

Cost Benefit Analysis of Intelligent Speed Adaptation

Doecke S. , Woolley J. , Anderson R. W. G.
Centre for Automotive Safety Research
email: sam@casr.adelaide.edu.au

Abstract

This paper details a cost benefit analysis of intelligent speed adaptation (ISA) in Australia. The extent of the problem of speed related crashes in Australia is estimated from mass crash data. An analysis of the benefits of ISA is conducted by describing the effect of the differing levels of ISA (advisory, supportive and limiting) found in the UK-ISA trial on the distribution of speeds of vehicles. These effects are applied to distributions of speeds measured on Australian roads and the resulting distributions are multiplied by Kloeden's risk curve for free travel speed to determine the benefits of ISA. The costs of dedicated in-vehicle ISA devices and digital speed limit map production and maintenance are estimated. Economic analyses are conducted on implementation scenarios, including installing ISA on all vehicles, new vehicles and fleet vehicles. Navaid devices are also considered. ISA was determined to be able to reduce injury crashes by 7.7%, 15.1% and 26.4% for advisory, supportive and limiting ISA respectively. In monetary terms this equates to \$1,226 million per year saved with advisory ISA, \$2,240 million per year saved with supportive ISA and \$3,725 million per year saved with limiting ISA, if fitted to all vehicles. Limiting ISA produced the highest benefit cost ratio (BCR) and break even price. The new vehicles scenario generally produced the highest BCR.

Keywords

Intelligent Speed Adaptation, Cost Benefit Analysis, Crash Reduction, Speed

Introduction

The problem of travelling above the posted speed limit, commonly referred to as speeding, has been well documented in the literature, as has the potential of intelligent speed adaptation (ISA) to reduce the problem. ISA devices can be divided into three categories: advisory, supportive and limiting. Advisory devices communicate to the driver that they are travelling above the speed limit by using audio and visual signals. The audio signal can be a simple beep or a statement delivered such as "you are driving above the speed limit". The driver is not obliged to slow to the speed limit but some advisory devices encourage this by using more annoying audio signals the longer the speed limit is exceeded or the greater the amount the limit is exceeded by. Supportive devices prevent the vehicle breaking the speed limit by various methods such as 'hardening' the accelerator pedal, cutting fuel supply, electronically manipulating the throttle, applying the brakes or a combination of these methods. Supportive devices allow this control to be overridden. A limiting device operates in the same way as a supportive device except that it can not be overridden by the driver. This paper discusses the potential costs and benefits of adopting the different forms of ISA in Australia.

Method

The literature typically reports the effects of ISA by quoting changes in mean speeds where mean speed is defined as the average of the speed measurements in the given study. The results of field trials of ISA vary quite widely in this respect [1-10]. Much of this variability can be explained by the extent of the speeding problem in the trial area. The effect of ISA on mean speed tends to be much higher in areas where the mean speed is well above the speed limit and tends to be lower in areas where the mean speed is at, or below, the speed limit. Studies that compare the different levels of ISA reveal that limiting ISA is most effective at reducing mean speed, with lesser effects from supportive and advisory ISA systems [1, 3, 6, 11]. Some studies report the speed distributions before and after ISA. These studies reveal that the shape of the distribution changes with ISA.

