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THE RELATIONSHIP BETWEEN FUEL ECONOMY AND SAFETY OUTCOMES

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Abstract:

This report examines the possible safety benefits from driving in a manner that results in lower fuel consumption and emissions. It attempts to assess the potential of promoting additional motivations to drive safely – better fuel economy and other environmental outcomes, and reduced running costs.

Reducing speeding, lower speed limits and modifying driving style were found to improve fuel economy and other environmental outcomes in addition to improving safety. Community attitude surveys suggest that there will be greater support for measures that aim to improve fuel economy than for those measures that attempt to reduce vehicle travel. In addition, reducing fuel consumption rate without requiring a change in vehicle choice may be more acceptable and more easily implemented in the short-term. Programs such as these that result in reduced fuel consumption in addition to safety are more likely to be implemented because the benefits (in terms of fuel cost savings) flow directly to the vehicle owner.

The case study found that the fuel consumption rate of crash-involved vehicles was higher than that of vehicles not involved in crashes and demonstrated the feasibility of this method. Comparisons before and after training in driving to reduce fuel consumption and analytical studies based on fleet data are recommended as measures of the safety effects of fuel-efficient driving. Studies of the effects of instructions in driving style have the potential to provide useful information about the best ways in which to bring about fuel-efficient driving.

Key Words:
Environment, Fuel consumption, Vehicle emissions, Road safety, Driver behaviour

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EXECUTIVE SUMMARY

Both road safety and the environment are critically affected by the extent of the use of motor vehicles and the specific ways in which they are driven. This report examines the possible safety benefits from driving in a manner that results in lower fuel consumption and emissions. It attempts to assess the potential of promoting additional motivations to drive safely – better fuel economy and other environmental outcomes, and reduced running costs.

From an environmental perspective, fuel consumption results in the production of vehicle emissions which can be classified into air pollutants (which affect health) and greenhouse gases (which affect the environment). Fuel consumption also depletes stocks of non-renewable fossil fuels. Total fuel consumption can be decreased by reducing vehicle travel or by reducing fuel consumption rate (improving fuel economy). This report focuses on the safety effects of measures that improve fuel economy, rather than the effects of reduced vehicle travel. The scope of the report is confined to passenger cars and light trucks.

The safety benefits of driving in a manner that reduces fuel consumption

Driver behaviours that affect fuel consumption rate and safety include: choice of travel speed, smoothness of driving, choice of travel route, use of air conditioning and use of cruise control. Smoothness of driving and choice of travel route both affect fuel consumption rate by modifying the speed profile.

Reductions in travel speeds will result in crash savings in all scenarios. The reductions may be greatest in urban areas because of the significant representation of unprotected road users and because vehicles are better at protecting their occupants at urban speed levels. In urban areas, some fuel consumption and emissions reductions will follow from lower travel speeds but the bulk of the benefit will be to road safety. For open road travel, the crash savings associated with lower speeds are likely to be significant. The fuel consumption savings are likely to be greater than at urban speed levels.

Smoother driving has greater potential for reducing fuel consumption and emissions in urban areas than in open road travel. At the level of the individual vehicle, smoother driving can lead to greater reductions in fuel consumption than lower travel speeds in urban areas. The resulting reduction in emissions of air pollutants is expected to be greater than the reduction in greenhouse gas emissions. The environmental benefits of smoother driving may be greater than the road safety benefits but this is yet to be established.

More information is needed about the road safety effects of smoother driving. The possible effect on following distance of drivers attempting to maintain a steady speed (or avoid braking) has not been investigated. The nature of instructions to be given to drivers, particularly of automatic vehicles, needs further study. Further work on the interaction between driving style, speed limit and street length should be undertaken to establish whether different instructions should be given according to these variables.

Likely community acceptance

Given that reducing speeding, lower speed limits and modifying driving style can improve fuel economy and other environmental outcomes in addition to improving safety, there is a need to assess another aspect of implementation: the extent to which drivers are motivated by fuel costs and environmental effects.

Community attitude surveys suggest that there will be greater support for measures that aim to improve fuel economy than for those measures that attempt to reduce vehicle travel. In addition, reducing fuel consumption rate without requiring a change in vehicle choice may be more acceptable and more easily implemented in the short-term. Programs such as these that result in reductions in fuel consumption in addition to safety are more likely to be implemented because the benefits (in terms of fuel cost savings) flow directly to the vehicle owner.

Measuring the safety benefits

The case study found that the fuel consumption rate of crash-involved vehicles was higher than that of vehicles not involved in crashes and demonstrated the feasibility of this method. It also showed that while fuel consumption may be easier to measure than safety levels (crash costs), data manipulation and quality control may be time-consuming. The analytical approach is likely to be simpler and more likely to show reliable results if the fleet chosen has well-maintained fuel and crash databases. To show significant effects, the fleet needs to be reasonably large (about 500 vehicles). Analyses with smaller fleets could be undertaken over a longer period but if the period becomes too long, then vehicle and employee turnover may complicate the analyses.

Comparisons before and after training in driving to reduce fuel consumption and analytical studies based on fleet data are recommended as measures of the safety effects of fuel-efficient driving. Studies of the effects of instructions in driving style have the potential to provide useful information about the best ways in which to bring about fuel-efficient driving.

1 INTRODUCTION

1.1 BACKGROUND

Both road safety and the environment are critically affected by the extent of the use of motor vehicles and the specific ways in which they are driven. In 1998 Australians drove a total of 173 billion kilometres, 75% of this in passenger cars consuming 2/3 of all fuel used for road transport (Austroads, 2000). In that year the average distance travelled per car was 14,400 km. Between 1970 and 1996 there was a 39% increase in road travel per person. In fact, many variables have increased at a rate of at least double the increase in the population (e.g. number of licensed drivers, fuel consumption, vehicle registrations, billion vehicle-km travelled). All other factors being equal, an increase in total kilometres travelled results in more fuel consumed, more emissions and more road trauma.

Use of motor vehicles can reduce the quality of the air environment through:

- Polluting exhaust gases such as nitrogen oxides and hydrocarbons
- Evaporative emissions from fuel systems
- Particles in the exhaust gases of diesel vehicles
- Particles from tyre and brake wear

Motor vehicle use reduces the quality of the water environment through discharges to the environment which are eventually washed into waterways. This can result from material shed on the roadway from tyre and brake wear and oil leaks. Noise from car use can also reduce the quality of the environment.

The road toll has a high public profile, due at least in part to the often sudden and spectacularly severe consequences of a vehicle crash. The health effects of the pollution caused by motor vehicles receives a somewhat lower profile, possibly due in part to the usually slower decline in health as a result of exposure to these pollutants.

An EPA (2000a) study examined illness records and pollution data for Melbourne for the period 1991 to 1996. It was found that after controlling for the weather and other confounding factors, air pollution in Melbourne was associated with increases in daily mortality. The types of pollution found to bear the strongest relationships with mortality rate were those where the primary source was motor vehicles. The study notes that the relationships found are consistent with research from other Australian capital cities and cities in other countries. For example, air pollution, to which transport is the major contributor, is responsible for over 200 premature deaths in south-east Queensland each year (Meers and Roth, 2000).

In Australia motor vehicles account for over half of the emissions of oxides of nitrogen and carbon monoxide and almost half of the hydrocarbon emissions (Austroads, 2000). Cars consume 62% of the energy used by the road transport sector and emit 64% of the $CO_{2\text{-}e}$ (carbon dioxide equivalent gases in terms of their greenhouse effect). According to the US EPA's website (www.fueleconomy.gov/feg/drive.shtml), transportation vehicles produce 25-75% of key chemicals that pollute the air, causing smog and health problems.

It has been estimated that the average cost to society from emissions generated by the Australian motor vehicle fleet is 0.11 cents per kilometre, and that ozone-related health effects caused by motor vehicle emissions in Melbourne cost between $0.3 and $4.4 million in 1992-1993, while cancers cost between $26 and $45.2 million in 1990 (ABS, 1997). In 1995 the NRTC estimated annual noise costs to be between $200 and $400 million (ABS, 1997).

A US Department of Transport report on Transportation and Global Climate Change (1998) states that there are three principal ways of reducing greenhouse gas emissions from personal vehicle travel:

- reduce vehicle travel
- increase fuel economy
- switch to fuels with a lower life-cycle carbon content

This report examines a range of factors that impact both road safety and fuel economy in the transport system, focussing particularly on passenger cars and light trucks, where it is considered that the largest improvements might be made.

1.1.1 The relationship between fuel economy and safety outcomes

The relationship between fuel economy and safety outcomes forms part of the interface between the safety and environmental aspects of transport. From the widest view, the relationship is almost certainly inverse. Many studies have shown that the crashworthiness of larger vehicles (which generally consume more fuel than smaller vehicles) is greater than that of smaller vehicles (e.g. Buzeman, 1997). A number of studies have warned of the possibility of negative safety consequences resulting from reducing the size and/or mass of passenger vehicles in order to reduce fuel consumption (Buzeman, 1997; Fildes, Lee and Lane, 1993).

This project seeks to explore another aspect of the relationship where much less is known: the possible safety benefits from driving in a manner that results in lower fuel consumption and emissions. It attempts to assess the potential of promoting additional motivations to drive safely – better fuel economy and other environmental outcomes, and reduced running costs. The potential value of establishing such a link is to provide drivers, in particular fleet vehicle owners and drivers, with an additional financial incentive, through reduced operating costs, to adopt or encourage safer driving practices.

There is also the potential to build partnerships with other government initiatives to provide an integrated message about the benefits of better driving. In the end, both improved safety and environment combine to improve the life and well-being of people.

The motivation to reduce fuel consumption is increasing. The Sustainable Transport Team of the Australian Greenhouse Office has developed an Environmental Strategy for the Motor Vehicle Industry that aims to significantly enhance the environmental performance of the automotive industry through measures such as Consumer Information Programs and Fuel Consumption targets.

Identifying means of improving the fuel consumption of current vehicles by safer, more environmentally friendly ways of driving provides a mechanism to improve the fuel consumption of the existing vehicle fleet. Given the relatively slow turnover of vehicles in

Australia, this has the potential to complement measures that will be introduced to improve the fuel economy of new cars.

According to Bouwman and Moll (2000), cutting motor vehicle energy use in half in the Netherlands is possible by 2020, with a 60% reduction by 2050 using only technological improvements and without impacting mobility. When non-technological options are added, requiring major behavioural modifications, an 80% reduction could be achieved by 2050.

In summary, this research project aims to develop the techniques that will be required in the future. While interest in this area is increasing from low levels, there is a need to develop techniques for when they will be required.

1.2 PROJECT OBJECTIVES

The objectives of this project are to:

1. explore whether there are likely to be safety benefits in driving in a manner that minimises fuel consumption

2. investigate the feasibility of analytic and other studies to measure the safety benefits of fuel-efficient driving

1.3 REPORT STRUCTURE

This report consists of two parts: Part 1 is a review of the literature, and Part 2 is an examination of the feasibility of different methods of measuring the safety benefits of more fuel-efficient driving.

The literature review incorporates searches of publications databases, web sites and other electronic material, and contacting organizations which are known to have knowledge in this area. It focuses on:

- the factors affecting fuel economy and safety and the relationship between these factors
- the appropriate measures of environmentally friendly driving and of safety (e.g. the relative importance of fuel consumption and emissions)
- the extent to which drivers are motivated by fuel costs, environmental effects etc.
- safety effects of programs to reduce fuel consumption and vice versa

The literature review aims to assess the likely strength of the relationship between fuel economy and safety and guide the specific hypotheses that should be tested in the feasibility study.

The feasibility study examines the availability of different types of safety and fuel consumption data and the extent to which these would be useful to test the hypotheses identified in the literature review. One of the issues addressed is the range of variability in fuel consumption (if there is little variability, large data sets may be required to demonstrate a strong relationship with safety).

A range of methods for measuring the safety benefits of fuel-efficient driving will be discussed, including:

1. comparing fuel consumption before and after training in driving to reduce fuel consumption

2. observational studies to assess whether drivers who are observed driving in a particular manner have higher or lower fuel consumptions

3. simulator or on-road studies with instructions to drive in a particular manner

4. analytical studies to examine whether crash-involved drivers have higher fuel consumptions

The feasibility study discusses the relative needs for analytic versus experimental studies, and whether analytic studies should focus on particular company fleets or aim to include a wide range of vehicles for which fuel consumption data is available.

1.4 SCOPE OF THE REPORT

There are a number of factors that affect both the safety of the public road system and fuel consumption. These factors have been generally divided into vehicle factors such as cruise control, road or infrastructure factors such as extending the freeway network, and road user factors such as driver training. The emphasis of this report is on those factors that are related to “driving style” - driver behaviours while driving. These behaviours include: choice of travel speed, smoothness of driving, choice of travel route, use of air conditioning and use of cruise control.

A further measure that has the potential to significantly reduce both the amount of fuel consumed and the number of road incidents involving injury or death would be to limit the number of kilometres and trips that people drive. Among other aspects, limiting mobility involves road use and fuel pricing and infrastructure decisions, both of which are beyond the scope and focus of this report. Public transport issues are also relevant in a broader discussion but are not considered directly relevant to an individual’s fuel consumption rate. For a comprehensive overview of these factors the reader is referred to US DOT (1998), Murphy and Delucchi (1998), and Crist (1997).

This report also does not deal with noise as an adverse environmental outcome of vehicle use.

2. FUEL CONSUMPTION AND EMISSIONS

2.1 DEFINITIONS AND MEASUREMENT OF FUEL CONSUMPTION AND ASSOCIATED TERMS

The terms “fuel economy”, “fuel consumption” and “fuel efficiency” are often used interchangeably when discussing vehicles, initiatives and policies. There is some benefit to defining each of these terms, as technically they relate to different aspects of a vehicle’s performance.

2.1.1 Fuel consumption

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 and Watson, 1994, p. v). In a metric system, this volume of fuel is generally expressed in litres.

Fuel consumption per kilometre is also known as ‘specific fuel consumption’ (Van den Brink and Van Wee, 2001). Nairn et al (1994) refer to litres consumed per 100 kilometres travelled as “fuel consumption rate”.

In some studies that compare alternative fuel sources, fuel consumption rate is measured in megajoules per kilometre travelled.

Measurement of fuel consumption rate

The Australian Greenhouse Office regularly issues guides that detail the fuel consumption of new vehicles so that vehicles of the same class can be compared according to their rate of use of fuel. These official fuel consumption figures are the results of tests carried out in accordance with Australian Standard 2877 for fuel consumption testing. The testing is carried out under identical, controlled conditions in a laboratory to allow for comparisons between vehicles.

There are two fuel consumption tests: one for city driving and one for highway driving. The city driving test simulates a 12-km, stop-and-go trip with an average speed of 32 km/h. The test includes time spent idling and cold and hot starts. The highway driving test represents ‘non-city’ driving over a distance of 16.48 km, at an average speed of 77 km/h. The test is run from a hot start and has little idling time and no stops (Australian Greenhouse Office, 2000).

The in-service fuel consumption of vehicles is generally higher than that quoted in the official fuel consumption figures. A study of the in-service fuel consumption of the Australian passenger car fleet found that on average drivers used 15 per cent more fuel than the Guide figure in city conditions and 34 per cent more in highway driving (study cited in Australian Greenhouse Office, 2000).

Factors affecting fuel consumption rate

The Biggs-Akcelik instantaneous model of fuel consumption and emissions is described in Dyson, Taylor, Woolley, and Zito (2001). In this model, the characteristics of the vehicle that affect fuel consumption are vehicle mass, the fuel used in maintaining engine operation (estimated by the idle rate), engine efficiency in general, energy efficiency during acceleration, rolling resistance and aerodynamic resistance.

The primary characteristic of the roadway that affects fuel consumption is percentage gradient.

Fuel consumption increases with speed because the total tractive force needed to drive the vehicle increases. Aerodynamic resistance increases more than proportionally with speed. Fuel consumption also increases with acceleration.

