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Reviewing in-vehicle systems to improve fuel efficiency and road safety

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Abstract

Road transport plays a significant role in various industries and mobility services around the globe and has a vital impact on our daily lives. However it also has serious impacts on both public health and the environment. In-vehicle feedback systems are a relatively new approach to encouragingdriverbehaviorchange for improving fuel efficiency and safety in automotive environments. While many studies claim that the adoption of eco-driving practices, such as eco-driving training programs and in-vehicle feedback to drivers, has the potential to improve fuel efficiency, limited research has integrated safety and eco-driving. Therefore, it is crucial to understand the human factors related theories and practices which will inform the design of an in-vehicle Human Machine Interface (HMI) that could provide real-time driver feedback and consequently improve both fuel efficiency and safety. This paper provides a comprehensive review of the current state of publishedliterature on in-vehicle systems to identify and evaluate the impact of eco-driving and safety feedback systems. This paper also discusses how these factors may conflict with one another and have a negative effect on road safety, while also exploring possible eco-driving practices that could encourage more sustainable, environmentally-conscious and safe driving behavior. The review revealed a lack of comprehensive theoretical research integrating eco-driving and safe driving, and no current available HMI covering both aspects simultaneously. Furthermore, the review identified that some eco-driving in-vehicle systems may enhance fuel efficiency without compromising safety. The review has identified a range of concepts which can be developed to influence driver acceptance of safety and eco-driving systems within the area of HMI. This can promote new research aimed at enhancing our understanding of the relationship between eco-driving and safety from the human factors viewpoint. This provides a foundation for developing innovative, persuasive and acceptable in-vehicle HMI systems to improve fuel efficiency and road safety.

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*Keywords***:** Eco-driving; Safety; In-vehicle system; Human machine interface; Driver feedback; Driver behaviour

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1. Introduction

Road transport is increasing worldwide, with subsequent increases in greenhouse gases and road trauma which have serious effects on both human health and the planet. Transport safety and reduction in fossil fuels dependency have been identified as urgent societal needs that should be met by scientific and technological researchers and industrial developments [1]. The number of studies endeavoring to address the need to improve fuel efficiency and road safety is growing. To date, reducing carbon emissions and making driving more ecological and safe have generated different forms of intervention. Such interventions include: promotion of electric cars, improving energy intensity of driving [2], educational and in-vehicle interventions. In-vehicle systems are fast becoming a key instrument in encouraging the adoption of eco-driving practices and have the potential to lead to reduction in fuel consumption and improved road safety by providing eco-driving advice to drivers [3]. Eco-driving refers to cost-effective driving styles that helpto reduce fuel consumption and vehicle emissions.

Eco-driving has been trialed in a number of countries and there is growing evidence suggesting it is a cost-effective approach for reducing fuel consumption. However, little research has examined its effects on safety. Driving in a manner that is eco-friendly and safe requires drivers to make driving task decisions, as well as interactions with other road users. Theoretically, driving in 5th gear at 80 km/h smoothly, without stopping, will result in very low fuel consumption and emissions. However, increasing speed (e.g., exceeding the speed limit) in traffic streams increases the risk of crashes and there may be conflicts between crash rates and fuel consumption [4].

The past thirty years has seen increasingly rapid advances in the field of Advanced Driving Assistance Systems (ADAS). Some systems have been integrated into new vehicles, while others have been incorporated into aftermarket products and other technologies such as smart phones and heads-up displays, which have been brought into the vehicles to provide feedback to drivers. However, along with this growth, there are increasing concerns regarding the use of these in-vehicle systems on safety.

To date, there are a number of studies proposing independent strategies to address safety or ecological driving [5, 6]. However, few research studies have comprehensively integrated safety and ecological in-vehicle systems [5]. Whilst some in-vehicle systems have been shown to be effective in reducing fuel consumption, they do not address impacts on safety and they have not rigorously considered the user acceptance and human factors aspects during the design of new systems [7]. A major challenge into the future is to increase driver acceptance and safety, while also improving fuel efficiency.

This paper reviews the literature on in-vehicle systems which provide information and feedback to drivers on eco-driving, both in terms of their effectiveness for improving eco-driving while also investigating the road safety implications of these systems. Moreover, the paper seeks to identify factors which can be developed to influence eco-driving, safety and driver acceptance. The paper begins with a brief description of the terminology and search methodology used to conduct the literature review, before introducing the relationship between in-vehicle eco-driving and safety systems, providing a critical review of the literature, and discussing future research directions.

