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# Ecodrives as a road safety tool for Australian conditions

June 2009





**Australian Government**  

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**Department of Infrastructure,  
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# **Ecodrives as a road safety tool for Australian conditions**

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**Abstract**

Ecodriving involves driving more smoothly by anticipating changes in the traffic, operating the vehicle within an optimum rev range, skipping and changing up gears as soon as possible, and avoiding sudden or substantial episodes of braking or acceleration. A substantial body of literature promises mild to substantial benefits from ecodriving in terms of fuel saved, emissions reduced, and possibly crashes averted. However, many of the published trials can be criticised for various methodological shortcomings, particularly the lack of a control group, not testing in a real-world traffic environment, and limited attention given to assessment of long-term behaviour changes.

A trial was conducted with heavy vehicle drivers operating in real traffic, with follow-ups at six and twelve weeks. Comparisons were made with a control group and pre versus post training, and improvements were evident in fuel use, the number of braking applications, and the number of gear changes, without any sacrifice in overall speed or driving time. The effects were either still present three months later or in some cases progressively improving. However, the trial was not large enough to be conclusive and testing was carried out on a pre-determined route. The results do, however, warrant a larger trial, particularly a naturalistic one in which telematics are used to capture in-service data as the drivers go about their daily work.

Despite the need for further research, ecodrive holds significant promise for implementation in Australia. An ideal opportunity exists now, before widespread take-up in Australia, to a) empirically identify the critical content and optimal methods of delivery for an ecodrive curriculum; b) explore the role that technology can play in not only evaluating the impact of ecodriving but also in supporting drivers to make more informed vehicle control decisions; and c) develop a best-practice model, informed by cost-benefit analyses, that might be disseminated widely for corporate use and built into novice driver training.

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**Notes**

- (1) The Department's reports are disseminated in the interest of information exchange.
  - (2) The views expressed are those of the author(s) and do not necessarily represent those of the Australian Government or the Department.
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## EXECUTIVE SUMMARY

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When expressed as a function of exposure – number of vehicles registered, distance travelled, or fuel consumed – Australia’s road crash fatality rate has fallen in recent years, along with gradual increases in each of these exposure measures. In turn, these steady increases in driving are a concern from an environmental point of view. In response to changing community and government attitudes, vehicle manufacturers are currently working to improve the fuel efficiency of the vehicles they sell, but given the age of Australia’s national fleet and the time it will take for such advances to sufficiently permeate the community, it will be some time before these initiatives have a substantial effect. Changes in driver behaviour, however, can make a difference now, creating a ‘triple-bottom-line’ effect – financial savings for the individual and/or company in terms of reduced fuel and maintenance costs; benefits for the environment in a slowed depletion of resources and reduced emissions (particularly greenhouse gases); and savings to society that arise from fewer crashes, less road trauma and a reduced detrimental health impact of pollution generated by automobiles. Seemingly a panacea for both road safety and environmental concerns, these behavioural changes are promised via a relatively new style of driving – generically known as ecodriving.

Ecodriving essentially involves driving more smoothly – ‘flowing’ the vehicle. Drivers are encouraged to look further ahead to better anticipate changes in the traffic and road environment, operate the vehicle within an optimum rev range, skip and change up gears as soon as possible, avoid sudden or substantial episodes of braking or acceleration, check tyre pressures regularly, and so on. While primarily developed and applied in Europe, this advice would seem easily transferable to Australian conditions. An internet search quickly reveals what would seem to be a wealth of ecodriving information and trial outcomes, some of which is published in the scientific literature, and all of which promises mild to substantial benefits from ecodriving in terms of fuel saved and emissions reduced.

While there would seem to be no negative ecodriving results and few studies that suggest no benefit at all, some cautionary notes arise from a more critical review of the literature. Most of the published trials can be criticised for various methodological shortcomings, the most common of which is a lack of a control group. A set of control drivers would not have undergone the ecodriving training and associated activities against which to make comparisons. Most of the reports of ecodriving outcomes are pre- versus post-trial comparisons. A control group is needed to isolate the *cause* of the reduction in fuel use and determine whether the training course per se is the critical element. Additionally, a proportion of the research can be criticised to some extent for not testing in a real-world traffic environment. Finally, longer-term follow-up is rare, which is a requirement to determine the longevity of any behaviour changes and evaluate whether there is a road safety advantage.

A small trial based on the outcomes of the literature review was carried out with heavy vehicle drivers, including a control group, driving in real traffic, and employing 6- and 12-week follow-ups. Results in terms of fuel consumed, number of braking applications and gear changes were positive and in some cases substantial compared to both pre-course measures and data taken from the control group, without any sacrifice in terms of speed or driving time. The effects were either still present three months later or in some cases progressively improving. Importantly, the trained drivers were very positive about their own outcomes, despite some pre-course scepticism. This trial is not conclusive, however, due to its scale in terms of both driver numbers and vehicle types.

Both the uncertainties highlighted by the evaluation of the literature and the positive, but not conclusive, benefits demonstrated by the quite rigorous trial are certainly solid support for a larger trial, particularly a more naturalistic one in which telematics are used to capture in-service data as the drivers go about their daily work. A number of other elements could be built into a large scale



trial to determine *which* elements of the ecodrive training are critical, if indeed it *is* the training itself that is responsible for the positive outcomes. This in turn would enable the development of a best-practice curriculum for Australian conditions and afford the possibility for cost-benefit analysis to consider a wide-spread implementation.

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## ABBREVIATIONS

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ABS	Australian Bureau of Statistics
DITRDLG	Department of Infrastructure, Transport, Regional Development and Local Government
OECD	Organisation for Economic Cooperation and Development

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# 1 INTRODUCTION

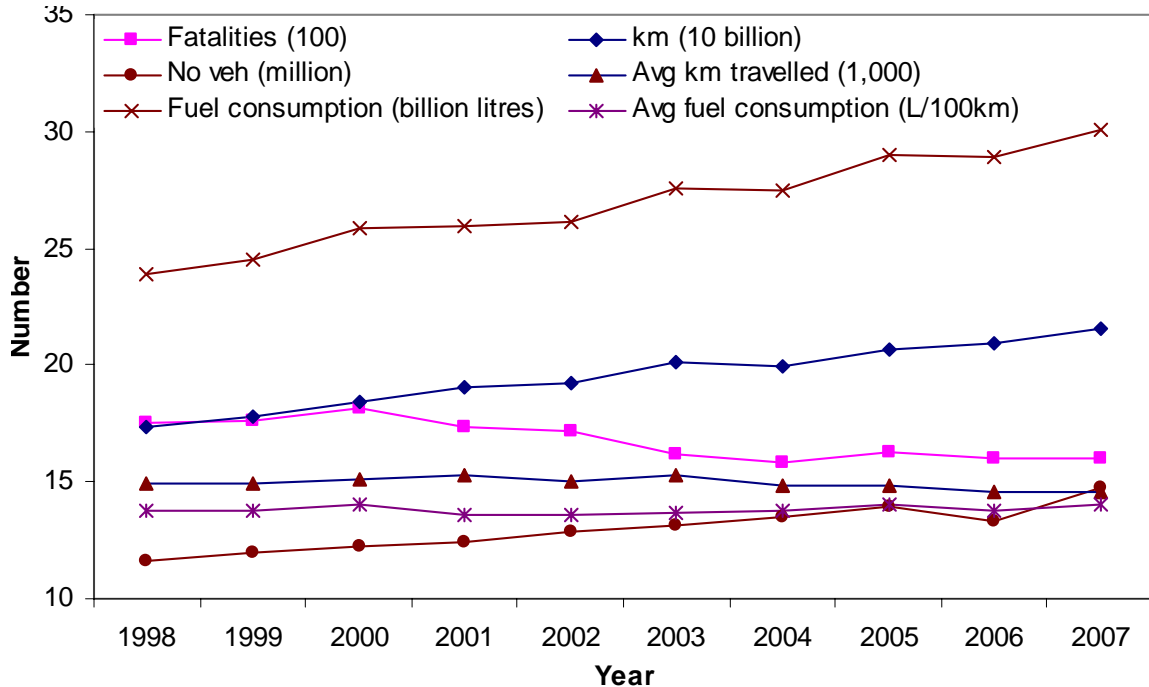
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## 1.1 Background

There is an increasing concern for environmental issues at all levels of society. The greenhouse effect and global warming, habitat destruction and fragmentation, and species extinction, are all currently topical. High levels of attention have also been afforded to transport issues, such as equality and convenience of access, the cost of fuel, congestion, the social and financial cost of casualties, and the health effects of pollution. There is clearly an overlap between environmental concerns and road transport safety – for example, all other things being equal, any decrease in road transport should result in reduced emissions and fewer crashes. However, all other things are rarely equal and so proponents of one are not necessarily strong advocates of the other. For example, there are safety benefits in the construction of freeways to move traffic out of residential and shopping districts, a move that would be criticised for the likely environmental damage caused by the road's construction and the increased capacity that is likely to induce additional travel.

Figure 1 plots a number of road safety or environmentally relevant variables across a ten-year span from 1998-2007 (adjusted in various powers of ten to enable them to be shown against a single y-axis). The number of fatalities has gradually declined over that period, from a high of 1,817 in 2000 down to 1,602 in 2007 (2004 represents the lowest number of fatalities at 1,583) – on average 4.6 individuals are killed in road crashes across Australia each day.

**Figure 1: Road fatalities, number of registered vehicles, total and average per vehicle fuel consumed, and total and average per vehicle kilometres travelled for Australia 1998-2007**

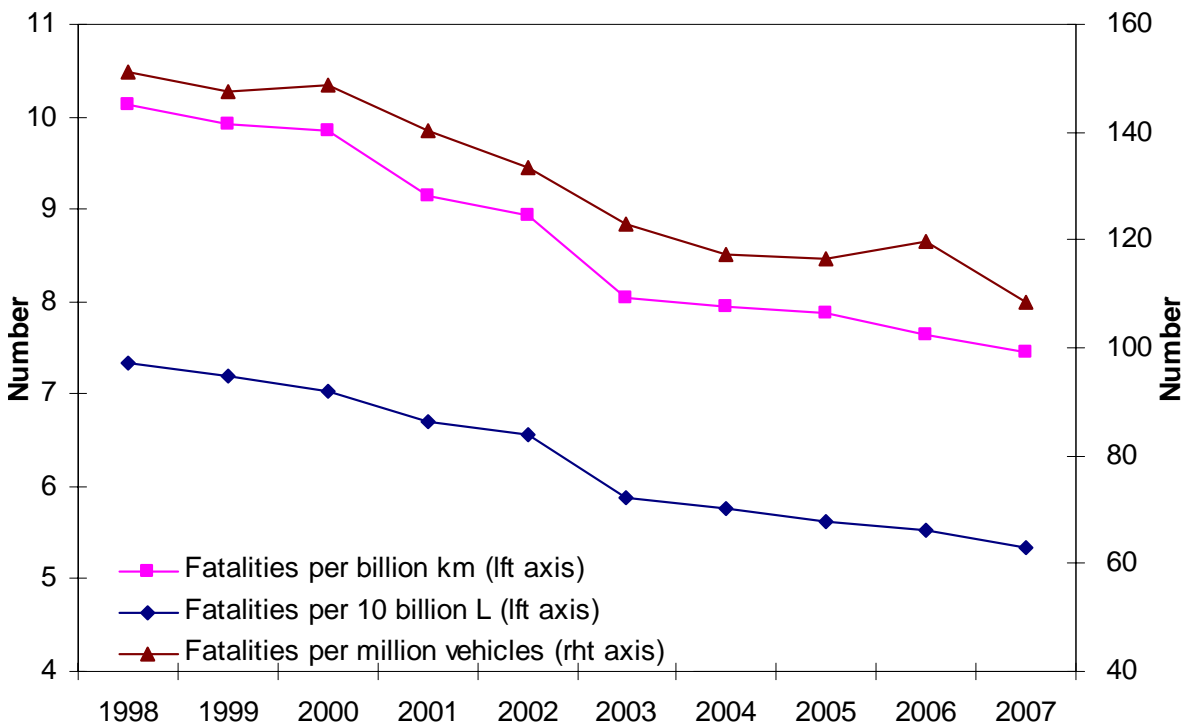


Data sources: Fatal Road Crash Database (DITRD LG, 2008); Survey of Motor Vehicle Use (ABS, 9208.0: 2000, 2007, 2008)

The true improvement in road safety is not fully represented by a consideration of the number of fatalities, however. The decrease in fatalities has occurred despite the gradual climb in both the number of vehicles on the road and the total distance travelled (as shown in Figure 1) – in both cases substantially increasing exposure. The number of registered vehicles on Australia’s roads has also increased every year, from 11.6 million in 1998 to 14.8 million in 2007, travelling 173 billion kilometres in 1998 up to 215 billion kilometres in 2007. The average distance travelled per vehicle, however has remained relatively stable over that ten year period at around 14,900 kilometres per year. In a less positive outcome for the environment, fuel consumption has climbed markedly over that decade, and despite the gradual modernising of the national fleet, the average fuel consumption per vehicle has remained between 13.6 and 14 litres per 100 kilometres. In both 2005 and 2007 the average fuel consumption was 14 L/100km, indicating no improvement at all (in fact it is now marginally worse).

To better take account of the increase in exposure the number of fatalities is plotted as a function of the number of kilometres travelled, fuel consumed and vehicles registered (see Figure 2). The number of road deaths has consistently fallen in the ten-year period 1998-2007 when considered against the substantial increase in exposure. Given the consistency in average annual travel per vehicle and fuel consumption (L/100km), all three measures depicted in Figure 2 are almost parallel. A decrease in travel has clear road safety and environmental benefits but would require concomitant improvements in public transport both to encourage such behaviour change and address equity and mobility issues. A decrease in fuel consumption, however, need not be realised through reductions in mobility, nor must it be met with government support for alternative means of transport.

**Figure 2: Road fatalities per billion kilometres travelled, per 10 billion litres of fuel consumed, and per million registered vehicles for Australia 1998-2007**



Data sources: Fatal Road Crash Database (DITRDLG, 2008); Survey of Motor Vehicle Use (ABS, 9208.0)

Factors related to the way a vehicle is driven, the time of day it is driven, the duration of the journey, and the condition of the roads all have a bearing on the likelihood of a crash. Likewise, the

same factors are determinants of how a particular journey impacts on the environment. For example, aggressive driving increases the risk of being involved in a crash, uses 30-34% more fuel (Van den Brink & Van Wee, 2001; Department of Primary Industries and Energy, 1991), and produces a correspondingly larger volume of harmful emissions. The focus of this study is the environmental and safety outcomes of changing driver behaviour to a style of driving often referred to as 'ecodriving' (or EcoDriving).

Ecodrive initiatives are designed to encourage lower driving speeds and adoption of a more anticipatory, and therefore defensive rather than aggressive, style of driving. The high cost of fuel and concerns over local and global environmental impacts provide an ideal context within which to engage drivers and fleet managers on the potential to reduce fuel consumption and emissions by changes in driving style. Importantly, those same driving behaviours could be expected to deliver reductions in the frequency and severity of crashes. An enhanced understanding of the impacts of eco-driving is therefore of relevance not only to individual motorists and fleet managers, but also to transport and road safety and health policy makers because of its potential to deliver a 'triple-bottom line' effect: financial savings for the individual and/or company in terms of reduced fuel and maintenance costs; benefits for the environment from a slowed depletion of resources and reduced emissions (particularly greenhouse gases), including particulate pollution; and savings to society that arise from fewer crashes, less road trauma and a reduced detrimental health impact of pollution generated by automobiles.

In terms of the potential health benefit, it is estimated that in the year 2000 alone, motor vehicle pollution accounted for 900 to 4,500 additional cases of cardio-vascular and respiratory diseases and between 900 and 2,000 early deaths, costing between \$1.6 billion and \$3.8 billion (BTRE, 2005). In that same year there were 1,817 fatalities in Australia arising from road crashes. In a more in-depth analysis, Roberts and Arnold (2007) determined that if transportation fuel consumption in the US had been reduced by 7% in 1990 (to meet Kyoto Protocol requirements), in 2003 there would have been 16,386 fewer traffic deaths.

## **1.2 Aims & Objectives**

This study seeks to critically assess the applicability of eco-driving, primarily developed and evaluated in Europe, to Australian conditions, vehicles, and drivers. The study was designed to:

- Characterise and assess international and local eco-drive initiatives in order to develop a 'best practice' model for implementation in Australia
- Critically assess previous eco-drive evaluation methods and results and devise a method to evaluate Australian eco-drive trials
- Use a case study method to investigate the actual difficulties and real-world advantages of implementing eco-driving within Australian fleets.

## **1.3 Report structure**

The initial chapters of this report explore the tenet that changes in driving style will save fuel and reduce the number and severity of road crashes. Consequently, Chapter 2 examines factors that determine vehicle fuel consumption while Chapter 3 presents the case that driving behaviour, including travel speed and driving aggressivity, directly impact crash likelihood and outcome. From that foundation, Chapter 4 then examines a body of eco-driving literature, with Australian contributions provided separately in Chapter 5. Chapter 6 then describes the method and results of an eco-drive trial informed by the review and designed and conducted by the current authors. Finally, Chapter 7 presents a set of conclusions for eco-drive training and research in Australia and the potential outcomes that may be expected, along with suggestions for follow-up research.

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## 2 FACTORS THAT AFFECT VEHICLE FUEL CONSUMPTION

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### 2.1 Definitions

Though they actually relate to different aspects of a vehicle's performance, the terms 'fuel economy', 'fuel consumption' and 'fuel efficiency' are often used interchangeably. *Fuel consumption* is simply the "total quantity of fuel consumed by a vehicle, or specified segment of the vehicle fleet, in a road network in a specified area and time period" (Nairn and Partners, Leonie Segal Economic Consultants & Watson, 1994, p. v). 'Specific fuel consumption' is the amount of fuel consumed per unit of power output, usually expressed as mass or volume per unit power per unit time (BTCE, 1996), or more generally the fuel consumption per kilometre (Van den Brink & Van Wee, 2001). Nairn et al. (1994) refer to litres consumed per 100 kilometres travelled as 'fuel consumption rate'.

*Fuel economy* is the inverse of fuel consumption rate – the distance that can be travelled using a certain amount of fuel. Fuel economy was traditionally measured in miles per gallon – the metric equivalent of kilometres per litre is rarely used. According to BTCE (1996), the number of kilometres travelled by a vehicle per litre of fuel is actually a measurement of fuel efficiency rather than fuel economy. BTCE defines 'fuel intensity' to be the inverse of fuel efficiency, typically measured in litres per 100 kilometres.

A standard dictionary definition of efficiency in mechanical terms is essentially the ratio of the work or energy output of a machine or process as a function of the work or energy input, often expressed as a percentage. Due to forces such as friction and inertia, this ratio generally does not reach 100%. *Fuel efficiency*, therefore, is the work output of an engine in terms of vehicle travel as a function of the energy content of the fuel expended in the operation of the vehicle. As such, the fuel economy of a vehicle can be enhanced by improving the fuel efficiency. Accordingly, fuel efficiency is a function primarily of the vehicle, while fuel economy will take account of the driver's behaviour as well as the capabilities of the vehicle.

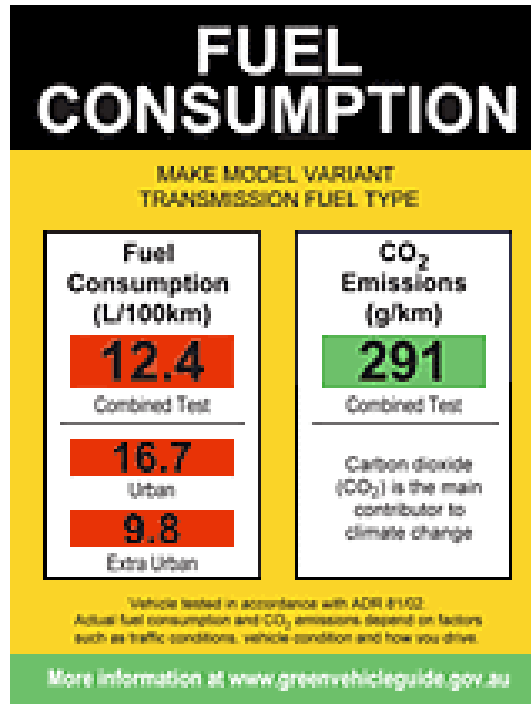
### 2.2 Measuring fuel economy

Via a Commonwealth Government website <<http://www.greenvehicleguide.gov.au>>, the Green Vehicle Guide allows prospective car buyers to select and compare modern vehicles weighing up to 3.5 tonnes available for sale in Australia. A search can be mounted for specific vehicles or on the basis of vehicle type (e.g. small cars, off road vehicles, etc). The site returns ratings and values for greenhouse gases and other pollutants, fuel consumption (L/100km), as well as noise levels. An overall star rating is the sum of the air pollution and greenhouse ratings.