2.1.2 Fuel economy

Fuel economy is the inverse of fuel consumption rate, it is the distance that can be travelled using a certain amount of fuel. Fuel economy was traditionally measured (and still is in some areas) in terms of miles per gallon in the imperial system. The metric equivalent is kilometres per litre, but this is rarely used.

2.1.3 Fuel efficiency

The 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 car can be enhanced by improving the fuel efficiency.

As Figure 2.1 demonstrates, about 18% of the energy content of fuel is used to move a car along the road, split between overcoming rolling friction, aerodynamic drag, and inertia (US DOT, 1998). The remaining 82% of the initial energy is lost as heat in the engine.

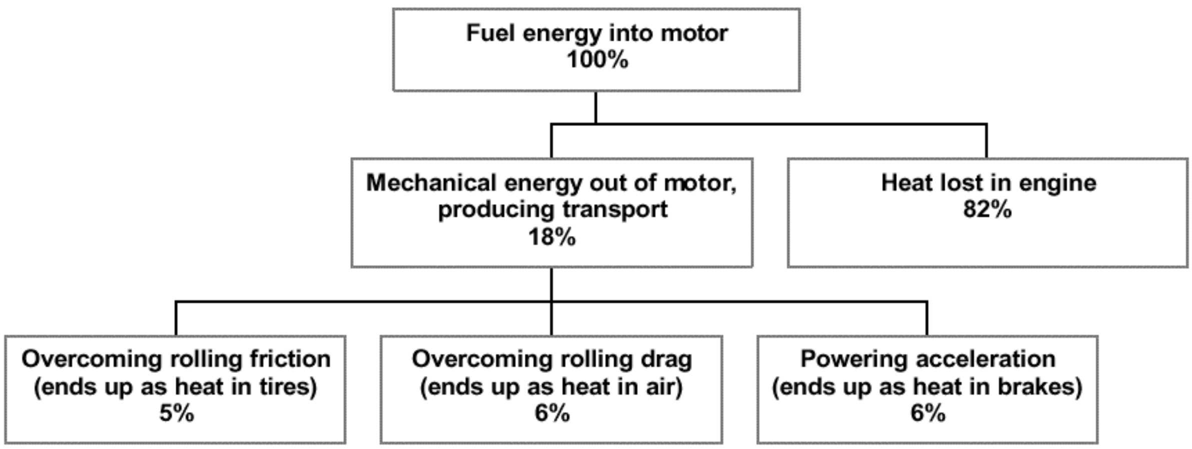

Figure 2.1. Energy consumption by petrol engines (from US DOT, 1998)

2.2 EMISSIONS

2.2.1 Vehicle operation and emissions

Heywood (1988, cited in Robertson, Ward, Marsden, Sandberg and Hammarström 1998) provides a detailed description of the fundamentals of engine design and combustion processes which is summarised in Robertson et al. (1998). The level of emissions of NO, HC and CO emitted by a given engine depends on the air to fuel mixture ratio. CO emissions increase with decreasing air-fuel ratios below optimum (as mixture becomes richer). CO emissions are low for diesel engines because they operate on the lean side of optimum. NO emissions are highest at the optimum air/fuel ratio. If spark timing is not optimum, there will be an excess of unburned hydrocarbons.

Catalytic converters reduce levels of pollutants through oxidation of hydrocarbons and CO to CO_2 and water, and also by reduction of NO_x to N_2 and O_2. The effectiveness of catalytic converters is markedly reduced if the engine temperature is insufficient (during cold starts) or if the engine mixture is outside the operating limits.

Evaporative emissions occur when volatile hydrocarbons escape from the fuel system through evaporation from the fuel tank or from the hot carburettor cooling down when the engine has been switched off.

Particulates are generated by wear of consumable components of vehicles, notably the tyres and brakes.

Vehicle emissions can be classified into air pollutants (which affect health) and greenhouse gases (which affect the environment).

2.2.2 Health effects of air pollutants in vehicle emissions

Motor vehicles are major contributors to total emissions of CO, oxides of nitrogen (NO_x), volatile organic compounds (VOCs, sometimes termed hydrocarbons, HCs) and lead, and are also significant sources of emissions of particles with an aerodynamic diameter less than 10 and 2.5 micrometres (PM_{10} and $PM_{2.5}$) (EPA, 2000b).

Carbon monoxide (CO) is an odourless, colourless gas that is formed when the carbon in fuels does not completely burn. Carbon monoxide concentrations are typically highest during cold weather, because cold temperatures make combustion less complete and trap pollutants low to the ground. Carbon monoxide enters the bloodstream through the lungs and binds chemically to haemoglobin, the substance in blood that carries oxygen to the cells. Thus it reduces the amount of oxygen reaching the body's organs and tissues. People with cardiovascular disease may experience chest pain and more cardiovascular symptoms if they are exposed to carbon monoxide, particularly when exercising (US EPA, 2000). Exposure to high levels of carbon monoxide may impair alertness and vision in healthy individuals.

Nitrogen dioxide is formed when nitric oxide reacts with oxygen in the atmosphere. Exposure to nitrogen dioxide can cause coughing, wheezing and shortness of breath in children and adults with respiratory disease. Short-term exposure can also increase the risk of respiratory illness in children (US EPA, 2000).

Some hydrocarbons are carcinogenic e.g. benzene and toluene.

Oxides of nitrogen and volatile organic compounds react together in the atmosphere under stable atmospheric conditions and strong solar radiation to form photochemical smog. Ozone in photochemical smog can irritate the respiratory system (coughing, irritation and uncomfortable sensations in the chest), reduce lung function, inflame and damage the lining of the lung and aggravate asthma (US EPA, 1999).

Particles with an aerodynamic diameter less than 10 (coarse particles) and 2.5 micrometres (fine particles) (PM_{10} and $PM_{2.5}$) are a health concern because they can be inhaled into the respiratory tract and deep into the lungs. Coarse particles can aggravate respiratory conditions such as asthma. Exposure to fine particles is associated with serious health effects, including premature death for the elderly and people with existing heart or lung diseases. Some small particles can be carcinogenic.

There are two atmospheric issues that concern ozone (EPA, 2000b). A layer of ozone occurs naturally in the stratosphere (15-20 km above the earth) and filters out harmful ultraviolet rays. Ozone-depleting substances are affecting this layer. Ground level ozone occurs in the troposphere (near to the earth's surface) and is the principal component of photochemical smog. It is harmful to human health and other aspects of the environment. The two forms of ozone are chemically identical but the location, source and effect differ.

2.2.3 Greenhouse gases

Carbon dioxide is an emission resulting from complete combustion of fuel. While it is not considered an air pollutant, it is considered a greenhouse gas because it contributes to global warming by preventing heat from escaping the earth's atmosphere.

2.2.4 Approaches to reducing air pollutants and greenhouse gases

The approaches taken to reduce air pollutants and greenhouse gas emissions differ somewhat. Production of carbon dioxide is generally proportional to fuel consumption. Therefore moves to reduce greenhouse gas emissions basically involve approaches to reducing fuel consumption. Reduction in vehicle travel is the most fundamental of these measures. Making cars more fuel efficient by producing or promoting new cars that consume less fuel or by better maintenance of existing cars are also ways of reducing fuel consumption.

Measures to reduce air pollutants generally focus more on measures to improve combustion (which has the added effect of reducing fuel consumption and greenhouse gases).

3 FACTORS AFFECTING BOTH ROAD SAFETY AND FUEL CONSUMPTION

There are a number of factors that affect both the safety of the public road system and fuel consumption rate, as summarised in Table 3.1. For convenience, these factors have been generally divided into vehicle factors such as cruise control, road or infrastructure factors such as extending the freeway network, and road user factors such as driver training.

A number of other factors affect both safety and affect overall fuel consumption by reducing vehicle travel. These factors are summarised in Table 3.2. While these factors are important, they are not the focus of this report. The reader is referred to US DOT (1998), Murphy and Delucchi (1998), and Crist (1997) for a fuller discussion of these factors.

In some cases implementing a particular initiative can have positive benefits for both areas. For example, maintaining correct tyre pressure improves safety in terms of road handling and grip, and improves fuel efficiency due to the minimum road friction attainable with an acceptable level of safety. However, other initiatives may improve either safety or the environment at the expense of the other factor. For example, encouraging the use of motorcycles is expected to result in an overall saving in fuel, but as a mode of transport motorcycles are not as safe as cars (Wigan, 2000). Other factors may affect safety and environmental outcomes in a more complex manner. Speed is one such factor that will be discussed later in this section.

The emphasis of this report will be on those factors that are related to "driving style" - driver behaviours while driving. These behaviours include: choice of travel speed, smoothness of driving, choice of travel route, use of air conditioning and use of cruise control. Smoothness of driving and choice of travel route are discussed as different factors but the underlying mechanism of their effects on fuel consumption is modification of the speed profile.

For each of these factors, the safety and environmental benefits will be discussed and any disbenefits noted.

Table 3.1. Summary of factors that influence road safety and fuel efficiency.

	General influence on	
	Safety	**Fuel economy**
Vehicle factors		
Vehicle mass increase	Improve[1] for occupants Worsen[2] for others	Worsen
Vehicle safety features	Improve	May[3] worsen
Air conditioning	Improve	Worsen
Smoother vehicle profile (e.g. aerodynamics, bullbars)	Improve	Improve
Cruise control	Improve	Improve
Engine power increase (with driving style unchanged)	May worsen	Improve
Road/infrastructure factors		
Traffic calming	Improve	Worsen
Replace traffic lights with roundabouts	Improve	Improve
Decreased residential speed limits	Improve	May worsen
Decreased open road speed limits	Improve	Improve
More freeways	Unclear	Improve
Increase public transport infrastructure &/or services (with assumed increase in patronage)	Improve	Improve
Decrease congestion	May reduce total number of crashes but increase average severity	Improve
Rebuild more direct/straighter/ level roads	Improve	Improve
Road user factors		
EcoDriver training (attitudes & skill)	Improve	Improve
Increased speed limit enforcement	Improve	Improve
Aging of vehicle fleet	Worsen	Worsen
Regular vehicle maintenance	Improve	Improve
Correct tyre pressures	Improve	Improve
Annual roadworthiness inspections	Improve	Improve
Motorcycle use	Worsen	Improve
Better informed vehicle choice	Improve	Improve
Speed limiting devices	Improve	Improve
Fuel consumption feedback devices	Worsen (if causes distraction)	Improve

[1]'Improve' indicates that as the factor increases in size the level of safety/fuel economy improves.
[2] 'Worsen' indicates that as the factor increases in size the level of safety/fuel economy deteriorates.
[3] 'May worsen' indicates that as the factor increases in size the level of safety/fuel economy may deteriorate, but probably by a negligible amount.

Table 3.2. Summary of road user factors that influence road safety and fuel economy by reducing vehicle travel.

Road user factor	**General influence on**	
	Safety	**Fuel economy**
Restrict car travel	Improve	Improve
Car pooling / car sharing	Improve	Improve
Cycling, walking, etc. (assuming special paths)	Improve	Improve
"Gas guzzler" taxes and other fees or taxes (assuming decreased private car use)	Improve	Improve

3.1 TRAVEL SPEED

To understand the effects of travel speed on safety and fuel economy, it is necessary to clarify the different terms and measurements related to speed.

Speed is defined as the rate of change of distance with respect to time. On any given trip, a vehicle will spend some time at rest, some time accelerating, some time cruising (constant speed) and some time decelerating. The pattern of speeds over the trip is termed the *speed profile* of that vehicle for that trip. The total distance travelled on the trip divided by the total elapsed time provides the *average speed* for that vehicle for that trip. The speed of the vehicle at any point in time is termed the *instantaneous speed*.

Speed measurements and terminologies become somewhat more complex when more than one vehicle is considered. A set of measurements of instantaneous speeds of a series of vehicles gives a *speed distribution*. The *mean* and the *85th percentile* of the speed distribution are commonly reported statistics. The percentages of vehicles exceeding certain cut-off values (eg. the posted speed limit, 10 km/h above this limit, 20 km/h above this limit) are often reported.

Often only *free speeds* (speeds of vehicles unrestricted by preceding vehicles) are measured and reported in speed distributions. The free speeds will generally be higher than the speeds of following vehicles. Thus the means and 85th percentiles of distributions of free speeds will be higher than the corresponding figures for the entire traffic stream.

SMEC (1998) simulated the relationships between average (all – not just free) speeds and cruise speeds in different road environments. For residential streets in Melbourne zoned 60 km/h they estimated that average speeds were between 12 and 28 km/h lower than cruise speeds. The differences between average (all) and cruise speeds were estimated to be greater in peak than off-peak periods and increased with cruise speed. Over an increase of 15 km/h in cruise speed (from 47 km/h to 62 km/h), average (all) speeds increased by only 3 km/h (peak) to 6 km/h (off-peak).

3.1.1 The relationship between travel speed and crashes

There is overwhelming international evidence that lower speeds result in fewer collisions, and lesser severity in the crashes that do occur. Accident frequency rises approximately with the square of the *average* traffic speed (Taylor, Lynam and Baruya, 2000).

The increase in severity with an increase in speed is demonstrated by the model developed by Andersson and Nilsson (1997). The model was essentially based on studies of the effects of speed limit changes in Sweden, and states that the probability of a fatal accident is related to the fourth power of the speed. This means that a 10% reduction of mean speed results in a reduction of the number of fatalities of approximately 40%. Figure 3.1 shows the predicted outcome of a change in mean speed on the number of accidents, fatal and serious injury accidents, and fatal accidents.

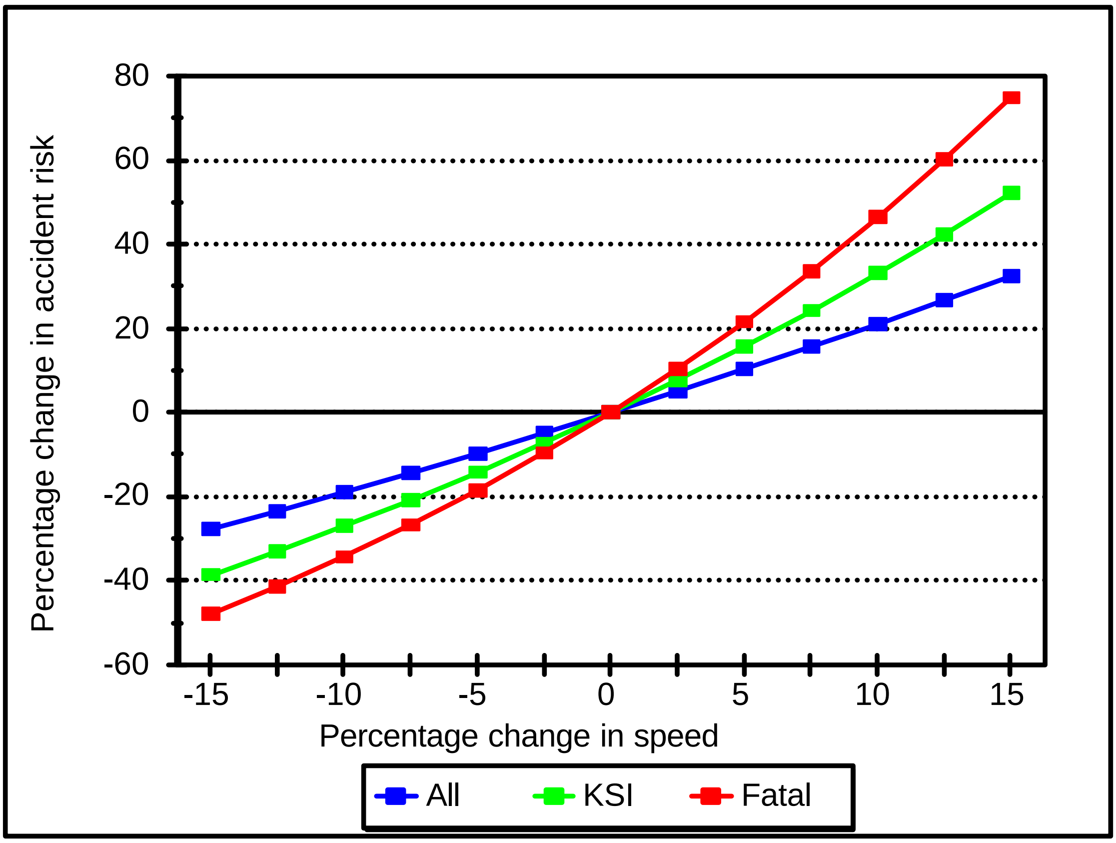

Figure 3.1. The percentage change in all accidents, killed and serious injury (KSI) accidents and fatal accidents (y-axis) as a function of percentage changes in mean speeds (x-axis). The steepness of the curve increases with accident severity. Based on Andersson and Nilsson (1997)

Research undertaken in the USA after the raising of the interstate speed limits (cited in Finch, Kompfner, Lockwood and Maycock, 1994) has shown that an increase in mean speed of 2-4 miles/h (approximately 3-6 km/h) resulted in an increase of the number of fatalities of 19-34%. This roughly translates into a 8 to 9 per cent increase in fatalities on USA interstate highways for every 1 mile per hour change in mean speed.

