Direct or indirect sensor enabled eco-driving feedback: Which preference do corporate car drivers have?

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Abstract – **The increasing demand for energy is rapidly exhausting our planet's natural resources (e.g. fossil fuels). Corporations with increasingly large car fleets significantly contribute to the volume of CO_2 emissions released into the atmosphere. Further investigation is needed to help reduce this escalation in global warming utilizing eco-friendly yet cost effective measures. Internet of Things solutions, using sensor enabled feedback technologies with GPS and accelerometer, offer a medium which provides drivers with eco-driving feedback services. A field-test with 50 corporate car drivers demonstrated an overall improvement in fuel efficiency, supporting literature findings claiming that direct feedback has a greater impact on energy savings than indirect feedback approaches. In this study monetary incentives were irrelevant, as corporate car drivers fuel costs are reimbursed by the company. This provides an attractive opportunity for corporations looking to reduce their CO_2 footprint and petrol costs by offering their employees eco-driving applications at minimum costs.**

Keywords - sensor enabled eco-feedback technologies; GPS; accelerometer; fuel efficiency; corporate car drivers; services

I. INTRODUCTION

The personal transport contributes significantly to the overall release of greenhouse gases into the atmosphere; targeting this sector will prove to be most valuable in ensuring that an increase in energy consumption is sustained at a minimal level [1]. Where governmental legislations and in-vehicle technological advancements fall short, cost-effective education programs can empower drivers to adapt their driving style to embrace eco-friendly driving habits; this is known as eco-driving. Eco-driving is an economical way to improve drivers' fuel efficiency by teaching them driving techniques, such as anticipating traffic flow, eradicating aggressive driving, and shifting up to a higher gear as early as possible, which reduce their overall fuel consumption [2]. Recent studies in Europe within this field have shown an improvement from 5% to 15% in fuel efficiency once drivers have attended an eco-driving training program [3]. However, other studies uncovered a deterioration in fuel efficiency shortly after participating in training as drivers resorted back to their old driving habits [3].

The Information Communication and Technology (ICT) discipline, specifically in combination with Internet of Things (IoT) sensor enabled technologies such as smartphones, has the potential to support environmental sustainability, be it through improving individuals' awareness of ecological issues or by means of modifying current practices and patterns of human behavior [4][5]. [6] outlines three factors that impact the duration of a specific driving route: a) the geographical element of the route, b) the traffic flow on the route and, c) the user's driving behavior. A potential platform that can effectively modify the user's driving behavior and is built on the foundations of eco-driving concepts, is to promote eco-driving behavior with the utilization of mobile eco-feedback technologies. Technologies currently available on the market have integrated tracking sensors, such as GPS and accelerometer, and have the ability to improve users' awareness of their behavior to promote sustainable behaviors; e.g. pinpoint energy intense driving maneuvers [7] or tracking green transportation habits [4]. In a study by [2], conducted with 20 drivers, showed an improvement in participants' fuel efficiency of 1% on highways and 6% on city streets after partaking in an eco-driving training program and having access to a vehicle with an on-board feedback device, which provided them with instantaneous fuel consumption information.

Together with the advancements of sensor enabled feedback technologies, when and which type of feedback provided is important, especially during driving; e.g. the effectiveness of providing direct or indirect eco-feedback at the appropriate time without distracting the driver's attention away from road safety yet assisting them in adapting their driving behavior can be acclaimed, especially when aided by the advancements of modern technology [8]. In a relevant study conducted by [9] subjects demonstrated the ability to reduce their fuel consumption by up to 16% with the support of a prototype feedback device, which provided clear and concise advice on a screen without inflicting more work for the driver. On the contrary, [10] exposed a deterioration in fuel efficiency as drivers' task loads were increased as a consequence of using an eco-driving support system. Although both examples are limited to a simulation test environment, the significance of the evidence attained reveals the importance of providing the correct feedback can have in the field of promoting fuel efficiency.

