PEDESTRIAN INJURY MITIGATION BY AUTONOMOUS BRAKING

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ABSTRACT

The objective of this study was to calculate the effectiveness of a pedestrian injury mitigation system that autonomously brakes the car prior to impact at reducing fatal and severe injuries.

The database from the German In-Depth Accident Study (GIDAS) was queried for pedestrians hit by the front of cars from 1999 to 2007. Information on vehicle and pedestrian velocities and trajectories were used to estimate the field of view needed for a vehicle-based sensor to detect the pedestrians one second prior to the actual crash. The pre-impact braking system was assumed to provide a braking deceleration up to the limit of the road surface conditions, but never to exceed 0.6g. New impact speeds were calculated for pedestrians that would have been detected by the sensor. These calculations assumed that all pedestrians that were within the given field of view and not hidden by surrounding objects would be detected. The changes in fatality and severe injury risks were quantified using risk curves derived by logistic regression of the accident data. Summing the risks for all pedestrians, new casualty numbers were obtained.

The study documents that the effectiveness of reducing fatally (severely) injured pedestrians reached 40% (27%) at a field of view of 40°. Increasing the field of view further led to only marginal improvements in effectiveness.

1. INTRODUCTION

A study by Transport Research Laboratory (TRL) under contract by the European Commission (Lawrence et al., 2006) predicts that the current functionality of brake assist systems can substantially reduce pedestrian fatality rates. The effectiveness at reducing the numbers of fatally and seriously injured pedestrians was estimated to be approximately 10%. One explanation for this finding is that even slight reductions in impact speeds have a large effect on the injury outcome for pedestrian victims (Davis, 2001; Hannawald and Kauer, 2004; Rosén and Sander, 2009; Tharp and Tsongos, 1977).

There are at least two advantages of pre-impact braking: The impact energy is reduced, leading to lower risk of injury, and the secondary impact when the pedestrian hits the ground is mitigated. Injuries are often caused by the secondary impact (Gavrila et al., 2003). Pre-impact braking has been suggested as one method to reduce their severity (Meinecke et al., 2003).

However, as brake assist systems have been predicted to activate in only about 50% of all accidents (Hannawald and Kauer, 2004), a natural evolution would be to complement future systems with a suitable sensor that autonomously activates the brakes if the driver fails to take action (Lawrence et al., 2006). The current study is an attempt to analyse the effectiveness of such an enhanced brake assist system. Like the studies by Aparicio (2005) and Hannawald and Kauer (2004), this study is based on models of real-world accident data. We extend those models to predict the reduction of pedestrian injuries from an autonomously activated brake assist system. Our approach is in line with the method proposed by Lindman and Tivesten (2006).

Studying real-world accident data is a viable way to gain an increased understanding of the pre-crash movements of vehicles and pedestrians. Currently, the most detailed accident databases include vehicle travel and impact speeds, driver braking and steering manoeuvres as well as detailed sketches of the accident scenes. By combining this information it is possible to derive the pedestrian location relative to the vehicle as a function of time during the pre-crash phase. Such extended reconstructions can also serve to establish the time to collision and pedestrian location at the instant when he/she would have become detectable by a vehicle based sensor (regardless of type) and when he/she stepped out into the road. This information can guide the understanding of real-world requirements and their influence on potential system effectiveness.

The hypothetical system considered in this study contains a forward looking, vehicle-based sensor with a given field of view. The signal from the sensor is processed by a computer algorithm. If a pedestrian collision is predicted to occur, the system will autonomously activate the vehicle's brakes. The effectiveness of such a system depends on five main parameters: the field of view, detection range and accuracy of the sensor and the duration and level of the applied brake force.

Naturally, a larger field of view will detect more pedestrians. However, this also implies that the system will have to consider pedestrians further away from the road. This, in turn, will increase the sensor requirements and the complexity of activation strategies. With a greater detection range, it is possible to increase the braking duration, which will reduce the vehicle speed further before impact. However, autonomous braking implies a rather severe intervention that may or may not be welcomed by the driver. A system that activates too early may negatively affect the driver's ability to stay in control of the vehicle (ECE, 1968). Furthermore, the perceived level of system intrusion is likely larger for harder braking and longer braking durations. Earlier predictions by the system will also increase the uncertainties regarding the intent of other road users, which may lead to higher rates of false activations. In sum, there are many arguments against assuming that it is necessarily preferable for autonomous breaking systems to have a larger field of view and an earlier activation time.

