A Behavioral Approach to Energy-efficient Driving

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Abstract: The increase of energy efficiency and reduction of greenhouse gas emissions have become important targets of EU initiatives. Energy efficient driving techniques can significantly reduce emissions, but practical solutions which are based on scientific findings are scarce. Since mobile apps are versatile in their functionality, characterized by a short time to market and low product development costs, this literature based study develops criteria for effectively supporting energy efficient driving using mobile applications and supports the findings using a proof-of-concept implementation.

Keywords: energy-efficient driving, eco-driving feedback

1 Introduction

The increase of energy efficiency and reduction of greenhouse gas emissions have become important targets of EU initiatives (European Commission 2014). Road transportation is a key source of worldwide CO_2 emissions (Fuglestvedt et al. 2008) and 90% of personal transport emissions are caused by private vehicles (Barkenbus 2010). Energy efficient driving techniques, or eco-driving, can realize energy savings up to 20% (Stillwater et al. 2012). Together with behavioral approaches, which are increasingly being used by governments (Cabinet Office 2012), these techniques represent a promising way to increase energy efficiency in the transport sector. Yet, practical solutions which are based on scientific findings are scarce. Since mobile apps are versatile in their functionality, characterized by a short time to market and low product development costs, they can represent a solution. The research question therefore is: How can a mobile application be designed to contribute effectively to energy-efficient driving?

2 Theoretical Background

This section provides background information on factors affecting vehicle consumption, techniques for energy efficient driving and existing feedback for eco-driving.

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2.1 Vehicle Energy Consumption Factors

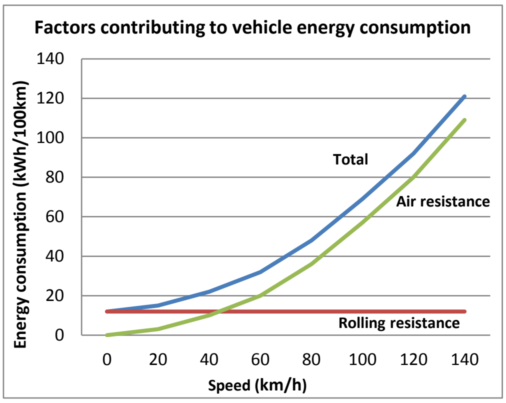


Figure 1 Physical factors accounting for energy consumption (MacKay 2008)

Eco-driving describes the adoption of driving styles and practices that reduce energy consumption and allow more efficient driving. To understand why and how eco-driving techniques can help reduce fuel consumption, it is helpful to take a look at the physics of driving: The main forces a vehicle has to overcome while driving at constant speed on a plane road are air resistance and rolling resistance. Rolling resistance is independent of speed, however the force required to overcome air resistance increases disproportionately with speed (MacKay 2008). illustrates the relationship between energy consumption and the vehicle's speed. Therefore driving at high speed should be avoided to increase energy efficiency (Young et al. 2011). Optimal speed has been determined to be between 60 and 80 km/h, as it optimizes the trade-off between overcoming rolling resistance of the car's tires and the rapidly increasing air resistance (Young et al. 2011).

High engine speeds (>3500 rotations per minute) which in most cases occur due to late gear changing from second to third gear (Ericsson 2001) and acceleration greatly impact a vehicle's energy consumption as well (Ericsson 2001; Birrell et al. 2014; Waters, Laker 1980). Waters, Laker 1980 demonstrated that the optimal acceleration rate was 0.7 m/s^2 while an increase in acceleration to 1.765 m/s^2 (corresponding to 0-100 km/h time of 15 seconds) already leads to an increase in energy consumption by 20%. Maintaining a constant speed is also essential: Speed oscillations during cruising of 5 km/h increase fuel use by 30% at 40 km/h and by 20% at 120 km/h (Waters, Laker 1980).

2.2 Eco-Driving Techniques

But what do these physical factors and driving parameters mean for drivers? To adopt a more efficient driving style, acceleration, top speed and engine rotations have to be minimized. This translates to the eco-driving techniques described in the following:

To limit acceleration, drivers should accelerate (and decelerate) smoothly and try to maintain steady speeds (European Environmental Agency 2011; Neumann et al. 2014). It is helpful to anticipate traffic flow in order to prevent having to brake suddenly (and consequently having to accelerate again) and to avoid complete stops (city driving). In addition coasting to a stop and engine braking are eco-driving techniques (Graving et al. 2010; Neumann et al. 2014).

