Measurement Model for the Construct “Eco-Driving”: A Mockup for Real-Time Eco-Feedback

Completed Research

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Abstract

A large number of studies have dealt with eco-driving, have defined rules, and have provided eco-feedback to make drivers aware of energy efficiency. However, the found rules are vague, and eco-feedback neither refers nor recommends an action to increase fuel efficiency concerning all aspects of eco-driving. Hence, we analyzed concepts of eco-driving to develop a measurement model for eco-driving contributing to an understanding of the interplay between Green IS and eco-driving. Conducting (1) a literature review, we identified six components of eco-driving, (2) synthesized a descriptive measurement model for eco-driving disclosing dependencies between these components, (3) evaluated the model by expert interviews, and (4) implemented the model through a mockup of an eco-feedback dashboard. This article provides an overview and discloses the dependencies of components measuring eco-driving. Researchers can use the findings for evaluating designs of eco-feedback. Practitioners can implement eco-feedback systems in detail for user performance on fuel consumption.

Keywords

Measurement Model, Interplay Green IS and Eco-driving, Eco-driving, Mockup.

Introduction

The acceleration of environmental pollution and climate change attracts the interest of Information Systems (IS) research; for example, IS can help to reduce pollution through the maximization of the energy efficiency of cars (Loock et al. 2013; Watson et al. 2010). However, besides engineering, the energy efficiency of cars is based on an energy-efficient driving style. Therefore, several studies reveal the human driving behavior itself as a significant impact on energy consumption (Evans 1979; McIlroy et al. 2013). Already in 1979, Evans illustrates that a reduction of fuel consumption by up to 14% is possible in the event drivers follow instructions to lower acceleration levels and drive gently (Evans 1979). In addition, Gonder et al. (2012) evinced significant fuel changes through a reasonable change in the driving style. The optimization of all components of driving performance, including the elimination of unnecessary idling and stop-start maneuvers and the adjustment of acceleration rates and speed behaviors, can obtain fuel savings of up to 30% (Gonder et al. 2012). This full optimization is not achievable without Green IS, as the driver can save 5 – 20% in fuel by using an appropriate real-time eco-feedback Green IS solution such as dashboards (Gonder et al. 2012).

Feedback systems support drivers in complex situations with information regarding a change in the car or its environment (Donmez et al. 2007). For example, the systems support the driver with information about the energy consumption in order to drive energy-efficiently. In specific, avoiding insufficient braking can save up to 28% in energy (U.S. Environmental Protection Agency 2015). Hence, in previous findings from Evans (1979), an aggressive driver in a high-density traffic scenario needs 14% more energy compared to an energy-conscious driver by producing an energy zigzag consumption curve. This is due to accelerating and braking in a continuous manner vs. a smooth driving manner. Hence, it raises the question of how Green IS can contribute to the reduction of energy consumption (Loock et al. 2013; Watson et al. 2010). Previous research has developed rules and eco-feedback solutions (Beusen et al. 2009; Boriboonsomsin et
al. 2010; Jamson et al. 2015; Kaufmann-Hayoz et al. 2012; Wada et al. 2011), but the rules are vague or insufficient. In addition, they neither refer to nor recommend measurable action such as maintaining a steady speed by anticipating traffic flow to increase fuel efficiency to all aspects of eco-driving (Azzi et al. 2011; Barbé et al. 2007; Beusen et al. 2009; Boriboonsomsin et al. 2010; Jamson et al. 2015; Sivak and Schoetzle 2012).

