COLLISION WARNING WITH AUTO BRAKE - A REAL-LIFE SAFETY PERSPECTIVE

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ABSTRACT

Automotive safety has gained an increasing amount of interest from the general public, governments, and the car industry. This is more than justified by traffic accident statistics, as each year around 1.2 million people die due to road traffic accidents. For these reasons safety remains a core value of Volvo Cars. This paper presents some of the latest active safety developments within Volvo Cars.
Rear-end collisions are common accident scenarios and a common cause of these accidents is driver distraction and thus not reacting in time. No vehicle system is a substitute for the most important safety feature in any vehicle: the driver. However, Volvo is harnessing innovative technologies to help alert drivers to avoid potential collisions and reduce the potential impact speed when a collision cannot be avoided.
One of those systems is Collision Warning with Auto Brake where the area in front of the vehicle is continuously monitored with the help of a long-range radar and a forward-sensing wide-angle camera fitted in front of the interior rear-view mirror. A warning and brake support will be provided for collisions with other vehicles, both moving and stationary. Additionally, if the driver does not intervene in spite of the warning and the possible collision is judged to be unavoidable; intervention braking is automatically applied to slow down the car. This aims at reducing impact speeds and thus the risk for consequences.
This system has been verified using innovative CAE methods and practical tests. Finally, it is discussed how the benefit of such systems can be judged from real-life safety perspective using traffic accident statistics.

INTRODUCTION

Over the years, automotive safety has gained an increasing amount of interest from the general public, governments, and the car industry. Traffic accident statistics more than justify this focus, as each year around 1.2 million people die due to road traffic accidents [1].
Safety is and remains a core value of Volvo Cars, and it has a long tradition. A successful way to attain continuous improvements in safety development is a working process based on real world situations and the feed-back of this information into the product development. This working method has been found very effective in passive safety development [2]. The present study applies this working process into development of new active safety systems. Active safety systems require a wider scope of the study and performance goals, thereby expanding to accident occurrence beside injury protection and opponent vehicle beside host vehicle. The aim of this paper is to present some of the latest active safety developments within Volvo Cars and to put them into context of the working process [2].

REAR-END COLLISIONS

This section will put the area of rear-end collisions in the context of real-world situations. Accident data will be used as the basis for the problem definition as well as for the calculation of benefit. A brake-down of the problem definition is used to guide the evaluation and performance prediction process. For this purpose, three different sets of accident data will be used.

Statistical accident data bases

Three databases from three different countries are used as the basis for the problem definition.

Figure 1. Volvo's Traffic Accident Research.

Volvo's statistical accident database contains Volvo vehicles in Sweden in which the repair cost due to an accident exceeds a specified level, currently SEK 45000. The database, which contains information about the crash, the vehicles and the

occupants including injuries if any, is further described in [2].
The GIDAS database (German In-Depth Accident Study) is the second European database used in this study. Traffic accidents within Hanover and Dresden and the rural areas surrounding these cities are investigated according to a statistical sampling process [3].
As a complement to the European data, NASS/CDS (National Automotive Sampling System Crashworthiness Data System) is also used [4]. CDS provides in-depth crash investigations of a representative sample of police-reported tow-away crashes throughout the United States. Data is weighted to provide a nationwide estimate of all types of crashes and injuries.

Problem definition

Compared to the evaluation of passive safety systems, active safety systems require a wider scoop of the study and performance goals. It includes accident occurrence together with injury protection for opponent vehicles as well as for the host vehicle, as illustrated in Figure 2.

	Minor-Severe Accidents	**Occupant injuries**
Host vehicle	reduction ↘	reduction ↘
Opponent vehicle	reduction ↘	reduction ↘

Figure 2. Problem definition active safety.