Current studies aimed at exploring the potential improvement sensor enabled feedback technologies can have on fuel efficiency were conducted with private car - or truck drivers; few investigate the impact this technology has on corporate car drivers. Corporate car drivers (i.e. work-related driving) usually drive on average 21,500 miles per year compared with 8500 miles per year by private car drivers [11]. This reflects that corporate car users could embark on high fuel savings if they were to adopt eco-friendly driving styles, especially as new vehicles or in-vehicle technologies do not have to be purchased. However, corporate car drivers are often alleviated from the financial burden of running their car, as most companies reimburse their employee's fuel and maintenance costs; consequently, eco-driving will not reek financial benefits for them. Previous studies have shown an improvement of 1% to 16% in the overall fuel efficiency when delivered using sensor enabled feedback technologies to improve drivers' fuel efficiency [2][7][9][12], however, which eco-driving feedback type was the greater preference for corporate car drivers remains unexplored.

This study expands on the accepted paper at Ubicomp 2012 [7]. The paper investigated the overall effect an eco-driving smartphone application has on corporate car drivers' fuel efficiency. An improvement of 3.23% in participants' fuel efficiency (statistically significant with $P < 0.01$) was attained using an eco-driving smartphone application [7]. The opt-in field test was conducted with 50 corporate car drivers, which were assigned to either the Control Group (CG) or the Treatment Group (TG), over a duration of eight weeks. In addition to measuring what impact the application had on fuel efficiency, other aspects were also evaluated but not yet published. This paper therefore focuses on the preferred type of eco-driving feedback, i.e. real-time/ direct versus offline/ indirect feedback. Direct feedback provides immediate feedback during driving, whereas indirect feedback provides feedback at specified intervals or after the journey through other mediums such as online portals or email [13][14]. In this study, data were constantly collected and sent to a server from the eco-driving smartphone application after each journey; this made it possible for participants' feedback preference to be evaluated. Since the duration of direct or indirect feedback type usage was automatically collected in seconds once the application was activated, independent data were gathered without the need for participants to provide self-reports; this minimized potential flaws in data collection, such as reporter bias.

Results indicated that direct/ real-time feedback was more relevant than providing indirect feedback. Participants opted to use the real-time feedback in order to promote their ability to immediately implement improved driving strategies that are ecologically favorable. This supports existing findings in the literature that claim real-time and context related feedback have a greater impact on behavioral change towards energy reduction in comparison to providing indirect feedback [14] [39][40]. This study extends the literature in the field of sensor enabled eco-feedback technologies and that even under conditions whereby monetary incentives are irrelevant; direct feedback was preferred over indirect feedback.

The paper is structured as follows: the next section critical evaluates relevant literature in the field of sensor enabled feedback technologies and feedback types. After, the eco-driving smartphone application with the direct and indirect eco-driving feedback meter options is introduced, followed by the explanation of the research gap and hypothesis. The experimental setting explains the nature of the mixed-method research approach, and the discussion critical evaluates the findings with reference to existing literature. The final chapter outlines the limitations, future research and completes the paper with a conclusion.

II. Related Work

A. Sensor enabled eco-driving feedback technologies

Reference [15] defined the term 'Captology', which refers to ICT artifacts such as computers, websites, and information systems, combined with behavioral changing concepts. He classified persuasive technologies as "any interactive computing system designed to change people's attitudes or behaviors" [15]. When the system provides feedback and informs an individual or group about environmental aspects, this is referred from [5] to as 'eco-feedback technologies'. Eco-feedback technologies have the potential to bridge the gap between individuals' lack of environmental awareness and how their everyday behavior, such as driving to work, impacts on the environment; this is termed 'environmental literacy gap' [5]. Eco-feedback technologies have been successfully applied in the automotive industry, as studies have shown changes in driving behavior encompassing eco-friendly driving habits [2][10][12][16]. Within the minority of studies that reviewed on-board systems, a palpable link between financial benefits and individual's motivation to reduce their fuel consumption was highlighted [17]. For example, financial savings had a strong influence in motivating individuals to improve their fuel efficiency when fuel-efficient driving [19] or change in transportation modes (e.g. public transport where transportation passes were reimbursed) directed related to monetary savings [18]. In [16] pioneering study, they found improvement in fuel efficiency even though financial rewards were not offered. In a Postal Service company they provided instant feedback via an on-board system in delivery trucks to motivate postal-workers to drive more sustainably. An overall reduction in fuel consumption of 7.3% was achieved. However, further interventions such as class-room training, regular meetings, and management commitment to reduce the fuel consumption by 5% were applied. Hence, it is not exactly clear which type of feedback; direct feedback via the on-board system or offline feedback provided during class-room training or regular meetings, had the strongest impact [16].

