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# Interface design considerations for an in-vehicle eco-driving assistance system

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ABSTRACT

This high-fidelity driving simulator study used a paired comparison design to investigate the effectiveness of 12 potential eco-driving interfaces. Previous work has demonstrated fuel economy improvements through the provision of in-vehicle eco-driving guidance using a visual or haptic interface. This study uses an eco-driving assistance system that advises the driver of the most fuel efficient accelerator pedal angle, in real time. Assistance was provided to drivers through a visual dashboard display, a multimodal visual dashboard and auditory tone combination, or a haptic accelerator pedal. The style of advice delivery was varied within each modality. The effectiveness of the eco-driving guidance was assessed via subjective feedback, and objectively through the pedal angle error between system-requested and participant-selected accelerator pedal angle. Comparisons amongst the six haptic systems suggest that drivers are guided best by a force feedback system, where a driver experiences a step change in force applied against their foot when they accelerate inefficiently. Subjective impressions also identified this system as more effective than a stiffness feedback system involving a more gradual change in pedal feedback. For interfaces with a visual component, drivers produced smaller pedal errors with an in-vehicle visual display containing second order information on the required rate of change of pedal angle, in addition to current fuel economy information. This was supported by subjective feedback. The presence of complementary audio alerts improved eco-driving performance and reduced visual distraction from the roadway. The results of this study can inform the further development of an in-vehicle assistance system that supports 'green' driving.



## 1. Introduction

Minimising fuel consumption has many advantages to the average motorist, including a reduction in the financial cost and the environmental impact of a journey. Savings will continue to be made with the ongoing design of more fuel efficient vehicles. However, even without complex powertrain modifications, significant gains can be made by modifying driver behaviour to encourage 'eco-driving', a driving style that reduces fuel consumption, greenhouse gas emissions, and accident rates. This paper focuses on the first stage of the design of an in-vehicle eco-driving assistance system that provides guidance to the driver on how to improve fuel consumption whilst driving.

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It has long been known that changing driver behaviour has the potential to create substantial fuel savings (Evans, 1979). However, since this early experimental work, many subsequent research studies and policy initiatives have focussed on reducing the environmental impact of road transport through changes in vehicle design or by affecting an individual's choice of vehicle or mode (Stanley et al., 2011). The behaviour of the driver has been identified as an area that should be targeted to achieve substantial improvements in $CO_2$ emissions (Barkenbus, 2010).

Huge potential fuel savings of up to 60% are considered obtainable with optimisation of all of the components of driving performance, including the elimination of unnecessary idling and stop-start manoeuvres and the adjustment of acceleration and cruising speed behaviours (Gonder et al., 2011). Whilst these savings are unlikely to be achievable in reality, it has been predicted that fuel efficiency can be improved by 5–10% with the provision of appropriate feedback to the driver; perhaps reaching 20% for aggressive drivers (Gonder et al., 2011). Driver education and training has been used to improve an individual's eco-driving performance (Martin et al., 2012). However, these effects are often transient and not sustained in the longer-term (af Wåhlberg, 2007), thus meaning that other methods should be considered to encourage changes in driver behaviour (Delicado, 2012).

### 1.1. In-vehicle eco-driving support

The development of an in-vehicle system to provide eco-driving assistance to the driver is an alternative approach to tackling fuel inefficient driver behaviours. There are systems on the market currently that are capable of providing guidance to the driver before, during or after a trip. This paper focuses on a system that presents eco-driving information during the trip, as many car manufacturers currently do (e.g. Honda *EcoAssist*, Ford *SmartGauge* or BMW *EcoPro)*.

This article reports on a driving simulator study in which a number of potential in-vehicle eco-driving support system interfaces were compared, both in terms of their impact on driver fuel efficiency, and the impact on driving performance in general. The study focused on identifying interface design characteristics that facilitate effective, safe and user-friendly interactions between the driver and the in-vehicle system.

Gonder et al. (2011) highlight the need to inform drivers of the most fuel efficient action rather than simply advising of their errors, as a means of achieving their proposed fuel economy improvements of up to 20%. The deficiency in many current systems is that they only inform the driver about what they are doing wrong. Even some systems that provide guidance on how to improve behaviour, only do so after the event (van der Voort et al., 2001). The work undertaken in this study aimed to develop an in-vehicle system that could continuously support the driver in real-time to achieve optimum fuel efficiency. The feedback provided to the driver informed on the current fuel economy and about the action required to improve their fuel consumption.

### 1.2. What guidance should be provided?

The content of feedback that is provided during a drive is often restricted to relatively simple fuel economy or $CO_2$ emissions information (e.g. Graving et al., 2010; Boriboonsomsin et al., 2010), or guidance on speed and gear choice (Nouveliere et al., 2012). Whilst useful, these types of in-vehicle displays are providing the driver with a straight-forward measure of their fuel efficiency at that moment. The driver can infer the actions that they must take to reduce their fuel consumption; however the exact action, and scale of such action required may be difficult to identify. For example, it may be easy for a driver to work out that they are currently accelerating too much and so need to release the accelerator to improve their current sub-optimal fuel efficiency. However, the precise reduction in acceleration that is required to achieve optimal fuel efficiency, may be more difficult to grasp. The absence of real-time guidance on how to improve fuel efficiency, and the resulting reliance on driver understanding of the information and underlying eco-driving principles (e.g. Wada et al., 2011) may not provide the most direct route to improving eco-driving performance. The next step in the design of in-vehicle eco-driving assistance systems seems to be the creation of a system that not only provides the driver with an accurate picture of the current fuel consumption, but also guides them towards the most effective response to enhance their performance. One approach would be the provision of real-time feedback on accelerator pedal usage, which impacts on driver acceleration, braking behaviour and speed choice behaviour. Such an approach is adopted in this study.

### 1.3. What modality should be used for eco-driving guidance?

The majority of past research appears to focus on the use of the visual modality for presenting eco-driving advice, via colour-coded or numerical displays of fuel economy (Graving et al., 2010; Nouveliere et al., 2012; Meschtscherjakov et al., 2009). This inspired the design of three visual eco-driving displays for consideration in this study, whereby the effective components of prior designs were retained, whilst developing features of the displays that might require improvement. The provision of multi-modal feedback has been considered for use in in-vehicle applications to assist with eco-driving, with complementary audio signals being shown to have positive effects on fuel efficiency relative to a visual-only display (Kim and Kim, 2012). A multi-modal eco-driving interface was introduced by testing the three visual interfaces both with and without complementary auditory tones.

There is plentiful evidence to suggest that a continuous, visual in-vehicle display can produce negative side-effects on driving performance due to its potential to distract the driver from looking at the road (see Regan et al., 2009 for a review).