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Safe driving in a green world: A review of driver performance benchmarks and technologies to support 'smart' driving

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ABSTRACT

Road transport is a significant source of both safety and environmental concerns. With climate change and fuel prices increasingly prominent on social and political agendas, many drivers are turning their thoughts to fuel efficient or 'green' (i.e., environmentally friendly) driving practices. Many vehicle manufacturers are satisfying this demand by offering green driving feedback or advice tools. However, there is a legitimate concern regarding the effects of such devices on road safety – both from the point of view of change in driving styles, as well as potential distraction caused by the in-vehicle feedback. In this paper, we appraise the benchmarks for safe and green driving, concluding that whilst they largely overlap, there are some specific circumstances in which the goals are in conflict. We go on to review current and emerging in-vehicle information systems which purport to affect safe and/or green driving, and discuss some fundamental ergonomics principles for the design of such devices. The results of the review are being used in the Foot-LITE project, aimed at developing a system to encourage 'smart' – that is safe and green – driving.

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1. Introduction

Driving is a highly complex task, comprising over 1600 separate tasks over five behavioural levels (Walker et al., 2001). Drivers simultaneously control the vehicle, adjust speed and trajectory, deal with hazards, evaluate progress towards their goal, and make strategic decisions such as navigation. Groeger (2000) suggests that driver behaviour is very much goal-directed, and drivers may have multiple goals (safety, speed, economy etc.), which at any one point in time might be in conflict. Drivers appraise these conflicts and plan their driving accordingly.

With climate change becoming increasingly prominent on social and political agendas, many drivers have a new goal in mind – 'green', or environmentally friendly, driving. Whereas to date the key focus of ergonomics research in transportation and other applied domains has – quite properly – been to enhance vehicle safety and performance efficiency, it now behoves the ergonomics community to contribute to the development of systems which encourage green driving behaviour. Road transport is a significant source of both safety and environmental concerns, accounting for 2.1% of global mortality (Peden and Sminkey, 2004) and nearly 20% of total greenhouse gas emissions (EEA, 2007). Clearly, then, this is an area where ergonomics can have a meaningful impact.

'Foot-LITE'[1] is a multidisciplinary consortium project aimed at developing a system which will encourage drivers to drive in a safer and greener manner through on-board advice and post-drive feedback. The system comprises two aspects: an in-vehicle interface, which delivers real-time feedback on driving style, and a post-drive component for longer-term advice and information. The in-vehicle module is connected to the on-board diagnostic system and uses additional monitoring sensors to provide feedback on elements such as speed, acceleration, gear use, lane position and headway. Journey data are then downloadable to the off-line, web-based system for more detailed analysis and links to driver coaching modules. Foot-LITE is above all an advisory system, providing information and feedback without intervention, on how the driver's behaviour relates to aspects of safe and green driving, with the aim of modifying such behaviour to improve both aspects – encouraging what has come to be known as 'smart' driving. In order to achieve this goal, the first objective is to ascertain the driver behaviours pertaining to both safe and green driving, to determine whether there are any conflicts between these goals, and to establish the information requirements for the driver. In other words, before we can develop a specification

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[1] For more information on the Foot-LITE project, see www.foot-lite.net.

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for the Foot-LITE system, we need to define what we mean by 'smart' driving.

In this paper, written at the outset of the Foot-LITE project, we aim to establish such benchmarks for smart driving, laying the basis for further development and specification work for the Foot-LITE system – or, indeed, any such system. We first review the components of safe and green driving independently, before examining where the two goals overlap and where they compete. We then close with a discussion of the driver's information requirements for smart driving, including a summary of the positive and negative aspects of in-vehicle information systems (IVIS), such as satellite navigation, congestion assistants, intelligent speed adaptation, and other prototype green driving tools which are relevant to Foot-LITE. With 'green ergonomics' growing in popularity as an important research field (as evidenced by the recent formation of the special interest group within the UK Institute for Ergonomics and Human Factors), we hope this paper serves as a useful reference in a domain of key relevance to environmental and ergonomics issues.

