Ministry of Transport
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Understanding Transport Costs and Charges

Phase two - Costs and benefits of selected road vehicle technologies

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1 Introduction

New Zealand is a small country with a relatively small population which is dispersed over a wide geographic area, and with a major concentration of people and services in several urban centres. Therefore, road travel is an essential form of transport for most New Zealanders. The key challenges are how to improve road safety and the efficiency of transport to make driving more economic, and socially and environmentally friendly.

Road vehicle technologies play a significant role in improving the safety and the efficiency of operation of our light vehicle fleet.

Over the last decade the safety of our light vehicle fleet has improved by around four percent each year as safer vehicles have replaced less safe ones.

Furthermore, over the five years to 2009, technology has also improved the fuel economy and efficiency of new light vehicles (with engine sizes over 1600cc) entering the New Zealand fleet, by around one percent per year[1].

However, the fitment of various vehicle technologies does come with a cost. For certain technologies, there will be net safety, environmental and economic benefits. For other technologies, the economic costs may be higher than the benefits they deliver.

The purpose of this research is to investigate the potential costs and benefits of selected road vehicle technologies. Such information will help to inform the benefits of encouraging vehicle purchasers to buy vehicles with these features.

The findings of this research can also help to inform policy development related to achieving the following short to medium-term impacts sought by the Government Policy Statement on Land Transport Funding 2009/10 – 2018/19:

- reductions in deaths and serious injuries as a result of road crashes
- reductions in adverse environmental effects from land transport
- contributions to positive health outcomes

This is supplementary research being undertaken as part of the Understanding Transport Costs and Charges (UTCC) project.

Section 2 discusses road safety-related road vehicle technologies and includes a summary of the costs and benefits of the three selected road vehicle technologies (electronic stability control, side curtain airbags and intelligent speed assist) for improving road safety.

Section 3 provides an overview of fuel consumption-related road vehicle technologies and the potential benefits from switching to more fuel efficient vehicles.

Section 4 summaries the results.

[1] Source: Ministry of Transport, unpublished statistics.

2 Road safety and vehicle technology

2.1 Role of technology in vehicle safety

Vehicle technology improvements have reduced the occurrence and severity of road crashes over the last few decades, despite the increasing demand for driving. For example, anti-lock braking systems, airbags and seat belts are examples of features that have saved many lives since their invention.

Some of the more recent emerging in-vehicle technologies (IVTs) take a step further by allowing a computer to take over control of a vehicle in an emergency to avoid a crash.

There are three major types of safety-related IVTs.

- ***Advisory or warning*** – these refer to features that are designed to identify crash or injury risk and provide advance warning or advice to allow the driver to take precautionary actions (e.g. following distance warning and blind spot information systems to inform drivers of potential hazards).
- ***Pre-crash assistance or crash avoidance*** – these refer to features that actively assist the driver to avoid a crash (e.g. traction control systems to detect and prevent potential wheel spin due to excessive driving torque, and brake assist systems to ensure the brakes are fully operated during an emergency stop).
- ***Crash impact reduction* –** these refer to features that help to reduce the severity of injury to vehicle occupants when a crash cannot be avoided (e.g. airbags and seat belts).

2.2 Road safety problems

There are three broad categories of crash contributing factors: namely human, vehicle or road factors. However, many road crashes involve a combination of various factors.

Tables 1 and 2 tabulate the top ten crash contributing factors and the movement classification of injury crashes. Vehicle technology has the potential to reduce the number and severity of many of these crash types. However, there appears to be particular potential for reducing the number of crashes associated with losing control and travelling speeds through the use of vehicle technologies.

Table 1: Top ten probable crash contributing factors (2005 – 2009)

Probable contributing factor	% fatal crashes	% injury crashes
Lost control	34.3	22.6
Too fast for conditions	31.7	15.9
Alcohol or drugs	30.3	13.7
Inattention or attention diverted	15.8	20.5
Failed to keep left	13.4	3.4
Driver tired or fell asleep	12.5	5.7
Road factors	11.1	12.0
Inexperienced	10.6	8.4
Failed to give way or stop	10.3	23.5
Did not see other party	8.9	19.9

Note: Figures are not additive as many crashes have multiple contributing factors.

Table 2: Top ten movement classifications of injury crashes (2005 – 2009)

Movement	% fatal crashes	% injury crashes
Lost control while cornering	28.8	23.1
Head on	25.1	6.3
Lost control on straight	11.4	11.2
Pedestrian crossing road	6.3	6.5
Overtaking or lane change	5.6	3.6
Pedestrian other	4.0	1.2
Crossing no turns	3.2	6.9
Crossing vehicle turning	3.1	7.0
Miscellaneous	2.7	0.8
Right turn against	2.4	7.5

2.3 Costs and benefits of selected vehicle safety technologies

There are a number of IVTs that are now available in the car market (for example, electronic stability control, adaptive cruise control and seat belt reminders). Many of the latest vehicle technologies are designed to lessen or mitigate factors that contribute to road crashes.

Table 3 provides a list of some IVTs that have been discussed in COWI 2006, Paine et al., 2008 and eIMPACT, 2008.

While some of the new IVTs appear to have great potential for reducing road trauma, many still have to be properly tested and developed to ensure their reliability and safety operation. Also some IVTs rely heavily on the availability of suitable infrastructure (e.g. a speed limits database for speed assistance systems).

The key question is: which IVT can deliver enough safety benefits to outweigh the costs of their installation?

