

Research issues in Eco-driving

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ABSTRACT

Transport is a key economic sector, supporting economic development and growth, and facilitating exchange. At the same time, motor vehicles are major emitters of gaseous and particulate pollution in urban areas. The transport industry's quest to limit its impact on the environment and improve road safety continues to drive policy, research and development. Eco-driving is a well-established, affordable and simple behavioural change intervention, which could reduce fuel consumption up to 20%. Fully electric vehicles are predicted to be available for the mass market by 2020, however an energy efficient driving style will still be necessary for these vehicles due to a relatively poor battery performance. Furthermore Eco-driving could be applied to electric or thermal vehicles. Despite a widespread adoption of Eco-driving, its safety benefits have not been clearly established. This paper discusses research issues related to Eco-driving interventions. It covers policy, industry practice and research approaches ranging from education to in-vehicle technology. This paper demonstrates the lack of comprehensive systemic research analyzing the impacts of Eco-driving on road safety. Most of the methods used to assess the benefits of eco-driving lack scientific rigour and have methodological shortcomings. Ecological Driving Assistance Systems (EDAS) has emerged as a viable ITS intervention addressing Eco-driving but the associated Human Machine Interface is still neglected. Furthermore, there is not enough research assessing the long-term effects of Eco-driving driving.

INTRODUCTION

Transport is a key economic sector, supporting economic development and growth, and facilitating the exchange of goods. However, transport could damage the health of humans and the planet by creating road trauma, air pollution and greenhouse gases. Reductions in road trauma in Australia and across the

Organisation for Economic Co-operation and Development (OECD) have stalled in the last five years and innovative interventions are needed to address this impasse. At the same time, passenger and freight travel are growing, with consequent increases in gaseous and particulate pollution in urban areas which have serious health effects, including respiratory and cardiovascular diseases

Eco-driving attempts to change drivers' behaviour through advice such as driving more smoothly by anticipating changes in the traffic, shifting gear sooner, operating the vehicle within an optimum range of engine revolutions, avoiding jerky braking/acceleration and avoiding traffic congestion. Many countries have promoted Eco-driving as a key element of national strategies to reduce CO₂ emissions but have not examined the safety effects (ECODRIVEN, 2009). European Union regulations already require Eco-driving to be taught to novice drivers. Japan achieved its 2010 goal of reducing CO₂ emissions by 31 million tons below 2001 levels by encouraging drivers to use their vehicles more efficiently through Eco-driving (Transport America, 2010). The claimed advantages of the Eco-driving approach are that it can apply to vehicles of any age or size, it can take effect across the entire fleet of vehicles immediately at low cost (as opposed to being phased in), and that it can result in immediate savings to individuals from greater fuel efficiency, better safety and perhaps lower insurance rates (Barkenbus, 2010).

TECHNOLOGICAL LIMITATIONS

Eco-driving goals are easily pushed to the background when they conflict with other goals, particularly goals related to safety and time saving (Dogan et al., 2011). Helping the driver to choose the best compromise between safety and CO₂ reduction driving techniques can be the goal of a new type of advanced systems called ecological driving assistance

systems (EDAS). This can be achieved through two different approaches:

- Adapt existing speed management systems developed within the area of Intelligent Transportation Systems such as Intelligent Speed Adaptation (ISA).
- Design a specific EDAS merging safety and environmentally driving tips.

The first possible solution relies on the assumption that controlling speed is sufficient to reach a reasonable level of fuel economy. Such an hypothesis has been tested through the impacts of ISA systems on fuel consumption. An ISA system monitors the location and speed of the vehicle, compares it to a defined set speed, and takes corrective action such as advising the driver and/or governing the top speed of the vehicle. There are several ISA implementation methods, based on how the set speed is determined (see Carsten & Fowkes (2000) for a review), but the most common implementation is the variable version. In this case, the set speed is determined by vehicle location, which leads the equipped vehicle never to exceed the speed limit for a given area. The French ISA system (LAVIA) has been extensively studied by the French public works laboratory (LCPC). A recent re-analysis of the collected data shows that there is no fuel consumption reduction (Saint Pierre & Ehrlich, (2008)) as was predicted by the models. This result is similar than recent findings for other ISA implementations (Regan et al., 2008; Carsten et al., 2008). ISA systems are therefore not so effective in preserving the environment, as speed advice alone is not precise enough to deal with the complexity of eco-driving behavior. Other tested devices such as a simple acceleration advisory tool have also lead to disappointing results (Larsson & Ericsson 2009).