2. Safe driving

Throughout the literature, excessive driving speed consistently emerges as the single biggest predictor of both crash risk and crash severity (Haworth and Symmons, 2001; Taylor et al., 2002; af Wahlberg, 2006; Aarts and van Schagen, 2006). Exceeding the speed limit or driving too fast for the conditions were identified as contributory factors in 15% of all accidents on UK roads in 2005 (Robinson and Campbell, 2006). Conversely, similar research indicates that for every 1mph reduction in speed, a 5% drop in accidents is observed (Taylor et al., 2000). It has further been suggested that accident frequency (whether fatal, serious or minor) increases with driving speed to the power of approximately 2.5 (Taylor et al., 2002). In other words, a 10% increase in mean speed would result in a 26% increase in the frequency of all injury accidents. This increases to 30% when considering just KSI (killed or serious injury) accidents (Taylor et al., 2002). When considering the severity of an accident in crash statistics, speed factors contributed to 26% of fatal accidents – which in turn accounted for 28% of all road fatalities (Robinson and Campbell, 2006).

It is worth noting that absolute speed is not necessarily the problem – the emphasis is on excessive speed, or inappropriate speed for the road and/or conditions. Indeed, many roads traditionally associated with higher speeds (such as motorways) are actually safer in terms of road traffic accidents (COM, 2006; Taylor et al., 2002). Nonetheless, it is well established that speeding (i.e., breaking the speed limit) is dangerous, particularly in urban environments (Haworth and Symmons, 2001; Aarts and van Schagen, 2006) where the number of vulnerable road users is greater. Haworth and Symmons (2001) cite evidence that '…the risk of a pedestrian receiving fatal injuries at an impact speed of 50 km/h is approximately ten times higher than at an impact speed of 30 km/h'. Likewise, the tipping point between a survivable and fatal collision for a pedestrian occurs between 50 and 60 km/h.

Various parameters of speed (i.e., average speed, speed distribution, speed profile, cruising speed, standard deviation, and free speed) are commonly used when considering accident frequency or prediction. Related measures such as acceleration/deceleration behaviour (af Wahlberg, 2006) and driver headway (Brackstone and McDonald, 2007) have also been used. These will become pertinent as we go on to discuss and contrast safe driving techniques with the components of green driving.

Whilst speed has been identified as a major factor for unsafe driving, it is by no means the sole contributor; others may include aggressive driving behaviours or risky driving manoeuvres. In a review of published literature on aggressive driving, Tasca (2000, p. 2) proposed a formal definition of aggressive driving: 'A driving behaviour is aggressive if it is deliberate, likely to increase the risk of collision and is motivated by impatience, annoyance, hostility, and/or an attempt to save time'. Similarly, a report published by the National Highway Traffic Safety Administration (NHTSA) states that aggressive driving '…is generally understood to mean driving actions that markedly exceed the norms of safe driving behaviour and that directly affect other road users by placing them in unnecessary danger' (NHTSA, 2004). Tasca (2000) further outlined some specific driving behaviours that meet the proposed definition, including tailgating, weaving in and out of traffic, failure to yield the right of way to other road users, preventing other drivers from passing, driving at speeds "far in excess of the norm," running stop signs or red lights, and several others.

Whilst definitions for aggressive driving have been established, the actual effect that it has on accident statistics is more difficult to establish. A research update completed for the American Automobile Association Foundation for Traffic Safety on aggressive driving (AAA, 2009) suggested that 56% of fatal accidents between 2003 and 2007 involved one or more actions typically associated with aggressive driving, with excessive speed being the number one factor. The report does recognise that these statistics may overstate the actual effect, as ideally an estimate of the prevalence of aggressive driving would include only instances in which such actions were performed intentionally. A more accurate measure may be when an accident was coded as having two or more of these potentially-aggressive actions, as the report suggests that '…it is more likely that a driver's actions were committed deliberately, as opposed to accidentally, when a driver was coded as having committed multiple potentially-aggressive driving actions.' (AAA, 2009, p. 8). When taking these accidents into consideration they account for 8.4% of crashes. Interestingly, in 2004 the US database of fatal vehicle crashes (NHTSA's Fatality Analysis Reporting System, or FARS) added a new code for 'Road Rage/Aggressive Driving'. The identification of a fatal accident using this code is very rare, accounting for only 0.2% (AAA, 2009) of crashes.