Recent work on speed and accidents has indicated that the relationship derived by Finch et al (1994) 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 and Baruya, 2000). However, greater accident reductions per 1 km/h reduction in speed are achieved on residential and town centre roads, and lower reductions are achieved on higher-quality suburban and rural roads.

Recent Australian research has generated new evidence on the increases in crash risk with increasing travel speed. For example, a study in metropolitan Adelaide reported that travelling at 5 km/h over the speed limit doubles the risk of an injury crash, the same effect as BAC of 0.05 (Kloeden, McLean, Moore and Ponte, 1997). For pedestrian crashes, McLean, Anderson, Farmer, Lee and Brooks (1994) reported a strong relationship between impact speed and injury severity.

Vehicle speeds affect pedestrian safety in a number of ways:

> lower vehicle speeds increase the time available to a driver to detect and react to risky or inappropriate pedestrian behaviour, lower vehicle speeds provide for shorter braking distances to minimise or eliminate the risk of collision with pedestrians, and lower vehicle speeds allow more time for a pedestrian to detect and react to the presence of the vehicle on the roadway. (Gibson and Faulks, 1998, p 92)

Several studies have shown that the risk of a pedestrian receiving fatal injuries at an impact speed of 50 km/h is approximately 10 times higher than at an impact speed of 30 km/h. The power functions are even steeper for pedestrians than for vehicle occupants. About 90 percent of pedestrians struck at 65 km/h will be killed in comparison to about 10 percent for those struck at speeds at or below 35 km/h (Ashton and Mackay, 1979). The change from mainly survivable injuries to predominantly fatal ones takes place between 50 and 60 km/h.

3.1.2 The relationships between travel speed and fuel consumption rate and emissions

Fuel consumption rates and emission rates 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 is a more important determinant of fuel consumption rate and emissions than the average speed for the trip. Some reporting of effects of travel speed on fuel consumption and emissions has been clouded by an incomplete description of what is being measured (André and Hammarström, 2000).

Constant (cruise) speed

In a modern vehicle, travelling at a constant speed allows the engine management system to optimise the fuel flow into the combustion cylinder. This minimises fuel consumption and emissions (Robertson et al., 1998).

Curves relating emissions to constant speeds have been produced by a number of research projects (summarised in André and Hammarström, 2000). Unfortunately, the shapes of the curves differ among the studies. For example, Samaras and Ntziachristos (1998, cited in André and Hammarström, 2000) report that CO emission reaches a minimum at about 70 km/h whereas Joumard et al. (1999, cited in André and Hammarström, 2000) report that CO emissions decrease monotonically with speed.

Figure 3.2 summarises one set of data on the effect of different levels of constant (cruise) speed on emissions (from Ward, Robertson, S. and Allsop, 1998). CO emission has a minimum at 40 km/h and is about 50% higher at 70 km/h. Emissions of HC reach a minimum at 80 km/h. Emissions of NO_x increase with cruise speed. Emissions of particles reach a minimum at 50 km/h. According to these data, the optimum cruise speed to minimise emissions of CO, NO_x and particulates is probably about 40-50 km/h.

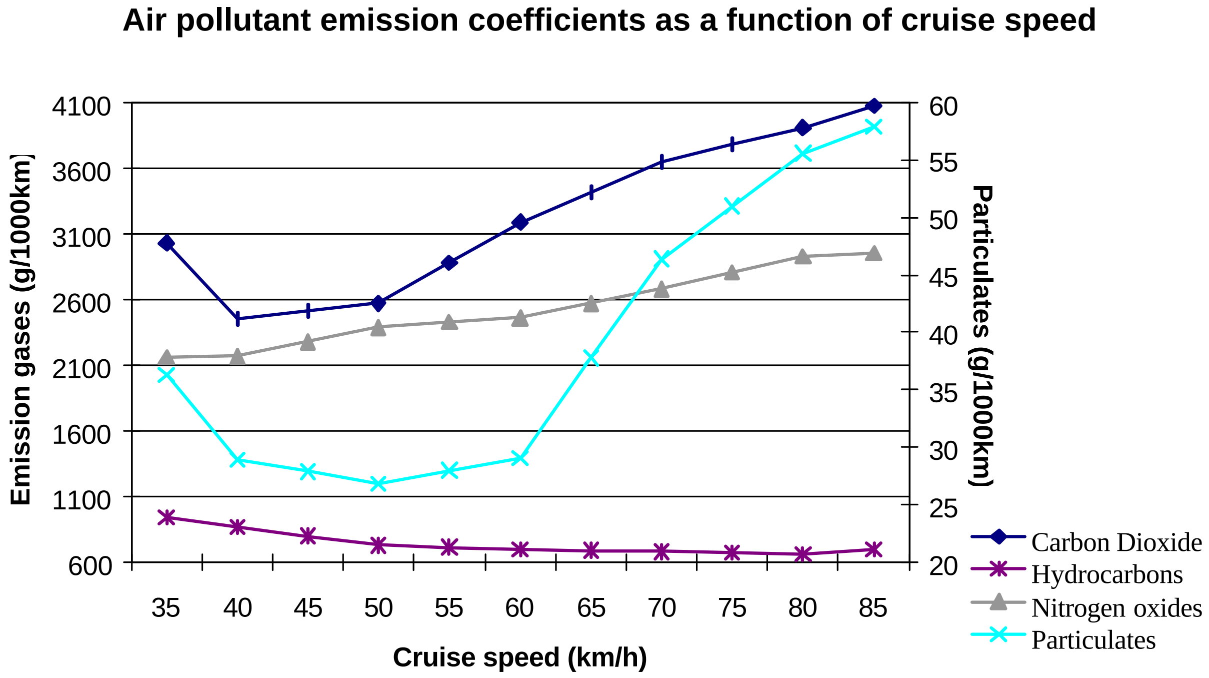

Figure 3.2. Relationship between cruise speed and emission rates (from Ward et al., 1998).

Different studies of the effect of cruise speed on fuel consumption have found conflicting results. Using an instrumented car, Lines and Morgan (1992, cited in Walsh, 1999) found that a car travelling at a steady speed of 50 km/h uses 4.2% less fuel than at 60 km/h, and at 40 km/h it uses 14.5% less fuel than at 60 km/h. At lower speeds, the idle fuel consumption rate is of primary importance, with the result that fuel consumption (as measured by consumption per unit distance) is higher at low speeds because it takes longer to travel a nominated distance. The fuel consumption rate increases significantly at speeds above 50 km/h, primarily because of the increase in aerodynamic drag force that occurs at higher speeds.

Newer European data appears to show different patterns. Samaras and Ntziachristos (1998, cited in André and Hammarström, 2000) found that fuel consumption for 1993-96 European vehicles of 1.4 to 2.0 litres (with a three-way catalyst) reached minimum fuel consumption at 80 km/h. However, Joumard et al. (1999, cited in André and Hammarström, 2000) found that CO_2 production (which is usually proportional to fuel consumption) continued to fall with increasing speed.

Acceleration and deceleration

During acceleration, the fuel to air ratio is higher than optimal. This results in large increases in CO and HC emissions (Robertson et al., 1998).

There is less evidence available about the effect of deceleration on emissions. Most research relates to use of the brakes rather than pure deceleration (Robertson et al., 1998). In general, deceleration emissions are significantly lower than acceleration emissions. Given that there is no throttle input in deceleration, the air-fuel mix will tend to be leaner than optimal, resulting in lower emissions of CO and HC. The lower combustion temperature will result in lower NO_x emissions. Robertson et al. (1998) speculate that using engine braking alone will lead to higher emissions than using the brakes because the engine speed will increase and the engine will operate fuel rich for a short period. However, their review did not identify any research into the differences in the two types of deceleration.

Robertson et al. (1998) conclude that "vehicle emissions are not simply linked to speed. The acceleration characteristics of the vehicle and driver will also contribute significantly. In attempting to introduce traffic calming measures care should be taken not only to decrease speeds but to smooth the overall journey for the driver" (p.16).

Average speed

As noted earlier, the average speed for a journey incorporates components of acceleration, deceleration and cruise speeds. A number of attempts have been made to estimate the relationship between average speed and fuel consumption and emissions. Clearly the precise nature of the relationship will depend on the assumptions about acceleration and deceleration components.

Figure 3.3 presents typical emission and fuel consumption rates as a function of average speed for vehicles conforming to Economic Commission for Europe (ECE) 15-04 regulations (Eggleston et al., 1992, cited in Smith and Cloke, 1999). Emissions of Volatile Organic Compounds (VOCs or HCs) and carbon monoxide (CO) generally decrease as average speed increases. At high levels of average speeds (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. 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/ and then increase.

Given the strong relationships between travel speeds, crashes and fuel consumption and emissions, there is a clear case to reduce travel speeds. There have been three general approaches to reducing travel speeds:

- reducing speeding
- reducing speed limits
- reducing speeds within the posted speed limit

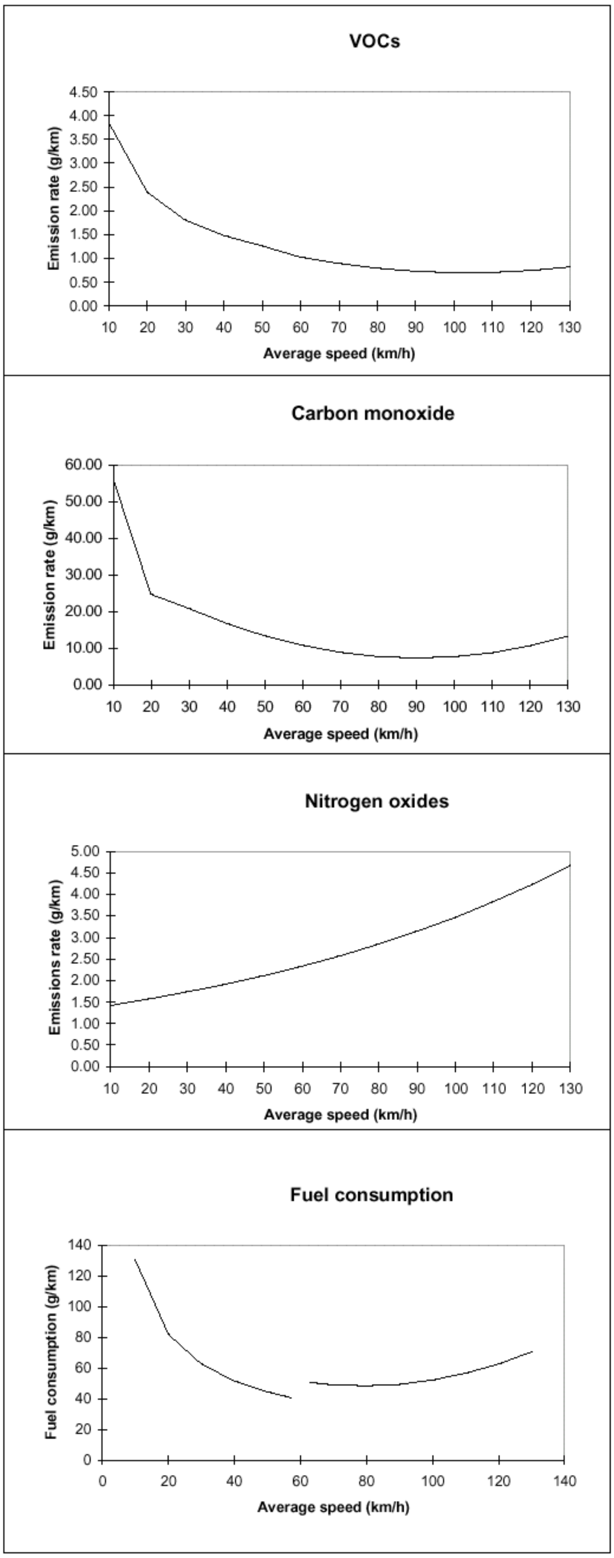

Figure 3.3. Typical emission rates for Volatile Organic Compounds (VOCs – elsewhere termed Hydrocarbons – HC), carbon monoxide, nitrogen oxides and fuel consumption as a function of average speed for passenger cars conforming to ECE 15-04 regulations (Eggleston et al., 1992, cited in Smith and Cloke, 1999).

3.1.3 Reducing speeding

Speeding is defined here as exceeding the posted speed limit.

Citing Taylor, Lynam and Baruya (2000), DETR (2000) suggests that reducing the number of speeding drivers and the speeds of these faster drivers would have a significant effect on the number of crashes. They say that a doubling of the proportion of speeders increases accidents by 10%, and that if the average speed increases by 1 mph, and all other factors are held constant, accidents go up by 19%. OECD research (2000) claims that one third of road fatalities in OECD countries is due to excessive speed.

While a majority of drivers say that speed limits should only be broken in exceptional circumstances, a majority of vehicles exceed the limit on motorways, dual carriageways and residential urban streets (DETR, 2000). According to DETR (1997, cited in Comte, Wardman and Whelan, 2000), 70% of UK car drivers exceed urban speed limits and between 30% and 55% exceed the limits on motorways and dual carriageways. According to Rothengatter (1992, cited in Coesel and Rietveld, 1998), 80% of EU drivers transgress highway speed limits, and for two-lane roads it is 50%.

It is likely that a large proportion of the drivers who exceed the speed limit are aggressive, time-pressured drivers who not only use more fuel due to their high speed, but are more likely to accelerate and decelerate at higher rates as they thread their way through traffic – increasing their fuel consumption dramatically.

Estimates of possible effects from improved speed enforcement

A study of the costs and benefits of reducing the speed of private cars in the Netherlands 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 11%, and nitrogen oxide emissions by 15%. These benefits would lead to savings of about $US260 million per year (van Uden, 1997).

Meers and Roth (2001) estimated fatality and greenhouse gas savings from major Queensland road safety and environmental programs (see Table 3.3). The fatality savings have been calculated from Queensland Transport's regular evaluation of road safety initiatives; the CO_2-e savings from the reduced fuel consumption generated by the initiatives.

According to Meers and Roth (2001), the speed camera program has reduced speeds at speed camera sites by approximately 10 per cent. Overall, speed reductions of around five per cent across the network have been achieved. This has resulted in a decrease of an estimated 164 fatal crashes in the period 1998-2000. The speed reduction equates to approximately a three per cent reduction in CO_2-e emissions. This translates into a reduction of 400,000 tonnes per annum using 1999 emission data.

The Random Road Watch (RRW) Program encourages more prudent driving behaviour and has resulted in an annual average saving of 83 fatal crashes. This prudence includes lower speeds, reduced drinking and driving and increased compliance with road rules generally. RRW also saves around the same amount of CO_2-e emissions as random breath testing (RBT) or the 50 km/h local speed limit (see Table 3.3).

In terms of CO_2-e reductions, the lower speeds that result from the road safety programs are the primary driver of the benefits. As Table 3.3 shows, the speed camera program produces the greatest saving in CO_2-e emissions – six times that attributable to the "Fatal 4" campaign and ten times that of each of RRW, RBT and the 50 km/h local limit.

Table 3.3. Fatality and CO_2-e savings from road safety programs in Queensland 1998-2000. From Meers and Roth (2001).