Designing a new type of ecological device seems to be a more promising approach as many automakers are developing their own monitoring devices. Ranges of ITS-based interventions have been developed to facilitate the maintenance of the Eco-driving style once training is completed. In commercial fleets, IT applications are available that monitor fuel economy in real time and provide instantaneous readouts to drivers, or to fleet managers via mobile communications systems (Int Transport, 2008). Most of these devices are available as features of hybrid-electric vehicles with the purpose of providing instant feedback to the driver of the vehicle's fuel economy performance. Some of the newest

hybrid-electric vehicles coming to market not only provide driver feedback, but also establish driving parameters for the vehicle that can assist in eco-driving. For example, Honda provides their insight hybrid model with a driver-activated ECON mode that adjusts vehicle performance for fuel efficiency purposes. The Toyota Prius allows the driver to receive fuel economy information through three different displays all delivering slightly different fuel economy information. Such monitoring devices are also present in other brands, but up to now they are equipping mainly hybrid-electric vehicles. For example, Honda has developed an Eco Assist dashboard display which uses a simple colour-coded display of "leaves" (the more leaves the better) to provide the driver with an assessment of how successful he/she is in achieving maximum fuel economy, while Ford uses the same principle with their SmartGauge system (White, 2009).

Since better fuel economy is the primary selling points for these vehicles, the importance of these devices is well understood. European project results (ECODRIVE) indicate that most drivers welcome feedback devices in their vehicles and are ready to modify their driving habits. Most of them will attempt to make a game out of it, searching for the best way to drive to maximize fuel efficiency.

But little scientific research has been published on the effects of such ITS devices on driver behaviour, fuel consumption and emissions and how to optimise the feedback to the driver.

EFFECTS OF ECO-DRIVING ON CONSUMPTIONS AND EMISSIONS

Despite its popularity, there is poor and inconsistent research evidence regarding the effects of Eco-driving on both fuel consumption and emissions. Most research projects on Eco-driving have demonstrated reductions in fuel consumption (Barth & Boriboonsomsin, 2009) and emissions (Barth & Boriboonsomsin, 2009; Carlsaw et al., 2010). Other studies related to the use of different Advanced Driving Assistance Systems (ADAS) as opposed to eco-driving devices, have shown no impact (Larsson & Ericsson, 2009) or increased fuel consumption with the use of Intelligent Speed Adaptation (St Pierre & Ehrlich, 2008).

Research into the long-term (>3 years) effectiveness of Eco-driving training found that average fuel consumption fell by 5.8%

four months after initial training (Beusen et al., 2009). Most drivers had an immediate fuel consumption improvement that was stable over time but some tended to fall back into their original driving style. Eco-driving style is difficult to turn into driving habit as it is dependent to the driving situation such as traffic, environment and personal motivations (Dogan et al., 2011).

The impact on emissions (CO₂, CO, NO_x, PM and CH) has been estimated with simulation models. Simulation has been shown to produce valid estimations. Smit et al (2010) conducted a meta-analysis of 50 studies dealing with the validation of various types of traffic emission model by taking into account average speed, traffic situation, traffic variables, cycle variables and modal models. The results of the meta-analysis indicate that the mean prediction errors are generally within a factor of 1.3 of the observed values for CO₂, within a factor of 2 for HC and NO_x, and within a factor of 3 for CO and PM. A positive mean prediction error for NO_x was established for all model types and practically all validation techniques. Their statistical analyses show that the mean prediction error is generally not significantly different ($p < 0.05$) when the data are categorised according to model type or validation technique. Such results are promising.

Carslaw et al. (2010) have conducted a large field trial in which they developed individual vehicle model emissions models for CO₂ for 30 Euro III and Euro IV cars using Generalized Additive Models. Their models describe how emissions from individual vehicles vary depending on their driving conditions, taking account of variable interactions and time-lag effect.

EFFECTS OF ECO-DRIVING ON SAFETY

Little is known about the relationship between Eco-driving and safety. Driving safely requires drivers to make decisions about their own actions, as well as requiring interactions with other road users. Individual actions include decisions about speed choice (speed limits, or condition considerations), as well as skill errors (lapses or slips), or violations (Knapp et al, 2003; Vershuur & Hurts, 2008). Reducing speed decreases the likelihood and severity of crashes. Evidence has shown that greater speed variability in traffic streams increases the risk of crashes (Knapp et al. 2003). A low speed variability manifests in avoiding rapid starts and stops; maintaining a steady speed when travelling on highways;

keeping rolling in traffic; and using the highest gear possible. These are several key safe driving behaviours, which also form the basis of Eco-driving (The Alliance of Automobile Manufacturers, 2010; Beusen et al, 2009). While many of these behaviours may improve safety (e.g. maintaining a steady speed may decrease speed variability on road segments), others may have a negative impact on safety (e.g. keeping rolling in traffic).