Although it may be argued that there are many other facets to safe driving, in this review we have focused on those most prominent in the literature (and it is notable that speed emerges conspicuously throughout, even as a consequence of aggressive driving), as well as those which have most relevance for green driving behaviours. As we shall see in the next section, speed and aggressive driving have effects on eco-driving as much as they do on safe driving.

3. Green driving

Surprisingly, in our review we found relatively more scientific literature on the effects of driving style on fuel economy and emissions than on how driving style affects safety outcomes. Whilst there are several facets to the concept of green driving, for the private driver the key controllable factors are fuel consumption and emissions. Studies suggest that simply asking drivers to drive economically can reduce fuel consumption by 10–15% (van der Voort et al., 2001; Waters and Laker, 1980). When drivers are asked to drive more efficiently, they generally interpret this as to drive slower. Indeed, Anable and Bristow (2007) estimated that enforcing the 70mph speed limit on dual carriageways and motorways in the UK could save around one mega-tonne of carbon per year. Reducing the speed limit to 60mph would almost double the saving to 1.88 mega-tonnes. Generally, though, it is thought that fuel efficiency is at its maximum between 60 and 80 km/h, as this optimises the trade-off between overcoming rolling road resistance and increasing wind resistance (Andre and Hammarstrom, 2000; Haworth and Symmons, 2001; El-Shawarby et al., 2005).

Clearly, then, simply reducing speed is not the only – nor is it the optimal – strategy for eco-driving, especially considering the implications for journey time. In fact, there are several factors other than speed which can influence both fuel consumption and emissions; data from a study by Ericsson (2001) suggests the focus should be on avoiding heavy acceleration, large power demands and high engine speeds. Similarly, Johansson et al. (2003) found certain characteristics of driving behaviour that were significantly correlated with good fuel economy, such as avoiding unnecessary stops, maintaining low deceleration levels, minimising the use of 1st and 2nd gears, increasing the use of 5th gear, and block changing gears where possible. Exploiting the vehicle's maximum acceleration capabilities can use up to 60% more fuel than mild or normal acceleration levels (El-Shawarby et al., 2005). More specifically, Waters and Laker (1980) demonstrated that the optimal acceleration rate was 0.07g, with fuel consumption increasing by 20% as acceleration increased up to 1.8g.

A report published by the Commission for Integrated Transport in the UK (CfIT, 2007) cited other evidence in favour of adopting an economical driving style for cars, vans, buses and rail. The report contains results from a year-long study conducted in the Netherlands, which showed that car drivers whose self-reported driving behaviour displayed eco-driving techniques consumed 7% less fuel over the course of the study.

Some drivers associate green driving with avoiding unnecessary stops and reducing deceleration rates. When Evans (1979) asked drivers to minimise fuel consumption, two distinct responses were seen – reducing speed and accelerations, and minimising stops (which often result in increased acceleration). Fuel consumption savings were different for each strategy: 6.4% for the 'speed reduction' strategy, and 13.9% for the 'minimising stops' subgroup. Furthermore, trip times increased by 8.2% for the speed subgroup but only 1.5% for the stops subgroups. Combining these observations with the other studies reviewed here leads to the following consensus for what constitutes green driving:

- Plan ahead to avoid stopping
- Use moderate engine speeds and a uniform throttle for steady speeds
- Change gear up as soon as possible using positive (but not heavy) acceleration
- Avoid sharp braking
- Use engine braking for smooth deceleration

4. Safe vs. green driving

Thus far, we have seen that there are some broad overlaps between driver behaviours for safe and green driving, but also some specific differences. Speed, for instance, is a significant factor in safe driving, but less important (though still relevant) for fuel economy and emissions. Conversely, acceleration is perhaps more related to green driving, although it is still a factor in safe driving (af Wahlberg, 2006). Nevertheless, in each of these cases the relationship is a positive one – changing the behaviour to improve road safety also improves one's green credentials, and vice-versa. On the other hand, some techniques that improve green driving may have detrimental effects on safety. For instance, maintaining a constant speed through the avoidance of braking may compromise headway; travelling in the highest possible gear may adversely affect vehicle control. At the extreme, practices such as 'drafting' (closely following large vehicles in order to reduce drag) can be positively dangerous. Haworth and Symmons (2001) identified a series of other factors associated with the vehicle, the environment, and the driver, which could affect safety and/or fuel economy. Notwithstanding these particular conflicts between safe and green objectives, when it comes to driving style, on the whole a safe driver is a green driver, with anticipation, smoothness, and sensible speed being the defining characteristics.

