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Assessing the Impacts of Ecodriving on Fuel Consumption and Emissions for the Australian Situation

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Abstract

Road traffic is an important global source of air pollution and greenhouse gas emissions and its significance is increasing. It is therefore not surprising that reduction of transport emissions (both air pollutants and greenhouse gases) is now high on political agendas around the world. This paper will focus on one particular operational measure, i.e. "ecodriving", which has seen application in other parts of the world. There has also been growing interest in Australia as evidenced by presentations from many States at the National Ecodriving Symposium held in Melbourne on in late 2009. Although there is significant interest in Australia to develop and roll-out an ecodriving program, it is important to first assess the impacts and cost-effectiveness of such a measure. This will ensure that ecodriving tips are appropriate for the Australian situation and that the available budget is used in the best possible way with a maximum impact on fuel efficiency and without perverse effects. This paper explores and discusses the different options to quantify the impacts of ecodriving on vehicle emissions for the Australian situation. It will also showcase one particular route, namely the combination of measured driving behaviour data and simulation of vehicle emissions.

1. Introduction

Road traffic is an important global source of air pollution and greenhouse gas emissions and its significance is increasing. It is therefore not surprising that reduction of transport emissions (both air pollutants and greenhouse gases) is now high on political agendas around the world. Two types of policy measures to reduce emissions and fuel consumption can be distinguished – technological and operational. Hybridisation, electrification, engine downsizing, and use of alternative fuels are examples of technological measures. Examples of operational measures are the implementation of specific traffic management measures (e.g. dynamic speed limits, optimised traffic signal coordination, ramp metering) and measures to influence travel/driving behaviour (e.g. travel demand management, programs designed to change driving style).

This paper will focus on one particular operational measure – ecodriving. At its core, ecodriving involves monitoring engine revolutions (or revs) to make timely gear changes, travelling at an optimum speed, and anticipating traffic conditions in order to maximally conserve momentum. Thus ecodriving emphasises a smooth driving style. Drivers are encouraged to “flow” the vehicle, anticipating potential interactions by looking further down the traffic stream so they can brake less forcefully and less often and avoiding unnecessary acceleration. Other elements of ecodriving include using the air conditioner sparingly, minimising idling, optimising aerodynamic profile, minimising unnecessary weight, adhering to a regular servicing regime, and ensuring tyres are inflated to their maximum advisory pressures.

Ecodriving has generated considerable interest in Europe (Symmons et al, 2009). Four key points emerge from a recent review of the ecodrive literature (Symmons et al, 2009). First, a relatively modest number of separate field trial studies are reported in the English literature, though some of them have involved large numbers of drivers. Second, European studies clearly dominate the available literature, with Switzerland being disproportionately represented. Third, almost without exception the studies report a positive effect in terms of reductions in fuel consumption. Fourth, most studies lack scientific rigour, or at least do not report sufficient detail to determine the degree of rigour. Two studies (af Wåhlberg, 2007; Rose and Symmons, 2009) stand out because they provide comprehensive details of their field trials, which reflect a rigorous approach to experimental design, and they report their results in peer reviewed publications. They both employed a longitudinal comparison between treatment and control groups. af Wåhlberg considered a large sample of bus drivers (nearly 250 who received training and 150 who acted as controls) while the Rose and Symmons study was a pilot that involved training eight drivers and using four others as controls. Only one other study identified in the review was published in a peer review journal. Zarkadoula et al (2007) is a ‘note’ rather than a full paper, and reports results from a study of three drivers without a comparative control group. Taken overall, the literature suggests that ecodriving shows potential as a policy tool but that more research is needed to fully understand the extent and longevity of its effects.

There has also been growing interest in Australia as evidenced by presentations from many States at the National Ecodriving Symposium held in Melbourne in late 2009 to highlight initiatives to either promote or develop and deploy ecodriving programs. However, it is important to first assess the impact and cost-effectiveness of ecodriving programmes. This will ensure that ecodriving tips are appropriate for the Australian situation and that resources are expended in the best possible way, with an optimum impact on fuel efficiency and minimisation of perverse effects. We will therefore explore and discuss the options to quantify the impacts of ecodriving on vehicle emissions for the Australian situation.