Najm *et al.* [5], focusing on light vehicle crashes in the NASS/GES database, show that rear-end collisions are most frequent among all crash types accounting for 29% of all crashes. In the present study, the numbers of occurrences are clustered in impacts instead of collisions. Note that a collision is an event where possibly several vehicles can be involved and an impact is a consequence for a single vehicle. The aspects of self protection are accident reduction and occupant injury reduction from the host perspective. Partner protection is thus accident reduction and occupant injury reduction from the opponent perspective. Below, these will be dealt with separately.

Self protection

The distribution of impact configurations is shown in Figure 3. Approximately 50% of all impacts are to the front of the vehicle. Frontal impacts into an opponent motor vehicle's rear end account for 6-9% of the total share. Even though different selection criteria for the different data sets are used, the distributions are quite similar.

The occupant injury share from this type of impact situations can be seen in Figure 4 of all MAIS2+ injuries. In the three datasets used, frontal impacts into an opponent motor vehicle's rear end account for up to 5% of the total share of MAIS2+ injuries. The relatively small share is mainly due to the relatively low impact severity level in comparison to the other frontal impact situations.

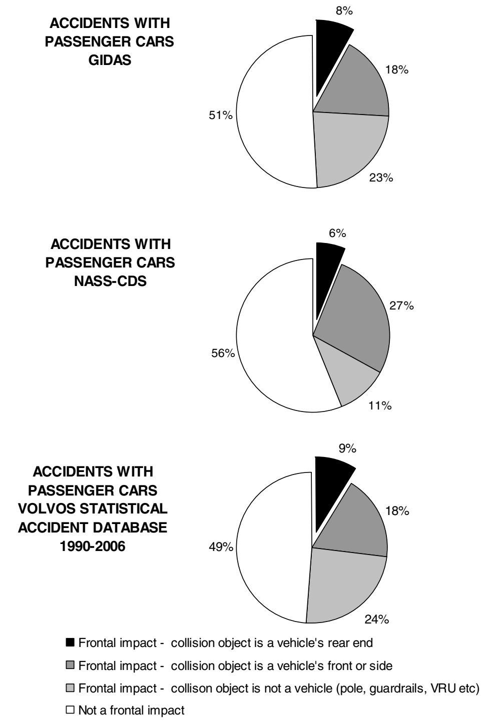

Figure 3. Distribution of impact configuration from a host perspective.

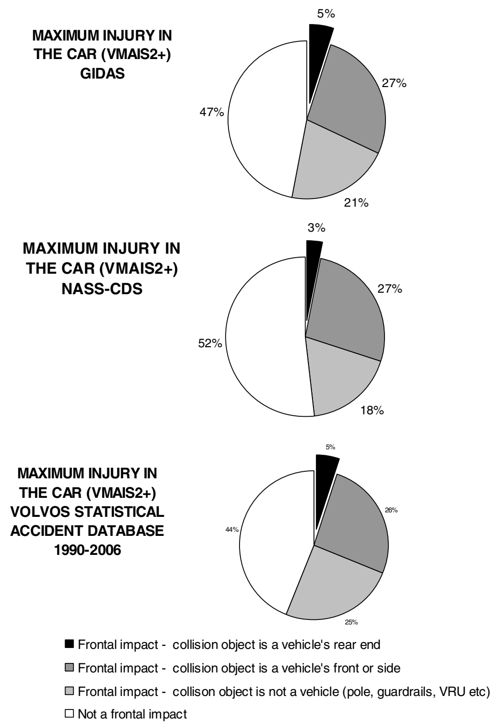

Figure 4. Distribution of MAIS 2+ injuries from a host perspective.

However, excluded in Figure 4 are all AIS1 injuries, such as *e.g.* AIS1 neck injuries. These injuries are frequent, can occur even at low impact severity and are the most common injury type of all in a frontal impact according to Volvo's statistical data base [6].

Partner protection

If considering impact situations from a partner protection perspective, the majority of impacts to the rear of the car is due to another passenger vehicle running into them. As can be seen in Figure 5, 12% in GIDAS, 6% in the Volvo data and 4% in NASS/CDS of the totals, were vehicles impacted from the rear by another passenger vehicle. These differences probably reflect the differences in collection criteria for the different data sets. NASS/CDS only covers tow-away situations; the Volvo data is collected based on a repair cost limit, including also situations without tow-away. In GIDAS even low-impact severity events are included and by that the most comparable set to the data in NASS/GES as used by [5].