These characteristics of smart driving are already exemplified in some post-licensure driver training programmes, such as that offered by the UK's Institute of Advanced Motorists (IAM). Using an adaptation of the police 'System' of car control (Police Foundation, 2007; see also IAM, 2007), the IAM approach is to deal with hazards consistently with a procedure of 'information, position, speed, gear and acceleration'. A rigorously controlled study over eight weeks (Stanton et al., 2007) found that IAM coaching resulted in improvements in driver skills, knowledge and attitudes. Other research cited by Stanton et al. (2007) suggests that IAM coaching also reduces frequency of traffic offences, as well as frequency and severity of accidents. Moreover, direct opinion from the IAM for the Foot-LITE project is that the System of car control – designed to improve safety – also encompasses the 'vehicle sympathy' consistent with eco-driving. Thus although the IAM programme has long been associated with safe driving, more recently it has been promoted as a route to eco-driving as well.

Further evidence for the overlap between safe and green driving emerges from research into eco-driving programmes, which typically advocate a smoother driving style and embody the principles listed at the end of the previous section. Haworth and Symmons (2001) cited data showing a decrease of around 35% in accidents rates following eco-driving training, in addition to an observed reduction in fuel consumption (11%) and emissions (23–50%). In another case study of the effectiveness of economical driver training for van fleets, Hedges and Moss (1996) showed that accident rates dropped by 40% after eco-driving training. Moreover, eco-driving training resulted in a 52% decrease in accident costs payable by the company and an increase in fuel efficiency of over 50%.

Whilst driver training and coaching programmes can clearly result in benefits for safety and the environment, it has been suggested that the positive effects of training can wane over time, as drivers forget or do not feel motivated to maintain aspects of the driving style (af Wahlberg, 2007; Johansson et al., 2003). Continuous advice and real-time feedback can, on the other hand, enhance and maintain the benefits (Waters and Laker, 1980). For instance, Isler and Starkey (2010) researched the use of a sudden braking warning system – which, in addition to the brake lights, flashed the hazard warning lights above a threshold *g*-force for deceleration. This system benefitted following vehicles, resulting in not only faster reaction times to the braking event, but also a smoother deceleration – thus offers theoretical improvements in fuel consumption. Moreover, there is evidence that such advice could influence both current behaviour as well as potentially inducing longer-term behavioural adaptations (van der Voort et al., 2001; Waters and Laker, 1980).

An in-car system such as Foot-LITE could provide just such support through real-time driver feedback based on advanced or eco-driving techniques to improve both safety and efficiency. Indeed, the role of future technologies in road safety has been acknowledged by the eSafety Working Group (2002) as well as other more recent policy documents (e.g., PACTS, 2007) – as long as it is implemented with care. Haworth and Symmons (2001) cautioned that fuel consumption feedback devices may be detrimental to safety if they cause a distraction to the driver. It is important to bear in mind the driver's task demands before thinking about how to design such a device.

5. In-vehicle information systems

Driving is widely accepted as being a predominantly visual task (Kramer and Rohr, 1982; Spence and Ho, 2009), yet it is necessary to share this resource between the forward view of the road and other visual distractors. Whilst it has been suggested that drivers might have up to 50% spare attentional capacity when driving (Hughes and Cole, 1986), visual competition in driving is already high, and is a crucial factor in driving performance (e.g., Antin, 1993). With the proliferation of IVIS and similar nomadic devices, many authors have expressed their concerns about the potential distraction or overload which such devices may cause (Donmez et al., 2007; Harbluk et al., 2007; Horberry et al., 2006). Performance problems may be especially pronounced if workload is already high (e.g., in urban driving; Liu and Lee, 2006) or if the driver has a lower capacity to respond (e.g., in the elderly; May et al., 2005; Sixsmith and Sixsmith, 1993). Research completed for the 100-car naturalistic driving study by the National Traffic Highway Safety Administration (NHTSA) in the US (Klauer et al., 2006) concluded that 78% of all crashes involved some degree of driver inattention. More specifically, drivers distracted by a secondary task contributed to over 22% of all crashes and near-crashes, with over a third of these secondary tasks involving interaction with a wireless device such as a cell phone (Klauer et al., 2006).

