Benefit Estimation Model for Pedestrian Auto Brake Functionality

M Lindman*, A Ödblom*, E Bergvall*, A Eidehall*, B Svanberg* and T Lukaszewicz**

*Volvo Car Corporation, SE-405 31 Goteborg, Sweden
**Ford-Werke GmbH, Henry-Ford-Straße 1, 50735 Köln, Germany

Abstract

Accident data shows that the vast majority of pedestrian accidents involve a passenger car. A refined method for estimating the potential effectiveness of a technology designed to support the car driver in mitigating or avoiding pedestrian accidents is presented. The basis of the benefit prediction method consists of accident scenario information for pedestrian-passenger car accidents from GIDAS, including vehicle and pedestrian velocities. These real world pedestrian accidents were first reconstructed and the system effectiveness was determined by comparing injury outcome with and without the functionality enabled for each accident. The predictions from Volvo Cars' general Benefit Estimation Model are refined by including the actual system algorithm and sensing models for a relevant car in the simulation environment. The feasibility of the method is proven by a case study on a authentic technology; the Auto Brake functionality in Collision Warning with Full Auto Brake and Pedestrian Detection (CWAB-PD). Assuming the system is adopted by all vehicles, the Case Study indicates a ~24% reduction in pedestrian fatalities for crashes where the pedestrians were struck by the front of a passenger car.

INTRODUCTION

Road traffic accidents involving Vulnerable Road Users are one of the world's largest health problems. Of all road traffic fatalities, between 41% and 75% worldwide [1] and 14% in the EU-14 countries [2] are pedestrians. Passenger cars are with 74% reported as the most frequent collision opponents in fatal pedestrian accidents [3]. In the majority of car-pedestrian accidents (65%-71%) the pedestrians were struck by the front of the car [3-5].

This health problem has been recognized by several organizations and governments. Public domain testing was first introduced in 1997 by EuroNCAP [6] and the first regulatory requirement came into effect in 2005 in EU and Japan. Rating and regulatory test methods used are based on physical component testing and simulate frontal impacts with adult and child pedestrians aiming to reduce the injury risk at impact. To meet the safety rating and regulatory targets *injury risk reducing*, *i.e.* protective devices, are introduced by car manufacturers. Studies on their effectiveness have been presented [5, 7-8] and further developments and updates of test methods are under way and will be introduced in a few years.

Collision avoidance and mitigation systems are intended as *accident risk reducing,* i.e. preventive devices, by reducing impact speed. Such systems are estimated to effectively reduce the number of injured pedestrians [8-16] and pre-impact braking is suggested to be an efficient protection measure for vulnerable road users [17]. Collision Warning with Full Auto Brake and Pedestrian Detection (CWAB-PD) is the third generation of Volvo Cars (VCC) system that helps drivers to avoid collisions and is launched in the Volvo S60 MY2011. The first 2 generations [18] provide warning, brake support and partial automatic emergency braking of up to 5 m/s^2 in rear-end accidents with moving and stationary vehicles. The innovations in the third generation system are: Full Automatic Emergency Braking (AEB) up to 10 m/s^2, warning, brake support and automatic emergency braking in pedestrian accidents and automatic collision avoidance.

Several methods for predicting real-life safety improvements of preventive safety system have previously been presented [19-27]. Specifically, the effect of pre-impact braking in pedestrian accidents has been targeted in many studies [5, 14-16, 28-33]. In late 80'ies, a real-world performance estimation model developed at Volvo Cars was presented [34], combining traffic accident data with crash testing. This method was further developed in the Benefit Estimation Model [19] taking into account preventive aspects as well. Next step in this progress is to further refine the separate modules in this the Benefit Estimation Model and hence improve the accuracy and enhance the quality of the results.

The objective of this study is to provide an enhanced method for estimating the effect of preventive safety functionality in terms of injury outcome and accidents avoided or mitigated. This method is based on traffic accident data available and support the system development process by offering an opportunity to alternate input parameters, such as system setup, in order to determine the effect of these changes.

METHOD

The overall workflow is described in Figure 1. As INPUT to the benefit analysis, in-depth traffic accident data defines the overall potential and outlines the pre-impact scenarios. Also a relevant description of the system of interest is defined. While PROCESSING DATA, the preventive safety system model is applied to scenarios based on accident data to calculate changes in impact speed. OUTPUT of this method is expressed in terms of avoided and mitigated accidents as well as reduction in fatal injuries. These steps are described in detail in the following sections, accompanied by a CASE STUDY of a pre-impact braking functionality.

INPUT	**PROCESSING DATA**	**OUTPUT (Result)**
A real world traffic accident data	**C** calculation of impact speed reduction in each case	**E** impacts avoided and mitigated
B system functionality definition	**D** calculation of injury outcome	**F** reduction of injuries

Figure 1. Method for estimating the benefit of autonomous braking systems, overview. Each step is presented in detail - following the headlines - in the upcoming sections.