Road safety program	**Fatal crashes saved per annum**	**CO_2-e reduction factor**	**CO_2-e saved per annum (k tonnes)**
Random road watch	80	More consistent driving behaviour, lower speeds	40
Random breath testing	210 [1]	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 50km/h routes	33
Fatal 4 public education campaign	20 [2]	More consistent driving behaviour	67

1 includes injuries
2 1997/98 data

The Fatal 4 campaign supports enforcement programs such as RRW, speed cameras and a 50 km/h residential limit. There has been a five percentage point reduction in the proportion of people who think that travelling 10-15 km/h over the speed limit is not speeding. If that reduction is translated into behaviour, five per cent of people are travelling 10-15 km/h slower. Across Queensland, a 10 km/h speed reduction for five per cent of vehicle kilometres travelled (vkt) produces a CO_2-e saving of 67,000 tonnes per annum.

While it is targeted at drink driving, random breath testing (RBT) encourages more prudent driving behaviour in a similar manner to RRW. Similar CO_2-e reductions would be expected from this program.

Nairn and Partners, Segal and Watson (1994) estimated the potential effects of strategies to reduce cruise speeds and thereby reduce fuel consumptions 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 average fuel consumption rate would reduce from 8.2 L/100 km to 8.1 L/100 km. Similar calculations for 75 k/h speed limits (which have been largely superseded by changes to speed zoning practices in Victoria) gave estimated reductions from 9.1 L/100 km to 8.8 L/100 km. Unfortunately, much of the data on speed profiles used in the calculations were collected before full implementation of the speed camera program and therefore may no longer be applicable.

3.1.4 Estimates of possible effects from lower speed limits

Lower speed limits have been examined or introduced in a number of jurisdictions to improve road safety. In the United States, the original reduction of the upper speed limit from 65 mph to 55 mph was undertaken at the time of the Oil Crisis for environmental reasons.

Preston (1990) found that countries in Europe and North America with an urban speed limit of 50 km/h or less had an average death rate of pedestrians (aged 25-64 years) 30 per cent lower than countries with an urban speed limit of 60 km/h.

After Norway reduced its urban speed limit from 60 km/h to 50 km/h, the average speed fell by 3.5-4 km/h and the number of fatal accidents was reduced by 45 per cent (Norwegian Traffic Safety Handbook, cited in Jorgensen, 1994). Denmark reduced the general urban speed limit of 60 km/h to 50 km/h in 1985. On major roads, the average speed of 50 km/h fell by 2-5 km/h, whereas on minor roads, which had lower speed limits initially (45 km/h), the reductions experienced were only up to 1 km/h (Engel and Thomsen, 1991).

When the speed limit in Zurich was reduced from 60 km/h to 50 km/h, pedestrian collisions fell by 20 per cent and pedestrian deaths by 25 per cent (Walz, Hoeflinger and Fehlmann, 1983). The general urban speed limit in France was reduced from 60 km/h to 50 km/h in 1990. In its first two years of operation, the 50 km/h speed limit was estimated to have prevented 14,500 injury accidents and 580 fatalities, or 3 per cent of the annual French road toll (Page, 1993).

In Australia (as at May 2001), 50 km/h limits on local roads in built-up areas had been introduced in parts of New South Wales and Queensland and across Victoria. The lower limits have been introduced for a trial period in the Australian Capital Territory and the implementation process has commenced in Western Australia.

New South Wales

A detailed evaluation of the crash savings resulting from the implementation of 50 km/h speed limits in residential streets in some areas of NSW has been undertaken (RTA, 2000). In summary, the accident analysis showed that over a 21 month period there were approximately 262 fewer accidents on those streets speed-zoned at 50 km/h than otherwise expected. The percentage reduction in crashes was greater in urban than rural areas. The cost saving to the community that has resulted from the accident reduction on the 50 km/h streets in the 22 local government areas involved in the evaluation has been estimated to be $6.5 million for the 21-month period.

Queensland

The 50 km/h local street speed limit initiative was successful in reducing speeds on local streets in south east Queensland. Meers and Roth (2001) concluded that over the period 1998-2000, this factor alone saved 19 fatal crashes each year in south-east Queensland alone (a decrease of 15% in fatal crashes). Travel in south east Queensland makes up 50 per cent of the total annual vehicle kilometres travelled in that state and approximately 10 per cent of that travel is on local streets. A 10 km/h speed reduction equates to a 5 per cent reduction in CO_2-e at around 60 km/h. Based on that data, a saving of 33,000 tonnes CO_2-e per annum has been generated by the 50 km/h initiative.

Victoria

The likely benefits which were considered in the Regulatory Impact Statement (VicRoads, 2000) for the introduction of a 50 km/h default urban speed limit in Victoria were reductions in both crashes and fuel consumption, which consequently reduces vehicle operating costs and greenhouse gas emissions.

Based on the NSW results, the RIS chose a 7% reduction in casualty crashes and a 16% reduction in property-damage only (PDO) crashes as the lower limits of the possible crash reductions. Based on Kloeden et al's (1997) work and assumptions of less than complete compliance, a figure of 15% was chosen as the likely upper limit of the possible reduction in casualty crashes. The upper limit for PDO crashes remained at 16%, given no other data. The estimated overall road safety benefits were estimated to range between $34.4 million and $48.2 million.

The RIS provides upper and lower estimates for reductions in fuel consumption and greenhouse gas savings resulting from the 50 km/h initiative. The upper bound estimates are based on figures in Austroads (1996) and Roper and Thoresen (1996, cited in VicRoads, 2000). This assumes that a reduction of 1 km/h in average speed will reduce fuel consumption by 0.3 per cent, translating into an annual fuel saving of 1.8 million litres. At a resource cost of 45 cents/litre, this means a cost saving of $812,000 per annum. If greenhouse gas reductions are valued at the accepted value of $82 per tonne, then the value of reduced emissions is $421,000 per year.

The lower bound estimates assume no reductions in fuel consumption or greenhouse gas emissions. These estimates are based on the NSW Environmental Protection Agency's submission to the NSW Staysafe Inquiry (Staysafe, 1996).

Environmental effects of lower speed limits

Concern has been expressed in Australia that the lower speed limit may result in less fuel efficient driving as many vehicles or drivers may not be able to easily travel at this speed in top gear, meaning more gear changes and increased engine speeds (Van Every and Holmes, 1992). However, the majority of the passenger vehicle fleet in Australia have automatic rather than manual transmissions, and the engine management system of an automatic vehicle will always seek the highest possible gear. As long as the driver does not accelerate aggressively or manually change gear, an automatic vehicle will likely have improved fuel economy at the lower speed.

According to Lines and Morgan (1992, cited in Walsh, 1999), a car travelling at a steady speed of 50 km/h uses 4.2% less fuel than at 60 km/h, and at 40 km/h it uses 14.5% less fuel than at 60 km/h. Combining the lower residential speed limit with well-placed traffic calming measures, so that there is not enough length to encourage drivers to accelerate, may actually produce less emissions and use less fuel, particularly for cars with automatic transmissions.

Swedish research has shown that at a constant speed, the fuel consumption in cars with modern motors is higher at 30 km/h than at 50 km/h. On the other hand, a speed of 30 km/h entails less fuel consumption when stopping and accelerating. Hydrocarbons, carbon monoxide and nitrogen dioxide are greatly affected by changes in speed. It has been calculated that of the total emissions in the year 2000 there will be 4% less hydrocarbons, 7% less carbon monoxide, 8% less nitrogen dioxide and just under 1% less carbon dioxide at speeds of 30 km/h compared with 50 km/h. It has also been calculated that fuel consumption will decrease by a little less than 1% (Ministry of Transport and Communications, 1997).

Several studies have attempted to assess the optimum travel speed when both safety and environmental factors are considered. Cameron (2000) concludes that the optimum speed on residential streets depends on the actual values of crash cost savings that are used. If the "human capital" valuations of road trauma costs are used (as in BTE, 2000), then the optimum speed is 55 km/h. If costs are based on willingness to pay (as in BTCE, 1997), the optimum speed on residential streets is 50 km/h. If higher values of crash cost savings are used, then the optimum speeds would be lower.

In terms of the upper speed limit, according to the 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. They also reported that fatalities increased by 30% on rural interstate and other highways where the speed limit was raised from 88 km/h (55 mph) to 104 km/h (65 mph).

3.1.5 Reducing speeds within the posted speed limits

There are occasions when the posted speed limit is inappropriate for the particular driving conditions. For example, weather conditions may necessitate driving at a slower speed due to slippery roads or reduced visibility. Another transient factor that may affect speed is congestion. As intelligent transport systems (ITS) develop, the opportunity will arise to set the speed of a particular section of roadway based on a range of variable factors. The device will interact with each vehicle's intelligent cruise control system within range and maintain a maximum speed that is less than the posted speed limit. For example, on smog-alert days the speed limit may be set to a substantially lower level while pollution/fog is measured to be above a set threshold.

The safety and fuel economy benefits of a lower cruise or average speed have been explored earlier. An additional benefit arises from smoother travel where traffic must travel at a slower speed than the posted limit.

3.2 APPROACHES TO DECREASING FUEL CONSUMPTION BY MODIFYING DRIVING STYLE

Given that acceleration and deceleration contribute significantly to fuel consumption and emissions (in addition to cruise speed), there has been significant interest in decreasing fuel consumption by modifying driving style to minimise acceleration and deceleration. Modifying driving style in this context is essentially smoothing the speed profile.

3.2.1 Estimates of possible effects from smoother driving

There have been many claims about the possible effects of smoother driving. According to the US EPA's website (www.fueleconomy.gov/feg/drive.shtml), practising fuel efficient driving can improve fuel economy more than 10%. Di Genova and Austin (1994, cited in

Holmen and Niemeier, 1998) claimed that driver behaviour can alter average per-mile emissions by more than an order of magnitude. A British driver training organisation has claimed that driver training could save company fleets 10% in fuel and maintenance bills. It is also beneficial to the company's reputation and there is less stress for the driver. Their program includes safety as well as fuel consumption training (Drivers.com staff, 1999). Bongard (1995) claimed that it takes about 3 months to adopt a new style of driving – gliding through traffic. Experienced drivers can save up to 30% on fuel consumption. Beginners save on average 1 litre per 100 km in comparison to conventionally trained drivers.

Nairn and Partners, Segal and Watson (1994) have estimated the potential effects on average fuel consumption, hydrocarbon (HC) and NO_x emissions of strategies to achieve smoother driving patterns without changes in average speeds. The types of measures that they considered were:

- driver education
- speed advice, and
- route guidance.

They provide more details of specific techniques within these three types of measures. They note that the effects and cost-effectiveness of the different approaches are likely to vary significantly across urban road types. They consider that driver education could be effective across all road types and in all urban areas, whereas speed advisory systems are likely to be most effective on long stretches of high volume arterial roads and are only likely to be implemented in capital cities.

Nairn et al. (1994) use positive kinetic energy (PKE) as an indicator of the smoothness of driving. PKE is estimated from the positive speed changes in the instantaneous speed of a vehicle and has the same units as acceleration (m/s^2). Smooth driving is associated with a low level of PKE. The lowest value of PKE results from a driver maintaining a constant speed.

Figure 3.4 shows that for average speeds within the range of 40 km/h to 90 km/h, PKE has a significant effect on fuel consumption rate, HC emission rate and NO_x emission rate. Compared to steady speed (PKE = 0), fuel consumption at PKE = 0.8 m/s^2 is increased by between 50% and 100%. The effect of PKE on HC emission rate and NO_x emission rate is even more marked. At each level of average speed, the effect of smoothness of driving (as measured by PKE) is much greater than the effect of a change in average speed.

Nairn et al. (1994) provide estimates of the linear relationships between PKE and average speed based on earlier estimates of PKE on arterial road sections in the Melbourne Statistical District. They estimate that the size of the reductions in PKE would increase in the following order: driver education, speed advice, and route guidance. The likely reductions in fuel consumption, CO_2, HC and NO_x emissions compared to the current traffic conditions are summarised in Table 3.4.

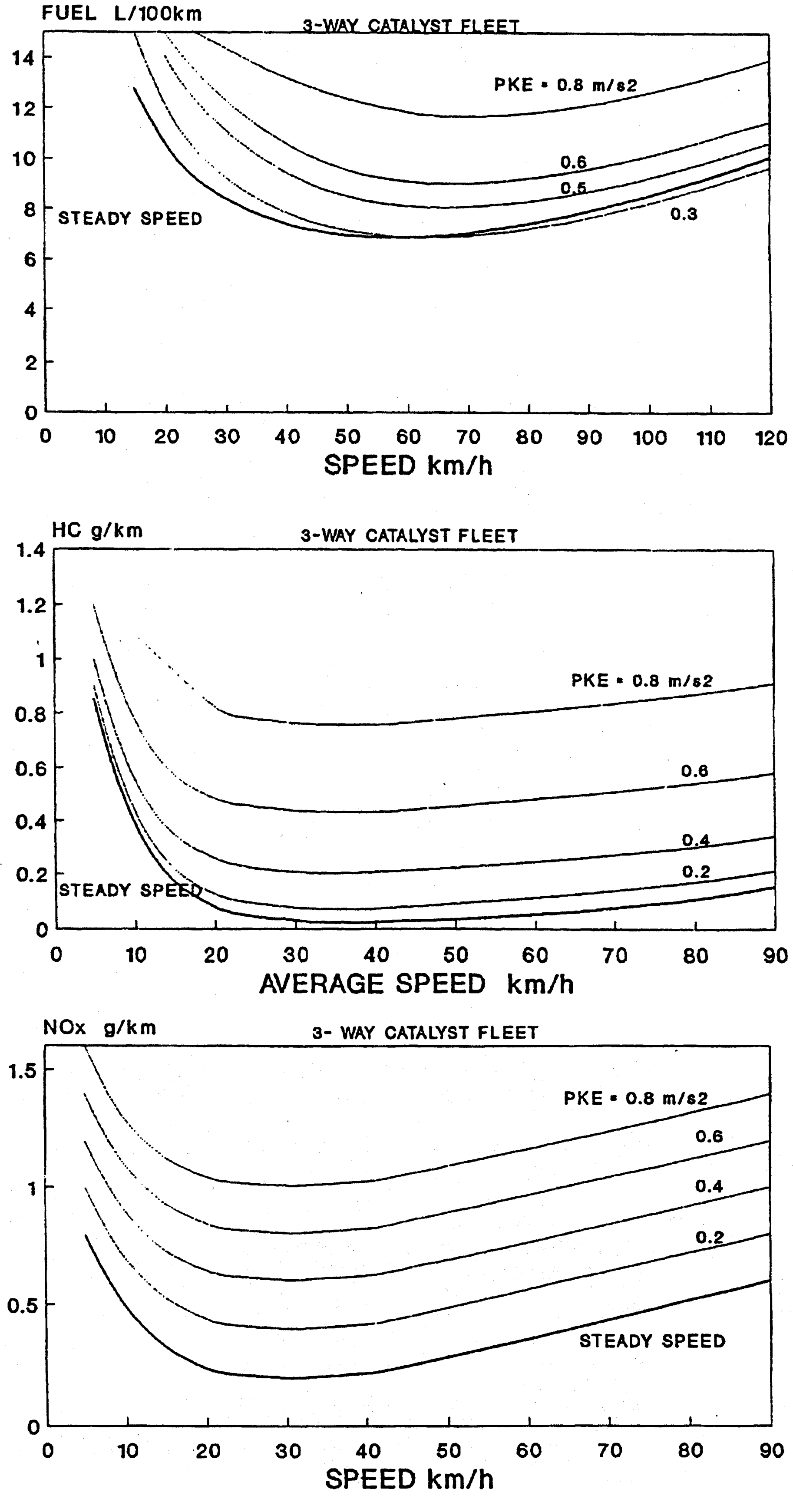

Figure 3.4. Estimated effects of Positive Kinetic Energy (PKE) and average speed on fuel consumption, hydrocarbon (HC) emissions and NOx emissions. From Nairn et al., 1994.

Table 3.4. Likely reductions in fuel consumption compared to the current traffic conditions in Melbourne Statistical District. The inner area contains the CBD and some adjacent areas. From Nairn et al. (1994).