2. OBJECTIVE

The main goal of this study was to estimate the potential reduction of fatally and severely injured pedestrians by an autonomous braking system as a function of the sensor field of view given a pre-impact braking activation time of one second and a maximum braking deceleration of 0.6g. These system parameters were chosen as a reasonable balance between high protection level (early brake activation and high deceleration), reduced risk of assumed negative driver reaction, and influence on ambient traffic from instances of false system activation. Although the system was likely to be beneficial both for pedestrians struck by the front and side of vehicles, our method to estimate effectiveness was more reliable for those struck by the front. The reason was that the relation between injury risk and vehicle impact speed was less clear for pedestrians struck by the side, since only some of those receive a substantial impulse, or change of momentum, in the crash. Hence, we chose to include only pedestrians struck by vehicle front ends in the detailed analysis, although some results will be presented for the full target population as well.

3. DATA AND METHODS

3.1 Data

The German In-Depth Accident Study (GIDAS) is based on accident data collected from the cities of Hanover and Dresden and their surroundings. The availability of recent, in-depth, accident reconstruction data, access, and familiarity with the database made GIDAS a natural choice for this study. A detailed account on GIDAS is provided by Otte et al. (2003). The work shifts for the GIDAS teams are specified by a statistically developed sampling plan and cover half the hours of each day and night (Otte et al., 2003; Pfeiffer and Schmidt, 2006). The GIDAS database therefore contains a fairly representative sample of German accidents with pedestrian injuries. However, a certain bias towards severe and fatal accidents is present and a method to adjust for that was used (Rosén and Sander, 2009). That study found that cases coded as "ambulant" (less than 24h medical treatment), "in-patient" (more than 24h medical treatment), and "fatal" (dead within 30 days from the accident) should be weighted with the relative factors 1.0, 0.49, and 0.36 respectively.

Injuries were coded according to the Abbreviated Injury Scale (AIS98), which is an injury classification system using standardised criteria for describing injury severity (AAAM, 2001). The system comprises six levels of injury severity, where AIS1 denotes minor injury, 2 moderate, 3 serious, 4 severe, 5 critical, and 6 fatal (currently untreatable) injury. The Maximum AIS (MAIS) gives the severity of the worst injury (of the several sustained by the victim). For example, MAIS3+ denotes cases where the severity of the worst injury was AIS3 or higher. In the following, we have denoted cases with MAIS3+ as severe and cases with less severe injuries (MAIS1 and MAIS2) as slight. Cases where the pedestrian died within 30 days were classified as fatal. All fatal cases with MAIS3+ injuries were also considered severe, which was different from the analysis of Lawrence et al. (2006) where a serious case could not be fatal.

The target population for the autonomous braking system included pedestrians struck by the front and side of motorised vehicles. However, the detailed analysis of this study was restricted to those struck by the front of a car, SUV, minibus, or van. Of all pedestrians in GIDAS struck by such vehicles, 66% were hit by the front, 29% by the side and 5% by the rear. For the fatally (severely) injured pedestrians, 90% (74%) were struck by the front, 8% (21%) by the side, and 3% (4%) by the rear. We further restricted the target population by taking into account only pedestrians who were not suspected of being intent on suicide and who were struck once by a vehicle that did not have an initial collision with another object. These restrictions excluded only a small number of cases.

From the years 1999 to 2007, 755 cases were gathered, including 38 fatally and 123 severely injured pedestrians, in which the vehicle impact speed was assessed by a GIDAS reconstruction. Of these, 243 cases contained sufficient information to estimate the pedestrian location relative to the car one second prior to impact. This final dataset contained 46 severely injured pedestrians, of which 11 were fatalities. Furthermore, 232 of the striking vehicles were passenger cars. The remaining cases included seven minibuses, one pick-up truck, one off-road vehicle, one minibus shaped, and one van. Of the fatally (severely) injured pedestrians, 10 (45) were struck by cars and 1 (1) by a minibus.

3.2 Estimating the Effect of the Autonomous Braking System

The hypothetical autonomous braking system consisted of an extension to a brake assist system that would autonomously activate the vehicle brakes when an activation signal was provided by the sensing system. As shown in Figure 1, the sensor was mounted in the centre of the vehicle front and had a given field of view. Furthermore, the sensor was assumed to operate in all light and weather conditions, but could only detect pedestrians that were within the given field of view and not obstructed by other vehicles or fixed objects such as buildings.

For each accident, information on the exact accident spot, the impact and travel speeds of the car, the exact impact location of the pedestrian on the car front, and approximate trajectories of the car and pedestrian a few seconds prior to impact were provided by the original GIDAS reconstructions. The reconstruction methods are described by Rosén and Sander (2009). Driver braking and steering manoeuvres were also given, including an estimate of the mean braking deceleration and the braking distance. Finally, pedestrian walking speeds were coded using four categories: (1) walked, (2) walked slowly, (3) walked briskly and (4) ran.