To develop a valuable Green IS feedback solution, we have to consider how to illustrate unnecessary energy consumption. Unnecessary energy consumption is non-optimal energy usage. This feedback might enable drivers to change their behavior to a smooth driving style. Hence, to reduce the fuel consumption, the driver needs eco-driving rules to drive more energy efficiently (Ando and Nishihori 2011; Barkenbus 2010). Thereby, eco-driving is separated into ecological and economical driving; further being segregated into three levels: strategic, tactical and operational. On the strategic level, eco-driving consists of assuring regular vehicle maintenance, such as checking tire pressure regularly. The tactical level includes decisions such as the route selection. The operational level includes all decisions that the driver can make during the ride (Sivak & Schoetzle, 2012). This study focuses on the operational decisions of eco-driving; we aim to analyze measures for energy-conscious driving as preparation for experiments designed to evaluate the mockup solution. As a result, we pursue the research question: What measures are used for the design of valuable Green IS feedback solutions for energy-conscious driving?

**Methodology**

To construct a Green IS measurement model for eco-driving, we apply a four-step approach. In the first step, we used the paradigm from vom Brocke and Simons (2009) and conducted a forward and backward search according to Webster and Watson (2002). To identify relevant literature in the field of IS, Transportation Research (TR), and Human-Computer Interaction, we searched the databases EBSCOhost, IEEE Xplore and ACM Digital Library using the keywords eco*, energy efficient, and driving, as well as combinations of these words. We consider the journals TR Part C, TR Part D, and TR Part F and the “Senior Scholars’ Basket of Journals”. Moreover, we included conference articles on human-computer interaction (CHI, SIGCHI) and on automotive user interaction (AutomotiveUI). We rated the found articles as relevant by looking at the title, the abstract, and the keywords. In the second step, we identified components of eco-driving measures, followed by the use of the six components to verify the relevance of the articles. Finally, we selected 32 relevant articles. Based on the identified articles, we analyzed dependencies and interrelations between each component and synthesized our findings in a measurement model. In a third step, we validated the developed Green IS measurement model by interviewing experts in the fields of eco-driving, drive engineering, and automotive engineering. Thereby, we considered authors of reviewed literature, academics, automotive suppliers and car manufacturers. In this field of research, we found five interviewees who were willing to take part (one from the reviewed literature, four from mechanical engineering). For the interviews, we used a partially standardized and guided questionnaire that was divided in two (Bogner et al. 2014). During the interviews, we applied closed-form questions as well as open-ended questions to ask for improvement (Raab-Steiner and Benesch 2010). The experts were asked to answer the questions either with yes/no or with a seven-point unipolar Likert scale, where the one is the most negative option (Raab-Steiner and Benesch 2010). The interviews lasted between 31 and 73 (M = 46) minutes. We first asked questions before presenting the model to gain an unbiased impression and then showed the model to the experts to validate the presented groups of eco-driving measures and their dependencies. Afterwards, we evaluated the interviews using the point estimators’ arithmetic mean and variance. Because of the small sample size of five experts, we could not apply hypothetical tests (Bortz and Schuster 2010). However, the arithmetic mean takes the scores of all experts into account and shows the central tendency of their evaluation (Bortz and Schuster 2010). Additionally, we considered the variance to analyze whether experts’ opinions differ massively (Bortz and Schuster 2010). To evaluate the open questions, we coded the statements. In the last step, we developed a mockup of a Green IS real-time eco-feedback dashboard based on the validated model. This article results in a synthesized measurement model with identified components of eco-driving from the selected literature.

**Results**

Some identified eco-driving rules, such as shifting up as soon as possible (Beusen et al. 2009) or shifting down late are vague (Kaufmann-Hayoz et al. 2012), while other rules present more concrete measures, such
as calculating an optimal acceleration pedal angle and measuring the deviation from this angle (Jamson et al. 2015; Wada et al. 2011). Despite that, current eco-feedback solutions do not provide feedback on all components of the driving task. Furthermore, the solutions do not provide real-time guidance on how to change the components to increase energy efficiency. Thus, the drivers have to infer eco-friendly reactions to the feedback by themselves. For instance, eco-feedback mostly provides only guidance on speed and gear choice or simple fuel economy information (Boriboonsomsin et al. 2010; Jamson et al. 2015). To create a Green IS eco-driving solution, we analyzed previous concepts and components of eco-driving from literature. We enriched our findings by conducting expert interviews to composite an integrated and comprehensive Green IS model for eco-driving.

