AUTONOMOUS BRAKING SYSTEMS AND THEIR POTENTIAL EFFECT ON WHIPLASH INJURY REDUCTION

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ABSTRACT

The paper estimates the benefits of low speed autonomous vehicle braking technologies (e.g. City Safety from Volvo) on reducing whiplash injuries, and whether driver adaptation is likely. Potential UK whiplash injury reduction and cost savings associated with autonomous braking systems are calculated. Assuming standard fleet wide fitment, predictions show autonomous braking systems (City Safety) could annually prevent 263,250 crashes, mitigate 87,750, and prevent 151,848 injuries, equalling nearly €2 billion savings in repair costs and whiplash compensation. In driver adaptation testing participants drove toward an inflatable target car at 15km/h without braking. Responses were collected from 99 driver tests, where the vehicle autonomously brakes preventing impact. 11% of drivers braked instinctively when approaching targets, and 95% of drivers stated they would not rely on City Safety for normal driving, and understood that it was for emergency braking only. Feedback was also gathered from 11 drivers experiencing the system on thousands of kilometres of normal UK roads. None reported either positive interventions or false interventions. City Safety, an example of low speed autonomous braking systems, shows huge potential for reducing crashes and whiplash injuries valued at nearly €2 billion in insurance claim savings. Other current autonomous braking systems operating at higher speeds require driver activation, and can only mitigate impact speeds. City Safety operates autonomously at low speeds and can prevent collisions occurring completely, so no risk compensation issues are expected.

INTRODUCTION

Over the last few years vehicle manufacturers have been launching a wide range of primary safety technologies. These are technologies that are designed to prevent a collision from occurring by warning the driver to intervene, or to lessen the speed and severity of the collision by autonomous vehicle braking. Some examples are Adaptive Cruise Control (ACC), Automatic Emergency Braking Systems (AEBS), and Low Speed Avoidance technologies.

ACC and AEBS

ACC uses a radar unit mounted on the front grille of the car to sense the proximity and speed of vehicles ahead. This allows the functionality of a standard cruise control system to be extended to control braking as well as acceleration. The driver can then let the ACC control acceleration and braking, and only has to provide steering input. ACC is designed to work on motorways and dual carriageways and most systems are only operational at over 30 km/h.

ACC systems also have the facility to provide a warning to the driver if the car is at risk of a collision. These warnings can take many forms including visual symbols or lights, audible beeps or ‘bongs’, or a haptic tug on the seat belt.

A further development of ACC is AEBS, which will automatically apply the vehicle brakes when an imminent collision is identified. AEBS aims to prevent the collision or to mitigate severity by reducing speed. AEBS functionality is known by different names by individual manufacturers, such as Collision Mitigation Braking System (CMBS) by Honda, or Collision Mitigation by Braking (CMbB) by Ford.

So both ACC and AEBS use radar sensors and show some potential for mitigating crashes, but they are not designed to prevent crashes from occurring completely. The potential effect for reducing crashes and injuries may also be limited by certain HMI (Human Machine Interface) issues. The systems are only operational when activated by the driver, and can be turned off easily if the driver chooses. The systems also issue warnings to the driver that they need to intervene to prevent a collision. Since different systems issue different types of warnings there is potential for confusion that might lead to either a lack of response from the driver, or an inappropriate response, which limits the effectiveness of the warning.

An example of a Low Speed Avoidance technology is City Safety, and that does not appear to have these associated HMI issues. This uses LIDAR

(**Li**ght **D**etection **a**nd **R**anging) sensors, which is an optical remote sensing technology that measures properties of scattered light (laser) to find range information of a distant target (vehicle in front). These LIDAR sensors are mounted behind the windscreen and scan the road ahead for approximately 6m. In a situation with a likely collision, the system will pre-charge the brakes to give a faster response if the driver does brake. Should the driver still fail to brake in an imminent collision situation, automatic braking power up to $5m/s^2$ is applied, and throttle control by the driver is disconnected. In tests at speeds up to 22 km/h undertaken by Thatcham a car fitted with the City Safety system successfully prevented contact with another car. At speeds of up to 30 km/h the system is able to mitigate collisions by 50%. The system is active for speeds up to 30 km/h. To prevent drivers from adapting their normal driving to the system the design of the system is intended to give a harsh/unpleasant braking sensation. The system is not operational against on-coming traffic, and is operational against stationery or moving traffic. The system calculates that the driver is taking evasive action if they give a large steering, throttle, or brake input, and the system is therefore overridden by the driver.