Determining the benefits of ISA

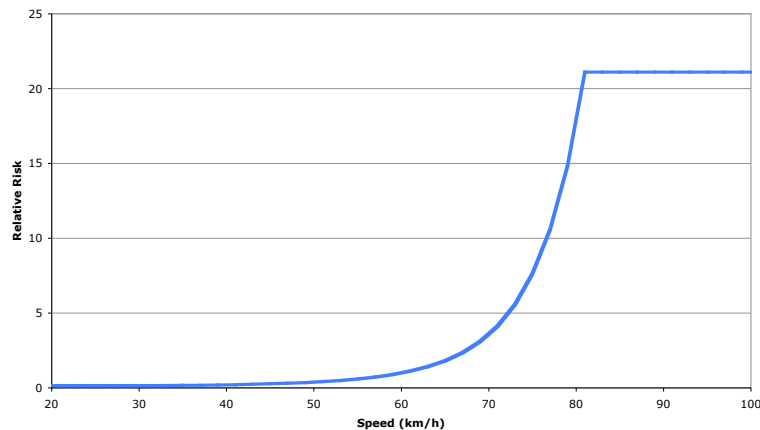
A starting point was to estimate the extent of the problem of speed related crashes from mass crash data. This should be treated as indicative only as speed involvement in the crash data is likely to be under-reported. This data is useful in identifying trends in speeding crashes rather than providing a reliable measure of the benefits of ISA. There is a large body of research on the effect of travel speed on crash risk and the overwhelming conclusion has been that when travel speed increases the risk of having a crash or being injured in a crash increases [12]. This conclusion is not only supported by many studies using empirical data but by the laws of physics and a basic understanding of the limitations of the human body. For these reasons it was deemed desirable to understand the effect ISA would have on the distributions of speeds in Australia and then apply crash risk curves to the speed distributions with and without ISA. This method was utilised in Tate and Carsten's implementation scenarios report on the ISA-UK project in 2008 [11].

One of the widely recognised studies on the relationship between travel speed and crash risk was conducted in Australia by Kloeden et al. in 1997 [13] and was further developed in 2001 [14] and 2002 [15]. The equations for risk relative to travel speed (for 50 and 60 km/h roads) and mean speed (for 80 km/h and above roads) presented in these reports were used in this analysis for three reasons; they are widely accepted in the road safety community, they have been applied to determining the benefits of ISA previously [11] and they are based on Australian conditions. It should be noted that these studies considered injury crashes and so they cannot necessarily be applied to PDO crashes, although it is likely that the introduction of ISA would produce some reduction in PDO crashes. In this sense the analysis is conservative. It should also be noted that Kloeden et al.'s work used free travel speed whilst in this study a combination of free and non-free travel speeds are used in the analysis. A vehicle is said to have a free travel speed if it has at least a four second headway gap to the preceding vehicle and is therefore not influenced by the preceding vehicle's speed [16].

The ISA-UK project [11] measured changes to speed distributions, which can be expressed as changes to the percentages of vehicle numbers in 2 km/h speed bands. To determine the effect that the differing levels of ISA would have on the Australian speeds, equivalent changes were applied to Australian speed distributions on 50, 60, 80, 100 and 110 km/h roads. The results from the ISA-UK project were used, as this is a robust and recent trial of ISA that contained sufficient data necessary for this analysis. As the speed limits in the United Kingdom are given in miles per hour, the effect of ISA was applied to Australian data relative to the speed limit rather than directly applying the change to the corresponding speed band. For example, if the number of vehicles travelling 10 to 12 km/h over the speed limit in 40 mph speed zones was found to reduce by 50% with limiting ISA in the ISA-UK project, the same reduction was applied to the number of vehicles measured travelling 10 to 12 km/h over the speed limit in 60 km/h zones. The resulting speed distributions were normalised by expressing them as a percentage of the total number of speed measurements.

The Australian speed data comes from 171 sites in South Australia and Queensland and is based on over 5.3 million individual speed measurements taken in 2008 and 2009. The data from Queensland that was available did not contain any 110 km/h zones so only South Australian data could be used for this speed zone. More detail on the speed measurement sites can be found in Kloeden, 2009 [17] and Kloeden and Woolley, 2009 [16]. The speed measurements have been combined with equal weight given to every measurement, hence the sites that have a greater volume of traffic passing the speed measuring equipment have more effect on the distribution. It should be noted that the speed distributions in the ISA-UK project related to the ISA equipped vehicles' travel speeds over the length of their journeys during the study while the speed distributions from Australia represent vehicle speeds measured at discrete locations.

The risk curve was capped above 80km/h in 50 and 60km/h zones and at 30km/h above the mean speed in 80, 100 and 110km/h zones to minimise the impact of small, potentially variable, amounts of high level speeding. If the risk curve had been capped at a higher speed the analysis would have shown a greater impact of ISA hence this approach is conservative. The risk curve that was applied to speed measurements taken from 50 and 60 km/h zones is shown in Figure 1.

