CITY SAFETY
– A SYSTEM ADDRESSING REAR-END COLLISIONS AT LOW SPEEDS

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ABSTRACT

Rear-end collisions account for a substantial amount of crashes. The vast majority of rear-end collisions occur at speeds up to 30 km/h, mostly in city traffic. A common cause of these crashes is driver distraction. A rear-end collision might lead to soft-tissue neck injuries for the occupants in both vehicles involved, as well as material damages. The objective of this study is to present and discuss the potential benefit of a production system helping the driver to mitigate and in certain situations avoid rear-end collisions in low speed.

City Safety monitors the traffic in front with the help of a laser sensor that is built into the windscreen's upper section. It can detect the rear-end of a vehicle in front of the City Safety equipped car. If the driver is about to drive into the vehicle in front and does not react in time, the car brakes itself. The scope for the system is every day low speed scenarios, like cues or entering roundabouts, situations where a large portion of collisions appear due to distracted drivers. City Safety is active at speeds up to 30 km/h. If the relative speed difference between the vehicles is less than 15 km/h it can help the driver to avoid a collision completely. In relative speed differences above 15 km/h up to an absolute speed of 30 km/h the objective is to reduce speed as much as possible before a collision occurs.

Independent evaluation has shown that this technology offers the potential benefits of reducing collisions, leading to a substantial reduction in car damage costs and injuries to the occupants. Based on available statistics and dose-response model techniques, the reduction of impact severity is estimated to have the potential to reduce the risk of soft-tissue neck injuries in the rear-end impacted car by approximately 60%. Real-world retrospective studies of the production system will enable more precise quantification of the effect in the future.

INTRODUCTION

Focusing on light vehicle crashes Najm et al. (2007) using the NASS/GES database, show that rear-end collisions are the most frequent among all crash types, accounting for 29% of all police-reported crashes in the United States, summing up to approximately 1.8 million annually. In Japan, ITARDA data reveals rear-end collisions consistently being the most numerous of all types of crashes (Watanabe and Ito, 2007). In 2005, they accounted for approximately 32% of all crashes, representing approximately 300,000 collisions. The numbers of rear-end collisions in UK are around 26% of the approximately 2.7 million motor crashes resulting in insurance claims, annually (Avery and Weeks, 2008).

Studying German GIDAS data, Eis et al. (2005) found that most of the car-to-car single rear-end collisions occurred on urban roads. Using reconstruction techniques, Eis et al. show that approximately 70% of the striking cars in car-to-car single rear-end collisions have an impact speed lower than 30 km/h. Another German study found that the difference in speed between the vehicles at the time of the collision was less than 15 km/h in more than 70% of 496 random sampled rear-end collisions involving personal injury (Langwieder et al. 1998).

A typical causation of low speed rear-end collisions is driver distraction or inattention. In the so called US 100 car study, the first of its kind where detailed information on a large number of near-crash events is collected, nearly 80 % of all crashes and 65 % of all near-crashes involved driver inattention just prior to the onset of the conflict (Neale et al. 2005). Inattention was a contributing factor for 93% of rear-end collisions. Half of these drivers did not brake before the impact. This is found in statistical crash data collections as well. Analyzing UK National accident database (STATS19) from 2005, Grover et al. (2007) found that the drivers in 44% of the vehicles in the sample took no avoiding action prior to the impact.

For occupants in cars being impacted from the rear, soft tissue neck injuries are the most frequent injury type. Although usually not life threatening it can result in long term pain and disability. Seat technology such as WHIPS (Lundell et al. 1998) and SAHR (Wiklund et al 1998) are developed and found very effective in reducing the risk of neck injuries in a rear-end impact (Viano and Olsén 2001, Farmer et al. 2003, Jakobsson and Norin 2004, Kullgren et al. 2007). Jakobsson et al. (2008), summarizing almost ten years of experience of Volvo cars equipped with WHIPS, stated that although the risk is higher in higher impact severity, a large number of occupants reporting neck injuries is found in impacts, only requiring repair of the bumper system. For total injury reduction, low impact severity events are just as important to focus.