**Conceptualization and Components of Eco-Driving**

Based on our literature review, we conceptualized the findings to derive components that influence energy consumption by the driver during the trip. To identify these components, we used the six “golden rules” of eco-driving: (i) shifting up as soon as possible, (ii) using the highest gear possible and driving at low engine speed, (iii) shift down late, (iv) maintaining a steady speed by anticipating traffic flow, (v) accelerate swiftly, and (vi) decelerating smoothly while leaving the car in gear (Beusen et al. 2009; Kaufmann-Hayoz et al. 2012). As the identified rules are vague, in a second step, we conducted expert interviews resulting in six components describing (7) eco-driving: (1) anticipatory driving [environment], (2) engine speed, (3) gear, (4) speed, (5) acceleration, and (6) deceleration. Figure 1 illustrates the development process and how the components relate to the rules.

Creating the model and programming the mockup requires a basic understanding. Figure 1 illustrates the components related to (7) eco-driving. The components are (1) anticipatory driving, (2) gear shifting, (3) engine speed, (4) speed, (5) acceleration, and (6) deceleration split into engine braking, idling, and active. To ensure optimized Green IS energy consumption, we have to derive formulas that assume the current consumed energy deviates from the optimal amount (see Figure 1). We have to minimize the deviation $\Delta EC$ and determine $EC_{opt}$ to illustrate an energy-efficient driving style. Therefore, we look at each component in detail to minimize the delta of them.

**Figure 1. Development Process from Literature to Mockup.**

In the following, we name and analyze the Green IS feedback solutions incorporating these rules. **Anticipatory driving** is looking ahead as far as possible and anticipating future traffic to avoid unnecessary braking, accelerating, and gear-shifting maneuvers (Andrieu and Saint Pierre 2014; Kaufmann-Hayoz et al. 2012). The experts agree to the influence of anticipatory driving on energy consumption. First, the component anticipatory driving more reflects the driver’s behavior and attitude than the driving performance. Second, the measurement options for anticipatory driving are vague, and the measurement is not possible with a performance metric, contradicting the scope of our measurement model. We found no precise measurement to synthesize anticipatory driving impacts, leading to the dropping of this component from our model after expert validation.
**Speed**, meaning the instantaneous velocity of a vehicle, influences eco-driving and fuel consumption in general (Barth and Boriboonsomsin 2009; Saboohi and Farzaneh 2009), confirmed by both the literature review as well as the expert validation. Avoiding driving at high speeds leads to less used fuel (Evans 1979; Kircher et al. 2014), and an average reduction in speed saves energy (Helmbrecht et al. 2014). Driving too slowly can also have a negative impact on energy consumption. For example, energy can be saved by increasing average velocity, as speed is usually below the optimal speed range while driving inside city limits (Evans 1979). Fuel consumption is an inverted-U-shaped function of speed and of revolutions per minute (rpm, also rounds per minute) (Sivak and Schoettle 2012), being the best ratio between speed and fuel consumption, resulting in fuel efficiency.

Furthermore, the component speed includes the aspect steady speed driving. This driving style means driving at constant speed compared to a stop-and-go manner over a period of time to reduce fuel consumption (Ericsson 2001). The speed over time depends on the measurement of the variance of acceleration and deceleration.

The research thoroughly explored the measurement of the instantaneous speed of a vehicle. The component speed is measured using the current speed (Kircher et al. 2014) or provided by Global Positioning System (GPS) sensors (Beusen et al. 2009; Helmbrecht et al. 2014). As an example, Kircher et al. (2014) present a Green IS feedback in the dashboard and distinguish between the continuous and intermitted presentation of eco-driving information. Fuel-efficient velocities range from 50-70 km/h (Ericsson 2001) or 60-70 km/h (Hiraoka et al. 2009) in the highest gear, depending on the surroundings such as gearbox or car type. A specified tolerance range is necessary for displaying the corridors from Ericsson (2001) and Hiraoka et al. (2009). As an optimal speed to keep the driving speed constant and drive fluently, Andrieu and Saint Pierre (2014) suggest the legal speed limit.