Occupants in the opponent vehicles are also exposed for possible occupant injuries. In the vehicle impacted from the rear, the most common injury type is AIS 1 neck injuries, often referred to as whiplash injuries [7]. These injuries are very frequent and can occur even at low impact severity.

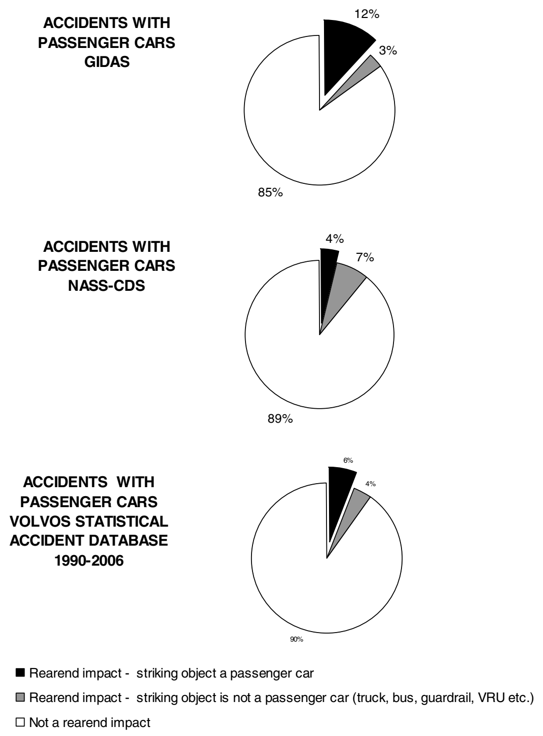

Figure 5. Distribution of impact configuration from an opponent perspective.

Accident occurrence

For intervention and development of active safety systems it is also important to understand the parameters influencing the accident type and traffic situation of interest and further consider reasons behind accident occurrence. It is not only important to understand what happened in an accident, but also to understand why an accident happened in the first place

Driver inattention and thus not reacting in time is a major cause of rear-end accidents. In the 100-Car Naturalistic Driving Study, the first study of its kind where detailed information on a large number of near-crash events is collected, nearly 80 percent of all crashes and 65 percent of all near-crashes involved driver inattention just prior to the onset of the conflict [8]. Inattention was a contributing factor for 93 percent of rear-end-striking crashes.

The problem definition points out the importance of the area as well as the focus in the development process. In the next section Collision Warning with Auto Brake is introduced. A detailed description of the system, as well as brief summary of the difference between the first and second generation, will be presented.

COLLISION WARNING WITH AUTO BRAKE

Collision Warning with Auto Brake is an active safety system that helps the driver to avoid or mitigate rear-end collisions. It uses forward-looking sensors to detect obstacles ahead of the vehicle. When a high risk for a rear-end collision is detected the system helps the driver by providing a warning and brake support. If the driver does not react in time and a collision is judged to be unavoidable, the system will automatically brake the vehicle. This may not avoid the accident, but the consequences can be reduced.

This system is introduced in two steps. The first generation, called Collision Warning with Brake Support, is currently on the market in the new Volvo S80 allowing activation on vehicles that are moving or have been detected as moving. The second generation, called Collision Warning with Auto Brake, will be introduced in the near future. The latter system includes the functionality of the prior system but will also activate for stationary opponent vehicles in certain scenarios and will provide auto brake. The differences and the motivation for the two generations are explained in Coelingh *et al.* [9].

Sensor System

Information about the traffic situation in front of the host vehicle is obtained from two sensors:

- A 77-GHz mechanically-scanning forward-looking radar, mounted in the vehicles grille, which measures target information such as range, range rate and angle in front of the vehicle in a 15 degree field-of-view.