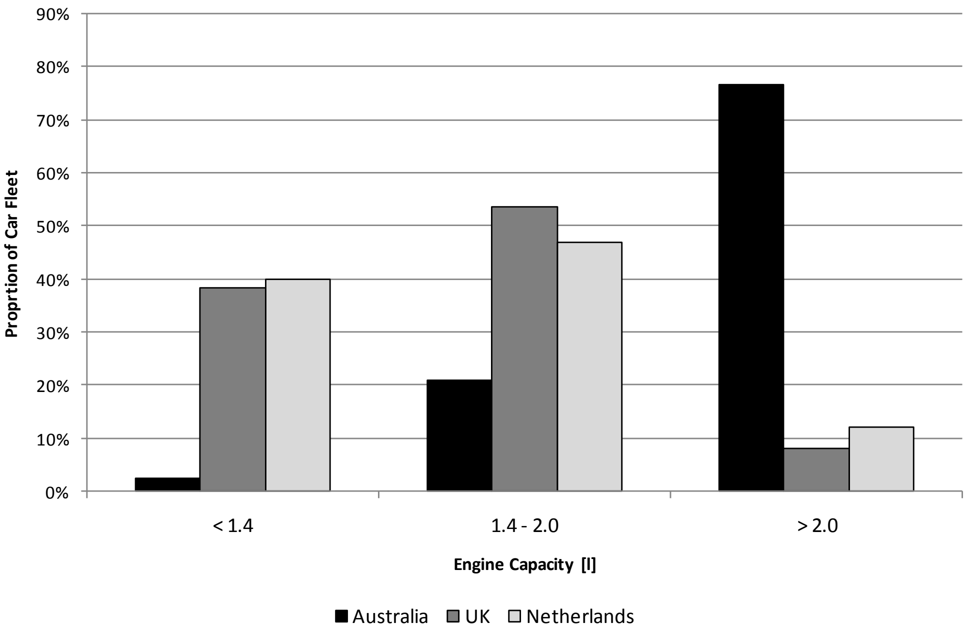
2. The Need for a Quantitative Assessment

Quantification of the impacts of ecodriving on fuel consumption and emissions, now and in the future, is essential to design an effective program in terms of both costs and impacts for the Australian situation, reflecting positive as well as potential negative effects.

Vehicle emissions and fuel consumption are very sensitive to actual driving conditions and gear shift behaviour. Measurements in Europe (e.g. TNO, 2006) have shown that there are positive effects of ecodriving on fuel consumption and CO_2 emissions that are relatively minor (3-11%), but statistically significant. It was also found, however, that in certain driving conditions there can be adverse effects on air pollutant emissions that can be quite substantial. One example is a measured and statistically significant increase of 30% in NO_x emissions for diesel cars in urban driving conditions when ecodriving tips were applied. As NO_x is a critical air pollutant this is not a trivial issue, particularly in Europe, and increasingly in Australia, where diesel cars make up an increasing proportion of the car fleet.

There are also questions of generalisability as the Australian vehicle fleet is quite different from European fleets, upon which most of the published data is based. This is important with respect to road transport emissions. The Australian car fleet, for instance, is characterised by a large proportion of large engines. This is shown in Figure 1, which demonstrates that the majority (about 75%) of the Australian car fleet has an engine capacity of more than 2 litres [(1)]. This contrasts with the UK and Dutch car fleets where these vehicles only make up about 10% of the fleet because smaller engines are dominant.

Figure 1: Australian, UK and Dutch Car Fleet Composition in terms of engine capacity



On one hand the higher proportion of larger engines also increases the potential fuel benefits of ecodriving, which are larger for large cars/engines than for small cars. On the other hand, this means that one has to be careful using overseas data or models to assess impacts for the Australian situation, a point discussed further later. It has been demonstrated elsewhere that directly applying overseas models in Australia can lead to substantial errors (e.g. Smit & McBroom, 2009a; 2009b). Another important aspect of the Australian car fleet is the large share of cars with automatic transmissions – about 70% [(1)]. This implies that gear shift behaviour can only be directly influenced for a relatively minor portion of the car fleet, and that the promotion of other tips (e.g. smooth driving, avoiding stops, moderate acceleration) would perhaps be more appropriate in Australia.

[1] It is difficult to find detailed information on Australian and overseas vehicle fleets. We have used information from various Australian emission testing programs (Anyon et al, 2000; Orbital, 2005; 2009) – which are designed to be representative of the Australian fleet - to analyse Australia's fleet composition. Data on the composition of the UK fleet was derived from LAT (2009) and data for the Dutch fleet was provided by Klein (2009).

3. Different Approaches to Quantification

Assessment of the impacts of ecodriving on emissions and fuel consumption consist of two main steps:

1. quantification of driving behaviour ("baseline" and "ecodriving"); and
2. quantification of the impacts on vehicle emissions.