A) Real world traffic accident data

Crash severity reduction computation is based on data from the GIDAS database. Traffic accidents in Germany are thoroughly investigated and analyzed in an extensive and welldefined process [35]. For this study, a subset of accidents from 1999-2007 are selected where the pedestrian was struck by the front of a passenger car, and where initial and collision speed were assessed in the case analysis. In GIDAS, vehicles are classified by a set of general front shapes [4]. To improve the matching with Volvo passenger car vehicles, the data set is restricted to vehicles with the front shapes illustrated in Figure 2. The accidents are first assigned to clusters of moving patterns as described in Figure 3. These patterns are then combined with information on several other variables in order to form the accident scenarios which the crash severity reduction calculation process (described below) is based on. These additional variables include pedestrian velocity, vehicle speed at impact, speed prior to driver action, driver initiated acceleration (brake) level, maximum acceleration level given road conditions, pedestrian-car 1:st impact in lateral direction, lateral distance from car to object and obscured sight.

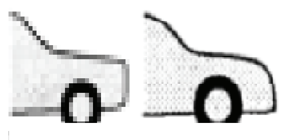

Figure 2. Front shapes selected from GIDAS.

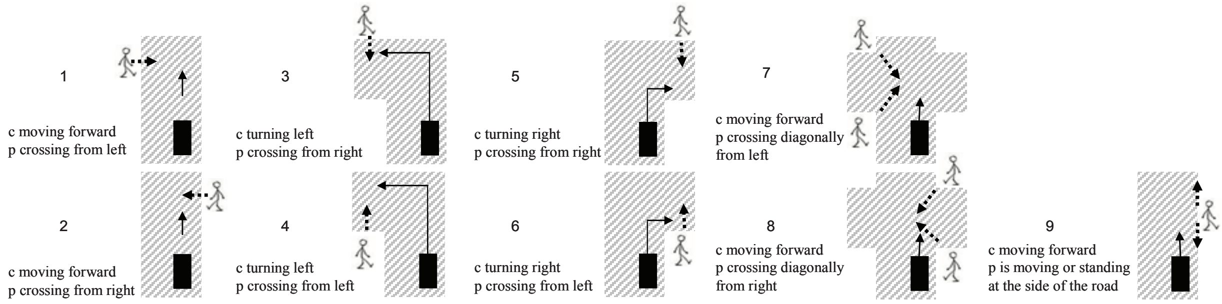

Figure 3. Moving patterns in pedestrian-car accident scenarios, c= car, p=pedestrian.

B) System definition

A detailed functionality description is vital, since this is a major input for a benefit analysis. At the same time, it is very difficult to estimate system effectiveness while it is being designed. This method addresses that problem by introducing a production-intent model of the actual system of interest. For the Case Study, the effect of CWAB-PD is investigated.

The objective of Automatic Emergency Braking (AEB) systems is to automatically avoid or mitigate an accident in case a driver does not react in time. Mitigation is obtained by decreasing the collision impact speed and thereby the risk for injury for the persons involved. In low speed scenarios, the collision can be avoided completely. For higher relative velocities the collision can not be avoided, but impact speed is still reduced.

CWAB-PD uses a combination of long-range radar and a forward-viewing wide-angle camera to continuously monitor the area in front of the vehicle. A 640 by 480 pixel black and white progressive scan CMOS Forward Looking Camera (FLC), mounted behind the windscreen, is used mainly for classifying the objects *e.g.* vehicles or pedestrians, in a 48º Field of View (FoV). Since the FLC is used for reporting both vision objects and lane markings, the field of view was chosen to work for both. For a pedestrian to be reliably detected, he or she needs to have a pedestrian shape, with head, shoulders and legs. This means for instance that a sitting pedestrian or a pedestrian who is partially occluded is less likely to be detected, nor can the camera detect pedestrians in darkness. Figure 4 show a typical example of how pedestrians are detected by the FLC. A 77 GHz electronically scanning Forward-Looking Radar (FLR), which is mounted in the vehicle grille, measures target object information in front of the vehicle in a 15º (FoV), *e.g.* range, range rate and azimuth angle.


Figure 4. Visualization of how pedestrians are detected in Collision Warning with Full Auto Brake and Pedestrian Detection (CWAB-PD).

Figure 5. From left: Electronic Scanning Radar (FLR) in the grille, Forward Looking Camera (FLC) mounted behind windscreen and the Forward Sensing Module (FSM) control unit.

Data from these two sensors is fused in a separate control unit, the Forward Sensing Module (FSM). Fusing data from two sensors with different characteristics reduces the risk of detecting false targets and increases the confidence in, and data accuracy of the detected target. This is important in order to allow for hard and early braking in accidents scenarios while simultaneously keeping the risk of false brake interventions at an acceptably low level. Figure 5 show the FLR, FLC and the FSM hardware. CWAB-PD will provide a warning and brake support when there is a credible risk for an accident. Additionally, if the driver does not intervene in spite of the warning and the possible collision is imminent, intervention braking is automatically applied to slow down the car. The functionality will auto brake for pedestrians up to driving velocity of 80 km/h and for vehicles at any speed. Note that the warning-part described is not under consideration in the Case Study that embraces Auto Brake functionality.