Due to the recent emergence of mobile smartphone devices, several applications are available which use the phone's in-build sensor technologies, such as GPS and accelerometer, to measure driving behavior such as acceleration, braking, cornering and to show relevant feedback according to the context situation. These applications run on the iOS from Apple or Android operating system and examples are: BlissTrek, DriveGain, Fuel Saver, GoDriveGreen, EcoDriving from Axa insurance, EcoDrive, greenMeter, Green Driver, Green Gas Saver, and iEcoMeter. These eco-driving applications empower the driver by providing feedback and recommendations as to how they can drive in a more eco-friendly manner. Research findings in the field of sensor enabled eco-driving smartphone applications in comparison to other existing technologies such as on-board systems or in-vehicle technologies seem, at present, underutilized [5]. Reference [4] operated this type of mobile technology when recording the daily transportation behavior of participants, e.g. if the person used the bus or bike, which presented a positive outcome for a small sample group (n=13) and field test duration of only three weeks. Reference [21] suggested "a device is required that gives the driver immediate and accurate fuel consumption information, yet is not a distraction from safe driving". However, until recently, a limited sample of mobile eco-feedback devices have been pioneered for vehicles; in spite of the ongoing advancements in technology, a large percentage of feedback devices are utilized for hybrid or electrical vehicles as more ecological driving behavior extends the overall driving range of the battery run vehicle types [22].

With the promising results suggesting how sensor enabled mobile eco-feedback technologies support drivers, and growing interest from the industry and academia in this domain, further enquiry is required to address how and when the feedback should be displayed on such devices to offer useful services to improve fuel efficiency. These findings will provide a greater understanding of how eco-feedback interventions influence individuals' behavior, a perspective which was not thoroughly possible to attain in the past [5]. The types of feedback, eco-feedback devices can employ, are discussed in the following chapter.

B. Direct and Indirect Feedback Types

Feedback geared towards promoting sustainable driving can be presented using various mediums, such as: email, brochures, classroom training, driving simulator, videos, online portals or mobile devices. In relation to driving behavior, the fuel efficiency of cars is stated using a numerical value (e.g. 7.5 in liters per 100 km) in real-time or accumulated when reflecting average liters per 100 km on the car dashboard computer. It is important to consider when and what type of feedback is required to ensure the success of an eco-driving intervention. The transport sector report produced by the International Energy Agency analyzed the short-term and mid-term impact of eco-driving initiatives [3]. Immediately after eco-driving training average fuel efficiency improved between 5 – 15 %. Mid-term (<3 years), an improvement of approximately 5% was maintained without further feedback and, 10% with continuous feedback after the training (i.e. trip and driving style analysis). A five percent improvement in fuel efficiency can be sustained when using eco-driving in-car equipment or an on-board computer, which provides feedback on the fuel consumption, correct gear change, or cruise control function. [23] justified that feedback information generated from solitary data which is not considered within the correct context will bear no benefits at all. Direct feedback should not endanger driver's safety [8]. Distraction is a crucial factor which must be considered because it can lead to increased risk levels and even fuel efficiency [12]. Indirect feedback, on the other hand, can be proclaimed to be 'richer'. For instance, feedback presenting electricity consumption for households includes data reflecting the actual consumption shown on tables, graphs, charts, or scales [14]. In the following section, a list of feedback types relevant for this research will be introduced and should instill a fundamental understanding of how and when eco-driving feedback can be utilized.

Context-sensitive feedback is defined by [24] as "any information that can be used to characterize the situation of entities (e.g. person, place, or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves". Reference [25] used context-sensitive feedback with a sensor enabled logging device to remind individuals to appropriate driving techniques to reduce their stress and improve safety. Studies by [12][26][27] have demonstrated an impact on drivers' performance when providing feedback about their driving ability through a support system. Consequently, they found that the driving performance can be enhanced by providing feedback in relation to the specific context.