For each of these steps there are two basic options – to measure or simulate. The use of field data has a clear advantage in terms of real-world accuracy when compared to simulation. However, measurement has its own issues, as will be discussed later in this section. Simulation generally has the advantages of lower costs, greater freedom to manipulate the environment, vehicles and traffic conditions to assess their relative impacts, and it may be less involved in terms of the amount of work and timeframe. But in order to obtain valid outcomes, the model needs to comply with a number of criteria, which are discussed in more detail later in this section.

3.1 Quantification of Driving Behaviour

Given the almost infinite number of combinations of driving conditions, driving styles and vehicle characteristics (e.g. power-to-weight ratio, vehicle size), a wide variation in driving behaviour is observed in the real world. This behaviour is very specific in terms of time and location. For emissions purposes, driving behaviour is usually measured and quantified through a speed-time profile (i.e. a unique series of idling, acceleration, cruising and deceleration sequences). Speed-time data and gear-shift data would ideally be measured in the field with some form of instrumented vehicle. As will be described in more detail shortly, there is also the option to synthetically generate this data using outputs from traffic microsimulation models.

3.1.1 Measurement of Driving Behaviour

The most reliable way to assess driving behaviour is to record speed/gear-shift data in the field. This can be done using, for instance, on-board sensors, data loggers and GPS equipment employing a floating car or chase-car technique or by driving "as usual" (instrumented vehicle approach), or road-side video sensor and image processing technology. Note that gear-shift data can only be collected in the instrumented vehicle approach. The term "driving cycle" is often used in the field of vehicle emission measurement and modelling. A driving cycle is a time-series of speed and (possibly) gear-shift points of limited duration that is used for emissions testing (typically 1 Hertz and less than one hour duration). Driving cycles are synthesized from measured speed/gear-shift data following specific procedures (e.g. TNO, 2007) and they aim to be representative of traffic conditions and typical driving behaviour in a particular geographic area (Zito et al, 2004).

3.1.2 Simulation of Driving Behaviour

As an alternative to measurement, microscopic traffic simulation models can generate speed-time data for each vehicle in the traffic stream or "driving simulators" can generate speed/gear-shift data.

3.2 Quantification of Emission Impacts

Given the large number of on-road vehicles and the large variety in vehicle types, ages and fuel types along with the range in engine and emission control technology and traffic situations, vehicle emissions are highly variable. It is a major challenge to adequately capture this variability and obtain accurate estimates of vehicle emissions. As with driving behaviour, vehicle emissions can be either measured or simulated.

3.2.1 Measurement of Emission Impacts

Different technologies are available for measuring emission impacts:

- laboratory (dynamometer) testing,
- on-board measurements, and
- field experiments.

An advantage of laboratory measurements is that they are conducted under controlled conditions, which enables detailed investigation of specific aspects on emissions, such as ecodriving and gear-shift behaviour, as well as a consistent base upon which to make comparisons between vehicles. Disadvantages of this method include the limitation on the number of vehicles or engines that can be tested due to time and budget constraints and concerns over the extent to which they replicate actual on-road conditions and/or driver behaviour. This is not a trivial issue. Individual vehicles can have widely different emissions profiles, so a large and representative sample of on-road vehicles in different traffic situations is required to obtain an accurate measurement of ecodriving effects on emissions. Research has shown that a level of accuracy of 10% in emissions factors expressed as grams per km (i.e. a 95 percent confidence interval divided by the mean ≤ 0.10) requires testing of at least 600 vehicles of the same type over a given driving cycle (Smit et al, 2005).

Researchers have also used vehicles with on-board measurement systems to collect emissions and driving pattern data while they are driving on the road. Although there is less control over both the driving and ambient conditions, these measurements include factors that are (often) not reflected in laboratory test data, but which are known to be relevant, such as road grade effects, air conditioning use, and personal driving style. On-board measurements can also generate substantially more information on patterns of emissions and driving, compared with laboratory tests that typically test vehicles over one or a few driving cycles to keep costs within acceptable limits. Although problems with detection limits and data quality issues have been reported (TNO, 2004), improved new systems have emerged (Frey et al, 2002; North et al, 2005).

On-board measurements are now increasingly used in practice. However, measurement on a large number of vehicles can still be restricted by labour and other costs, particularly for older vehicles, which require more set-up time as relevant operational data may not be readily extracted from the engine management systems (North et al, 2005). Nevertheless, on-board monitoring could be a reliable and feasible approach to quantify the impacts of ecodriving programs when smaller on-road fleets are of interest (e.g. commercial bus or truck fleets).