Test track data shows that up to approximately 35 km/h the collision can be avoided completely, and above that velocity, the functionality reduces the impact speed. Performance depends for example on the friction between the tires and the road surface. Besides the positive performance of AEB systems, *i.e.* the performance in collision situations, one has to address negative performance as well. The risk of automatic emergency braking has to be minimized in non-collision situations in order to not interfere during normal driving situations. CWAB-PD has been extensively tested on public roads in different traffic environments, in different countries and by different types of drivers. It has been confirmed with sufficient confidence that the risk for false interventions is acceptably low.

The system also include a brake support functionality that will boost the driver initiated braking in cases where the driver is braking with less than necessary force. If the driver is already breaking this is considered as an extra confirmation of a threat and auto brake can be triggered earlier in order to increase the benefit. The CWAB-PD functionality is optional and works in parallel to City Safety [36] that is designed to help the driver to mitigate, and in certain situations avoid, rear-end collisions at low speed. The brake functionality executes the maximum brake request from the two features in case these are not the same.

C) Estimation of impact speed reduction

Each real-world GIDAS accident scenario is reconstructed using Volvo Cars Traffic Simulator (VCTS). Each scenario was run three times. First to set up impact time and velocity to produce the same initial velocity and impact speed as well as impact location as was found in the GIDAS data, thus creating a Volvo car baseline. Then with Emergency Brake Assist (EBA) activated to establish a speed reduction baseline, and finally with EBA and CWAB-PD enabled to evaluate benefit vs baseline.

VCTS is a modular simulation platform for development and evaluation of preventive safety functionality, developed at Volvo Cars. Traffic simulation analysis can be performed with production-intent preventive safety functionality models in the loop (MIL), with compiled controller software in the loop (SIL) as well as with compiled software implemented in physical electronic control unit hardware in the loop (HIL). These simulation analysis platforms have been validated against in-vehicle testing results.

The structure of VCTS reflects normal driving situations along desired paths in a road network in a traffic environment also populated with other movable traffic objects. The static environment includes single and multiple road topologies with intersections and roundabouts synthesized manually, or generated from real road data or extracted map data. Road structure information is available such as lane markings and barrier positions. The dynamic environment includes for example other vehicles and pedestrians. The host vehicle module includes a model of a complete car, described at various level of detail. For up to mid-range dynamic lateral maneuvers a 7 degrees of freedom chassis model is sufficient with filters mimicking pitch and roll motion to account for weight redistribution during steer and brake manoeuvres. Tire nonlinearities are accounted for in the simulations by employing the magic formula description [37]. Chassis and tire parameters are either taken directly from supplier (in-house or external) or from simulations using ADAMS software.

For the present Case Study analysis tasks, the detailed complexities of the controlled engine, transmission and driveline are avoided by using low order models. Similarly, models of steering and braking are also kept simple using only a few parameters such as steering gain and force to pressure conversion. However, the limitations of the controlled brake pumps, used to realize the CWAB-PD brake request, are accounted for by including a 0.1 s actuation delay and a jerk limiter of 20 m/s^3 followed by conversion to pressure. In the simulations, all driver brake actions during CWAB-PD interventions are amplified instantaneously by a factor 2 by Emergency Brake Assist (EBA) activation. Also, EBA activation without CWAB-PD, so called base-EBA, is accounted for by a factor 2 gain of driver brake pressure when driver braking is sufficiently rapid.

Preventive safety functionalities are easily integrated without modifications into VCTS, which also allows for full control of model approximations. VCTS includes models of geometrically ideal radar as well as camera sensors using supplier specified lateral, vertical and range field of view, sample time and other parameters. The driver controller model acts based on preview sensing to actively follow prescribed path and velocity profiles. Other vehicles and pedestrians can move arbitrarily relative to the road for example by performing lane and velocity changes. For the present analysis, it is sufficient for the pedestrians to cross or move along the road. While in practice many different types of software are available for this type of simulation, the benefit of using an in-house model is that the software implementations of preventive safety functionalities can be used as is, without modifications.

Driver braking is constructed to reproduce GIDAS-data deceleration level and speed reduction, taking into account deceleration capacity limitations due to the road conditions of the real accident; for dry roads maximum deceleration was limited to 9 m/s^2, for moist and wet roads limits were set to 8 and 7 m/s^2 respectively, and for roads covered with ice or snow the limit was set to 3 m/s^2. For scenarios where the driver in the real accident did not brake, the set speed is constant up to system intervention. During simulation without preventive safety functionality enabled, the simulated throttle and brake pedal positions are recorded. These recorded signals are then used as input when the same scenario is re-run with the Auto Brake functionality in CWAB-PD enabled. Thus, driver behavior is identical in simulations with and without preventive safety functions enabled, except that the driver throttle pedal position is set to zero during brake interventions to guarantee that the driver longitudinal controller would not counteract CWAB-PD brake requests. The pedestrian is assumed to be moving at constant speed. GIDAS supplies a qualitative estimation of the pedestrian speed that is translated into a quantitative value [38], thus, it is straightforward to find an initial position for the pedestrian such that both impact speed and position are the same as in the accident data. In simulations of cases where GIDAS denoted obscured sight, the pedestrian is assumed to become visible to the vehicle sensors when the lateral distance between the vehicle front centre and the pedestrian centre is 1.6 m or less. The pedestrian detection is not depending on day/night state in the simulation, instead a general estimation of the relevance of light condition is performed. A conservative approach for camera based detection is used, requiring the pedestrian to be entirely within camera sensor field of view for at least five consecutive frames before detection is signalled.