Excessive high speed (e.g. on the freeway) also increases energy consumption disproportionately (European Environmental Agency 2011; Ericsson 2001) and should be avoided. High engine speed can be avoided by accelerating smoothly and by shifting to a higher gear as soon as possible (Boriboonsomsin et al. 2010; Ericsson 2001; Young et al. 2011).

Keeping the vehicle in good maintenance is also important to reduce fuel consumption. For example, frequently checking tire pressure is recommended, as too low tire pressure increases rolling resistance (Boriboonsomsin et al. 2010).

The eco-driving techniques identified in literature are summarized in Table 1**.**

All vehicles	
Moderate acceleration / avoiding strong acceleration	Boriboonsomsin et al. 2010, Neumann et al. 2014, Ericsson 2001, Young et al. 2011
Maintaining constant speed	Boriboonsomsin et al. 2010, Neumann et al. 2014, Young et al. 2011, Waters, Laker 1980
Avoiding high top speeds, obeying speed limits	European Environmental Agency 2011, Neumann et al. 2014, Young et al. 2011
Avoiding high engine power / shifting to high gear, no more than half throttle	Boriboonsomsin et al. 2010, Ericsson 2001, Young et al. 2011
Anticipatory driving style / anticipating traffic, keeping a suitable following distance	Boriboonsomsin et al. 2010, Young et al. 2011
Maintenance (e.g. proper tire pressure)	Boriboonsomsin et al. 2010, Neumann et al. 2014
Decelerating (braking) slowly, engine braking	Boriboonsomsin et al. 2010, Neumann et al. 2014, Young et al. 2011
Letting the car coast / roll, avoiding complete stops	Neumann et al. 2014, Graving et al. 2010, p. 4
Energy efficient route	Neumann et al. 2014
Minimizing payload	Neumann et al. 2014
Electric / hybrid vehicles	
Using regenerative braking	Neumann et al. 2014
Avoid auxiliary functions (e.g., air conditioning, radio)	Neumann et al. 2014

Table 1 Overview of eco-driving techniques

2.3 Eco-Driving Feedback

A range of eco-driving feedback technologies already exists and can be structured using the following dimensions: Feedback channel, feedback content, behavioral mechanisms, temporal aspect, hardware and the data sources employed (cf. Table 2).

Feedback channel refers to the medium through which feedback is given and includes visual, acoustic and haptic / sensory feedback: Visual displays were found to be effective for reducing energy consumption (Adell et al. 2008) and can animate drivers to experiment with the energy use and to build eco-driving skills (Graving et al. 2010). Acoustic feedback was found to be more effective than visual feedback in simulations, but is easily perceived as disturbing (Adell et al. 2008; Brookhuis, Waard 1999). Haptic feedback includes feedback given using the gas pedal, either through vibration or by stiffening the gas pedal which can communicate that a high amount of energy will be consumed. While haptic feedback reduces driver distraction and workload (Birrell et al. 2010), it is not favored by drivers and requires physical modifications to the vehicle (Adell et al. 2008).

The feedback information can be organized in the categories driving parameters (e.g. vehicle speed, engine speed (rpm), acceleration), environmental information, (e.g. CO_2 emission), financial information (cost savings) and gamification elements.

User interface elements that influence behavior include setting consumption goals (Stillwater, Kurani 2012) and gamification elements such as scoring systems, competitive elements, rankings, or achievement badges which rely on user motives such as striving for achievement or social recognition (Blohm, Leimeister 2013).

The dimension temporal aspect refers to the time when feedback information is given. Stillwater, Kurani 2012 found that instant performance feedback is used by drivers primarily for experimentation and learning of new eco-driving behaviors while average performance feedback is used primarily for goal-setting and goal achievement.

The dimension hardware refers to the physical components for administering feedback, while data sources refer to the feedback inputs.

Dimension	Values			
Feedback channel	Visual	Auditory	Sensory / haptic	
Feedback content	Driving parameters	Environmental information	Financial information	Gamification
Behavioral Elements	Goal setting	Gamification		
Temporal aspect	Before driving	During driving (real-time feedback or accumulated)	After driving	
Hardware	Vehicle built-in	Mobile Application		
Data source	Vehicle data	User input	Mobile device sensors	

Table 2 Multidimensional classification of eco-driving feedback

3 Research Method

To determine how an information system can be used effectively to increase energy efficiency in transportation, the design science research method was employed, backed by a literature and market research. The goal of design science research is „to create innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, management, and use of information systems can be effectively and efficiently accomplished“ (Hevner et al. 2004, p. 76).