2. Search methodology

This study critically examines existing in-vehicle systems and their potential to improve fuel efficiency and safety. In order to identify relevant studies, the initial search was limited to the combination of keywords including, eco-driving, green driving, fuel efficiency, road safety, crash, injury, and in-vehicle systems in the context of driving. Papers published from 1970, when the first driver feedback related to fuel consumption was introduced, were considered for the review. Both published and grey literatures from multiple disciplines were included. Only papers written in English were included. Relevant papers were identified by searching various scientific databases (e.g., Google Scholar, Science Direct, Web of Science, PsycINFO,Transportation Research Information Services). In addition, the references cited in each identified paper were reviewed to discover additional sources of information.

Although we found that there are many factors affecting fuel consumption studied in [8-10], in this review we have focused on those related to driver behavior and specifically assessing in-vehicle systems. Therefore, papers studied the other factors affecting fuel consumption has been excluded in this review. Next, we define key terms that are used in driving domain briefly in Table 1.

Table 1.Key Terminology in driving domain.

Term	Description
Fuel consumption	Total quantity of fuel consumed by a vehiclein specific area and time period (cited in [4])
Fuel consumption rate	Total quantity of fuel consumed by a vehicle per unit distance (commonly expressed in liters/100kilometers)
Fuel economy	Inverse of fuel consumption rate, define as distance travelled per unit of fuel consumed (kilometers/liter)[4]
Fuel efficiency	Ratio of the work or energy output of an engine to the work or energy input[4]
Eco-driving	Cost-effective driving styleto reduce fuel consumption and vehicle emissions
Eco-safe driving	Driving style that improves fuel efficiency without comprising safety
Gamification	Using game design in a non-game context in an attempt to boost drivers' motivation and commitment to use a new in-vehicle system [11]

3. Results

3.1. Relationship between eco-driving and safety

Prior research has identified three broad eco-driving interventions designed to improve fuel efficiency. The decision to perform eco-driving can be studied at three levels (i) strategic decisions (e.g., selection of vehicle); (ii) tactical decisions (e.g., route selection and vehicle loading); and, (iii) operational decisions (driver style) (cited in [11]). However, improving driving style has been shown to be an important step to reducing fuel consumption and vehicle emissions compared to other eco-driving decisions, such as vehicle maintenance[12]. According to Alam and McNabola [11], many countries have adopted eco-driving policies within the transport sector in a bid to reduce energy consumption and CO2 emissions. Therefore, the benefits of eco-driving are widespread over the past few decades. Young et al. [13] have suggested a number of practices for eco-driving, including: planning ahead to avoid unnecessary stopping; choosing moderate engine speeds and uniform control to achieve continuous speed; shifting to higher gears as soon as possible, using positive (but not heavy) acceleration; avoiding sharp braking and using engine braking for smooth deceleration.

However, whilst many existing eco-driving practices may improve fuel efficiency, they may also compromise safety. Young et al. [13] identified a number of potential conflicts between safety and eco-driving practices. For example, they argue that driving in fifth gear with a speed between 60 and 80km/h, without stopping, will reduce fuel consumption and CO2 emissions, but may result in shorter following distances and thus an increased risk of rear-end collisions. It has also been argued that maintaining speed through intersections, instead of slowing down, increases the likelihood that a driver will fail to detect other road users and that distraction may result from using in-vehicle eco-driving systems [4]. In addition, one study undertaken in 2004 by the Turku University in Finland (cited in [14]), identified various situations where eco-driving practices may compromise safety, including: Drifting around junctions and pedestrian crossings in an attempt to avoid stopping; Reducing headway to the vehicle in front in an effort to maximize speed homogeneity; coasting prematurely, disrupting the pattern of traffic to the rear and increasing the risk of a rear-end collision; Rapid acceleration to cruising speeds which may result in shorter safety margins to the vehicle in front; Trying to stay in a high (fuel-efficient) gear, resulting in maneuvering at inappropriately high speeds (e.g., when cornering); and, Switching off the engine at short stops, which may lead to the steering wheel locking in some vehicles.

Many of the safety issues cited above may occur while practicing eco-driving. Mark, et al. [5]reviewed a number of studies and concluded that whilst there are large overlaps between eco-driving and safe driving behavior, in some traffic situations they are in conflict with one another (e.g., maintaining a constant speed may cause late breaking and risk of rear-end collision). Similarly, Symmons and Haworth [15] reported a negative relationship between fuel consumption and crashworthiness. However, Wu, et al. [16] argue that the solution may be to develop feedback mechanisms from in-vehicle systems based on immediate traffic conditions, such as headway spacing and traffic light. In a study conducted by [17], 18 Swedish drivers were interviewed regarding their views on eco-driving. The results revealed that drivers are not always aware of their actions and may be less motivated to perform some eco-driving practices due to disbelief in the benefits that could result from their actions. Therefore, maintaining continuous and real-time feedback over time can increase motivation for eco-safe behavior (both green and safe). Indeed, Strömberg, et al. [17] suggest that in-vehicle systems should be included in more vehicles to provide real-time and continuous feedback to drivers on their actions.