The pollution specifications are detailed in Australian Design Rule (ADR) 79 Emissions Control for Light Vehicles. The current rating scale came into effect at the beginning of 2006 and allows for manufacturers to certify vehicles to the most stringent current Euro 4 standard. The specifications for measuring fuel consumption and carbon dioxide (CO<sub>2</sub>) emissions are contained in ADR 81 Fuel Consumption Labelling for Light Vehicles, which were updated in 2008 for application from April 2009 onwards. The test methods are contained in the United Nations Economic Commission for Europe Regulations (UN ECE R83 and R101), and involve controlled laboratory testing of both urban and highway drive cycles. The urban trip simulates approximately 7.3 km of stop-start driving with an average speed of 18.8 km/h. The highway portion of the simulation covers a distance of about 3.7 km at speeds over 100 km/h. The entire test is 11 km long with an average

speed of 33.6 km/h. The resultant fuel consumption and carbon dioxide results are listed on official windscreen stickers that must be affixed to all new vehicles sold in Australia (see Figure 3). The actual in-service fuel consumption of vehicles is generally higher than that quoted in official fuel consumption figures – up to 15% more in city conditions and 34% in highway driving (AGO, 2000).

**Figure 3: Fuel consumption label fixed to the windscreen of all new Australian cars.**



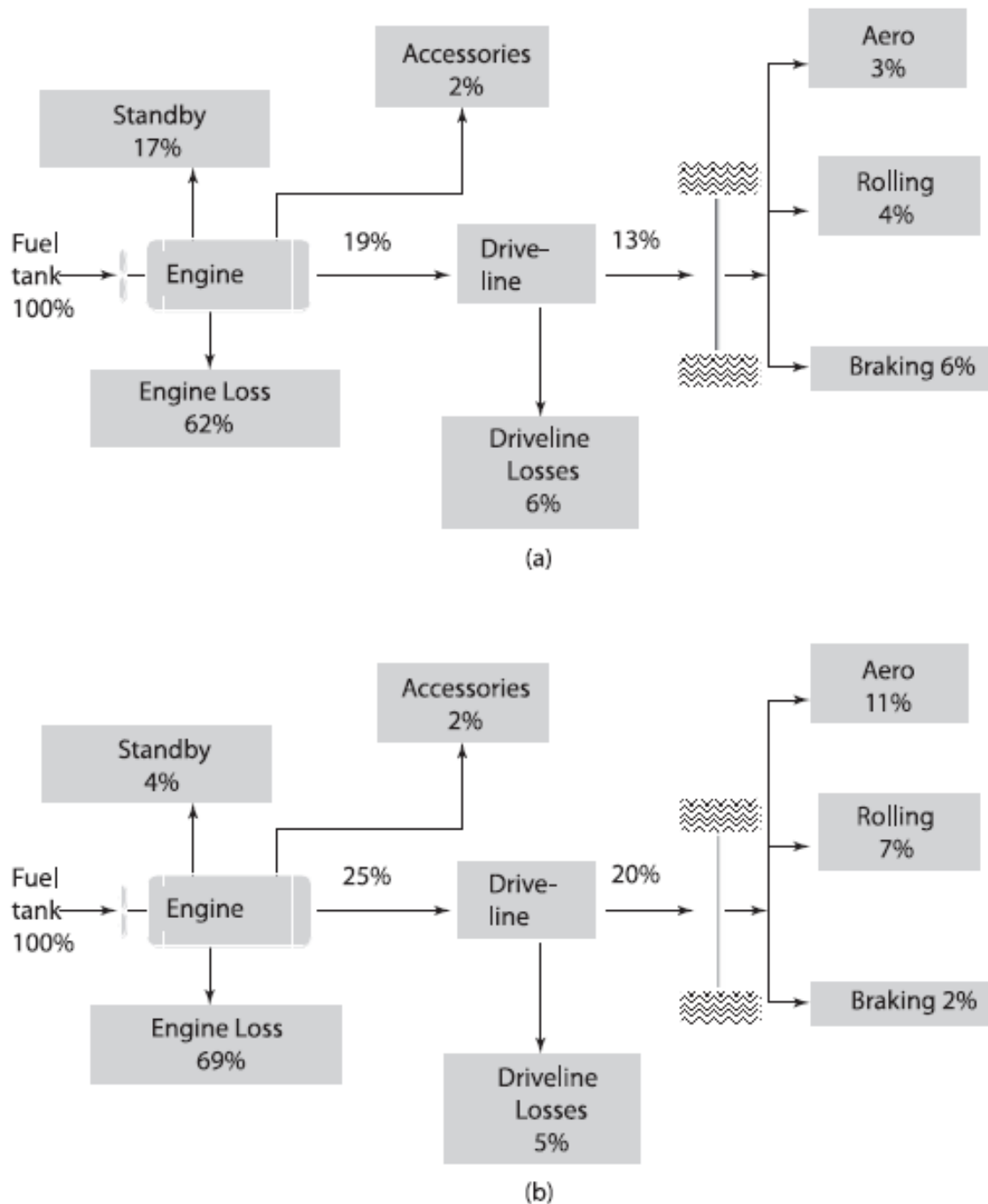
Source: <<http://www.environment.gov.au/settlements/transport/fuelguide/label.html>>

## 2.3 Vehicle energy use

Figure 4 is a reproduction of a chart published by the Transportation Research Board (TRB, 2006) highlighting the various energy flows and sinks for a midsize passenger car for both urban and highway driving. Around two-thirds of the chemical energy contained in petrol is lost in the conversion of heat to mechanical energy in the engine. After idling, powering accessories, and driveline losses, only 13% of the original energy remains to turn the wheels in urban driving – 20% for highway driving. Of these figures, 3% and 11% are consumed overcoming aerodynamic drag for urban and highway driving respectively, 4% and 7% are sapped by rolling resistance from the contact between the tyres and the road, and 6% and 2% are required for cycles for braking and acceleration to recover the lost speed.



**Figure 4: Components of energy loss converting fuel to vehicle travel for a typical mid-size passenger car for (a) urban driving, and (b) highway driving**



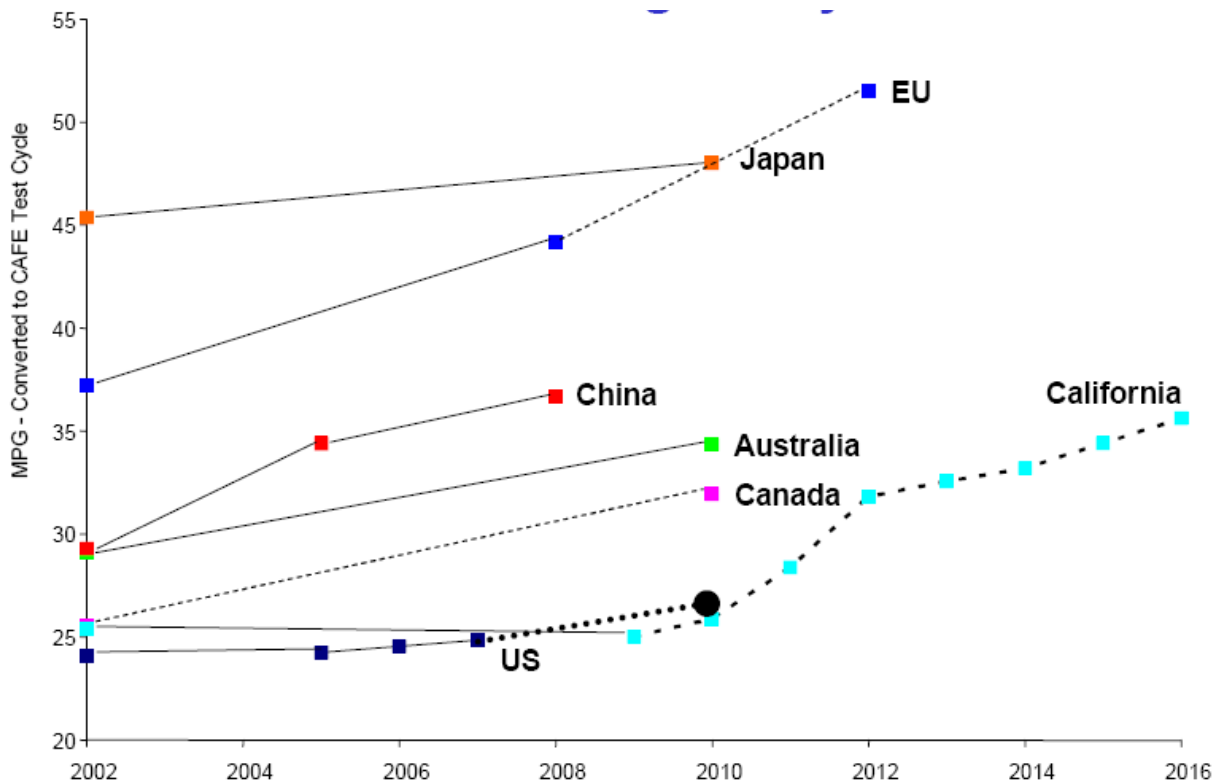
Source: TRB, 2006

The resistance due to aerodynamic drag increases more than proportionally with speed. As an indication of the importance of this factor, driving a car within 50 m behind a heavy vehicle at 85 km/h can lower fuel consumption by 6-12% (Hammarström, 2000). Decreasing air drag by 10% leads to a 4% decrease in specific fuel consumption (Van den Brink & Van Wee, 2001). Further development of smoother shapes may be able to decrease drag by a further 20-30% (EPA [US], 2001). Rolling resistance is in turn affected by tyre pressure. Tyres that are under-inflated 15-25% increase fuel consumption by 2-2.7% (Treatise UK, 2007, Jonsson, 2007), and up to 12% of

vehicles on US roads have at least one critically under-inflated tyre (Tyrrel, Balk, Switzer, & Brook, 2007).

Australia’s performance amongst a number of other jurisdictions in terms of national fleet-averaged fuel economy (miles per gallon adjusted to Corporate Average Fuel Economy – CAFE – equivalent) is shown in Figure 5. That performance is clearly superior to that of the US, but substantially lower than that in the EU and Japan.

**Figure 5: Australia’s performance in terms of CAFE-equivalent miles per gallon compared with other jurisdictions**



Source: An and Sauer, 2004, cited in An, 2006

## 2.4 Vehicle mass, size and shape and fuel use

As the weight of a vehicle is directly proportional to its fuel economy, lighter cars are significantly more fuel efficient than their heavier counterparts. If a vehicle is made 10% lighter, fuel efficiency improves by 5-8% (EPA (US), 2001, Van den Brink & Van Wee, 2001). Driving an 850 kg car instead of a 1000 kg car has an immediate benefit of around 9% in fuel use. The Bureau of Transport and Regional Economics (2002) demonstrated that average fuel consumption of new passenger vehicles sold in Australia fell during the 1980s. It then remained constant over the 1990s, though if cars alone are considered, a fall in fuel consumption of 6% occurred during the 1990s. Engine technology has improved substantially over the last 20 years but potential fuel savings have been offset by increases in vehicle power and weight.

A lighter car will use less fuel, but all other things being equal, a heavier car is safer in terms of crash involvement in regards to its occupants. However, more critical is the mismatch between the masses of the vehicles in a crash. The likelihood of injury or death for the occupants of a lighter car is increased because it must absorb more of the impact energy (IIHS, 1998). Drivers and occupants

in smaller vehicles are thus more likely to be killed in collisions with larger passenger vehicles (Fredette, Mambu, Chouinard, & Bellavance, 2008, Attwell & McFadden, 1999).

In order to reduce weight and therefore improve fuel economy without sacrificing safety, traditional materials such as steel are being increasingly replaced by lighter materials such as aluminium. Methods of using alloys and carbon fibre materials to maintain or increase the strength of the structure while decreasing the weight are under development. Bouwman and Moll (2000) suggest that a 20% improvement in fuel economy due to weight changes is possible by 2015. The use of lighter materials has the additional safety benefit of allowing the manufacturer to maintain the current physical size of the vehicle. It may be that the trend in consumer preference for heavier vehicles (Bouwman & Moll, 2000; Heavenrich & Hellman, 1999) is actually an issue of size rather than weight. Accordingly, a lighter car of the same size may be acceptable to consumers – maintaining safety levels and reducing fuel consumption.

Heavenrich and Hellman (1999) suggest that the increase in new vehicle weight in the US is a function of the consumer demand for more power and features – vehicles currently sold in the US are 20% heavier compared to the average in 1986, have 58% more power, and are able to reach 60 mph (~96.5 km/h) 19% quicker – with a 7% improvement in fuel economy. An increase in engine power can have environmental benefits. An engine that can produce more power at lower engine speeds may use less fuel than another car that requires a higher engine speed to produce the same power (Van den Brink & Van Wee, 2001), particularly if the power is increased without a corresponding increase in the size and weight of the engine. In terms of safety, a larger engine will absorb more energy in a crash, decreasing the injury risk for the car's occupants. However, anecdotally at least, driving a more powerful vehicle may encourage some drivers to drive faster and more aggressively.

## 2.5 Conclusions

The fuel efficiency of a vehicle is affected by factors such as its weight, shape, and engine power. A similar set of variables also determine how safe that vehicle will be in the event of a crash. For example, with equivalent safety equipment, a heavier vehicle will consume more fuel in order to overcome the increased inertia, but will be safer for its occupants in a crash (though less safe for a pedestrian, cyclist or the occupants of a lighter car involved in the same collision). Fuel efficiency will be relatively constant for the vehicle. Fuel economy, however, is a function of the vehicle's fuel efficiency and the way in which the vehicle is driven. Thus the total amount of fuel consumed will depend on factors such as travel speed and acceleration aggressiveness.

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## 3 SPEED VS CRASHES & FUEL CONSUMPTION

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The primary interface between road safety and environmental outcome is travel speed. An increase in speed generally increases the likelihood of a crash due to a reduction in the time available to identify, interpret and react to a hazard, and increases the severity of any crash that does occur. An increase in travel speed also results in an increase in fuel consumption and emissions, though the relationship is not linear. In an Australian self-report survey, Pennay (2008) found that 6% of respondents ‘always’, ‘nearly always’, or ‘mostly’ drive 10 km/h over the speed limit, while 75% of drivers exceed the limit by 10 km/h at least occasionally. According to DETR (1997, cited in Comte, Wardman & Whelan, 2000), 70% of UK car drivers exceed urban speed limits and between 30% and 55% exceed the limit on motorways and dual carriageways. Rothengatter (1992, cited in Coesel & Rietveld, 1998) found that 80% of EU drivers transgressed highway speed limits, and for two-lane roads it was 50%. This chapter examines in some detail the relationships between travel speed and road safety and environmental outcomes<sup>1</sup>.

### 3.1 Inappropriate vs excessive speed

While they are often used interchangeably in the literature, the term ‘excessive speed’ generally denotes travelling at a speed in excess of the prevailing speed limit, and the term ‘inappropriate speed’ indicates travelling at a speed unsuitable (or unsafe) for the prevailing conditions and road environment, and/or exceeding the capabilities of the driver, and/or exceeding the tolerances of the vehicle and its equipment. Inappropriate speed is particularly transitory; for example, weather conditions can change quickly and a driver’s level of alertness or vigilance can vary moment to moment due to a number of factors, and need not always reliably decrease with time spent driving. For example, the driver’s familiarity with a particular section of roadway and a particular vehicle can have negative consequences – both high and low familiarity can be problematic if the driver is complacent or not expecting a transitory hazard such as gravel on the road, respectively. A myriad of variables can determine whether a particular travel speed is inappropriate, particularly if the speed is not in excess of the speed limit.

Coupled with the transitory nature of the appropriate speed is the complication that a speed in excess of the prevailing speed limit may in fact *seem* quite safe for a particular section of road – a subjective rather than objective conclusion. Further, this conclusion is likely to be reinforced for the driver when they do indeed successfully negotiate that section of road while exceeding the speed limit. However, such a conclusion can only be drawn post-hoc – we can only be certain that it *was* safe, not that it *will be* safe, owing to the unexpected nature of the road environment and other factors. Travelling at or below the speed limit should always reduce the likelihood of being involved in a crash as well as the severity of any crash that does occur. OECD (2000) research claims that one-third of road fatalities in OECD countries are due to excessive speed.

### 3.2 The speed-crash relationship

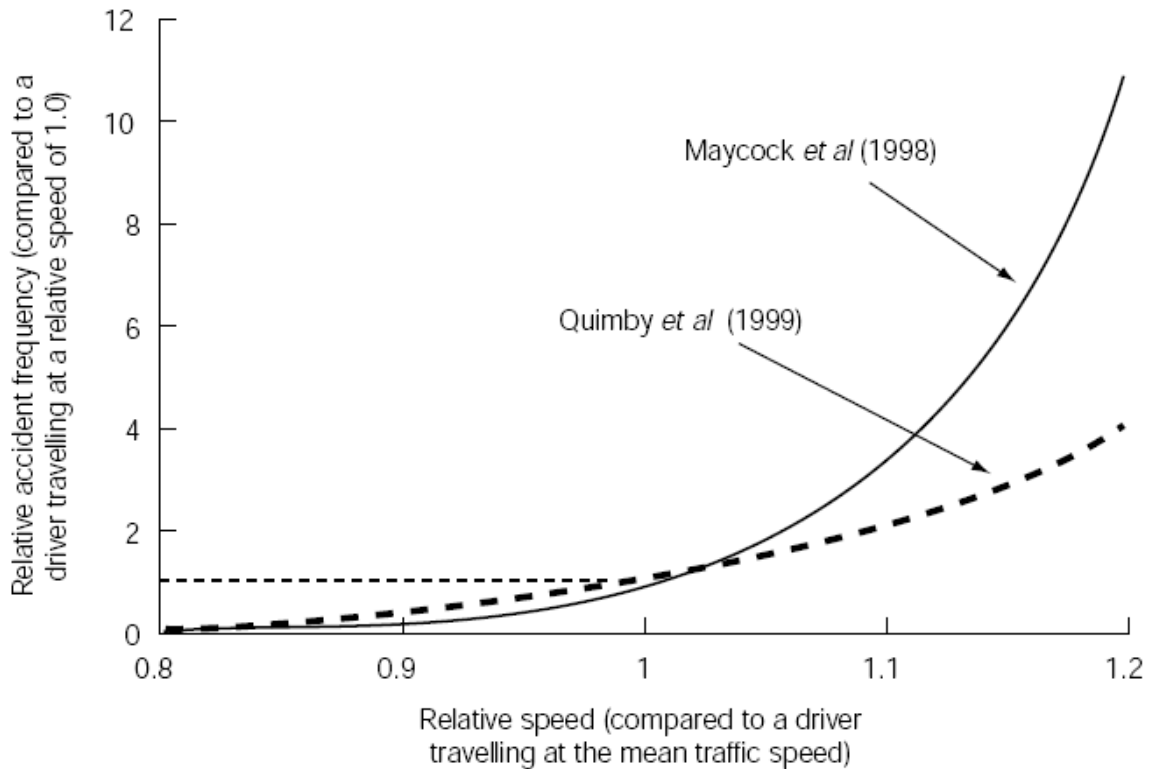
According to UK’s Transport Research Laboratory (cited in T&E, 2005), a reduction in average speed across Europe would save 5,000 to 6,000 lives and 120,000 to 140,000 crashes each year, representing a saving of 20 billion Euro. However, average travel speed is not in itself a sole

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<sup>1</sup> Note that some of the material reported here was also reported in an earlier ATSB report: Haworth, N., & Symmons, M. (2001). The relationship between fuel economy and safety outcomes. MUARC report 188. Canberra: Commonwealth of Australia.

determinant of crash risk. In a summary report DETR (2000) reproduced a figure from Taylor, Lynam and Baruya (2000), presented as Figure 6 below, that shows the relative crash involvement of a driver travelling faster or slower than the surrounding traffic compared to that of a driver travelling at the average speed (i.e., one with a relative speed of 1.0). Travelling at a speed 10% greater than the average would seem to increase risk (i.e., the number of crashes), ranging from a doubling to approximately 3.5 times. DETR report that doubling the proportion of speeders increases crashes by 10%, and that if the average speed increases by 1 mph (~1.6 km/h), and all other factors are held constant, crashes rise by 19%.