Also, for the occupants in the impacting car, there is a risk of sustaining injuries such as soft tissue neck injuries (Kullgren et al. 2000, Jakobsson et al. 2004, Jakobsson 2004). Airbags and seat belt pretensioners have been found effective in reducing AIS1 neck injuries in frontal impacts (Kullgren 2000), although this is not applicable at severities below activation levels.

Ultimately, systems of avoidance would be optimal, eliminating the impact as such. In recent years, collision avoidance or mitigation systems have been introduced with the aim to alert the driver of an impending impact into the rear of the car in front. Forward collision warning with auto brake is such a technology (Coelingh et al. 2007), warning the driver and pre-charging the brakes if there is a risk of running into the car in front and in case the collision is imminent applying the brakes to mitigate the impact.

This study presents the most recent system put in production that can help the driver to avoid rear-end collisions in low speeds.

CITY SAFETY - SYSTEM DESCRIPTION

City Safety is a low speed collision avoidance and mitigation system with the aim to mitigate and in certain situations avoid rear-end collisions. The scope for the system is to assist in every day scenarios like cues, entering roundabouts or parking situations, scenarios that may end up in collisions due to drivers being distracted or inattentive, Figure 1.

Figure 1. City Safety – a low speed auto brake system

If the vehicle in front suddenly brakes and City Safety determines that a collision is likely, the brakes are pre-charged. If the driver remains inactive, the car automatically applies the brakes. If the relative speed difference between the two vehicles is less than 15 km/h then City Safety may help to entirely avoid the collision. In relative speed differences above 15 km/h up to an absolute speed of 30 km/h, the focus is on reducing speed as much as possible prior to impact.

City Safety is always on at startup but the driver has the possibility to temporarily turn off the system if this is required in a specific situation, e.g. off-road driving. City Safety is developed to react to vehicles in front that are either at a standstill or are moving in the same direction as the car itself.

Once the system has activated, the driver is given a message as shown in Figure 2. There is no warning given. To help prevent drivers from adapting their normal driving to the system it is deliberately designed to give a harsh/ unpleasant braking sensation, with brake activation that is intentionally set late to be outside the drivers comfort zone.

Figure 2. City Safety activation message

Sensor system

The City Safety system actively scans the area in front of the vehicle through the use of an infrared laser sensor (LIDAR) integrated into the top of the windscreen at the height of the rear-view mirror, Figure 3. The position ensures a clear view since the area in front of the sensor is cleaned by the windshield wipers.

Figure 3. Placement of City Safety laser sensor behind the windshield.

The sensor utilizes 905 nm laser light. It has multiple IR laser channels to detect at which lateral position in front of the vehicle a potential target vehicle is placed. The transmitted laser light is reflected by the reflective surfaces of the target and the sensor uses the time of flight principle to calculate the distance to potential targets. In other words, the time from transmission to reception determines the distance to the potential targets. Relative velocity and acceleration is derived from multiple distance measurements. Vehicles within 10 m in front of the sensor are detected.

City Safety Controller

Scenario Detection

City Safety has been developed to assist in a large number of real world situations addressing rear-end collisions, exemplified by; stationary and moving objects, straight roads and when negotiating a curve, different road conditions, speeds (<30 km/h) and car-to-car overlaps, day and night. Although the system can not detect distraction as such it is developed with distraction in real life driving situations in focus, exemplified by; the rush hour queue 'eyes and mind somewhere else', 2nd car in roundabout 'finding your gap', parking lot driving 'finding the spot', city driving 'finding your way' and other in-car and road-side distractions.

Continuously when driving, the path of the City Safety equipped vehicle (host) is calculated and a potential target vehicle in the host vehicle path is evaluated by the threat assessor (see Figure 4). Vehicle cut-ins and cut-outs are also treated as unique scenarios.

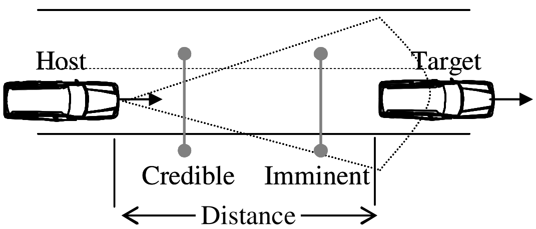

Figure 4. Illustration of threat assessment

Threat Assessment

Based on the speed and acceleration of the host vehicle, the speed and acceleration of the target vehicle and their relative distance, the system makes 50 calculations per second to determine what deceleration would be needed to avoid a potential collision. The calculation includes compensations for system response times.

