Towards the Design of Eco-Driving Feedback Information Systems – A Literature Review

André Dahlinger[1], Felix Wortmann[1]

[1] Universität St. Gallen, Institut für Technologiemanagement, andre.dahlinger@unisg.ch
[1] Universität St. Gallen, Institut für Technologiemanagement, felix.wortmann@unisg.ch

Abstract

Road transportation contributes to about 17% of worldwide CO_2-emissions, thereby accounting heavily for the still accelerating climate change. Eco-efficient driver behavior is a cost efficient, yet powerful means to significantly decrease emissions from road transportation. Using feedback IS in the car to support and promote drivers towards a less fuel consuming driving style has shown to be effective in a variety of studies. However, there are many ways for designing an eco-driving feedback IS (EDFIS). What is still missing is a general design theory for EDFIS. To fill this gap we conducted a systematic literature review that covers research on EDFIS of the IS community and beyond. A detailed set of evaluation criteria gives an overview of the status quo on EDFIS research that might serve as a basis of upcoming work towards the developments of an EDFIS design theory, thus leveraging the potential contribution of eco-driving behavior for future green transportation.

1 Introduction

As recent research reveals, accelerating climate change is mainly man made with CO_2-emissions being the most significant driver (IPCC 2014). In general, road transportation contributes to about 17% of worldwide CO_2-emissions (OECD 2010). Consequently, significant investments are being made into the improvement of automotive technology. The technical progress already led to a considerable worldwide increase in average fuel efficiency. Contemporary light-duty vehicles, for example, have nowadays an average fuel consumption which is more than 10% lower than in 2005 (GFEI 2014). However, advancing automotive technology is cost intensive. Also, the adoption of eco-efficiency means needs time. Only about 7% of our vehicles are replaced per year (Davis et al. 2008), so that e.g. the average U.S. car has been on the road for 11 years (USDT 2013). Hence, human driving behavior has been studied intensively as an additional driver for eco-efficiency. First of all, because it is known to have a very significant impact on fuel consumption (Barić et al., 2013). And second, because changing human driving behavior, e.g. through education, training or feedback is accompanied by exceptionally low costs compared to technology research and development (Auto Alliance 2014).

At the same time, researchers have started to study the potential of information systems (IS) to influence human actions and contribute to changes for more sustainable lifestyles, e.g. in the context of Green IS literature (Dedrick 2010; Watson et al. 2010; Flüchter and Wortmann 2014). IS have been proven to be high-scale and low-cost means of communication to apply psychological theories and enable large-scale feedback interventions to promote socially desirable behaviors (Loock et al. 2013; Flüchter and Wortmann 2014). In the context of eco-driving, in-vehicle IS have been leveraged for more than a decade to foster sustainable mobility on the basis of driving feedback (Barkenbus 2010). Today, pervasive usage of smartphones (Falaki et al. 2010) and connected cars (GSMA 2012) open up completely new possibilities for the development of IS-enabled eco-driving feedback interventions (Barkenbus 2010).

This research ultimately wants to help developing a design theory (Gregor and Jones 2007) that facilitates the design of eco-driving feedback information systems. Thus, the design science research paradigm (March and Smith 1995; Hevner et al. 2004) is leveraged. Specifically, our design theorizing is directed towards the specification of a comprehensive set of goal-oriented prescriptions (Giessmann and Legner 2013) on designing eco-driving feedback information systems. The goal-oriented prescriptions explain "why" and "how" (Baskerville and Pries-Heje 2010) to construct effective eco-driving feedback information systems (EDFIS). This literature review hopefully helps answering the following question (Levy and Ellis 2006): What are goal-oriented prescriptions on designing EDFIS? Therefore, this work has two objectives:

1. To provide an initial set of evaluation criteria that helps us to assess the current state-of-the-art of existing EDFIS.
2. To provide a literature review on the current state-of-the-art of existing EDFIS and their impact on fuel efficiency across different scientific communities.