Direct or real-time feedback also known in the literature as 'just-in-time' feedback provides immediate feedback within a certain situation [15] and has been applied in various fields to motivate behavioral change, e.g. encourage seat belt use [28] and reduction of electricity consumption [14][30]. With the emergence of sensor-enabled mobile persuasive devices and their capabilities of collecting data through GPS and acceleration sensors, it is now possible to provide context-sensitive just-in-time feedback to drivers [5]. It highlights various driving habits, e.g. aggressive or smooth acceleration and braking, which is immediately illustrated through screen color changes, fuel or CO_2 emissions consumption scores or an odometer [5]. One must consider the vital notion of ensuring just-in-time feedback that does not compromise the safety of its user by increasing their cognitive workload and distracting their attention from the act of driving [8]. As driving conditions have the tendency to change rapidly, feedback can impede on the driver's ability to respond to the task demands and impair their task performance [25]. This must be taken into consideration when providing eco-driving real-time feedback to corporate car drivers. The impact that eco-driving this feedback has on fuel efficiency for participants who do not gain a financial advantage has yet to be evaluated.

Information required to provide *indirect feedback* is collected over a duration of time, which may range from several minutes to one or more driving cycles, affording drivers an insight into their general driving style and how this may evolve over time. It can be shown in different forms, e.g. in an accumulated form or offline [14]. *Accumulated feedback* can be imparted using either fuel consumption figures or using schematics, e.g. leaves growing [13]. The notion of rewards is conceptualized by accumulated feedback, as the more efficient the driver evolves the more advanced the figures or schemas become. Examples of systems that can be attributed to this category are Ford's SmartGauge [13] and Honda's EcoGuide [5]. A prototype sensor enabled mobile tool, evaluated by [4], illustrated that users were capable of positively perceiving accumulated feedback regarding green transportation practices. Acknowledgment can be given to the rewarding nature of advanced technologies that inspire users to adapt their behavior and continue to reduce their energy consumption [5]. *Offline feedback* is a decontextualized type of feedback; e.g. a detailed breakdown of driver's fuel consumption, CO_2 emissions, acceleration, braking, and gear shifting patterns is formulated once their general driving behavior is monitored and analyzed. Evidently, feedback is not provided during the act of driving and so can be combined with social networks, where challenges from within the online community could potentially improve behavior and enhance goal setting [29]. This feedback known as social normative feedback and was defined by [32] and applied to change environmental behavior contributing to littering, towel reuse [33], and energy consumption [34]. Fiat's eco:Drive is an example of where this type of feedback is used. Drivers are able to compare their own fuel efficiency with other peers on Fiat's eco:Drive online community.

Indirect feedback can also be provided prior to driving, as this category includes systems aimed at informing the driver about the planned route. This information is largely delivered in the form of navigation systems or internet websites through which multiple routes are presented to drivers regarding distance, travel time or fuel optimization. This enables drivers to make an informed decision about the best possible route to meets their situational demands.

In summary, sensor enabled feedback technologies were used to provide the technological foundation from which participants will receive feedback, either directly or indirectly. The feedback intervention type must be displayed so that obstruction is minimal, and that users are able to decipher relevant information easily using their peripheral vision without much effort or increased cognitive workload [12]. Motivating participants to improve their driving behavior will play a significant role in promoting fuel efficiency. When deliberated within the correct context, eco-feedback must correlate with drivers' personal beliefs and culture to influence them to modify their behavior [35]. Further research is required to attain a better understanding of when feedback should be delivered to promote sustainable driving. The following section looks into how the different feedback types were applied using the eco-driving smartphone application.

III. Overview of the Eco-Driving Smartphone Application

An eco-driving smartphone application called DriveGain [36], a product of DriveGain Ltd., UK, was used for the purpose of this study. After extensive evaluation of the aforementioned products, this application was chosen due to the quality of the feedback and the access to the data collected by the application from the drivers participating in the field test. The application provides different feedback types related to the eco-driving concepts, such as correct gear change during acceleration and braking, and most efficient average speed depending on the vehicle type. Similar feedback types were also tested by [9]; there, authors showed that drivers were able to reduce their fuel consumption by 16% when using the support tool. It is important to acknowledge that this test was confined to a driving simulator. Feedback types identified to reduce fuel consumption were: correct gear changing during acceleration and smooth acceleration. These feedback types were also implemented within the DriveGain application as illustrated in Fig. 1 and Fig. 2.

The top third of the interface screen illustrates: optimal gear change (recommended gear), journey score, and type of vehicle. Feedback meters are located in the central third of the screen and below this, functions to: activate music, reset the journey scores, upgrade with new feedback meters and settings of the application reside. Once the application has been started, the car type chosen and a GPS signal received, it will log and monitor the driving behavior.