**Gear Shifting** is an appropriately timed change of the gear to achieve eco-driving (Ericsson 2001; Jamson et al. 2015). Therefore, e.g., Ericsson (2001) presents driving patterns to present Green IS feedback. The gear depends mainly on the engine itself, or more specifically, the torque (Saboohi and Farzaneh 2009) and the gearbox. Using higher gears (Hiraoka et al. 2009) or the highest possible gear (Beusen et al. 2009; Saboohi and Farzaneh 2009) is recommended. Shifting gears up early (Kaufmann-Hayoz et al. 2012; Rakotonirainy et al. 2011), or as soon as possible (Beusen et al. 2009; Boriboonsomsin et al. 2010; Cho 2008; Saboohi and Farzaneh 2009), is suggested. Unlike shifting up early, shifting down should be done as late as possible (Kaufmann-Hayoz et al. 2012). From the expert interviews, we know it is better to have a gear selected rather than idle, i.e., rolling downhill, driving up to a red traffic light.

For the calculation of an optimal gear, we need the selected gear. We can calculate the gear with an analysis of the electronic engine data (Beusen et al. 2009). The experts said the optimal gear strongly relates to the optimal engine speed range. The inserted gear causes inefficient energy consumption (too low/too high).

**Engine Speed:** The reviewed literature and the interviewed experts agree on the correlation between gear and engine speed. The level of engine speed depends on the engaged gear and the motive of changing gears appropriately (Andrieu and Saint Pierre 2014; Barbé et al. 2007; Dogan et al. 2011; Ericsson 2001). The gear and the engine speed depend on the specific engine of the vehicle. The speed of the vehicle influences them (Ericsson 2001). The driver can handle the engine speed indirectly via gear changing. The equation from Barth and Boriboonsomsin (2009) does not consider the gear and depicts speed and acceleration as the influencing factors. This equation stems from physics and the construction of the automotive itself, such as the vehicle mass, the gravitational constant, the road grade angle, the rolling resistance coefficient, and the aerodynamic drag coefficient (Barth and Boriboonsomsin 2009).

The engine speed is measured in rpm (Beusen et al. 2009). The reviewed articles recommend operating the vehicle at low rpm instead of high rpm to decrease fuel consumption (Beusen et al. 2009; Hiraoka et al. 2009; Kaufmann-Hayoz et al. 2012; Magaña and Muñoz-Organero 2011).

In the literature, we found no general, vehicle-independent optimal engine speed (Azzi et al. 2011; Barbé et al. 2007; Beusen et al. 2009; Ericsson 2001; Jamson et al. 2015). However, the optimal engine speed is specific to the particular vehicle and the context of the study. The most frequently mentioned range lies between 2000 and 2500 rpm to show Green IS feedback (Andrieu and Saint Pierre 2014; Barkenbus 2010). The interviewed experts do not endorse engine speed as a control variable, but the equation from Barth and Boriboonsomsin (2009) results in an indicator for efficient driving. In principal, a higher engine speed results in higher fuel consumption. Understanding this fuel consumption while driving is an issue. To
design human-understandable eco-feedback, it is necessary to provide an understanding of why the driving style is not energy efficient.

To indicate an energy-efficient driving style, the engine speed alone is, in specific cases, no good indicator such as active braking while an inserted gear, or riding downhill with an inserted gear. Therefore, adding the information of an optimal speed and optimal acceleration is required. Further, engine speed is optimal in a range of a particular gear. Discrete values indicate three states: under optimal engine speed, optimal engine speed, and over optimal engine speed.