By default the system is always turned on when the vehicle starts, so it is always on and able to activate to mitigate/prevent a collision. Once the system has operated the driver is given a display notice, but there is no warning given prior to intervention of City Safety. It is not possible to give a driver warning of a potential collision since there is not enough time available once a collision risk is identified. Because City Safety is always turned on, and because it has no warnings, the HMI issues associated with ACC and AEBS are not problems for City Safety.

The City Safety system was launched as standard at the end of 2008 on the Volvo XC60, and it is expected to be fitted on other models from Volvo as well as other manufacturers. However it will still be a number of years before enough evidence can be gathered about the effectiveness of City Safety in the real world to form a conclusion as to its potential for crash and injury prevention. This paper outlines estimates of crash reduction and cost savings offered by City Safety. It also presents two preliminary studies that have aimed to investigate whether drivers are likely to adapt their driving habits to the City Safety system by relying on its crash prevention technology, with the risk that they consequently negate any advantages offered by the system by paying less attention to the road.

POTENTIAL CITY SAFETY EFFECTIVENESS ESTIMATES

Since City Safety is designed to prevent low speed collisions, it shows potential for reducing not only these crashes and the associated repair costs, but also whiplash injuries and costs. The main focus of whiplash injury reduction countermeasures has been with better seat design. Data indicates that 75% of all crashes occur below 30 Km/h [1] with the front to rear end crash at intersections being the most prevalent. British insurers report a cost in excess of €3 billion annually in the United Kingdom due to whiplash [2]. In Sweden 70% of all injuries leading to disability are due to whiplash injuries [3]. According to Watanabe [4] et al. 43.5% of all injuries from vehicle crashes were from rear impacts, and approximately 90% of these injuries were to the neck. Whiplash is an AIS 1+ injury and the vast majority of occupants who suffer initial soft tissue neck injuries typically recover fully, although around 10% of the occupants with initial neck injury symptoms continued to have symptoms after one year [5,6,7]. However collision avoidance technology offers a huge potential to avoid the sorts of collisions that typically cause whiplash injuries.

Based on dose-response models Kullgren [8] has made estimates of the effectiveness of City Safety, which indicates a 60% reduction in injured occupants. It is only possible to make estimates of the effectiveness of the system for preventing crashes at present, with only a small number of vehicles in the fleet fitted with the system. Once a greater number of vehicles can be found on the road in the real world it will be possible assess the effectiveness of the system in detail. However by identifying those typical crash scenarios where the system can be expected to have benefit, it is possible to make some estimates of the potential savings in crash reduction, both in terms of damage and injury costs.

Potential Crash Reduction

Although there are many well established crash frequency databases, such as GIDAS or CCIS, most of the criteria for inclusion relate to serious injures and typically require Police involvement or tow-aways. When comparing these to insurance statistics it is clear that the total amount of all crashes is far higher than the established databases report. The types of crash and direction of impact also tend to differ considerably. Overall there is a huge amount of under reporting is present in most published crash data sets when considering whiplash injuries or non-injury crashes handled by insurers. For example the Department for Transport reported 247,780 casualties on UK roads in 2007 [9], and yet there are around 2.7 million motor crashes resulting in an insurance claim annually in the UK [10].

