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A critical review and assessment of Eco-Driving policy & technology: Benefits & limitations

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ABSTRACT

Eco-Driving has received significant attention in literature and among policy makers for its claimed benefits in reducing CO_2 emissions and fuel consumption. Many investigations of Eco-Driving policy have reported potential reductions in fuel consumption and CO_2 emissions ranging from 5% to 40% across various jurisdictions and initiatives. This paper comprises a review and assessment of Eco-Driving policy and its claimed benefits. The possible negative impacts of Eco-Driving, often neglected in previous research, are also highlighted. These include policy limitations which may result in increases in accident risk, and CO_2 emissions at traffic network level. In addition, the limitations of certain Eco-Driving technology are also highlighted. The results of this review and assessment reveal that Eco-Driving Policy has the potential to reduce CO_2 emission and fuel consumption in certain circumstances, but in congested city centre traffic many conflicting views exist in the literature, resulting in some doubt over the effectiveness of the policy in such circumstances.

1. Introduction

Air pollution emissions have a negative environmental impact both on human health (Ye et al., 1999), and climate change (Strawa et al., 2010; Uherek et al., 2010). It has been noted that transport emissions comprise 26% of the overall CO_2 emissions in the EU and these are a major contributor to air pollution worldwide (Nocera and Cavallaro, 2011). To limit and reduce these negative impacts many air pollution control initiatives have been taken in the transport sector.

Air pollution control policies and technology have included measures to reduce the concentration of air pollutants (g/m^3), measures to reduce the emissions rate (g/s) of pollutant sources and measures to reduce the emissions quantity (g). Examples of the control of emissions rate include: the introduction of carbon based vehicle tax systems (Lautso et al., 2004); improvements in vehicle technology such as catalytic converters, alternative fuels, and engine efficiency (Manzie et al., 2007). Interventions which have seen a reduction in emissions quantity have included congestion charging and improvements in incentives for the use of public transport (Atkinson et al., 2009; González-Díaz and Montoro-Sánchez, 2011).

Another technique which encourages the reduction of vehicle emissions intensity is Eco-Driving, a driver behaviour based method which has begun to receive more focused attention in literature (Beusen et al., 2009; Barkenbus, 2010; Sivak and Schoettle 2012). Eco-Driving has been defined as a decision making process which will influence the fuel economy and emissions intensity of a vehicle to reduce its environmental impact (Sivak and Schoettle, 2012). These decisions include: strategic decisions (vehicle maintenance), tactical decisions (route selection & vehicle loading) and operational decisions (on-road driver behaviour).

This paper provides a review and assessment of the Eco-Driving policy. Examples of Eco-Driving in existing practice are presented and discussed as are relevant investigations into its potential environmental impacts. The barriers to the widespread implementation of Eco-Driving are also highlighted as well as a number of potential limitations to the policy which may have been overlooked in previous research.

2. Eco-driving initiatives: claimed benefits and possible limitations

Several techniques have been highlighted in the literature to facilitate the Eco-Driving decision making process. Using a similar definition structure to that proposed by Sivak and Schoettle (2012), examples of Eco-Driving technology, training and practices are outlined below:

2.1. Strategic decisions

Strategic decisions which may aid in the reduction of the environmental impact of travel and hence contribute towards

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Eco-Driving include the regular maintenance of vehicles (Sivak and Schoettle, 2012). Vehicle maintenance keeps vehicles emitting within their desired limits. Maintaining optimal tyre pressure and maintenance of the emission control system are the two key features among maintenance techniques. Tyres with increased rolling resistance can cause a significant drop in fuel economy (Sivak and Schoettle, 2012), while it has been reported that up to 40% of excess vehicle emissions can be attributed to the deterioration of vehicle emission control systems over time (An and Ross, 1996).

2.2. Tactical decisions

Tactical decisions can also be made to limit the negative environmental impact of travel as part of Eco-Driving. These could include issues such as the optimum choice of route to limit CO_2 emissions or choices on vehicle loading to reduce fuel consumption and CO_2 emissions. It has been noted that an extra 45 kg of load in a vehicle was found to cause a 2% increase in fuel consumption (EPA, 2011). This increase in fuel consumption is also clearly dependent on the size of the vehicle, the length/time of travel, and the driving style of the driver. Smaller engined vehicles would result in a higher increase in fuel consumption for the same increase in vehicle load, compared to vehicles with larger engines (EPA, 2011).

