An estimate of the future road safety benefits of autonomous emergency braking and vehicle-to-vehicle communication technologies

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Key Findings

• Autonomous emergency braking and vehicle-to-vehicle communication technologies has the potential to prevent a substantial number of both injury and fatal crashes.
• The full benefits of these technologies will only be realised when a substantial fraction of the Australian vehicle fleet has them installed.
• A faster rate of introduction of these technologies into new vehicles will prevent more crashes over many years, than a slower rate of introduction. Any mechanism that hastens the uptake of these technologies should be considered to improve road safety.

Abstract

The aim of this study was to examine the benefits of hastening the introduction of new passenger vehicle technologies on future reductions in fatalities and serious injuries on Australian roads. This was done specifically for Autonomous Emergency Braking (AEB) and Vehicle-to-Vehicle (V2V) communications, which represent the two most promising technologies in the short-term and medium-term future. The results demonstrate that a delay in introduction, or a slower rate of introduction, can have a substantial effect on how long it takes for the safety benefits to be realised in the greater vehicle fleet.

Keywords

Autonomous Emergency Braking (AEB); Vehicle-to-Vehicle (V2V) communication; Safety performance; modelling; technology introduction rate; crash reduction

Background

Autonomous Emergency Braking (AEB) in Australia, is a relatively new technology whereby forward facing sensors continually monitor the road ahead and are used to detect when a collision with another road user in its path is probable. When a forward collision is likely, the vehicle provides the driver with an initial warning to react, and subsequently, in the absence of any driver reaction applies a significant braking force to reduce the vehicle’s speed. In an optimal situation the crash is avoided entirely, however even if the crash is unavoidable, the impact speed may be reduced thereby reducing the crash injury severity.

In Searson, Ponte, Hutchinson, Anderson and Lydon (2014), AEB was identified by every interviewed vehicle safety expert as being likely to have a significant road safety benefit in Australia over the next five to ten years. The literature has predicted that the benefits of AEB are potentially large using reconstruction and simulation techniques. Fildes et al. (2015) surveyed the literature for predicted benefits and showed estimates ranging between 4.3% and 44.0% crash reductions (for a range of impact scenarios including pedestrians). Fildes et al. (2015) also demonstrated an on-road reduction in rear-end low-speed crashes of 38% (confidence interval 18% - 53%), thereby verifying the potential magnitude of these estimates. Individual manufacturers have their own proprietary AEB systems and these act in according to their own algorithms, and at different maximum speeds (Hulshof,
Knight, Edwards, Avery & Grover, 2013). Some operate as low speed AEB to avoid crashes in city traffic, while others can operate at high speed and may prevent crashes at highway speeds. The actual AEB effectiveness of an individual car is dependent on the specifics of the installed AEB system.

Vehicle-to-Vehicle (V2V) communications is another relatively new technology where vehicles communicate with each other via dedicated short-range communication devices (DSRC). If they are reporting their position, speed and direction to each other, then each will be able to determine if a crash between them is likely. If a crash is imminent the vehicle could take evasive action, including application of the brakes to avoid the crash occurring.

Searson et al. (2014) also found that V2V is a technology that interviewed experts believe may have a significant effect in the longer-term future. Although there are no results from long term trials that confirm this, research is promising and it is likely that V2V may fill the ‘gaps’ left by AEB by providing emergency braking that avoids or mitigates crashes. Doecke, Grant and Anderson (2015) showed that V2V communications could have a substantial reduction in crash occurrence of more than 90% under a range of crash configurations.

The rate at which each of these technologies is introduced into the vehicle fleet will be influenced by various factors. Among these is that they could be pushed into the market by government intervention, or they could be pulled by consumer demand. Government, through its design rules, potentially has the most power to encourage these technologies to be implemented quickly. Relying on individual consumers to voluntarily purchase for their own technology is possibly the slowest method of introducing the technology. More recently however, strong consumer advocacy groups such as the Australasian New Car Assessment Program have had the ability to encourage various technologies by rating cars as safer if they are equipped with this technology, and subsequently marketing the safety ratings to both fleet buyers and consumers. The speed that the technology is introduced is, however, an important factor in how effective it will be in the short and medium terms, regardless of the push and pull factors that are responsible for encouraging its introduction.