- A 640*480 pixel black and white progressive scan CMOS camera, mounted behind the windscreen, which is used for classifying the objects, *e.g.* as vehicles, in a 48-degree field-of-view. Since the camera is used for reporting both vision objects and lane markings, the field of view was chosen to work for both.

The combination of these two independent and complementary sensors provides high-confidence in lead-vehicle detection. This is important as the system should not be activated for stationary objects that are part of the normal driving environment, *e.g.* manhole covers. With only a radar sensor one cannot distinguish between reflections from a vehicle and reflections from any other object. However, the additional object classification of the camera is used to distinguish between vehicles and non-vehicles therefore the risk for false activations can be significantly decreased.

Collision Warning

The Collision Warning (CW) function is targeting to avoid or mitigate collisions by means of warning the driver ahead of a possible collision. The system requires high usability, low number of nuisance alarms and an efficient Human Machine Interface (HMI). The Collision Warning system should provide a relative late warning in order to reduce nuisance alarms and to reduce the possible misuse where an early warning system may build a trust that is falsely interpreted by the driver to allow for execution of non-driving tasks. The activation of the Collision Warning will therefore approximately occur when the driving situation is considered to be unpleasant. However, it shall allow the driver to brake to avoid or mitigate an accident provided the following distance was initially longer than the warning distance (refer next paragraph).

Threat Assessment

The aim of the threat assessment is to understand if the information from the forward sensing system shows that there is a risk for collision. The first step is to approve a lead vehicle as staying in the forward path within a given time to collision utilizing intra-vehicle and yaw-rate information. Given an approved lead vehicle a second step calculates a total warning distance, *i.e.* the predicted distance required for avoiding a collision. The total warning distance base calculation is derived from a sum of three distinct distance calculations. The first is the driver reaction distance which is obtained from the predicted driver reaction time multiplied by vehicle speed. The second is the system reaction distance which is obtained from the system reaction time multiplied by vehicle speed. The third is the braking distance to avoid impact using the current physical states of the lead vehicle and the host vehicle using the constant acceleration model for the behavior of the host and the target vehicle closely mimicking the CAMP late warning algorithm [10]. The sum of above provides a total warning distance. If the distance to the forward vehicle becomes lower than the total warning distance a warning is to be issued.

Furthermore, in order to further reduce nuisance alerts, a predicted driver reaction time modulated by driver action is used. As an example the predicted reaction time is normal when the driver has the foot on the pedals and is following the lead vehicle in a common way. In the event the driver is releasing the throttle or starting to brake, the predicted reaction time is reduced since the system predicts that the driver is aware of a potential danger ahead. Another action performing similar reduction is negotiating a curve. The reduction of the driver reaction time leads to a lower warning distance and consequently less risk of alerting a driver in a normal driving situation.

Collision Warning HMI

An efficient HMI for a warning system is characterized by a low driver reaction time, as this is crucial for improving the possibility for the driver to mitigate or even avoid a collision. Moreover, an efficient HMI puts requirements on low false and nuisance alarm rates, since there is a risk for overexposure that may lead to drivers deactivating the system. A number of studies have been executed related to efficient visual warning interfaces. The selected warning interface is a dual modality warning incorporating visual and audible channels. The visual warning is a flashing red horizontal line located in the lower part of the windshield in the forward direction of the driver, refer Figure 6. The sound consists of tone burst with harmonics content. When the audible warning is active the sound system is muted.

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Figure 6. Collision Warning head-up display.

The Collision Warning can be turned off by a main switch. The system includes a warning distance setting using three levels. The levels have been defined by balancing driver behavior in late brake situations versus normal driving behavior. The warning distance settings are differentiated by the deceleration level used in the different settings, *i.e.*

the predicted brake ability by the driver. They also reduce warnings in normal driving situations to different levels.