**Acceleration** is the most applied measure for eco-driving, and its influence on fuel consumption is undisputed among the experts (Bingham et al. 2012; Cho 2008; Ericsson 2001; Evans 1979; Helmbrecht et al. 2014; Jamson et al. 2015; Pace et al. 2007; Wada et al. 2011). Acceleration is an increasing change in velocity of a particular speed A to a specific speed B, e.g., from 0 to 50 km/h, and is the deviation of speed over time.

Regarding optimal acceleration, moderate usage of the accelerator pedal is recommended to accelerate smoothly and not too quickly (Barkenbus 2010; Barth and Boriboonsomsin 2009; Boriboonsomsin et al. 2010; Cho 2008; Helmbrecht et al. 2014; Neumann et al. 2015; Saboohi and Farzaneh 2009). Evans (1979) shows that moderate usage of the accelerator pedal can reduce fuel consumption by about 15%.

The most common variant to measure the acceleration is the angle of the accelerator pedal and presenting feedback on this (Azzi et al. 2011; Beusen et al. 2009; Dogan et al. 2011; Ford Motor Company 2016; Jamson et al. 2015; Wada et al. 2011). Jamson et al. (2015) recommend an optimum pedal angle of 7% while driving with constant speed and 23% for the acceleration phase. The pedal angle is 100% if the accelerator pedal is fully depressed. To aid the driver with eco-feedback to choose the right pedal angle, a signal on the dashboard is shown to present Green IS feedback. The signal is a green symbol and stands for a pedal error of ±1% (proper pedal pressure). Furthermore, a blue or red symbol stands for a pedal error of more than -6% (insufficient pedal pressure), or +6% (too much pedal pressure), respectively (Jamson et al. 2015).

**Deceleration** decreases the velocity of an individual speed C to a specific speed D, e.g., from 60 to 30 km/h. We identify two types of deceleration: (i) active and (ii) passive. Active decelerating is depressing the brake pedal. Passive decelerating is slowing down without using the brake pedal while releasing the accelerator pedal and running the car in idle mode (idling) or leaving the car in gear (engine braking) (Beusen et al. 2009; Hiraoka et al. 2009; Kircher et al. 2014).

Decelerating smoothly and avoiding harsh braking is the recommendation for drivers to reduce fuel consumption (Andrieu and Saint Pierre 2014; Beusen et al. 2009; Boriboonsomsin et al. 2010; Cho 2008; Helmbrecht et al. 2014; Jamson et al. 2015). Smooth deceleration can be achieved by passively decelerating (Ando and Nishihori 2011; Andrieu and Saint Pierre 2014; Beusen et al. 2009; Hiraoka et al. 2009). Active decelerating should be avoided since braking causes unnecessary energy consumption (Ericsson 2001; Kircher et al. 2014; Saboohi and Farzaneh 2009). Moreover, deceleration influences energy consumption in such a way that using the engine brake or the brake pedal too early results in stopping too early, which results in the necessity to accelerate again. Thereby, additional energy is consumed.

Like acceleration, the pedal angle could measure deceleration. To measure active decelerating, the angle of the brake pedal measures the pressure as a percentage (Dogan et al. 2011). Recording whether the accelerator and brake pedal angles are zero and if the gear is in idle mode (idling) or not (engine braking) could measure passive deceleration. However, external factors independent of the driver’s choice can cause the necessity for braking. Therefore, determining optimal deceleration and providing real-time feedback on efficient deceleration is hard to implement. To avoid accidents and make optimal use of engine braking, it needs additional information about the environment. Kircher et al. (2014), for example, present a coasting guide as Green IS feedback, which shows the elevation profile of the road and illustrates to the driver when to release the gas pedal and make use of the engine brake. Most studies only provide indicators that consider the entire trip and are calculated afterwards. Subsequently, these measures are not suitable for providing real-time guidance on decelerating.