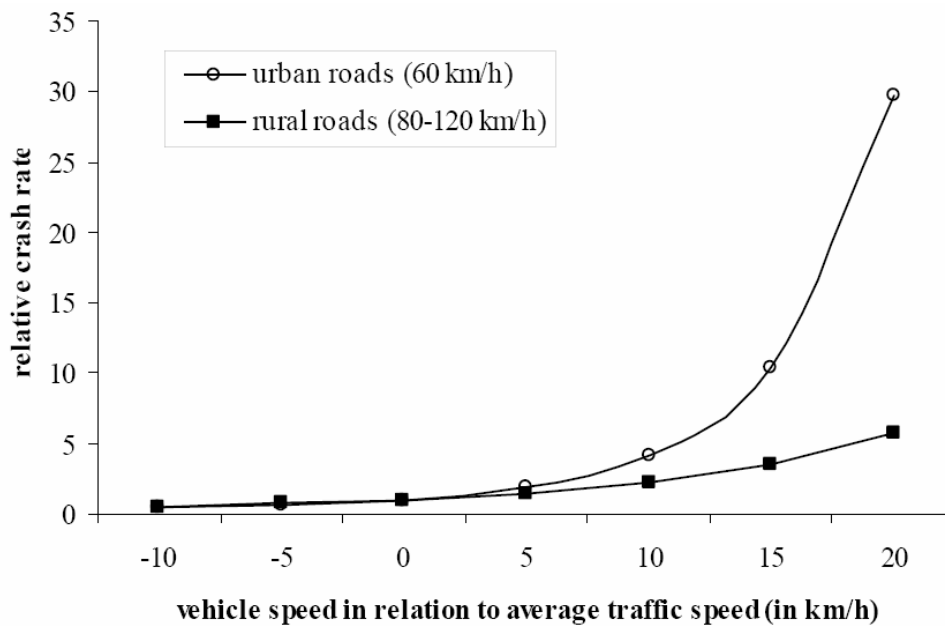
**Figure 6: Relative crash frequency as a function of deviation from average traffic speed**



Source: DETR, 2000

ERSO (2006) note that the complexity of the road environment also plays a part, such that risk curves start to climb earlier and more steeply as the number of intersections increases, traffic becomes heavier, pedestrians are more likely, etc. This can be seen in the difference between the urban and rural crash rate curves in Figure 7, which is produced by ERSO based on three separate reports prepared by Kloeden and colleagues using Australian data. The relative crash rate increases more quickly for urban than rural roads, even though speeds on the latter are likely to be higher. For urban roads an increase in a vehicle's speed by 10 km/h doubles the risk, and at 20 km/h more the risk increases by a factor of six (ATSB, 2004). Based on coroner's records, the authors of the ATSB report note that inappropriate speed (referred to as 'excessive speed' in their report) is a causal factor in around 26% of fatal crashes.

**Figure 7: Relative crash rate as a function of relative traffic speed for urban and rural roads**

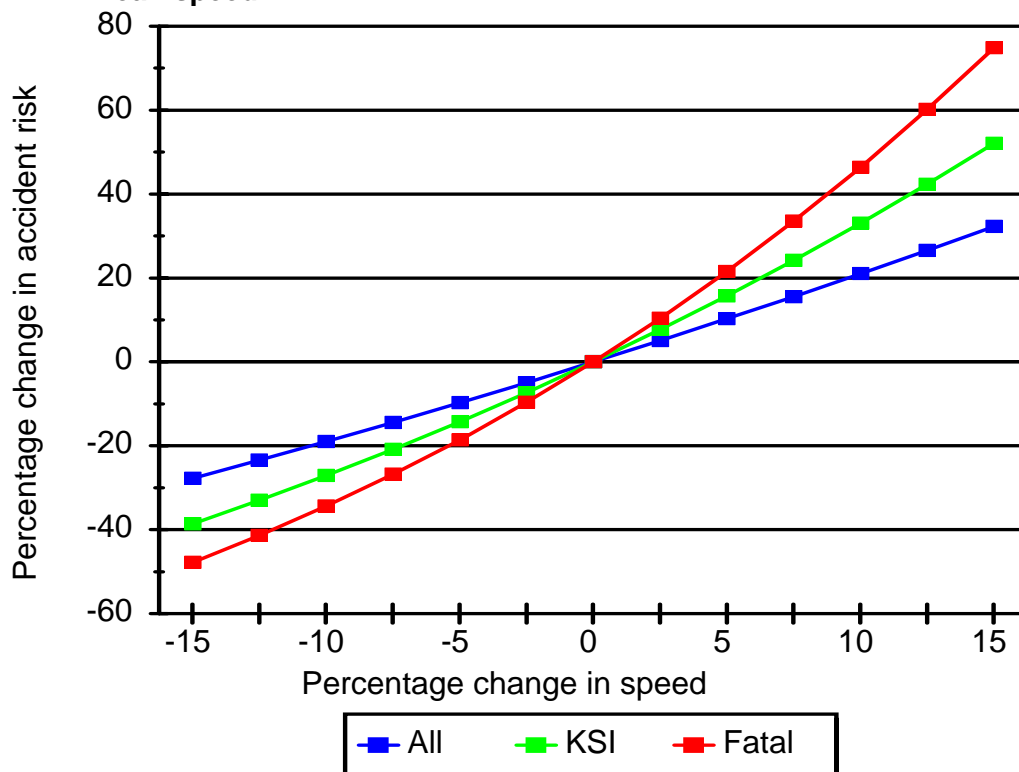


Source: ERSO, 2006, based on data from Kloeden & colleagues, 1997, 2001, 2002

McLean, Kloeden and Anderson (1999) conducted a case-control study of cars that crashed in free-flowing 60 km/h speed zones. They found that the risk of involvement in a casualty crash doubled with each 5 km/h increase in speed above 60 km/h. Extrapolating their data, they calculated that a uniform 10 km/h reduction in travel speeds would reduce the number of crashes by 42% and the severity of the crashes that did occur by 39%. A 5 km/h reduction would result in a 15% reduction in crashes and a 24% reduction in the severity of crashes. Further, complete compliance with the 60 km/h speed limit would reduce the number of crashes by 29% and the severity of crashes by 22%.

Andersson and Nilsson's (1997) model (reproduced in Figure 8) is based on change in speed and separately plots fatality and non-fatal injury crashes. It demonstrates that the probability of a fatal crash is related to the fourth power of the speed. Accordingly, a 10% reduction in mean speed results in a 40% reduction in the number of fatalities. ERSO (2006) note that according to this model a 1% change in speed would result in a 2% change in injury crashes, a 3% change in severe injury crashes, and a 4% change in fatal crashes.

**Figure 8: Percentage change in crash risk as a function of percentage change in mean speed**



Note: KSI denotes Killed or Seriously Injured.

Source: Andersson & Nilsson, 1997

Research undertaken in the USA after interstate speed limits were raised (Finch, Kompfner, Lockwood & Maycock, 1994) has shown that an increase in mean speed of 2-4 mph (approximately 3-6 km/h) resulted in an increase in the number of fatalities by 19-34%. This roughly translates into an 8-9% increase in fatalities on USA interstate highways for every 1 mph change in mean speed. Further work indicated that this relationship holds for the general case: i.e., every 1 km/h reduction in speed across the network leads to a 3% drop in accidents (Taylor, Lynam & Baruya, 2000). However, greater crash reductions per 1 km/h reduction in speed are possible on residential and town centre roads, with somewhat lower reductions achieved on high-quality suburban and rural roads. A study in metropolitan Adelaide revealed that travelling at 5 km/h over the speed limit doubles the risk of an injury crash, the same effect as a blood alcohol content (BAC) of 0.05 (Kloeden, McLean, Moore & Ponte, 1997).

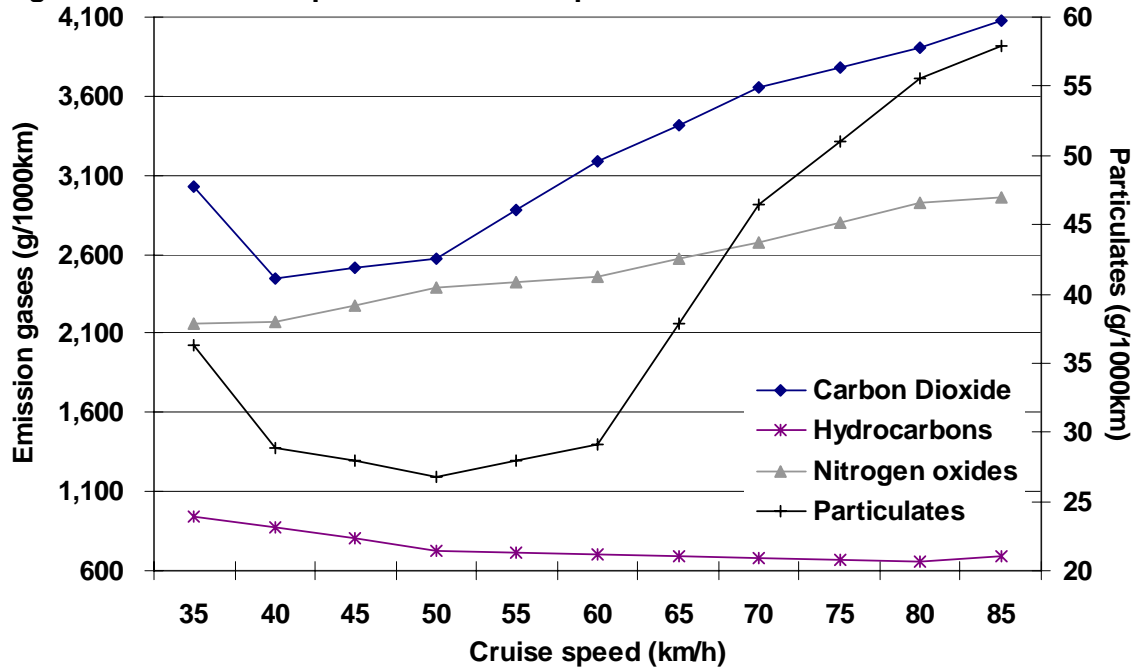
Several studies have shown that the risk of a pedestrian suffering fatal injuries at an impact speed of 50 km/h is approximately 10 times higher than at an impact speed of 30 km/h. About 90% of pedestrians struck at 65 km/h will be killed in comparison to about 10% for those struck at speeds at or below 35 km/h (Ashton & Mackay, 1979). The change from mainly survivable injuries to predominantly fatal ones takes place between 50 and 60 km/h. Vehicles are becoming more pedestrian friendly, but progress in altering the national fleet is slow, so while this data is dated the situation is probably not much better now.

### 3.3 Travel speed, fuel consumption & emissions

Fuel consumption and emissions depend not only on instantaneous speed but also on whether the vehicle is accelerating, cruising or decelerating. Therefore the speed profile of a vehicle during a

trip, an indication of the aggressivity of driving, is a more important determinant of fuel consumption and emissions than the average speed for the trip. Figure 9 summarises one set of data on the effect of different levels of constant (cruise) speed on emissions (from Ward, Robertson, & Allsop, 1998). Carbon monoxide (CO) emissions, which are proportional to fuel use, have a minimum at 40 km/h and are about 50% higher at 70 km/h. According to these data, the optimum cruise speed to minimise emissions of a variety of pollutants is in the range 40-50 km/h.

**Figure 9: Relationship between cruise speed and emission rates**



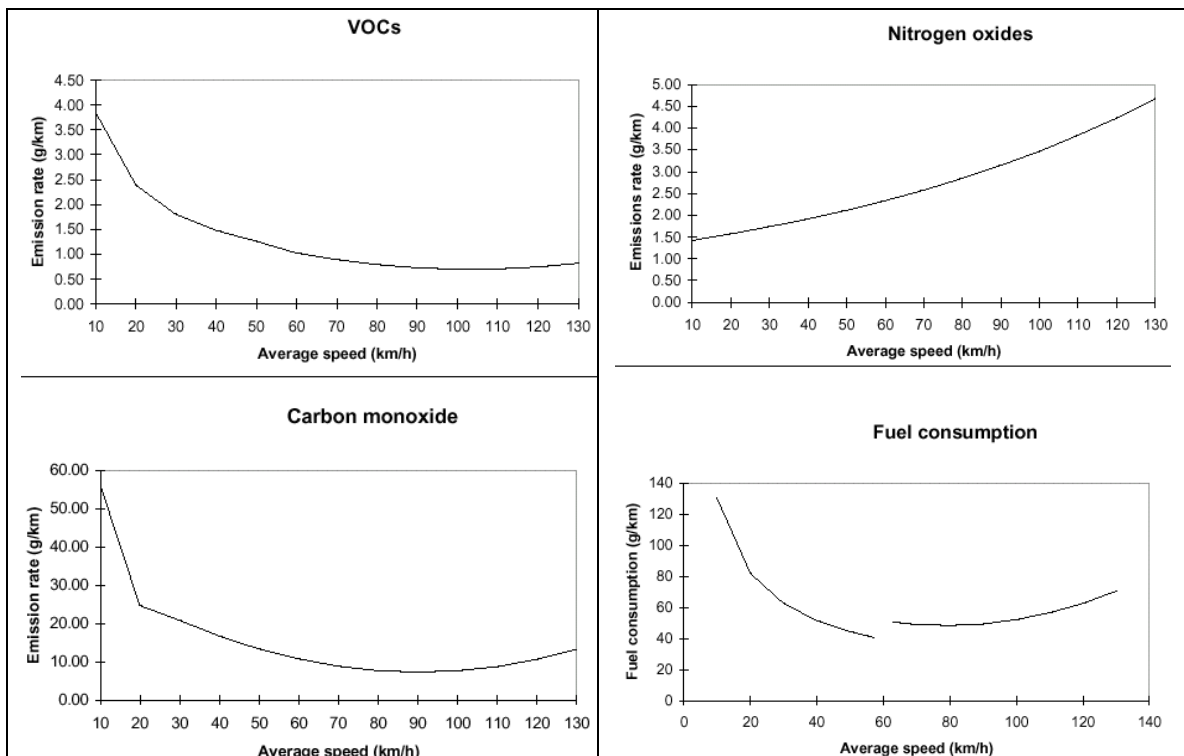
Source: Ward et al., 1998

Samaras and Ntziachristos (1998, cited in André & Hammarström, 2000) found that fuel consumption for 1993-96 European vehicles (1.4-2.0 litres with a three-way catalyst) reached minimum levels at 80 km/h. However, Joumard et al. (1999, cited in André & Hammarström, 2000) found that CO<sub>2</sub> production, which is usually proportional to fuel consumption, continued to fall with increasing speed. This data is somewhat dated and European emission requirements are now substantially more stringent. However, in 2007 the average age of all vehicles registered in Australia was 10 years and 21.9% of the total Australian fleet was more than 15 years old (the average age of passenger vehicles was 9.7 years with 20% manufactured before 1992) (ABS, 2007). Thus it takes some time for new vehicle technologies to permeate throughout the national fleet.

Figure 10 presents typical emission and fuel consumption rates as a function of average speed for vehicles conforming to earlier, less stringent Economic Commission for Europe (ECE) emission regulations (Eggleston et al., 1992, cited in Smith & Cloke, 1999). Emissions of volatile organic compounds (VOCs or hydrocarbons – HCs) and CO generally decrease as average speed increases, a position inconsistent with that shown previously from Ward et al (1998). At high levels of average speed (approximately 100 km/h and over), emission rates for VOCs and CO increase slightly. Emission rates for nitrogen oxides increase more than proportionally with average speed. Figure 10 also shows that the relationship between fuel consumption and average speed is somewhat more complex. It appears to decrease as average speed increases to about 60 km/h to 80 km/h and then increase.



**Figure 10: Typical emission rates for a range of emissions**



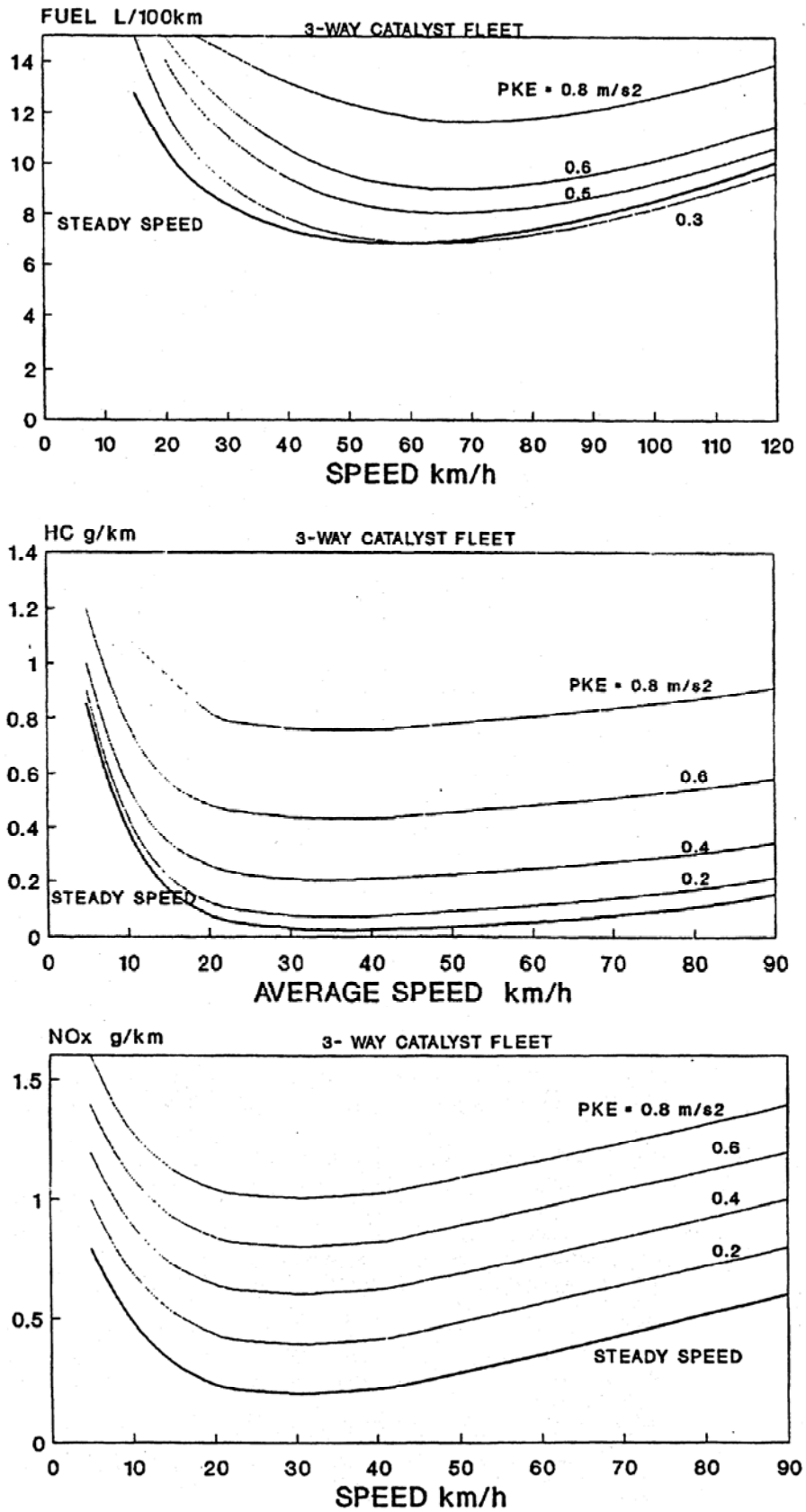
Volatile Organic Compounds (Hydrocarbons – HC), carbon monoxide, nitrogen oxides and fuel consumption as a function of average speed for passenger cars conforming to ECE 15-04 regulations

Source: Eggleston et al., 1992, cited in Smith and Cloke, 1999

According to Advocates for Highway Safety (1995), passenger cars and light trucks use approximately 50% more fuel travelling at 120 km/h than they do at 88 km/h and emit 100% more carbon monoxide, 50% more hydrocarbons and 31% more nitrogen oxides. In a similar vein, Meers and Roth (2001) say that a reduction in speed from 110 km/h to 100 km/h cuts average fuel consumption by 9%, and that a decrease in speed from 70 km/h to 60 km/h reduces the fuel consumption by 5%.

Ward et al. (1998) concluded that vehicle emissions are not simply linked to speed – the acceleration characteristics of the vehicle and driver also contribute significantly. Nairn et al (1994) used positive kinetic energy (PKE) as an indicator of the smoothness of driving. Smooth driving is associated with a low level of PKE such that a value of zero represents a driver maintaining a constant speed. Figure 11 shows that for average speeds within the range 40 km/h to 90 km/h, PKE has a significant effect on fuel consumption and emissions. Compared to steady speed driving (PKE = 0), fuel consumption at PKE=0.8 m/s<sup>2</sup> is increased by between 50% and 100%. The use of acceleration profiles was also specified as a preferred means of analysing behaviour change in af Wählberg's (2007b) rather critical review of ecodrives evaluations.