Policy instrument	% Reduction in			
	fuel consumption	CO_2	HC	NO_x
Arterial roads in MSD				
Education	1.6	0.55	5.1	2.3
Fixed advisory signs	0.5	0.17	1.0	0.5
Variable message signs	4.9	1.67	9.0	4.5
Instructions to individual passenger vehicles	6.5	2.21	11.9	6.0
Route guidance	9.8	3.33	17.7	9.3
Arterial roads in Inner area				
Education	1.9	0.12	1.2	0.5
Fixed advisory signs	0.6	0.04	0.2	0.1
Variable message signs	5.6	0.38	2.1	1.0
Instructions to individual passenger vehicles	7.5	0.51	2.7	1.4
Route guidance	11.2	0.76	4.1	2.1

Dyson et al. (2001) modelled the fuel consumption and emissions of a vehicle being driven by a slow, conservative driver, an average driver and an aggressive driver (see Table 3.5). In their first scenario, the slow conservative driver accelerated slowly to the speed limit, then cruised for a period of time at the limit, then decelerated slowly to rest. In their second scenario, the average driver accelerated at an average rate, cruised at the speed limit and then decelerated at the average deceleration rate (-3.5 km/h/sec). In their third scenario, the aggressive driver accelerated hard to the speed limit, cruised at the speed limit for a period of time and then decelerated at a high rate (-6.5 km/h/sec). Each of the scenarios was applied to a 1250m street in 60 km/h and 40 km/h speed limit cases.

The total CO_2 emissions were similar for hard and medium acceleration scenarios (for both 40 km/h and 60 km/h speed limits). This resulted from a smaller amount of emissions being produced during the hard acceleration and deceleration phases due to a smaller amount of time being spent in these phases. This was then balanced out by more emissions being produced in the cruise phase of the hard acceleration scenario since a longer time was spent cruising.

For streets that were long enough for the 40 km/h speed limit to be attained (1250m), the emissions of CO_2 were greater under the slow acceleration scenario than under the medium or hard acceleration scenarios. Effects on fuel consumption were not reported in the paper.

Table 3.5. Rank ordering of scenarios from highest total emissions to lowest total emissions for 40 km/h and 60 km/h speed limit for streets longer than 1250 m. From Dyson et al. (2001)

Rank order	CO_2	CO	NO_x	HC
Highest	Conservative 40	hard 60	conservative 60	conservative 40
	medium 40/ hard 40	hard 40	conservative 40	conservative 60
		medium 40	hard 40/ hard 60	hard 40
	medium 60/ hard 60	conservative 60		medium 40
		conservative 40/ medium 40	medium 40	hard 60
Lowest	conservative 60		medium 60	medium 60

3.2.2 EcoDriving

There is a strong impetus in many European countries for drivers to improve their fuel economy through changes in their travel behaviour. The EcoDrive concept includes advice for car manufacturers and policy changes for roads and infrastructure changes, but its primary thrust is a smoother driving style – gliding through the traffic.

The basic principles of EcoDriving are (Johansson, 1999, Preben, 1999):

- When heading off one should change up to second gear as soon as possible and then to higher gears at one-third to half-throttle.
- Engine speed should not exceed 3000 rpm (or level of highest torque).
- Drivers should look and plan ahead and coast to traffic lights or intersections so that there is no unnecessary braking and the timing is such that the vehicle does not come to a complete stop.
- Driving to match the rhythm of the traffic.
- Use the upper gears as much as possible and keep engine speeds down.
- In vehicles of increased power and higher torque make the engine work more rather than changing down a gear.
- Skip gears when it is appropriate.
- Keep engine idling to a minimum
- No “warming-up” time is required when a car is first started.

Many of the practices of EcoDrive differ from the driving style generally advocated a generation ago. With many new drivers being taught how to drive by their parents, EcoDrive proponents suggest that many people are driving new cars with an obsolete and inappropriate driving style. In a bid to counter faulty driving practices already learned and teaching novices the new ‘correct’ way to drive, EcoDrive concepts are being used by driver trainers, taught in schools and instituted as part of fleet training programs.

Effects of EcoDrive training

A number of studies have measured the effect of EcoDrive training on fuel consumption and emissions. According to Wilbers (1999), drivers can save 5-10% in fuel use, and some drivers have reached 20% with the right changes to driving style. Wilbers reported that a group of driving instructors undergoing training saved 13% over a 40 km journey.

Using an unfamiliar car and unfamiliar 10 km route, Johansson (1999) compared a group of EcoDrive trainees pre- and post-training and found that the average speed did not change, nor did the average acceleration. The degree of deceleration decreased, indicating less use of the brakes, and so 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. However the amount of time spent at half-throttle doubled after instruction. It was suggested that this was a failing in the teaching of this concept.

Fuel consumption and carbon dioxide emissions were reduced by an average of 10.9%. All students reduced their fuel consumption. Other emissions did not provide a clear picture and could not be statistically analysed – some students increased their emissions while others demonstrated a reduction. It was suggested that the use of the accelerator can be reduced to decrease the emission of hydrocarbons and carbon monoxide without increasing fuel consumption and the emission of nitrogen oxides. Time taken to travel the test route also decreased in many instances. Drivers were looking further ahead and planning more. However, those drivers who initially had an aggressive driving style tended to maintain that style after instruction.

The effects of EcoDrive training on safety have not been as widely examined. Preben (1999) claims that EcoDrive training has led to safety improvements but gives no further details. Johannson (1999) cited a long term study in Finland that found a significant decrease in fuel consumption and a reduction in costs associated with accidents in a government fleet.

Other studies have examined the effects of EcoDriving both in terms of fuel consumption and crash risk. Reinhardt (1999) analysed the results of a training scheme instituted in Canon's corporate fleet. He found 35% fewer accidents, 22% higher mileage per accident, 28% less Canon driver-induced accidents, 50% less CO, 31% less CH and 23% less NO_x. With the publicity surrounding the scheme, there was also an image improvement for the company and driver motivation increased. Another company training program claimed an 11% fuel saving from 1990 to 1994, and 35% improvement in accident rate (Smith and Cloke, 1999).

EcoDrive and similar programs are primarily aimed at drivers of manual cars. While manual cars might predominate throughout much of Europe, the majority of passenger cars in Australia (and the US) have automatic transmissions. The principles are the same in that the driver should gently accelerate to allow the transmission to change itself into either higher or lower gears at lower engine speeds – driving smoothly rather than aggressively. Driving with an increased awareness of what the traffic is doing downstream rather than only focusing on a car or two in front is also transferable between manual and automatic cars.

Australian work in this area

In Australia, promotional material has been developed by environmental agencies (e.g. the Victorian Environment Protection Authority), the Australian Greenhouse Office and motoring organisations. For example, the Australian Greenhouse Office Fuel Consumption Guide 1999-2000 (AGO, 2000) includes “10 top tips for fuel efficient driving”, which are consistent with the EcoDrive principles.

Clifford (1988) discusses a financial incentive scheme in an Australian trucking company, where drivers share in the savings in fuel consumption. The company also experienced savings in maintenance costs. Clifford suggests that as drivers pay more attention to their driving style to drive more efficiently, they are paying more attention to driving in general, which should make it significantly safer. The fleet fuel consumption over a 12-month period improved by 3.5% and the financial savings more than covered the cost of the bonus scheme. Individual drivers had improved by as much as 15% and there was a slight reduction in accident/incident frequency.

In Victoria, the Environment Protection Authority and the Sustainable Energy Authority Victoria are working together to develop a driver education program that puts a new emphasis on the environmental consequences of car use. A feature of the new course will be its highlighting of the commonality of driver behaviour that improves safety, fuel use and environmental aspects of car use.

The course is initially being developed for EPA and SEAV staff but it is intended that through the development of new approaches and new course materials where necessary, it might serve as a pilot project for the development of a driver education program for drivers across the Victorian public sector. The course has a one-day format and is being trailed in June and July 2001.

3.3 ROUTE CHOICE

The choice of route can affect the speed profile and thus the safety, fuel consumption and emissions associated with the trip. Features of routes that have been discussed as relevant to both safety and environmental outcomes are: presence of Local Area Traffic Management devices, street layout, types of intersections, roadway topography and congestion.

3.3.1 Local Area Traffic Management/Traffic Calming Measures

Many residential areas have instituted traffic calming measures, such as speed humps and traffic islands. In general, speed humps and similar devices cause drivers to decelerate as they approach the device and accelerate after the device. As discussed earlier in this report, deceleration and acceleration lead to increases in emissions and fuel consumption (at least for acceleration).

A number of studies have assessed the effects of traffic calming measures on fuel consumption and emissions. According to Van Every and Holmes (1992), physical speed control devices could increase fuel consumption by 30-50% beyond that expected whilst driving at a consistent speed. A theoretical study by Webster (1993, cited in Robertson et al., 1998) found that road humps produced an increase in fuel consumption of between 10% to 25%. Smaller increases were associated with assumptions of smoother driving between the humps. Webster found an increase in emissions of CO, CO_2 and HC with a slight increase in NO_x. However, an Austrian study (AIT/FIA Traffic Commission, 1994, cited in Robertson et al., 1998) found that rapid deceleration and acceleration of an instrumented vehicle before and after speed humps led to a ten-fold increase in NO_x emissions and a three-fold increase in CO_2. The acceleration and deceleration rates in this study were considerably greater than those observed in practice and therefore the increases in emissions are likely to be inflated.

Table 3.6 presents a summary of the changes in emissions after implementation of different measures to reduce speed in different German towns and cities (German Ministries of Regional Planning, Transport and Environment, 1992 cited in Robertson et al., 1998, Table 3). CO_2, fuel consumption and CO emissions increased as a result of implementation of extensive traffic calming measures. NO_x emissions were reduced, but there was no clear effect for HC emissions. By comparison, CO_2 and fuel consumption reduced as a result of implementation of 50 km/h speed zones and other emissions tended to reduce. The results for 30 km/h zones were intermediate between the other measures.

Table 3.6. Changes in emissions and fuel consumption after implementation of different measures to reduce speed in different German towns and cities. Positive values indicate an increase in emissions after traffic calming. (German Ministries of Regional Planning, Transport and Environment, 1992 cited in Robertson et al., 1998, Table 3)

Measure	NO_x	HC	CO	CO_2 and fuel consumption	Comments
Area with extensive traffic calming measures (slow speed)	-38% to –60%	+10% to –23%	+71% to +7%	+19% to +7%	Results from 3 test routes in Berlin-Moabit
Tempo 30 km/h zone	-5% to –31%	+2% to –23%	+28% to –20%	+14% to –6%	Results from 5 test routes in Buxtehyde, 4 in Mainz and 1 in Esslingen
50 km/h speed restriction on main road	-15% to –33%	+2% to –20%	+7% to –10%	-4% to –13%	Results from measures at village entrances on test routes in Mainz, Esslingen and Buxtehyde

3.3.2 Street layout

Dyson et al. (2001) present data showing that the length of the street may affect the optimum speed profile in terms of fuel consumption and emissions (at least for medium to hard acceleration). For streets shorter than 550 metres, CO_2 emission (which is proportional to fuel consumption) is less for travel up to a 40 km/h speed limit than for travel up to a 60 km/h speed limit. For streets longer than 550 metres, the reverse is true. This is because the amount of time spent cruising for the lower speed limit more than compensates for the extra emissions produced in accelerating from 40 km/h to 60 km/h and in decelerating from 60 km/h to 40 km/h. Thus, for longer streets, the emissions for the cruise phase predominate.

3.3.3 Types of intersections

Hyden and Varhelyi (2000) conducted a pre and post examination of the installation of a series of roundabouts and found that they were effective in reducing the number of conflicts between cars and pedestrians and lowering the speed of any conflicts that did occur. Trip time was decreased when the roundabout replaced a signalised intersection. The emissions (CO and NO_x) also decreased overall.

According to Hyden and Varhelyi (2000) there were also speed reductions in the links between the roundabouts so long as the difference was less than 300 m. Average speeds throughout the city did not increase during the trial, indicating that drivers did not attempt to make up for lost time elsewhere. The number of expected injury accidents went down by 44%; bicycle and pedestrian-involved crashes decreased by 60 and 80% respectively. The roundabouts produced a very significant risk reduction for vulnerable road users, but there was no reduction for car occupants.

3.3.4 Roadway topography

Choosing a route that has better vertical and horizontal curvature can have both road safety and environmental benefits. Improved vertical curvature is estimated to lead to crash reductions of up to 52 per cent and improved horizontal curvature will also have crash reduction benefits (Ogden, 1996, cited in Meers and Roth, 2001). Improved vertical and horizontal curvature can lead to smoother speed profiles and thus lower fuel consumption. This is particularly true for heavy vehicles. One of the benefits of the Pacific Highway realignment at Buladelah in Northern NSW is considered to be the reduction in fuel consumption by heavy vehicles that will result (RTA, 2000b).

3.3.5 Congestion

Choosing a route to avoid congestion may have significant fuel consumption and emission benefits by decreasing the amount of time spent in slow traffic. However, the detour may actually increase the total volume of emissions if it is a less direct route (i.e. the total distance is increased), or if the detour is not a high volume road and there are additional intersections and traffic lights (and so there are actually more stop-start manoeuvres). There is little information available about the likely safety benefits or disbenefits that may accrue in either scenario, although if the detour includes more intersections then it is likely that there will be more potential for traffic conflicts.

3.4 USE OF CRUISE CONTROL

Cruise control is an in-car device that has the potential to increase safety and fuel economy. Assuming that it is not used to exceed the speed limit, cruise control can save an average of 5% in fuel use (Wilbers, 1999). If it is used to prevent inadvertent speeding, the maximum speed of the vehicle will be lower and the likelihood or severity of a crash will be decreased (see effects of speed on safety).

3.5 USE OF AIR CONDITIONING

Air conditioning lowers fuel efficiency both by increasing the weight of the vehicle and being directly driven by the engine. Operation of the air conditioner increases fuel consumption by 10-15% (Wilbers, 1999). The alternative is simply to open the windows, however this increases the aerodynamic drag above a certain speed to some level in excess of the fuel required to counteract the air conditioner. Of all Australian households owning motor vehicles, only 18% had vehicles without air conditioning in 2000 (ABS, 2000).

Air conditioning is specified for most fleet vehicles, mainly for comfort, but it is also considered that it might counteract fatigue to some degree. On the basis of laboratory research, air conditioning could be expected to reduce the development of fatigue in warm conditions (Mackie and O'Hanlon, 1977). Air conditioning may also be viewed as a safety feature because it can be used to de-mist the windows rapidly.

3.6 SUMMARY AND CONCLUSIONS

Total fuel consumption can be decreased by reducing vehicle travel or by reducing fuel consumption rate. The effects of driver behaviours on fuel consumption rate and safety were discussed in this section. These behaviours included: choice of travel speed, smoothness of driving, choice of travel route, use of air conditioning and use of cruise control. Smoothness of driving and choice of travel route were discussed as different factors but modification of the speed profile underlies their effects on fuel consumption rate.

There is overwhelming international evidence that lower speeds result in fewer collisions, and lesser severity in the crashes that do occur. Fuel consumption rates and emission rates 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 is a more important determinant of fuel consumption rate and emissions than the average speed for the trip.

Different studies of the effect of cruise speed on fuel consumption have found conflicting results. Estimates of the speed at which fuel consumption rate is lowest vary from 40 km/h to 80 km/h. One study found that fuel consumption continued to fall with increasing cruise speed. Differences in the types of vehicles being tested (year of manufacture, emissions and other standards and engine size) and differences in testing methods may contribute to some of these conflicts. There are similarly conflicting results in studies of the relationships of emissions with cruise speed.

During acceleration, the fuel to air ratio is higher than optimal, resulting in increased fuel consumption and large increases in CO and HC emissions. In general, deceleration emissions are significantly lower than acceleration emissions.

The average speed for a journey incorporates components of acceleration, deceleration and cruise speeds. Thus the precise nature of the relationship between average speed and fuel consumption rate (and emissions) will depend on the speed profile. Fuel consumption rate appears to decrease as average speed increases to about 60 km/h to 80 km/ and thereafter increases. The patterns for particular air pollutants differ and are discussed in the text.