Table 3: A summary of selected IVTs as discussed in COWI (2006); Paine et al. (2008) and eIMPACT (2008)

Technology	Potential effects on road safety	Potential aggregate road safety benefits (L – low M – medium H - high)	Potential unit cost (L – low M – medium H - high)
Intelligent speed adaptation/ assistance	reduction in rear end, head on and intersection speed-related crashes	M - H	M – H
Electronic stability control	reduction in loss of control crashes	M - H	M
Brake assist system	reduction in the risk of multi-vehicle crashes and run-off-road crashes	M	L
Anti-lock braking system with electronic brake distribution	reduction in the risk of multi-vehicle crashes and run-off-road crashes	M	M
Lane departure warning/lane keeping support	reduction in head-on and side crashes	M	M - H
Side airbags with head protection	reduction in injury severity in side-impact crashes (and possibly in roll-over crashes)	L - M	M
Seat belt interlock/reminder	reduction in injury severity in crashes where occupants were not wearing seat belts	L	L
Blind spot mirrors	reduction in crash risk for vulnerable road users by vehicle turning right	L	L
Intelligent daytime running lights	reduction in multi-party daytime crashes	L	L
Tyre pressure monitoring system	reduction in tyre pressure-related crashes	L	L – H
Reversing collision avoidance	reduction in risk of crashes during reversing	L	L – H
Adaptive cruise control	reduction in rear-end crashes	L	M - H
Under-run protection	reduction in injury risk to vulnerable road users	L	H

2.3.1 Selection criteria

To select the vehicle technologies to be investigated further, the following selection criteria have been used:

- **Proven technology**: international evidence is available to help gauge the potential for reducing overall road trauma
- **Technological readiness**: technologies are available for use by the general vehicle fleet
- **Timeliness**: technologies can be implemented within the next three years

2.3.2 Selected road vehicle technologies

For IVTs that is not yet technologically ready (i.e. either in the initial research phase or in the prototype development stage that has not been widely adopted), there will be considerable uncertainties relating to the costs and benefits of installation.

Many of the IVTs tabulated in Table 3 have either relatively low aggregate safety benefits (e.g. blind spot mirrors); high compliance costs (e.g. under-run protection) or high levels of voluntary uptake or compliance (e.g. seat belt reminder systems).

Loss of control, head-on and speed-related crashes are by far the leading contributing factors to fatal and serious crashes. Therefore, IVTs that have a potential to reduce the risk associated with these crashes are likely to result in significant aggregate safety benefits to society.

We have therefore selected three IVTs for this paper. They are:

- **Electronic stability control (ESC)** – a crash avoidance system that helps to minimise the risk of crashes associated with loss of control
- **Side-curtain airbags (SCA)** – a passive safety feature that helps to minimise the possibility and severity of injuries if a crash cannot be avoided
- **Intelligent speed adaptation/assistance (ISA)** – a speed alert system that has the potential to minimise speed-related crashes.

These technologies have also been discussed in the *Safer Journeys* road safety strategy[2] that was released in early 2010.

The following sub-sections (2.3.3 to 2.3.5) have been extracted from the corresponding costs-benefit analyses carried out by the Ministry's Financial and Economic Analysis Team.

[2] www.saferjourneys.govt.nz.

2.3.3 Electronic Stability Control

2.3.3a What is Electronic Stability Control and how does it work?

Electronic Stability Control (or ESC)[3] is a crash avoidance system that uses sensors to monitor the vehicle's direction and the speed of each individual wheel. ESC attempts to prevent a collision from occurring, or to reduce its intensity if it does occur, by helping a driver remain in control of the vehicle during a sudden manoeuvre.

When ESC senses that the steering wheel angle does not match with the actual direction in which the vehicle is moving, it will automatically actuate the brakes at one or more wheels and / or reduce engine power. ESC is automatically set to "ON" whenever a driver starts an ESC-equipped vehicle unless this function has been disabled by the driver.

2.3.3b How effective is ESC?

While ESC can prevent many types of crash, it is especially effective in preventing vehicle crashes that result from a loss of control. A brief literature review shows that ESC's effectiveness is relatively high (Table 4), especially for loss-of-control-related single vehicle crashes.

While the majority of brand new light vehicles would have ESC as standard or an optional extra, for vehicle models in which ESC has not been built in, it is impractical to retrofit it. Due to this reason, almost all of the used imports entering New Zealand do not have ESC.

In 2008 approximately 20 percent of the light vehicle fleet was equipped with ESC. Under the business-as-usual scenario, the ESC fitment rate among the light vehicle fleet would increase to approximately 60 percent by 2030, as newer vehicles start replacing older ones. Given the effectiveness of the ESC technology, there may be considerable safety gains from accelerating such an uptake.

Table 4: Average effectiveness of ESC (reduction in injury crash risk)

Vehicle type	Movement type	Single vehicle crashes	Multiple vehicle crashes
Cars	Loss of control	38%	15%
	Rollover	31%	-
Vans & others	Loss of control	51%	24%
	Rollover	57%	-

2.3.3c What is the safety problem?

Over the three years to 2008, light vehicle crashes involving loss of control resulted in a total of some 600 deaths, 3,300 reported serious injuries and 13,900 reported minor injuries. The average annual social cost of these injuries is estimated at $1.6 billion, in June 2009 dollars. If the entire light vehicle fleet was fitted with ESC, even a small percentage reduction in risk could mean a large reduction in road trauma.

However, as noted in VicRoads (2009) consumers tend to "bundle complex safety features together in their minds" and therefore tend to underestimate the benefits of individual technologies.

Thus there could be significant benefits from accelerating the rate of ESC fitment among vehicles entering the fleet.

2.3.3d ESC uptake scenario

This analysis looks at the costs and benefits of having ESC available on all new light vehicles entering the fleet from 2014 (and used vehicles from 2015).