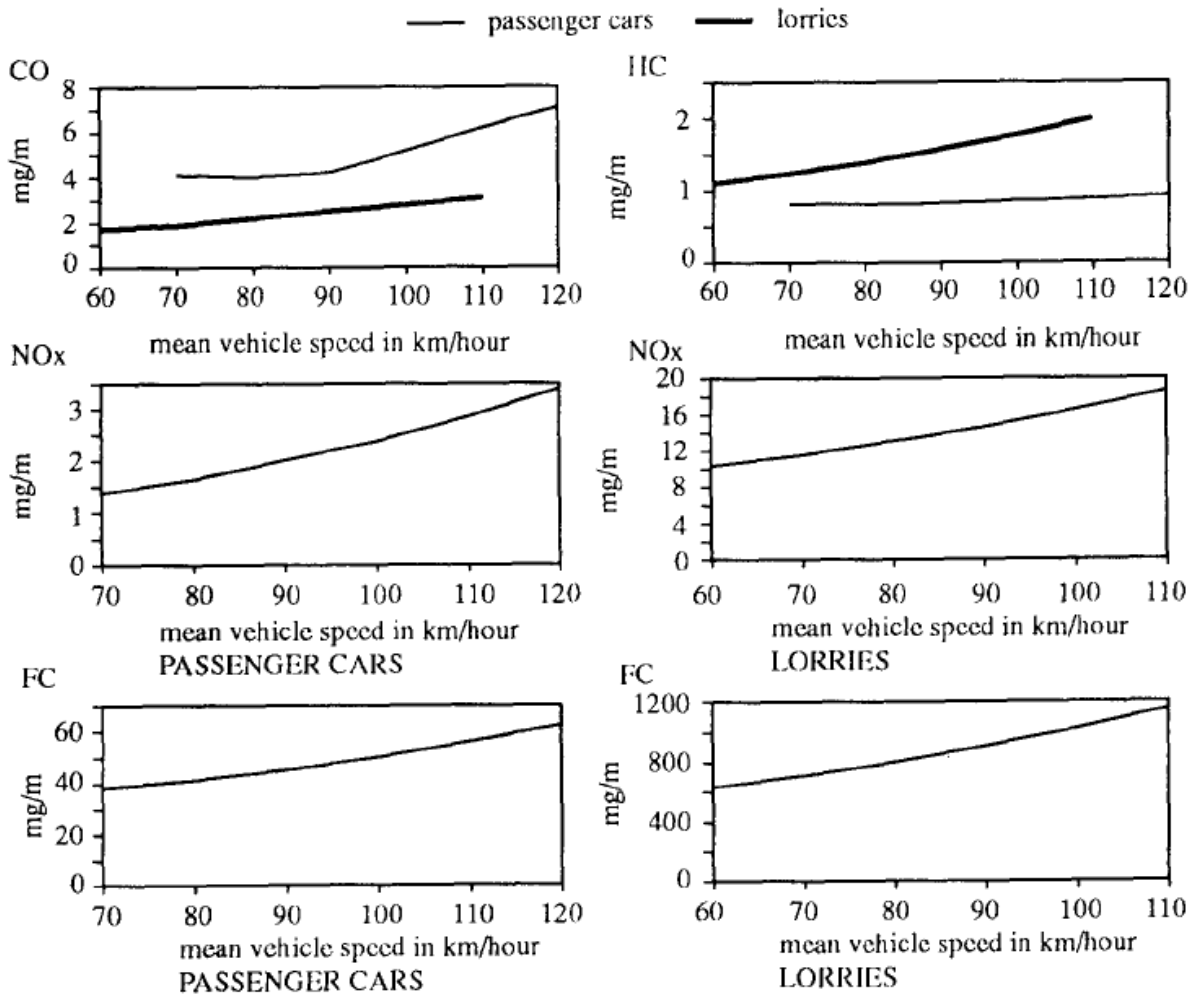
Figure 11: Estimated effects of Positive Kinetic Energy (PKE) and average speed on fuel consumption, and emissions (HC & NOx)



Source: Nairn et al., 1994

den Tonkelaar (1994) measured emissions and fuel consumption in actual traffic for passenger cars and heavy vehicles on motorways in the Netherlands as a function of actual travelling speed (see Figure 12). All relationships presented are substantially more linear than demonstrated in the preceding figures.

**Figure 12: Emissions & fuel consumption in actual traffic for passenger cars & lorries as a function of actual travelling speed**



Source: den Tonkelaar, 1994

Increasing the price of fuel also has the potential to reduce fuel consumption. In a study of the impact of the price of fuel on fuel consumption, the US Congressional Budget Office (2008) found that a 20% increase in the fuel price can reduce weekday rail-accessible freeway traffic by 0.69%. Further, slowing from 70 mph (112.65 km) to 65 mph (104.61 km) – a 7.1% reduction – reduced a typical vehicle’s fuel consumption by 8.2%. At \$3 per gallon, the fuel savings are worth 0.9 cents per mile (0.6 cents per kilometre), with a corresponding travel time increase of around 4 seconds per mile (2.5 seconds per kilometre).

### 3.4 The effects of modifying & enforcing speed limits

Based on research in the Netherlands, den Tonkelaar (1994) found that lowering the motorway speed limit from 120 km/h to 100 km/h (and strictly enforcing the new speed limit) had a beneficial impact on fuel consumption and emissions. Shortly after the new speed limits were introduced, the average driving speed of passenger cars and heavy vehicles decreased dramatically. This resulted in a reduction in both fuel consumption and emissions of carbon dioxide and other pollutants. Unfortunately, without persistent enforcement of the new speed limits, average speed gradually increased and any benefits have seemingly vanished within a four-year period.

van Uden (1997) analysed the costs and benefits of reducing the speed of private cars in the Netherlands and concluded that the maximum enforcement of current limits alone would reduce hospital admissions by 15% and deaths by 21%. Fuel consumption and carbon dioxide emissions would decline by 10-15%, leading to savings of about \$US260 million per year.

Similarly, the European Environment Agency (EEA, 2008) reviewed several fuel saving programs, including a speed control program in Rotterdam (Netherlands). By reducing and strictly enforcing speed limits the scheme successfully reduced CO<sub>2</sub> by 15% in its first year. This equated to approximately 1000 tonnes of CO<sub>2</sub>.

Meers and Roth (2001) estimated fatality and greenhouse gas savings (CO<sub>2</sub>-e – carbon dioxide equivalent) of major Queensland road safety and environmental programs (see Table 1). The speed camera program reduced speeds at speed camera sites by approximately 10% and around 5% across the network. This decline in speed equates to approximately a 3% (or 400,000 tonnes per annum) reduction in CO<sub>2</sub>-e emissions on 1999 emission data.

**Table 1: Fatality and CO<sub>2</sub>-e savings from road safety programs in Queensland 1998-2000**

Road safety program	Fatal crashes saved per annum	CO <sub>2</sub> -e reduction factor	CO <sub>2</sub> -e saved per annum (k tonnes)
Random road watch	80	More consistent driving behaviour, lower speeds	40
Random breath testing	210 <sup>1</sup>	More consistent driving behaviour	40
Speed cameras	82	10% average speed reduction	400
50 km/h local street speed limit	19	10% average speed reduction on 50 km/h routes	33
Fatal 4 public education campaign	20 <sup>2</sup>	More consistent driving behaviour	67

<sup>1</sup> includes injuries

<sup>2</sup> 1997/98 data

Source: Meers and Roth, 2001

Nairn et al (1994) estimated the potential effects of strategies to reduce cruise speeds and consequently fuel consumption and emissions in Melbourne. The types of measures that they considered were driver education and enforcement of existing speed limits, and lowering speed limits. They estimated that if education and enforcement of existing speed limits resulted in all drivers travelling at or under posted 60 km/h speed limits (the default residential speed limit at the time), the average fuel consumption rate would reduce from 8.2 to 8.1 L/100 km. Similar calculations for other speed limits also result in reductions in fuel consumption.

McLean et al (1999) calculated that total compliance with the 60 km/h speed limit would reduce the number of crashes by 29% and crash severity by 22%, and a 50 km/h speed limit with compliance levels evident at the time would produce a 33% decrease in the number of crashes and a 38% decrease in crash severity. Pre-dating the change to a default 50 km/h speed limit for local streets, they estimated that such a regime would reduce crashes by 6.1% and reduce the severity of crashes by 4.7%. As part of evaluations of the implementation of 50 km/h speed limits in residential streets some jurisdictions estimated emissions reductions as well as crash savings. According to Meers and Roth (2001), implementation in Queensland resulted in 19 fewer fatal crashes each year (1998-2000) in south-east Queensland alone (a decrease of 15% in fatal crashes). The 10 km/h speed reduction equated to a 5% reduction in CO<sub>2</sub>-e at around 60 km/h, saving 33,000 tonnes CO<sub>2</sub>-e per annum.

Based on NSW data, VicRoads (2000) estimated a 7% reduction in casualty crashes and a 16% reduction in property-damage only (PDO) crashes as the lower limits of crash reductions for implementation of the 50 km/h default speed limit. Based on Kloeden et al's (1997) work and assumptions of less than complete compliance, a figure of 15% and 16% were chosen as the likely upper limit of the possible reduction in casualty and PDO crashes respectively. The estimations for upper and lower fuel consumption and greenhouse gas reductions savings were 0.3% per 1 km/h reduction in average speed, translating into an annual fuel saving of 1.8 million litres.

### **3.5 Conclusions**

Exceeding the speed limit and travelling at a speed inappropriate for the prevailing conditions can coincide or be mutually exclusive. Both increase the likelihood of being involved in a crash and increase the severity of any crash that does occur. Likewise, fuel consumption generally increases with speed, though the relationship is not monotonic – speeds of around 50-80 km/h produce the best environmental outcome in terms of reduced emissions and fuel use. Keeping traffic moving at optimum speeds and removing the need to substantially and repeatedly slow down or stop and re-accelerate would improve fuel economy, decrease emissions and decrease the crash risk by virtue of smoother traffic flows (Metcalf, 2000).

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## 4 ECODRIVING: THE LITERATURE

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Though it may have had a variety of names (hence the use of the generic term ‘ecodrive’ in this report), the concept of ecodriving has been in existence for at least 16 years, and its use has been widespread in Europe – between 1993 and 1999 more than 27,000 individuals were trained in its use in Switzerland alone (Hornung 2004). In a broader form it includes advice for car manufacturers and policies for road and infrastructure management, but its primary thrust is a smoother driving style – ‘gliding’ or ‘flowing’ through traffic – with the principal aim of reducing fuel consumption and emissions. The purpose of this chapter is to provide an overview of ecodriving literature, separated for convenience into results for passenger vehicles and results for heavy vehicles. Australian results, for light and heavy vehicles, are described separately in Chapter 5.

### 4.1 Key ecodriving behaviours

In a generic form, ecodriving usually involves the following behaviours<sup>2</sup>:

- Shifting up through the gears as soon as possible
- Skipping gears when it is appropriate
- Using the highest gear possible
- Maintaining a steady speed in the optimal engine rpm range
- Avoiding heavy and/or sudden acceleration or braking
- Looking ahead as far as possible in order to anticipate the actions of other drivers and predict likely changes and interruptions to the traffic flow
- Minimising idling time
- Coasting to traffic lights or intersections so that there is no unnecessary braking
- Monitoring and maintaining appropriate tyre air pressures
- Ensuring that recommended servicing intervals are met and maintenance carried out
- Maximising vehicle aerodynamics and minimising unnecessary weight
- Not ‘warming-up’ the vehicle when it is first started
- Making smart use of in-car devices such as the air conditioner

Specific advice will vary according to the vehicle type. For example, the optimal range of engine revolutions for heavy vehicle diesel engines is significantly lower than that for petrol engine cars. According to Bon Beter Leefmilieu (2008), drivers of petrol or LPG cars should shift up before 2500 rpm, while truck drivers should change to a higher gear before 1500 rpm. Even though specific advice may vary, the list of ecodrive behaviours is consistently described in the literature.

### 4.2 Ecodriving for passenger vehicles

Bongard (1993) describes an initiative developed in Germany to reduce driver fuel consumption, reported more fully in a UNESCO report published in early 1993 (no longer available). Novice drivers were trained with either the new curriculum or the standard curriculum and compared immediately after training and again at six and 12 months post training. They do not seem to have been assessed prior to the course, though that may have presented difficulties if they were ‘raw’ novices with little familiarity with driving at all. Bongard reports that the ecodrivers saved an average of 1 litre per 100 kilometres compared with the group who undertook the standard training curriculum. Driving instructors trained to deliver the new course estimated three months for drivers

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<sup>2</sup> As they are presented in a multitude of papers and internet sites, these advised behaviours are not referenced to a specific source.

to adopt the new style. 'Experienced drivers' undertaking the course could reportedly save up to 30% on fuel consumption. Unfortunately further details are no longer available to evaluate the rigour of the study(ies) that generated this data.

The Swiss-based Quality Alliance Eco-Drive organisation published a summary review of five ecodrives undertaken between 1995 and 2003 (Hornung, 2004). Each of the summarised studies had been published in German and so were not obtained in their original for this project. A 1995 study involved a full-day course for twenty novice drivers with an on-road component. Using a simulator, the trainees were compared to a group of novices who had undergone the 'standard' training. After eight months the ecodrivers recorded 12% lower fuel consumption, with 21% lower fuel consumption after 17 months. After four years of the new course another evaluation was carried out with 75 graduates who had accumulated between six months and four years of driving since completing the ecodrives training course. This time the evaluation was carried out on-road, using a 12 km test route. The ecodrivers achieved a 12% reduction, on average, in fuel consumption compared with 75 randomly selected drivers – they do not seem to have been matched for variables such as gender, driving experience, infringement history and other variables that might impact driving behaviour, and therefore fuel consumption. In neither study was a pre-course evaluation carried out to determine change in fuel consumption. Though they were novices, a pre-course evaluation could have been safely carried out using the simulator.

Hornung (2004) then summarised an ecodrives course delivered by a simulator (in 2001) within a half-day course. Data was collected from both simulator and on-road sessions. Seventy-nine participants were assessed prior to the course and 7-9 weeks later and compared with data obtained from a control group. The ecodrivers were 17% lower in their consumption and used a third fewer gear changes compared with their pre-training performance, without any reduction in travel speed. The experimenters also measured a 'comfort' factor, which was based on the output of an accelerometer. After training the ecodrivers were 21% less comfortable in their driving, though this difference was not statistically significant. One would have expected familiarity with the simulator *and* ecodrives training to both positively influence comfort (i.e. acceleration variability) level, though a lack of practice at ecodriving and the lack of real acceleration forces inherent in simulators are both likely to have counteracted those effects. In contrast, the decline in the comfort factor in the simulator evaluation was not present in the standard course graduates, though Hornung does not mention whether comfort *improved* for the latter group – which would be expected after ecodrives training in which smoother acceleration and braking were emphasised.

Overall, the simulator-trained ecodrivers performed better in terms of fuel consumption than the other-trained ecodrivers, but their pre-course results were much worse and so there was more room for improvement (Hornung, 2004). This low level of pre-performance may have been due to the somewhat artificial nature of the simulator. While Hornung did not seem to think this might be an important issue, around 30% of the participants noted in their evaluation of the course that the simulator was 'insufficiently realistic'. Additionally, three-quarters of the simulator participants thought that sitting in the simulator was *not* like sitting in a real car. Despite these somewhat negative views, 86% of the participants thought the simulator was a useful tool for teaching ecodriving concepts, though two-thirds would prefer practical training in a real vehicle.

Two more ecodrives studies were conducted by the Swiss, both in 2003 (Hornung, 2004). One involved a 15-minute simulator course and the other a four-hour course, which included a demonstration by the instructor in his/her own car. In both cases the fuel consumption data was collected via the simulator. The simulator short-course participants saved 25% in fuel consumption compared to their pre-course levels, though familiarisation with the simulator may have been a factor, and there does not seem to have been a comparison with novice simulator drivers to isolate this effect. Contrary to the other studies, no statistically significant difference was found between the novices trained with ecodriving and the novices trained in the standard manner.

Using an unfamiliar car and an unfamiliar 10-km route, Johannson (1999) compared a group of ecodrive trainees pre- and post-training and found that their average speed did not change, nor did their average acceleration. However, the severity of deceleration decreased, indicating a lower level of brake use, suggesting that drivers were anticipating forward conditions and driving more smoothly. The students spent more time in top (fifth) gear and there were 25% fewer gear changes. The maximum engine speed (according to ecodrive principles) was exceeded before and after instruction but the percentage of time during which it was exceeded declined after instruction. Importantly, fuel consumption and CO<sub>2</sub> emissions were reduced by an average of 11%, and all participants reduced their fuel consumption to some degree. The time taken to travel the test route also decreased in many instances. Those drivers who were initially deemed to have an aggressive driving style tended to maintain that style after instruction, which would ordinarily serve to worsen fuel economy.

Wilbers (1999) reported the results of an ecodrive training program conducted for driving instructors. Over a 40 km journey participants achieved an average saving of 13% in fuel consumption, ranging from 5-20%, with no reduction in circuit completion time.

In a large controlled fleet comparison study, Siero, Boon, Kok and Siero (1989) found a 7% fuel saving after six months of intervention using a range of measures to change driving style. Five months after the end of the program the experimental fleet drivers still achieved a fuel saving of almost 6% compared to the control fleet.

Reinhardt (1999) analysed the results of a training scheme instituted in a corporate fleet and found 35% fewer accidents, 22% higher mileage per accident, 28% less fleet driver-induced accidents, and 50% less CO emissions. They also found that the publicity surrounding the scheme resulted in a measurable image improvement for the company, and driver motivation increased. Another company conducted a similar training program and claimed an 11% fuel saving from 1990 to 1994, and 35% improvement in accident rate (Smith & Cloke, 1999).

de Vlieger (1997) compared calm (anticipating other motorist's movements and avoiding sudden acceleration), normal, and aggressive (sudden acceleration and heavy braking) driving behaviours (all within the speed limit). Emissions from aggressive driving in urban and rural traffic were up to four times higher than those from normal driving, and fuel consumption increased by 30-40%. Calm driving generally resulted in decreases in most of the variables compared to normal driving. Similarly, Lenaers and de Vlieger (1997) found that carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxide (NO<sub>x</sub>) emissions increased by a factor of 1.2 to 3 for aggressive driving compared with normal driving.

In later work, De Vlieger, Keukeleere and Kretschmar (2000) tested an onboard fuel consumption and emissions monitoring device and found that, depending on road type and vehicle technology, fuel consumption could increase by 12 to 40% for aggressive driving compared to normal driving (and emissions increased by up to a factor of 8). However, calm driving compared to normal driving only produced a 5% decrease in fuel consumption. The type of driving was categorised according to the driver's average accelerations over a trip.

Redsell, Lucas and Ashford (1988, cited in Stead, 1999) found that 'expert' driving can result in a 9% reduction in fuel consumption under urban driving conditions, 10% in suburban, and 24% on motorways compared to a 'typical' driving style. No further details were provided regarding how these styles were characterised.

Treatise (2005) very briefly mentioned the outcomes, but not the details, of four ecodrive initiatives. A 2004 UK trial of a two-hour course resulted in fuel savings of 8.5% in before versus after measures on a set course. In the Netherlands in 2002, 6,000 drivers were asked whether they would describe themselves as ecodrivers. Over 12 months the ecodrivers reported using 7% less fuel per kilometre than those who did not describe themselves as ecodrivers. A Spanish trial in 2003 found a



13.4% fuel saving. One of the few studies to examine crash rates was a 2003 German study involving 91 delivery van drivers. The drivers were found to use 5.8% less fuel over six months and were involved in 40% fewer crashes compared with pre-training levels.

### 4.3 Ecodriving for heavy vehicles

Most of the previous research has focused on passenger cars. There are fewer instances of ecodriving being applied to heavy vehicles. While there are fewer heavy vehicles on the road, their average annual distance of travel is significantly larger than that for cars – in 2007 the average Australian passenger vehicle travelled 13,700 kilometres, while rigid trucks and articulated trucks travelled 22,000 and 93,200 kilometres respectively (ABS, 2008). Additionally, heavy vehicles use substantially more fuel per kilometre travelled – 28.5 and 54.6 litres per 100 kilometres for rigid and articulated heavy vehicles respectively, versus an average of 11.5 litres per 100 kilometres for passenger vehicles. Accordingly, the potential benefits in terms of fuel saved from more efficient driving could be greater on a per-driver basis for heavy vehicle drivers.

Parkes and Reed (2005) used a full motion platform heavy vehicle simulator to compare almost 300 qualified heavy vehicle drivers on 6.7 miles of simulated UK road before and after an ecodriving training session. The route included a variety of traffic and roadway conditions. Data was collected before and after watching an instructional ecodriving video. In the pre-instruction simulator drive they found that increasing driver age resulted in progressively higher speeds and deteriorating fuel economy. This effect might be explained by a potentially increased adaptability to the simulator by younger drivers. Additionally, those who completed the circuit slowest were significantly less likely to have previously been involved in a crash.