Estimates of the effectiveness of City Safety for reducing all crashes (not just casualties) can be generated from the insurance claims data. These estimates assume a fleet wide fitment of City Safety. According to analysis of motor insurance claims data, around 26% of claims are for rear-end impacts where one vehicle runs into the back of another [11]. This represents 702,000 crashes from the 2.7 million motor crashes that result in an insurance claim [10]. Many of these crashes occur at intersections, junctions and traffic islands and result from poor driver attention. Most of these crashes occur at low speed (under 30km/h) in the speed range where City Safety is active. City Safety is designed to specifically operate on rear-end impacts, but it could also have a positive effect in other crash types. Effectiveness estimates for City Safety are therefore only focussed on the front-into-rear impact scenario.

Research [12] has shown that in a front-into-rear collision situation 50% of drivers will respond by applying braking. When City safety detects that the driver is braking it will disengage since the driver is in control. However for the other 351,000 crashes (50%) the driver will not brake and the system could therefore help to prevent or mitigate the crash. Previous estimates were made by the authors in [13]. These were more cautious estimates based on only 30% of drivers no applying braking [14], rather than the 50% [12] used in this paper to show the greater potential effectiveness.

Over 75% of crashes are at speeds under 30 km/h [1]. This data suggests that for the 263,250 crashes that are under 30 km/h City Safety could help to prevent the impact from occurring completely, and for the other 87,750 crashes it could help to mitigate the severity (speed) of the impact.

According to crash repair costs analysis [15] the average repair cost per vehicle is €1,868 making a total repair cost of €3,736 per crash. So for the 263,250 crashes under 30km/h that City Safety could help to prevent this equates to a saving of €983,502,000. For the 87,750 higher speed crashes it is assumed that City Safety lowers the crash speed and consequently the repair costs are brought down to the average level of €3,736 per crash, equating to a saving of €327,834,000. This gives a total saving of approximately €1.3 billion, as summarised in Table 1.

Table 1.
Summary of Estimated Crash Repair Cost Savings from City Safety

	Crash prevention	**Crash mitigation**
% of crashes over/under 30km/h	75% under 30km/h	25% over 30km/h
Number of crashes without driver braking	263,250	87,750
Average crash repair cost	€3,736	€3,736
Sub-total repair cost savings	€983,502,000	€327,834,000
Total repair cost saving	€1.3 billion	

Potential Whiplash Injury Reduction

Whiplash is a high cost burden to both the motor insurers, all those who purchase motor insurance and the wider society in general. Costs in excess of £2 billion are reported annually by British insurers due to whiplash [2]. Statistics from the Comité Européen des Assurances [16] show that four countries have a very high rate of claims for whiplash injuries, including the United Kingdom (76% of bodily injuries), Italy (66%), Norway (53%), and Germany (47%). Average claims costs linked to cervical trauma can be very high, for example Switzerland has the highest average cost per claim [16] with approximately €35,000 per claim, followed by the Netherlands (€16,500), and Norway (€6,050).

The annually UK has 432,000 whiplash injury insurance claims [17]. Analysis by Thatcham of whiplash injury claims cases [18] reveals that 70% of whiplash claims come from front impacts and rear impacts, which equates to 303,696 whiplash injuries.

Until now there have been no technologies to prevent or mitigate whiplash injuries in frontal collisions. City Safety is the first technology that offers any potential to tackle the issue of frontal whiplash, and can prevent this injury from occurring at low speeds which is an important contribution to reducing the societal burden of whiplash.

In order to calculate the possible effect on whiplash frequency the same method of estimates was used to calculate the efficacy of the City Safety system. With acceptance criteria of low speed rear end crashes where the striking car does not brake (50%

of crashes) 151,848 whiplash injuries would be saved.

The average whiplash claim cost is €4,000 [2]. This equates to an estimated cost saving of €607,392,000 for the 151,848 whiplash injuries that could be saved by City Safety. Combined with the repair cost savings of €1.3 billion, a City Safety equipped fleet could potentially reduce Insurance Claims by nearly €2 billion annually.