We took pedestrian age into account to generate quantitative estimates of pedestrian walking speeds in km/h (Eberhardt and Himbert, 1977). Combining this with information about the point of collision and pedestrian trajectory, it was possible to estimate the location of the pedestrian one second prior to impact. The location and travel speed of the car one second prior to impact was derived by a similar backwards calculation, beginning from the accident spot, taking impact speed, braking deceleration and vehicle trajectory into account. The locations of both the car and pedestrian enabled us to calculate the field of view needed for a sensor on the car front to detect the pedestrian. Pedestrians for which obstacles in the environment obstructed the sensor line of sight during the pre-crash phase were considered to be “not visible”.

Following Danner and Halm (1994), the maximum possible braking deceleration was assessed for each case using GIDAS information on the road surface type and condition. A maximum deceleration of 0.6g was applied to all cases where the road surface type and condition allowed. In the other cases, the maximum possible deceleration was chosen. It was also assumed that the brake force had a linear ramp up time of 300 ms and then remained at a constant level. The chosen values of ramp up time and maximum braking deceleration are in line with those reported by Grover et al. (2008) for automated emergency brake systems.

The final step was to calculate new impact speeds, v', for cases were the pedestrian was visible and within the given field of view one second prior to impact, so that the autonomous braking system could have been activated. The new impact speeds followed from basic kinematics combined with the work-energy principle. In cases where the driver had braked, the original impact speed was kept if it was lower than the one provided by the autonomous braking system. In cases where the sensor would have detected the pedestrian less than one second prior to impact, the system was assumed to have no effect, even though pre-impact braking would have lowered the impact speed.

3.3 Injury Risk Functions

In order to derive injury risk functions for fatal injury and for severe (MAIS3+) injury, weighted logistic regression analysis was conducted following Rosén and Sander (2009). In order to increase statistical robustness, the larger GIDAS sample was then used, comprising 755 pedestrians of which 38 were fatally injured. To verify data quality, all fatal accidents, crashes with impact speeds exceeding 65 km/h, and 20 randomly selected cases were studied in detail. This was done by considering accident sketches, photographs, police reports, medical records, etc. As a result of these investigations, two accidents with pedestrians surviving impact speeds of 77 km/h and 108 km/h respectively were excluded from the sample due to