The measured information is used to determine the probability of running into a stationary or moving potential target vehicle in the host vehicle path. If the calculated deceleration needed to avoid a collision exceeds a certain level without the driver responding, the system determines that the probability of a collision is credible. If the needed deceleration rises even higher it is judged to be imminent, see Figure 4.

System Activation

If the threat assessor is judging the collision probability as credible, the brake system is pre-charged for faster brake response. If determined to be imminent, auto brake is activated and emergency brake assist sensitivity is raised.

Once City Safety is activated it helps either to avoid or reduce the severity of the collision by automatically braking the car with on average 0.5 g and reducing the throttle opening. At the same time, the brake lights are activated to warn the traffic coming from behind. The symbol as in Figure 2 will inform the driver about the activation. When a collision towards a stationary vehicle is avoided, the host vehicle is kept stationary by the brakes for approximately 1.2 second, after which the brakes are released.

Driver Override

The system is overridden by the driver if he/she gives a large steering or throttle input, the system having calculated that the driver is taking evasive action and is aware of the situation.

SYSTEM PERFORMANCE

Verification methods

To validate and verify the functionality of City Safety, extensive testing was carried out. The tests were performed on test tracks as well as in real traffic on public roads in order to:

- verify that the system provides an intervention in the driving scenarios that constitute a high probability for a rear-end collision and does not fail to intervene in these collision scenarios, and to
- verify that the system does not disturb the driver with false activations, under normal driving conditions.

Test track tests

The positive system activation (intervention as intended) performance was verified in a large variety of rear-end collision scenarios performed at different test tracks. The scenarios were based on situations identified as frequent and important from real world driving situations. Numerous test set-ups were established using stationary and moving target vehicles of different sizes and shapes; a combination of straight roads and when negotiating a curve in different angles; a variety of different lateral offsets between host and target vehicle; varying roads, weather and light conditions in different accelerations and speeds. Differences in driver behavior were also considered.

Special test equipment was developed and used for the different test purposes. Target vehicles were represented by large inflated balloon cars (Figure 5) and modified vehicles (Figure 6) that allow for possible collisions with the host vehicle. The balloon car can also be attached to a horizontal beam connected to a vehicle such that it also can represent a moving target in different scenarios.

Figure 5. Target vehicle represented by an inflated balloon car.

Figure 6. Target vehicle represented by a half real vehicle body.

Public road tests

Extensive testing on public roads was performed to verify that the system does not disturb the driver with false activations under normal driving conditions. During these tests, the system automatic brake intervention was not active. However, data was collected and analyzed with respect to whether an activation would have occurred or not.

Normal driving conditions were defined using real-world user profiles. A profile represents the contextual conditions in terms of road type, lighting and weather condition as well as input from the driver population. A total of one million kilometer relevant data was collected, stored and analyzed. The data was collected in all major European cities, in Sweden, cities in Thailand, Malaysia as well as the west and east coast of United States. Emphasize was put on gathering information from different types of city traffic as well as with different types of driving attitude and other driver characteristics (age, experience etc). A blend of defensive and offensive drivers including professional were used. Tests were also run during extreme weather situations, such as desert heat and Nordic winter weather.

The purpose of the testing was to gather data to provide input for the system performance when exerted to all possible situations in real traffic with the goal to ensure that false activation was minimized.

EFFECTIVENESS

Data from Germany indicates that in approximately 70% of car-to-car single rear-end collisions the striking car impacts with speeds below 30 km/h (Eis et al. 2005). Other studies claim that in approximately half of the cases the driver do not brake at all before the collision, mainly because of distraction (Neale et al. 2005, Grover et al. 2007). In these cases, City Safety could make a crucial difference. City Safety brakes the car automatically if the driver is about to drive into the vehicle in front. A collision can either be entirely avoided or if this is not possible, the damage to cars and people can be reduced, for absolute speeds up to 30 km/h.