In the following section we provide a short overview of the main theoretical characteristics of EDFIS (section2). We then specify the evaluation criteria for the following literature review. The search process is described in section 3. In section 4, we present results of the literature review. Finally, the results are discussed and the paper closes with a short conclusion.

2 Theoretical Background

2.1 Changing Driver Behavior with Feedback IS

There are three prominent methods for changing driver behavior towards a less fuel consuming driving style: (1) education, (2) training and (3) feedback (Wengraf 2012). (1) Education concerns the provision of static, general information on what to do in order to drive in an eco-efficient manner. (2) Typically, individuals practice this knowledge in short, laboratory training sessions (Mayhew et al. 1998). (3) Feedback is dynamic information provided to the driver reflecting her performance in a continuous way (Fogg 2003). In this research we focus on the feedback, as there is strong evidence that feedback is more effective than education and training (van der Voort et al. 2001; af Wahlberg 2007; Barkenbus 2010).

Feedback is especially useful in cases where information about the difference between actual and target performance as well as the means to reduce this difference are unknown or fuzzy (Hattie and Timperley 2007). When it comes to accelerating, breaking, managing speed and rpm as well as shifting gears, the target performance for each of these behaviors is mostly non-overt to the driver

(e.g. optimal way of acceleration, optimal speed). With IS this information can be computed precisely and presented in "real-time" to the driver with hardly any delay between behavior on the one side and feedback of performance and target on the other side (Kopetz 2011). However, there are several ergonomic aspects influencing the effectivity of feedback systems (Hattie and Timperley 2007). These include the way how feedback is designed visually (Davis 1989) and the frequency of information provision (Fischer 2008).

Moreover, feedback systems can be used to increase motivation by goal setting (Locke and Latham 1990; Stillwater and Kurani 2012; Loock et al. 2013). Even attitudes towards eco-behavior can be changed on the basis of feedback systems (Siero et al. 1989). Finally, feedback systems can also be used to provide external incentives to drivers (Stern 1999), such as badges (Bang et al. 2007) or comparisons to others (Loock et al. 2011). External incentives however, may lead to a crowding out of people's intrinsic motivation (Frey and Oberholzer-Gee 1997). This is important when looking at long-term effects of interventions (Flüchter and Wortmann 2014).

2.2 Evaluation Criteria

In line with prior work on feedback (Fischer 2008), study settings (Shadish et al. 2002) and eco-driving (Fogg 2003) we use the following evaluation criteria for our literature review:

1. *Publication source:* To provide a thorough and complete picture on the activity of different research communities in the domain of EDFIS, we selected publications from four research communities: (1) IS research, (2) Transportation Systems Research, (3) Ergonomics and (4) Ecology and Environment Science.
2. *Study-settings:* We evaluated several aspects of the corresponding study settings in respect to their main validity characteristics:
    a. Sample size: Sample size is an important driver of statistical inference power (Bortz and Schuster 2010).
    b. Duration of observation: Appropriate observation periods have to be chosen to demonstrate the sustainability of intervention effects (Shadish et al. 2002).
    c. Environment: Environment depicts whether driving behavior was measured in the field, on a predefined route or in a laboratory setting with a simulator. Laboratory settings usually have higher internal validity but face problems in external validity, while for field studies the opposite is true (Shadish et al. 2002).
    d. Type of use: It is well known, that private and professional usage of cars is characterized by different behavior (Tulusan et al. 2012) as e.g. fuel costs are often less relevant in a professional usage scenario.
3. *Feedback:* Feedback can differ in many ways. Key characteristics are (Fischer 2008):
    a. Type of information: As there are several means to increase fuel efficiency (see 2.1) a key question emerges: Which types of feedback information are most effective in the context of behavioral change?
    b. Information frequency: Studies in the field of eco-behavior indicate that real-time feedback is more powerful than "blockwise" ex-post feedback (Fischer 2008).

c. Information channel: There are many possible channels for providing a driver with relevant information. These channels should be evaluated in respect to distraction (Young and Regan 2007) as well as user experience (Hassenzahl et al. 2010).

d. Incentives: Another critical aspect in intervention studies is the way subjects are incentivized. Incentives are known to have a major influence on short-term as well as long-term user motivation and behavior (Frey and Oberholzer-Gee 1997).