Some advice may therefore appear to be in conflict in specific situations. For example, when driving in a crowded urban area, it can be difficult to maintain a steady speed with a high gear, and safety should be prioritized by adopting a low speed although it is not fuel efficient. An experienced driver may understand easily that the best compromise depends on the situation, but problems may arise when trying to teach the Eco-driving style to young drivers. It should be noted that driving habits learned by experience could also be hard to change. CIECA (2007), has identified the following potential conflicts:

- Drifting around junctions and pedestrian crossings in an attempt not to stop.
- Driving too close to the vehicle in front in an effort to maximize your evenness of speed.
- Coasting too early and disrupting the pattern of traffic to the rear, thereby increasing the risk of a rear-end collisions.
- Rapid acceleration to cruising speed could cause shorter safety margins to vehicles in front.
- Trying to stay in a high (fuel-efficient) gear, but therefore manoeuvring at too high speed (e.g. cornering).
- Switching off the engine at short stops can lead to the steering wheel locking.

Eco driving tips need to be adapted depending on the driving context, and “drive safely and use eco-driving techniques where possible” is perhaps a more appropriate rule of conduct, although it may not emphasize Eco-driving as much as some experts would wish.

Driving behaviours can influence both fuel economy and safety. A positive correlation between crash rates and fuel consumption was found in a large corporate fleet (Haworth & Symmons, 2001). In contrast, another study demonstrated that the drivers who had the lowest fuel consumption were not necessarily the safest or those who complied with the Eco-driving instructions (Saint Pierre et al., 2010). Speed profile has a fundamental influence on both safety and environmental outcomes. For

example, stop-start driving increases emissions, with the major reason for this being the acceleration component (Jayaratne et al., 2009). Motorists in a recent survey by RoadPilot reported that rising fuel costs affected their choice of speed more than speed cameras did. There remain cultural and educational barriers inhibiting the adoption of safe driving behaviours. An educational message related to reducing air pollution was more effective than safety messages in getting drivers to keep to the speed limit (Delhomme, Chappe, et al., 2010). This suggests that Eco-driving could be employed to achieve two goals simultaneously. A recent French study involving 1,200 passenger vehicles has shown that most of the drivers ignore the main Eco-driving instructions despite their strong motivation in reducing their fuel consumption (Delhomme, Paran & Nicolas, 2010).

There is very little scientific knowledge regarding the most effective driving behaviour for safety and fuel economy. Saboohi and Farzaneh(2009) defined an optimal eco-driving of passenger vehicle based on the minimum fuel consumption. They showed, with a traffic simulator, that an optimal driving strategy based on coordination of speed and gear ratio through engine load would lead to minimization of fuel consumption in an intense traffic flow.

Kamal et al. (2010) defined a predictive control model of a vehicle in a varying road-traffic environment for Eco-driving. The model is based on vehicle dynamics and includes factors such as resistances and traction forces, engine characteristic and road map. In addition the eco-driving performance index is based on driving efficiency instead of speed.

The emphasis on gear changing in Eco-driving reflects its European origins and it may not be as effective in the US or Australia where cars mostly have automatic transmissions. Symmons et al. (2009) note that “given that Eco-driving has been in official existence for some 20 or so years there actually seems to be remarkably few trials published in the peer-review literature” (p.49). Wahlberg (2007) concurs, stating that:

“The claims regarding the Eco-drive benefits were mainly made by educators and bureaucrats, and lack scientific backing. More specifically, no literature on Eco-drive was found after a thorough literature search in major academic databases covering transport, energy, and psychology”.

HUMAN MACHINE INTERFACE OF ECO-DRIVING

There is a large body of research on how in-vehicle technologies such as navigation systems could distract the driver. However there is little understanding of the side effects of most new eco-driving technologies instructions on driver safety performance. The main research questions, which remain unanswered in eco-driving, are how in-vehicle eco-driving systems may influence driving behaviour; and whether they might distract drivers, particularly during potentially dangerous manoeuvres.

According to expert knowledge (interviews with eco-driving professionals), displaying the fuel use as an instantaneous variable can be difficult to interpret and can be misleading. Reaching a good level of fuel efficiency driving can be difficult as many parameters can impact. Displaying the fuel use, or the battery gauge, is not sufficient to help the drivers in understanding the dynamic relationship between driving actions and fuel efficiency: Sometimes, it is interesting to keep accelerating in order to reach a more efficient engine operating state. As most of the people want to keep ecological driving assistance systems (EDAS) simple (See for example Young Birrel Stanton “Design for Smart Driving: A Tale of Two Interfaces”, (Young et al., 2009)), we believe that a global indicator, merging different driving parameters can be more efficient than fuel consumption.