However, most in-vehicle systems currently provide feedback on only one of two important factors: (i) eco-driving or (ii) safety. The separation of these types of feedback may encourage drivers to base their decision-making on only one of them. Therefore, it is crucial to review the current state of knowledge on in-vehicle systems and understand their impact on fuel consumption and safety. This will further inform the design of in-vehicle systems that could provide real-time driver feedback and consequently improve both fuel efficiency and safety. This paper further seeks to identify eco-safe driving parameters, as a basis to promote positive driving behavior which can improve both fuel efficiency and road safety.

3.2. Effective use of in-vehicle systems on fuel consumption and safety

In-vehicle eco-driving systems are intended to support drivers to improve fuel efficiency and reduce vehicle emissions (e.g., CO2) by giving real-time feedback on fuel consumption. Horberry, et al. [18]classify in-vehicle feedback systems in three groups: informing, warning and intervening. *Informing* systems provide relevant information to the driver that they might otherwise miss themselves. Alternatively, *warning* systems alert the driver to take necessary action if they do not respond appropriately to a particular situation, while *intervening* systems go one step further and take control of the vehicle in a critical situation. This feedback can be presented in the form of an auditory, visual or tactile alert via the in-vehicle system.

Driver feedback related to fuel consumption was first introduced in the early 1970s, after the first oil crisis, to improve fuel economy (e.g., manifold vacuum gauges fitted in vehicles) [19]. This technology has continued to develop, for example in hybrid-electric vehicles such as the Toyota Prius (1997) and the Honda Insight (1999), which included innovative dashboard displays [20]. Various in-vehicle devices and technologies continue to be developed to give eco-driving feedback to drivers and improve fuel efficiency, such as dashboard displays (e.g., SmartGauge[1], EcoAssist[2]), heads-up displays and smart phone applications (e.g., Fiat Eco:Drive system[3]and more; see [21] for a comprehensive review of existing in-vehicle eco-driving systems and functionalities).

Evidence from current literature shows that eco-driving in-vehicle systems have positive effects on fuel consumption and can improve fuel efficiency. Barth and Boriboonsomsin [22]found that speed feedback via in-vehicle dashboard displays can reduce fuel consumption by 10-20% depending on the context of the driving scenario. Similarly, reductions of 6.8% in fuel consumption have been observed when bus drivers received instantaneous feedback on their driving through in-vehicle eco-driving systems [23]. However, Haworth and Symmons [4] advised that in-vehicle systems are not always safe to use if they cause distraction to drivers. Overall, the majority of eco-driving systems have sought to maximize environmental benefits without considering potential safety outcomes and in most of the studies, the effect of safety has not been studied comprehensively, or in some cases at all. Therefore, it is important to look at driver behavior in different driving contexts and highlight the parameters affecting fuel consumption and safety.

3.3. Driving parameters influencing fuel consumption and safety

As mentioned above, different factors influence fuel consumption and safety. In this section, we review those factors related specifically to driver behavior in response to advisory feedback from in-vehicle systems. Based on the review of the literature, we have summarized a set of driving behavior parameters that influence fuel consumption and safety (see Table 2). These parameters are highly dependent on the context of the surrounding traffic situation and affect both fuel consumption and safety [24].

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[1]http://smartdesignworldwide.com/work/ford-smart-gauge/
[2]http://automobiles.honda.com/insight-hybrid/fuel-efficiency.aspx
[3]http://www.fiat.com/ecodrive/

Table 2. Driving Parameters Influencing Fuel Consumption and Safety.