Given the strong relationships between travel speeds, crashes and fuel consumption and emissions, there is a clear case to reduce travel speeds. There have been three general approaches to reducing travel speeds: reducing speeding, reducing speeds within the posted speed limit and reducing speed limits.

British authorities consider that the greatest reduction in casualties could come from reducing the speeds of the faster drivers. International and Australian studies have shown significant reductions in both casualties and fuel consumption and greenhouse gas emissions could result or have resulted from enforcement programs that reduce speeding.

Casualty savings have been shown to result from lower urban speed limits. Savings in fuel consumption and greenhouse gas emissions have also been estimated. Generally, the estimated cost savings resulting from casualty reductions have been much higher (roughly an order of magnitude) than the estimated cost savings resulting from reduced greenhouse gas emissions. These studies have not estimated the cost savings associated with reduced emission of air pollutants (carbon monoxide, hydrocarbons, nitrogen oxides, particulates), however.

The increases in fuel consumption rate (and thus greenhouse gas emissions) are greater at higher open-road speed limits than at different levels of urban speed limits. For example, travel at 120 km/h compared to 88 km/h increases fuel consumption by 50% (and doubles CO emissions and increases emissions of other pollutants of 30-50%).

Given that acceleration and deceleration contribute significantly to fuel consumption and emissions (in addition to cruise speed), there has been significant interest in decreasing fuel consumption by modifying driving style to minimise acceleration and deceleration.

Claims about the possible fuel consumption reductions of smoother driving have ranged from about 10% to 30%. Some evidence suggests that smoothness of driving affects fuel consumption and emissions much more than changes in average speed. The reductions in emissions of air pollutants from smoother driving may be greater than the reduction in fuel consumption (and greenhouse gases). Medium or hard acceleration to the urban speed limit may result in less fuel consumption and emissions because the time spent accelerating is shorter than lighter acceleration.

The European EcoDrive concept includes advice for car manufacturers and policy changes for roads and infrastructure changes, but its primary thrust is a smoother driving style. Studies have measured the effect of EcoDrive training have reported fuel consumption reductions of between 5% and 20% (commonly about 10%). The effects of EcoDrive training on safety have not been as widely examined but two studies have reported reductions in crash rates of about 35%.

In Australia, interest in driving to reduce fuel consumption is increasing. Promotional material has been developed by environmental agencies and a course in fuel-efficient driving is being developed by the Environment Protection Authority and the Sustainable Energy Authority Victoria.

The choice of route can affect the speed profile and thus the safety, fuel consumption and emissions associated with the trip. Local Area Traffic Management devices such as speed humps have been demonstrated to increase fuel consumption because of braking approaching the device and acceleration leaving the device. In contrast, replacement of signalised intersections with roundabouts has been shown to reduce crashes and reduce emissions.

Street layout may affect the optimum speed profile in terms of fuel consumption and emissions (at least for medium to hard acceleration). Lower travel speeds may result in lower fuel consumption and emissions in short streets (less than 550 metres), but the opposite pattern in longer streets. Choosing a route that has better vertical and horizontal curvature can have both road safety and environmental benefits, particularly true for heavy vehicles.

The safety and environmental effects of choosing a route to avoid congestion vary with a number of factors such as the total distance travelled and presence of intersections.

Whether drivers use cruise control or air conditioning has the potential to affect both a safety and fuel economy. If it is used to comply with the speed limit, cruise control can save an average of 5% in fuel use and there may be crash savings. Operation of the air conditioner increases fuel consumption by 10-15% but at higher speeds this is similar to the increase in aerodynamic drag that results if a window is opened. Air conditioning may play a role in reducing the development of fatigue in warm conditions

3.6.1 Conclusions

Reductions in travel speeds will result in crash savings in all scenarios. The reductions may be greatest in urban areas because of the significant representation of unprotected road users and because vehicles are better at protecting their occupants at urban speed levels. In urban areas, some fuel consumption and emissions reductions will follow from lower travel speeds but the bulk of the benefit will be to road safety.

For open road travel, the crash savings associated with lower speeds are likely to be significant. The fuel consumption savings are likely to be greater than at urban speed levels.

Smoother driving has greater potential for reducing fuel consumption and emissions in urban areas than in open road travel. At the level of the individual vehicle, smoother driving should reduce fuel consumption in urban areas more than lower travel speed. The reduction in emissions of air pollutants should be greater than the reduction in greenhouse gas emissions. The environmental benefits of smoother driving may be greater than the road safety benefits but this is yet to be established. There is a need for more information about the road safety effects of smoother driving.

4 DRIVER MOTIVATION AND IMPLEMENTATION ISSUES

This project attempts to assess the potential of promoting additional motivations to drive safely with better fuel economy and other environmental outcomes and reduced running costs. Section 3 has demonstrated that reducing speeding, lower speed limits and modifying driving style can improve fuel economy and other environmental outcomes in addition to improving safety. This section examines another aspect of implementing these improvements: the extent to which drivers are motivated by fuel costs and environmental effects.

4.1 INCREASING FUEL ECONOMY COMPARED WITH REDUCING VEHICLE TRAVEL

The US Department of Transport report on Transportation and Global Climate Change (1998) states that there are three main means of reducing greenhouse gas emissions from personal vehicle travel:

- reduce vehicle travel
- increase fuel economy
- switch to fuels with a lower life-cycle carbon content

The measures that were discussed in Section 3 are all ways of increasing fuel economy, i.e. they are all ways of reducing fuel consumption (and emissions) while maintaining the same level of vehicle travel. The community may be more supportive of these types of measures than those measures which attempt to reduce vehicle travel.

Community attitude surveys suggest that concern for the environment is not bringing about a reduction in vehicle travel. According to Nilsson and Kuller (2000) 50% of all journeys within urban areas in Sweden, most of them less than 5 kilometres, are made by car, and car use is increasing. Yet 60% of Swedes perceived air pollution from transport as a serious environmental problem. Initial choice of transport might depend on attitudes, but this relationship weakens when the choice becomes habitual. No relationship between factual knowledge of the consequences of traffic pollution or of how to drive to reduce pollution and travel behaviour was found. However, knowledge of environmental impact caused by traffic was positively correlated with an attitude of environmental concern.

Australians rely on private vehicles to a large extent. As of March 2000, 89% of Australian households owned registered vehicles, with 48% owning two or more (ABS, 2000). During the month of the ABS survey, 76% of Australians drove a car, truck or van to work or study, and 12% used public transport. Of those who used public transport, in 34% of cases it was due to a lack of a car – only 2% of people used public transport for environmental reasons. Of those who did not use public transport, 30% said they did not have access to it and 26% said that the timetabling was inconvenient. Eighty-seven percent of the sample preferred to use their vehicles for non-commuting daily travel.

While the benefits of improving fuel economy may be less than those of reducing vehicle travel on a per trip basis, it may be that the greater likelihood of implementation of fuel economy measures will mean that their overall benefit may exceed those of reduction of vehicle travel, at least in the near future.

4.2 INCREASING FUEL ECONOMY OF CURRENT CARS COMPARED WITH CHANGING CHOICE OF VEHICLES

Despite concern about environmental issues and rising fuel prices, consumers do not seem to have been pressuring car manufacturers to produce vehicles with better fuel economy. Fulton (2000) suggests that the technologies exist to improve fuel economy and emissions substantially (15-20% by 2010), but a major obstacle to actually achieving these gains is the lack of consumer interest in these issues coupled with a popular desire for ever-larger, heavier and more powerful vehicles. Indeed the energy use per unit weight of new cars has decreased dramatically since 1980, but the fuel use has not declined with it due to the increased weight. This in turn discourages car manufacturers from designing and implementing initiatives that will improve the environmental impact of their product.

4.3 RELATIVE IMPORTANCE OF FUEL CONSUMPTION COMPARED WITH ENVIRONMENTAL ISSUES

Many surveys have found that there is a concern for environmental issues within the community. For example, a survey of 1623 Australian drivers found that 75% of respondents were concerned about the environmental effects of the car – particularly air pollution (ANOP, 1999). In terms of issues rated as important by these motorists, environmental issues rated second highest, behind fuel prices.

Cost is the major factor considered in the purchase of household vehicles (54% of survey respondents), followed by fuel economy or running costs, and vehicle size (both 36%) (ABS, 2000). Environmental impact was the least important factor in choosing a new car at 3% of survey respondents. These findings suggest that the financial incentive of saving fuel is strong, and so a program to encourage motorists to save fuel and therefore money by driving more smoothly is also likely to produce safety benefits as well. Promotion of the environmental benefits may provide an added impetus to program implementation, but it is likely to be the smaller incentive for many people.

In the corporate environment, implementation of environmental policies and achievement of greenhouse gas reduction targets may provide an additional motivation for uptake of programs to improve fuel economy.

4.4 CONCLUSIONS

Measures to reduce fuel consumption rate (to improve fuel efficiency) are likely to be more acceptable to the community in the short-term than measures to reduce vehicle use. In addition, reducing fuel consumption rate without requiring a change in vehicle choice may be more acceptable and more easily implemented in the short-term. The most likely scenario is parallel introduction of measures to reduce vehicle travel and improve fuel efficiency.

5 MEASURING THE SAFETY BENEFITS OF FUEL-EFFICIENT DRIVING

The fuel consumption reductions of a program that seeks to influence both safety and fuel consumption are likely to be much easier to measure than the safety effects. Fuel consumption can be easily and regularly measured, even at the level of an individual vehicle, and its cost is known. In contrast, even a large reduction in crash risk may not be measurable in the short-term or at the level of the individual vehicle. Overall crash costs for an organisation are often poorly estimated. Thus using fuel consumption as a performance indicator may help to sustain and encourage programs that also have safety benefits.

This section addresses the potential for reductions in fuel consumption and methods of measuring the safety benefits of fuel-efficient driving. It discusses the relative advantages and disadvantages of analytic and experimental studies, and whether analytic studies should focus on particular company fleets or aim to include a wide range of vehicles for which fuel consumption data is available.

5.1 POTENTIAL FOR REDUCING FUEL CONSUMPTION

The published highway and city driving cycle fuel consumption rates (AGO, 2000) can be used as target measures for fuel consumption. The in-service fuel consumption of vehicles is generally higher than that quoted in these figures. A study of the in-service fuel consumption of the Australian passenger car fleet found that on average drivers used 15 per cent more fuel than the Guide figure in city conditions and 34 per cent more in highway driving (cited in AGO, 2000).

Driving style is only one determinant of fuel consumption; a number of other factors can also lead to variability in fuel consumption (eg. urban versus rural driving). Thus, one would expect some variability in fuel consumption even within the same driver. The section that follows examines the extent of variability in actual fuel consumption of a fleet of vehicles and presents the results of some fuel consumption trials conducted by the RACV.

5.1.1 Variability in fuel consumption of a fleet of vehicles

One of the issues to be addressed is the range of variability in fuel consumption (if there is little variability, large data sets may be required to demonstrate a strong relationship with safety).

Table 5.1 presents means and standard deviations of fuel consumption rate for an actual fleet. It shows that the actual mean fuel consumptions (from Apelbaum, 2000) are generally greater than those provided in the Fuel Consumption Guide (AGO, 2000). The difference is greater for non-urban than for urban driving. This pattern is similar to that found in the study cited in the Fuel Consumption Guide.

In general, the variability in fuel consumption, as measured by the standard deviation, is more than 1.5 litres/100 kms. The variability in fuel consumption appears to be greater for the larger vehicles than for the smaller vehicles.

Thus there is potential for reducing fuel consumption, both because the mean values are greater than those cited in the Fuel Consumption Guide and because there is significant variability.

Table 5.1. Actual fuel consumptions compared with city and highway cycle values for a sample of passenger vehicles from a fleet. Vehicles where numbers are less than 10 have been excluded. All data refer to automatic vehicles. City and highway cycle values refer to the automatic sedan version of the 2000 model of that vehicle. Where there are multiple engine sizes, this is noted (numbers in parentheses are engine capacities in litres).

Vehicle type	Urban			Non-urban		
	Mean	Standard deviation	City cycle	Mean	Standard deviation	Highway cycle
Camry	10.29	1.60	10 (2.2) 11 (3)	10.19	2.15	6.6 6.8
Commodore	13.49	2.45	11.5-12	11.71	2.27	6.8
Corolla	8.87	1.47	8.5	*9.95*	*0.10*	6.6 (1.6) 6.8 (1.8)
Falcon	13.26	2.33	11.5 (4) 13.5 (5)	11.74	2.03	6.8 8.5
Magna	11.91	1.50	10 (3) 11 (3.5)	10.22	1.37	6.4-6.6 6.6-6.8
Spacia	13.30	0.64	10	11.88	1.94	8.5
Tarago	12.94	1.60	10 (2.4) 11.5 (2.5)	12.31	1.26	6.6 8
Vienta	12.57	1.63	11	*10.00*	*0.93*	6.8

5.1.2 RACV Fuel Smart Trial

In 2000 the RACV undertook a comparison of the effects of different size vehicles and driving styles on fuel consumption. The trial involved driving from the RACV's Noble Park complex, travelling to the city centre along the Princess Highway, and then returning via Victoria Street, Barkers Road, Canterbury Road and Springvale Road. The route comprised 61 kilometres of suburban traffic, including over 80 sets of traffic lights. The vehicles ran the course twice with three different drivers. One trial was driven with aggressive acceleration away from stops but without exceeding the speed limit, and the other in a smoother, more flowing style.

The two test vehicles were the current 4.0 litre AU Ford Falcon wagon and a 1.8 litre Mazda 323 Astina automatic sedan. The runs were conducted at the same time each morning and afternoon, avoiding peak traffic.

The trial found that the average time to complete the circuit (94 minutes) varied by less than five minutes between smooth and aggressive driving. Perceived gains in accelerating past traffic at the lights to achieve an advanced position on the road were negated in the overall trip.

The fuel consumption figures are summarised in Table 5.2. For the Ford Falcon, the fuel consumption under the smooth driving style was 30% lower than under the aggressive driving style (13.9 L/100km down to 9.6 L/100km). Smooth driving reduced the fuel consumption of the Mazda by 29% (11.6 l/100k down to 8.4 l/100k). The average reduction in fuel consumption from the large car to the small car was between 18% and 20%.

Table 5.2. Summary of fuel consumption figures (litres/100 km) in RACV Fuel Smart trial.

Vehicle	Smooth driving		Aggressive driving	
	Range	Mean	Range	Mean
AU Falcon 4.0 l	9.2 – 10.5	9.6	11.0 – 15.6	13.9
Mazda Astina 1.8 l Automatic	7.9 – 8.7	8.4	10.3 – 12.8	11.6

The RACV also compared the fuel consumption of the Ford Falcon in their current test with that used in a test in 1990. They found that smooth driving produced a greater improvement in the 2000 model than in the 1990 model. Driven aggressively, the AU Falcon recorded an average 13.9 l/100k, similar to a Falcon of ten years previous. Driving economically, the new Falcon averaged 9.6 l/100k compared to the older car's 11.8 l/100k, an 18.6% improvement.

The RACV concluded that "The advances made by vehicle manufacturers, making their cars capable of using less fuel, has resulted in a larger potential variation in fuel economy depending on driving style. Contrary to our findings in 1990, a large vehicle driven conservatively can now better the fuel economy of a smaller car driven aggressively" (personal communication).

5.2 METHODS FOR MEASURING SAFETY BENEFITS OF MORE FUEL-EFFICIENT DRIVING

The range of methods for measuring the safety benefits of fuel-efficient driving include:

1. comparing safety and fuel consumption before and after training in driving to reduce fuel consumption

2. observational studies to assess whether drivers who are observed driving in a particular manner have higher or lower fuel consumptions

3. simulator or on-road studies with instructions to drive in a particular manner

4. analytical studies to examine whether crash-involved drivers have higher fuel consumptions

These methods differ in the extent to which, and how, they measure safety outcomes.