Searson et al. (2014) demonstrated that an aggressive approach to introducing these technologies into the Australian car fleet would see their benefits realised faster than a slower approach to their introduction. This paper updates that analysis to include the current rates of fitment of AEB technology.

This paper is not an analysis of the effectiveness of these technologies; it is, however, an analysis of the speed of introduction of these technologies. To achieve this aim, three different introduction rates are considered:

- an aggressive approach – possibly reflecting a design rule demanding that the technology is implemented;
- an encouraged approach – possibly reflecting a consumer organization marketing the benefits of the technology and rewarding vehicles using the technology with higher ratings; and
- a slow approach – possibly reflecting an adoption of the technology driven by individual consumers, without encouragement.

The timeframes adopted to model the effects of these different introduction rates (described in detail below) reflect the thoughts of the experts surveyed by Searson et al. (2014) about their potential availability in the market.

Method

AEB and V2V fitment rates

To model future fitment rates of the technology into new vehicles entering the fleet, a normal cumulative distribution curve was used. To define this curve, two endpoints were defined: an introduction year and a saturation year. The introduction year was the latest year in which less than 4% of new vehicles had the technology fitted. The saturation year was the latest year when less than 4% of new vehicles did not have the technology fitted. For the normal cumulative distributions, the mean was taken as the average of the introduction year and the saturation year and the standard deviation was one fifth of the time from the introduction year to the saturation year.

For the fitment of AEB, the saturation year for the aggressive introduction scenario, encouraged introduction scenario and the slow introduction scenario is 2020, 2025 and 2030,
respectively. For AEB, there is already some introduction of this technology in the current Australian fleet. The rates of fitment of AEB from 2010 to 2015 are known for standard (not optional) new vehicle sales in the March to June quarter of each year (R. L. Polk Australia Pty Ltd, 2010-2015) and these are shown in Table 1. The breakdown of the operating capabilities of these AEB systems is not known. For the purposes of fitting the normal cumulative distribution curve, the introduction year in each introduction scenario was iteratively selected so that the fitment rate in 2015 was equal to 9.6% of vehicles in 2015, this being the actual percentage of vehicles fitted with AEB according to the data.

Table 1. Actual AEB Fitment rates (standard fitment) (R. L. Polk Australia Pty Ltd, 2010-2015)

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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<tbody>
<tr>
<td>Actual AEB installation % (March to June Quarter)</td>
<td>1.5%</td>
<td>1.7%</td>
<td>2.2%</td>
<td>3.8%</td>
<td>6.6%</td>
<td>9.6%</td>
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It is also assumed that V2V technology will be introduced at a fitment rate that follows a normal cumulative distribution. The introduction year (less than 4% of all new vehicles fitted with V2V technology) for each of the scenarios is set to be 2020. The year of saturation (96%) of all vehicles fitted for the aggressive introduction scenario, encouraged introduction scenario and the slow introduction scenario is 2030, 2035 and 2045, respectively.

The rates of new car fitment, along with the percentage of vehicles fitted with the technologies is shown in Figure 1. The aggressive introduction curve is quite similar in shape to the electronic stability control introduction curve (ESC) in Gargett et al. (2011), although due to regulation for ESC occurring very quickly, early ESC prevalence was quite high. The initial and saturation years for the fitment rates are shown in Table 2.