**Evaluated Measurement Model and Development Mockup**

We synthesize the five considered components to develop a measurement model for eco-driving. We distinguish between driver-dependent components and engine-dependent components. The driver can
influence the driver-dependent components speed, gear shifting, acceleration, and during the trip. However, the environment limits the scope of the driver’s decision-making. The decision regarding absolute velocity or braking usually does not depend on the driver’s choice, but only on the environment such as traffic density, weather conditions, and speed limits. The engine-dependent components engine speed and gear depend on the particular engine of the car. The driver can only indirectly steer these components. We consider gear shifting as a driver- and engine-dependent component because the driver can select a gear directly, but the engine speed determines his decision to avoid damage to the engine. Besides the driver-dependent components, the driver can influence the energy consumption through further components such as air conditioning, radio, or cruise control. However, these components are outside the scope of our research. Therefore, we conclude the identified components to a component other. The component other does not relate to the driving task but influences energy consumption. The analysis of energy consumption values from the deviations of the current and optimal consumption values for the driver-dependent components enables the provision of eco-feedback for eco-driving. Therefore, we can use the driver-dependent component values as proxies for eco-driving. Additionally, measuring the energy consumption from the driver-dependent components can be applied as a measure for eco-driving. Figure 2 illustrates the model for eco-driving, exposing all relevant components and their dependencies on each other. It depicts an indirect influence of the driver to the engine-dependent components.

Figure 2. Measurement Model for Eco-driving.

The originality of our solution is the integration of all presented components in one Green IS eco-driving solution, while previous solutions consider the components separately and not as an overall composition. Furthermore, mechanical engineering forms the basis for Green IS enabled concepts to implement modern dashboards. The dashboard allows drivers to reduce fuel consumption; to gather the information as to which component is used efficiently, inefficiently, or optimally; and to increase traffic safety by lowering the speed. In addition, within the field of Green IS, researchers can use the proposed concept as a basis for eco-feedback, e.g., communication among things such as car-to-x.

Applying the model, we use the five identified components to construct a Green IS dashboard mockup for providing real-time feedback on all aspects of eco-driving. This Green IS dashboard enables the driver to change his behavior and drive energy-efficiently. Figure 3 depicts the mockup of the dashboard. It gives information on the need to change the gear (arrow in the middle) as well as the quality of the actual speed (color at the inside of the speedometer) and acceleration (braking) for eco-driving (shoes in the middle).

We use color-codes to provide real-time visual feedback on the identified components, as suggested by Jamson et al. (2015): green means that the component currently ranges within an energy efficient bound. More importantly, the feedback points out both (i) a deviation of the current state from an energy-efficient state (all components) and (ii) how to react appropriately to drive energy-efficiently (gear shifting, acceleration, braking). This feedback guides the driver to keep these green components constant. The color red symbolizes that the current value of the component is above the energy-efficient value. It encourages the driver to decrease the value of this component, i.e., to slow down (speed), to shift down (gear), or to reduce the pressure on the accelerator pedal (acceleration) or the brake pedal (deceleration). Opposite the color red, the color blue symbolizes that the current value of the component is below the energy-efficient value. As the use of the accelerator and brake pedal are mutually exclusive, one of each is at least colored gray. Hence, the engine speed indicates a red color to protect the engine at too high of rpm.
Discussion

We identified five components that influence eco-driving, namely speed, acceleration, deceleration, gear shifting and engine speed. However, the driver cannot control all of them directly; which is why we grouped them into two components: driver-dependent and engine-dependent. The driver can only actively choose her/his action among the driver-dependent components speed, gear shifting, acceleration, and deceleration. He cannot decide flexibly upon the engine-dependent components engine speed and gear shifting. As an outcome of the interview, the driver cannot steer the component engine speed directly, but she/he can influence it by way of gear shifting or accelerating.