In the after-training simulator drive, Parkes and Reed (2005) found an almost 7% reduction in circuit completion time, a 13% decrease in the number of gear changes used (though they suggested 11%, which does not seem to match their tabulated data), and a 3% increase in fuel economy (mpg), which was not significant overall but did reach significance for the rural component of the route. The lack of a significant fuel economy change is of concern, particularly given the large sample size of almost 300 drivers, though this might be explained to some extent by the relatively short circuit or the use of the simulator. Given that the test route was only 11 km long and in the very controlled environment of a simulator, a control group who also undertook both test drives is a critical oversight, especially as there were sufficient drivers to segregate into three or even more groups. A control group would have ensured that practice with the simulator and the test route was not the principle factor that caused the changes in the results rather than the training, especially given that the training was delivered as a video with seemingly no opportunity to ensure that the drivers understood the concepts of ecodriving, rather than through any interactive means. Additionally, Parkes and Reed do not mention whether other vehicles or infrastructure such as traffic lights were programmed into the simulation, but building in such interactions would have allowed a test of the safety implications of ecodriving in the fail-safe environment of the simulator, and there were clearly sufficient participants to build this in as an additional between-groups variable, particularly since they collected information about crash history from their participants.

Zarkadoula, Zoidis and Tritopoulou (2007) instrumented a pair of buses to collect in-service data from three drivers on a range of variables. A 15 km circuit was driven immediately before and after the ecodriving instruction, across which two of the drivers reduced their fuel consumption and driving time by an average of 16% and 6% respectively (though no inferential statistics are reported to determine whether any of the changes are statistically significant). The third driver, who demonstrated the best pre-training levels for both fuel consumption and circuit time recorded an increase in fuel consumption of 2% and an increase in circuit time of 41%. Zarkadoula et al also collected in-service data for six weeks prior to training and for eight weeks post training on two

selected urban routes and report an average of 4.5% and 4.2% reduction in fuel consumption. Unfortunately they do not present this data as a factor of the three drivers or over the post-training period to determine whether the improvement for the two drivers (and deterioration for the third driver) was consistent over that time, or trended towards pre-training levels. The authors do not explore explanations for the deterioration in performance for one of the drivers, which is clearly a critical consideration. Given the substantial increase in circuit time it is unlikely that the fuel consumption worsened as a result of increased speed, however other changes in driving behaviour may have resulted in a decrease in safety for that driver.

UK's Department for Transport provides advice and assistance to operators of larger vehicles in the freight industry through its Safe and Efficient Driving (SAFED) standard. Accredited training organisations provide a day-long training course that can be centrally subsidised. The instructor:trainee ratio is 1:2 and the course includes two 'runs' in which each candidate drives for an hour each – an assessment drive and an instruction drive. The SAFED (2007) website promises lower costs, improved profit margins, reduced emissions, increased safety (and therefore decreased downtime and decreased insurance premiums – AXA insurance in the UK offers a 5% reduction in premiums if all drivers are SAFED trained), and a fuel saving of 1,000 litres per year. Their site pitches the scheme to companies, individual drivers and potential instructors. After approximately six months some 1,400 drivers had been trained across a variety of truck and industry types in Scotland. SAFED provides brief descriptions of case studies but with insufficient detail to make any critical evaluation. Overall, after implementation in Scotland SAFED claims a 10% reduction in fuel consumption and 33% reduction in gear changes (SAFED, 2007). All changes are before versus after and did not involve a control group in determining the true benefit of SAFED.

By the end of 2007, 12,000 truck drivers and 7,500 van drivers had undergone the SAFED training since its inception in 2003 (SAFED, 2007). The site claims that the van drivers had achieved an average 16% reduction in fuel consumption, 34% reduction in the number of gear changes, and 56% fewer driver faults. Elsewhere on their site SAFED claims an evaluation of data from just over 6,000 drivers (it would seem that not all variables were available for all drivers) to arrive at a 10% reduction in fuel consumption, 37% reduction in gear changes, and a 1% improvement in the time taken to complete a test run – no further details were provided of the evaluation, nor an explanation of the difference between these figures and those elsewhere on the SAFED site.

Seemingly a sister site to SAFED and also associated with UK's Department for Transport, the Freight Best Practice internet site also provides resources and case studies for ecodriving and related activities. In one trial by BOC gases (Freight Best Practice, 2006), fuel consumption was improved by 3.6% by replacing wide single steer-axle tyres with standard tyres. Clearly reducing the surface area of rubber in contact with the road surface will reduce rolling friction and accordingly lower fuel consumption. However, there may be a safety compromise as the increased rubber of a wider tyre will improve traction and, on the front axle in particular, steering responsiveness. The same report noted that setting a heavy vehicle's cruise control to match the speed of greatest fuel efficiency raised fuel economy by almost 19%, though the terrain of travel for that trial was not described.

Treatise (2005) mentions a trial conducted in the Netherlands spanning the period 1995-2003. Overall there was a 2.1% reduction in fuel consumption, a 3.5% lower level of maintenance, and a 14.2% reduction in crash damage (it is not clear whether that indicates fewer crashes, greater mileage per crash, or lower levels of damage in crashes, or a mixture of these or other variables).

Boocock (2001, cited in Coyle & Brown, 2004) randomly selected 177 drivers from a variety of freight companies across the UK for an ecodriving-type training program. Fuel consumption data was collected on a set route before and after the intervention. All drivers improved their fuel economy by amounts ranging from 1.7% to 34%, with an average improvement of 13.4% across all 177 drivers. No additional detail was provided.

Holcim (2005) describe a trial that involved a one-day training session for 8 to 12 drivers. Performance was measured before and after the training (on the same day). The average fuel consumption reduction was about 8.5% while the average speed around the 30-km test circuit *increased* by about 9%. Thus rather than taking longer as might be expected, the adoption of the ecodriving style enabled the drivers to complete the circuit more quickly. Importantly, the fuel consumption reduction of trained drivers was found to still be 5.6% after 7 months, signifying the possibility of a long-term effect.

af Wählberg (2007) attempted to overcome issues of external validity by conducting a four year study of the fuel use across five buses. He established pre-training fuel-use measurements by assessing bus company records and then trained 247 drivers in ecodriving and compared them with 147 control drivers. It was found that although the effect on fuel consumption during training was strong, the ecodrive training did not transfer well into the drivers' working situation. Over a 12 month period the average reduction in fuel consumption was 2% after training. However, in earlier work the Stockholm bus authority calculated that training its bus drivers in gentle and economical driving was more profitable than another initiative of shifting to ethanol-fuelled buses (Kagerson, 2000).

Ecodrive principles advise that engine idling should be minimised. Abrams (2000) estimated that over the course of a year, heavy vehicle idling in the US adds about 97,000 tons of carbon monoxide to the air and wastes 900 million gallons (3.4 billion litres) of diesel fuel. Abrams suggested that one of the reasons for this excessive idling is the need to keep warm while sleeping. Such climatic issues would be significant in Europe, but may not apply to the same extent in Australia.

#### **4.4 Assistance from Intelligent Transport Systems (ITS)**

Providing instantaneous in-vehicle feedback to drivers about their current driving actions has the potential to modify their behaviour and result in a reduced crash risk (Wouters & Bos, 2000). Thus any lessons learned by drivers undertaking ecodrive training may be reinforced and consolidated and hence result in longer term behaviour modification using an instantaneous reminder. What form that feedback might take to maximise its value but minimise its distractibility is yet to be determined. Devices such as vacuum gauges and warning lights that indicate when more fuel is entering the combustion chamber than can be efficiently burned have been in existence for some time. More recently they have been replaced by digital readouts in the form of trip computers that can provide drivers with instantaneous and average fuel consumption, along with various other items of information such as estimated distance likely with remaining fuel in the tank. The additional information provided by trip computers and the fact that digits must be read are potentially more distracting than a gauge or warning light, which can be glanced at provided it is a sufficiently intuitive message.

Van der Voort, Dougherty and van Maarseveen (2001) describe a fuel efficiency feedback device that consists of sensors, a data processing module and an interface with the driver. The device determines the current conditions and compares actual driving behaviour with a theoretical ideal, and then issues advice accordingly. An indicator shows the degree of deviation from the ideal in variables such as fuel economy or safety considerations such as headway. The device was tested in a driving simulator environment and was found to significantly improve fuel economy by up to 16% overall, or 23% in the urban environment (compared to normal driving). Travel time did not significantly change (and thus neither did average speed). The improvements came mainly from adjustments to gear changing behaviour during acceleration.

A particularly intuitive delivery system could involve providing force-feedback through the accelerator pedal to indicate when acceleration is wastefully aggressive. An adaptive system could

be set to a variety of modes to provide feedback in a ‘super economy’ setting that would be different to ‘normal’ and even ‘sport’. In the last case the system would alert the driver that the optimum acceleration has been reached and additional pressure on the accelerator pedal will simply waste fuel. Providing force-feedback via the accelerator pedal has already been successfully trialled for intelligent speed adaptation (ISA) – it could easily be adapted for fuel economy feedback. Using vibration as well as upward pressure should enable an ‘intelligent accelerator pedal’ to provide both messages – travelling too fast and/or too uneconomically.

A number of manufacturers are now exploring and implementing technologies to reduce fuel consumption, such as engine management systems that allow a vehicle to operate on fewer cylinders (e.g. a six-cylinder engine able to shut down two cylinders and continue to operate smoothly, albeit at reduced power), or to automatically switch the engine off (and re-start) rather than idle when stationary in traffic (currently available in the Smart fortwo model in Australia). It is beyond the scope of this report to review such technologies. However, the degree of control over such functions afforded the driver and the requisite feedback to allow the driver to make such decisions is worth consideration. It would seem that the most economical mode of operation for any vehicle should be set as the standard or default. The opportunity to select a ‘performance’ or ‘sports’ mode for overtaking or merging with freeway traffic could be provided to drivers as a temporary setting – perhaps two minutes or so – before the vehicle returns to ‘normal’ – i.e. most economical – mode. Switching to a ‘power’ setting for operations such as towing, which would be needed for an entire trip rather than a short burst of speed, could require the vehicle to be at a complete stop and even the engine turned off before they could be selected to discourage use on a whim.

Local morning ‘drive-time’ radio commonly provides traffic updates to drivers, advising of bottlenecks, locations of incidents, and updates on congestion levels on primary commuting routes. An application currently offered in Australia is the provision of ‘go-around’ advice that can be sent to portable GPS-based route guidance devices. Variable message signs have been used for such purposes in the past but while drivers feel that they are useful they do not often act on the advice (Chatterjee, Hounsell, Firmin & Bonsall, 2002), perhaps due at least in part to a lack of familiarity with the advised alternate route – an issue that would in large part likely be rectified with the use of in-car navigation systems. Ericsson, Larsson and Brundell-Freij (2006) proposed a navigation system that would suggest the most economical route to the driver’s destination rather than the quickest or least congested. An ecoroute feature is now available on some navigation systems sold in Australia.

It is likely that most drivers would ordinarily assume that a less congested route that results in a shorter travel time, even if it is longer than a more direct but more congested route, would save both fuel and emissions. However, Ahn and Rakha (2008) cast doubt on such an assumption. They found that a longer, but quicker highway route used more fuel and resulted in more emissions than a shorter but more congested and therefore lower speed arterial route with traffic lights and other traffic control infrastructure. This is likely to be counterintuitive to many drivers, necessitating a device such as the economical route navigation system proposed by Ericsson et al (2006). Ericsson et al found that for 46% of trips, the driver’s spontaneous choice of most economic route was in fact not the most fuel efficient, and that had they taken the ‘better’ route an average fuel saving of 8% would have been realised.

Taking a more holistic approach, ideally the navigation system would take into account road safety as well as fuel and emission efficiencies. For example, Ahn and Rakha’s (2008) study did not analyse the crash profile of the two routes to complement their environmental outcomes. A higher number of crashes may occur on the arterial route due to shortened headways and cross-directional interactions, but they are likely to be lower speed crashes and therefore of lower severity in peak travel times compared with fewer but more severe crashes on the higher-speed highway.

In 1995 a UK haulage company fitted data logging devices to a number of trucks in its fleet that beeped or flashed a warning to a driver when set parameters (e.g. speed) were exceeded and instances recorded for management action (Freight Best Practice, 1999). They found that the automatic monitoring allowed them to identify brake and speed limiter problems, cut crashes, and improved fuel economy by 4.4% to 8.4% depending on vehicle type. Importantly, they also found that the benefits generalised to other vehicles in the fleet not equipped with the data loggers, possibly reflecting a culture change in the drivers, resulting in general attitudinal and behavioural improvements. Even with a parallel system of manual recording for fuel and related activities, the system had paid for itself within a year. The same company was the subject of a follow-up study in 2007 (Freight Best Practice, 2007). They had updated their in-cab warning and monitoring devices and instituted an incentive scheme in which drivers were grouped into teams of 12. League tables were accompanied by a weekly debrief and drivers had 12-week rolling performance targets. If they met those targets they were rewarded with a financial bonus equivalent to 5% of their regular earnings over the following 12-week period. The incentive scheme in particular seemed to have arrested and reversed a decline in the benefits achieved in the earlier scheme. Over the period 2000-2003 the average fuel consumption improved in the range of 1.4% to 10.8%, depending on the vehicle type. The payback period for the updated system and other capital expenditure was 18 months.

A relatively new concept entering the Australian marketplace that has the potential to reduce fuel consumption through reduced driving is Pay-As-You-Drive (PAYD) insurance in which premiums are based on distance traveled and/or driving location. As data loggers are required to make such a scheme work, it may not be any more difficult or technically challenging to institute an insurance scheme based on ecodrive outcomes as well as, or instead of, driving distance; this could have the effect of rewarding more positive behaviours, rather than effectively punishing drivers for maintaining their mobility.

Competition is a feature of driving for many drivers, whether it is speed, first to arrive, 'making' a set of traffic lights as they cycle to a red phase, etc. The same instinct may be harnessed to encourage efforts to save fuel. A commercial operation based in Germany, FleetBoard <<http://www.fleetboard.com>> fits a telematics system to Mercedes brand heavy vehicles to automatically report in-service variables such as fuel consumption and location for fleet and logistics management functions. An ecodrive-type performance is also available for each driver on the internet to enable individuals to strive to improve their own profile or that of other drivers. The company suggests that it is realistic for a driver to save two litres of fuel over 100 kilometres. In 2008 the company's 'Driver's League' involved more than 4,000 Mercedes drivers, twenty of whom had been elevated to 'Master Class' status to compete for a racing event package. The winning driver's company wins free hire of a Mercedes truck, along with the positive exposure. Such a system would be easily adaptable to Australian conditions.

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## 5 AUSTRALIAN ECODRIVE TRIALS

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### 5.1 The Australian Experience

A number of ecodrive-type trials and initiatives were obtained from a variety of sources. They are detailed in a separate chapter because the focus of this project is on the use of ecodrive under Australian conditions.

Compared to the situation in Australia, the European fleet is likely to consist of a larger proportion of vehicles, particularly passenger vehicles, with a manual rather than automatic transmission. While the gear-change advice may not be relevant to many Australian drivers, most of the other advice could be followed in Australia. For example, the driver of an automatic should still 'gently' accelerate to allow the transmission to change itself into a higher gear at lower engine speeds – driving smoothly rather than aggressively. Driving with an increased awareness of the traffic situation downstream rather than only focusing on a car or two in front is also transferable between manual and automatic cars, as is keeping idling to a minimum and driving off immediately upon starting the vehicle rather than waiting for the engine to warm up.

One of the earlier published accounts of an ecodrive-type trial in Australia was reported by Clifford (1988). Drivers for a haulage company were offered a share in the financial savings of any reduction in the driver's fuel consumption. Over a 12-month period fuel consumption improved by 3.5% and the financial savings more than covered the cost of the bonus scheme. Individual drivers improved by as much as 15% and there was a slight reduction in crash/incident frequency. Clifford suggested that as drivers pay more attention to their driving style in order to drive more efficiently, they are paying more attention to driving in general, which should make them significantly safer. The company also experienced savings in maintenance costs.

Australia's Department of Primary Industries and Energy (1991) estimated that driver education programs could improve the fuel efficiency of the existing fleet by up to 15%. In a more holistic approach, they also suggested that any training scheme should include a range of factors, such as using vehicles less, increasing vehicle occupancies, changing peak hours, and considering parking infrastructure.

In 2000 and 2001 the then Victorian Environment Protection Authority (EPA) and Sustainable Energy Authority Victoria (SEAV) undertook a joint project to develop a driver education program that placed an emphasis on the environmental consequences of car use and the facets of driver behaviour that can improve road safety. The course had a one-day format and was trialed in June and July 2001 (one of the authors of this report participated in the trial). No further mention of the course or its outcomes was found.

While not an ecodrive trial per se, Haworth and Symmons (2001) reported an analysis of a large corporate fleet in which fuel economy data from fuelling records were cross-matched with crash records for the year 2000. Out of some 500 vehicles, 29 cars had fuelled in the months of April, May and June, and had crashed at some time during that year. A sample of 63 non-crashed control vehicles from the same fleet that had also re-fuelled in April, May and June were matched to the crashed cars on the variables of make, model, body type, and year of manufacture. The crashed sample had worse fuel economy than the group that had never crashed: 13.4 versus 11.6 L/100km respectively.

With little literature available on ecodrive in Australia, particularly recent publications, the authors used industry contacts to probe deeper. While these enquiries suggested a growing interest in the concept of ecodriving, there appears to be limited systematic exploration of training to reduce fuel

consumption and emissions. Three initiatives are reviewed, with particular attention to issues of adoption and wide-scale rollout.

### **5.1.1 LinFox Logistics**

As a major supply chain solution provider in the Asia-Pacific region, Linfox Logistics operates a fleet of nearly 5,000 vehicles across 11 countries. In the 2006-07 period, 80 per cent of the company's greenhouse emissions arose from the use of diesel fuel (Linfox, 2008). As part of its overall corporate environmental policy, Linfox Logistics has set an initial target to reduce the rate of greenhouse emissions by 15% by 2010 based on its 2006-07 emissions. While a range of initiatives have been identified to achieve that target, strategies to reduce fuel use are explicitly included in the company's three year (2008-2011) implementation plan. Those strategies include:

- Trialing a new fleet tracking system to provide dynamic and cumulative fuel use data
- Moving to hybrid vehicles for company cars (other than utes) and hire cars
- Developing and delivering an ecodrive training program to all Linfox employees to encourage fuel efficient driving at all times.

A management representative of Linfox Australia (personal communication) indicated that their focus has two key dimensions: speed limiting vehicles and roll out of driver training. On certain road types, the Linfox fleet will be speed limited to 80 km/h since this has been identified as an optimal speed for fuel economy given tradeoffs in drivers' wages, engine performance and fuel costs. This speed governing will only apply on dual lane carriageways where the fleet would regularly be able to travel at up to 100 km/h. That network restriction was seen as important to minimise broader impacts on the traffic stream and allow other drivers to overtake safely.

The driver training program is being developed for rollout over a two year period. On the basis of overseas experience, Linfox aims to reduce fuel consumption by 4.8% through adoption of more economical driving habits. The driver training will be delivered at weekly 'toolbox' sessions that are held with drivers at individual depots. On the basis of their experience with training their drivers, they believe the most effective delivery for their staff is for individual topics to be dealt with in 20 minute toolbox sessions. The topics to be covered include idling, acceleration, gear changing, etc., and are broadly in line with the content of other ecodrive training schemes described earlier. The training will be delivered by the Site Manager or other depot personnel qualified at Certificate IV level in Training and Assessment. For some topics, the training session will be supported by a DVD.

Prior to rollout of the training, benchmarking of fuel consumption is being undertaken at the level of depots or driving groups that comprise between 5 and 35 vehicles. Feedback will be provided at the group level with the company seeking to achieve a reduction in fuel consumption of over 4.8% following the training.

### **5.1.2 Grenda Transit Management**

Grenda Transit Management oversees five separate bus and coach operations in the Greater Melbourne/Mornington Peninsula region. Drawing on a fleet of over 470 buses, their operations are responsible for over 15% of Melbourne's public bus system (Grenda Transit Management, undated). The company has a commitment to driver training not only at the time of staff induction to the company but also at regular intervals thereafter (usually on a 12 to 24 month interval).

Grenda's driver training program includes material in the general area of ecodriving specifically relating to vehicle performance management, including the importance of smooth acceleration and deceleration. Links are also drawn between that material and other training content relating to driving for the comfort of the passengers. A representative of Grenda Transit Management indicated

that the company has been trying to identify new ways to undertake regular training with their drivers. This need is complicated by the fact that it has been a considerable challenge to recruit sufficient drivers to keep up with demand. The lack of relief drivers means it is not possible to take drivers off the road to undertake training (the lack of heavy vehicle drivers and aging of the current driving workforce – bus and truck – is proving to be a significant issue across the industry nationally). Presenting training in ‘toolbox’ sessions like Linfox also presents difficulties because of the range of shifts that the drivers work.

Fleet-wide average fuel consumption is included as part of a summary of Key Performance Indicators displayed at each depot. However, since one bus can have four or five drivers in one day, it is not possible to link fuel consumption to individual drivers or their driving style. To date the company has not explored the option of downloading fuel consumption data from the vehicle engine management system primarily because they do not have staff available to undertake the analysis of that data once it became available.