Field experiments include near-road air quality measurements, tunnel studies and remote sensing studies. These methods are commonly used for emission model validation purposes. There are, however, several features that make this kind of data collection unsuitable for an ecodriving impact assessment. Perhaps the most important problem is the lack of control over and information about actual ecodriving behaviour in the field. But there are other issues, such as:

- the local nature of remote sensing data and near-road air quality data (i.e. a specific point near the road), which deviates from the spatial scale that is needed for the impact assessment, i.e. representative road sections or journeys in a road network; and
- the limited range of operating or traffic conditions in tunnels (typically ‘smooth’, uncongested, high-speed driving where ecodriving would have minimal impact).

In conclusion, measurement of emissions impacts of ecodriving is possible through either laboratory or on-board testing. On-board data collection has the advantage of simultaneous collection of both speed/gear-shift time data and emissions data, but less control over driving conditions. Furthermore, the quality of the emissions test data needs to be verified and a sufficient (and probably substantial) sample size is required. Provided that the on-board equipment can be readily installed and transferred from vehicle to vehicle, use of on-board emissions testing equipment appears to be a good approach for the assessment of ecodriving impacts on fuel consumption and emissions.

3.2.2 Simulation of Emission Impacts

Model simulation provides a cost-effective approach to estimating emissions for situations where no measurement data are available. Vehicle emissions are a function of many, often interacting, variables including fuel composition, vehicle technologies, traffic conditions and driving behaviour. Due to these complex relationships, models are commonly used to predict and evaluate impacts and determine solutions. There currently are a large number of models and model types available (for a classification and a detailed discussion of emission models refer to Smit et al, 2009). Importantly, each type of emission model has its own intended and appropriate scale of application. For instance, average speed models are applied at road network level, whereas more detailed and complex models are used for local impact assessment.

For the assessment of ecodriving impacts on fuel consumption and emissions an appropriate simulation tool is required. In order to make a valid assessment it should comply with a number of criteria. It must:

1. be sensitive enough to compute the effects of changes in driving behaviour;
2. be based on Australian test data;
3. be based on an appropriate sample to reflect variability in emission profiles;
4. include all relevant vehicle classes; and
5. be up-to-date;

Ideally it would also include input variables which could be varied to examine the effects of future technologies.

The model must be sensitive to changes in driving behaviour to make it appropriate to use in cases where policy or traffic measures aim to influence driving behaviour, such as ecodriving. It must also reflect vehicles used in Australia. It has been shown that directly applying overseas emissions models or overseas traffic models with emission prediction capabilities to Australian conditions can lead to large errors in the emission predictions (Smit and McBroom, 2009a; 2009b), up to orders of magnitude. At least one reason for these large errors can be attributed to the substantial differences between the Australian and overseas vehicle fleets. So, use of specific Australian emission algorithms is essential to prevent poor infrastructure decisions and poor policy outcomes. In order to adequately reflect the large inter-vehicle variability in emissions in traffic streams, the model needs to be based on a large body of test data for as many (representative) vehicles as possible.

The model should also use a vehicle classification scheme that considers the most important classes. A vehicle classification scheme is normally used to take into account the differences in vehicle design characteristics that significantly impact on emissions and fuel consumption, such as the reality that a limited number of vehicle classes and vehicles dominate vehicle emissions due to their relatively high emission levels and/or high usage. For instance, it has been reported that about 65% of road traffic NO_x emissions are caused by diesel trucks, despite the fact that they have a share of about only 10% in total travel (Smit, 2006).

Similarly, within a particular vehicle class, the majority of the vehicles will have relatively low emissions, but some vehicles exhibit (very) high emission levels. This is not only due to the penetration of cleaner vehicles into the fleet in time, but also to the presence of vehicles that are badly tuned or tampered with or have malfunctioning or partly functioning emission control systems ("high-emitters"). It is important that these vehicles are included in the assessment of ecodriving impacts, as they may respond differently (both in absolute and relative terms) to changes in driving behaviour.

The model must be up-to-date with respect to the emissions test data on which it is based in order to reflect the latest developments in engine and emission control technology.