D) Estimation of injury outcome

According to the methodology described by Korner [34], injury outcome is presented as the product of injury risk as a function of crash severity and crash severity distribution, see Figure 6. By predicting new injury risk related to a protective device under development, it is possible to forecast real life crash worthiness in the whole spectrum of real world accidents. However, by adding a speed reducing functionality to a car, the injury risk reducing status, and consequently the injury risk in this car will remain unchanged. Instead, crash severity distribution, *i.e.* exposure, will change as shown in Figure 7. Presumably the number of accidents will decrease and exposure will shift towards lower crash severities and hence lower associated injuries. In the same way as when the injury risk reducing device alters the injury risk function, the new exposure will influence the distribution of injuries.

For the present Case Study analysis, crash severity in terms of car to pedestrian impact speed based on real world accident data is used. The accident scenarios are simulated in VCTS as described in the previous section with the safety functionality enabled to obtain the induced impact speed. The fatality injury risk function used in the present study depends on impact speed and is partly based on the same pedestrian accident cases in the GIDAS-data that forms the basis for the present study, matched to national statistical data[11].

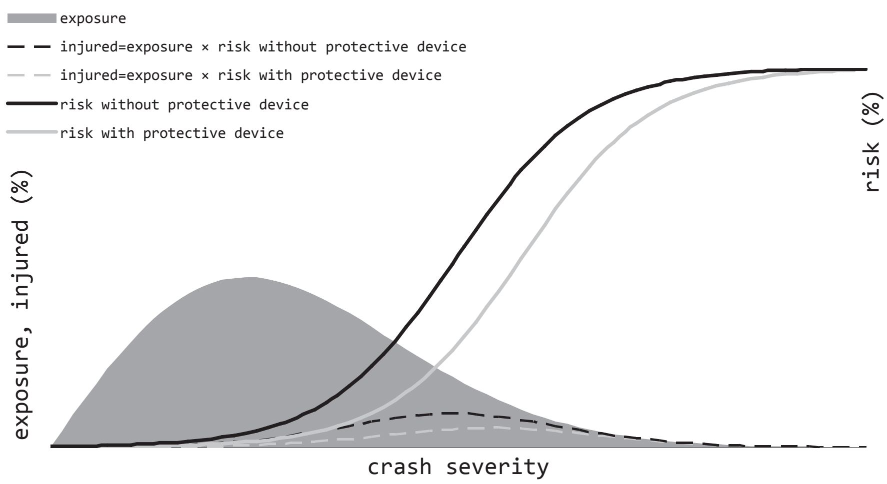

Figure 6. Illustration of the estimation of new injury outcome related to a protective device, adapted from [36].

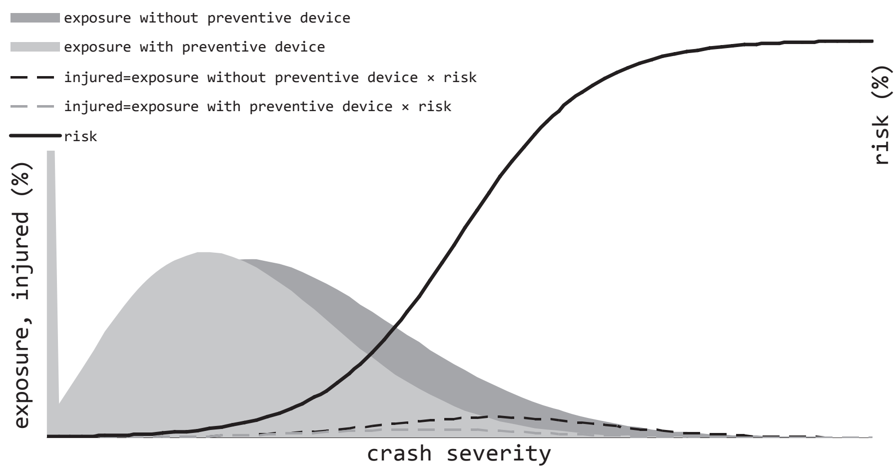

Figure 7. Illustration of the estimation of new injury outcome related to a preventive device.

E) Collisions avoided and mitigated

The output of pedestrian accident scenario reconstructions with and without preventive safety system can be expressed using crash severity distributions, see Figure 7. In the Case Study, car to pedestrian impact velocities without and with the Auto Brake functionality in CWAB-PD are investigated. The influence of light conditions was briefly examined. The share of accidents avoided and mitigated is calculated and additional information of average speed reduction is provided.

F) Reduction of injuries

The benefit of the system analyzed is the relative difference between the injury outcome for vehicles with and without system activation. With system activation, the crash severity distribution takes another form and, consequently, the overall probability of injury sums up to a new value; see Figure 7. This new value is compared with the area value for the original exposure derived from cases without system activation.