Figure 1: Risk curve applied to speed measurements for 50 and 60 km/h roads

Crashes were monetised according to costs estimated by BITRE [18]. To estimate the total costs of crashes in Australia, the Bureau of Infrastructure, Transport and Regional Economics adopt a "bottom-up" approach where details of costs associated with individual crashes are totalled [18]. The total costs of all crashes at each severity level are then averaged. It should, however, be understood that BITRE estimate that the number of crashes in Australia far exceeds the number of crashes recorded by state transport authorities. Therefore, when applying the average costs of crashes to reductions in police reported crashes, some adjustment is required to maintain consistency with the BITRE estimate of the costs of crashes in Australia.

In essence, calculations need to account for under-reporting and the non-processing of crash reports. A comprehensive treatment of this issue is given by BITRE, 2009 [18]. They used data from multiple sources, and examined crash ratios across jurisdictions to impute the numbers of crashes not appearing in official statistics at each level of severity. In summary, they found that there is effectively no under-reporting of fatal crashes, but at each subsequent level of severity, a greater proportion of crashes tends to be "missing" from crash databases maintained by state transport authorities.

One method of accounting for missing crashes in the present paper would have been to impute the numbers of missing crashes using the methods applied by BITRE. Instead, the approach that was adopted was to apply a factor to monetised estimates of reductions in recorded crashes to account for the estimated savings associated with the reduction in crashes that are not recorded. These under-reporting factors were determined to be 4, 1.5 and 1 for minor, serious and fatal injury crashes respectively. The cost of a crash as reported by BITRE was converted to 2009 dollars using the consumer price index reported by the ABS [19]. The resulting costs of crashes for minor, serious and fatal crashes was \$16,014, \$288,972 and \$2,889,297 respectively. All benefits calculated in this paper are calculated and expressed in 2009 dollars. The benefits were expressed in monetary terms by multiplying the expected crash savings by these monetary values and the under-reporting factor.

Determining the cost of ISA

Two main costs are associated with ISA: the cost of creating a digital map of speed limits, and the cost of the in-vehicle device. State government representatives were contacted to discuss the current progress of their speed limit mapping and the cost associated with producing and maintaining the map. Industry representatives were contacted to discuss the current ISA devices available, and the costs of their devices. They were asked to discuss costs considering three different sales volumes: a single unit, 50,000 units per year and one million or more units. They were also asked how they would expect the cost of the technology to change over time.

Economic analysis of implementation scenarios

Several implementation scenarios were considered for economic analysis. These included fitting ISA in all vehicles, new vehicles, and in fleet vehicles, via a market driven mechanism, in heavy vehicles, as applied to young drivers, and in conjunction with navaid devices, although not all of these are discussed in this paper. Two particular economic indicators were calculated; the benefit-cost ratio (BCR)

and the break even price. These have been calculated considering a benefit period of 20 years. Because ongoing cost and benefits would be incurred for the foreseeable future under all these scenarios the benefit period used is not indicative of the expected life of the technology but rather addresses the questions ‘what would the return on investment be after 20 years?’ with the BCR and ‘what would the cost of the technology need to be to achieve no net gain or loss after 20 years?’ with the break even price.

Discount rates that are applied to safety technologies and transportation can vary from 3% to 10% [11, 20, 21, 22]. It can also be argued that discounting the benefits of crash reductions is incorrect as attributing less value to future crash reductions is unfair to the future population. Taking this into account three different discount rates were used in the analysis; 0%, 4% and 8%.

All types of vehicles are included in the analysis. The underlying assumption is that ISA can be applied to all types of vehicles and will have the same effect for all these vehicles. This may not be the case for motorcycles; motorcycles appear to be overly represented in excessive speed crashes and it may be technically more challenging to implement ISA on a motorcycle.

The scenarios do not allow for ISA vehicles affecting other vehicles. It may be the case that when a certain level of penetration of ISA into the fleet occurs those vehicles that are not equipped with ISA will be affected by the ISA equipped vehicles. In this sense the analyses are conservative.

Only the cost of the devices themselves and the mapping are included in the economic analysis. Costs associated with installation, enforcement of any implementation (such as ensuring devices are not being tampered with), kerbside speed enforcement resources and increased travel times have not been included. Conversely only the benefits associated with crash reductions have been included. The benefits of reduced fuel consumption, reduced emissions and the potential for smoother traffic flow have not been included.