The application has several feedback meter options which need to be downloaded and purchased separately related to acceleration, braking, CO_2 emissions, and costs. In this field test though indirect and direct feedback meter types were activated and provided feedback according to the driving context. The first known as 'Advanced Savings' (see Fig. 1) provides direct/ real-time feedback which combines acceleration & braking and the current vehicle speed. The aggressiveness or smooth acceleration and braking is also shown in an efficiency score that is calculated in a percentage value (100% being best). Additionally, the current speed is shown on a scale.

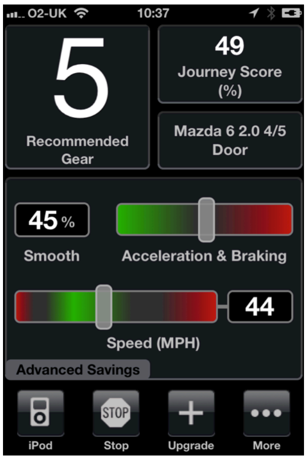

Figure 1. Avanced Savings Feedback Meter (direct feedback) [36]

The second meter, known as 'Fuel Savings' (see Fig. 2), provides indirect accumulated feedback in a three-minute interval of the average figures for acceleration, braking, and vehicle speed. Acceleration, braking, and vehicle speed is measured by the GPS receiver. All three feedback measurements are displayed on a scale categorized red to green (green being most ecological), as well as a numerical score from 0 (being least -) to 100 (representing most ecological).

Figure 2. Fuel Savings Feedback Meter (indirect feedback) [36]

The journey score visible on the top right corner of the screen, 0 (least) and 100 (most ecological), is calculated from data collected regarding acceleration, braking and speed values with respect to each car type. The recommended gear feature prompts drivers with a manual gearbox when to change gear. Only two gears, ‘P’ for parking and ‘N’ for driving, will be represented for cars with automatic gearboxes. Additionally, the following data relevant for this study are collected from the application: 1. Journey start and end location (measured by the GPS receiver); 2. When and duration application was used in seconds; 3. Distance travelled in meters per journey; 4. Duration each type of feedback meter was used in seconds; 5. Values for acceleration, braking and vehicle speed.

Besides the eco-driving information displayed on the application, additional data sets were recorded by the application and automatically transmitted to the company's server after each journey. This data were accessible on an online driving portal (ODP) (see Fig. 3).

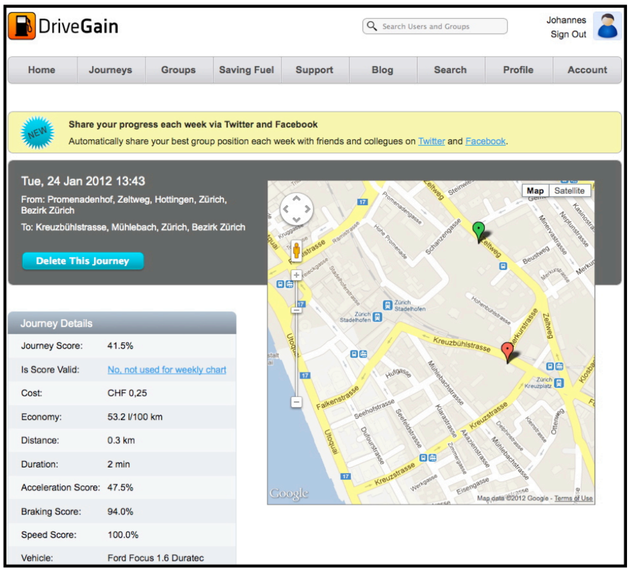

Figure 3. Detailed journey view shown in Online Driving Portal [36]

This information was ‘richer’ in detail, as the raw data were evaluated by an information system and made visible to the individual user on their ODP account. An overview cockpit summarized recent journeys driven, fuel usage, fuel efficiency, high speeds, and CO_2 emissions on the first page; further details were broken down on a dedicated sub-page for each section. This allowed appraisal of offline feedback during the experiment, as every driver had to register as a user to the ODP where they were then able to review their information after any driving episode.