[3] Electronic Stability Control is also known as Dynamic Stability Control, Vehicle Stability Control, Active Stability Control and Vehicle Dynamic Control, etc.

2.3.3e Costs of ESC

A feature of adopting vehicle safety technologies is that, while there is a high upfront cost (a likely increase in vehicle purchasing costs in this case), vehicle owners can enjoy the benefits of the safety feature for the remaining lifespan of a vehicle.

Listed below are the major costs from the adoption of ESC.

- The additional cost of purchasing a vehicle is estimated to be between $500 and $900 per vehicle that is currently not fitted with ESC. This cost is likely to reduce in real terms over time due to technology advancement and economies of scale.
- The additional cost of increased fuel consumption is estimated to be negligible (about one litre for every 10,000 to 40,000 kilometres).
- The additional cost of entry inspection is estimated to be $5 per vehicle imported.
- The additional cost of amending the motor vehicle registration database to record whether a vehicle is fitted with such device is estimated at $1 million.

2.3.3f Benefits of adoption of ESC

The main benefit from the adoption of ESC is a potential reduction in the number of loss-of-control-related road crashes (and the associated injuries). The annual safety benefits would increase as the overall additional uptake of ESC fitment, relative to the business-as-usual scenario, increases over time and peaks in around 2030.

It is estimated that, if ESC becomes available for both new and used imports, it could reduce annual road trauma by nine fatalities and 45 serious injuries in the year 2020, with a cumulative total reduction, from 2014 to 2020, of 32 fatalities and 170 serious injuries (Table 5). These estimates include the effects of early scrappage due to road crashes and other reasons, the general safety gains from fleet replacement over time, the level of voluntary uptake under the status quo, and any cumulative effects from the increased ESC uptake.

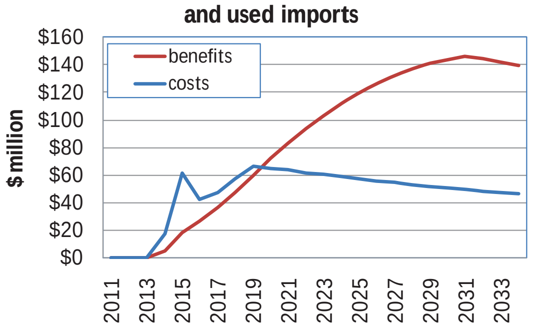
Table 5: Estimated reduction in road trauma

	Fatalities	Serious injuries
Year 2020	9	45
Total from 2014 to 2020	32	170

2.3.3g Estimated benefit-to-cost ratio

Based on the benefits and costs up to the year 2034 (Figure 1) and an annual discount rate of eight percent, the estimated benefit-to-cost ratio (BCR) of ESC uptake is 1.5.

Figure 1: Estimated total costs and benefits of making ESC available for new and used imports



A sensitivity analysis shows that the BCR could vary between 0.9 and 2.9, depending on the assumptions made on the effects and costs of ESC.

A change in the assumption regarding import volumes would affect both the safety benefits and the total cost of having a higher level of ESC fitment, and would thus have little impact on the BCR.

2.3.3h Conclusion

Our analysis suggests making ESC available for all new and used light vehicles entering the fleet is likely to be cost beneficial.

2.3.4 Side curtain airbags

2.3.4a How do side curtain airbags work?

An airbag is a passive safety feature to help to reduce the probability and severity of an injury resulting from a crash. Side airbags can protect the head, the chest, or both, depending on their design. Torso side airbags protect passengers in a side-impact crash by lessening and distributing impact forces to the passenger's chest and abdomen from the intruding vehicle side. Head side airbags protect passengers from striking interior vehicle structures or being struck by external objects intruding into the vehicle and can therefore prevent very serious head injuries. Side curtain airbags (SCA) with head protection is a system that protects the head and the chest of the passengers.

2.3.4b How effective are SCA?

A brief literature review found that, on average, SCA can reduce the number of deaths and serious injuries in side-impact crashes by between 37 and 45 percent for cars, and by 52 percent for sports utility vehicles. Apart from side-impact crashes, SCA might also be able to lessen head injuries to occupants in rollover crashes. However, research has shown that the use of SCA does not reduce the risk of minor injury, possibly because the number of minor injuries saved by SCA could have been offset by those induced by airbag deployment.

2.3.4c What is the safety problem?

In 2008, about 13 percent of the light vehicle fleet was equipped with SCA. Following similar trends observed overseas, the uptake of SCA fitment among new vehicles entering the fleet has increased significantly – from less than 10 percent in 2000 to around 70 percent by June 2008. It is estimated that, under the business-as-usual scenario, the SCA fitment rate among the total light vehicle fleet will increase over time, to around 29 percent by 2030, as newer vehicles start replacing older ones.

SCA are effective in reducing the severity of injury from side-impact crashes and the associated social cost to society. Over the five years to 2008, side-impact crashes involving light vehicles resulted in 130 driver deaths, 720 reported serious injuries, and 5,050 minor injuries to drivers (or 26 deaths, 144 serious injuries and 1,010 minor injuries per annum). The average annual social cost of these injuries is estimated at $181 million, in June 2009 dollars. The statistics above do not include injuries to the front-seat passengers, as most side-impact crashes result in injuries to the driver. When these passenger injuries are also included, the social cost increases to $241 million. If the entire light vehicle fleet is fitted with SCA, even a small percentage reduction in risk could mean a large reduction in road trauma.

As discussed earlier, consumers tend to bundle complex safety features together in their minds and therefore tend to underestimate the benefits of individual technologies. Thus there may be significant benefits from accelerating the rate of SCA fitment among vehicles entering the fleet.