Auto Brake

Although it is expected that a large share of drivers unaware of a hazardous traffic situation, will be able to escape this situation due to the received collision warning, there are cases when drivers are not able to react in time to the warning. In that case it is beneficial to the driver to get support in the upcoming collision event. This can be achieved by reducing the collision energy by optimizing driver-initiated braking or through automatically putting on the brakes prior to the collision event, see also [11] and [12].

When providing autonomous interventions that override or complement the driver's actions, one has to ensure that customer satisfaction is not negatively affected by false interventions. Customer acceptance is crucial in order to increase take rates and thus to increase the overall real-life safety benefit of the system. It is therefore necessary to implement a decision making strategy that reduces the amount of false interventions while not missing collision events where the driver needs support.

Therefore, an intervention decision should be based on two main information categories: traffic situation data and driver actions. The traffic situation data is used to quantify the risk for a collision event, in other words a threat assessment is performed. This assessment will never be perfect as sensor information is usually a subset of the totally available information and mostly affected by latencies. So, a collision may appear to be unavoidable but is in reality avoidable. Hence, a driver that takes distinct steering and/or braking action is judged to be in control of the situation and should be trusted. The driver override function is to detect these distinct driver actions.

As soon as the support system has performed the threat assessment and driver override detection, the outcome can be weighted by the brake intervention strategy and a decision on an autonomous brake intervention can be taken.

Threat Assessment

The aim of the threat assessment is to fuse sensor information from the vehicle environment to a collision risk. The collision risk is a probability for a collision to take place, given that the currently observed physical states will be governed by a model for the traffic scenario until the collision instant. The current implementation of the threat assessment makes use of a constant acceleration model for the behavior of the host and target vehicles.

When it comes to the quantification of the collision risk, the motion of the host vehicle in relation to the target vehicles is analyzed. A possible collision event is said to be imminent as soon as neither steering nor brake action would lead to an avoidance of the collision. In terms of accelerations this means as soon as the maximum achievable lateral and longitudinal acceleration due to steering and braking action is less than the needed respective accelerations, a collision is imminent. The ratio of the needed acceleration and maximum achievable acceleration for braking and steering actions is denoted braking threat number (BTN) and steering threat number (STN), respectively, and has been introduced in [13] as quantifier for the collision risk. In [14] this concept is extended to a more generally valid approach.

A derivation of the BTN and STN can be found in [13]. Principally, the idea is to treat the longitudinal and lateral dimension as being independent. Then the BTN can be estimated from the host acceleration, range, range rate and range acceleration measurements. In case of the STN, the derivation requires two steps. First, the time until the possible collision instant is computed and second, the needed lateral acceleration that would lead to a lateral displacement for avoiding the target at the collision instant is estimated. Thus, measurements for lateral offset between host and target at the collision instant is needed, as well as measurements for host and target widths. Both BTN and STN are used in the decision process.

Threat assessment is based on a pure physical interpretation of traffic situation data that is reported by a sensor system. Although this information could suffice to determine if a possible collision event requires immediate braking action, a driver might be fully aware of the situation but has more information available than the sensor system can report. It is therefore necessary to consider driver actions in order to determine if the driver is overriding the support system.

Driver Override

The objective of the driver override function is to inhibit a brake intervention when the driver has the situation under control. However, this is difficult or even impossible to measure and therefore driver inputs as steering and braking activities are considered instead, as these are the natural countermeasures in a collision event. Furthermore, the release of the accelerator pedal is considered, as this indicates that any further acceleration is undesired, and it can be assumed that the driver is thereby acknowledging a collision risk.

Since the level of action that is required to activate a steering or brake override depends on the driver and on the traffic situation, the decision threshold is empirically determined through extensive testing in real life traffic situations with a large number of drivers.