Typical amongst IVIS devices are satellite navigation systems, but other emerging systems include congestion assistants, intelligent speed adaptation, as well as a number of prototype IVIS devices which purport to affect safety and/or fuel economy.

5.1. Satellite navigation systems

Satellite navigation systems are already very popular with motorists, and have implications for safe and green driving. Many functions of modern satellite navigation systems take considerably longer to complete and require more glances compared to conventional controls and displays (such as headlights and windscreen wipers, or visually checking the speed and fuel gauge). A series of related studies (Antin, 1993; Dingus et al., 1989; Wierwille et al., 1991) attempted to assess the visual attentional demand of moving-map displays relative to other in-car tasks. General conclusions were that navigation tasks and displays place higher demands on attention than do conventional (as measured by total glance duration, single glance times, and number of fixations). However, it was also found that drivers adapt to changes in driving demand by altering their scan patterns, suggesting that there may be enough spare capacity to operate a navigation display (Antin, 1993). Dingus et al. (1989) suggested some design improvements to reduce the demand of navigation displays (and hence their impact on the driving task). These were primarily aimed at improving the availability of information on the displays, to be more compatible with the driver's short glance strategy.

Of primary concern for distraction is when the driver interacts actively with the navigation system (such as entering destination information) rather than when they are passively following its directions. Tijerina et al. (1998) conducted a test track study comparing the task of destination entry to two other common in-vehicle tasks – entering a mobile phone number, and tuning the radio. Their findings suggested that, compared to the other tasks, destination entry results in longer completion times, greater eyes-off-road times, longer and more frequent glances to the device and a greater number of lane excursions. Using a voice only system (with no visual display) ameliorated the impact, but not to the level of the two comparison tasks (Tijerina et al., 1998). A later study by Nowakowski et al. (2000) supported these findings. Nevertheless, other research suggests that despite the long task times for destination entry (around 30–40 s), the associated glance durations and eyes-off-road times for the task are still within guidelines for safe operation (Chiang et al., 2004).

Many satellite navigation products can optimise a route for shortest distance or fastest time, as well as by other preferences. Ericsson et al. (2006) investigated the ability of these systems to optimise route planning for lowest fuel consumption, using data from a pre-existing database. The analysis suggested that 46% of trips were not maximally fuel efficient, and that using a fuel optimised navigation system could have reduced fuel consumption by 8.6%, corresponding to a 4% reduction across all journeys. Moreover, the most fuel efficient route also saved on average 8.5% in journey time. Enhancing the navigation system to include real-time congestion monitoring led to a further 7.6% reduction in fuel consumption, though naturally this had the most potential in congested areas. The authors suggested existing navigation systems can offer a fuel saving potential, since 82% of the most fuel efficient routes were the same as the standard shortest route option.

5.2. Congestion assistants

Given the consequences of traffic jams for fuel consumption, two studies have investigated the impacts of a congestion assistant (CA) on driving behaviour, acceptance and workload in a driving simulator (Brookhuis et al., 2009; van Driel et al., 2007). The CA consisted of three functions: congestion warning and information, an active gas pedal (counterforce is applied to the pedal when approaching the jam if the system judges speed to be too high), and 'stop and go' (the longitudinal driving task is taken over by the system when in the jam). Whilst the congestion warning had no impact on driving behaviour, the active gas pedal reduced mean speed across the trial, and the stop and go function reduced acceleration levels as well as headway when in congested traffic. The authors concluded that these systems improved safety (by reducing speed on approach to a traffic jam), enhanced traffic efficiency (due to reduced headway times), and reduced emissions (through lower accelerations). Whilst workload was observed to be reduced during the congestion period, there was potential for workload increases to be observed on the approach to congestion. As a negative consequence of using the system, time headway for manual driving was shorter after the jam than before – possibly a result of acclimatisation to shorter headways with the CA system. Furthermore, whilst driver acceptance of the stop and go system was good, the active gas pedal was the least accepted function by drivers in this study, a finding in common with research suggesting that systems which restrict driver's control are less likely to be accepted (van der Laan et al., 1997).