It is assumed for the purpose of these analyses that the ISA device operates whenever the vehicle is turned on. The exception to this is the Navaid scenario. Such an assumption would be unreasonable for such devices.

Results

Benefits of ISA

Excessive speed in crashes

Table 1 shows the percentage and total number of crashes that were reported as involving excessive speed between 2004 and 2008 in each state of Australia (note that data from Queensland is for mid 2003 to mid 2008 due to data issues). In South Australia and Victoria data was only available for fatal crashes. It is clear that excessive speed is a significant factor in Australian crashes although the prevalence can vary considerably from state to state. The variation may be partially explained by the different methods that are employed to determine speed involvement or it may represent a real difference between states. The difficulty associated with accurately determining the presence of excessive speed in crashes means the table should be regarded as indicative only.

Table 1: Percentage of crashes involving excessive speed in Australian states by injury severity and average number of crashes by injury severity and state per year (2004-2008)

Injury Severity	TAS	SA	NSW	WA	VIC	QLD	Total Number
PDO	13.2%	-	17.3%	2.4%	-	6.4%	6,297
Minor	20.8%	-	15.9%	3.3%	-	3.9%	3,583
Serious	30.7%	-	15.9%	13.2%	-	6.8%	1,101
Fatal	66.1%	39.6%	37.2%	33.2%	30.9%	22.0%	450
Total Number	1,014	44	7,664	1,291	93	1,325	11,431

Table 2 shows the injury crashes (minor, serious and fatal) reported as being due to excessive speed disaggregated according to location, road alignment, driver age group and vehicle type. Data could not be disaggregated along these lines in all states as not all these variables are recorded in state crash databases. In multiple vehicle crashes, the driver age and vehicle type are those of the speeding driver/vehicle. While there is obvious variation between states some overall comments can be made. There is a similar level of excessive speed crashes in rural and metropolitan areas. Roads with curved alignments appear to have an over representation of excessive speed crashes. Young drivers are over

represented in excessive speed crashes. Motorcycles are also over represented; they accounted for 4% of all registered vehicles in Australia in 2009 [23] but are involved in 13-18% of excessive speed crashes.

Table 2: Percentage of injury crashes involving excessive speed in Australian states by location, road alignment, age group and vehicle type (2004-2008)

		TAS	SA*	NSW	WA	VIC*	QLD
Location	Metropolitan	-	42.5%	40.7%	68.1%	54.1%	42.0%
	Rural	-	57.5%	59.3%	31.9%	45.9%	58.0%
Road Alignment	Straight	-	76.6%	24.0%	59.0%	67.9%	-
	Curve	-	23.4%	76.0%	41.0%	32.1%	-
Age Group	16-24	39.6%	37.1%	39.8%	-	-	67.4%
	25-50	46.7%	52.1%	43.2%	-	-	29.7%
	51+	13.7%	10.8%	17.1%	-	-	2.9%
Vehicle Type	Heavy	4.5%	2.4%	12.7%	-	5.0%	3.8%
	Light	82.7%	79.6%	70.1%	-	79.7%	82.1%
	Motorcycle	12.8%	18.0%	17.2%	-	15.3%	14.1%

*Fatal crashes only

Speed risk analysis

An example of the baseline speed distributions (no ISA) and the derived distributions with different levels of ISA are shown in Figure 2. It can be seen that supportive and limiting ISA changes the shape of the speed distribution, shifting those that were speeding by more than a few km/h back to just above the speed limit. Advisory ISA also changes the shape of the distribution although the change appears slight relative to supportive and limiting ISA.