Brake Intervention

When both collision risk and driver override flags are available a decision on a brake intervention can be made. Since there are two numbers available that quantify the collision risk, these number need to be fused. Clearly, several methodologies can be employed. Most straight forward approaches are the usage of the min or max operator yielding a conservative or progressive approach, respectively. A more thorough discussion of the decision concepts for collision avoidance is given in [11] Still, it can be reasoned what role the BTN has when it come to autonomous brake intervention. When the STN reaches or exceeds one, the driver is no longer able to steer away. In other words, the only option that remains for the driver is to brake. Additionally, it can be shown that the BTN is larger than the STN in many traffic scenarios. Usually, in the remaining situations the BTN has rather large values but still below one. This suggests that the STN alone can be used to trigger autonomous braking, yielding a mixture between the conservative and the progressive approach.

When a progressive intervention strategy is used for a support system the false intervention rate is usually increased. In order to achieve a progressive intervention approach with a low false intervention rate, the override flags play a key role. Making use of flag timing in relation to collision risk enables an inhibit strategy that reduces the false intervention rate. Naturally, the trimming of the inhibit strategy is based on physical interpretation of traffic situations and testing results with either artificially generated traffic situations or real-life traffic situations.

In the first stage there are two intervention types: pre-charge and increased sensitivity for Emergency Brake Assist. In a scenario where the rear-end collision risk is judged to be credible, meaning that the BTN and STN are increased but have not yet reached one, these intervention types are activated simultaneously. The pre-charge prepares the brake system for upcoming brake activation in order to reduce latencies. Furthermore, an increased level of pre-charge is applied upon indication that the driver has released the throttle pedal in response to the threat of collision. The brake system continuously monitors the brake pressure and brake pressure gradient of driver-initiated brake applies. When both exceed a certain threshold, full braking is applied automatically until the brake pedal is released (EBA), refer [15]. When a rear-end collision is judged to be credible, this threshold will be lowered, such that the driver can obtain full braking faster and with less effort. At low relative velocities, this brake boosting function can help to avoid a collision, alternatively it will mitigate it, *i.e.* reduce impact speed.

In the second stage, the above described idea is expanded by adding the autonomous braking to the intervention types. Again, the same sequence as above is valid, but as soon as the imminence of the collision is reached and the target object is confirmed as a vehicle, the auto brake command is issued and the host vehicle is slowed down at a deceleration of 0.5g. Moreover, the engine torque is automatically reduced to a level comparable to a full release of the accelerator pedal.

As a precaution, the autonomous intervention length in time is bounded to 1.0 seconds. According to first principals the collision has to occur within that time frame, and thus a longer intervention is not needed. In the rare case of a false intervention the intervention length and thus the inconvenience for the driver is limited.

By using the principles described above, auto brake can reduce the impact speed with up to 15 km/h, depending on the driving scenario.

SYSTEM PERFORMANCE

In the verification of the complete Collision Warning with Auto Brake system, validating both the function performance and the chosen concept are of importance. Minimum requirements for true positive and false positive performance need to be fulfilled and verified with a certain confidence level. The objectives of the tests are:

- to verify that the system provides an intervention in driving scenarios that constitute a high risk for a rear-end accident (true positives) and does not fail to intervene in these collision scenarios (false negatives);
- to verify that the system does not disturb the driver with false activations, under normal driving conditions (false positives).

The true positives are verified in a set of rear-end accident scenarios that have been defined based on real-world accident statistics. These vary in terms of absolute speed and acceleration of host and target vehicle, lateral off-set between host and target, driver behavior *etc*. For all scenarios acceptance criteria for the collision warning activations have been defined.

The false negatives are verified during extensive testing on public road. Normal driving conditions have been formally defined using a real-world user profile. This profile represents the driving conditions in terms of road type, lighting and weather conditions, driver population *etc*.

Verification Methods

The Collision Warning with Auto Brake system has been verified in the selected real world scenarios using different verification methods. In a specially developed simulation environment, Volvo Cars Traffic Simulator (VCTS) realistic Simulink models for traffic environment, driver, vehicle dynamics, sensors, actuators *etc*. are incorporated. The Collision Warning systems can either be represented by Simulink models (off-line simulation) or by the embedded control unit (hardware-in-the-loop simulation).