5.3. Intelligent speed adaptation

Intelligent Speed Adaptation (ISA) is another system which faces similar issues of driver acceptance and behavioural acclimatisation (Lai et al., 2010). Nevertheless, the safety case for ISA has been well documented (e.g., Carsten and Tate, 2005; although see Young et al., 2007, for a view of some safety concerns with ISA), and ISA may have environmental benefits too, by encouraging a smoother traffic flow. Servin et al. (2006) used simulation modelling to demonstrate that ISA could reduce fuel use by up to 70% and emissions by up to 93%, although the effects would be restricted to highly congested conditions. In these conditions, the system also reduced travel time by 15%. These data are optimistic, though, as the savings were calculated against a 0% penetration rate (i.e., no cars fitted with ISA) compared to 100% penetration (every car fitted with ISA). Nevertheless, with high congestion it was shown that a penetration rate of only 20% would deliver a 40% saving in fuel consumption and would reduce emissions by 30–80% in ISA-fitted cars.

Table 1
Summary of design principles for a hypothetical smart driving advisor.

Principle	Source
Exploit multimodal displays to minimise visual demand	Spence and Ho (2009)
Improve availability of visual information to be compatible with drivers' visual strategies and mental models	Dingus et al. (1989), Stanton and Young (2005)
Provide positive as well as negative feedback to facilitate behavioural change	van Driel et al. (2002)

5.4. Other green driving systems

More specific prototype green driving tools have also been investigated. Widodo et al. (2000) estimated fuel consumption and emissions using a green driving style (reducing speed on approach to red traffic lights) either with or without in-vehicle advice about the state of the traffic lights ahead. In the study, fuel use and emissions decreased by between 8 and 30%. When traffic volume was high, using the in-vehicle advice was more efficient than applying the driving style alone; the reverse was true under low traffic volumes. Similarly, van der Voort et al. (2001) used a driving simulator to evaluate different levels of green driving feedback against normal driving. Drivers either used an existing system (which gave average miles per gallon and LEDs for an indication of fuel economy) or were given enhanced advice about optimal gear shift behaviour. The enhanced advice reduced fuel consumption by 16% over normal driving, and again the benefits were particularly pronounced in an urban environment. As with other green driving techniques, there was no significant difference in trip time between any of the trials – mainly by avoiding unnecessary stops.

In sum, various types of IVIS device that can contribute towards smart driving have been available for some time now, and more are emerging. Several systems (e.g., satnav, congestion assistants, ISA) can have ancillary benefits for both safe and green driving, while specific devices for green driving assistance are emerging. The evidence suggests that these tools are most effective in urban environments, and that – unlike training programmes – the benefits are maintained over time. Whilst such devices may offer tangible benefits, the increased competition for limited attentional resources within vehicles may ultimately affect performance (Schlegel, 1993); thus devices should be designed according to robust ergonomics principles to ensure positive benefits are gained while negative impacts on workload or distraction are avoided. Indeed, codes of practice for the design and development of such systems are beginning to emerge (e.g., Amditis et al., 2010; Cotter et al., 2006). More specifically, work conducted by van Driel et al. (2002) presents some lessons learned in this area based on user needs and evaluations of a green driving advice tool similar to the Foot-LITE concept. It was suggested that future devices should support drivers by giving directed advice – including positive feedback – to improve fuel economy or driving style.

6. Summary and conclusions

This paper aimed to set the benchmarks for what constitutes 'smart' (i.e., both safe and green) driving, as a basis for determining the driver's information requirements for a smart driving IVIS tool such as Foot-LITE. We reviewed the ergonomics and related driving performance literature to establish these benchmarks and the viability of the Foot-LITE system. It was clear that driving style can measurably impact upon safety and environmental friendliness, and for the most part the behaviours affecting these two objectives (such as speed and aggression) are correlated. Furthermore, there was evidence that although driver training can improve driving behaviour, the effects are outlived by ongoing feedback, such as that provided by an IVIS advisor. Various types of existing IVIS device were reviewed which can have ancillary benefits for both safe and green driving, while there is a burgeoning market for specific green driver assistance products. The evidence suggests that – as with training programmes – these tools are most effective in urban environments, and that – unlike training programmes – the benefits are maintained over time. Thus there is a good basis for the Foot-LITE system to effectively contribute to both safe and green driving.