Table 2. Curve fitting parameters used for future fitment rates

<table>
<thead>
<tr>
<th>Introduction Scenario</th>
<th>AEB</th>
<th>V2V</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Initial year*</td>
<td>Saturation year</td>
</tr>
<tr>
<td>Aggressive</td>
<td>2014.25</td>
<td>2020</td>
</tr>
<tr>
<td>Encouraged</td>
<td>2013.50</td>
<td>2025</td>
</tr>
<tr>
<td>Slow</td>
<td>2012.73</td>
<td>2030</td>
</tr>
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*Initial year for AEB was selected iteratively to closely match 9.6% fitment in 2015

AEB and V2V effectiveness

The effectiveness of AEB and V2V technologies will be assumed to be as is reported in the literature. As discussed previously, this paper is not about the effectiveness of the AEB and V2V technologies but an analysis of the effect of introduction of these technologies, and the consequences of different introduction rates. Consequently, the choice of effectiveness value although important, is an adjustable parameter. As discussed in the background section, there are a range of effectiveness values that can be applied to AEB and V2V technologies. Some of these have been derived using simulation and reconstruction, others after investigating the effectiveness of technologies in the market.

For AEB effectiveness, Fildes et al (2015) reported an effectiveness of AEB of 38% in on-road low speed read end crashes. Lower values of effectiveness will be used in this analyses: 34% for injury crashes and 28% for fatal crashes, effectiveness values predicted from reconstruction by Anderson et al (2012) which includes additional crash types, and differentiates between fatal and injury crashes. For V2V effectiveness, Doecke and Anderson (2014) reported the marginal benefits of V2V as 16.0% for injury crashes and 11.9% for fatal crashes over and above the effectiveness of AEB (using their conservative ‘restricted view’ connected system). In this paper, the effectiveness of AEB is defined collectively over the entire fleet, ignoring the capabilities of individual installed systems.

The benefits accrued due to AEB are assumed to be proportional to the percentage of total vehicles with the technology installed. This is because AEB can be effective even when only installed in one vehicle involved in a crash.
The benefits accrued due to V2V however, are assumed to be proportional to the square of the percentage of total vehicles with that technology installed. This is because both vehicles in a two car collision require the technology for it to be effective in mitigating the crash.

Age of vehicle fleet

The vehicle age profile was from the 2011 ABS Motor Vehicle Census (ABS, 2011). The census listed the number of registered vehicles by manufacturing year, as of 31 January 2011. As such, the data were adjusted to represent average age in years. The number of vehicles aged zero were those built in 2011 (of which only one month had passed), plus 5/12 multiplied by the number of vehicles built in 2010. The number of vehicles aged one was 7/12 multiplied by the number of vehicles built in 2010, plus 5/12 multiplied by the number of vehicles built in 2009 and so on. This adjustment reflects the concept that in January of a new calendar year no vehicles manufactured in that year have yet been manufactured, whereas by December all of the vehicles will have been manufactured, and on average throughout the year, half of all vehicles made during the year will have completed their run through the vehicle manufacturing plant.

Figure 2 shows the percentage of all vehicles by age. Note that for the grouping aged 21-30 years, this is the average percentage per year of age for vehicles in that age group, and similarly for 31-40 and 41-50. Note that the height of the bar for vehicles aged zero is approximately half the height of those following: if it is assumed that a roughly linear introduction of vehicles into the fleet during their year of manufacture, this is what would be expected.

Percentage of vehicles in the future vehicle fleet

Each year, every vehicle would become one year older. Consequently, if 40% of new vehicles were fitted with AEB technology in a given year, then 40% of all 1-year-old vehicles would have AEB technology in the next year.

The proportion of vehicles at each age was used for all future years. No attempt was made to adjust the attrition rates of vehicle that are fitted with or without the crash avoidance technology, even though these technologies could possibly reduce attrition rate because of a lower number of crashes that occur.

Outcome measures

Outcomes of interest were the penetration of the technology into the total registered vehicle fleet and the predicted percentage of fatalities and injuries that were prevented by the presence of the technologies. The safety benefits that arise because of the AEB technology (“AEB only”) are evaluated separately from the benefits that arise due to both the AEB and V2V technology (“AEB + V2V”) being in the vehicle fleet.