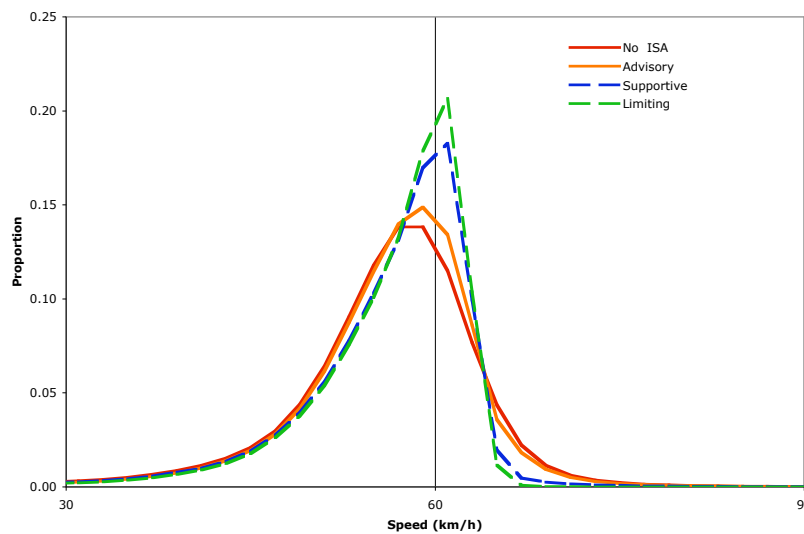


Figure 2: Speed distributions with and without ISA for 60 km/h zones

Relative risks associated with each speed distribution were estimated by multiplying the proportion of vehicles in each 2 km/h band by the relative risk at the average speed for that band (refer to Figure 1). Summing over the distribution produced a total relative injury crash risk. Reductions in the injury crash risk were then determined for the each level of ISA by comparing overall risk with the no-ISA distribution. Table 3 shows estimated reductions in injury crash risk at different speed limits according to the level of ISA implemented. Of interest is the difference between supportive and limiting ISA given their similar speed distributions. This highlights the risk reduction produced by ensuring that it is impossible to exceed the speed limit by more than a few kilometres per hour. The results were such that advisory ISA is predicted to be most effective in 80 and 100 km/h zones while supportive and limiting ISA is predicted to be very effective in 50 and 100 km/h zones. Generally, limiting ISA was the most effective at reducing crash risk, followed by supportive ISA with advisory ISA being the least effective.

Table 3: Percentage injury crash risk reduction by level of ISA and speed zone

Speed Limit (km/h)	Advisory	Supportive	Limiting
50	6.5%	19.6%	42.4%
60	2.1%	9.4%	15.8%
80	14.4%	12.3%	23.3%
100	17.3%	28.8%	35.9%
110	4.6%	12.4%	21.7%

The overall crash reductions and monetised savings were calculated by multiplying the risk reductions in Table 3 by the number of crashes of differing severities in the given speed zone, the cost per crash and the under-reporting factor. The results are also shown in Table 4. Full implementation of advisory ISA could be expected to save \$1.2 billion per year while \$2.2 billion could be saved per year with supportive ISA and \$3.7 billion could be saved per year with limiting ISA.

Table 4: Crash risk reduction by level of ISA and injury severity and monetary savings per year by level of ISA

	Advisory	Supportive	Limiting
Fatal	11.0%	18.4%	28.3%
Serious	8.3%	15.6%	26.5%
Minor	7.4%	14.8%	26.3%
Total	7.7%	15.1%	26.4%
Savings per year (\$M)	1,226	2,240	3,725

Costs of ISA

Cost of producing a digital speed limit map

The money spent by road authorities creating digital speed maps varies from State to State. VicRoads has spent \$700,000 on completing its map although a further \$1.9 million was spent on the project as a whole. Most of this \$1.9 million was spent on developing a system to update and maintain the map. Between \$350,000 and \$400,000 per year has been budgeted to keep the database up to date. The New South Wales RTA has spent \$800,000 mapping its southern region, one of its six regions. Given that this does not include Sydney it could be estimated that the total cost of mapping New South Wales would be between five and six million dollars. Tasmania has set aside \$350,000 to complete its map. If Victoria is used as the average state then a total of \$15.6 million may be spent completing speed limit maps in all six states. A further \$2.4 million may be spent every year keeping the maps up to date.

A commercial enterprise known as Speed Alert has also undertaken its own mapping of speed limits in Australia. Currently coverage includes all roads in the capital cities and surrounding suburbs, other major towns and many of the major interconnecting highways. This mapping cost around \$1.8 million with a further \$100,000 to \$160,000 spent each year updating it.