2.3.4d SCA uptake scenario

This analysis looks at the costs and benefits of making SCA available on all new light vehicles entering the fleet from 2014 (and used vehicles from 2015).

2.3.4e Estimated costs of SCA uptake

There are two additional costs from making SCA available in addition to ESC.

- The additional vehicle purchasing cost of between $1,000 and $2,250 per vehicle that is currently not fitted with SCA. This cost is likely to reduce in real terms over time due to technology advancement and economies of scale.
- The cost of a small increase in fuel consumption will be negligible (about one

litre for every 20,000 to 40,000 kilometres).

2.3.4f Estimated safety benefits

The main benefit of making SCA available on both new and used imports is a potential reduction in deaths and injuries resulting from side-impact crashes. As is the case for adopting ESC, the annual safety benefits from SCA would increase with the overall additional uptake.

It is estimated that making SCA available for both new and used imports could reduce annual road trauma by two fatalities and between 11 and 14 serious injuries in the year 2020, with a cumulative total reduction, from 2014 to 2020, of between seven and nine fatalities and between 40 and 50 serious injuries (Table 6).

As is the case for the ESC analysis, these estimates include the effects of early scrappage due to road crashes and other reasons, the general safety gains from fleet replacement over time, the level of voluntary uptake under the status quo, and any cumulative effects from the increased SCA uptake.

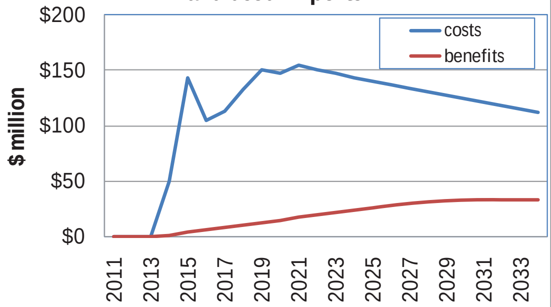
Table 6: Estimated reduction in road trauma

	Fatalities	Serious injuries
Excluding rollover crashes		
Year 2020	2	11
Total from 2014 to 2020	7	40
Including rollover crashes		
Year 2020	2	14
Total from 2014 to 2020	9	50

2.3.4g Estimated benefit-to-cost ratio

Based on the benefits and costs up to the year 2034 (Figure 2) and an annual discount rate of eight percent, the estimated benefit-to-cost ratio (BCR) for mandating SCA is 0.13.

Figure 2: Estimated total costs and benefits of making SCA available for new and used imports



A sensitivity analysis shows that the BCR could vary between 0.18 and 1.1 for new light vehicles and between 0.11 and 0.71 for used light vehicles[4], depending on the assumptions on the effects and costs of SCA.

A change in the assumption regarding import volumes would affect both the safety benefits and the total cost of having a higher level of SCA fitment, and thus have little impact on the BCR.

2.3.4h Conclusion

Our analysis suggests that making SCA available for used light vehicles entering the fleet is unlikely to be cost beneficial. But it could be cost beneficial for new light vehicles.

[4] The higher end estimates include an estimate of the potential safety benefits from rollover crashes.

2.3.5 Intelligent speed adaptation/assistance

2.3.5a What is intelligent speed assistance (ISA) and how does it work?

Intelligent speed assistance[5] is a system that monitors a vehicle's speed and the speed limit (legal, advisory, temporary and variable) on a section of road, and implements an action within the vehicle when a violation of the speed limit is detected.

Broadly speaking there are two major forms of such a system: an advisory (passive) form or an intervening (active) form. An advisory ISA system alerts the driver by providing audio or visual signals (e.g. via alarms or lights) when the travelling speed exceeds a limit set by the driver or the legal speed limit. Under an advisory form of ISA, the driver remains responsible for maintaining a safe and proper speed.

Under an intervening ISA system, once it is triggered the driving systems of the vehicle are controlled automatically to reduce or limit the travelling speed. This may be voluntary, where the driver can override the system or choose when to have the system enabled, or mandatory (non-overriding), in which case no override is possible.

To facilitate its proper operation, an ISA system must contain information about the legal or advisory speed limit on the road the vehicle is travelling on. It is likely that an effective ISA system will require the use of Global Positioning System (GPS)-based technology with dead reckoning, as the primary tool. This could be supplemented by roadside radio beacons at locations with limited satellite coverage and sites where a temporary speed limit is in place (e.g. road works).

2.3.5b How effective is ISA?

An ISA system can reduce the number of speed-related crashes by actively or passively helping drivers to stay within the speed limit. Some ISA systems also help the driver to maintain a safe distance from the vehicle in front, which reduces the risk of rear-end crashes.

Based on the results of trials overseas, and depending on the degree of uptake, ISA has the potential to reduce mean speeds by an average of one to two kilometres per hour. This reduction in mean speed has a tangible road safety benefit (to be discussed in section 2.3.5e). As expected, the scope for speed reductions tends to be greater at higher speed limit locations. In addition, a mandatory active system tends to be more effective in reducing vehicle travel speeds than either the voluntary or advisory systems.

2.3.5c What is the safety problem?

Since the speeds of the vehicles involved in a crash will affect the severity of the crash, ISA systems have the capacity to reduce the severities of any crash, not just those where travelling too fast is a contributing factor. Thus, if the majority of light vehicles were fitted with an ISA system, even a moderate reduction in the risk of crash involvement would mean a large reduction in road trauma and result in economy-wide benefits.

At present, there are only a limited number of light vehicle makes and models that are ISA compatible. This technology is relatively new and its implementation depends on the availability of suitable data and the physical infrastructure to support an ISA system. However, over time this technology will become widely available and the cost of such systems will also decrease.