IV. RESEARCH GAP AND HYPOTHESIS

The literate indicates a discrepancy about whether an eco-feedback technology is able to influence the driving behavior ecologically. Generally speaking, the approval of numerous in-vehicle feedback systems is largely reflected on in a positive manner [2][10][12][16]. Reference [12] highlighted that inflated risk levels can be induced by distraction through inappropriate feedback. This was further illustrated by [10] who found that drivers, as a result of amplified cognitive workload and stress levels, ignored feedback provided by a non-user-friendly design or a poorly positioned system on their dashboard during a field test. However, real-time and context related feedback is integral when promoting fuel efficiency of individuals during driving. Also, the ability to control the frequency of the feedback received has been proven to motivate users to change their behavior. This is known as “feedback control”; e.g. individuals are able to control the amount and timing of the feedback they receive [31]. The DriveGain application allows corporate car drivers to choose between different feedback types; e.g. ‘Advanced Savings’ with direct feedback, which presents real-time feedback concerning one’s actual driving style and, ‘Fuel Savings’ with a three-minute interval feedback that provides the feedback in an accumulated form. Therefore, hypothesis one was defined as: Corporate car drivers who use an eco-driving smartphone application use the real-time feedback for longer periods of time when compared to accumulated feedback, with $\mu 1$ representing average time in seconds regarding real-time feedback and $\mu 2$ representing average time in seconds of which accumulated feedback was used.

$$\text{(H1) } H_0 = \mu 1 \leq \mu 2;\ H_1 = \mu 1 > \mu 2.$$

Drivers were also able to review their eco-driving data offline, known as indirect feedback, and summarized in the ODP. Literature in the field of energy savings in households reflects that feedback related to energy consumption should also be provided immediately using a non-obstructive form [37][38]. This enables individuals to relate feedback directly to a specific behavior prompts an immediate response [14][39]. The importance of indirect feedback in relation to eco-driving is not clear and so hypothesis two was defined as: Corporate car drivers who use an eco-driving smartphone application prefer to receive feedback during driving in comparison to offline feedback provided via a ODP, with $\mu 1$ representing the preference of receiving feedback during driving through the smartphone application and $\mu 2$ representing the preference of receiving the feedback via a ODP.

$$\text{(H2) } H_0 = \mu_1 \leq \mu_2;\ H_1 = \mu_1 > \mu_2.$$

V. EXPERIMENTAL SETTING

From the previous paper [7] a within subject independent samples t-test which compared the average fuel efficiency between the CG and TG resulted in an improvement of 3.23% with a statistically significance ($P < 0.01$), in which the users in the TG used the eco-driving application for eight weeks from 10/24/2011 until 12/16/2011 (see Fig. 4 white boxes). For this study a mixed-method design approach was used through which quantitative and qualitative data were collected (see Fig. 4 grey boxes). Data recorded during driving, once the application has been started, was automatically transmitted from the smartphone to the DriveGain Ltd. server after each recorded route. The participant’s agreement to automatically transmit the collected data of each route was mandatory to participate in this field test. Thus, it made it possible to verify, without self-reporting errors, frequency-use of the application together with the duration each type of feedback meter was used by each driver.

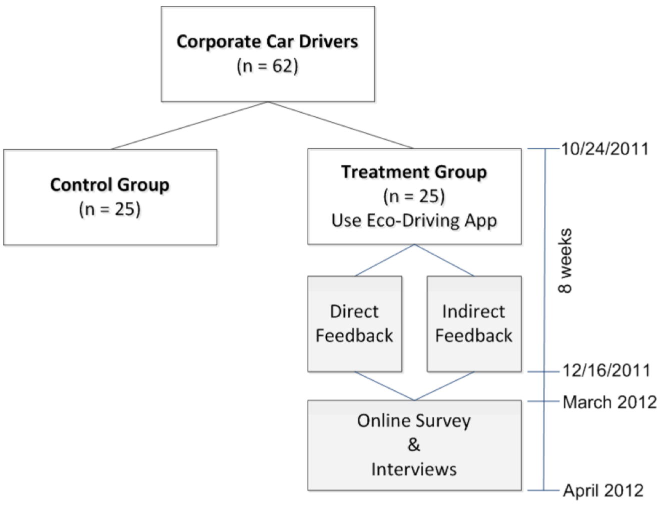

Figure 4. Experimental Design

After the field test, from March to April 2012, a 15-minute online post-survey that verified the usage of the application, improvements and environmental attitude was completed by 24 participants in the TG. Furthermore, 15 semi-structured interviews were conducted to support the quantitative findings through a more explorative understanding. Details about the relevance of feedback types, e.g. real-time vs. accumulated vs. offline feedback and the combination of a smartphone application with an ODP were further explored. Each interview lasted 20 minutes.