Driver adaptation

The potential effectiveness of any automatic braking system like the City Safety system depends upon whether a driver will adapt and rely on it, negating any crash reduction potential. There are progressively more and more automotive primary safety technologies coming onto the market from increasing numbers of manufacturers, including technologies offering similar automatic braking systems to City Safety. However there is little commonality between the different systems in terms of functionality and system operation. The introduction of these new systems raises a number of important questions. Will drivers understand the meaning of a warning when it is given, what the warning is referring to, and its criticality? More importantly will they react appropriately? Will drivers adapt to these technologies reducing any safety benefits that may have been available? In a worse situation, if one vehicle usually indicates a non-critical occurrence such as low fuel, in another vehicle a similar warning may indicate an imminent collision. Such misunderstandings could be potentially fatal.

Two test types were undertaken on the City Safety system. The first test involved creating a collision scenario that is prevented by the system. The second test type was normal driving on public roads with the system operational, followed by questionnaires used to investigate drivers' reactions and opinions of the system.

DRIVER COLLISION ASSESSMENT TEST

Method

The participants drove the test car toward an inflatable target car at 16km/h (10m.p.h.) without braking. The City Safety system autonomously braked the vehicle so preventing the impact. To avoid risk of damage to vehicles or injury to participants an inflatable target was used. The inflatable target was a life sized representation of a car to elicit the appropriate response from the driver – many people were frightened by its realistic dimensions. Prior demonstrations of the system using traffic cones revealed that whilst the system was activated correctly, driving toward the traffic cones did not alert the driver in a realistic manner because it did not resemble a real crash situation. The realistic size and shape of the inflatable car aids the drivers understanding of the situation, and so gives a more realistic response.

The collision assessment tests were carried out on a test track. The driver was asked to drive normally toward the stationery inflatable car at the required speed, but not brake (see Figure 1). The test conditions and timings varied, for example some tests were in the rain with the windscreen wiper system in operation, some in normal dry daylight conditions, and some in partial darkness.

There were 99 participant drivers. Participants were aged from 20 to 70 years, and all of them were qualified to drive in the UK. Not all participants were from the UK, with 10% from other countries internationally. Most drivers were asked to complete the survey immediately after completion of the test, and some were given chance to reflect upon their experience.

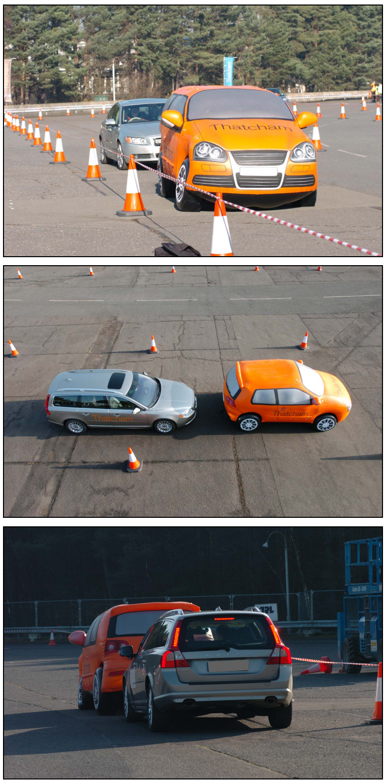

Figure 1. Driver Collision Assessment Test.

Results

Only 4% of drivers believed prior to the test that the car would not actually brake. 37% of drivers had seen the system operate for another driver so believed that the car would brake automatically. 59% of drivers believed prior to the test that the car would brake without having seen it operate previously.

67% of drivers felt the urge to apply the brakes as they approached the target balloon car and did not act upon it. 11% of drivers felt the urge to brake and actually applied braking by pressing the brake pedal. Some of these drivers actually had to repeat the test several times in order to overcome their instinctive fear of a collision and their consequent urge to apply braking. 22% of drivers did not feel any urge to brake as they approached the target.