Results

The results are summarized for the effect of AEB only, in Table 3 while the combined effect of AEB and V2V are shown in Table 4. Both tables show:

- the year in which the technologies have a 50% vehicle fleet penetration
- the percent reduction in crashes for the year 2030
- the year in which 25% of crashes are prevented based on the modelling assumptions.

![Figure 2. Age distribution of vehicles in the Australian fleet in 2011. Where range of years is given, the percentage is the average percentage per year of age for vehicles in that age group.](image)
For the AEB only case, an aggressive introduction scenario achieves a 50% fleet penetration of AEB four years earlier than the slow introduction scenario. This earlier ‘intervention’ results in an additional 7.9% of injury crashes and 6.5% of fatal crashes being prevented in the year 2030 comparing the aggressive AEB introduction scenario to the slow AEB introduction scenario. A 25% reduction of both injury crashes and fatal crashes is achieved 6 years earlier under the aggressive AEB introduction scenario compared to the slow AEB introduction scenario.

Considering AEB + V2V, an aggressive introduction scenario achieves a 50% fleet penetration of the two technologies 5 years earlier than the slow introduction scenario. An aggressive introduction of the combined technologies could potentially result in an additional 9.1% reduction in injury crashes and 7.4% reduction in fatal crashes in the year 2030 comparing the aggressive AEB + V2V introduction scenario to the slow AEB + V2V introduction scenario. A 25% reduction of both injury crashes and fatal crashes is achieved 5 years earlier under the aggressive AEB + V2V introduction scenario compared to the slow AEB + V2V introduction scenario.

These results are plotted for every year between 2010 and 2042 in Figures 3 to 5. The penetration of AEB and V2V technology into the vehicle fleet is shown in Figure 3; the percentage of fatal and injury crashes that are prevented in each year due to AEB only is shown in Figure 4; and the percentage of fatal and injury crashes that are prevented each year due to both AEB and V2V communications is shown in Figure 5.

The figures show that the faster introduction rates prevent a higher number of fatal and injury crashes prevented in each and every year than the slow introduction rates. This means there will be a strong cumulative effect of the crashes being saved every year adding up to ever increasing number of prevented crashes over and above the number prevented by the slower introduction rate.

**Conclusions**

Autonomous emergency braking technology has been proven to be effective in a range of crash scenarios in the real-world (Fildes et al. 2015; Rosén et al., 2010), despite low prevalence in the vehicle fleet. Its utility has been demonstrated extensively in a theoretical sense and in the early studies of this technology.

Using assumptions about the effectiveness of AEB and V2V based on previous studies, this paper has shown that these technologies, particularly AEB, have the potential to substantially reduce both injury and fatal crashes now and in coming years. The extent to which these technologies can reduce injuries and fatalities is highly dependent on the speed in which they are introduced into new vehicles and consequently into the total registered vehicle fleet. The faster they are introduced in new vehicles, the more crashes will be ultimately prevented.

As noted previously, there are vehicles currently available with various versions of AEB. The vehicle speeds at which these systems operate vary, with some systems focussing on avoidance of low speed rear-end collisions, which may represent the most frequent crash type although may not operate at higher speeds. Other systems are designed for higher travelling speeds, focussing on crash prevention or crash severity mitigation with all road-users. Historically, the focus generally is to market and sell the safety features of AEB to the vehicle purchaser as a means to protect the occupants of that vehicle, like traditional technologies such as seatbelts and airbags.