Driving Parameters	Influence on		Example of In-Vehicle System Technologies
	Fuel consumption	Safety	
Speed~ 60-80 km/h	Decrease fuel consumption	May increase risk of crashes due to excessive speed	• Speed Recommendation • Intelligent Speed Adoption
Follow speed limit	May increase fuel consumption in low speeds	Decrease risk of crashes	
Cruising speed	Decrease fuel consumption	Decrease risky manoeuvres	• Cruise Control
Smooth Acceleration	Decrease fuel consumption	Decrease aggressive driving	• Haptic Pedal Feedback
Smooth deceleration	Decrease fuel consumption	May increase risk of crashes due to shorter headway	
Sharp braking	Increase fuel consumption	May increase risk of crashes due to risk of rear-end collision	
Highest gear possible	Decrease fuel consumption	May leads to less control of the vehicle	• Gear change advice • Gear Shift Indicator
Idle time	Decrease fuel consumption (no more than ~ 30 Sec)		
Safe Headway		Prevent rear-end collision (TTC~ 2-4 Sec)	• Collision avoidance/warning system
Lane Position		Decrease risk of crashes due to maintain the car in the lane	• Lane departure warning
Aggressive driving	Increase fuel consumption due to hard acceleration/deceleration	Increase risk of crashes	

A number of parameters emerged from studies examining the relationship between advisory in-vehicle systems and fuel consumption, including: *speed choice, acceleration, deceleration, gear shifting and idling*. These parameters are consistent with earlier research conducted by Hooker [25], suggesting that driver behavior has a significant effect on reducing fuel consumption. Not surprisingly, speed was reported to be a main parameter in most studies. The field trial experiments conducted by Barth and Boriboonsomsin [22] found that providing speed recommendations (based on real-time, dynamic traffic sensing and telematics data) to drivers via a dashboard display reduced fuel consumption by 13% and reduced vehicle emissions, compared to a control group. However, different studies have reported different approaches to the provision of in-vehicle speed feedback, including: acceleration, cruising and deceleration. For example, a study investigating the effect of an accelerator advisory tool, which exercised resistance in the acceleration pedal when drivers try to accelerate too rapidly, found a reduction in emissions during two of three routes examined, as well as a significant reduction in strong/heavy acceleration [26]. However, the study only found a small reduction in fuel consumption when driving with only the acceleration advisory feedback activated.

The reviewed literature suggests that there are overlaps between eco-driving and safety behavior. An inspiring review conducted by [5], discussed some of the in-vehicle systems that influence safe and/or eco-driving (e.g., satellite navigation systems, congestion assistants, intelligent speed adoption). In fact, eco-safe behaviors heavily depend on the driving context and there are several situations where eco-driving and safety are in contrast with one another. For instance, maintaining a constant speed in an attempt to avoid braking may compromise headway, while travelling in the highest possible gear may adversely affect vehicle control. Overall, safety parameters associated with in-vehicle systems that have been studied by the literature include: *safe headway, lane position, vehicle speed*, and *aggressive driving*.While all proponents of in-vehicle systems note the importance of eco-driving and safety parameters, few examples were found in the literature assessing the reality of actually applying them.

Although the reviewed studies acknowledged the positive effect of in-vehicle systems, it is argued that more attention must be given when designing in-vehicle eco-driving systems to the potential distraction and heightened mental workload that may result from using these systems [27]. Haworth and Symmons[4] warned that eco-driving feedback systems may have negative effects on safety if they distract drivers. Indeed, it is important to bear in mind the drivers' task demands before thinking about designing such a device. Hence, a well-designed in-vehicle system can support drivers to encourage both eco-driving and safe behavior, if implemented with careful consideration.

3.4. Driver acceptance of in-vehicle systems

There have been a number of studies of in-vehicle systems which provide feedback on vehicle fuel consumption and safety concerns [19, 20, 28, 29]. However, in-vehicle feedback systems are beneficial if accepted by drivers. Previous research suggests that feedback can only advise, and will not necessarily stimulate sustainable ecological behavior unless the driver already possesses a strong inclination to drive in an eco-friendly manner [30] and perceives in-vehicle feedback systems to be effective. According to Adell [31, p31], driver acceptance is “the degree to which an individual incorporates the system in his/her driving”. This definition suggests that acceptance is related to the actual use of the system by an individual. Similarly, Jamson [32] defines acceptance as how much the system would be used and drivers are willing to buy it. It is important that the effective use of the in-vehicle system understood and valued by drivers. And, this is highly depends on driver’s attitudes, expectations and their experience using the in-vehicle systems (cited in [33]). Consequently, in-vehicle systems will only be accepted if valued and satisfying to use by driver.