Psychological theory strongly confirms that unless the individual can see or feel the results of their actions - preferably on an immediate and continuous basis - that individual is unlikely to maintain the behaviour over time (Huang et al., 2005). Feedback about the effectiveness of an individual's behaviour has long been recognized as essential for learning and motivation. There is a need for feedback related to driving performance such as eco-driving to be delivered to the driver in order to facilitate change or improvement. Both concurrent and retrospective feedback types have been found to help drivers to improve their performance (Donmez, Boyle, & Lee, 2008), and have been adopted by different car manufacturers. Feedback could give fuel saving a competitive game-like aspect, making the goal more challenging and more involving (Barkenbus, 2010). Research has indicated that drivers welcome feedback devices in their vehicles, and alter their driving habits as a consequence (Kurani, 2007). Particular care should be given to the design of the feedback

mechanism to avoid driver distraction (Donmez et al., 2008).

Drivers do not simply react to their immediate environment, but are involved in complex forethought and decision-making. A substantial body of converging evidence shows that perceived self-efficacy significantly influences human self development, adaptation and change (Bandura, 1997). Self-efficacy is a social cognitive theory in which perceived self-efficacy is a major determinant of intention. A decision based on misjudgements of driving capabilities could produce detrimental consequences; and proper appraisal of one's own efficacy has considerable value. There is no all-purpose measure of perceived self-efficacy (Bandura, 1997) so there is a need to use self-efficacy theory to assess driver's judgement of capability to perform Eco-driving tasks by developing a new questionnaire tailored to the Eco-driving. In order to have a lasting behavioural changes, drivers need to (i) feel capable of adopting Eco-driving behaviour and (ii) be convinced that such behaviour will effectively reduce their consumption and emission.

RESEARCH NEEDS

As for road safety, there are still cultural, technical, and educational barriers inhibiting the adoption of eco-driving practices. A US survey showed that people mistakenly believe that fuel consumption decreases linearly rather than nonlinearly as a vehicle's gas mileage (Larrick & Soll, 2008). It has been shown that efficiency improving actions (e.g. installing more efficient appliances) generally save more energy than curtailing the use of inefficient equipment (e.g driving less, turning off lights) (Gardner & Stern, 2008). However, household perception of the most effective strategy that they could implement to conserve energy is the complete opposite (Attari et al., 2010). This suggests that caution is required in designing interventions related to energy savings such as eco-driving.

Given the worldwide popularity of Eco-driving instructions, it is of the utmost importance to not only assess the real changes in terms of fuel consumption and travel time, but also on emissions and safety. The joint consideration of optimal benefits for road safety and vehicle emissions is an area that merits further research because benefits to both issues are highly desirable (Carslaw et al., 2010). Specifically, there is a need to conduct research in which safety, fuel economy and

emissions are jointly modelled and assessed and conveyed to the driver.

Ecological Driving Assistance Systems (EDAS) will become a standard part of future driving assistance systems. The heterogeneity of vehicles, the complexity of the driving task and variability of driving style will require simple advices through the use of aggregated indicators to safety and ecology. Furthermore, interventions focusing on continuous self-assessment and self-learning are more likely to be adopted by drivers. Such in depth study will help road transport stakeholders to identify and promote interventions to improve the likelihood of adopting Eco-driving behaviour

CONCLUSION

Pascala and Socolow (2004) demonstrated that increasing energy efficiency and curtailing activities that consume energy may be our cheapest options for stabilizing CO₂ concentrations below a doubling of preindustrial concentrations. Eco-driving provides one such strategy.

Most of the methods used to assess the benefits of eco-driving lack scientific rigour and have methodological shortcomings (e.g no control groups). They do not explicitly address the safety implications and have not provided sufficient attention to the human factors aspects such as acceptability of the intervention and willingness to adopt it.

There is an alarming lack of Eco-driving experiments, knowledge and data worldwide. Yet the potential economic and environmental benefits are large. The Swedish National Roads Administration estimate that 1 kg of CO₂ costs between 0.1 to 0.3 Euro to society and that Eco-driving can reduce fuel consumption by 5 to 15%. Applying these estimates to the 12 million vehicles in Australia that consume approximately 30,000 million litres of fuel per year, leads to potential CO₂ savings valued at between \$250 and \$750 million per year and fuel savings of between \$1,800 million and \$5,400 million per year. This would reduce the pressure on world oil supplies. While the health benefits of improving fuel consumption, and the resulting lower emissions, are harder to determine, there is a growing consensus that they do exist. Improving safety also has financial and health benefits. Road trauma results in high economic and social costs, both in lost productivity and demands on the health system.

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