VI. RESULTS

The analyses of driver data sets, inclusive of 800 recorded journeys, were used to compare the variations in duration-use of direct versus indirect feedback. Qualitative interpretation of data collected via the online survey (24 answered from the total of 25 drivers) were evaluated in % (1% least preference to 100% highest preference) or on a scale from one to seven (1 = strongly disagree, 2 = disagree, 3 = partly disagree, 4 = neutral, 5 = partly agree, 6 = agree, 7 = strongly agree). Furthermore, 15 interviews to get a better qualitative understanding were analyzed following an axial coding process defined in the grounded theory to be able to compare the rich answers. Participants for this study were selected from one company's pool of drivers. As it was an opt-in field test, participants who chose to take part in the experiment may have already had a pro-environmental attitude or were technological affine, exposing a degree of bias in the sample selection. It was possible to control this aspect by analyzing their environmental beliefs and technological affinity using validated scales from energy saving literature in the post-survey. Findings indicated that drivers only had moderate (=partly agree) pro-environmental attitude (5.02 out of 7.0) as well technological affinity (5.1 out of 7.0); this reflects that results of this study should be possible to relate to other corporate car drivers with a similar environmental attitude and technological affinity. 96% of participants used their car every day or 5-6x per week and 92% drove on average more than 15,000 miles per year, which conforms with the corporate car drivers criteria [11].

Findings related to the two hypotheses defined are outlined accordingly:

(H1) The total time the application was used by all participants during the field test was 416 hours. Data collected revealed that the real-time feedback meter was used 85.11% (354 hours) of the time compared to the accumulated feedback with only 2.65% (11 hours). For the remaining 51 hours (12.24%) the application was suspended due to no GPS signal, e.g. driving through a tunnel, which is quite common in the country where the participants are living. A bivariate Pearson correlation coefficient was computed to identify the relationship between the total duration of application usage and duration of direct or indirect feedback type used. Findings showed a strong positive correlation with statistical significance ($P < 0.01$) between the total duration of application usage and usage of direct/ real-time feedback, $r = .878$, $n = 759$, $p = .000$. When comparing the total duration of application usage and usage of indirect/ accumulated feedback, a weak correlation with no statistical significance ($P > 0.05$) was shown with $r = .190$, $n = 95$, $p = .065$.

The post-survey supports these findings, as participants who preferred to use real-time feedback ranked 6.06 out of 7.0 on the scale compared to only 2.41 for those who opted to use accumulated feedback. Furthermore, when considering the usefulness of the application in stimulating eco-friendly driving behaviors, real-time feedback ranked 5.06 and accumulated feedback only ranked 2.0. The post-experimental interviews were valuable in attaining an insight into why participants favored real-time feedback; the immediate nature of real-time feedback enabled participants to directly link eco-driving principles to their driving practices. Accumulated feedback lacked any significance regarding usefulness when driving on motorways, as very similar feedback was given to drivers when not much traffic existed. With respect to these findings one is able to reject the H_0 in favor of the H_1, in conclusion real-time feedback was more eminent compared to accumulated feedback.

(H2) H2 was appraised using the results from both the survey and interviews. The post survey indicates that 71% of participants reviewed their journey scores on the ODP once or twice per week and only 12.5% three to four times. Furthermore, they preferred to receive real-time feedback during a driving episode (87.50%) or in summary weekly (62.50%). The interviews clearly identified that participants felt the ODP was beneficial as a summary supporting an improved understanding of driving behavior/ patterns, but did not play an influential role in modifying their actual driving style. As the qualitative data collected during the survey and interviews cannot be statistically validated this hypothesis cannot be accepted or rejected. However, a trend towards receiving direct feedback compared to the indirect/ offline feedback through an ODP can be implied.

VII. DISCUSSION

The data recorded from this application provided important insights into driving behavior and what kind of feedback the participants preferred. A strong positive correlation between total application and real-time feedback usage underlines the assumption that real-time feedback was used more than indirect/ accumulated feedback. Findings are in accordance with literature in the field of energy savings, which also identified direct/ real-time feedback as being favorable to participants [14][39]. Explorative findings from the interviews provides additional support to this outcome, as influencing driving styles to incorporate more eco-friendly behaviors required immediate prompts when directly involved in the act of driving. This was especially important for the more experienced drivers, e.g. corporate car drivers, as their driving habits are that much more internally engrained [41].