A final point is the consideration of future changes in the fleet composition with respect to vehicle and engine technology. Apart from an expected further diversification of personal mobility options reflecting increased use of innovative vehicle designs, including non-motorised and motor-assisted vehicles (Rose and Richardson, 2009), motor vehicles are expected to be further optimised for fuel efficiency, which would include (further uptake of) e.g. hybridisation, engine downsizing, variable valve timing and direct injection petrol engines. It is generally assumed that future vehicles will have less potential to reduce fuel consumption by adaptation of driving style because of their already optimised fuel efficiency. It is not clear, however, how much this will change the impacts of ecodriving programs in both absolute and relative terms, and this needs to be further investigated. Driving behaviour would be expected to continue to have a direct impact on fuel consumption and emissions, as it does now (Symmons et al, 2009), simply because the amount of energy used per kilometre is a function of this driving behaviour. Further, because the average age of Australia's national fleet is more than a decade old, and in many states the median age is much higher (ABS, 2009), such optimisations will take some time to make a significant impact on Australia's total emissions.

Prior to running the model simulation, the relevant input data need to be collected. In order to assess the changes in fuel consumption and emissions, the input data needs to establish:

1. the baseline driving behavior; and
2. how the driving behavior is changed in practice.

This can be done by developing a driving cycle and a gear shift profile, as will be shown later. In addition to this, other factors will need to be considered in the final assessment, such as how many people will change their driving behavior, the progressive impact of an ecodriving program, and the durablility of the changed behavior.

4. Quantification for Australian Conditions – An Example Approach

This section will showcase one possible approach to quantifying the impacts of ecodriving on fuel consumption and air pollutant emissions for Australian conditions. This approach has also been applied to examine the impacts of another type of traffic measure, a lower speed limit (Smit and McBroom, 2009g). We will use overseas driving cycles reflecting baseline and ecodriving conditions (input for simulation, section 4.1) and apply Australian emission algorithms (simulation tool, section 4.2) to do this (section 4.3).

4.1 Quantification of Driving Behaviour (Driving Cycles)

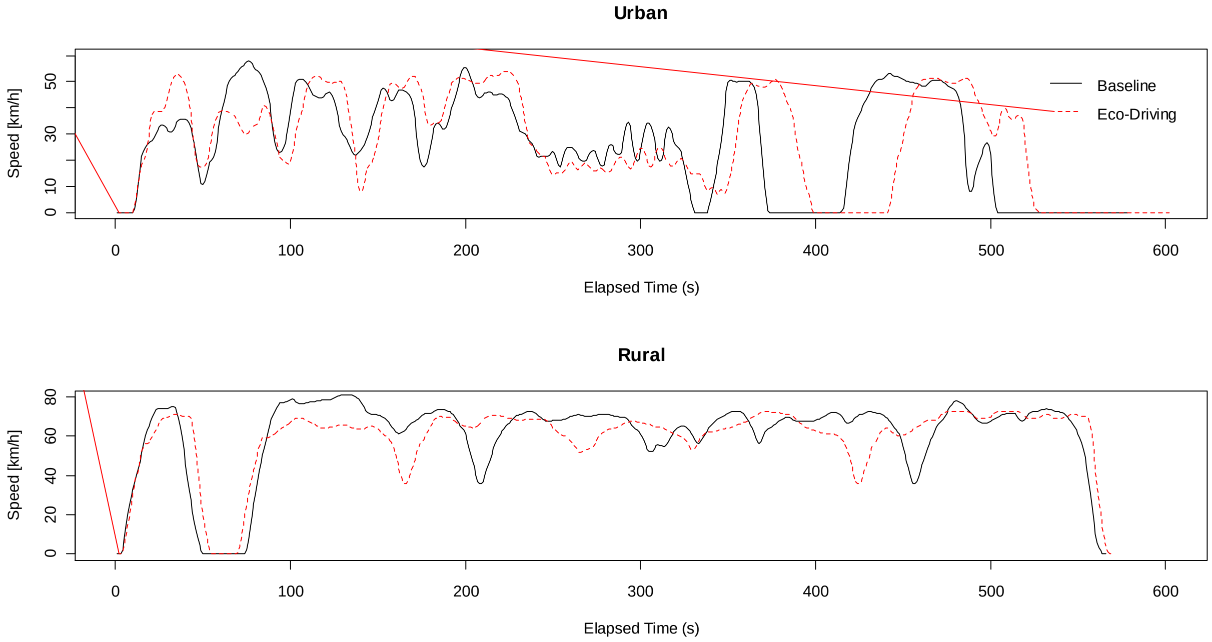
We have sourced four driving cycles from an overseas study (TNO, 2006) that represent the baseline and the ecodriving situation separately for urban and rural driving conditions. These driving cycles were developed from on-road driving behaviour measurements in the Netherlands. Driving parameters like vehicle speed, throttle position and engine speed were recorded while 24 drivers drove on a number of predetermined routes after rush hour through urban and rural areas using one diesel and one petrol car. Each driver drove the route three times, once to get used to the vehicle and the route, then with ‘normal’ driving behaviour (no instructions) and then finally after ecodriving instructions. The drivers varied in age between 25 and 67 years and had at least five years of driving experience. They were recruited through advertising in a local newspaper.