While the general driver training at Grenda Transit Management includes dimensions of ecodriving, there has been no explicit evaluation undertaken to measure the impact of the training on fuel consumption.

### **5.1.3 Waste Collection Vehicles in Shire of Nillumbik, Victoria**

The Shire of Nillumbik, with a population of approximately 61,000, is located about 25 kilometres north-east of Melbourne. A representative of the Shire (personal communication) described instrumentation fitted to the fleet of waste collection vehicles in order to improve fleet management. Each vehicle was equipped with a data logger that recorded position data from the Global Positioning System (GPS) along with a range of variables from the Engine Control Unit (ECU) and other sensors. The location data has specific application in resolving complaints about whether the waste collection vehicles passed a given property on the nominated collection day, but it could also be used as part of an ecodriving management system.

For internal fleet management, cross referencing the data from the engine control unit and other sensors with the location data provides a valuable tool for monitoring fleet performance. A device fitted to the brake pedal provides data on the amount of braking, specifically the frequency, duration, and severity of brake applications. Data on gear changes is not currently recorded but could be sampled through the ECU. Idling can also be recorded on the data logger. A maximum speed can also be set in the data recorder and instances of over-speeding can then be logged.

When the system was being developed there was an expectation that fuel consumption and maintenance costs could be reduced by providing detailed feedback to drivers that would stimulate changes in driving style. While not designed as an ecodriving training initiative, the instrumentation provides insight into the types of data that could supplement training and assist in inducing a change in behaviour.

In the case of this Shire, there has been little engagement from the drivers. It is perceived that this is largely because under the terms of their enterprise agreement (a Start and Finish Contract) the drivers finish work once they get back to the depot. The drivers see no incentive to make any change in their driving behaviour and are motivated to complete their duties and return to the depot as soon as possible so that they can then leave work. Drivers under a set eight hour day style contract may be more amenable to making changes in their driving style since they do not simply finish work when they return to the depot.

In this case the drivers have not received any formal ecodriving training that might help them understand the scope to reduce fuel consumption and wear and tear on the vehicle through a change in driving style. Evidence presented later suggests that adoption of an ecodriving style does not



adversely impact travel times and so the drivers may not be at any disadvantage from changing their driving style.

## **5.2 Conclusions**

There is a distinct lack of Australian ecodriving data. Although many ecodriving principles are recognised in this country, there is a deficit of controlled trials. The recent initiatives described are probably a few of many that have arisen due to increasing fuel prices and concerns about environmental consequences and a pending emissions trading scheme for Australia. However they have not been evaluated.

Across the three current initiatives there are clearly different models for the type and delivery mode of ecodriving training and challenges in implementing the organisation's plans, regardless of its size. The financial incentive directly tied to improvements in fuel economy as described by Clifford (1988) may solve some of those issues. As that incentive comes from each driver's performance-based savings it is not a new financial burden on the company – indeed the company would also 'profit' from the scheme both directly and more indirectly via reductions in maintenance costs and improvements in its corporate image and ability to attract and retain drivers in a tightening labour market.

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## 6 AN AUSTRALIAN ECODRIVE FIELD TRIAL

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It is apparent that there is growing interest in ecodrive type initiatives and the potential savings that can result. However, few organisations seem to have undertaken a detailed examination or critical evaluation of its potential. One exception was the Australian Cement Industry Federation (CIF). As part of an industry action agenda developed in conjunction with the Commonwealth Government (Commonwealth of Australia, 2006) to reduce the environmental costs of manufacturing and distributing cement, the CIF identified fuel consumption and emissions from its transport operations as potentially amenable to improvement. The diversified location and nature of raw materials and energy sources, the quality and quantity of transport infrastructure, and the distribution of markets all result in logistics being a critical issue for the cement industry. Ninety per cent of the transport required to produce and distribute cement is road-based. Each year in Australia approximately 15 million tonnes of cement is transported by road, equating to about 1% of all road freight carried.

Considering the literature, it is reasonable to expect that an ecodrive training program for heavy vehicle drivers in the cement industry would result in a fuel consumption saving, despite the geographical, environmental and regulatory differences between European conditions and those in Australia. What is less clear is the likely size of that effect and its statistical significance. Accordingly, a small-scale trial represented a logical first step. Consequently, the CIF, in conjunction with Sustainability Victoria facilitated a small scale ecodrive trial involving cement tankers operating in Victoria. The trial was modelled from one conducted in Europe by Holcim (2005) and involved measuring the impact of an ecodrive training program on fuel consumption over a designated test route.

Given the direct relevance of this trial to understanding the potential of ecodrive training under Australian conditions, the nature and insight from the trial are considered in detail. In this chapter the design of the trial is described, along with the nature of the training, and the results are reviewed in terms of the changes in fuel consumption and driver behaviour. Finally, outcomes from this trial are identified, which have relevance to the design and evaluation of future ecodrive initiatives in Australia.

### 6.1 Method

In defining the design of the cement industry field trial it is necessary to consider a range of dimensions. These include:

- The vehicles used and the selection of drivers to participate in the trial
- The nature of the ecodrive training program
- The specification of the route over which the evaluation measurements were taken
- The data collected in the field trial
- The experimental design that guided the field trial.

Each of those issues is addressed in the subsections which follow.

#### 6.1.1 The training program

The theory session included:

- What is a smart driver?
- Vehicle maintenance
- 6-point-system of vehicle control
- Progressive shifting
- Smooth operation and ‘flowing’ the vehicle

- Progressive braking and auxiliary braking systems
- Scanning the road ahead
- Excessive idling
- Greenhouse effects
- Putting it all together

The drivers completed a pre-drive with no formal ecodrive training, during which their behaviour was assessed. The drivers then attended a classroom session on the principles of ecodriving. The drivers then completed a second drive around the circuit and their behaviour was again recorded for comparison with the first drive.

### 6.1.2 The vehicles

The vehicles used in the field trial were two 25 metre, 68 tonne B-doubles (see Figure 13). Both trucks were Mack Super Liners, with 18 speed gearboxes, powered by 550 horsepower Cummins Diesel engines. The trucks had almost identical specifications, aside from a difference in the gearing ratios. The A-B trailer sets were also matched. The literature review did not identify any published ecodrive trials using vehicles of this size, power and mass.

**Figure 13: Mack B-double cement truck used in the trial**



### 6.1.3 The drivers

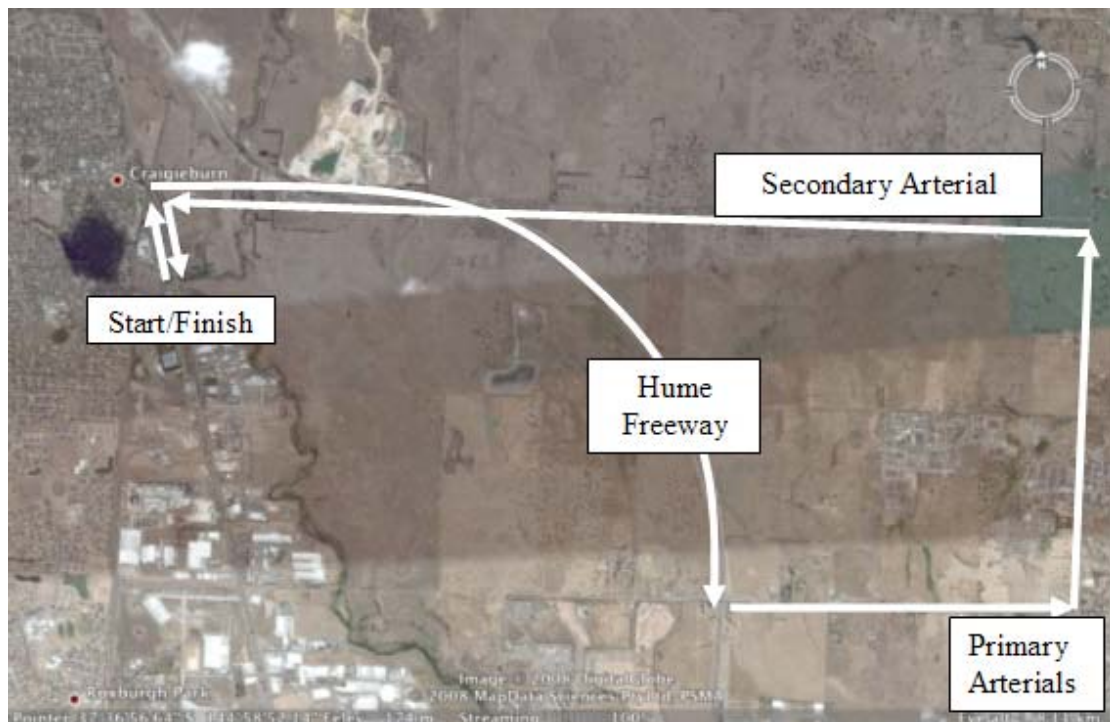
The dates chosen for the trial were based on building industry rostered days off to reduce the impact of the trial on the company's operations (a building industry rostered day off results in a reduced demand for cement, resulting in a lighter workload for company drivers and trucks). After consulting their own rosters, the company nominated a pool of 30 drivers who could be available to participate in the research. The pool included drivers based at three sites. All potential participants were licensed to drive B-double configurations.

Trial drivers were randomly chosen from the pool by the research team and randomly allocated to experimental groups. This procedure served to eliminate potential confounding and extraneous variables such as driving experience or duration of employment with the current company. The trial drivers had between 6 and 45 years of heavy vehicle driving experience, with an overall average experience of 22 years ( $SD = 12$  years).

#### 6.1.4 The route

Consistent with the Holcim (2005) ecodrive trial, the test circuit was 30 km in length. Located in the outer northern suburbs of Melbourne, the circuit started and finished at a fuel station to enable efficient and consistent refuelling between circuits (or trials). The circuit (see Figure 14) reflected the outer suburban nature of the company's operations and included a section of the Hume Freeway as well as outer urban arterial roads, strip shopping and residential areas, and a segment of rural arterial. The drivers had to contend with a full range of speed limits from 50 km/h through the shopping area, to 80 km/h on the urban arterials, to 100 km/h on the freeway and rural arterial sections. There was also a mix of traffic controls – including roundabouts, traffic lights, and slip-lane intersections – and grades, with slight to moderate climbs and descents.

**Figure 14: Field trial test circuit (adapted from Google Maps)**



The entire route was B-double compliant. Given that it was close to their base of operations, all of the drivers were sufficiently familiar with the route that they did not require assistance with navigation, nor were they caught off-guard by any of the circuit (e.g. all of the drivers knew when and where to make the necessary turns and were never caught in the wrong lane of a multi-lane carriageway, nor were they ill-prepared to stop at intersections, etc.). The circuit was a reliable reflection of the mixture of roads and traffic environments that these drivers negotiate on a daily basis.

### 6.1.5 The data

The collected data was a mixture of objective and subjective measures and included both quantitative and qualitative variables. The principal variable of interest was fuel consumption. This measurement was based on the quantity of fuel used for each circuit. At the beginning of a test session both trucks were driven to the fuel station and their dual fuel tanks filled to a set point on the tank's inlet pipe. At the conclusion of each circuit the tanks were topped up to the same point. To ensure consistency, the re-fuelling was supervised by the same researcher each time.

The time to complete each circuit was also recorded, from the moment the truck left the fuel station until they exited the arterial to re-enter the fuelling station on their return.

A number of driving behaviour measurements were taken. Each driver was accompanied by an observer who sat in the passenger seat of the truck and made tallies for each variable. In order to run the two test trucks simultaneously (but with staggered starting times to ensure neither driver saw the other truck on the circuit), two observers were employed. Both observers possessed a heavy vehicle licence and had varying degrees of heavy vehicle driving experience. The observational data were the number of:

- Gear changes
- Instances of over revving (1800+ rpm)
- Brake applications
- Instances of insufficient scanning ahead
- Instances of insufficient following distance

All in-cab data were recorded on a score sheet as the drive progressed.

### 6.1.6 The design

Though not always explicit, it would seem that the ecodrive evaluations examined in the literature review were principally within groups designs – comparisons of each driver's before and after performance scores. A between groups design would entail the comparison between different groups where each group has a different experience or treatment. The current study employs a mixed design, with both within and between comparisons. The within comparison is the test of whether the drivers' scores and behaviours change from before the training to after. The between comparison is whether the scores of the fully trained drivers differ from those of a group who undertook an alternative type of training and a third group who undertook no training.

Random selection of study participants from the pool should result in a representative sample of the company's drivers undertaking the training. However, making the between groups comparison with the third no-training, or control, group provides for a check on this assumption – a confirmation of whether the test group happened to contain particularly good or particularly bad drivers compared with the rest of the pool.

Three experimental groups were formed from the pool of available drivers:

- Group 1 – full course: drivers participated in the complete ecodrive training program
- Group 2 – classroom: drivers participated in a classroom ecodrive training session only
- Group 3 – control: drivers did not participate in any training

The full ecodrive course, as designed by the training provider, would ordinarily include both pre- and post-course assessment drives in which the driver is accompanied by an instructor. The purpose of the pre-drive is for the instructor to gain an overview of each driver's behaviours in order to make reference to them during the training. Ordinarily the purpose of the post-course accompanied drive is to allow the instructor to offer feedback to consolidate learning outcomes from the course, and make reference to obvious improvement since the pre-drive assessment. In this trial the pre- and

post-course accompanied drives were used for data collection rather than feedback. As the ecodrive classroom session was consistent for Groups 1 and 2, the accompanied (measurement) drives marked the only difference.

Two groups of four drivers were randomly chosen from the available pool to undertake the training in Groups 1 and 2, with a further four chosen for the Control group. The full training course group was limited to four drivers because the drivers and trucks had to be removed from service for each day of the study, and in some cases relocated to one depot from another, representing a significant financial and logistical impost on the company. Each element of the study was therefore confined to a single day, and an on-road window (9am to 3pm) that avoided peak traffic times in the morning and afternoon.

Two trucks and two assessors were used so that two drivers could be assessed simultaneously (though there was a 15 minute gap in circuit departure times to ensure no interaction took place between drivers).

In order to evaluate the longevity of any effects of the ecodrive training, measurement was taken at three times: the day of the training, six weeks after the training, and twelve weeks after the training. The same trucks were used for each day of testing such that drivers drove the same truck each time. Logistical considerations as described previously dictated that not all three groups could be assessed at each of point in time. Table 2 summarises the activities undertaken for the field trial and the groups involved.

**Table 2: Field trial schedule for training and assessment**

	<b>Day 1</b>	<b>Day 2 (+ 6 weeks)</b>	<b>Day 3 (+ 12 weeks)</b>
Group 1: Full course	<ul style="list-style-type: none"> <li>• Observation pre-drive</li> <li>• Classroom session</li> <li>• Observation post-drive</li> </ul>	<ul style="list-style-type: none"> <li>• Observation drive</li> </ul>	<ul style="list-style-type: none"> <li>• Observation drive</li> </ul>
Group 2: Classroom only	<ul style="list-style-type: none"> <li>• Classroom session</li> </ul>	<ul style="list-style-type: none"> <li>• Observation drive</li> </ul>	
Group 3: Control		<ul style="list-style-type: none"> <li>• Observation drive</li> </ul>	

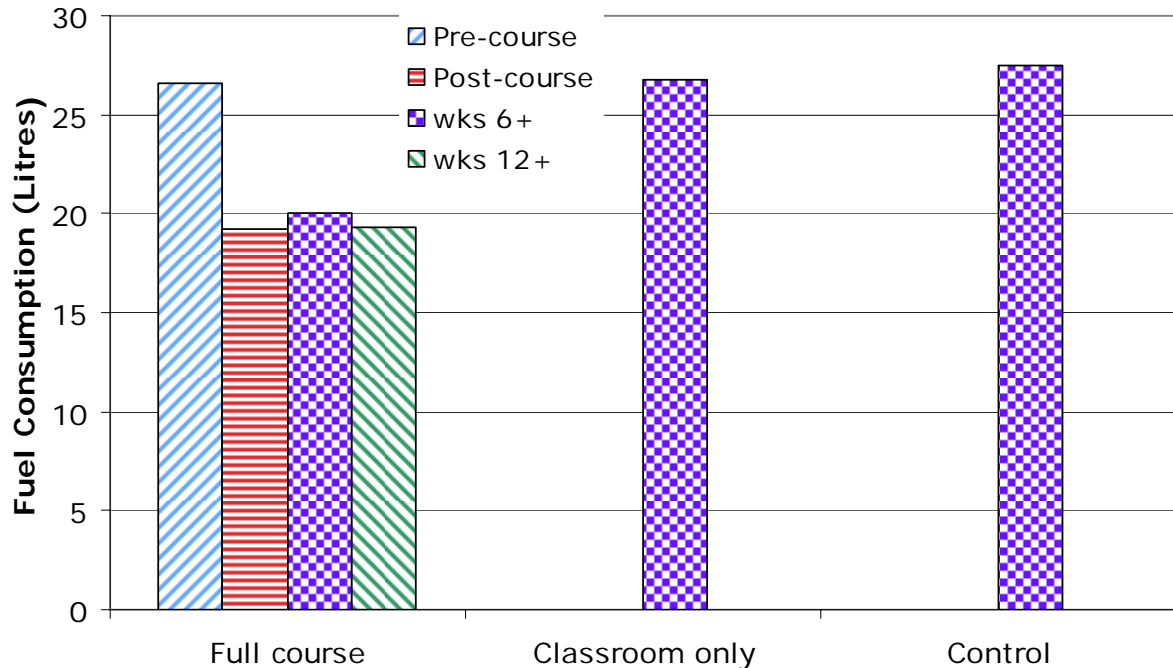
## 6.2 Results

The ecodrive field trial sought to assess the impact of a training program designed to reduce fuel consumption in a group of heavy vehicle drivers. The results will be presented in two sections: quantitative and qualitative. The quantitative data (i.e. count- or time-based measures) primarily consists of the fuel used, circuit travel time and the in-cab assessments of the number of gear changes, brake applications, etc. The less numeric qualitative data were principally generated by surveying the participants on issues such as their use of ecodriving principles and their perceived value of the course.

### 6.2.1 Fuel consumption

The average fuel consumption across the experimental groups and across the trial is displayed in Figure 15.

**Figure 15: Fuel consumption across time for fully trained group and between groups at 6 weeks post-course**



On average, the fuel consumption of the drivers who completed the full course decreased by 27% between the pre-course drive and the post-course drives. Importantly, those drivers maintained these lower levels of consumption at six and twelve weeks after the training, suggesting a potentially long-term, robust effect. Additionally, the pre-course fuel consumption for the full course group was of the same order as that obtained for the control group tested six weeks post-course. The lack of difference here is important for two reasons.

Had the four drivers chosen for the full course group been significantly different in any way from other drivers in the pool, that difference should have been reflected in measures of pre-training fuel consumption. For example, the pre-course fuel consumption for the full-course drivers should have been better than that obtained for the control group, even though the latter were tested six weeks later. Additionally, had some event occurred during the six week period that might have explained the reduction in fuel consumption, such as a change in work environment, a change in the traffic conditions on the course, or something related to enforcement or road safety, then the same reduction should have been seen in the control group as well – the only difference between the groups was participation in the course.

It is possible that the full-course drivers discussed the course and their progress during the twelve week period, or perhaps competed (overtly or covertly) with each other on saving fuel between testing. Rather than a source of criticism, if this had occurred it is actually a positive benefit since it would have resulted from the drivers completing the course. Indeed knowledge amongst the control drivers (who were not chosen for the control group until just prior to the six-week follow-up) of the benefits seen by the full-course participants would serve to make the comparison more conservative – it would work *against* finding a difference between the two groups and therefore increase the

respectability of the outcome. There was no reason to expect that the six-week control group or a fresh control group would have reduced their fuel consumption at the 12-week follow-up, so a control group at that time did not seem necessary.

Interestingly, the classroom-only group's fuel consumption did not vary from the full-course group's pre-training consumption or the control group's six-week consumption (all three groups were essentially equivalent until the full course was implemented). It would seem that either or both of the circuit drives on the day of the course (pre- and post-course) are important for achieving the fuel consumption improvements, despite the fact that no feedback was provided by the in-cab observers. Many or all of the classroom-only drivers drove a heavy vehicle on the day of the course anyway, so just driving on the day of the course does not seem to be important. Perhaps the immediacy and connection of driving the circuit after the course, and/or the presence of the observer in the cab are critical elements. The results of the pre-course drive were also discussed in the training course and this could help drivers to focus on behaviours they are able to change, such as the number of times they change gear and when they apply the brakes, in order to adopt an ecodriving style. Additional research is needed to establish how and why pre- and post-training driving seems to be critical to success.

### **6.2.1.1 Statistical analyses: Fuel consumption**

Despite the magnitude of the reduction in fuel use for the fully trained drivers, a within-groups ANOVA statistical test indicated that the main effect for reduction in fuel consumption was not statistically significant [ $F(3,9)=2$ ;  $p>0.05$ ], though the difference between the pre- ( $M=26.4$  litres) and immediately post-course ( $M=19.2$  litres) approached significance according to post-hoc testing ( $p=0.05$ ).