RESULTS

The workflow described, see Figure 1, embraces a number of steps in the Benefit Estimation Model that each produces sub-deliveries. First, INPUT in terms of traffic accident data defines the overall potential and outlines the pre-impact scenarios. Also, the system to be investigated is defined. While PROCESSING DATA, the INPUT data is applied and examined resulting in OUTPUT expressed in terms of avoided and mitigated accidents as well as reduction in fatal injuries.

INPUT
In the GIDAS dataset used, 5% of the pedestrians were fatally injured. 56% of the drivers had applied the brakes before impact. 57% of the accidents occurred during daylight and 70% on a dry road. In 53% the car had an initial speed below 35 km/h. 92% of the accidents were assigned to the moving patterns illustrated in Figure 3. Remaining cases correspond to moving pattern 9; examples of these are pedestrians that just left their car as they got hit, were moving towards the car on a parking lot or got stuck between the car and a parked vehicle.

The Auto Brake functionality in CWAB-PD is targeting pedestrians approaching in the front of a passenger car at driving velocities up to 80km/h and are detectable by the sensor system. The functionality is integrated without modifications into the VCTS analysis tool.

PROCESSING DATA
The simulated car-pedestrian scenario was tuned to the same initial velocity and impact speed and impact location as in the accident data, but in the reconstruction the vehicle was replaced with a Volvo car model. Then the scenarios were re-run with the Auto Brake functionality in CWAB-PD enabled. Figure 8 shows the pedestrian position at time for brake intervention and illustrates the large variation in scenario conditions resulting from both car movement and pedestrian speed and moving direction.

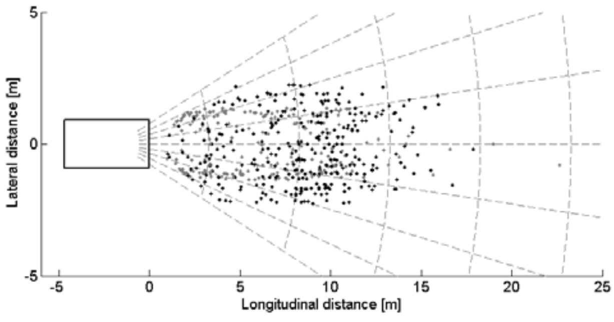

Figure 8. Predicted pedestrian-car relative position at time for brake intervention in cases the Auto Brake functionality in CWAB-PD. Light markers represent initially hidden pedestrians.

OUTPUT

The result of the pedestrian accident reconstructions in terms of impact speed distributions with and without the Auto Brake functionality in CWAB-PD is presented in Figure 9. CWAB-PD is predicted to reduce impact speed in 61% of the considered cases. Collisions were completely avoided in 30%. Assuming functionality also in darkness, impact speed is reduced in 86% of the considered cases.

Average speed reduction was 19,6 km/h for the entire dataset with the Auto Brake functionality in CWAB-PD, compared to 9,6 km/h without (i.e. where acceleration originating from driver initiated braking prior to impact).

Using impact speed distributions together with the injury risk, Figure 10, the relative difference in injury outcome with and without CWAB-PD is estimated to 24%, see Figure 11.

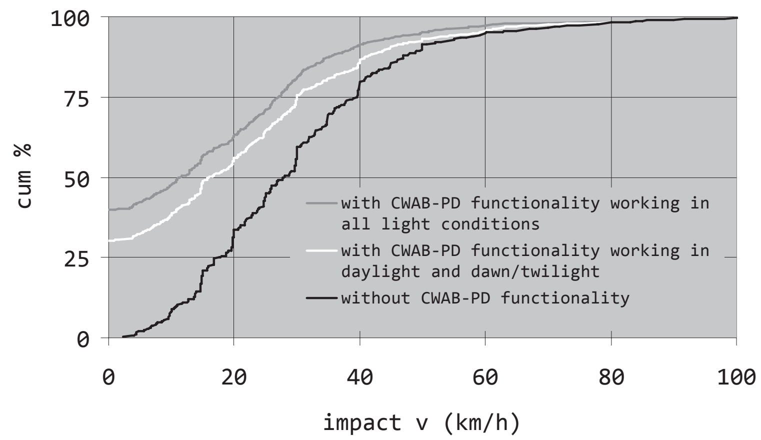

Figure 9. Predicted cumulative distributions of impact speed without and with the Auto Brake functionality in CWAB-PD for all light conditions and for functionality in daylight and dawn/twilight assuming fleet penetration.