The area of predicting the real-life safety benefit of an active safety systems covers a broad variety of aspects from the driver-car interaction to issues such as socioeconomic impact by reducing accidents and occupant injuries. This area is complex and today impossible to cover completely. Even the more limited focus of a car manufacturer is wide; accident avoidance and accident severity reduction addressing both potential injury reductions in host as well as target vehicle are key areas. To this can also be added the potential savings in terms of car damage costs and repair time.

A study by Thatcham stated that the City Safety system by preventing common low speed rear-end collisions, where soft tissue neck injuries typically occur shows great potential for reducing the burden on insurers and the wider society (Avery and Weekes 2008). The authors estimate that the system, if available in all cars, could affect 210,600 collisions in the UK annually by preventing or mitigating the collision. This includes over 91,000 collisions involving soft tissue neck injuries estimated to save costs of 1.1 billion Euros.

A study by IIHS in US estimates that systems focusing prevention or mitigation of frontal impacts by intervening in these situations address a very large amount of relevant situations (IIHS, 2008). No details are given in the study with respect to impact speeds or other circumstance, whereby no more detailed benefit estimation of what a system like City Safety would offer is to be found.

A Volvo car equipped with City Safety offers a range of benefits both to the occupants in the City Safety equipped vehicle and to the occupants in the potential target vehicle in its path.

Occupants in City Safety equipped vehicle

Impacting a vehicle in front of you can be both a physically harmful and an emotionally unpleasant experience. By reducing the velocity prior to the impact, City Safety reduces the injury risks for the occupants, or even eliminates them completely if the collision is avoided.

Using information from crash recorders, Kullgren (2008) found that long term (>1 month) soft tissue neck injury risks in frontal impacts are approximately 10% in 15 km/h change of velocity and 20% in 30 km/h. Crash recorder data from Volvo cars in frontal impacts confirms that there is an increased risk of soft tissue injuries with increased change of velocity (Jakobsson 2004). It is also seen that soft tissue neck injuries are found in very low speed frontal impacts. Jakobsson (2004) also concludes that not only the crash pulse measures influence the injury occurrence, but other parameters related to occupant and sitting posture are probably of equal importance. None of the two studies provide details enabling to sort out the rear-end collision types of frontal impacts as the City Safety target; making it difficult to quantify the total potential effectiveness of such a system. However, these overall facts and figures provide support that the occupants in the City Safety equipped vehicle have much to gain by avoiding or mitigating a potential low speed rear-en collision.

Occupants in potential target vehicle

For the occupants in the target vehicle, City Safety will offer a less severe impact or no impact, saving health, time and money. Soft tissue neck injuries are frequent in rear-end impacts, even at rather low impact severity (Jakobsson et al. 2008).

Based on crash recorder data and long term neck injury risks in rear-end impacts, using dose-response models, Kullgren (2008) has made estimates of the effectiveness of City Safety. Assuming that all rear-end impacts can be regarded as rear-end collisions and that the reduction in change of velocity would be approximately half of the reduction in impact speed, a system that automatically brakes in rear end collisions with 15 km/ at impact speeds below 30 km/h, has the potential to reduce the number of injured occupants by 60%.

Reduced owner costs

Even collisions at the lowest speeds can result in significant costs and repair time. City Safety helps the owner to reduce time-consuming contacts with the workshop and insurance company. This has been acknowledged by several insurance companies that are now providing incentives such as insurance premium discounts for cars equipped with City Safety.

In UK, Avery and Weeks (2008) estimate that a system like City Safety would save a large amount of repair costs. They base the calculations on the fact that rear-end collisions account for 26% of the totally around 2.7 million motor crashes resulting in an insurance claim annually in the UK and that 75% of these occur at speeds below 30 km/h. Avery and Weeks estimate that in 30% the driver does not apply the brake, acknowledging that the estimate is currently conservative since insurance data indicates that for up to 50% of cases the driver does not apply braking. Based on these assumptions they identify 157,950 collisions that City Safety could help to prevent, with estimated savings of €590,101,200 and additional 52,650 collisions with reduced repair costs estimated to savings of €196,700,400.