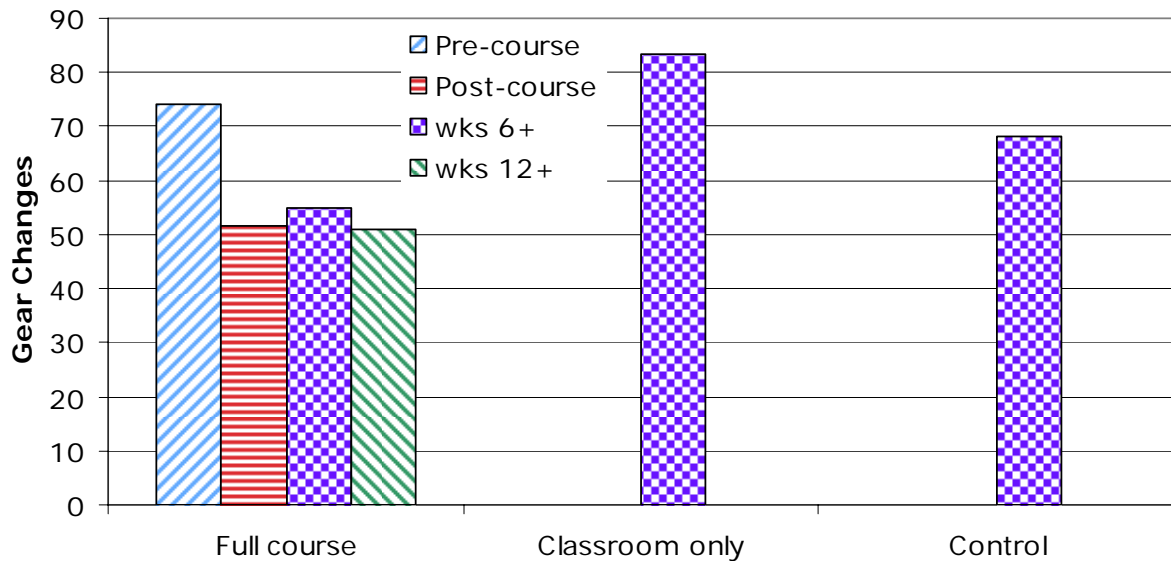
Due to logistical constraints in terms of truck, trainer and driver availability, data was not collected for the classroom training only group and the control group on the day of training. However, their data can be compared with the fully trained drivers using a between-groups ANOVA for each of the dependent variables at six weeks post training. The difference in fuel consumption was significant [ $F(2,9)=7$ ;  $p<0.05$ ] such that the fully trained drivers differed from both the classroom and control groups ( $M=20.1$  litres vs.  $M=26.8$  litres,  $p<0.05$  and  $M=20.1$  litres vs.  $M=27.5$  litres,  $p<0.01$  respectively). The classroom group did not differ significantly from the control group ( $M=26.8$  litres vs.  $M=27.5$  litres,  $p>0.05$ ) at the six week point.

### **6.2.2 Gear changes**

The average number of gear changes across experimental groups and trials is displayed in Figure 16.



**Figure 16: Gear changes across time for fully trained group and between groups at 6 weeks post-course.**



Participants in the ecodrive course were encouraged to reduce the number of gear changes they made when driving, using the brakes rather than the engine to decelerate when appropriate, using the engine's high torque at low revolutions, and changing up as soon as possible. Drivers in the full course reduced the number of gear changes they employed to complete the circuit by 29%, and again the reduction seems to have been maintained through the 12 weeks of follow-up testing.

The fully trained drivers again seem representative of the pool of drivers, using slightly more changes pre-course compared with the control group. The classroom-only group's gear changes at six weeks post-course indicate that their training had no benefit – indeed they used more gear changes than either the fully trained or control groups.

### 6.2.2.1 Statistical analyses: Gear changes

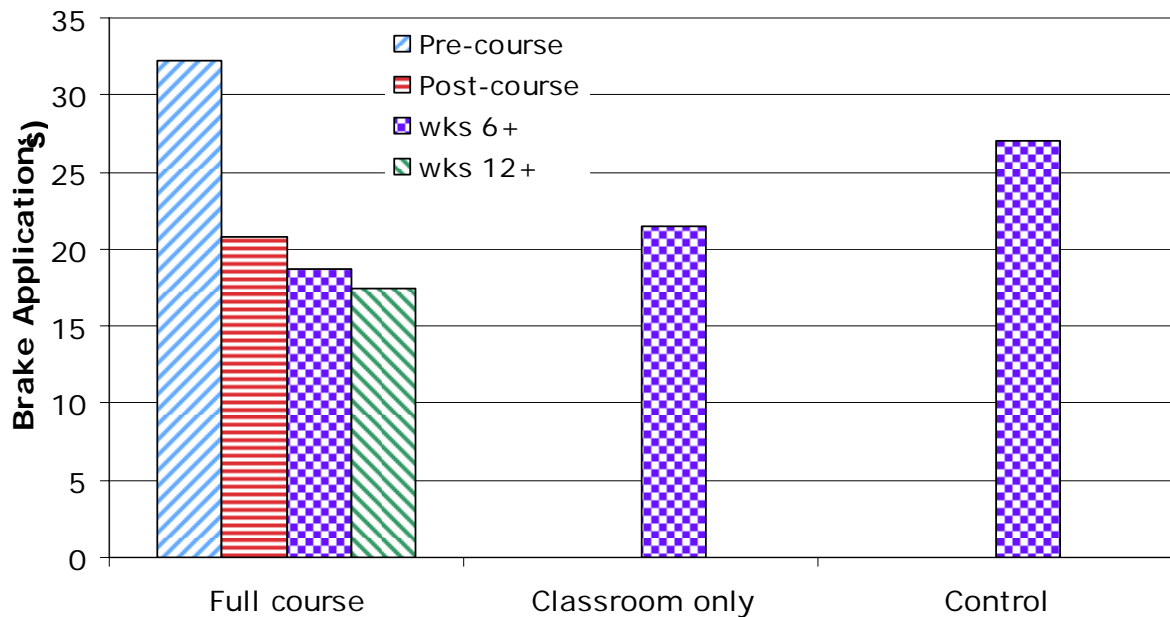
According to a within-groups ANOVA the main effect for gear changes was statistically significant [ $F(3,9)=7.9$ ;  $p<0.01$ ] across trials for the full-course group. Post-hoc testing revealed a significant difference between pre-course and immediately post-course gear changes ( $M=74$  vs.  $M=51.8$  changes respectively,  $p<0.01$ ) and pre-course and 12 weeks post-course gear changes ( $M=74$  vs.  $M=50.8$  changes respectively,  $p<0.05$ ).

A between groups ANOVA comparison of gear changes across the groups at six weeks post-training revealed a significant difference [ $F(2,9)=7$ ;  $p<0.05$ ], driven only by a significant difference between the fully trained and the classroom only groups ( $M=55$  changes vs.  $M= 83.3$  changes,  $p<0.01$ ).

### 6.2.3 Brake applications

The average number of brake applications across experimental groups and across trials is displayed in Figure 17.

**Figure 17: Brake applications across time for fully trained group and between groups at 6 weeks post-course**



Ecodriving principles dictate that braking is reduced commensurate with better reading of the traffic and scanning ahead. The fully trained drivers reduced their braking by an average of 41%, ranging from a 36% reduction immediately post-course to a 46% reduction 12 weeks after training. After the initial (substantial) drop this group would seem to be progressively reducing their braking over time. It should be noted, however, that the measurement here is the number of brake applications rather than the amount or intensity of braking, a variable to consider in any future studies.

### 6.2.3.1 Statistical analyses: Brake applications

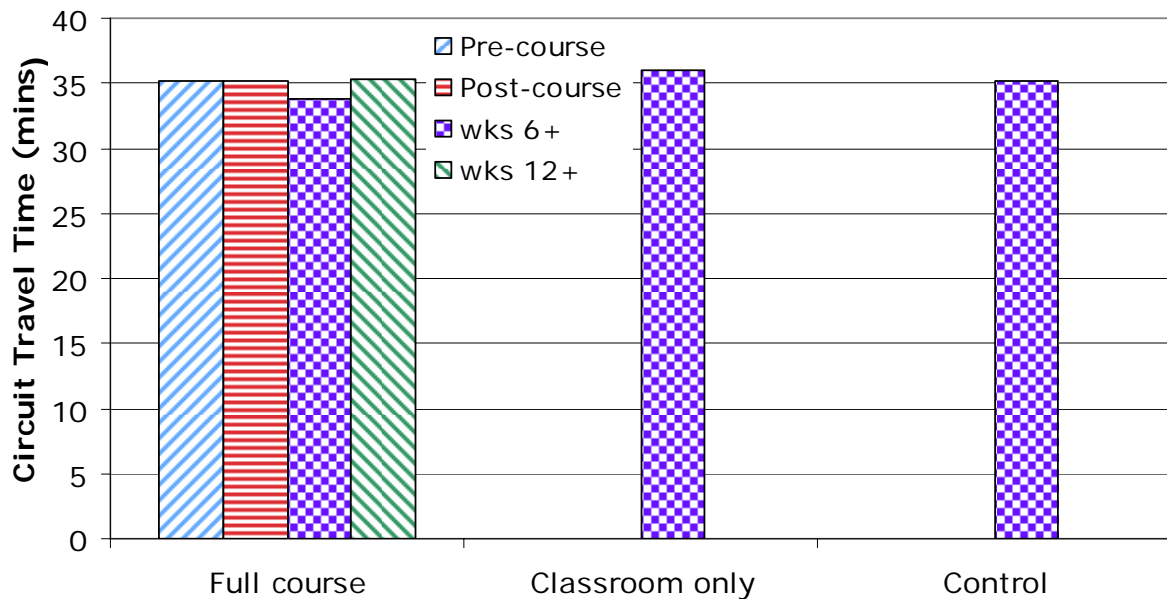
The main effect for brake applications within the fully trained group was statistically significant [ $F(3,9)=4.1; p<0.05$ ]. According to post-hoc testing the differences between pre-course and immediately post-training ( $M=32.3$  vs.  $M=20.8$  braking episodes respectively) and between pre-course and six weeks post-training ( $M=32.3$  vs.  $M=18.8$  braking episodes respectively) both approached statistical significance ( $p=0.05$  in both instances).

The difference in brake applications between the groups at 6 weeks post-course was not significant [ $F(2,9)=3.5; p>0.05$ ], though post-hoc testing revealed a statistically significant difference between the full course group and the control group ( $M=18.8$  applications vs.  $M=27$  applications;  $p<0.05$ ).

### 6.2.4 Circuit time & travel speed

The average circuit travel times for various experimental groups at various times during the experiment are displayed in Figure 18.

**Figure 18: Circuit travel time across time for fully trained group and between groups at 6 weeks post-course**



There was very little variation in the average time taken to complete the circuit – 35 minutes across all 24 circuits – with little discernible difference across time for the fully trained group or between any combination of fully trained, classroom only and control groups (see Figure 18). This result may be counterintuitive in that one might expect that a smoother, more anticipatory, and therefore cautious driving style may require a sacrifice in driving time for reductions in fuel, but this does not seem to be the case. The course was intentionally chosen for its mix of driving conditions in order to approximate everyday in-service situations for the drivers in question. The seemingly more cautious ecodriving approach may lose time in heavier traffic as other motorists cut into the additional headway allowed by the heavy vehicle driver. Conversely, anticipating traffic light changes at greater approach distances may result in a reduced loss of momentum and reduce travel times. A closer examination of the traffic conditions is required to address these questions.

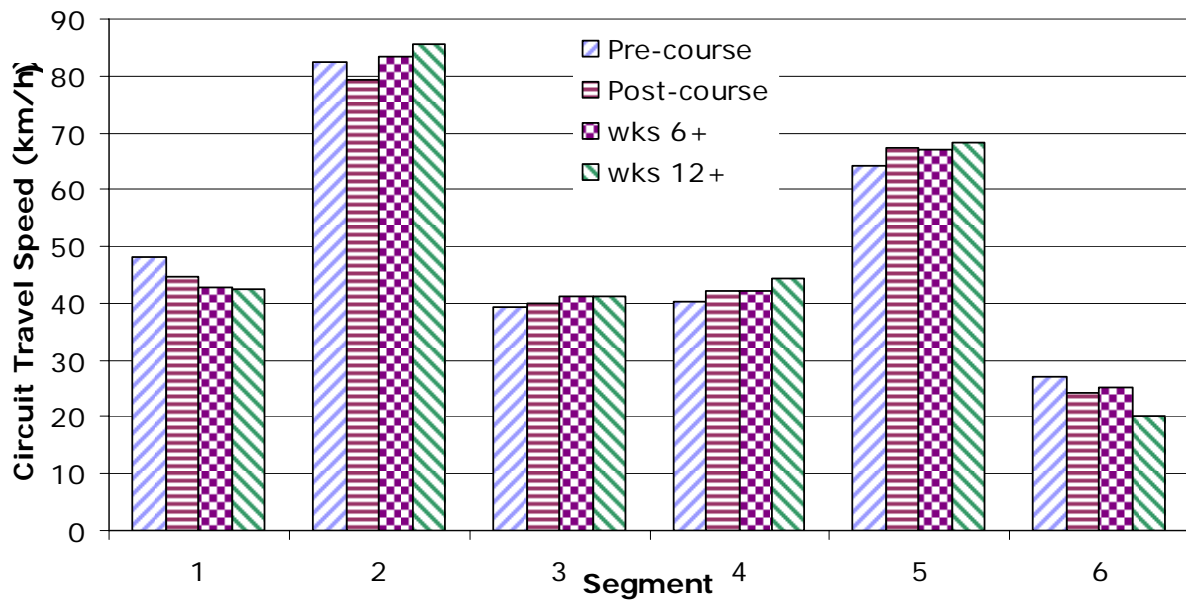
Each truck was equipped with a portable GPS device that logged position as a function of elapsed time while completing the circuit. The circuit itself was divided into six separate segments defined on the basis of major intersections. Bordering segments also represented different combinations of traffic density, road type, speed zone, and density of traffic control (e.g. roundabouts, traffic lights, pedestrian crossings, etc). Table 3 lists and briefly describes each of the segments.

**Table 3: Description of each circuit segment beginning from fuel station on Hume Highway**

Segment	End intersection	Distance	Predominant speed zone	Traffic conditions
1	Craigieburn Rd / Hume Fwy on-ramp	3.4 km	80 km/h	Industrial, single carriageway, two-way, light traffic
2	Hume Fwy / Cooper St off-ramp	6.8 km	100 km/h	Freeway, dual carriageway, one-way, moderate traffic
3	High St / Cooper St	2.9 km	80 km/h	Arterial, dual carriageway, two-way, moderate traffic
4	Epping Rd / Harvest Home Rd	3.3 km	60 km/h	Residential & strip-shopping, two-way, moderate traffic
5	Hume Hwy / Patullos La	11.9 km	100 km/h	Arterial, dual carriageway, two-way, moderate traffic
6	Fuel station	2.1 km	60 km/h	Industrial, single carriageway, two-way, light traffic

The overall average circuit time of 35 minutes corresponds to an average speed around the 30.4 km circuit of 51 km/h. However, the average travel speeds between the segments differed markedly. Figure 19 displays the average travel speed for each segment for the fully trained drivers at each of the four testing times. Not surprisingly, the highest speeds were on the seven kilometre freeway segment and the lowest speeds were on the segment just prior to returning to the fuel station, which included a small section of poorly maintained industrial road that linked the plant to the main arterial. Of most interest is the lack of a discernable pattern across the speed profiles: there was little difference in average speed between the pre-training drive and any of the three post-training drives (immediately after training, six weeks after, and 12 weeks after) for any of the segments, and no pattern of difference such that one drive was consistently the fastest or slowest across the segments.

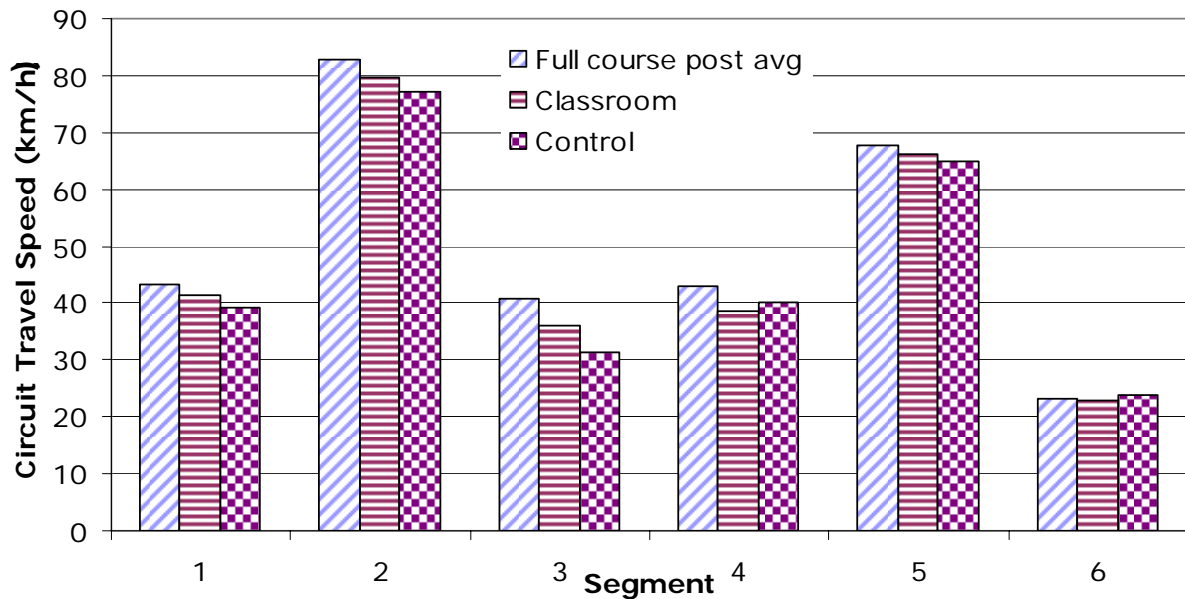
**Figure 19: Segment travel speeds for the fully trained group across the trial**



According to the evaluation of the Swiss Holcim (2005) trial, there was an improvement in travel speed of 9% following training. Across all segments the overall average speed for the fully trained group for the pre-course run was 50.2 km/h, 49.6 km/h immediately following training, and 50.3 km/h for both the six and 12 week tests. The immediately post-course speed differed the most from the pre-course speed, but that difference was only 1%, certainly within the realms of measurement error. The biggest change in speed, from pre-course to 12 weeks post-training, within any one segment was a 26% reduction in speed in Segment 6. This was followed by an 11% reduction in speed in Segment 1 – a mix of industrial precinct travel and 80 km/h arterial. The average speed increased in Segments 3, 4 and 5, but by no more than 5%. It would therefore seem that time of day (after avoiding peak commuting times) and actual day have little effect on average speed. The circuit is sufficiently long and varied that a ‘bad run’ in a particular segment due to heavier than usual traffic (etc.) is randomly balanced by a ‘good run’ in another segment, likely eliminating such factors as potential confounds. However, a larger number of drivers taking part in a study would provide more conclusive data on whether a pattern is present.

The three post-course speed scores (immediate, +6 weeks and +12 weeks) were averaged for each segment to make comparison with the classroom-only and control groups (see Figure 20). Interestingly, the fully trained group’s speeds after training were consistently higher than either the classroom or control groups, except for segment 6, and the overall improvement of the fully trained group was 8%. This increase in speed for the trained drivers was consistent with the 9% improvement found in the Holcim trial, though a larger sample size would indicate the reliability of that finding.

**Figure 20: Segment travel speeds for the overall average of the fully trained group versus the classroom and control groups**



### 6.2.5 Driver views & attitudes

At the conclusion of the three month assessment period, small group interviews were conducted with the drivers who had participated in the full training program. While this should be viewed as nothing more than qualitative data given the small number of drivers, these interviews provided a valuable insight into the drivers' perceptions of the program and its impact on their behaviour.

Assured of the confidentiality of their responses and the independence of the evaluation team, all four drivers commented positively on the training and the trainers. While they each had many years of driving experience they all believed the new driving style was worthwhile and had enabled them to reduce fuel consumption on a day-to-day basis. This was surprising to some of the drivers, who held a pre-conceived notion that the course would not really deliver much difference in their driving style or fuel consumption.