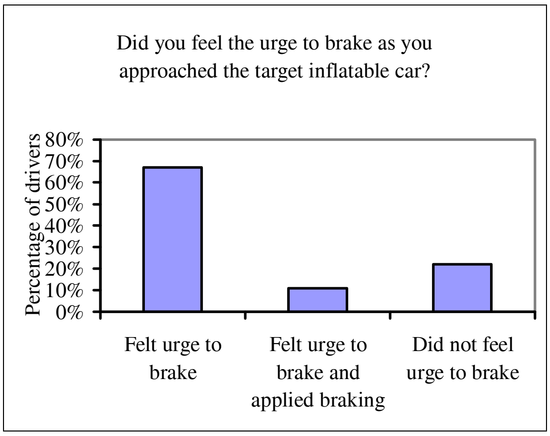

Figure 2. Drivers urge to brake in response to collision situation.

Assuming that they could afford it, 93% of drivers said that they would choose to have City Safety fitted on a car that they were purchasing.

Drivers were asked if they would rely on the City Safety system to brake for them during normal driving conditions i.e. that they would adapt their driving style to incorporate the functionality of the system. Only 5% of drivers stated that they would rely on City Safety during normal driving. 95% of drivers stated that they would not rely on City Safety during normal driving, and that it was only for automatic braking in emergency situations if the driver was distracted.

Discussion

The collision assessment survey results from drivers reveal a strong trend indicating that they are unlikely to adapt their driving style to a City Safety type system, and allow the system to brake for them. 78% of drivers felt the urge to brake when approaching the target and 95% of drivers stated that they would not rely on the system during normal driving. Driver adaptation to the City Safety system therefore seems highly unlikely.

There was also a group of non-participants i.e. those drivers who refused to participate. They were so afraid of relinquishing control of the vehicle braking to the vehicle that they would not participate in the collision assessment test. This also confirms the trend that drivers are unlikely to adapt their driving style to rely on the system to brake for them in normal driving. These 5 drivers' responses are not counted in the analysis of the 99 drivers who did participate in the tests.

2 drivers commented on their perceived increased risk of a rear-end impact in additional comments on the survey. Their concern was that the car behind would be more likely to run into the rear of their car when City Safety braked suddenly. These drivers were informed that City Safety cannot apply more braking force than the driver so cars autonomous braking is merely replacing that of the driver. If the car does not have City Safety fitted and the driver does not brake there would inevitably be a crash, consequently leaving the person travelling behind little time to respond either since no brake lights would show. The autonomous braking of City Safety activating the brake lights could indeed help to warn any following drivers earlier, hence adding to the potential benefit of the system.

ROAD DRIVING TEST

Method

Participants were loaned the test vehicle shown in Figure 3 for a period of up to one week to allow familiarisation with the controls. The test car was an S80 loaned by Volvo that was retro-fitted with the City Safety system for purposes of the research. The system is only fitted to new cars, and was launched on the XC60 in November 2008.

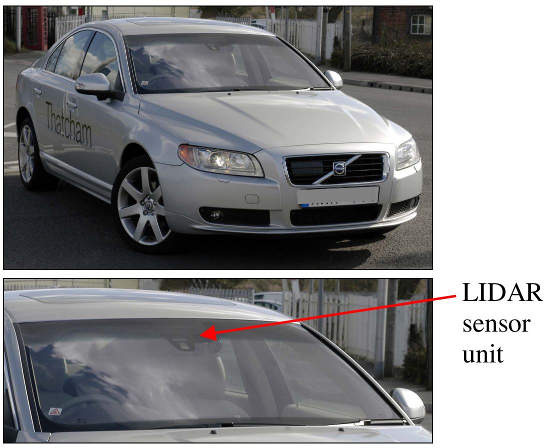

Figure 3. Road driving test vehicle fitted with City Safety.

The drivers used the car for normal road driving within the UK on varying urban and inter-urban journeys. Feedback was gathered from 11 drivers who regularly travel high mileages. The mileage travelled included an equal split between motorways as well as urban and rural roads, all of which were normal UK roads, for a combined distance of over 20,000 kilometres. Participants were aged between 25 and 55 years old, and all held full driving licences.