Cost of in-vehicle ISA devices

Industry representatives were contacted to discuss the current ISA devices available and the costs of their devices considering three different sales volumes, a single unit, 50,000 units per year and one million or more units. They were also asked how they would expect the technology to change in cost over time. Two advisory devices and one supportive and limiting device were available. The supportive and limiting device could not be installed in most vehicles manufactured before 2005. They estimated that:

- For the Speed Alert advisory device, a single unit costs \$800, 50,000 units cost \$500 per unit and one million units cost \$400 per unit, with expected reductions of 30% in 2011 and 50% in 2012 relative to current prices.
- For the Speedshield advisory device, a single unit costs \$1200, large orders could bring the price as low as \$300. No expected reductions in price with time were quoted.
- For the Speedshield supportive and limiting device a single unit costs \$1800, 50,000 units cost \$650 per unit and one million units cost \$520 per unit. No expected reductions in price with time were quoted.

- A subscription for up to date advisory ISA functionality on a navaid device costs \$29.90 per year.

Economic analysis of implementation scenarios

To determine the costs and benefits in a given scenario several quantities have to be known. The first of these quantities is the initial number of vehicles that will be fitted with ISA devices. The most recent motor vehicle census recorded 15,298,693 vehicles in the Australian states on the 31st of March 2009 [23]. Supportive and limiting ISA device cannot be installed on most pre 2005 vehicles. The number of vehicles in the census that were manufactured after 2004 was 4,099,965. It was estimated that 14% (or 2,141,817) of all vehicles are fleet vehicles.

The second quantity is the proportion of all vehicles that will be equipped with ISA over the twenty year period that is being examined. This is termed the market penetration curve. The curves used are shown in Figure 3. The post 2004 and new vehicles market penetration curves are based on the current age profile of vehicles as reported in the motor vehicle census [23]. The fleet vehicles penetration curve is derived from the current age profile, the previously stated assumption that 14 % of vehicles are fleet vehicles and the fact that 54% of a sample of South Australian vehicles were found to have originated from a fleet (government and private fleets). This proportion was assumed to apply to the other states.

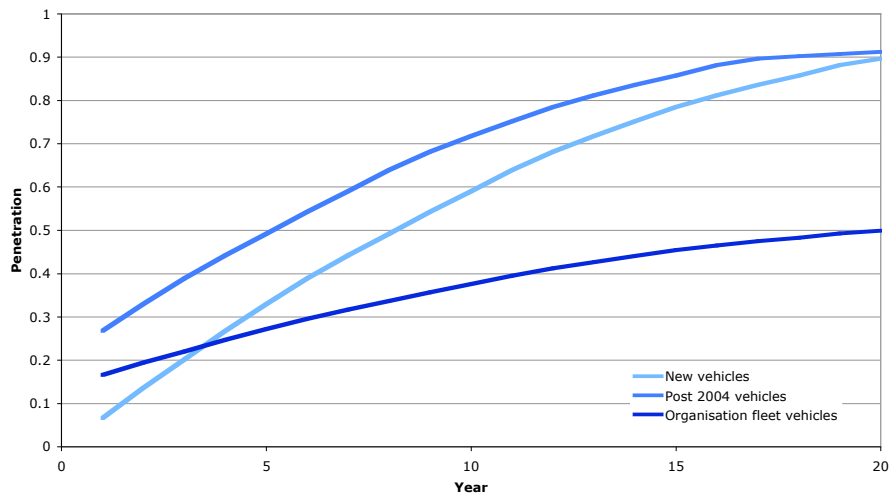


Figure 3: Market penetration curves of the implementation scenarios

The third quantity is the number of vehicles that need to be fitted with ISA devices per year under each scenario. For both the “all vehicles” and “new vehicles” scenario, this quantity was assumed to be 1,000,000. Annual new vehicles sales have been around this value between 2005 and 2009. As mentioned earlier, fleet vehicles are assumed to make up 54% of sales of new vehicles (based on a South Australian sample). This means 540,000 devices would be fitted each year under the fleet vehicles scenario.

The final quantity that is used is the price per unit. The price per unit that was used in the all and new vehicles scenarios was the price quoted for one million units per year. For the fleet vehicles scenario the price used was for a single unit as a single fleet is unlikely to be of the order of 50,000 vehicles.