A key criterion of design research is that its technology output must be a useful artifact. To be useful, an artifact has to be relevant to the practical problem it aims to solve. Relevance is „evaluated by utility provided to the organization and developers“ (Cole et al. 2005). Design research should contribute to theory, and not merely be successful in the market. An artifact should „pass both the tests of science and practice“ which means that it should „incorporate theory in the development of the artifact as well as make a theory-building contribution“ (Cole et al. 2005, p. 326). In addition to designing the artifact, researchers must rigorously demonstrate the „utility, quality, and efficacy of a design artifact“ (Hevner et al. 2004). Possible means to validate the artifact include descriptive / informed arguments which are based on existing literature.

Existing solutions were extensively researched to develop a useful and innovative artifact: On the one hand, scientific studies were examined to establish the state-of-the-art of research on the topic and to identify how a contribution can be made. On the other hand, a thorough market analysis, based on keyword searches of the Android and Apple App stores, was conducted to establish which functionalities are offered by apps available today. Both the literature findings and the results of the market research were used to develop the criteria for the solution to be developed and to create a prototypic implementation to validate the concept and prove that it is new and useful.

4 Eco-Driving Design Criteria and Prototypic Implementation

Based on the literature review in the fields of energy-efficient driving, behavioral mechanisms and persuasive technology, the criteria for the development of an eco-driving app were derived. The market research was conducted to build on existing solutions and to avoid reinventing existing approaches. The criteria identified are summarized in Table 3. The main criteria were implemented in a prototype to demonstrate and validate the findings, as illustrated in Figure 2.

Criterion	Source	How it can be implemented (derived)	Proto-type
High context feedback	Tulusan et al. 2012; Bartusch 2011; McCalley, Midden 2002	Provide immediate feedback to convey the connection between driving behaviors and energy consumption impact.	x
Goal setting	Loock et al. 2013; Stillwater, Kurani 2012	Let the driver define their own consumption goals to increase energy savings.	x
Avoid information overload, post trip feedback	Young et al. 2011; Meschtscherjakov et al. 2009	Limit user interface elements shown during driving and display more complex consumption statistics after the trip.	x
Efficient driving information	Stillwater, Kurani 2014	Provide background information explaining what techniques save energy.	x
Game design / gamification	Market research, Blohm, Leimeister 2013	Employ proven game design elements, including scoring, ranking and benefitting from user playfulness.	x
Social pressure / normative feedback	Market research, Loock et al. 2013	Compare energy saving performance to other drivers.	
Adapting to driver motivation	Stillwater, Kurani 2014	Provide feedback type that corresponds to the driver's reason for driving efficiently.	
Range increase	Franke, Krems 2013	Increase awareness of eco-driving as a way to increase the range of electric vehicles.	x
Support electric vehicle use	Neumann et al. 2014	Driving logs and simulations to alleviate range anxiety, create transparency about range requirements, recommend ideal electric vehicle models, and suggest behavioral adaptations for electric vehicle use.	x

Table 3 Design criteria for fostering energy-efficient driving

The criteria are described in the following:

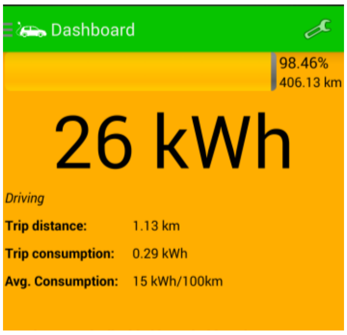
High context feedback

Feedback is most effective when it is highly contextual (Tulusan et al. 2012), for example when given in real-time. Feedback at a later time, such as in an interview or on a website, lacks the context that immediate feedback can provide. Momentary energy consumption feedback helps build up understanding of how driving affects energy consumption (Stillwater, Kurani 2012). Real-time acceleration feedback has been employed and found to be effective (Adell et al. 2008). Real-time feedback should not be given merely in abstract numbers in order to be easily understood. Ambient displays are suitable for feedback devices, as they convey information at a single glance (Kappel, Grechenig 2009) or are perceivable in the driver‘s peripheral vision to minimize driver distraction (Tulusan et al. 2011).