To date, manytheories and models have been used and developed to describe the acceptance of technology such as, Theory of Planned Behavior (TPB) based on the Theory of Reasoned Action; the Technology Acceptance Model (TAM); the Unified Theory of Acceptance and Use of Technology (UTAUT) (also see [18, 34]). The main element in all these is the behavior; which is related to the use of the new system. However,Horberry, et al. [18]presented various existing theories and models behind driver acceptance of technology from the perspectives of researchers, product designers and policymakers and argued thatmany of these models were initially developed for non-driving context and there is no specific and universally accepted model that widely agreed by all domainsfor developing new driver acceptance technologies such as increasing safety. However, [35] identified a number of general consensus in regard to the acceptance of new technology, such as; (i) usefulness and ease of use the system is two key factors in acceptance of the new technology; (ii) acceptance depends on the individual factors such as gender, age, culture and personality; (iii) individuals have different judgements, accordingly, drivers-centric view is the requirement to predict and measure driver acceptance in individual level; (iv) for the system to be acceptable, drivers do not need to like the system, but rather find it effective, however, liking the system may increase the usability; (v) acceptance depends on the context of the use and whether the use of the system is voluntary and influenced by social and cultural norms. Last but not least, (vi) acceptance of the system may change over time, depending on different context or as the drivers’ experience of the system develops. It is also worth mentioning that, there is a lack of application of these models and concepts in the context of eco-driving in-vehicle systems in the literature. Therefore, better understanding of parameters influencing driver acceptance and applying them can support the potential design of eco-safe in-vehicle system which is also accepted by drivers [36].

3.5. Social concepts to motivate eco-safe driving

A large number of eco-safe driving behaviors are dependent on motivations, beliefs and cultural background of the driver, all of which are psychologically and socially complex issues. Rakotonirainy, et al. [37, p381] have indicated that social norms are “rules and standards that are understood by members of a group, and that guide and/or constrain their social behavior”. Therefore, it is important to investigate psychological and social concepts that motivate ecological behavior, as well as taking into account the real needs of drivers, levels of acceptance and the usability of the system, from the preliminary stages of design and development. Consequently, any theory or model of Human Machine Interface (HMI) in the context of sustainable energy behavior that fails to include social concepts could be argued to lack a critical element. Whilst there exists different in-vehicle HMI for eco-driving and safety [e.g. 38], there is little work on the use of psychological and social concepts and there is a gap in the literature on the use of in-vehicle systems to motivate sustainable, green and safe driving.

Very recently the use of gamification has emerged in the automotive industry, primarily for its motivating and inspiring potential [39, 40]. The term gamification refers to the use of game design, game playing techniques and game mechanisms to engage users and motivate positive behavior[41, 42]. Recent studies outlined by Jung, et al. [43] suggest that motivational affordance such as gameful design can motivate positive involvement. Some recent gamification applications have been reviewed by [44, 45]. However, the use of gamification in the automotive domain indicates some challenges and limitations that may result, including distraction from the driving taskresulting in violations of traffic laws [44]. Therefore, it is critical to evaluate any gamification application in the automotive domain before integrating it into in-vehicle interfaces to ensure it does not interfere with safe driving behaviors or increase the likelihood of driver distraction.

4. Conclusions

This paper presents a review of current state of published literature on eco-driving and potential conflicts with safety, with a focus on feedback from in-vehicle systems. There is evidence found in the literature that fuel efficiency is achieved as a result of positive interactions between in-vehicle systems and drivers. However, the review has also shown that much of the existing literature on in-vehicle system to date applies only to eco-driving or safety and there is lack of research integrating both comprehensively. While we argued that there are number of driving behavior parameters such as speed choice, deceleration, acceleration, idling, headway and lane deviation which all contribute to eco-safe behavior, few examples were found in the literature assessing the reality of actually applying them. Nonetheless, we also found there are still open questions with respect to driver acceptance of in-vehicle systems to support driver performance for eco-safe driving and consensus is lacking. Taken together, these findings enhance our understanding of factors such as acceptance which play a significant role in sustainable use of the in-vehicle system and caution that we cannot be sure the system will be beneficial if the acceptance of the system has not been considered. In addition, this review supports the concept of using gamification to motivate eco-safe cues among drivers. However, it is critical to evaluate any gamification application in the automotive domain before integrating it into the in-vehicle system to ensure it does not interfere with safe driving behaviors or distract the driver.

The present study is the first step in an on-going program of research to develop and design an innovative eco-safe in-vehicle feedback system to improve fuel efficiency and safety which can maximize driver acceptance and reduce driver distraction. Considerably more work will need to be done to understand driver behavior under technological instructions and ways to enhance drivers' motivation to use the in-vehicle system using gamification principles. More information on user acceptance would help us to establish a greater degree of accuracy in design and development of the in-vehicle system. Ensuring appropriate systems can enhance the potential of using these technologies to promote environmentally friendly driving, reducing emissions and save human life.

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