[5] Intelligent speed assistance is also known as intelligent speed adaptation.

2.3.5d Costs of ISA

Carsten and Tate (2005) noted that the majority (roughly 97 percent) of the costs of implementing an ISA regime are associated with the vehicle. An ISA system needs the following in-vehicle components:

- a display unit that shows the speed limit on which the vehicle is travelling on
- an appropriate sensor devices and computers for detecting and monitoring vehicle speed
- a GPS system, roadside radio beacons, digital maps and related hardware and software
- relevant feedback hardware and software – e.g. for warning tones, pressure back on the accelerator, the application of brakes, linking of pedal sensors with the engine control unit and the ISA control unit
- other features that may be relevant (e.g. a tamper-proof design and override ability)

On top of the above, there would be a one-off development cost for setting up a speed limits database, as well as its on-going maintenance and update costs. It is estimated that the cost of getting state highway speed limit information on to a GPS map system would be about $50,000. The cost of getting similar information for local roads (around 88 percent of the road network) is likely to be proportionately higher.

Further, there would be a small cost associated with the identification and allocation of a suitable radio spectrum for use as part of an ISA system.

New Zealand has a relatively small vehicle market and is therefore likely to be a price-taker. Considering the experience overseas, the total per-vehicle cost associated with an ISA system for New Zealand could be between $300 and $500 for an advisory system, and between $1,000 and $1,500 for an intervening system.

2.3.5e Safety benefits of ISA

Reducing the speed available to a vehicle has a twofold effect from a safety perspective: it reduces the risk of becoming involved in an injury crash and it reduces the severity of a crash when it does occur. The expected change in crashes due to reduced speeds is normally quantified using the speed power law (e.g. Nilsson, 1982 and Elvik, 2009). This law relates the change in crashes to the ratio of the mean speed before and after an intervention. However, a critical mass of vehicles with ISA would be required before there could be a meaningful impact on overall travel speeds across a network.

The safety effects of an ISA system will depend on a range of factors, including:

- the implementation regime (advisory, voluntary or mandatory)
- a speed limit data update regime (fixed, variable or dynamic[6])
- speed zones
- the level of uptake or penetration of ISA into the fleet

A preliminary analysis shows that the estimated safety benefits from a fixed advisory regime applying to all vehicles entering the New Zealand fleet from 2015 onwards would be around one death and 75 injuries per year by 2020, rising to nine deaths and 410 injuries saved per year by 2030. For a fixed mandatory regime of the same nature, the safety benefit would be around three deaths and 150 injuries per year by 2020, rising to 17 deaths and 820 injuries saved per year by 2030.

[6] For a fixed version, only posted speed limit details are loaded to vehicles. Under a variable version, vehicles are informed of changes at certain locations. Under a dynamic version, information on speed limits is kept current at all times.

In per-vehicle terms, if the entire vehicle fleet was fitted with ISA, the average reduction in social cost per year is estimated at approximately $120 for a fixed advisory regime and $240 for a fixed mandatory regime. Over the lifetime of a vehicle of, say, 15 years, the cumulative present value of the potential safety benefits would be around $1,000 and $2,000 per vehicle for fixed advisory and fixed mandatory regimes, respectively.

Since the projected savings are highly dependent on a range of factors, these calculated savings are indicative only.

2.3.5f Costs and benefits

Based on the average safety benefit per vehicle estimates (with 100 percent uptake), and the total per-vehicle cost of between $300 (advisory) and $1,500 (mandatory), the indicative BCR would range from 1.4 to 3.4.

However, to fully understand the costs and benefits of an ISA system, it is necessary to investigate the following:

- any legal issues relating to the accuracy of the speed detection devices
- the development and/or adoption of appropriate ISA quality standards
- the ability of aftermarket GPS devices to function as part of an ISA system
- the logistics and costs of ensuring speed limit map data are accurate and up-to-date, for both the state highway network and local roads
- the technical architecture required to enable an ISA system in a vehicle to interact with the GPS speed limit map system and related systems
- how New Zealand drivers behave when using the technology

The New Zealand Transport Agency (NZTA) is currently commissioning research on all of the above aspects. The research will also investigate the need, format and other details regarding a possible trial or pilot of an ISA system in New Zealand. It is expected that this research will be completed by 2012.

2.3.5g Conclusion

There appears to be safety improvement potential from adopting intelligent speed assistance technology in vehicles, provided that the level of uptake is sufficient to sustain network-wide speed reductions, and that there is no supply constraint. The research by the NZTA should provide important information to better understand the likely costs and benefits of an ISA system for NZ.

3 Emission, fuel consumption and vehicle technology

3.1 Role of vehicle technology

3.1.1 Emissions

Technology plays a major role in reducing harmful emissions as well as the fuel consumption of vehicles. However, fuel consumption is not a good indicator of harmful emissions and, all things being equal, vehicles with emissions control equipment will have lower levels of harmful emissions than those without.

Examples of emissions control equipment include catalytic converters and electronic engine management systems on petrol-powered vehicles, and exhaust gas recirculation systems, selective catalyst reduction, filters, particulate traps and electronic engine management systems on diesel-powered vehicles.

3.1.2 Fuel consumption

Due to technology advancements, newer vehicles are usually more fuel efficient and fuel economic[7] than those built one or two decades ago[8].

There are four major types of vehicle fuel efficiency and economy technologies.

- ***Energy source technologies*** – Diesel-powered vehicles are generally more fuel efficient than petrol-powered vehicles[9].

  Hybrid and electric vehicles have lower transmission losses, and the use of electric motors in city traffic conditions can significantly minimise fuel use (IEA/OECD, 2009).