4. *Effect:* Ultimately we want to depict the actual effectiveness of an EDFIS. Hence, we list the reported effects of the reviewed studies in terms of reduction of fuel emission.

3 Search Process

Following the guidelines proposed by Webster and Watson (2002), we started our literature search by including a set of top IS journals (Okoli and Schabram 2010; AIS 2011), namely the AI Magazine, Communications of the ACM, Decision Science, Decision Support Systems, European Journal of Information Systems, Information Systems Journal, Information Systems Research, Journal of Information Technology, Journal of Management Information Systems, Journal of Strategic Information Systems, Journal of the Association for Information Systems, MIS Quarterly and Management Science.

IS-supported eco-driving that leverages feedback mechanisms is a pretty young and scarcely investigated topic. Therefore, we chose a broad search strategy in order to include as much existing research as possible (vom Brocke et al. 2009). Our focus is on eco-driving, hence the title had to include one of the following expressions that covered different spelling styles and word-related expression (e.g., eco-driv*er*, eco-driv*en*, etc.): 'eco-driving', 'eco-drive', 'ecodriving', 'ecodrive'. In addition, one of the following words had to be found in the metadata (i.e. title, abstract, full text, notes, keywords, indexing terms): 'feedback', 'feed-back', 'gas', 'gasoline', 'fuel', 'CO_2'. That way we made sure contributions were included that, on the one hand, dealt with feedback but for some reason did not measure any kind of fuel consumption or emissions. On the other hand, we included contributions that investigated the relationship between eco-driving and fuel consumption or emissions, but did not explicitly mention working with feedback.

To our surprise the search revealed no relevant hit in the aforementioned IS-Journals. Hence we extended our range of possible research outlets using the IEEE Xplore library as well as in the transportation systems (TS) research community using the search engines TRID[1] and NTL[2] (Levy and Ellis 2006; vom Brocke et al. 2009). The IEEE Xplore library can be considered close to the IS community also including conference articles. The TS libraries where chosen due to their focus on transport and our subject, namely vehicles. TRID search revealed 105 hits, NTL provided 6 hits and with the IEEE Xplore library search tool we found 28 papers. All three libraries overlap in their journal coverage, resulting in a total of 119 unique hits. In a next step the 119 articles where validated on whether they fulfilled five criteria. The impact of an (1) IS-based feedback system (2) on fuel consumption (3) was empirically tested (4) in a close-to-realistic setting (i.e. minimum a

[1] TRID is a joint database for the Transportation Research Information Services (TRIS) database and OECD's Joint Transport Research Centre's International Transport Research Documentation (ITRD) database.
[2] The National Transportation Library (NTL) is a repository of the U.S. Department of Transportation.

professional driving simulator) (5) with at least one person involved (i.e. no autonomous solutions). The analysis revealed 13 articles that met the criteria.

An analysis of the 13 articles revealed further references not covered by the search engines (Levy and Ellis 2006). The references were checked towards meeting the aforementioned criteria. That way, another 12 articles were included. Not all of the latter articles meet scientific criteria but due to scarcity of research in the domain we did not want to withhold them. Yet, in Table 1 they are explicitly marked.

4 Results

Table 1 reveals that most published empirical work on EDFIS can be found within the TS research community (14 of 25). Less than a third of the articles were published within the IS outlets. The remaining four articles were published in the field of ergonomics (af Wahlberg 2007), alternative energy (Satou et al. 2010) or were not assigned to any scientific community due to a lack of scientific quality standards (Fleishman 2008; Enviance 2009).