Existing findings, from the energy savings in household literature [14], revealed that providing energy consumption feedback through an online portal made it possible to convince stakeholders to change their electricity consumption habits; particularly when accompanied by social psychological concepts [37]. When considering sustainable driving, findings from our interviews indicate that the ODP has a role in promoting participants awareness and understanding of eco-friendly driving concepts (e.g. details about acceleration/ braking per journey, total km driven, or average speed), but do not strongly influence behavioral modification to encompass eco-friendly driving styles.

It is apparent that the feedback source together with the frequency of feedback underpins the relevance sensor enabled services can have in shaping corporate car drivers' behavioral change towards eco-driving practices. When considering participants' control over the level of feedback they received, e.g. frequently through real-time feedback or intermittently via accumulated/ offline feedback, existing findings recommend that by bestowing this ownership on participants enhance their desire to modify their behavior [31]. Furthermore, if feedback from mobile feedback technology sources were given in conjunction with face-to-face feedback, e.g. by management, it can be predicted that a greater improvement in fuel efficiency may be found. This assumption is corroborated by [16]; they provided feedback via a mobile device as well as face-to-face and achieved an overall fuel efficiency improvement of 7.3%.

VIII. Limitations and Future Research

Generalization of these findings may be limited due to the small sample size. However, other studies in this research domain have involved even smaller sample sizes ($n < 20$) [4], or the treatment period was shorter [10] or based on a driving simulator [9][10]. Findings which entail a lager sample size were mainly conducted with truck drivers and did not evaluate an eco-driving smartphone application with different feedback meters in combination with ODP, rather a fixed installed on-board system that constantly monitored the driving behavior. Therefore, this paper provides a preliminary insight into how and when feedback should be provided using an eco-driving application with sensor enabled feedback technology, within a corporate context to promote improvement of fuel efficiency. Future studies with a larger sample size should evaluate how both feedback types combined, direct and in-direct, impact driving behavior in comparison to their impact when used separately.

As findings from qualitative research methods are more difficult to generalize, findings from the interviews, where n=15, should be met with caution. Hence, the validity of H2 requires further investigation by means of an additional experiment, which specifically evaluates the impact of indirect feedback provided via an online portal vs. direct feedback provided during driving.

IX. Conclusion

The paper expands on the findings of a field test from [7] which evaluated a sensor enabled mobile feedback technology with an eco-driving application. An improvement of 3.23% in fuel efficiency demonstrates that sensor enabled mobile feedback technologies can play an important role in reducing a company's overall CO_2 emission and petrol costs, even if monetary incentives are not relevant [7].

This paper appraised which type of feedback, direct or indirect feedback, offered by the application was preferred by the users. The application provided direct/ real-time or indirect/ three-minute accumulated interval eco-driving feedback to corporate car drivers. Additionally, participants were able to review further driving related data in greater detail using an ODP. It is justified to conclude that direct/ real-time feedback provided during a driving episode was largely preferred over indirect feedback delivered via accumulated or offline feedback. This conforms to findings of literature on energy savings in households that show that direct feedback is more influential [14][39]. The importance of an ODP within this eco-driving context appears to be limited, as participants indicated a greater preference to attaining direct feedback when driving; simply reviewing a summary of driving related figures on the ODP was not enough to warrant a change in their driving style. The main function of the ODP appeared to be in its summary of the driving routes available. Findings also strengthen existing theories; eco-feedback technologies support the notion that feedback provided through sensor enabled mobile devices can empower their users to drive sustainably [2][16]. These verdicts reinforce literature findings, as participants in this study were not motivated by financial rewards to adopt behavioral change.

These additional findings are also relevant for corporations with large corporate fleets, since corporate fleets are constantly growing in size [41]. In Germany for instance, ¼ of the new registered cars in 2011 (total of 3 Million) were corporate cars, which is a total increase of 7.1% [41]. Offering eco-driving classroom training (offline feedback) should be supplemented with ongoing services offered by eco-driving sensor enabled smartphone applications; especially, when deterioration in fuel efficiency is shown shortly after participating in eco-driving trainings as drivers resort back to their old driving habits [3]. Furthermore, the steady increase in smartphones on the market can enforce such a service at minimal extra costs to corporations and their employees.

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XI. References

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