Results

During the road driving trials all the 11 drivers had the City Safety system operational, since it could not be de-activated on the test vehicle. For all drivers, no positive interventions of the City Safety system were reported, and no false interventions either.

50% of drivers reported that they felt safer than usual knowing that they were driving the car fitted with City Safety that had the capability of preventing a low speed collision. 30% felt no different driving the test vehicle compared to their usual driving. 10% of drivers felt more confident driving the car fitted with City Safety, and the remaining 10% felt more nervous.

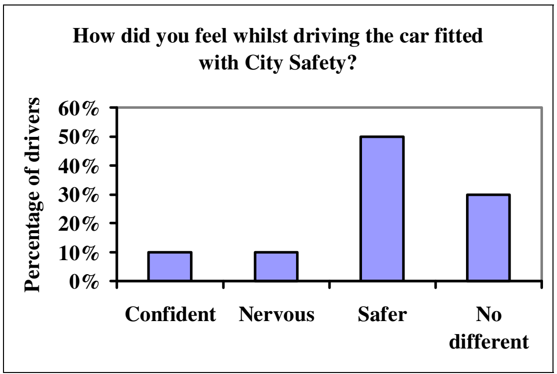

Figure 4. How drivers felt whilst driving car fitted with City Safety on normal UK roads.

Only 2 of the drivers were aware of the system whilst driving. These drivers were conscious that they could see the components of the system or they were monitoring whether the system was operating. The majority of drivers (82%) were not aware of the system during normal driving, so it was in the background and did not distract them.

Discussion

None of the drivers encountered an emergency situation where the system would activate, so the City Safety system did not actually intervene for any drivers during their road trials. None of the drivers encountered a situation where City Safety was required to prevent a collision. Furthermore there were no false interventions. False interventions could annoy drivers and lead them to mistrust such technologies preventing their widespread adoption in the vehicle fleet, so the lack of false interventions in this study is an important finding.

The majority of the participant drivers reported that they felt safer, or no different to normal, driving when using the system. This indicates that most drivers were content with City Safety on their car. The 2 road drivers who were aware of the system during normal driving noticed it because of the prototypical nature of the equipment fitted onto the loan vehicle's windscreen with visible components and wiring. Production vehicles have the system sensors cosmetically encased and will consequently be less noticeable.

CONCLUSIONS

In order to identify an impending low speed impact the City Safety system uses a LIDAR sensor mounted in the front windscreen. The car brakes are automatically applied when an imminent collision is identified. The automatic braking can prevent an impact under 15 km/h and can mitigate an impact between 15 and 30 km/h. The City Safety system prevents common low speed crashes where whiplash typically occurs. It shows potential for reducing the burden on the wider society as well as insurers. The UK estimates presented indicate the system could affect 351,000 crashes annually by preventing or mitigating the crash. The estimates show that City Safety could also save over 150,000 crashes involving whiplash injuries. This equates to an estimated cost saving of nearly €2 billion.

Studies of driver responses in normal road driving showed no interventions of the system, including no false activations. Collision prevention testing involved drivers driving toward an inflatable target car resulting in automatic application of the brakes to prevent an impact. In these collision assessment tests the majority of drivers felt the instinctive urge to brake in response to the collision situation that was created. Drivers also stated that they understood that the system is designed for emergency situations only and they would not rely upon the system in normal driving. This driver study indicates that driver adaptation to the City Safety system seems unlikely.

The City Safety system appears to offer significant benefits to all drivers in preventing the most common sort of impacts. The system is low cost and can be readily made available across a new car fleet. Estimates presented in this paper indicate that significant reductions in injuries and repair costs are possible. Due to the late activation of the system in the collision process and the harsh and unpleasant emergency braking applied, an activation of City Safety is expected to discourage drivers from adapting to the technology.

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