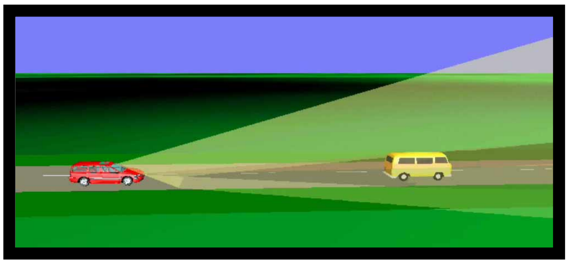

Figure 7. Volvo Cars Traffic Simulator.

The advantage of VCTS is the possibility to batch-analyze the collision warning systems in a large number of collision and non-collision scenarios, in a repeatable way. Acceptance criteria have been defined based on ground-truth data from the simulation environment.
In order to physically test the collision warning system in different collision scenarios, without any risk for personal injuries and property damage, special test equipment has been developed. Target vehicles are represented by large inflated balloons that allow for collisions with the host vehicle.

Figure 8. Physical test environment.

The balloon can be attached to a horizontal beam connected to another rig vehicle, such that it also can represent a moving target in different scenarios.

REAL-LIFE SAFETY EVALUATION

Predicting the real-life safety benefit of active safety systems covers the broad variety from the driver-car interaction to issues such as socio-economic 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. As illustrated in Figure 2; host as well as opponent vehicle, accident as well as occupant injuries are involved.

For the systems in the present study, diverse issues such as speed reduction and driver interacting (*e.g.* warning) are key items and need to be understood and handled separately.

In Lindman and Tivesten [16] a method for estimating the benefit of autonomous braking systems using accident data was presented. It specifically presents a method to estimate the effectiveness of reducing speed prior to impact. The method used for estimating effectiveness of reducing speed prior to impact [16] makes it possible to use any occupant injury risk estimation. Presuming 100% market penetration and system performance as well as optimum friction circumstances *etc*, approximately 50% of the 6-9% of frontal impacts where the collision object is the rear of a vehicle will be avoided, *i.e.* collisions at low speed. For many accident situations the impact speed and hence the consequences will be reduced. The most frequent occupant injuries in rear-end collisions are AIS1 neck injuries, both in the host as well as in the opponent car. AIS1 neck injuries in frontal impacts account for the majority of all AIS1 neck injuries although rear-end impacts account for the highest risk of acquiring this type of injury [7]. Even in these first stages of the development phase for autonomous driver support systems, the risks of AIS1 neck injuries can be considerably reduced both in the host and opponent vehicles just by avoiding a portion of host vehicle frontal impacts using a speed reduction system.

Understanding and quantifying driver-interacting aspects are more difficult than speed reduction calculation. The complete picture is only given in real world situations where, today, only limited data is available. In Najm *et al.* [17] 66 subjects participated in a FOT for a period of four weeks for the purpose of evaluate a combination of forward crash warning and adaptive cruise control. The study indicates that the system might prevent 3%-17% of all rear-end-crashes, expressed as a "conservative estimate".

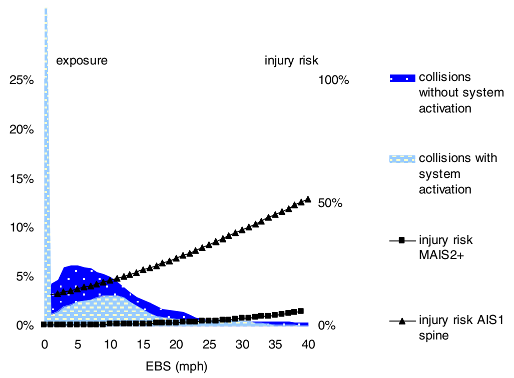

Figure 9. Exposure shift due to auto brake [16].