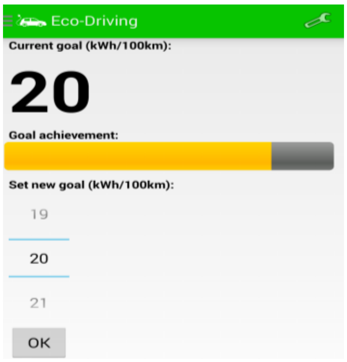
The prototype provides real-time feedback in the form of instant and average energy consumption and color-coded acceleration feedback (green / orange / red) which can be interpreted by the driver while keeping the eyes on the road.

Goal setting

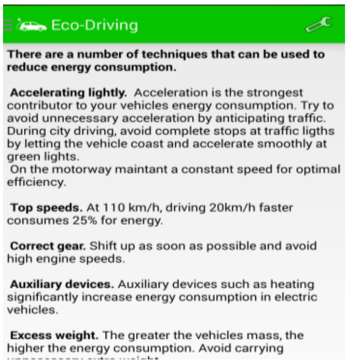
Letting user set goals has been found to be highly effective in influencing user behavior (Loock et al. 2013). Setting goals creates an anchoring effect – „arbitrary values placed in relation to information of interest influence user's understanding of what values may be considered high or low“ (Stillwater, Kurani 2012).



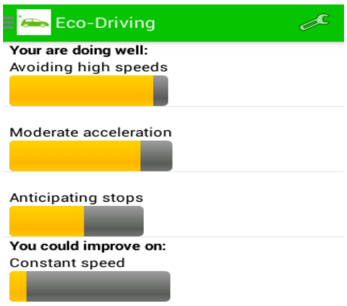
High context feedback / Avoid information overload



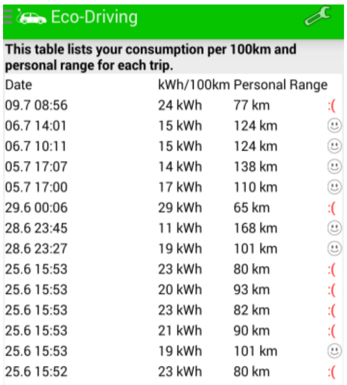
Goal-setting



Efficient driving information



Game design / gamification



Range increase / post trip feedback

Support electric vehicle use

Figure 2 Selected features of the prototypic implementation

The power of default goals that is shown to users should not be underestimated: Stillwater, Kurani 2012 found that a significant amount of drivers accepted the default goal and nonetheless responded strongly to it. The default goal that is shown to users should be designed with great care, as it has a substantial effect on the goal attainment.

The prototype allows setting one's goals and tracking goal achievement over time to motivate users to improve their eco-driving skills.

Avoid driver overload, post trip feedback

Although high context feedback is very effective, live feedback can cause driver distraction and information overload (Young et al. 2011), high risk levels (Meschtscherjakov et al. 2009) and the feedback mechanism to be rejected and ignored by users (Lee et al. 2010). Consequently, feedback interfaces should be visually designed to minimize driver workload and display more complex information after the trip. User studies show that clear visual feedback characteristics include good visibility, positioning and size, unobtrusive interfaces and convey clear and contextual information (Tulusan et al. 2012). More complex feedback should be displayed after the trip, also because users demand detailed information (Lee et al. 2010).

The prototype displays trip consumption averages, realizable range and progress towards goal achievement after the trip, while instant feedback focuses on simplified acceleration and current energy consumption.

Efficient driving information

Many drivers do not actively know how to change their driving style to be more efficient and ecological (Stillwater, Kurani 2014). Adding general information on eco-driving techniques can meet drivers' needs for information on how to improve their driving style (Stillwater, Kurani 2012).

Game design / gamification

Gamification uses elements originating in computer games, which are used to engage the user, e.g. to change their behavior in a desirable way (Blohm, Leimeister 2013). Examples of game mechanics include rewards for players who achieve desired targets or rankings and points that let players compete against each other. Eco-driving applications were found in the market research to extensively employ gamification elements.

The prototype employs gamification by visualizing user performance through progress bars which incentivizes users to achieve 100% by improving each eco-driving technique.

Social pressure, normative feedback

Normative feedback compares user's performance to other users and can have a powerful effect. Normative feedback can be employed in combination with goal setting, where goals inform users about the potential savings that can be achieved (Loock et al. 2013).

Adapting to driver motivation

Literature suggests that the best feedback type depends on the driver's motivation and should be adapted to it (Stillwater, Kurani 2014): Motivation for eco-driving can range from ecological reasons, financial reasons to political reasons (e.g. independence from oil), but there are also drivers who simply practice "hypermiling" for fun and to compare themselves with others.

