity of the participants with e-mobility. While the legal restrictions cannot be altered, some technical limitations can be attenuated. Especially the use of fully integrated and decoupled measurement devices might prove useful to generate data that is less influenced by the act of measurement itself. As these limitations concern both the industry and possible future research projects, the following recommendations for them as a part of the outlook are separated into these two aspects, which are also located in two individual subchapters: recommendations for continued and further research for the same or similar topics in chapter 6.3.1 and proposed actions and recommendations for industry and commerce in the adjacent chapter 6.3.2.

6.3.1 Further research

There is a wide variety of aspects that a future research can cover to further analyze energy efficiency in combination with driver behavior. Continuing the sequence of the previous chapters and the general aim of the thesis, the first aspect for a continued research concerns smart device based applications. As the number of possibilities for information presentation is almost unlimited, the determination of the on average best way for this information distribution is an important goal of a future research. It should hereby follow the general guidelines for designing user interfaces, e.g. a fast response time, a self-explanatory layout and a uniform concept of operation.[54] In addition, not only the data analysis that is done by the app is important, but also the benefit the app has to offer the driver, as an app having its end in itself would not be used in real life situations. This research should also take the different impacts and repercussions of different types of applications into consideration and furthermore determine how drivers can be triggered to alter their behavior in the intended way on a psychological level. This aspect is strongly related with the aspect of linkage between mobile devices and e-vehicles. While the industry is developing and integrating their linkage systems, their focus is currently on a feature set of personal information and communication. The aspect of energy efficiency remains more or less unheeded. Therefore a study that compares different types of information presentation in combination with the linkage of mobile systems into vehicles might be able to determine the best possible solution to trigger as many drivers as possible in the intended way.

Other studies might be able to deepen the research of this experiment and hereby verify the findings. The main tasks for such an experiment are increasing the representativeness and the attaining of a descriptive character instead of an explorative one. These tasks can mostly be fulfilled by having a larger sample size, e.g. more drivers that take part it in. Such a larger experiment could utilize multiple vehicles and have several people driving them in parallel. To improve the results and simultaneously reduce the limitations of surrounding conditions one possibility would be to ask owners of electric vehicles to take part in such a research project with their own vehicles over a defined and longer period of time. This will become more achievable once e-mobility has gained a further reach and share of the mobility market. These drivers would only be needed to use the selected application while continuing with their normal and daily routine. For the results, the data of the drivers before and after the usage of said application could be compared. For the time being, this type of practical experiment exhibits one drawback:

[54] c.f. Guhr 2013

the mobile device and the application need to be able to run on their own, as a linkage between them and the various vehicles on the market cannot be ensured.

Other fields of further research include technical as well as infrastructural aspects. The technical research, e.g. quick charging functionality, mostly concerns the OEM and supplier industry and technical university institutes. The infrastructural research is a task for organizations and institutes focusing on logistical and production economic problems. The tasks for them are various, as the distribution and allocation of recharging stations will become much more important in the future and are two of the key aspects that have to be solved for alternative forms of mobility and drive trains to become the successor of the current fossil fuel based mobility. Furthermore aspects such as solar charging, inductive roads and the combination of several techniques for so-called solar powered roadways show a promising potential for a sustaining change of the face of mobility and traffic as it is today.

As can be seen, there is a wide variety of aspects and topics for both scientific research and for the research and development departments of OEMs, mobile device manufacturers [*MDM*] and application developers. Beside these research aspects some recommendations for industry and commerce shall be presented for them in the following chapter to improve the image, the accessibility and the acceptance of e-mobility.

6.3.2 Industry and commerce

The most important aspect for industry and commerce concerns the public awareness about e-mobility and e-cars. This includes the image of e-vehicles, their accessibility for people and therefore the experiences these people make with them. Due to the nature of this theses, the recommendations concentrate on the combination of e-mobility with smartphone applications, while several other aspects are also possible and most likely also required to achieve the set goals.

Some of these goals can be achieved through marketing actions. Especially the creation of boundary points is hereby of importance. As the research shows, many people are interested in experiencing e-mobility on their own but lack access to these vehicles. For these points several aspects are possible. The classic test drive procedure can be adapted to a program that is designed to let people drive these cars without having a purchase intention. Another way is car sharing. While car sharing in German cities grows and gains more and more customers and users, the introduction of e-vehicles into the car sharing fleets would allow these customers to experience e-mobility without any additional expenditures. Such an integration would also support the further research of the behavior of electric vehicle drivers, as several people would drive these cars and their driving data could be analyzed as long as their data security is guaranteed and they agree to such an anonymous analysis.

For the marketing aspects in the context of this thesis, OEMs should not only advertise the communication and multimedia aspects and features of cars and mobile devices, which mostly consists of social aspects such as social networking sites, but also move the aspect of energy efficiency into the foreground. Hereby it is possible to explain the benefits to potential customers, which include a safe and secure onboard data generation that is logged for an automated analysis that then delivers personalized suggestions that fit the individual's preferences and driving style and helps him to achieve these personal benefits without patronizing the driver.

The app development is a task for all three primarily affected industries, the OEMs, the mobile device manufacturers and the application developers. While OEM and MDM have to make sure their systems are connectable and can communicate with each other, the MDM has to provide the developers with the appropriate interfaces to use the sensors integrated into the device. The OEM can provide car-specific interfaces and software routines for both MDMs and application developers so an application can gain access to the OBC of the car. The developers themselves have to determine the best form of such an app based on the further research and ideally develop a unique app that is able to work with as many different cars and systems as possible to reduce the fragmentation of the new found market of energy efficiency applications. Another requirement would be the independence from one single mobile OS to gain a further reach and a larger potential user base.

The concepts MirrorLink and CarPlay are the first step in this direction, even though this fragmentation can already be seen as each concept is OS-dependent and works only with devices from the same manufacturer as the mobile operating system itself. However, a future development in the same direction might prove to be useful to not only change an individual's driving style, but also to reduce the general energy consumption on average and thus help to economize the use of limited natural resources.