DISCUSSIONS

Soft tissue neck injuries as a result from rear-end collisions is despite effective seats in the impacted car still a frequent and costly injury in car crashes. Adding to the fact that the occupants in the impacting car also can sustain neck injuries and the time and money needed to repair the vehicles, it is easy to understand the high benefit of avoiding or mitigating rear-end collisions. City Safety addresses the frequent low speed rear-end collisions, usually occurring in heavy city traffic and often when the driver is distracted in some way.

Although City Safety is developed to react to vehicles in front that are either at a standstill or are moving in the same direction as the car itself, it might also detect other objects like pedestrians, appearing in front of the car. However, the main recognition pattern used to develop the system is that of the rear end of another vehicle. Other systems with higher effectiveness for vulnerable road users are under development.

City Safety does not offer a warning prior to activation. The reason for this is mainly the time available. At low speeds it is more effective to break to avoid a collision than to steer away from one making it possible to create a collision avoidance system by utilizing braking. City Safety is developed based on these principles. Other systems exists and are under development addressing other situations, where warning aspects are important.

The system is designed to give a late, harsh and unpleasant braking sensation to prevent drivers from adapting their normal driving to the system. Avery and Weekes (2008) concluded, based on collision assessment tests by 98 drivers using City Safety equipped vehicle towards an inflatable target vehicle, that driver adaptation to the system seemed highly unlikely. 78% of the drivers felt the urge to brake when approaching the target and 95% of the drivers stated that they would not rely on the system during normal driving. Thus it seems that the system works as intended.

The sensor behind City Safety offers not only the avoidance and mitigation aspect of safety, but also incorporates the functionality of further enhancing the passive safety by preparing the restraint systems in a frontal impact (so called Pre-prepared Restraints, PRS). This is a unique customer offer coupling active and passive safety using the same sensor technology hardware.

Independent evaluation has shown that this technology offers great potential benefits in substantial reduction of injuries and damage costs. Estimates based on crash recorder data and dose-response techniques predicts an effectiveness of approximately 60% for long term neck injuries in the potential target vehicle. The availability of precise low speed collision data is limited and thus influences the possibilities to calculate an effectiveness figure for the occupants in the City Safety equipped vehicle with respect to risk of injuries. However, based on the relatively high risk of neck injuries even in low impact severity, it is realistic to estimate an almost as high effectiveness figure as for the target vehicle. Real-world follow-up studies of the production system will enable more precise quantification of the effect.

The system does not only include benefits with respect to injury prevention and risk reduction but also include benefits with respect to cost of ownership with reduced repair costs. Low speed rear-end collisions with drivers being distracted or inattentive are very frequent so the effectiveness of a system like City Safety has great potential with respect to savings in costs and time for the owner. Also, less than a year after introduction, there are several insurance companies worldwide offering discounts for the cars equipped with the system, and thus consequently adding extra savings to the owner.

The estimated benefit calculations as presented in this study as well as by independent institutes in the United States (IIHS, 2008), the United Kingdom (Avery and Weeks 2008) and Sweden (Kullgren 2008) all identifies large potential benefits in reductions of crashes, injuries and thus reductions of costs and time savings both for the society and the individuals.

CONCLUSIONS

This study presents and discusses a new active safety system, City Safety. Being standard equipment in a Volvo model, it helps the driver to avoid rear-end collisions in low speeds. If the driver is about to drive into the vehicle in front and does not react in time, the car brakes itself. If the relative speed difference between the two vehicles is less than approximately 15 km/h then City Safety may help to entirely avoid the collision. In relative speed differences above 15 km/h up to an absolute speed of 30 km/h the focus is on reducing speed as much as possible prior to impact.

A car equipped with City Safety offers a range of benefits both to the occupants in the City Safety equipped vehicle and to the occupants in the potential target vehicle in its path. Also, City Safety helps the owner reduce time-consuming contacts with the workshop and the insurance company and saves costs for the repairs. In several countries insurance companies offer insurance premium discount, for cars equipped with City Safety. The benefit of such a system on the potential of soft tissue neck injuries in both the vehicles is obvious, and an important step towards prevention of neck injuries in minor impact severities. Independent evaluation estimates that City Safety has potential to reduce the risk of soft-tissue neck injuries in the rear-end impacted car by approximately 60%. Real-world follow-up studies of the production system will enable more precise quantification of the effect.

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