Before-instruction (baseline) and after-instruction (ecodriving) driving cycles were then developed from the collected speed-time data using an optimisation procedure. This procedure computed several statistics (e.g. average speed, mean engine RPM, average acceleration, positive kinetic energy - PKE, relative positive acceleration - RPA, etc.) for both the trip as well as many trip sections. The trip sections with the best fit (using $\chi 2$) to the full database were then selected (‘short-listed’). Although this seems somewhat arbitrary, the final driving cycles were then selected from this pool after consideration of the ‘most typical’ driver for each situation. The ecodriving advice that is reflected in the after-instruction cycles is as follows:

- shift up to a higher gear as soon as possible, with a maximum engine speed of 2500 rpm (for diesel a maximum of 2000 rpm);
- keep the speed as steady as possible;
- drive at low engine speeds in the highest gear possible;
- look ahead as much as possible and anticipate other traffic;
- if you have to decelerate or stop, release the throttle early and coast the vehicle with a gear engaged;
- stop the engine, even at shorter stops. Start again without pressing the throttle; and
- use, if possible, in-car instruments like a rev counter, cruise control and trip-fuel meter.

The driving cycles (2 for urban and 2 for rural conditions) are shown in Figure 2.

Figure 2: Baseline (Solid Line) and Ecodriving (Dotted Line) Driving Cycles for Urban and Rural Traffic Situations



4.2 Quantification of Emission Impacts (Australian Emission Prediction Tool)

In recent years a large body of test data has become available in Australia, amounting to about 800 hours of second-by-second emissions and driving behaviour data for all relevant vehicle classes (trucks, cars, LCVs, SUVs), measured over real-world driving cycles that were developed from Australian on-road driving data (for a summary of these studies refer to Smit and McBroom, 2009c).

The large amount of available test data inspired the development of a new hybrid emissions model with a number of innovative features (Smit and McBroom, 2009c). The model uses variables that reflect vehicle and driving aspects known to influence vehicle emissions (e.g. speed fluctuation, change in power, power oscillation) and employs a statistical approach to find the best empirical relationships. This instantaneous (or "second-by-second") emission model is designed to be sensitive to changes in driving behaviour, which makes it appropriate to use in the assessment of ecodriving impacts. Speed-time data for each basic vehicle class (e.g. passenger car, SUV, rigid truck, etc.) is required as input to make emissions predictions.

The model has passed the proof-of-concept phase but has not yet been fully developed, which means it has not yet incorporated the large body of Australian data mentioned previously. Preliminary results for a limited number of vehicles have shown that the new approach delivers good results in terms of model accuracy, reliability and robustness (Smit and McBroom, 2009c; 2009d; 2009e; 2009f; 2009g).

The model complies with criteria 1, 2, and 5 in section 3.2.2. Given the large body of recent Australian test data, emissions algorithms can be developed for many more vehicles, after which the tool would also comply with criteria 3 and 4. A seperate study would be required to first determine plausible fleet compositions for future years and then assess the impacts on the emission predictions to realise compliance with criterion 6.

4.3 Results

The driving cycles were used as input to the emission algorithms for six Australian vehicles to:

1. estimate second-by-second emission levels in grams per second, and subsequently
2. sum the second-by-second cycle emissions and divide by total distance to estimate mean emission rates in grams per km.

The vehicles represent a specific model, make and model year for six main vehicle types, namely:

- a small petrol passenger car (PC-S),
- a medium petrol passenger car (PC-M),
- a large petrol passenger car (PC-L),
- a diesel sport utility vehicle (SUV),
- a diesel light-commercial vehicle (LCV), and
- a diesel medium commercial vehicle (MCV).

Obviously there are other vehicle types such as articulated diesel trucks and petrol SUVs, and within the vehicle types there are many more combinations of model, make and model year, each with different emissions profiles, but the results presented here are purely for illustrative purposes. The results are presented in Table 1 for fuel consumption and Table 2 for NO_x emissions. Care needs to be taken in interpreting these figures since they provide an indication of the types of results that can be obtained with this form of analysis rather than reliable estimates under Australian conditions.