Article	Academic Community	Study Settings				Feedback Settings				Fuel Reduction in %
		Sample Size	Duration of Observation	Environment	Type of Use	Type of Info	Info Frequency	Info Channel	Incentives	
(af Wahlberg 2007)	Ergo	350	365	field	prof	a	rt	nav	none	4
(Ando and Nishihori 2012)	TS	50	126	field	prof	a, s	at	nav	rec	4.3
(Barić et al. 2013)	TS	75	nr	field	nr	rpm, s, f, g	rt	nav	nr	32
(Barth and Boriboonsomsin 2009)	TS	2	nr	field	nr	s	rt	dash	none	13
(Boriboonsomsin et al. 2010)	TS	20	14	field	priv	nr	rt	nav	none	1-6
(Chou et al. 2012)	IS	1	1	field	priv	s	rt	app	none	7
(Ecker et al. 2011)	IS	36	nr	field	other	s	rt	dash	snf	2.2
(Enviance 2009)	NS	400	150	field	nr	nr	at	nr	rec	10
(Fleishman 2008)	NS	55	102	field	nr	a, s	rt	ledd	none	7-11
(Hiraoka et al. 2010)	TS	4	300	sim	priv	km/l	rt	dash	none	10
(Hiraoka et al. 2009)	TS	12	1	sim	priv	km/l	rt	dash	none	9
(Larsson and Ericsson 2009)	TS	20	42	field	nr	a	rt	ped-res	nr	0
(Lee et al. 2010)	IS	14	1	course	prof	nr	rt	dash	none	0
(Magana and Organero 2013)	IS	5	<1	course	prof	s, a, rpm	rt	app	game	8
(Martin et al. 2013)	TS	18	60	field	priv	a, CO_2	rt	nav	none	1.4
(Satou et al. 2010)	ECO	~150	180	field	nr	nr	at	obc	snf	18

(Smit et al. 2010)	TS	24	nr	course	nr	nr	rt	nr	none	0-10
(Stillwater and Kurani 2014)	TS	118	18	field	priv	A	rt	dash	none	2.7
(Stillwater and Kurani 2011)	TS	98	28-42	field	priv	nr	rt & at	obc	none	nr
(Strömberg and Karlsson 2014)	TS	54	21	field	prof	a, s	rt	dash	none	6.8
(Syed and Filev 2008)	IS	1	1	sim	nr	a	rt	nr	nr	10
(Tulusan et al. 2012)	IS	50	56	field	prof	a, s	rt	app	none	3.2
(Vagg et al. 2013)	IS / TS	15	14	field	prof	a, g	rt	extd	none	7.2
(van der Voort et al. 2001)	TS	12	2,5	sim	nr	a, s, g	rt	nav	nr	6
(van Hiep et al. 2013)	TS	22	nr	field	prof	a	rt	app	none	2-6