The total benefit prediction is a combination of host and opponent vehicle protection. For the systems presented in the present study, Figure 9 illustrates the exposure shift with and without speed reduction and injury risk (MAIS2+ and AIS1 neck injuries) for the host vehicle with respect to accidents and occupant injuries based on Volvo passenger cars. A general assessment of injury reduction due to this system related to partner protection can also be performed, however then based on a diverse sample of cars, *i.e.* not only Volvo cars.
The benefit of a system is a sum of the four boxes in Figure 2 combining effects on driver interaction as well as speed reduction. By adding together the different known aspects a total estimation can be made.

SUMMARY AND DISCUSSIONS

A break-down of the problem definition was used to guide the evaluation and performance prediction process as well as the system development. In this particular case it was discussed that rear-end collisions are relatively frequent and expose the occupants in the host as well as in the opponent vehicle to possible occupant injuries. The challenge is to aim for reduction of accident occurrence and if not possible impact severity reduction for reducing likelihood of occupant injury.

Collision Warning with Auto Brake is the second generation of Volvo Cars' collision avoidance and mitigation system. Currently rear-end collisions are addressed and the amount of auto brake is limited. Different test methods were used to verify and validate the systems performance. The results show that warning and auto brake are activated according specification during the selected set of collision situations. Furthermore, on road evaluation shows that risk of disturbing the driver under normal driving conditions is acceptably low. However, it can never be guaranteed that the system will always activate during a collision and that there will never be a false activation, but verification showed that the Collision Warning function performs well in terms of balancing nuisance and false activations versus correct activations.

This study presents some initial steps in assessing the performance of the system from a real-life safety perspective:

1. Determine the speed reduction that is achieved by the system in all collision scenarios.
2. Determine how the driver population reacts to warnings in the set of collision scenarios; refer [10] and [18]. Among the four different setting evaluated in [18] the Collision Warning head-up display of Figure 6 showed favorable results. The average brake reaction times were significantly faster for the selected head-up display warnings (approximately 200 ms), as compared to alternative solutions. The same result was found for the median, minimum and maximum reaction times. The selected display also performed best related to low amount of missed warnings. Based on these results, the warning concept is promising, although more aspects of driver interaction are involved.
3. Determine how many drivers avoid a collision because of a warning and brake support or how much speed reduction is achieved by driver braking upon a warning. This is an extensive area for research and it is dealt with in a large number of scientific studies. The knowledge needed requires testing in realistic situations and it needs to be balanced with experiences from studies dealing with passenger car driver's behavior. *E.g.* Ljung *et al.* [19] show that reactions to a warning system's HMI depend on previous exposures to warnings.

These threes steps address the true positive performance and the majority of the challenges are found in the area of collision warning. Other aspects, which also need more focus, are driver acceptance of nuisance and false activations and system adaptation. These areas of performance evaluation will gain from using information collected in naturalistic driving studies and field operational tests with relevant selection of subjects. During the development of Collision Warning with Brake Support, field studies were done based on a real-world user profile. Another type of field operation test, with a different system, was performed by Najm *et al.* [17] and it addresses the issue of driver acceptance. The study by Najm *et al.* indicates the importance of finding a good balance of nuisance and false activations versus correct activations. System adaptation over time is an aspect that requires solid field data and is further discussed in [20], although not dealing with the particular system discussed here.

Future field follow-up of this system will not only give feedback regarding the performance of the system but also be the basis for future system development. Then enhanced data can be collected to give feed-back on collision avoidance as well as speed reductions. This needs to take into account issues such as speed reduction, driver reaction, system adaptation and customer acceptance, which all are important aspects in the total benefit estimation. This information will improve the prediction done in this study, although, the evaluation methods presented in this study show a good start for prognosis of real-world performance. As a result, the enhanced knowledge can be used to further develop system performance, possibly expanded to cover other situations as well.

CONCLUSIONS

This study presents a second generation of a collision avoidance and mitigation system, Collision Warning and Auto Brake, aiming at reducing the occurrences of as well as consequences of a rear end collision. The total safety benefit is difficult to predict in absolute numbers. The evaluation methods presented in this study show good prognosis for real-world performance by addressing occupant protection and accident avoidance both in host and opponent vehicle.

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