Numerous investigations have reported that a 15–40% increase in fuel economy can be achieved (subject to road grade and congestion) through selection of Eco-routes, i.e. the optimum route choice limiting CO_2 emissions and fuel consumption (Sivak and Schoettle, 2012). It has been estimated that the choice of route using a fuel consumption and emission model can result in energy savings of up to 23% if motorists choose lower emissions routes (Ahn and Rakha, 2008). An investigation was conducted in Sweden to analyse fuel consumption and CO_2 emission using a navigation system where optimisation of route choice was based on the lowest total fuel consumption. It was found that 46% of trips, which were the result of drivers' spontaneous choice of route, were not the most fuel-efficient. These trips could save, on average, 8.2% of fuel by using a fuel-optimised navigation system. This corresponded to a 4% fuel reduction for all journeys (Ericsson et al., 2006). While such positive results are encouraging, as discussed further in Section 5, there is a notably wide range in the claimed benefits of Eco-routing.

In order to facilitate the Eco-routing decision making process, driver assistance tools are required, such as on-board or online Eco-routing navigation systems, disseminating the optimum route choice to drivers. However, existing driver assistance devices for Eco-routing commonly use road-link based information to suggest eco-friendly routes (Barth et al., 2007). These models determine the total emissions from a certain route based on either historical traffic data or fleet-wide average emissions factors. Such models fail to take account of real world driving conditions, for example if all drivers were to use such technology in a particular area and take the suggested Eco-route, then this route would very quickly become congested, resulting in increased emissions. At present such an eventuality is not a problem as the penetration of Eco-routing navigation systems among the population of drivers in most countries is low. If, however, Eco-routing was to become widespread, current driver assistance technology would not operate satisfactorily in congested traffic networks. To avoid this limitation, it is necessary to connect such models with real time traffic information sources.

2.3. Operational decisions

Any vehicle is capable of producing much more emissions in real on-road driving conditions than its respective emission standard due to in-efficient driving styles, traffic congestion, road grade, heavy winds, etc. Changes in driving style can be incorporated into an individual's operational decisions as part of Eco-driving, reducing the emissions from a trip. Aggressive driving behaviour such as hard acceleration and braking, excessive speed, open windows, etc. results in higher emissions rates from a vehicle compared with a more gradual, smooth driving style. Such changes in driving behaviour have been shown to result in significantly higher reductions in emissions and energy consumption compared to other Eco-Driving decisions such as better maintenance practices (Shaheen et al., 2011). Numerous investigations have reported that maintaining an Eco-driving style can reduce fuel consumption by 5–30% (Zarkadoula et al., 2007; Barkenbus, 2010; Boriboonsomsin et al., 2010; Sivak and Schoettle, 2012). Such savings in fuel have subsequently resulted in monetary savings, for example, an estimation of 10.2% in fuel saving during an Eco-driving training session of bus drivers in Athens estimated savings of over €6 million per annum (Boriboonsomsin et al., 2010). Again, as discussed further in Section5, a notably wide range of potential savings has been reported in the literature.

Investigations have suggested that Eco-driving with the aid of driver assistance devices can play a significant role in reducing emission and fuel consumption (Yang et al., 2012). Eco-driving indicative devices are designed to provide instantaneous fuel rate and CO_2 emissions information, also advising on acceleration/braking rates (Beusen et al., 2009; Ando et al., 2010). In these devices, engine data in real time and/or GPS data are used for emissions calculations. However the models working behind these existing devices are also subject to limitations from an emission modelling perspective and have scope for improvement.

Similar to existing Eco-routing models, many of the available Eco-Driving models are limited by their use of average emission factors to predict CO_2 emissions over a specific travel distance. Such models fail to take account of the smooth or aggressive driving style of a driver and therefore do not give an accurate representation of the environmental impact of operational Eco-Driving decisions. Future developments in models of this nature should account for detailed vehicle trajectories (e.g. Beckx et al., 2010) in real time in order to capture periods of hard acceleration and increases in engine load.

Eco-Driving models with similar limitations have also been developed based on the average emission for a particular road link (e.g. link average speed or average emission factor) or based on normal driving cycles (Manzoni et al., 2011; Kang et al., 2011, CarbonDiem, 2012; Mensing, et al., 2014). Other important methodological limitations of existing Eco-Driving models are the omission of road grade information, wind impact, and hot/cold emission factors.

3. Eco-driving: existing policy

Based to a certain extent on the positive scientific evidence outlined in the previous section many national governments have adopted Eco-Driving policies as a means of reducing energy consumption and CO_2 emissions in the transport sector. Historical evidence for Eco-Driving was first found from an audience training background study by Department of Energy (DoE) in US in 1976. Other landmark training examples in this field included an effort by Wisconsin Clean Cities (US), a non-profit environmental group in 1994 and Eco-Driving training by the Swedish National Association of Driving Schools in 1998 (Quille et al., 2012).

In 2001, the European Climate Change Programme (ECCP) estimated the potential for a significant reduction of CO_2 from the implementation of Eco-Driving training and education (SenterNovem, 2005). Also in 2001, 'Eco-Driving Europe' began