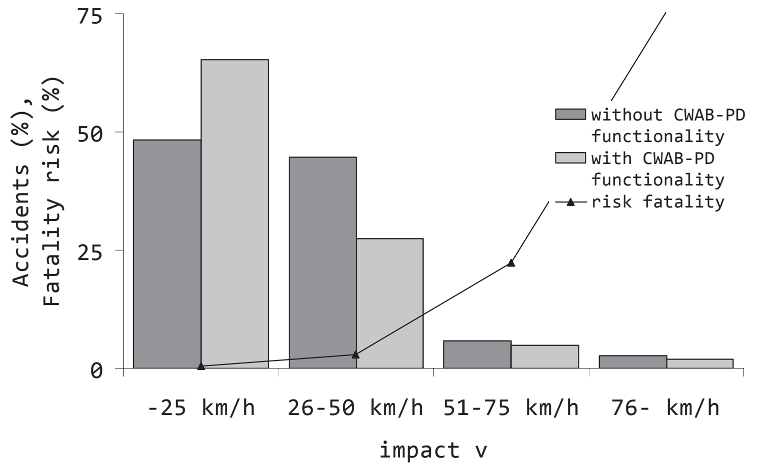

Figure 10. Predicted distributions of impact speed without and with the Auto Brake functionality in CWAB-PD binned into 25 km/h groups and average risk for fatal injury at corresponding impact speeds. Note that the Figure is schematic and omits all details; the calculations though are based on the actual figures for each case.

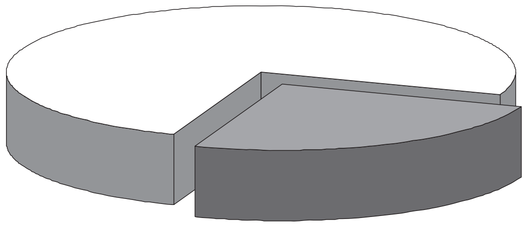

Figure 11. Fatal pedestrian frontal impacts and predicted reduction by the Auto Brake functionality in CWAB-PD in daylight and dawn/twilight assuming fleet penetration.

DISCUSSION

In total, the Auto Brake functionality in CWAB-PD is estimated to reduce fatal pedestrian injuries by 24% in accidents where the pedestrians are struck by a passenger car front. By adding this information to distributions of collision opponents and impact area of the car [3-5], it is likely that out of 3.500 pedestrian fatalities annually in EU14[2], the Auto Brake functionality in CWAB-PD can save the life of more than 400 killed pedestrians each year, assuming the system is adopted by all vehicles in the market.

Previous prediction studies of pedestrian fatality reduction by automatic brake functions [14, 30] and EBA [14-16], are all performed using different types of methods, data and hypothesized system setups. The Case Study presented here gives the first result for an actual production-intent technology algorithm, thus getting more realistic predictions. The results in Figure 8 show that about 30% of all pedestrian accidents are predicted to be avoided by CWAB-PD autonomous braking. In the remaining cases pedestrian accidents are not entirely avoided due to challenging scenario circumstances. For example, the autonomous brake intervention will come later when the pedestrian appears late within sensor FoV after initially being hidden behind other traffic objects, or entering the FoV from the side. Also, the brake intervention will intentionally come later if it is still possible to avoid the accident by a steering maneuver as is the case in large lateral offset collisions. Consequently, the predicted benefit in the Case Study reflects the frequency of various accident scenarios.

In the present study, the Volvo Cars' general Benefit Estimation Model is refined by introducing VCTS, an advanced module for reconstruction of accident scenarios and calculation of velocity with a preventive safety functionality included. VCTS is an in-house developed software implemented in Matlab / Simulink (Mathworks). An inherent strength of the VCTS environment is that it incorporates the actual functionality investigated, which is important in order to obtain consistent scenarios during dynamic closed-loop events such as the autonomous vehicle control interventions considered in the present work. Therefore, the sensors which monitor the surrounding traffic environment will produce signals consistent with the AEB induced vehicle motion during brake interventions. As in in-vehicle performance measurements on test track, on-center stationary pedestrian collisions are avoided up to approximately 35 km/h in VCTS when CWAB-PD functionality is enabled even though the driver disregards pre-crash warnings. For on-center stationary pedestrian collision scenarios with initial vehicle velocities well above the avoidance limit, the impact speed reduction is overestimated by approximately 1.4 m/s for VCTS as compared to test track measurements based on differential global positioning. Even though avoidance scenarios are well reproduced by VCTS, all factors influencing the outcome in a real life traffic scenario are not included in the traffic simulator.

The functionality investigated is implemented in one relevant car model instead of the variety of cars of different years of manufacturing as found in the accident database used. Thus, output from the baseline reconstruction of the accident scenarios differs from the original GIDAS-data since it takes into account the properties of the specific car chosen, for example the presence of base-EBA. The intended difference achieved enables a straightforward estimation of Auto Brake functionality in one baseline car, with and without CWAB-PD.

The method used brings together pre-impact scenarios from accident data and a advanced description of the system of interest. Hence, the relevance and accuracy of the traffic accident data is decisive for the results in two ways. First, regarding the estimation of change in injury outcome, a pedestrian fatality risk function [11] is used that is considered more pertinent than previously presented risk functions, mainly due to the size of and the variation within the pedestrian accident sample that it is based on. However, this risk estimate reflects the protective pedestrian safety measures of the cars in the GIDAS dataset, which are believed to deviate from Volvo's recent passenger car models (both in terms of geometries and dynamic performance) since the dataset comprises a small number of modern vehicles [7]. The need for a traffic accident dataset that is homogenous in terms of car models and thus more relevant for creating field injury risk functions is obvious. An alternative procedure for injury reduction calculation for a single car model uses performance criteria data from crash tests, as suggested in [5]. The relationship to real world fatality risk has to be established when calculating the injury outcome, though. Finally, the use of the injury shift method [7], which relies on injury classification scaling, is a possible method to estimate change in injury outcome. Second, the level of details in the accident scenarios simulated is crucial. It is clear that extensive work on reconstructing the pre-crash events in retrospective accident data [26] improves the possibilities in the research area. In a long term perspective, NDS/FOT studies [39] should provide even better information on both pre-impact and crash parameters. Solid knowledge on the course of event leading to the accident will limit the number of assumptions made when drawing the outline for the accident scenarios in the method proposed.