- ***Engine technologies*** – Technologies such as boundary engine friction reduction, direct injection, turbo-charging, stop-start ignition and variable valve-timing can improve fuel efficiency by reducing engine friction losses and improving thermal or thermodynamic efficiency during the process of converting the fuel source to kinetic energy.

- ***Transmission technologies*** – Transmission losses arise from the transfer of mechanical energy to the wheel axle.

  In general, manual and automatic manual transmissions are more fuel efficient than conventional automatic transmissions (IEA/OECD, 2009). These transmission technologies improve fuel efficiency through minimising losses associated with torque conversion and optimising the gear ratio spacing and transmission ratio to allow the engine to operate at higher efficiency.

- ***Non-engine related technologies and accessories*** – Rolling resistance, cooling systems and lighting all increase fuel consumption[10].

  Improving tyre design and using correct tyre inflation pressures can minimise fuel lost from rolling resistance.

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[7] Fuel efficiency concerns the process that converts potential energy from its source into kinetic energy for powering a vehicle. Fuel economy concerns the amount of fuel required to undertake a certain amount of travel (i.e. litres per 100 kilometres or kilometres per litre of fuel).

[8] For example, King (2007) estimated that over the 20 years from the mid-1980s, average long-term vehicle fuel efficiency improvements of 0.6 percent per year had been achieved in the UK. Despite such improvements, car buyers are also acquiring more powerful, but more fuel-consuming vehicles, thus nullifying some of the efficiency gains.

[9] But diesel-powered vehicles tend to be bigger in size (both the engine and the vehicle) and use more fuel.

[10] It has been estimated that roughly 20 percent of a vehicle’s fuel is used to overcome the rolling resistance of its tyres (OECD/IEA, 2007). Further, depending on climate and traffic conditions, cooling systems can responsible for six to 15 percent of the fuel used by vehicles (IEA/OECD, 2009).

Adopting advanced propulsion systems, using better insulation and solar reflective glass can reduce the fuel consumption for cooling purposes.

Enhanced vehicle designs such as improved aerodynamic efficiency and (weight reduction) material substitution can also improve fuel efficiency.

The fuel efficiency potentials of various technologies vary from one percent to as much as 20 percent, depending on vehicle makes and models, engine size and other characteristics.

However, an improvement in fuel economy can be achieved without adopting better technology *per se* – for example through engine or vehicle downsizing and weight reduction.

3.2 Rationale for government intervention

3.2.1 Emissions

Harmful vehicle emissions are currently regulated by the Vehicle Exhaust Emissions Rule, originally introduced in 2003 and updated significantly in 2007.

This Rule prescribes minimum emission standards (which tighten over time) that all vehicles entering the fleet have to meet. It also establishes a policy that New Zealand would adopt international emissions standards, such as the Euro standards, two years after the parent jurisdiction or on the same day as Australia. Standards for used vehicles would be implemented shortly afterwards.

Given the policy behind this Rule, there is no immediate need for further government intervention regarding harmful vehicle emissions for vehicles entering the New Zealand fleet.

3.2.2 Fuel consumption

As population grows, the demand for travel also increases. The growing light vehicle fleet[11], which is also getting bigger in both its physical and engine sizes, has increased its overall fuel consumption over time (by around 12 percent[12] from 2001 to 2009).

Improving the fuel consumption of the vehicle fleet has the potential to create significant economic benefits. It will not only reduce the costs associated with fuel use, but it will also improve energy security and greenhouse gas (GHG) emissions and the associated health effects.

However, the literature shows that fuel consumption is only one of the factors (often not the key factor) which vehicle buyers consider when making vehicle purchase decisions (e.g. Steiner, 2003; Turrentine and Kurani, 2007; and Covec, 2009). Factors such as price, reliability, performance, safety, number of seats and cargo capacity are often considered more important. For buyers who are looking for a multi-purpose vehicle, vehicle choice would be limited by the requirements of the most demanding use (e.g. towing a boat).

For vehicle buyers who do consider fuel efficiency and fuel economy, Covec (2009) asserts that they do not always do so in any detailed way. Literature (e.g. Sanstad and Howarth, 1994 and McKinsey, 2009) has found that most consumers do not account for cost savings from fuel efficiency beyond two to three years, despite the fact that car buyers may intend to keep the vehicle for longer.

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[11] Over the years from 2001 to 2009, the light passenger vehicle fleet has increased from 2.11 million to 2.57 million, with the associated vehicle kilometres travelled (VKT) increasing from 27.8 million VKT in 2001 to 30.9 million VKT in 2009. At the same time, the average engine size of the vehicle fleet has also increased, from around 2.1 litres in 2001 to nearly 2.3 litres in 2009. Source: MOT (2009)

[12] Unpublished estimate based on MOT (2009)

Since the average economic life of a brand new vehicle is over 15 years[13], this means that new car buyers are grossly under-valuing the total benefits (by some 70 percent)[14] of acquiring more fuel efficient vehicles.

Further, due to information gaps, consumers are not fully informed about the costs and benefits of their decisions. Under utility maximisation theory, a rational consumer will consider various costs and benefits in their purchase decisions. These include:

- vehicle purchase cost
- running costs (such as insurance, fuel, repair and maintenance) over their expected ownership duration
- utility (user benefits) derived from the vehicle, given the characteristics or features of the vehicle
- the expected revenue from the sale of the vehicle in the future (and the possibility of recovering some of the upfront cost of the premium paid for a more fuel efficient vehicle)

Unfortunately, apart from the car prices, most of this information is not readily available to vehicle buyers at the time when the vehicle purchase decision is made.