5.2.1 Comparing fuel consumption before and after training in driving to reduce fuel consumption

A number of reports discussing savings in fuel and emissions due to decreased driving speed and a less aggressive driving style, and EcoDrive training were discussed earlier (see Section 3.2.2). However, few studies have actually taken measurements comparing fuel consumption before and after training. Johansson (1999) had trainees drive a set route in a set vehicle and found that fuel consumption and therefore CO_2 decreased by 10.9% after training (the emissions of other pollutants were too variable to make a reliable comparison). Reinhardt (1999) analysed company reports for a large organisation after driver training and found significant savings in terms of both crashes (35% fewer), fuel use (greater than 6%), and emissions (23-50% less emissions of a range of pollutants).

While quasi-experimental studies such as Johansson's (1999) have the advantage of better control over route and vehicle factors, they are generally not able to measure effects on safety. Longer-term more naturalistic studies such as Reinhardt's analysis of company records are able to measure changes in both fuel consumption and safety.

5.2.2 Observational studies to assess relationships between driving style and fuel consumption

The literature review did not locate any reported observational studies of the relationship between driving style and fuel consumption. However, there are a number of ways in which such a study could be done. An indicator of driving style could be selected and information regarding fuel consumption could be collected from drivers who displayed this indicator. Then a comparison could be made with the fuel consumption of all drivers of that make and model of vehicle or of the fuel consumption of drivers of that make and model of vehicle who did not display the indicator. A range of possible indicators of fuel-inefficient driving could be developed, including speeding, hard acceleration from traffic lights, heavy braking or sharp acceleration or deceleration related to speed humps. The crash involvement or infringement histories of the two types of drivers could also be compared.

5.2.3 Simulator and on-road studies with instructions to drive in a particular manner

The RACV fuel consumption study reported earlier in this report (see Section 5.1.2) is an example of an on-road study of the fuel consumption effects of instructions to drive in a particular manner. While the number of trials in the RACV study was very limited, it demonstrated that these instructions can have a marked effect on fuel consumption for a given trip. More reliable information about likely effects on fuel consumption of different driving styles could be collected by similar studies with larger sample sizes and perhaps with a variety of routes and times of day.

A simulator version of this type of study would allow collection of more detailed performance and fuel consumption data. It would also allow the collection of headways and other measurements that could provide proxy measures of safety outcomes.

5.2.4 Analytical studies

Aggressive driving is likely to be associated with increased fuel consumption and an increased involvement in road crashes. A possible method of testing this hypothesis is to examine fuel use data and crash history for individual drivers. Such information is often kept by vehicle fleet operators. Fleet data has a range of advantages, including the high preponderance of late-model vehicles, an often high number of kilometres travelled by each driver, and a degree of similarity in the types of travel among the vehicles in the fleet. As the fleet operator pays for the vehicle, repairs and fuel, it is expected that the necessary data should be collected in the normal course of business.

Identifying fleet vehicles from mass crash databases

One approach to gathering data about crashes of fleet vehicles is to use the existing mass crash databases that are available in each jurisdiction.

Queensland is the only jurisdiction where information about business use of the vehicle is noted on the crash report form. Queensland Transport cautions, however, that this information should be considered as indicative, rather than strong evidence that it is a fleet vehicle.

For other jurisdictions, identification of crashes involving fleet vehicles is more difficult. In some jurisdictions (eg Western Australia), business ownership of the vehicle is recorded on the vehicle registration database. In this case, matching of the vehicle registration database and the crash database by registration number could identify the business vehicles. In Victoria, whether a vehicle is used for business or private purposes is not recorded on the registration database (because there is no cost differential between business and private registration) so there is no opportunity to examine crashes of business vehicles.

The case study

As a test of the feasibility of the analytical method and of the hypothesis that there will be a relationship between fuel use and crash history, fuel and crash data were obtained from a large fleet operator and analysed. A full description of the process is presented in the Appendix. This section summarises the results of the analysis and describes some of the lessons learned from the case study.

The fleet comprised 525 vehicles (482 passenger vehicles) operated under leasing arrangements. The crash database contained 604 recorded crashes during the period 1995 to 2000 (inclusive). A third set of data consisted of records of purchases using the corporate fuel cards during April, May and June 2000. The analyses were restricted to passenger vehicles.

A sample of crashed vehicles was selected. These vehicles were part of the fleet in 2000, purchased fuel in each of May, June and July 2000, and were listed in the crash database for an incident in 2000. Thirty cars satisfied these criteria.

A control sample of 63 vehicles was selected. These vehicles were also part of the fleet in 2000 and fuelled in each of the recorded months, but did not crash in 2000. The vehicles were chosen to match the crashed vehicles in terms of make, model, body type and year of manufacture (some of the determinants of expected fuel consumption). Each crashed vehicle was matched with at least one control vehicle.

The control sample was further divided into vehicles that had never crashed (according to the supplied data) and those that had crashed in 1998 or 1999.

Table 5.3 shows that the fuel consumption rate for the crash sample was higher than for the control sample (12.8 versus 11.4 L/100 km). The fuel consumption rates of the two sub-groups of the control sample were similar.

The fuel consumption rates calculated from the available data on fuel usage sometimes resulted in unrealistic estimates. For the purpose of the analysis, fuel consumption rates under 9 L/100 km or over 25 L/100 km were considered unreliable estimates. The right-hand columns of Table 5.3 shows the fuel consumption for each sample after vehicles with unreliable estimates were removed from the samples. Only one vehicle was removed due to an unrealistically high fuel consumption rate.

Table 5.3. Fuel consumption rate (L/100k) for cars crashed in 2000 compared to those not crashed in 2000. The latter group is also divided into those that have never crashed and those that crashed in 1998 or 1999 (but not 2000). Each group is also displayed without those cars with fuel consumption rates were considered unreliable (less than 9 and greater than 25 L/100km).

Crash category	Total cars	Fuel economy (L/100k)		Cars removed <9 L/100km & >25 L/100km		
				Cars	L/100k	
		Mean	SD		Mean	SD
Crashed 2000	30	12.8	3.6	29	13.4	3.6
No crash 2000	63	11.4	3.1	54	11.7	1.8
Never crashed	51	11.4	3.1	44	11.6	1.8
No crash 2000 but crashed 98/99	12	11.5	2.1	10	12.1	1.6

After removing vehicles with unrealistic estimates of fuel consumption rate, the fuel consumption rate for crashed vehicles was still higher than for the control vehicles. In addition, the fuel consumption rate for vehicles that had crashed in 1998 or 1999 (but not 2000) was higher than the rate for vehicles that had never crashed.

The case study suggests that there is a relationship between fuel consumption and crash rate. The lessons learned from the case study included:

- volatility of fleet composition
- shared versus allocated vehicles
- difficulties associated with the format of fuel consumption data
- accuracy of fuel consumption data
- difficulties associated with format of crash data
- scope of crash data
- veracity of crash data
- controlling for other factors affecting fuel economy

Volatility of fleet composition

Fleet vehicles are often only retained for a limited period of time or distance travelled (for example 2 years or 40,000 kms). Thus there is significant turnover of the fleet and any database of fleet composition is accurate only at a point in time. Even if vehicles are allocated to a particular driver, analyses over time at the driver (rather than the vehicle) level may be complicated by the need to link driver and (changing) vehicle.

Shared versus allocated vehicles

In the case study the vehicle was the unit of analysis. However, both the fuel consumption and likelihood of being involved in a crash depend on the driver's behaviour. The fuel card indicates which vehicle is fuelled, but not the driver. In the case study, about 70% of the crashed and control vehicles were pool vehicles that were shared among a group of drivers. Thus the effect of a particular driver's behaviour in terms of crash history and fuel consumption – is difficult to track and the emphasis of the analysis has to be on a fleet-wide comparison.

Difficulties associated with the format of fuel consumption data

The extent of time-consuming data manipulation needed to conduct the analysis is markedly affected by the format of the fuel consumption data. In the case study, summary details of each vehicle's fuel use were not available (despite this being an option offered by the fuel card company). In addition to the advantages of such summary data for analysis purposes, it suggested that the potential savings in encouraging drivers to use less fuel would more than likely cover the outlay for this feature in the accounting for fuel used.

Accuracy of fuel consumption data

Analysis of the fuel card data showed implausibly low fuel consumption rates in some instances. This suggests under-reporting of fuel expenditure. Further investigation showed that some drivers had purchased fuel themselves and were reimbursed through the petty cash system. The card data also showed some irregularities where it appeared that fuel was not the item being purchased despite the purchase being coded as fuel.

In some instances, odometer values appeared to be inaccurate. There were instances where consecutive odometer readings were conflicting, suggesting that the fuel card had been used for a different vehicle. In other instances, the odometer reading was not provided.

It may be that the fuel purchase data will be "cleaner" for some fleets than others. This may be a function of the extent to which such costs are managed.

Another issue affecting the accuracy of fuel consumption data is the possibility of "end-effects" when the analysis period is relatively short. The case study assumed that the level in the fuel tank was the same at the beginning and end of the analysis period, such that the amount of fuel purchased was equivalent to the amount of fuel used. Given the high number of kilometres travelled (and thus large number of litres purchased), any deviations resulting from this assumption were considered to be unimportant.

In the case study, the results were presented with and without removing fuel consumption values that were considered to be unreliable. The approach of removing unreliable values may be necessary in smaller studies.

Difficulties associated with format of crash data

The case study identified that crash data for some fleets may not be available in an electronic form. Considerable effort may be needed to develop a crash database.

Scope of crash data

The "crash data" is likely to be a collection of records of vehicles that were damaged and needed repair. It is often compiled for accounting or insurance purposes, rather than to provide information for road safety purposes. In the case study, some of the vehicles in the 'crash' categories were not actually involved in a road crash, but were simply broken into and so appeared in the crash database. Sometimes the details in the crash data are insufficient to determine whether the incident was a crash or some other form of damage.

Veracity of crash data

In the case study, the crash data forms contained self-report data. The likely veracity of reporting is of some concern.

Controlling for other factors affecting fuel economy

There are a number of conceptual issues related to separating out driving style contributions to fuel economy from other contributions. The other contributors include vehicle size (so need to look at a sample of similar vehicles), where driving occurs, time of year effects, time of day effects and so on. There may be a need to match vehicles on a number of dimensions before the effects of driving style can be adequately examined. The case study controlled for some of the vehicle-related factors and time of year effects only.

An additional potentially confounding factor in the data analysis was the lack of information to determine whether each vehicle operated primarily in rural or urban areas; it would be reasonable to expect that both fuel economy and crash rate per kilometre would improve for rural driving. The fuel use data indicated the name of the fuelling site, but this was often simply a street address or unique name, neither of which allowed a determination of actual locality.

5.3 CONCLUSIONS AND RECOMMENDATIONS

This section has addressed the potential for reductions in fuel consumption and examined methods of measuring the safety benefits of fuel-efficient driving.

One of the issues addressed was the range of variability in fuel consumption (if there is little variability, large data sets may be required to demonstrate a strong relationship with safety). It can be concluded that there is potential for reducing fuel consumption, both because the mean values are greater than those cited in the Fuel Consumption Guide and because there is significant variability in fuel consumption rates for the same types of vehicles, even within urban and non-urban driving.

The following methods for measuring the safety benefits of fuel-efficient driving were discussed:

1. comparing safety and fuel consumption before and after training in driving to reduce fuel consumption

2. observational studies to assess whether drivers who are observed driving in a particular manner have higher or lower fuel consumptions

3. simulator or on-road studies with instructions to drive in a particular manner

4. analytical studies to examine whether crash-involved drivers have higher fuel consumptions

Comparing safety and fuel consumption before and after training has been shown to be a feasible method in a number of overseas studies. The quasi-experimental version of this method can provide relatively controlled estimates of fuel consumption effects but gives little information about safety effects. The naturalistic version of this method (often using company fleet data) can measure real-life effects on fuel consumption and safety. This method has potential for use as an evaluation tool as well as potential for use as a promotional tool for demonstrating the relationship between safety and fuel consumption to a wider audience.

The literature review did not locate any observational studies, so the feasibility of this method is yet to be demonstrated. Observational studies have the potential to demonstrate the relationship between safety and fuel consumption but trialing of this approach would need to occur before any larger study was undertaken.

Small on-road studies of the effects of instructions in driving style have been undertaken and larger, more reliable studies are feasible. The small studies that have been reported have aimed to demonstrate the effects of driving styles on fuel consumption. An important potential role of this method is in countermeasure development. This may include optimisation of driving style instructions, both in terms of the behaviours to be promoted and the optimal methods of presenting such information (eg method and role of feedback to the driver). While on-road studies can measure fuel consumption under naturalistic conditions, they have the disadvantage of not providing an objective measure of the safety effects. The literature review did not identify any simulator studies of the effects of instructions in driving style on fuel consumption, however this method may provide a means of collecting objective safety-related measures.

No analytical studies of the relationship between crash involvement and fuel consumption were identified in the literature review. It is difficult to identify fleet vehicles from mass crash databases and obtain fuel data for large numbers of vehicles. Therefore the approach may best be applied in large company fleets. The company-based studies may be useful for promotion of the effects of driving style on fuel consumption and have the advantage of actually measuring crashes (although most crashes will not have resulted in injury and some recorded ‘crashes’ are actually other forms of vehicle damage).

The case study found that the fuel consumption rate of crash-involved vehicles was higher than that of vehicles not involved in crashes and demonstrated the feasibility of this method. It also showed that while fuel consumption may be easier to measure than safety levels (crash costs), data manipulation and quality control may be time-consuming. The analytical approach is likely to be simpler and more likely to show reliable results if the fleet chosen has well-maintained fuel and crash databases. To show significant effects, the fleet needs to be reasonably large. The case study found that a fleet of about 500 vehicles seemed sufficient. Analyses with smaller fleets could be undertaken over a longer period but if the period becomes too long, then vehicle and employee turnover may cause difficulties. An alternative would be to combine data from a number of small fleets.

In conclusion, comparisons before and after training in driving to reduce fuel consumption and analytical studies based on fleet data are recommended as measures of the safety effects of fuel-efficient driving. Studies of the effects of instructions in driving style have the potential to provide useful information about the best ways in which to bring about fuel-efficient driving.

6 OVERALL CONCLUSIONS

Both road safety and the environment are critically affected by the extent of the use of motor vehicles and the specific ways in which they are driven. This report examines the possible safety benefits from driving in a manner that results in lower fuel consumption and emissions. It attempts to assess the potential of promoting additional motivations to drive safely – better fuel economy and other environmental outcomes, and reduced running costs.

The potential value of establishing such a link is to provide drivers, in particular fleet vehicle owners and drivers, with an additional financial incentive, through reduced operating costs, to adopt or encourage safer driving practices. There is also the potential to build partnerships with other government initiatives to provide an integrated message about the benefits of better driving. In the end, both improved safety and environment combine to improve the life and well-being of people.

Identifying means of improving the fuel consumption of current vehicles by safer, more environmentally friendly ways of driving provides a mechanism to improve the fuel consumption of the existing vehicle fleet. Given the relatively slow turnover of vehicles in Australia, this has the potential to complement measures that will be introduced to improve the fuel economy of new cars.

6.1 FUEL CONSUMPTION AS AN ENVIRONMENTAL OUTCOME

From an environmental perspective, fuel consumption results in the production of vehicle emissions which can be classified into air pollutants (which affect health) and greenhouse gases (which affect the environment). Fuel consumption also depletes stocks of non-renewable fossil fuels. The latter outcome currently seems to be of lesser importance but is likely to increase in the future.

Complete combustion of fuel produces carbon dioxide which is the major greenhouse gas. Initiatives to reduce greenhouse gas emissions therefore typically aim to achieve reductions in fuel consumption. Reduction in vehicle travel is the most fundamental of these measures. Making cars more fuel efficient by producing or promoting new cars that consume less fuel or by better maintenance of existing cars are also ways of reducing fuel consumption.

Incomplete combustion of fuel produces air pollutants (eg carbon monoxide, hydrocarbons, nitrogen oxides). Initiatives to reduce air pollution typically focus on measures to improve the efficiency of combustion (eg ensuring that cars are correctly tuned, reductions in congestion). These measures also contribute to a reduction in fuel consumption and emissions of greenhouse gases.