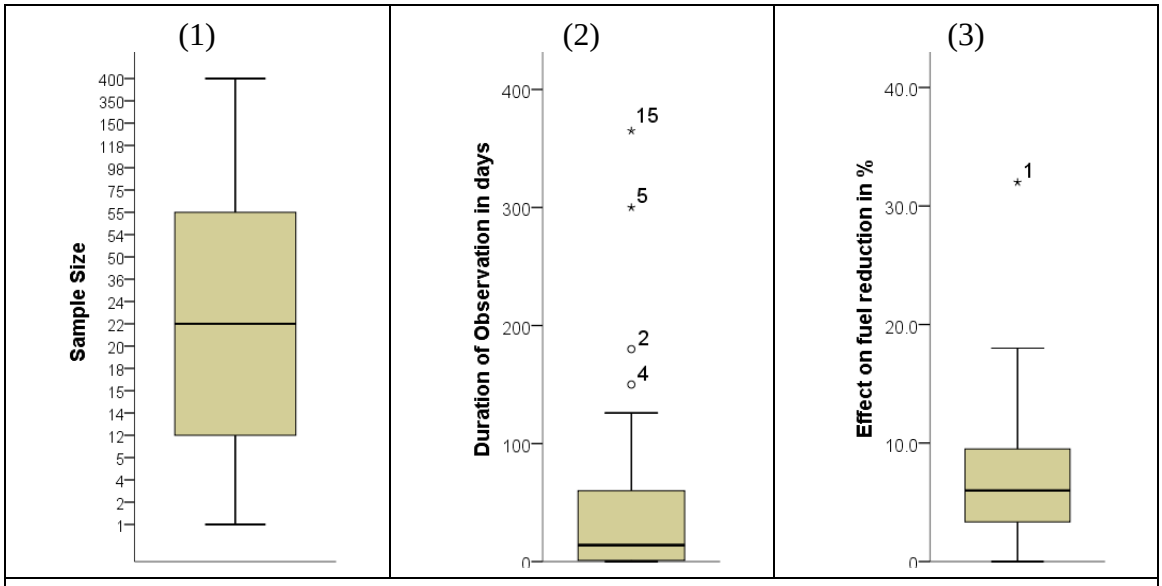
General: *nr = not reported*
Academic Community: *Ergo = Ergonomics; TS = Transportation Systems; IS = Information Systems; ECO = Ecology and Energy; NS = non-scientific*
Environment: *sim = simulator; course = predefined route*
Type of Use: *prof = professional; priv = private*
Type of Info: *a = acceleration; s = speed; rpm = revolutions per minute; g = gear-shifting; f = fuel consumption; CO_2 = carbon dioxide emission; km/l = kilometers per liter*
Info Frequency: *rt = real-time; at = after-trip*
Info Channel: *nav = similar to navigation system device; dash = displayed on the dashboard; app = smartphone app; ped-res = pedal resistance; extd = other external device; ledd = light-emitting diode device; obc = onboard computer*
Incentives: *rec = own record of driving skills; snf = social normative feedback; game = gamification rewards*
Effect: *a range (e.g. 0-10) implicates results in different circumstances, "nr" was a case of an electric vehicle* (Stillwater and Kurani 2011)

Table 1: Results of the Literature Review

In respect to study setting (sample size, duration time of observation, environment and type of use) most studies are based on a small sample size (see figure 1). 14 out of the 25 studies were conducted with a sample size smaller than 24 participants. In 14 cases, the period of measurement was less than 3 months. In six studies, this time period was exceeded with a maximum of one year (af Wahlberg 2007). Five articles did not report the time period. The experiments were mostly held in a field setting (19/25) where drivers could choose their driving routes. In two settings the routes were predefined (i.e. drivers had to stay on a "course"). The remaining experiments were performed within a car simulator. "Type of use" refers to the relation between the subjects and the vehicles used during testing. Own car usage (7/25) can be distinguished from professional care usage (8/25). This difference is important as one can assume that drivers in the private context have a bigger incentive to save fuel (they have to pay for it) while in the professional context these costs are usually covered by the employer (Tulusan et al. 2012). The results show that even without direct incentives in respect to saving money by consuming less fuel, EDFIS can affect driving behavior positively. Overall, the effects of an EDFIS on fuel consumption (figure 1) range from zero to an extreme of 32% (Barić et al. 2013), with three studies exceeding an improvement of 10%.

Feedback characteristics include the type of feedback information (acceleration, speed, etc.), feedback frequency (constant, after-trip), information channel and – if there has been one – the type

of incentives that were related to the performance of the driver. Unfortunately, six articles do not report what kind of feedback they provided. In the remaining 19 articles acceleration was included in at least twelve studies of which five were solely using acceleration as feedback information. Speed was the second most used feedback information (ten times) with three studies using it solely. In six studies other measures directly linked with the driving car where included (gear: 3x; rpm: 2x; cornering: 1x; throttle: 1x). Only in three cases feedback on fuel consumption itself was provided – two times solely. In respect to feedback channel different approaches could be observed. A very common one was to give feedback via the car's dashboard (7/25). Almost equally often external devices were used that are very similar to navigation systems (6/25). With the rise of smartphones and their technological improvements, smartphones are used especially in more recent research projects (4/25). Only one study worked with a tactile feedback system increasing resistance of the accelerator pedal in case the driver pushed the pedal to hard (Larsson and Ericsson 2009). Unfortunately some authors did not describe or depict their feedback solutions in sufficient detail, so that classification was impossible. Information about the incentive structure is reported rarely. Five feedback systems included a ranking and hence the possibility of comparison. Two of those provided the possibility to compare past scores to actual ones, the other three enabled a "competition" with other users. For the rest of the articles no incentives were depicted.