Table 1: Impact of Ecodriving on Fuel Consumption

Fuel Consumption			**Urban**			**Rural**		
Vehicle	Type	Fuel	Baseline [g/km]	Eco-Driving [g/km]	Difference	Baseline [g/km]	Eco-Driving [g/km]	Difference
Hyundai Accent (2002)	PC-S	Petrol	68	65	-4.3%	56	50	-9.6%
Kia Carnival (2002)	PC-M	Petrol	107	103	-4.1%	87	79	-9.8%
Ford Falcon (1988)	PC-L	Petrol	121	116	-3.8%	108	100	-7.0%
Toyota Prado (2001)	SUV	Diesel	104	103	-1.0%	84	81	-2.7%
Ford Courier (2004)	LCV	Diesel	88	89	+0.3%	77	77	-0.5%
Isuzu NPR (1991)	MCV	Diesel	137	137	-0.1%	151	149	-1.6%

Table 2: Impact of Ecodriving on NO_x Emissions

NOx			**Urban**			**Rural**		
Vehicle	Type	Fuel	Baseline [g/km]	Eco-Driving [g/km]	Difference	Baseline [g/km]	Eco-Driving [g/km]	Difference
Hyundai Accent (2002)	PC-S	Petrol	0.68	0.63	-7.7%	0.93	0.80	-14.0%
Kia Carnival (2002)	PC-M	Petrol	1.33	1.31	-1.2%	2.01	1.88	-6.7%
Ford Falcon (1988)	PC-L	Petrol	1.78	1.71	-3.9%	2.78	2.54	-8.5%
Toyota Prado (2001)	SUV	Diesel	1.72	1.64	-4.7%	1.59	1.43	-9.9%
Ford Courier (2004)	LCV	Diesel	1.17	1.13	-3.1%	1.31	1.22	-6.9%
Isuzu NPR (1991)	MCV	Diesel	3.65	3.67	+0.6%	2.89	2.88	-0.3%

It can be seen that ecodriving is predicted to have a fuel benefit varying from no effect up to about 10% depending on the vehicle (type). Similarly, NO_x emissions are predicted to vary from a reduction up to 14% to a small increase of 0.6%. These differences in emission behaviour are expected and are due to specific vehicle differences in aspects such as engine management systems (EMS) and emission control technology. They also align with the results found in measurement programs (e.g. TNO, 2006).

Nevertheless, the results have to be handled with care and caution should be exercised in using them. For instance, apart from reflecting the results for only six vehicles, using driving cycles that are developed for passenger cars for other vehicle categories such as light and medium commercial vehicles (in the absence of better data) is risky as these vehicles exhibit different driving profiles and vehicle loading characteristics. This is exactly where low and sometimes adverse impacts (e.g. marginal fuel penalty) are predicted. Clearly, more suitable driving cycles need to be developed for these vehicle categories.

Table 3 presents the results for CO_2, which were computed from Table 1 using conversion factors obtained from DCC (2008). This time the difference is expressed as g/km rather than as a percentage to highlight that heavier vehicles naturally have higher fuel consumption and thus CO_2 emission rates. As a consequence, ecodriving will generally have a higher impact on CO_2 emissions from heavier vehicles in absolute terms (g/km) when compared to lighter vehicles with the same relative difference (%). This is a relevant point to consider as the Australian fleet has a large proportion of heavy passenger vehicles when compared to overseas fleets.

Table 3: Impact of Ecodriving on CO_2 Emissions

CO2			Urban			Rural		
Vehicle	Type	Fuel	Baseline [g/km]	Eco-Driving [g/km]	Difference [g/km]	Baseline [g/km]	Eco-Driving [g/km]	Difference [g/km]
Hyundai Accent (2002)	PC-S	Petrol	212	203	-9.2	174	157	-16.7
Kia Carnival (2002)	PC-M	Petrol	335	321	-13.9	272	246	-26.6
Ford Falcon (1988)	PC-L	Petrol	377	363	-14.2	337	314	-23.6
Toyota Prado (2001)	SUV	Diesel	336	332	-3.3	269	262	-7.2
Ford Courier (2004)	LCV	Diesel	285	286	0.9	249	248	-1.2
Isuzu NPR (1991)	MCV	Diesel	441	441	-0.3	488	480	-7.9

Finally, a few words on other factors that influence the impact of an ecodriving programme on fuel consumption and emissions. We begin with the assumption that the results in Table 1 are indicative of the range of achievable effects, i.e. 0-10% reduction in fuel consumption. We then assume that in practice 35% of drivers apply the new driving style (EC, 2006) and that this effect is reduced over time, e.g. to 90% after a year (EC, 2006). This would mean that after the first year the actual fuel benefits are in the order of 0% to 3%. As a final step, these results could be combined with information on programme costs to assess the overall (anticipated) cost-effectiveness of an ecodriving measure.