Notwithstanding these positive conclusions, we also found that in specific instances, the behaviours for safe and green driving can be in conflict. A system such as Foot-LITE will need to manage these conflicts, and we steadfastly believe that the rational conclusion in these instances is always to prioritise safety. Bearing this trade-off in mind, we can revisit the green driving factors presented in Section 3 of this paper to propose a combined list of benchmarks for smart driving:

- Plan ahead to avoid stopping and minimise sharp braking
- Use smooth but positive acceleration to reach high gears sooner, and use engine braking for smooth deceleration
- Use moderate engine speeds and a uniform throttle for steady speeds
- Obey speed limits

The Institute for Advanced Motorists' 'system' of car control (IAM, 2007) is highly compatible with such smart driving, and the Foot-LITE project has adopted the IAM model as the basis for its driver feedback product. Whilst there is good evidence that IAM coaching improves driver skills (Stanton et al., 2007), as well as supposition that it can also benefit eco-driving, so far there is no objective data on the specific effects of IAM driving on fuel use and/or emissions. Establishing these data and validating the assumption is one of the research goals of the Foot-LITE project.

Having established, at a high level, the information requirements of the driver, we also considered the requirements for information presentation. Any IVIS interface must be designed with the driver's primary task in mind in order to preserve driving performance, and a safety-oriented system such as Foot-LITE must embody best practice ergonomics principles to minimise issues of distraction or overload from the information display. However, whereas there is ample research into the human factors implications of safety-related IVIS devices, in most cases the evidence regarding green driving IVIS tools is restricted to their effects on fuel economy and/or emissions. There appears to be little addressing any distraction or safety effects of using a green driving interface. Notably, many of the benefits of such tools are most evident during high congestion or urban driving conditions – but these are also conditions of high driver workload and so less spare capacity is likely to be available (Harms, 1991; Zeitlin, 1995), increasing the potential for distraction.

A system such as Foot-LITE could, therefore, improve both safety and efficiency, as long as it is designed according to robust ergonomics principles (summarised in Table 1). Lessons can and should be learned from analogous systems, and ergonomic design guidance for such systems has recently become available (e.g., Amditis et al., 2010; Cotter et al., 2006; van Driel et al., 2002). Both attention and mental workload must be considered as key human factors; many authors agree that a key goal of design is to maximise the match between task demands and human capacity (e.g., Bainbridge, 1991; Gopher and Kimchi, 1989; Lovesey, 1995; Neerincx and Griffioen, 1996). One way of achieving this, particularly in the visually intensive environment of driving, would be to exploit multimodal displays (cf. Spence and Ho, 2009). Where visual information is unavoidable, the interface should be designed to reduce visual demand by improving the availability of information, to be compatible with the short glance strategies used by drivers (cf. Dingus et al., 1989). Finally, in order to facilitate behavioural change for a hypothetical IVIS smart driving advisor (such as Foot-LITE), the feedback provided should be positive as well as negative (van Driel et al., 2002).

Following the outcome of this review, more research is clearly needed in several areas related to smart driving, and over the course of the Foot-LITE project these areas will be investigated. Fundamentally, a smart driving style (such as the IAM system) needs to be validated in contributing not only towards safe driving, but also eco-driving. More specifically, any proposed smart driving interface must be able to demonstrate an increase in desired behaviours while avoiding an increase in negative effects such as distraction. The possibility of an adaptive interface, which regulates the level of information (again prioritising safety-related information) according to task demands, will also be investigated. Driving according to smart principles may in itself be demanding, and consequently increase driver workload; this possibility needs to be factored into any evaluation in the same way as other performance implications (such as journey time) have previously been addressed.

From here, the next steps in the Foot-LITE project are: to elaborate on the information requirements using a Cognitive Work Analysis (CWA) process, to develop a set of candidate interface designs which meet the information presentation requirements stated above (including multimodal displays), and to test the effects of these interfaces on driver performance and workload. Although research has so far investigated safe and green IVIS devices separately, nobody has yet brought them together in a single integrated smart driving information system. Based on the review in this paper, the Foot-LITE project can progress to development of the system, ensuring that green driving does not come at the expense of safe driving. Indeed, whilst the growing interest in green ergonomics more generally is laudable, we would suggest that this should be an abiding principle across domains.

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