To reduce the number of injured pedestrians there are mainly two approaches. The predominant way forward is to lower injury risk by altering the design of the front of the vehicle, including the bumper and the bonnet. Studies presented describe the effectiveness of such protective safety systems [5, 40] suggesting a range of benefits. The second approach is to alter the distribution of impact speed with preventive safety functionalities, *e.g.* AEB. Impact speed reduction is expected to cut the number of injured pedestrians [8-16]. Specifically, in the potential secondary pedestrian impact to the ground where protective measures on the vehicle are not likely to reduce risks, collision avoidance will. In the present study, the preventive safety performance of one system is evaluated. However, all preventive as well as protective measures should be accounted for to give an accurate picture of a vehicle's injury preventing performance [22]. Combining more than one system in the evaluation process is a likely continuance of the refinement process of the Volvo Cars Benefit Estimation Model. While only the Auto Brake functionality in CWAB-PD was considered here, the CWAB-PD also provides a warning and brake support when there is a credible risk for an accident. The benefit of the warning part of the CWAB-PD functionality will be examined in future studies.

CONCLUSION

The refined method described follows and further develops the tradition of estimating the real-world performance of new car designs at Volvo Cars. The method is based on real world pedestrian accidents and predicts the effectiveness of a preventive safety system by comparing the injury outcome for a selected set of pedestrian accidents in simulations with and without the system enabled. A module that includes the actual system algorithm in a relevant car and sensing model enhances the quality of Volvo Cars' general Benefit Estimation Model presented. The feasibility of the method was proven by a Case Study of an autonomous braking functionality which detects pedestrians and automatically can avoid this kind of accidents in vehicle speeds up to 35 km/h. The Auto Brake functionality in CWAB-PD is estimated to contribute to reduce pedestrian fatalities by 24% pedestrian fatalities in accidents where the pedestrians are struck by the front of a passenger assuming the system has been universally adopted.