The BCRs and break even prices that were calculated from these four quantities are shown in Table 5 and Table 6. Limiting ISA produces the highest BCR and break even price. The new vehicles scenario generally produces the highest BCRs when discounting is applied at 4% or 8%.

Table 5: BCR by implementation scenario and ISA device

Implementation Scenario	Advisory Speed Alert			Advisory Speedshield			Supportive Speedshield			Limiting Speedshield		
	0%	4%	8%	0%	4%	8%	0%	4%	8%	0%	4%	8%
	All Vehicles	2.89	2.36	1.92	2.29	1.89	1.58	2.42	2.09	1.79	4.03	3.48
New Vehicles	3.35	2.98	2.63	2.29	2.05	1.83	2.42	2.17	1.94	4.03	3.62	3.23
Fleet vehicles	1.45	1.20	0.98	0.58	0.50	0.43	0.70	0.61	0.53	1.17	1.02	0.88

Table 6: Break even price by implementation scenario and ISA category

Implementation Scenario	Advisory			Supportive			Limiting		
	0%	4%	8%	0%	4%	8%	0%	4%	8%
All Vehicles	691	596	511	1,264	1,092	935	2,104	1,818	1,556
New Vehicles	691	620	553	1,265	1,135	1,014	2,104	1,891	1,688
Fleet Vehicles	689	598	515	1,263	1,097	945	2,104	1,828	1,576

The popularity of navaid devices has been noted as an opportunity to easily introduce advisory ISA to the vehicle market [24]. Calculating the cost effectiveness of such devices is confounded by two main issues. The first of these is the actual level of usage of the advisory ISA function, given that it does not automatically activate with the vehicle, and can be deactivated when the navaid is on. The second unknown is the effectiveness of such an advisory ISA system given that the user can adjust the operation of the system, including the speed tolerance before an auditory warning is sounded. There is likely to be interaction between these two, for example if the user cannot set the tolerance to their desired level they may be more likely to not use the ISA function of the navaid device.

The cost effectiveness of navaid devices with advisory ISA depends on how often the advisory ISA part of the system would be used, and how effective they are relative to dedicated advisory ISA devices. Calculations were made to determine the relationship between the BCR of advisory ISA navaid devices and their 'usage and effectiveness factor'. To obtain a BCR of one (4% discount rate, \$29.90 yearly subscription fee), the usage and effectiveness factor must be greater than 0.055. To get the same BCR as implementing Speed Alert's dedicated advisory ISA device on all vehicles shown in Table 5 (2.36), the usage and effectiveness factor would need to be 0.13. Such a usage and effectiveness factor would result if the navaid advisory ISA device was 50% as effective as a dedicated advisory ISA device and was used for 26% of the total distance driven ($0.5 \times 0.26 = 0.13$).

Discussion

A limitation of the costs determined in the economic analysis is that installation costs were not included. While this may change the BCR results, this does not affect the break even price. The break even price represents the cost of the device plus installation costs. When comparing the results of different implementation scenarios it should be noted that different costs were applied to each scenario, and these differences had a large bearing on the BCRs. These prices were estimates given by the companies that produce the devices based on discrete order sizes. While the price reductions quoted were due to buying power, economies of scale may produce similar price reductions. The general uncertainty regarding the cost of ISA suggests that the break even price may be more useful as a decision making tool if implementation requires a BCR of at least one.

The navaid scenario suggests that even if the devices are only used infrequently and less effectively than dedicated devices, they may still prove to be a cost effective option. But while BCRs may be greater than one, this represents a much smaller crash reduction than benefits flowing from dedicated systems.

Finally it should be noted that the benefits calculated do not include savings in property damage only crashes, the costs of which are thought to be substantial [18].

Conclusion

It was determined that:

- If advisory ISA was fitted to all vehicles it would reduce injury crashes by 7.7% and save \$1,226 million per year
- If supportive ISA was fitted to all vehicles it would reduce injury crashes by 15.1% and save \$2,240 million per year
- If limiting ISA was fitted to all vehicles it would reduce injury crashes by 26.4% and save \$3,725 million per year

The economic analysis revealed that ISA can be a cost effective way to reduce injury crashes in Australia.

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<http://www.dft.gov.uk/pgr/roads/vehicles/intelligentspeedadaptation/>

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