5. Discussion and Conclusions

Quantification of the impacts of ecodriving on fleet fuel consumption and emissions, now and in the future, is essential to design an effective program in terms of both costs and impacts for the Australian situation, reflecting positive as well as possible negative effects. We have discussed various ways this can be done and showcased one particular approach using measured driving behaviour data and emission modelling in Section 4.

Depending on the situation, the optimal (costs, accuracy) and feasible assessment approach could be measurement (e.g. small commercial fleet) or simulation (e.g. large complex fleet). Section 4 illustrated how the fuel consumption and emission benefits of ecodriving can be quantified for the Australian situation (large complex fleet). It also showed that the impact of ecodriving on emissions is a complex function of a number of interacting variables, namely

- the baseline emission levels for a particular driver/vehicle combination (weight, engine size, normal driving behaviour, EMS, etc.);
- the change in emissions due to ecodriving for the particular driver/vehicle combination (new driving behaviour, durability of change, etc.); and
- the proportion of all of these driver/vehicle combinations in the on-road fleet.

One obvious and necessary point of improvement described in section 4 is the use of Australian driving behaviour data instead of overseas driving cycles for all relevant vehicle classes (cars, light-commercial vehicles, SUVs, different types of trucks, buses) that both reflect our own baseline behaviour and the particular driving style tips that will be part of our anticipated ecodriving programme. In the absence of Australian data we have used overseas driving cycles for passenger cars in this paper for illustrative purposes only.

The combination of measured Australian driving behaviour data and simulation using an Australian emissions prediction tool would have the potential to be a cost-effective approach which could deliver results in the shortest possible time-frame. We also note that all collected driving behaviour data can be used as input in the emissions predictions. That contrasts with laboratory measurements that can only use a representative portion of the collected driving behaviour data (i.e. driving cycle) in order to keep costs at an acceptable level. It is important to note however that the latter laboratory approach would be expected to deliver greater accuracy in emissions measurement so long as the driving cycles used in the laboratory testing reflected actual on-road driving behaviour.

There are, however, also a number of issues with this approach. One important consideration is that changes in gear-shift behaviour cannot be modelled with the prediction tool, simply because there is no suitable empirical emissions test data in Australia. This may not be a big issue for light-duty vehicles, which have mainly automatic transmissions, but it certainly is a consideration for heavy-duty vehicles (HDVs). One solution may be to use overseas models for HDVs that have the capability to simulate changes in both speed-time profiles and gear shift behaviour. But the applicability of these models to the Australian fleet needs to be carefully examined, particularly given the rapid move of European truck fleets to automatic transmissions and the continuing preference of Australian fleet operators for American manual gear boxes, though this is changing.

It would be wise for the model to be further validated with emissions measurements on a limited number of representative vehicles. It may be most cost-effective to conduct on-board emissions testing on a sample of vehicles when Australian driving behaviour data are collected in the field. Alternatively, emissions may be measured in a laboratory, which has the advantage of generating high quality test data, but would require the development of representative driving cycles for each vehicle class. These options would require further examination, including costing and time schedules, to determine the best way forward.

In any case, it is important to compare the modelling results with other Australian measurement programs that generate independent data on fuel consumption benefits. It is then essential to examine whether the results are similar, and where this is not the case, to explore the reasons for any differences. We also emphasize the importance of including the effects of ecodriving measures on air pollutant emissions in order to prevent adverse policy outcomes. It would also be important to ensure that levels of uncertainty in key parameters and emissions were quantified and the analysis approach outlined above strengthened so that the modelling framework provided insight into the level of uncertainty in the results.

The approach outlined in this paper is a combined examination of the results of both vehicle emissions simulation and independent studies across Australia on ecodriving impacts on fuel consumption and air pollutant emissions. It has the potential to provide a sound and reliable foundation of evidence to enable the cost-effectiveness of ecodriving to be quantified and therefore would provide valuable insight to assist in assessing the role ecodriving programmes should play as a transport policy measure.

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