Drivers commented that they noticed it was physically easier to drive the vehicle while acknowledging that they needed to think more about how they were driving. Typical statements included:

*Instead of fighting the flow of traffic you are flowing with it.*

*Less hectic behind the wheel.*

*Seems smoother in the cab.*

*I feel like I am keeping the vehicle flowing rather than a lot of stopping and starting.*

Two drivers noted that as a result of the training they had also changed their behaviour when driving their private vehicles. One driver who drove a manual V8 car was doing more skip shifting and trying to flow his car with the traffic. Another driver with an automatic vehicle noted that he was anticipating traffic conditions more:

*I ease off the throttle rather than racing up behind cars at a red light and braking.*

The drivers noted that the allocation of two drivers per vehicle (one day and one night shift), with only one of each pair undertaking the full ecodrive training course, made it difficult to see much change in fuel consumption on an everyday basis. This was because, in their workplace, fuel consumption is reported for the vehicle rather than the individual driver. The drivers were concerned that any improvements they made would be masked by higher consumption by their co-drivers, yet at 12 weeks post-training this disincentive and lack of ongoing feedback did not seem to have negatively affected their enthusiasm for their new driving style. One driver did note that fuel savings that make the company's operations more economical could mean the difference between his employer maintaining a company fleet or subcontracting all freight to external providers.

Interestingly, the use of night-shift drivers may enhance the benefits of ecodrive training. Austroads (2007) recently published a report with some interesting arguments about particulate emissions and ground level ozone formation. For example, it is predicted that 50,000 trucks will be added to the national heavy vehicle fleet between 2005 and 2020. A consequence of the increased demand for road space will be increased movements of these vehicles at night. Although freight-carrying vehicles account for only 20% of the national vehicle fleet, studies have shown that these vehicles contribute the majority of particulate pollution and high levels of nitrogen oxides. In New Zealand, air quality research revealed that 91% of the human health effects of air pollution can be attributed to diesel vehicles that comprise less than 15% of the total fleet. Similar findings were found for Sydney, Melbourne, Brisbane and Perth. The release of particulate pollution under cool and still conditions can produce high ambient concentrations (brown haze). Night-time conditions during autumn and spring would facilitate brown haze formation. However, air quality impact is unlikely to be significant due to emissions occurring at times when (a) other traffic volumes are low, and (b) the absence of sunlight prevents formation of undesirable secondary pollutants (e.g. ground level ozone from nitrogen oxide emissions).

The drivers' comments about the need for personalised rather than truck-based feedback relate to the overall fleet management system – a 'partnership' model. Fuel consumption data is fed back to drivers but is currently reported as average values in terms of kilometres per litre for each vehicle. The use of a vehicle's engine to discharge the cement powder when completing a delivery can involve idling periods of an hour or more at a delivery site. Given the way fuel consumption is reported, these extended periods of idling can have an 'unfair' negative impact on fuel consumption results for a particular driver. However, technological solutions exist that could be programmed to assess fuel consumption only when the pumping equipment is not activated. Other solutions can provide shift-based, weekly or monthly fuel economy values for each driver via a code entered into an after-market device or the insertion of a personal key card. Such technology could be investigated for a larger trial that would allow data collection in everyday unaccompanied driving without the need to control refuelling.

## **6.2.6 Results summary**

Overall, the fully trained group performed better than either the control group or the classroom session-only group, indicating a benefit of the ecodrive training. Interestingly, since the performance of the classroom-only group was similar to the control group it would seem that presenting the information in this manner was not sufficient. Perhaps having the assessed drive immediately prior to the course enables better transfer of information and/or the drive immediately after allows the opportunity to immediately try the techniques just learned. In an ideal training situation the ride-along assessor would provide feedback and suggestions in the post-training drive to consolidate learning. Feedback was not provided in this experiment which had the unintentional benefit of making the comparison of results more conservative.

As a consequence of small sample sizes, substantial variability exists in each of the dependent variables (e.g. gear changes) which works against the potential for significant results. The magnitude of the changes, coupled with the consistent trends in the data and the likely improvement with even small increases in group size, warrant a larger trial to follow up the current pilot.

### **6.2.7 Implications of the results**

While very promising, the results of the pilot field trial need to be interpreted with some caution. It is important to keep in mind key parameters of this trial; it involved large, heavy vehicles, an outer metropolitan operation and, at the time when measurements were made, the driver was accompanied by an on-board assessor. The direction of results obtained here, and their magnitude, may not transfer to other vehicle types, other operating environments, or day-to-day operations. Nevertheless, the magnitude of reductions in fuel consumption and the retention of ecodriving skills by trained drivers suggest that this form of training could play a valuable role in reducing vehicle fuel consumption and related emissions.

To place the results in perspective, the participating company's operations in Victoria uses approximately 1.5 million litres of diesel fuel per annum. A 1% reduction in fuel consumption would translate into a financial saving of about \$15,000 and about 40 tonnes of CO<sub>2</sub> per annum. The recent rapid rises in diesel fuel prices would further magnify the financial savings.

The reductions in the number of gear changes also has relevance environmentally since brake pad deposits are a source of localised water pollution, particularly near intersections. The changes in gear use and brake applications could also have implications for reduced noise levels associated with the operation of the vehicle, which may be another local environmental benefit from the modified driving style, though any gains may be offset by increased use of engine or exhaust braking.

The reductions in gear changes and brake applications, and a smoother driving style would be expected to have implications for vehicle repair and maintenance costs as well as for driver fatigue. Over a 12 hour shift a driver might typically drive for about six hours. Based on an average of 75 gear changes and 27 brake applications over the test circuit prior to training that would mean a typical shift might involve about 770 gear changes and 550 brake applications. Adoption of an ecodriving style that reduced the number of gear changes and brake applications over a shift by 10% would translate into 77 fewer gear changes and 55 fewer brake applications. Even modest percentage reductions could lower driver fatigue toward the end of a shift that would have health and road safety implications.

## **6.3 Conclusions**

The pilot field trial described here sought to test ecodriving training under Australian conditions. The trial involved a within-groups comparison, in which one group of heavy vehicle drivers completed a circuit of varying traffic conditions before undertaking a brief course on ecodriving and driving the circuit again the same day, then six weeks after the course and again a further six weeks after that (12 weeks post-training). In addition, another group of drivers was assigned to a classroom-only course and a third group to a control condition to form a between-groups comparison with the fully trained group; these drivers completed an assessment circuit drive at the same six-week testing point. Twelve company drivers were randomly assigned to the three groups.

Compared to their pre-course measures, the fully trained drivers reduced their fuel consumption by 27%, reduced the number of gear changes by 29% and reduced brake applications by 41%. These



gains were not offset by increases in the time taken to complete the circuit. The benefits were retained up to 12 weeks after training, at which point the pilot trial concluded.

The nature and scale of the results reported here are very promising, though they are accompanied by a note of caution. The individual variability within driver performance is large and the small group sizes used here, governed primarily by logistical constraints, were not enough to smooth that variability. A larger trial is certainly warranted.

A follow-up trial could make use of in-service monitoring to measure fuel use for everyday driving, such as that used by Zarkadoula et al (2007). This would satisfy af Wählberg's (2007b) call for trials to be conducted in the driver's 'natural environment' to avoid the artificiality and inflated outcomes of experimental settings. Engine management computers monitor a wealth of information that could be logged. Combined with a GPS-based accelerometer system and programming to ignore fuel use while the cement pumping system is engaged, a number of variables could be automatically collected and, with GPRS (i.e. mobile phone) technology, configured to send the data to a server at a shift's end for central storage and analysis. Each driver could have a key card or code to log themselves into the system so that their data could be kept separate from that of other drivers using the same truck. All of the variables collected in the pilot could be collected by the in-service system: braking, gear changes, and speed profiles, as well as fuel injected into the engine (rather than fuel put into the tank), actual engine revolutions rather than just instances of over-revving, periods of idling separated into traffic- or loading/unloading-related (based on whether the vehicle was in neutral or a gear was engaged, or whether the 'maxi' [or parking] brakes were engaged), and acceleration profiles. Such devices in various combinations are already in use in heavy vehicles and are relatively inexpensive.

As well as collecting in-use data, the circuit test could also be replicated with a larger number of drivers to maintain a constant baseline comparison to take account of differing routes and work profiles of the driver sample. It would also be recommended that a classroom-only (or DVD-only) group be retained as this training option is significantly cheaper than a full training course and if it could be made to be as effective as a full training course, this would be particularly useful. A larger driver group will also allow for a wider range of vehicles to be tested, depending on the fleet profile of the company/ies involved in the larger trial.

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## 7 THE POTENTIAL FOR ECODRIVING IN AUSTRALIA

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Ecodriving is a somewhat more mature initiative in at least some European countries than it is in Australia. However, a set of standard recommendations are offered by many Australian organisations, both government and corporate, for modifying driving behaviour in order to reduce fuel consumption and emissions. Countries such as the Netherlands and Switzerland have gone significantly further and incorporated ecodriving into their novice driver training regimes.

van den Hoed, Harmelink and Joosen (2006) analysed three principle Dutch ecodrive initiatives: incorporation of ecodriving components into the driver training regime, a media campaign to deliver the message to existing drivers, and tax incentives for in-car devices designed to reduce fuel use. Driving instructors have been trained in ecodriving and ecodrive principles have been integrated into the novice driver curriculum and the driving theory test, and there are also plans to build an ecodrive aspect into the practical test for novice drivers. In order to influence other drivers, subsidised ecodrive training is offered to groups of professional drivers and an extensive mass media campaign promotes ecodriving principles and the importance of proper tyre inflation pressures. According to EEA (2008) vehicle purchasing advice will shortly also be incorporated into the Dutch novice driver curriculum. EEA (2008) claim that this comprehensive ecodrive program has reduced fuel consumption and maintenance costs, increased road safety, and reduced emissions and noise

As a highly motorised country with significant distances between population centres, Australia should be ideal for a widespread, properly resourced implementation of ecodriving en masse. However, the data is not currently available to perform a set of cost-benefit analyses to determine which, if any, scenarios for implementation are likely to be cost-effective for public implementation. Public and private corporations that operate fleets and employ drivers are in a position to trial ecodriving within their own organisation to determine its cost-effectiveness; it is not known how cost-effective a population-wide measure would be, though even a small benefit multiplied by a large number of drivers might result in a sufficiently substantial benefit.

Table 4 summarises some of the data presented by Golightly (2007) from an international survey of over 3,000 individuals across 11 countries. For the purposes of the table Australia and New Zealand (Au/NZ) have been grouped together to make comparisons with a European block constituted by the UK, the Netherlands, Denmark and Germany (EU). Just over half of the Au/NZ respondents felt they had control over their fuel economy performance compared with almost two-thirds of the European respondents. Despite these levels of perceived control, in both cases only around 40% of respondents considered themselves to be 'fuel economy active', which presumably means taking active measures to improve fuel economy. Substantially more Au/NZ than European respondents were more conscious of fuel economy than they were a year previously and just under half of the Au/NZ drivers had changed their driving behaviours in some way because of fuel prices.

**Table 4: Comparison between survey respondents in Australia & New Zealand (Au/NZ) versus UK, the Netherlands, Denmark & Germany (EU)**

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Item	Au/NZ	EU
Drive: days per week	5.66	5.12
Functional attitude toward the car	79%	71%
Feel control over mpg	54%	64%
Consider self to be fuel-economy active	44%	40%
More conscious of fuel economy than 12 months ago	59%	38%
Changed driving behaviour because of fuel prices	46%	32%

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Source: Golightly, 2007

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## 8 GENERAL DISCUSSION & CONCLUSIONS

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### 8.1 Ecodriving seems to be effective...

A substantial body of literature has reported savings in fuel consumed and reductions in emissions of various pollutants accompanying a change in driving behaviour to a smoother, more anticipatory style of driving – generally referred to as ecodriving. There is a lack of agreement as to the size of the benefit, but a positive benefit is almost always reported. The variability in the reported benefit is not surprising given that vehicle type, time of day, time of year, type of evaluation, driver variables, etc., can all influence the results.

Given that ecodriving 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. Much of the scientific ‘evidence’ for ecodriving effectiveness points to what would appear to be a small number of early studies, though it is often difficult to be certain as such figures are rarely referenced. Further, this earlier work is deemed, or at least implied, to be conclusive evidence for the effectiveness of ecodriving programs despite the fact that the original authors appropriately question the long-term benefits of their own findings.

Much of the ‘evidence’ uncovered was not published in the peer-review literature. The peer-review process weeds out studies with weaknesses or flaws in their design. For example, as well as describing the size of any effect, the editors of a peer-reviewed publication would also require statistical analyses of the results to determine whether they are statistically significant or are more appropriately explained by chance. There is no such filter on material published on the internet by individuals, companies or organisations. This does not necessarily indicate that a particular trial is flawed, but it does urge caution. There are, after all, many reasons not associated with quality for not submitting to a peer-review publisher.

### 8.2 ...though further research is needed...

The most common design used for past ecodriving trials is a simple before-after paradigm. Variables such as fuel economy are tested for a group of drivers who then participate in the training program. At some time later the drivers are tested again on the same set of measurement variables and a positive outcome generally results, suggesting that the training was responsible for the fuel savings and/or reduction in emissions, etc. However, such a design does not effectively isolate the *cause* of the change; it may have been the training program, but it may also have been some other event in the intervening period (especially if there is a delay between the training and the post-testing), or it may have been due to the attention and scrutiny afforded the drivers in the trial, or it may have been the interaction between the drivers during the training, etc. – the list of possible contributory causes is extensive.

Very few previous studies included a control group that did not receive the training but underwent the testing, and/or a group that participated in an alternative training program not specifically related to ecodriving (it could concern grooming and presentation or perhaps customer service). Such a model would enable more certain conclusions as to the reasons for any observed effect. Few of the studies encountered, particularly those proffered by training organisations as case studies, include a control group of any description.

The lack of longer-term evaluations are also criticised by some authors, but any follow-up period greater than a month or two and less than a year may in turn be confounded by seasonality effects. Coyle and Brown (2004) emphasise the importance of taking seasonality into account. Their data

suggests a trend for fuel economy to peak in (northern hemisphere) summer and trough in winter in the UK. Wet roads and windy conditions are likely to decrease fuel economy. Further, Coyle, Murray and Whiteing (1998) note that in the UK anti-waxing additives are added to diesel fuel, which can worsen fuel economy by 3%. There is likely to be a seasonal effect for Australia too, but it should be derived from empirical data rather than generalised from European or American research.

Coyle and Brown (2004) advise that in any evaluation, before, after, and 'as before' data should be collected to account for seasonal effects and caution that these trends are often overlooked and "can be exploited by unethical salespeople" (p. 17). The use of a control group tested at the same time as the trained drivers in the follow-up (a measure taken in the trial conducted by the current authors) would also improve the rigour of an evaluation without the necessity of waiting for a 12-month follow-up because seasonality should have the same effect on all drivers.

Some studies can also be criticised for their use of non real-world conditions such as off-road test tracks or simulators. While such environments allow more control over potential extraneous variables such as traffic, weather, and the road environment, critics will always question how transferable the results will be to the real world, particularly given that the drivers will have to put their training into place in the real world.

In many instances it is difficult to judge the soundness of a trial or study due to the paucity of detail published. Ideally an experiment or case study should be described in sufficient detail to allow for replication – a rarity in non-peer reviewed publications. In many cases the published information is really advertising, spruiking for business in driver training or fleet or logistics management. In such cases, such as the Fleet Best Practice and SAFED material included in the review, the detail behind the study may not be deemed important for the purposes of publication on the internet. While the lack of detail does not necessarily discredit a study's outcome, the vested interests of those conducting the trial and publishing the results should also be borne in mind.

Some of the more often-cited work on ecodriving is that of af Wählberg, though his findings for fuel savings are quoted rather than his rather critical views on earlier work by others. As recently as 2007 af Wählberg (2007b) asserted 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.*

af Wählberg (2007b) also claimed to have made personal contact with a variety of organisations and attempted to follow-up potential leads for rigorous research. His lack of success led him to conclude that

*...all claims about effects of EcoDriving and similar techniques, apart from fuel consumption and some types of emissions, are unsubstantiated. Also, the work on fuel consumption is scarce and of low quality...not how people drive in actual traffic (p.2).*

We share some of his concerns but seem to have had more success in identifying useful previous work, and while some of that work may lack some rigour, taken as a body the outcomes are certainly evidence of a trend if nothing else<sup>3</sup>. Future work needs to isolate the effective components

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3 With more detail about each study a meta-analysis would be a valuable exercise. Some of that detail might be obtained by directly approaching the authors and sponsoring organisations of previous trials, an exercise beyond the scope of the current project.

of ecodrive instruction so that training programs – if indeed actual training rather than simply providing better in-vehicle feedback and/or funding a mass media campaign is necessary – can be delivered as effectively and efficiently as possible.

### **8.3 ...particularly regarding safety outcomes and application to Australian conditions**

A small number of trials have been conducted in Australia. Our own field study was made as rigorous as possible given time, logistics and budgetary constraints. The pilot study did include a control group to ensure that comparisons were not limited to before versus after, and data were collected while drivers negotiated ‘normal’ traffic conditions in a variety of environments. Our findings for B-double heavy vehicle drivers in terms of fuel consumed, number of braking applications and number of gear changes are very promising, though not always statistically significant, and certainly not conclusive given the small number of drivers who participated. A larger trial using telematics to collect in-service data is certainly warranted, as is the inclusion of a wider range of vehicle types and a longer time frame to reach conclusions on road safety and maintenance outcomes.

Based on the range of outcomes across the studies reviewed, it would seem that any training that focuses on ecodrive principles has at least the potential to improve driver behaviour and reduce fuel consumption and emissions production, though Hornung (2004) found that simply presenting the information is not sufficient – it seems that a practical component is critical to achieving any real benefit. A practical component may also be critical to ensuring that the ecodriving behaviours do not actually *decrease* road safety. Not all behaviours undertaken to conserve fuel are bound to result in safer driving.

While much of the ecodrive work has been undertaken in Europe, a more extreme version is gaining popularity in the US and UK in particular – the ‘hypermiling’ movement. The aim of a hypermiler is to achieve the maximum fuel economy possible from their vehicle in normal traffic – Powell (2008) profiles a hypermile rally winner who achieved 124.6 mpg (1.89 L/100km). He also refers to a crossing of Australia’s Nullabor in 2001 at a rate of 128 mpg (1.84 L/100km). Preferring to travel at or near the speed limit, hypermilers use techniques such as ‘draughting’ in the slipstream of larger vehicles, driving barefoot (to increase the ‘feel’ and connection with the vehicle and the road), and inflating tyres to their maximum pressure rating. Slipstreaming can be useful. Hammarstrom (2000) reports that driving a car 50 m behind a heavy vehicle at about 85 km/h results in fuel consumption 6-12% lower than for a free vehicle at the same speed.

Shortening headways, or following distance, to achieve a reduction in fuel consumption also reduces visibility of the downstream traffic, particularly if the gap needs to be closed when following a smaller lead vehicle. This has the potential to increase the risk of rear-end crash. Preben (1999) also identified a number of potential negative side effects of ecodriving due to increased ‘freewheeling’, which may result in less use of brakes (also a practice of hypermilers who are loathe to give up any of their momentum lest they have to re-accelerate rather than cruise), resulting in shortened headways (even if they are only transient). However, no reports of actual, rather than supposed, increased crash risk or decreased safety as an outcome of ecodrive training were found, though that may in turn be due to an absence of a longer-term follow-up, and the fact that the authors and or benefactors of many of the published reports have a vested interest in the success of their training programs. Further, they may not look for or report potential negative road safety outcomes.

Changes in a driver’s profile in terms of headway, severity of braking as well as number of braking applications, lane changes, etc., could all be assessed with ITS-based devices as part of a well-resourced in-service trial. At this time it would seem that companies and organisations could stand

to make substantial savings in fuel from ecodrive training, and the community could benefit from officially incorporating ecodriving principles into all driver training and assessment, an initiative that was due to be instituted in the Netherlands from 2008 (Wardenaar, 2007).

## 8.4 Conclusions

Despite the need for further research, ecodrive holds significant promise for implementation in Australia. A number of local public and private corporations are already experimenting with ecodrive and seem to be reaping the benefits, though there is uncertainty as to the extent of those benefits in both size and type and the longevity of the effect before drivers return to their old habits. A proportion of individuals too would likely be receptive to the opportunity to reduce their fuel bill, and some others may also be responsive to the chance to help the environment and/or reduce the greenhouse effect; though market research should be carried out to tailor the right messages to the right groups. Fuel prices in Australia have spiked to record levels and then retreated significantly since Golightly's (2007) survey; however other factors mean that the retreat is not likely to dampen any existing enthusiasm for saving money at the fuel pump or reducing business costs.

An ideal opportunity exists now, before widespread take-up in Australia, to empirically identify the critical content and optimal methods of delivery for an ecodrive curriculum. There is also a need to explore the role that technology can play in not only evaluating the impact of ecodriving but also in supporting drivers in making informed vehicle control decisions. A best-practice model for implementation, informed by cost-benefit analyses, could then be efficiently and widely disseminated for corporate use and built into novice driver training, as is the case in some other countries. A thorough cost-benefit analysis should consider the potential for a triple-bottom-line improvement – financial savings, environmental benefit, and road safety and pollution-related health gains.

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