Note: *1* – (Barić et al. 2013) *; 2* – (Satou et al. 2010)*; 4* – (Enviance 2009)*; 5* – (Hiraoka et al. 2010)*; 15* – (af Wahlberg 2007)

Figure 1: Boxplots of (1) Sample Size (N=25), (2) Duration of Observation (N=20), (3) Fuel Reduction (N=24)

5 Summary and Discussion

In this literature review we present an initial set of EDFIS evaluation criteria and provide an overview of existing research on EDFIS. Finally, we now want to reflect our findings in respect to two questions: (1) What is the impact of existing EDFIS on fuel efficiency? Here, we also shed light on the methodological and reporting quality of the reviewed articles. (2) Are there already well-elaborated goal-oriented prescriptions for a design theory on EDFIS available?

In respect to the first question, we indeed realize that EDFIS most often lead to a less fuel-consuming driving style. We further observe a large range of effects, from no effect to a mesmerizing 32% (see table 1). Such a high variance could either be the result of methodological differences between the studies or differences in the design of the EFIS applied in the experiments.

Concerning the methodological quality of the reviewed articles, we discovered many shortcomings that limit the reliability of the reported results. Small sample sizes make the results prone to random effects (Shadish et al. 2002). Short observation periods raise the question whether the reported changes in behavior are sustainable. The reported methods often lack fundamental information, e.g. type of use often is not reported (see table 1). Overall, we found only three articles that met a minimal standard of methodological quality (af Wahlberg 2007; Stillwater and Kurani 2011; Tulusan et al. 2012). Accordingly, we would encourage improvements of research settings in future experiments in order to get reliable results other researchers can build upon.

Of special interest for the IS-research community is question two, i.e. how a feedback IS should be designed. Based on the depicted criteria, we derive the following conclusions:
Type of feedback information: Increasing fuel efficiency when driving can be achieved in many different ways. For each of these approaches, the driver has to be provided with appropriate information. However, in light of this potential variety, key questions remain unaddressed: Acceleration was by far the most used type of information (see Results), but is it really most effective? Are there certain combinations of information which outperform simpler feedback solutions? And using such a combination, what is the maximum amount of information drivers can process without exceeding a critical level of distraction (NHTSA 2012; Birrell and Fowkes 2014)?
Feedback frequency: The trade-off between efficacy of an EDFIS and its potential danger in terms of distraction also has to be considered when comparing real-time and after-trip feedback approaches. However considering power and convenience of real-time feedback, we propose not to neglect real-time feedback in future research simply because of distraction concerns.
Feedback channel: Most EDFIS in the reviewed articles used visual feedback. According to Tulusan et al. (2011) visual feedback is also most preferred by drivers. Unfortunately, visual distraction is the most dangerous for driver safety (NHTSA 2012). In addition, there are also feedback channels that are hardly investigated yet, e.g. haptic feedback. Larsson and Ericsson (2009) built an effective EDFIS with pedal resistance as a feedback channel. The current spread of wearables (PWC 2014) offers additional ways of haptic feedback such as rumbling smart watches.
Incentive systems: Last but not least, future work on EDFIS design and research should cover incentive systems that sustainably motivate people to drive eco efficiently. The effects of incentives on extrinsic and intrinsic motivation are manifold (Ryan and Deci 2000). IS might offer possibilities for using incentive structures that adjust in dependence of user characteristics such as personality traits (Komarraju et al. 2009). So far research on incentive systems has been very limited.

Generally, it is surprising how limited the contribution of the IS-community is in the field of eco-driving. The potential and demand for IS-based eco-driving solutions call for more attention from the IS-community. This literature review might serve as a first step towards the development of a general design theory for EDFIS that guides future developers of fuel saving feedback IS. That way we hope to help leveraging the potential of IS to enable a more sustainable use of transportation.

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