The results for the component gear shifting correlate well with the literature (Andrieu and Saint Pierre 2014; Barth and Boriboonsomsin 2009; Beusen et al. 2009; Dogan et al. 2011; Ericsson 2001), but the finding illustrates that it is an engine-dependent and driver-dependent component. The driver can steer the component gear shifting directly, though the particular engine limits her/his freedom to shift. The synthesized model focuses on vehicles with manual transmissions; it can be adapted for vehicles with an automatic transmission by dropping the component gear shifting.

The engine speed measures when to shift into a higher gear (Andrieu and Saint Pierre 2014; Beusen et al. 2009; Dogan et al. 2011). Therefore, measuring gear shifting and engine speed seems to be the same thing, and some interviewed experts deem the component engine speed redundant compared to gear shifting. In contrast to these earlier findings, we distinguish between the components gear shifting and engine speed. For example, driving downhill in a low gear results in high rpm and uses the engine brake. The signal to shift up or down shows the driver how to drive eco-friendly but not how he can achieve it. Such findings may result in more intuitive eco-feedback, such as gear shifting, than simply telling the driver to keep the engine speed at low rpm (Beusen et al. 2009; Hiraoka et al. 2009; Kaufmann-Hayoz et al. 2012; Magaña and Muñoz-Organero 2011). The mockup enables the driver to differ between the influencing components and to obtain accurate feedback as to why the gear is too low, i.e., too strong acceleration.

Many studies have reported similar results to measures engine speed for providing guidance on eco-driving (Andrieu and Saint Pierre 2014; Barth and Boriboonsomsin 2009; Beusen et al. 2009; Dogan et al. 2011; Ericsson 2001). In contrast to the results of the literature review, the interviewed experts do not deem engine speed as a universal control variable, but they consider it on par with the other components. Hence, we keep the engine speed as an indicator for eco-driving.

We put the component speed in front of the other driver-dependent components, especially in front of accelerating and decelerating. Both are consequences of the driver's decision on the instantaneous velocity. In most cases, the driver cannot decide freely about the instantaneous speed of the vehicle. The environment such as other vehicles, speed limits, or upcoming obstacles, e.g., traffic lights, determines this. The interviewed experts think in many cases that drivers do not have any other option but to brake to avoid an accident. We aim to guide the driver to avoid unnecessary braking (Neumann et al. 2015). The synthesized Green IS real-time eco-feedback dashboard enables the driver to change his driving style to an energy-efficient one, e.g., by using the engine brake instead of active braking.
The last point even raises the questions of what an energy efficient speed and energy efficient braking are and whether they could be achieved in reality at all. As fuel consumption is an inverted-U-shaped function of speed and rpm (Sivak and Schoettle 2012), studies specify speed ranges (Ericsson 2001; Hiraoka et al. 2009) as fuel efficient velocities. We extend these findings (Ericsson 2001; Hiraoka et al. 2009) through the color-coding, which makes it possible to have more than one specific range. The coding enables drivers to drive in flow with the traffic depending on the context such as urban, rural, or highway. For example, driving on the highway (speed limit 120 km/h) with a speed of 50 to 70 km/h (Hiraoka et al. 2009) may annoy other drivers. Driving 50 to 70 km/h in an urban section might be against the law. Consequently, energy could be saved by increasing average velocity in urban traffic or reducing average velocity on highways. However, it is not acceptable to guide the driver consistently within a specific range. Thus, future research in the field of Green IS can examine context-dependent eco-feedback with the mockup.

The component speed does not only contain the aspect of the absolute velocity level but the idea of guiding the driver to keep the speed constant to avoid unnecessary acceleration and braking maneuvers (Ericsson 2001). However, providing guidance on steady speed driving requires the knowledge of upcoming traffic events. The result correlates with the findings in the model from Ericsson (2001).