As noted by Covec (2009), the fuel economy labelling regime that was introduced in 2008 is meant to bridge the information gaps relating to vehicle fuel consumption. Unfortunately, at present many used vehicles do not have such data available. Further, even when the data does exist, not many vehicle buyers are able to correctly translate fuel consumption information into fuel cost savings.

For the reasons above and in the absence of external pressures such as a sustained increase in fuel price, voluntary uptake of fuel economic and efficient vehicles will be low without government intervention. The presence of external costs from fuel consumption and information gaps may justify a role for government intervention, provided that the intervention delivers net social benefits to the economy.

3.3 Cost-effectiveness of fuel efficiency vehicle technologies

To assess the costs and benefits of adopting a certain vehicle technology is not merely a matter of considering the incremental costs and benefits of the technology itself. For certain technologies, there are wider cost and benefit implications. From a national benefit perspective, the cost and benefit effects to consider include:

- the one-off development cost of the technology (including any infrastructure requirements to support the technology)
- the costs of the associated parts and accessories and installation costs
- incremental operation and maintenance costs
- impacts on fleet composition, fleet replacement rate and the level of travel
- enforcement or certification costs to relevant authorities (including any cost implications associated with meeting necessary legislative requirements)
- user benefits or disbenefits (including safety and mobility effects)
- likely reductions in fuel costs
- likely reductions in harmful and greenhouse gas emissions and their social costs

[13] At present, New Zealand new vehicles are scrapped at around19 years of age, while the Japanese used imported vehicles are scrapped at around 17 years of age.
[14] This compares the result of a three-year evaluation period with that of a 15-year one, based on an annual real discount rate of eight percent.

Table 7: Estimated fuel efficiency potentials and unit cost of selected vehicle technologies

Technology	Potential fuel efficiency %	Indicative unit cost (NZ$) (note)	Source of references
Engine technologies			
Engine friction reduction	1-4.5%	$440 - $1,000	ECMT (2005), UBA (2008)& IEA/OECD (2009)
Direct injection technologies	3-5% (petrol) 5-7% (diesel)	Can vary significantly between makes and models	IEA (2008) & UBA (2008)
Turbo-charging and engine downsizing	4-20% (petrol) 3-10% (diesel)	$330 - $2,240	TNO/IEEP/LAT (2006) & UBA (2008)
Stop-start system	8-15% (urban) 3-10% (full driving cycle)	$360 - $1,270	King (2007), IEA (2008), NHTSA (2008) & UBA (2008)
Variable valve timing	5-11%	$340 - $1,150	UBA (2008) & IEA/OECD (2009)
Transmission technologies			
Dual-clutch transmissions	4.5-7.5%	$1,020 - $1,160	TNO/IEEP/LAT 2006 & UBA (2008)
Automatic to manual transmissions	14-22%	Can vary significantly between makes and models	TNO/IEEP/LAT (2006), NHTSA (2008) & IEA/OECD (2009)
Non-engine related technologies			
Low rolling resistance tyres	3-4%	Under $100	Penant (2005), UBA (2008)
Cooling technology	3-4% (combined effect of several technologies)	$1,200-$3,700	IEA/OECD (2009)
Improved aerodynamic efficiency	1-3%	Can vary significantly between makes and models	UBA(2008) & IEA/OECD (2009)
Weight reduction of 5%	3.5%		UBA(2008)

Note: All cost estimates are sourced from UBA (2008) and IEA/OECD (2009) and have been converted to New Zealand currency based on NZ$1 = US$0.7 and NZ$1 = €0.55.

Since vehicles with a given fuel efficiency or economy technology may also have other fuel saving or safety features, it is difficult to find two vehicles with different fuel efficiency levels, but with all other features being identical.

Further, the cost associated with vehicle technology varies between makes and models, fuel types, engine sizes, production volumes, and a range of other factors. These make it difficult to determine the incremental cost of acquiring a specific technology and the corresponding cost effectiveness from adoption. As shown in Table 7, the fuel efficiency potentials and unit costs of selected technologies vary considerably.

For emerging technologies, the associated costs may be high initially, but such costs should reduce over time via technology learning and as economies of scale and scope become possible when production volumes increase.

To assist the assessment of the likely cost-effectiveness of any fuel efficiency technology, a break-even analysis has been carried out. Such an analysis is useful in situations where the total costs of an intervention are uncertain, but the potential benefits from the intervention can be calculated (and vice versa).

From the perspective of vehicle buyers, the potential fuel savings over the expected economic life of the vehicle from a given level of fuel consumption improvement[15] can be viewed as the break-even cost level, at which the total fuel savings will be just enough to outweigh the incremental cost of acquiring a more fuel efficient vehicle.

Table 8 summarises the estimated average annual fuel consumption, vehicle kilometres travelled and annual total fuel consumption per light passenger vehicle, by engine size. The average fuel consumption estimates[16] have been based on drive cycle test values plus a penalty to better reflect actual real-world travel conditions[17].

Table 9 shows that, at the current fuel price[18], the potential fuel saving (taxes inclusive) from a five percent fuel efficiency improvement is between \$210 and \$1,080 per vehicle. Thus, it would be cost beneficial if the cost of acquiring a more fuel economic vehicle was lower than these estimates. For a 20 percent improvement, the potential fuel savings (and hence maximum cost of investment) is between \$840 and \$4,330 per vehicle.

From the national perspective, the potential benefit from a five percent fuel efficiency improvement is between \$210 and \$680 per vehicle, exclusive of taxes and levies but inclusive of the social cost of CO_2 emissions[19]. For a 20 percent fuel efficiency improvements, the potential national benefit is between \$820 and \$2,730 per vehicle.

The above estimates are totals in present value NZ dollars, based on a 15-year evaluation period and an eight percent annual discount rate.