REFERENCES

1. Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A., Jarawan E., and Mathers, C., 2004. World report on road traffic injury prevention, World Health Organization, The World Bank, Geneva.
2. SafetyNet, 2008. Traffic Safety Basic Facts 2008, Pedestrians
3. Gavrila, D. M., Marchal, P.,. Meinecke, M.-M., 2003. SAVE-U Deliverable 1-A: Vulnerable Road User Scenario Analysis APVRU
4. Liers, H., Hannawald, L., Brehme, H,. 2007. Scope extension of Pedestrian Legislation to Vehicles above 2500 kg Gross Vehicle Weight. Technische Universität Dresden.
5. Kühn, M., Fröming, R., Schindler, V.,: "Fußgängerschutz. Unfallgeschehen, Fahrzeuggestaltung, Testverfahren", Fachbuch, ISBN-10 3-540-34302-4, Springer-Verlag Berlin Heidelberg 2007
6. EuroNCAP homepage, www.euroncap.com
7. Liers, H., Hannawald, L., Benefit Estimation of the Euro-NCAP Pedestrian rating Concerning Real World pedestrian safety, 2009
8. Hannawald, L., Kauer, F., 2004. Equal effectiveness study on pedestrian protection. Technische Universität Dresden.
9. Walz, F.H., Hoefliger, M., Fehlmann, W., 1983. Speed limit reduction from 60 to 50 km/h and pedestrian injuries. In: Proceedings of the 27th Stapp Car Crash Conference with International Research Committee on the Biokinetics of Impact (IRCOBI), pp. 277–285.
10. Davis, G.A., 2001. Relating severity of pedestrian injury to impact speed in vehicle pedestrian crashes. Trans. Res. Rec. Record No. 1773, 108–113.
11. Rosén, E., Sander, U., 2009. Pedestrian fatality risk as a function of car impact speed. Accident Analysis Prevention, doi:10.1016/j.aap.2009.02.002
12. Tharp, K.J., Tsongos, N.G., 1977. Injury severity factors – Traffic pedestrian collisions. SAE 770093.
13. Cuerden, R., Richards, D., Hill, J., 2007. Pedestrians and their survivability at different impact speeds. Proceedings of the 20th International Technical Conference on the Enhanced Safety of Vehicles, Lyon, France.
14. Busch, S., 2004. Entwicklung einer Bewertungsmethodik zur Prognose des Sicherheitsgewinns ausgewählter Fahrerassistenzsysteme. Fortschrittsberichte VDI, 2005, ISBN 3-18-358812-9.
15. Page, Y., Foret-Bruno, J., Are expected and observed effectiveness of emergency brake assist in preventing road injury accidents consistent? 2005. Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles, Washington D.C.
16. Oh, C., Kang, Y. S., Youn, Y., Evaluation of a brake assistance system (BAS) using an injury severity prediction model for pedestrians, International Journal of Automotive Technology, ISSN 1229-9138 (Print) 1976-3832 (Online) Issue Volume 10, Number 5 / October, 2009 , DOI 10.1007/s12239-009-0067-4
17. Meinecke, M.-M, Obojski, M.A., Gavrila, D., Marc E., Morris R., Töns M., Letellier L., 2003. SAVEU Deliverable D6: Strategies in terms of vulnerable road user protection.
18. Coelingh, E., Lind, H., Birk, W., and Wetterberg, D., 2006. Collision Warning with Auto Brake, FISITA World Congress, F2006V130, Yokohama Japan
19. Lindman, M., Tivesten, E., 2006. A method for estimating the benefit of autonomous braking systems using traffic accident data. SAE 2006-01-0473.
20. Najm, W.G., Stearns, M.D.Howarth, H., Koopman, J., and Hitz, J., 2006. "Evaluation of an Automotive Rear-End Collision Avoidance System," DOT VNTSC-NHTSA-06-01, DOT HS 810 569.
21. Pack, R., Najm, W.G., and Koopman, J., 2006, Exploratory Analysis of Pre-Crash Sensing Countermeasures, SAE 2006-01-1438
22. Hannawald, L., Brunner, H., 2008. Multivariate benefit estimation of future vehicle safety systems. ESAR
23. Burgett, A., Srinivasan, G., and Ranganathan, R., 2008. A Methodology for Estimating Potential Safety Benefits for Pre-Production Driver Assistance Systems, Washington D.C., DOT HS 810 945.
24. Schittenhelm, H., Bakker, J., Bürkle, H., Frank, P., Scheerer, J., 2008. Methods for analyzing the efficiency of primary safety measures based on real life accident data. ESAR
25. Carter A. A., Burgett, A., Srinivasan, G., Ranganathan, R., 2009. Safety Impact Methodology (SIM): Evaluation of Pre-production Systems, Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany.
26. Erbsmehl, C., Simulation of real crashes as a method for estimating the potential benefits of advanced safety technologies. 2009. Paper Number: 09-0162, Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany.
27. Gordon, T., Sardar, H., Blower, D., Ljung Aust, M., Bareket, Z., Barnes, M. Blankespoor, A., Isaksson-Hellman, I., Ivarsson, J., Juhas, B., Nobukawa, K., and Theander, H., 2010. Advanced Crash Avoidance Technologies (ACAT) Program – Final Report of the Volvo-Ford-UMTRI Project: Safety Impact Methodology for Lane Departure Warning – Method Development and Estimation of Benefits, Washington D.C., DTNH22-06-H-00068.
28. Schramm, S., Roth, F., 2009. Method to assess the effectiveness of active pedestrian protection safety systems. Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany.
29. Barrios, J.M., Aparicio, A., Dávila, A., de Miguel, J.L., Modrego, S., Olona, A., Badea, A., Furones, A., Páez, F.J. Martín, J.M., 2009. Evaluation of the effectiveness of pedestrian protection systems through in-depth accident investigation, reconstruction and simulation. Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany.

30. Rosén, E., Källhammer, J.E., Eriksson, D., Nentwich, M., Fredriksson, R., Smith,K., 2009. Pedestrian injury mitigation by autonomous braking. Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany.
31. Lawrence, G. J. L., Hardy, B. J., Carroll, J. A., Donaldson, W. M. S., Visvikis, C., Peel, D. A., 2006. A study on the feasibility of measures relating to the protection of pedestrians and other vulnerable road users - Final 2006. EC Contract No. ENTR/05/17.01.
32. Aparicio, F., 2005. EEVC WG19 Activities on primary and secondary safety interaction, Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles, Washington D.C.
33. Helmer, T., Ebner, A., Huber, W., 2009. Präventiver Fussgängerschutz – Anforderungen und Bewertung.
34. Korner, J., 1989. A Method for Evaluating Occupant Protection by Correlating Accident Data with Laboratory Test Data. SAE890747.
35. Otte, D., Krettek, C., Brunner, H., Zwipp, H., 2003. Scientific approach and methodology of a new indepth investigation study in Germany so called GIDAS. Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan.
36. Distner, M. Bengtsson, M., Broberg, T., and Jakobsson, L., 2009. City Safety – a system addressing rear-end collisions at low speeds. Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany.
37. Bakker, E., Lidner, L., Pacejka, H. B., 1989. A New Tire Model with an Application in Vehicle Dynamics Studies. SAE 890087.
38. Eberhardt, W., Himbert, G., 1977. Bewegungs-Geschwindigkeiten. Published by Ing.-Büro Simon-Himbert-Eberhardt,, Saarbrücken.
39. Euro-FOT, http://www.eurofot-ip.eu/
40. Oh, C., Kang, Y.S., Youn, Y., Konosu, A., 2008. Assessing the safety benefits of an advanced vehicular technology for protecting pedestrians. Accident Analysis and Prevention 40, 935–942.