Support electric vehicle use

Electric vehicles are an important component of energy-efficient driving, as electric vehicles are more efficient than internal combustion vehicles and driving efficiency is an enabler for electric vehicles due to the limited energy supply available to the driver. In addition, eco-driving has a positive effect on the attractiveness of electric vehicles which suffer from lower ranges: Since energy-efficient driving increases the distance that can be driven electrically, it reduces required battery capacity and consequently reduces vehicle purchasing costs. The market research revealed that there is a lack of applications promoting both energy efficient driving and the use of electric vehicles.

Being able to adapt one's driving style to use less energy in case it is needed creates range confidence, rather than range anxiety (Franke et al. 2012) which increases the attractiveness of electric vehicles.

The prototype supports electric vehicle use by creating transparency about the driver's individual range requirements and helps to understand that a lower battery capacity is sufficient for the majority of trips. This allows the driver to choose a more affordable vehicle which increases the attractiveness of electric vehicles.

Furthermore, a suitable electric vehicle is suggested based on the individual driving style and habits. Behavioral adaptations (driving more efficiently, avoiding long trips using the electric vehicle) are suggested which render electric vehicles more feasible.

Range increase

The advantageous effect of eco-driving can be presented in the context of increased range: Drivers benefit from the concrete advantage of having a greater range, which is especially relevant for electric vehicles. This addresses the issue that saving is usually not accompanied by a perceivable immediate benefit.

The prototype uses range to promote eco-driving by showing drivers their consumption and personal range for each trip.

5 Discussion

Based on a thorough evaluation of literature and available technology on the market, a comprehensive concept for a mobile application to support eco-driving was created and supported by a prototypic proof-of-concept implementation.

Contribution for science and practice

The value for science is the systematic identification of design criteria for fostering energy efficient driving using a mobile application. Further research can build on this criteria catalogue to determine empirically which criteria have the greatest impact on energy efficiency.

Additionally, it was found that a combined approach of fostering driving efficiency and electric vehicle use is highly sensible due to the effects of energy efficiency on range and electric vehicle attractiveness and vice versa. The combined approach is demonstrated in the fully functional prototype.

This possesses a high value for practice, since the market research revealed that solutions encompassing both aspects of energy efficiency and electric vehicle adoption have not yet been marketed. These solutions may be especially relevant for car manufacturers and utilities, as both have an interest in increasing energy efficiency and developing the electric vehicle market.

For practitioners and designers of similar apps this study provides concrete design and user-interface guidelines that were derived from an analysis of the user interface and behavioral elements described in literature and used in current applications. App designers and developers can build on these findings to create applications to effectively influence user behavior. These findings are not limited to electric vehicles, but can be applied to other areas as well.

Limitations

There are however limitations to the research conducted, including the lack of user experiments and possible side effects of eco-driving feedback.

The process which led to the application design, including literature and market research, was well documented. However this does not fully prove the effectiveness of the prototype. In a further step, the prototype can be tested to determine how each design criterion influences driving efficiency.

In addition eco-driving feedback can have negative side effects which have to be further examined empirically. Literature describes cases where more energy intensive behavior was caused by speed limit feedback (Brookhuis, Waard 1999) and financial feedback (Stillwater, Kurani 2012). Similar side-effects may occur in the application developed.

Future Research

In future studies the design criteria could be tested in user experiments to determine the quantified impact of each criterion on behavioral changes. Behavioral elements related to gamification and social comparison could be taken into account as well. Furthermore, the identified link between eco-driving and electric vehicles could be analyzed from an integrated perspective to determine the feasibility of promoting electric vehicle adoption using a mobile application.

6 Conclusion

The study developed a catalogue of scientifically grounded design criteria for a mobile app that supports energy efficient driving. The catalogue includes high context feedback, goal setting, electric vehicle use and social pressure. The benefits of assessing driving efficiency in the context of electric mobility were shown: Energy efficiency can successfully be increased when using hybrid and full electric vehicles. At the same time, these vehicles are most attractive when driving efficiently. An implementation of design criteria was demonstrated in a prototype implementation.

The systematic literature based assessment of design criteria can be the basis for further research on the relative impact of the criteria. The results possess a high value for practice as well, such as for vehicle manufacturers and utilities, since the research revealed that mobile solutions encompassing both aspects of energy efficiency and electric vehicle adoption are very promising, but have not yet been marketed.

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