Table 8: Estimated total fuel use per light passenger vehicle per annum by engine size

Engine size	Average fuel consumption (note)(litre/100 km)		Annual VKT (2008)	Estimated annual fuel consumption per vehicle (litres)	
	Petrol	Diesel		Petrol	Diesel
< 1300 cc	6.78	5.18	8,000	499	414
1300-1599 cc	7.29	5.56	10,100	670	562
1600-1999 cc	9.03	7.42	10,700	855	794
2000-2999 cc	10.62	9.94	8,400	791	835
> 3000 cc	12.99	11.37	10,700	1,208	1,217

Note: For light passenger vehicles entered the fleet during 2005 and 2009.

Data source: MOT (2009)

[15] For a complete analysis, other vehicle operating costs may also need to be considered. Further, for a national cost-benefit analysis, the social cost of carbon dioxide (CO_2) should be added.

[16] The average fuel consumption estimates are for vehicles entered the fleet during 2005 and 2009.

[17] Drive cycle tests results are often not replicated in real-world driving, so they have been increased by an arbitrary 10 percent. For vehicles that do mostly urban travel, the actual fuel consumption would be much higher.

[18] Pump price assumptions: petrol \$1.82/litre and diesel \$1.19/litre (or exclusive of taxes and levies of \$1.06 and \$1.05 per litre of petrol and diesel respectively).

[19] A social cost of \$40 per tonne of CO_2 equivalent (source: New Zealand Transport Agency's Economic Evaluation Manual) has been used in this analysis.

Table 9: Estimated potential fuel savings from a 5% and a 20% fuel consumption improvement, by engine size and fuel type (estimates in present value, NZ dollars)

Engine size	Per vehicle fuel savings from a 5% improvement in fuel consumption		Per vehicle fuel savings from a 20% improvement in fuel consumption	
	Petrol-powered	Diesel-powered	Petrol-powered	Diesel-powered
< 1300 cc	$420	$210	$1,690	$840
	$270	*$210*	*$1,060*	*$820*
1300-1599 cc	$570	$290	$2,290	$1,140
	$360	*$280*	*$1,450*	*$1,110*
1600-1999 cc	$750	$400	$3,010	$1,620
	$470	*$390*	*$1,900*	*$1,570*
2000-2999 cc	$690	$420	$2,780	$1,700
	$440	*$410*	*$1,750*	*$1,650*
> 3000 cc	$1,080	$620	$4,330	$2,480
	$680	*$380*	*$2,730*	*$2,410*

Note: Estimates in the white cells are based on fuel savings only (inclusive of taxes and levies). Estimates in the shaded cells are exclusive of taxes and inclusive of the social cost of CO_2. All estimates are based on an annual discount rate of 8 percent and over a 15-year period.

Table 10: Estimated potential benefits from downsizing (estimates in present value, NZ dollars)

Engine downsizing		VKT p.a.	Estimated benefits per vehicle over 15 years (note)	
from	to		Petrol-powered	Diesel-powered
1300-1599cc	<1300cc	10,100	$810	$530
			$570	*$560*
1600-1999cc	1300-1599cc	10,700	$2,890	$1,890
			$2,040	*$2,130*
2000-2999cc	1600-1999cc	8,400	$2,080	$1,360
			$1,470	*$1,680*
3000+cc	2000-2999cc	10,700	$3,960	$2,590
			$2,800	*$2,650*

Note: Estimates in the white cells are based on fuel savings only (inclusive of taxes and levies). Estimates in the shaded cells are exclusive of taxes and inclusive of the social cost of CO_2. All estimates are based on an annual discount rate of 8 percent and over a 15-year period.

As noted earlier, an improvement in fuel economy can be achieved through vehicle downsizing. Table 10 shows the estimated potential economic benefits (over a 15-year period) from such a move.

From the perspective of individual car buyers, the potential fuel saving from downsizing to the next lowest engine size class ranges from $530 to $3,960 per vehicle.

From the national cost-benefit perspective, the estimated potential benefits from downsizing, exclusive of taxes and levies but inclusive of any reduction in the social cost of GHG emissions, is between $560 and $2,800 per vehicle.

The potential fuel savings and national benefits can be very high for more than one size class change. For example, downsizing engine size of over 3000 cc by two engine size classes would save between $4,000 and $6,000 per vehicle on fuel, depending on fuel type, over a 15-year period (both taxes inclusive); with a national benefit of around $4,300 per vehicle.

In addition to potential fuel savings and reductions in GHG emissions, engine downsizing could also result in a reduction in vehicle purchasing cost, which could be significant.

The above analysis demonstrates that there are potential net benefits from switching to more fuel efficient and economic vehicles.

4. Summary

This paper provides an overview of the costs and benefits of adopting emerging in-vehicle safety and fuel consumption technologies.

In Section 2, three vehicle safety technologies were analysed. The results show that there is a potential net safety benefit from making electronic stability control available in all vehicles entering the fleet. The same conclusion cannot be drawn for side curtain airbags. However, under certain assumptions, making SCA available in all new light vehicles entering the fleet could deliver sufficient benefits to outweigh the cost of the SCA.

For intelligent speed assistance, there are still significant information gaps that need to be filled before a robust conclusion can be drawn. Based on the evidence collected so far, there may be a case for promoting such technology in the longer term.

In Section 3, the potential costs and benefits of fuel efficiency and fuel economy technologies were investigated. Analyses show that there are potential net benefits, at both the personal and national levels, from switching to more fuel efficient and economic vehicles.

It is important to note that technological improvements and economies of scale mean that installation costs are likely to reduce over time. Therefore, technologies that have a net cost at present may turn out to have a net benefit in the future.

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