In contrast to real-time guidance on energy-efficient deceleration, measuring acceleration is well explored. It is mostly done by measuring the angle of the accelerator pedal (Jamson et al. 2015). We extend the findings from Jamson et al. (2015) and add similar feedback for the brake pedal. Therefore, we can avoid harsh braking, as suggested (Andrieu and Saint Pierre 2014; Beusen et al. 2009; Cho 2008; Helmbrecht et al. 2014). With the aid of the coasting guide from Kircher et al. (2014), the mockup from the Green IS eco-feedback dashboard enables drivers to release the brake pedal or to brake appropriately.

Real-time or anticipatory environmental information would be necessary to guide the driver. Most studies provide eco-feedback with consideration of the entire trip that is calculable after the trip (Andrieu and Saint Pierre 2014; Beusen et al. 2009) or after obtaining the gas pedal release distance and the brake pedal push distance (Dogan et al. 2011). There are concepts for known road parts (Kircher et al. 2014), but the collection of all influencing surroundings is not solved yet. Merely measuring the angle of the brake pedal (Dogan et al. 2011) can be used for real-time feedback, while our model illustrates harsh braking. Consequently, the model extends the findings from Andrieu and Saint Pierre (2014), Beusen et al. (2009), and Dogan et al. (2011) by illustrating to the driver in real-time feedback as to what is wrong and why.

The presented mockup might cause information overload. Therefore, our model applied color-coding from Jamson et al. (2015) to reduce the number of information elements. In contrast to the displays from Kircher et al. (2014), our mockup presents a less or an equal number of information elements. To give adequate eco-feedback, the driver needs information about unnecessary energy consumption to drive more energy efficiently, as illustrated in Figure 1 in the mockup (7). Therefore, only presenting energy consumption as an element of information is not suitable.

Ford applies a brake coach within the SmartGauge® (Ford Motor Company 2016); we extend this design with a color-coded design for gear shifting, speed and acceleration. In addition, Ford presents a growing tree for energy efficiency that is similar to the score of Skoda DriveGreen, however, it does not show the amount of energy consumption in detail. In contrast, our approach illustrates a more comprehensive Green IS design. This design enables the driver to change her/his behavior on a broader information basis.

The limitation of the model evaluation is the number of experts available for the interview. Despite every effort, it was not possible to gain more than five experts for an interview since experts are rare. One of these experts is from the found literature and lowers the validity. However, the other experts from the field of mechanical engineering have an overweight to get an adequate validation. Furthermore, all car manufacturers refused to share their knowledge and to participate in an expert interview. Therefore, the interviews are only academics experts. Further research is required to assess (i) whether the feedback is intuitively understood, (ii) whether it distracts the driver from her/his primary driving task, (iii) whether the engine speed is an indicator for eco-driving, and (iv) whether it accomplished its purpose of saving energy.

**Conclusion and Future Research**

We present a measurement model for the construct eco-driving, we identify the components of eco-driving and their corresponding measures, and we apply the findings in a mockup for an eco-feedback dashboard.
This article contributes to theory with a synthesized and validated measurement model and a mockup of a real-time eco-feedback dashboard. The model illustrates the interrelations and dependencies between the five components of eco-driving.

The mockup is a first implementation of the identified components of eco-driving and visualizes guidelines on an eco-feedback dashboard. It must be tested and validated whether it supports drivers in saving energy without distracting them too much. We plan to evaluate the mockup in a driving simulator experiment in further research. Our work extends the design of eco-feedback. Based on our model, researchers can evaluate different eco-feedback designs and the impact of the design on specific components. Furthermore, Green IS can apply these components in various contexts and study their significance. This fruitful model might support the usage of interaction channels that have an impact on energy efficiency and lower driver distraction. Also, future research is required to identify a general, vehicle-independent optimal engine speed. Practitioners can implement more specific eco-feedback systems for improved user experience and user performance. In addition, drivers can identify a more energy efficient behavior with the eco-feedback.

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