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<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year in which 50% of the vehicle fleet is equipped with AEB</th>
<th>Total reduction in injury crashes in 2030</th>
<th>Total reduction in fatality crashes in 2030</th>
<th>Year in which a &gt;25% reduction in injury crashes is achieved</th>
<th>Year in which a &gt;25% reduction in fatality crashes is achieved</th>
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<tbody>
<tr>
<td>Aggressive introduction</td>
<td>2026</td>
<td>25.0%</td>
<td>20.6%</td>
<td>2030</td>
<td>2036</td>
</tr>
<tr>
<td>Encouraged introduction</td>
<td>2028</td>
<td>21.2%</td>
<td>17.5%</td>
<td>2033</td>
<td>2039</td>
</tr>
<tr>
<td>Slow introduction</td>
<td>2030</td>
<td>17.1%</td>
<td>14.1%</td>
<td>2036</td>
<td>2042</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year in which 50% of the vehicle fleet is equipped with AEB + V2V</th>
<th>Total reduction in injury crashes in 2030</th>
<th>Total reduction in fatality crashes in 2030</th>
<th>Year in which a &gt;25% reduction in injury crashes is achieved</th>
<th>Year in which a &gt;25% reduction in fatality crashes is achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggressive introduction</td>
<td>2034</td>
<td>26.5%</td>
<td>21.7%</td>
<td>2030</td>
<td>2033</td>
</tr>
<tr>
<td>Encouraged introduction</td>
<td>2036</td>
<td>21.9%</td>
<td>18.0%</td>
<td>2032</td>
<td>2035</td>
</tr>
<tr>
<td>Slow introduction</td>
<td>2039</td>
<td>17.4%</td>
<td>14.3%</td>
<td>2035</td>
<td>2038</td>
</tr>
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</table>
This paper has not discussed the various and numerous push and pull factors that might affect speed of introduction of these technologies. Whilst a governmental design rule could be used to force all new cars to have the technology installed quickly, other less forceful options are possible. These include: making the technology compulsory in 5-star safety rated cars; convincing large fleet buyers to make the technology mandatory on their new car purchases; marketing the technology to consumers through public-health sponsored advertising campaigns; and applying insurance premium discounts to vehicles fitted with the technology. These approaches, or any of many others, when used well, could encourage increased fitment rates.

In this analysis, the reduction in fatalities and injuries were calculated as percentage reduction. The absolute values were not calculated, as it is not known what future changes there will be to the ‘baseline’ numbers of fatalities and injuries outside of the effects of AEB and V2V. Importantly, however, it was shown that the aggressive introduction scenario is always ahead of the encouraged and slow introduction scenarios in terms of percentage of fatal and injury crashes prevented. This has a cumulative effect that needs to be acknowledged. If an additional 10 or 100 fatal crashes can be prevented every year, on average with a faster introduction rate, then over 20 years this means that there is an additional 200 or 2000 fatal crashes that are prevented. It is difficult to quantify what the total number of crashes this cumulative effect will prevent however, because it is not known what the ‘baseline’ numbers of crashes will be. The baseline will also be affected by other road safety investments such as to infrastructure, driver training and, potentially, autonomous vehicles.

The calculations in this analysis were based on the current distribution of crash types, and this distribution may change in the future. As technologies for preventing vehicle-to-vehicle crashes become more common, a greater proportion of road trauma may be associated with vulnerable road users. If this is the case, then technologies that prevent crashes with pedestrians, motorcyclists and bicyclists should be encouraged. The calculations in this analysis were also based on single, and possibly conservative, estimates of the effectiveness of AEB and V2V at preventing crashes.
The actual effect will be different depending on the actual effectiveness of these technologies. Despite this, however, the main analysis of this paper, which was the introduction rate of these technologies and its effect on future crash rates does not change with faster introductions leading to greater crash reductions.

This analysis has not considered the different use profiles of newer and older vehicles, including driven kilometres and driver ages. In the analysis, all vehicles were assumed to have a common baseline crash risk. Differences from this assumption could affect the results that were presented.

The technology will have a financial cost, and because this technology is fitted to individual vehicles the cost is most likely to be borne by the consumer. This needs to be balanced against the benefits that the technology is likely to have. For the consumer, there is the benefit of being less likely to be involved in an injury or fatal crash, as well as the benefit of being less likely to repair the vehicle after one of these crashes. For society, there is the benefit of fewer crashes resulting in fewer hospital admissions and economic losses. This paper has not attempted to quantify these costs and benefits, but this should be done before design rules are changed to influence the presence of these technologies.

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