Total fuel consumption can be decreased by reducing vehicle travel or by reducing fuel consumption rate (improving fuel economy). This report focused on the safety effects of measures that improve fuel economy, rather than the effects of reduced vehicle travel.

The measurement of vehicle emissions requires specialised equipment and is relatively expensive. Fuel consumption is easy to measure (at least at to a coarse level) and is directly related to greenhouse gas emissions. Thus fuel consumption provides an ideal proxy for at least one environmental effect of driving.

6.2 THE SAFETY BENEFITS OF DRIVING IN A MANNER THAT REDUCES FUEL CONSUMPTION

Driver behaviours that affect fuel consumption rate and safety include: choice of travel speed, smoothness of driving, choice of travel route, use of air conditioning and use of cruise control. Smoothness of driving and choice of travel route both affect fuel consumption rate by modifying the speed profile.

Reductions in travel speeds will result in crash savings in all scenarios. The reductions may be greatest in urban areas because of the significant representation of unprotected road users and because vehicles are better at protecting their occupants at urban speed levels. In urban areas, some fuel consumption and emissions reductions will follow from lower travel speeds but the bulk of the benefit will be to road safety.

For open road travel, the crash savings associated with lower speeds are likely to be significant. The fuel consumption savings are likely to be greater than at urban speed levels.

Smoother driving has greater potential for reducing fuel consumption and emissions in urban areas than in open road travel. At the level of the individual vehicle, smoother driving should reduce fuel consumption in urban areas more than lower travel speed. The reduction in emissions of air pollutants should be greater than the reduction in greenhouse gas emissions. The environmental benefits of smoother driving may be greater than the road safety benefits but this is yet to be established.

There is a need for more information about the road safety effects of smoother driving. One issue to be examined is the possible effects on following distance of drivers attempting to maintain a steady speed (or avoid braking). The nature of instructions to be given to drivers, particularly of automatic vehicles needs further investigation. Further work on the interaction between driving style, speed limit and street length is needed to establish whether different instructions should be given according to these variables.

6.3 LIKELY COMMUNITY ACCEPTANCE

Given that reducing speeding, lower speed limits and modifying driving style can improve fuel economy and other environmental outcomes in addition to improving safety, there is a need to assess another aspect of implementation: the extent to which drivers are motivated by fuel costs and environmental effects.

The above measures all aim to increase fuel economy, ie they are all ways of reducing fuel consumption (and emissions) while maintaining the same level of vehicle travel. Community attitude surveys suggest that the community may be more supportive of these types of measures than those measures that attempt to reduce vehicle travel. In addition, reducing fuel consumption rate without requiring a change in vehicle choice may be more acceptable and more easily implemented in the short-term. The most likely scenario is parallel introduction of measures to reduce vehicle travel and improve fuel efficiency.

Programs that result in reductions in fuel consumption in addition to safety improvements are more likely to be implemented because the benefits (in terms of fuel cost savings) flow directly to the vehicle owner. This scenario should be much more likely to ensure that any costs of the program are accepted than a program in which the costs are borne by one party and the benefits are spread across a number of parties (or across society). Safety programs and environmental programs often follow the latter scenario. Thus driving to reduce fuel consumption may be adopted from a perspective of enlightened self-interest, rather than one of overall benefit to the community.

6.4 MEASURING THE SAFETY BENEFITS

There appears to be sufficient variability in fuel consumption to demonstrate a relationship with safety using data sets that are of a realistic size.

The case study found that the fuel consumption rate of crash-involved vehicles was higher than that of vehicles not involved in crashes and demonstrated the feasibility of this method. It also showed that while fuel consumption may be easier to measure than safety levels (crash costs), data manipulation and quality control may be time-consuming. The analytical approach is likely to be simpler and more likely to show reliable results if the fleet chosen has well-maintained fuel and crash databases. To show significant effects, the fleet needs to be reasonably large (about 500 vehicles). Analyses with smaller fleets could be undertaken over a longer period but if the period becomes too long, then vehicle and employee turnover may cause difficulties.

Comparisons before and after training in driving to reduce fuel consumption and analytical studies based on fleet data are recommended as measures of the safety effects of fuel-efficient driving. Studies of the effects of instructions in driving style have the potential to provide useful information about the best ways in which to bring about fuel-efficient driving.

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APPENDIX 1. CASE STUDY OF ANALYTICAL APPROACH

The Data

The fleet operator provided a spreadsheet file listing 525 vehicles operated under leasing arrangements. The vehicles were leased as new from mid 1996 to late 1999. At the time that the file was provided (mid-late 2000) the operator was in the process of replacing the fleet with new vehicles. In late 2000 another file was provided listing 482 vehicles that were leased as new during 2000.

The operator also provided a database file of 604 recorded crashes during the period 1995 to 2000 (inclusive). The file was compiled from paper records by a subcontractor. While the file may not be a complete record of all crashes or a complete catalogue of all of the details for each crash, in the latter years (i.e. 1998-2000) the data should be more comprehensive. As the operator does not keep its vehicles for many years it is likely that vehicles involved in crashes prior to 1998 are no longer in the fleet.

A third set of data provided by the operator consisted of records of purchases using the corporate fuel cards during April, May and June 2000. As part of the service offered by the fuel provider for its card customers, the operator could have had a record of the fuel consumption of each vehicle. However, the operator had elected not to use the accounting features offered by the fuel provider (presumably due to the additional cost). The data was provided as three large text files that had to be converted into spreadsheet format.

The Fleet

Of the 525 vehicles leased by the fleet operator at the time that the file was provided, 482 were passenger vehicles – 312 sedans, 156 station wagons and 14 utilities – the remainder were mainly four wheel drives. Table A1 shows the make and model breakdown of the passenger car fleet (Falcon and Commodore utilities are included in this classification). Most of the passenger vehicles were Ford Falcons, Holden Commodores and Toyota Camrys; and overall there were around twice as many sedans as wagons, with comparatively few utilities.

Table A1. Make and model breakdown of the fleet according to car body type.

Make	Model	Sedan	Utility	Wagon	Total
Ford	Fairlane/ Fairmont	23			23
	Falcon	43	10	62	115
Holden	Acclaim	2		2	4
	Berlina	13			13
	Commodore	83	4	57	144
	Vectra	4			4
Mitsubishi	Altera	4			4
	Magna	26		12	38
	Verada	4			4
Toyota	Camry	104		23	127
	Corolla	2			2
	Vienta	4			4
Total		312	14	156	482

Crash history

It is not known what the criteria were for including an incident in the crash database. The subcontractor who compiled the file did so from paper records completed by the drivers of the particular vehicles, and did not know who completed each record or the criteria for doing so. A reasonable assumption is that if a repair were required then an accident history report would have to be completed. As the records seemed to be self-report data, there is some question as to their veracity. Many individual reports indicated that the damage had been noticed when the employee returned to the vehicle, suggesting that the employee was not responsible at all.

It is also relevant that there are two classes of car that make up the fleet – pooled and assigned vehicles. It is likely that damage is more liable to be noticed on a pool vehicle, as any particular driver would be aware that they might be held responsible for damage done by a previous driver, and so check the vehicle before taking it. An assigned vehicle may wear some damage for some time if penalties are a consequence for the driver reporting it.

Not all of the individual crash records listed the particular circumstances of the damage, but many instances seemed to suggest that the file was a 'damage' database rather than a crash database. For example, some listed causes of damage included vehicles that had been broken into or stolen, radio antennae broken, and quite a few instances of 'noticed on return'. Other records were obviously road crashes, such as 'hit three kangaroos', loss of control while towing, and 'occurred at stop sign'.

The database included a field for the speed of travel, but in most cases a zero was indicated, suggesting that this was the default value for missing data.

Fuel data

Unfortunately, the fleet operator had not availed itself of the facility of having the fuel supplier provide monthly fuel consumption data for each vehicle that fuelled under the card system. This data would have provided the operator with a check on the drivers and their use of fuel and the distance that they travelled. Such information, along with the locations of fuelling, would alert the operator to any unreasonable use of the operator's vehicles and fuel. It would also allow the opportunity for the operator to encourage a more fuel-economical style of driving, potentially cutting costs to the operator that could far outweigh the expense of this accounting facility offered by the fuel supplier.

As the fuel data was provided as a set of large text files, they had to be reformatted into a spreadsheet format. The spreadsheet listed each purchase on the operator's fuel card according to location, date and time of the item and the vehicle's registration number. All costs were listed, including car washes, account keeping fees and other unidentified items. Fuel purchases included the product (ie unleaded, distillate, etc.), the number of litres, several dollar costs (including a pump price and a contract price), and the odometer reading of the vehicle.

As the odometer readings were cumulative values, the file did not indicate how many kilometres had been travelled between fuel purchases. While an automated calculation could have been set up in the spreadsheet to calculate this for all fuel purchases, several problems were noted in the data. It was not uncommon for an odometer reading not to be recorded, suggesting that the service station operator did not insist that the driver supply it, and a default value of zero was entered. There were also occasional radical changes in the odometer readings that suggested that the fuel card was being used for another vehicle; however the card number is linked with a particular vehicle's registration number and so the fuel was attributed to the original car.

The fuel consumption for a sample of vehicles was calculated with obvious anomalies removed (such as the use of the card in other vehicles). This analysis revealed that there were unrealistically low and high fuel consumption figures. Depending on the time period that the fuel consumption was calculated over, an unreasonably low amount of fuel used may indicate that the vehicle was not filled with fuel at the beginning or end of the calculation run, and so it appears that not enough fuel has been used for the number of kilometres travelled. The vehicle may also fuel without using the fuel card. This may occur if the driver has the option of fuelling at a plant depot. Alternatively, the driver may pay for the fuel if he/she is using the vehicle for private purposes and not billing the fleet operator, or later claim the purchase from a petty cash source, possibly because the driver did not have access to the appropriately branded fuel supplier at the time that fuel was required. The car may appear to use too much fuel if it was not filled at the start of the calculation run but filled at the end. Alternatively the car may not use all of the fuel put into it – the tank may be siphoned.

The Case Study

A primary purpose of this exploration of fleet data was to explore whether there is a relationship between fuel consumption and crash history. A sample of vehicles was isolated from the fleet data, the selection criteria being that they must have been part of the fleet in 2000, purchased fuel in each of May, June and July 2000, and have been listed in the crash database for an incident in 2000. Table A2 describes the thirty cars that satisfied these criteria.

Table A2. Make and model breakdown of fleet vehicles that had fuelled in each of the recorded months and crashed in 2000 according to car body type.

Make	Model	Sedan	Utility	Wagon	Total
Ford	Fairlane/ Fairmont	5			5
	Falcon		1	7	8
Holden	Berlina	3			3
	Commodore	6	1	4	11
Toyota	Camry	2		1	3
Total		16	2	12	30

A control sample was selected that was also part of the fleet in 2000 and fuelled in each of the recorded months, but did not crash in 2000. Additionally, the vehicles in the control sample were chosen on the basis of a match with the crashed vehicles in terms of make, model, body type and year of manufacture (some determinants of expected fuel consumption). There were 15 categories of crashed vehicle based on these variables, each category containing between one and four separate vehicles. Each crashed vehicle was matched with at least as many control vehicles. Table A3 describes the control sample.

Table A3. Make and model breakdown of the matched fleet vehicles that did not crash in 2000 according to body type.

Make	Model	Sedan	Utility	Wagon	Total
Ford	Fairmont	9			9
	Falcon		3	9	12
Holden	Berlina	10			10
	Commodore	10	2	10	22
Toyota	Camry	5		5	10
Total		34	5	24	63

The fuel consumption rates for the crash and control samples are shown in Table A4. Some of the control vehicles had crashed in earlier years, however. Table A4 also shows the control sample separated into cars that had crashed in 1998 or 1999 and those that had never crashed (according to the supplied data). Fuel consumption rates were calculated for each of these sub-samples.

As discussed earlier, the fuel consumption rates calculated from the available data on fuel usage sometimes results in unrealistic figures. Table A4 also shows the fuel consumption for each category of vehicle after those cars that indicated a fuel consumption of either under 9 or over 25 litres per 100 kilometres were removed from the sample. Only one vehicle was removed due to an unrealistically high fuel consumption rate.

Table A4. Average distance travelled and fuel consumption rate (L/100k) for cars crashed in 2000 compared to those not crashed in 2000. The latter group is also divided into those that have never crashed and those that crashed in 1998 or 1999 (but not 2000). Each group is also displayed without those cars with fuel economies less than 9 and greater than 25 L/100km.

Crash category	Total cars	Distance travelled (km)		Fuel economy (L/100k)		Cars removed <9 L/100km & >25 L/100km		
						Cars	L/100k	
		Mean	SD	Mean	SD		Mean	SD
Crashed 2000	30	7407	3992	12.8	3.6	29	13.4	3.6
No crash 2000	63	7158	3728	11.4	3.1	54	11.7	1.8
Never crashed	51	7027	3712	11.4	3.1	44	11.6	1.8
No crash 2000 but crashed 98/99	12	7717	3492	11.5	2.1	10	12.1	1.6

The analyses reported in Table A4 show that those vehicles that had not crashed in 2000 had the lowest fuel consumption (and were equivalent to those vehicles that had never crashed), followed by those that had crashed earlier but not during 2000. The cars that had crashed in 2000 demonstrated the highest fuel consumption figures. This trend was particularly evident after those vehicles with an unrealistic fuel consumption had been removed from all samples.

As a single case study, the data used seems to suggest that in this particular fleet there may be a relationship between fuel consumption and crash rate. However, there are several cautionary notes in drawing conclusions based on this analysis, some of which are borne out by the rather high standard deviations listed in Table A4. There are also a number of factors that need to be taken into consideration in regards to the quality of the data used in the analysis.

Cautionary comments and data considerations

While the standard deviations of the samples are comparable, they are rather high – particularly amongst the vehicles that had crashed in 2000. These standard deviations could be reduced by further narrowing the range of acceptable fuel consumption figures from 9-25 L/100km (or by increasing the size of the samples).

Due to the quality of the data supplied, the actual types of crashes were not analysed. It is likely that a percentage of the vehicles in the 'crash' categories were not actually involved in a road crash, but were simply broken into and so appeared in the crash (read 'damage') database.

A potentially confounding factor in the analysis is city versus rural travel. It is reasonable to expect that the fleet vehicles that operated in rural areas would return better fuel consumption *and* probably a lower crash involvement per kilometre travelled. The fuel use data includes the site name of the fuelling location, however this often does not indicate the name of the locality. In a majority of (but not all) cases the crash data specifies the street address of the crash. However this information does not indicate where the majority of travel took place, particularly since some of the fleet vehicles definitely travel in both rural and suburban areas each month. Additionally, the crash file provides no information on the vehicles that did not crash.

Throughout this description the vehicles have been the unit of analysis. However, the fuel consumption and likelihood of being involved in a crash both depend on the driver's behaviour. The fuel card indicates which vehicle is fuelled, but not the driver. This particular fleet maintains two types of vehicle – pool cars and assigned cars. Nineteen of the crashed vehicles (63% of the total number of crashed vehicles in the analysis) and 44 (70%) of the non crashed vehicles were pool vehicles. Thus the effect of a particular driver's behaviour in terms of crash history and fuel consumption – is difficult to track and the emphasis of the analysis has to be on a fleet-wide comparison.

It was assumed that the car had a full tank of fuel at the beginning of the calculation run (ie after the first fuel purchase in April) and the driver topped the tank off to the same level at the final purchase in June. With the high number of kilometres that these cars are travelling and the fact that the driver does not personally pay for the fuel, there is no reason to think that the driver would not fill the car's fuel tank at each purchase.

In terms of the usability of the data, it would have been more convenient had this particular fleet operator had a more stringent system of recording details of crashes involving its vehicles. Additionally, a lot of basic calculation work would be saved if the fuel account was set up to provide summary details of each vehicle's fuel use an option that the particular fuel provider does offer at an additional fee. It is suggested that the potential savings in encouraging drivers to use less fuel would more than likely cover the outlay for this feature in the accounting for fuel used.