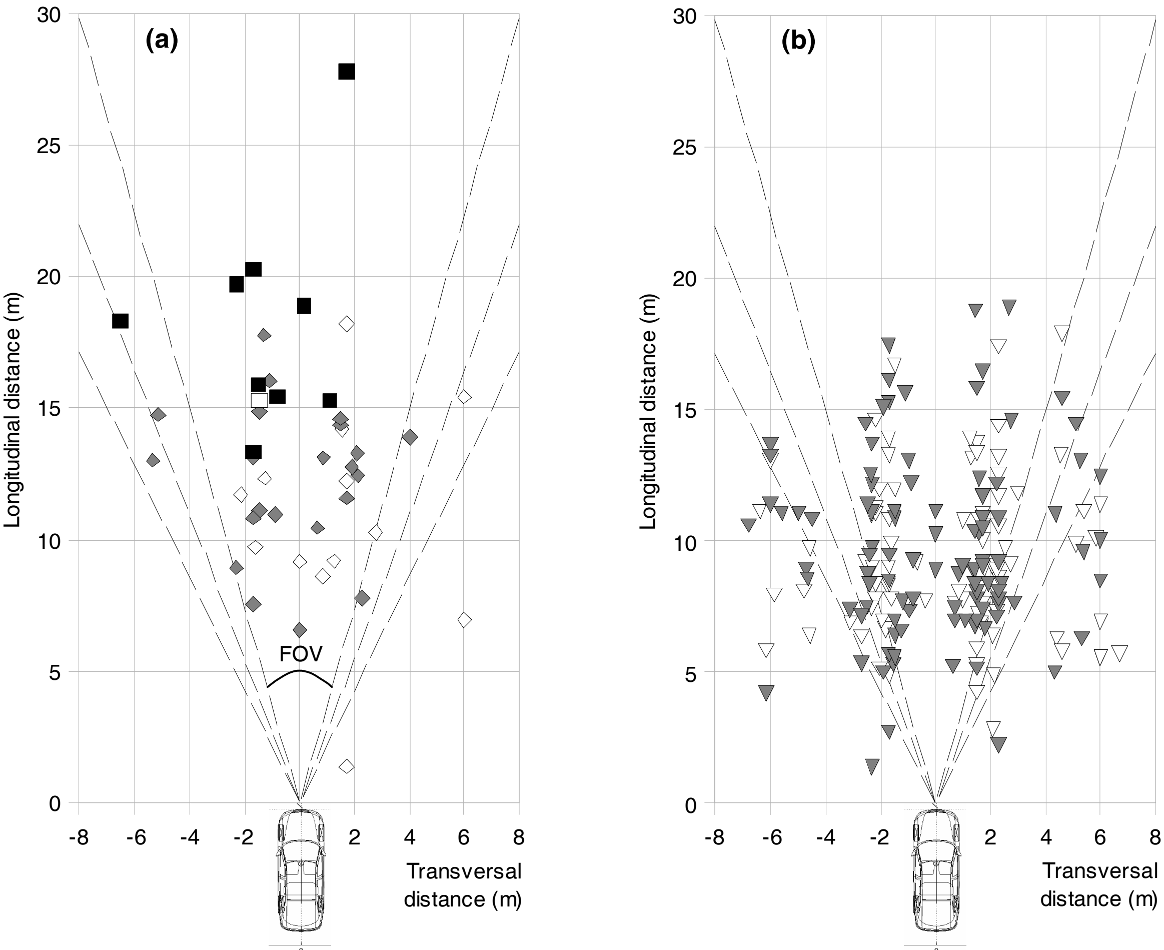

Figure 1. Pedestrian locations one second prior to impact. The dashed lines represent the field of views (FOV) 30°, 40°, and 50°. (a) Visible (not visible) fatally injured pedestrians marked with black (white) squares. Visible (not visible) severely injured survivors marked with grey (white) diamonds. (b) Visible (not visible) slightly injured pedestrians marked with grey (white) triangles.

interaction mainly with the side structure of the car. (In other words, these two pedestrians were "sideswiped" by the car and did not receive a substantial impulse in the collision.) Hence, the final sample consisted of 753 pedestrians. The fatality risk as a function of impact speed, $P_{fatal}(v)$, was then assumed to have the following form

$$P_{fatal}(v) = \frac{1}{1 + \exp(-a - bv)} \qquad (1)$$

where v is the impact speed and a, b two parameters to be estimated by the method of maximum likelihood (Dobson, 2002; McCullagh and Nelder, 1989).

A similar logistic regression analysis was conducted for the risk of sustaining at least one severe injury (MAIS3+) as a function of impact speed, $P_{severe}(v)$. For this analysis, a sub-sample of 694 pedestrians was used, for which the maximum AIS was known. Of these, 123 had at least one severe injury.

3.4 Effectiveness

The new impact speeds, v', achieved with the autonomous braking system implied reduced risks of fatality and severe injuries. With the reconstruction data and risk curve, $P_{fatal}(v)$, available, it was possible to estimate the effectiveness of the autonomous braking system. The effectiveness is defined as E=1–N'/N, where N is the weighted number of fatalities in the sample and N' is the estimated weighted number of fatalities with the braking system available. The calculations can be mathematically expressed as

$$E = 1 - \sum_{i=1}^{n} P_{fatal}(v'_i) w_i \Big/ \sum_{i=1}^{n} P_{fatal}(v_i) w_i \qquad (2)$$

where n is the number of cases (243 in this study), v_i and v'_i the original and new impact speeds, and

w_i the weight factor for the i:th pedestrian. Since the new impact speeds depended on the field of view of the sensor, so did N' and, hence, the effectiveness. This made it possible to study the effectiveness as a function of field of view. We calculated the effectiveness for the following field of views: 180°, 90°, 60°, 50°, 40°, 30°, 20°, and 10°. The same analysis was then conducted for severe injury.

Let us write the number of fatalities as $N=N_{nb}+N_b$, where N_{nb} is the number of fatalities in accidents where the driver had not braked, and N_b the number of fatalities in accidents where the driver braked. Analogously, we write the estimated number of fatalities with the autonomous braking system available as $N'=N'_{nb}+N'_b$ with the same interpretation of the subscripts "nb" and "b". By restricting the sums in equation (2) to these two different subgroups, N_{nb}, N_b, N'_{nb}, and N'_b were estimated. The ratio $(N_{nb}-N'_{nb})/(N-N')$ then gave the percentage of the fatality reduction that came from cases where the driver had not braked.

The influence of braking duration was also briefly considered by calculating the effectiveness when activating the brakes at 2s, 1.5s, 1s, and 0.5s prior to impact. This analysis could not be conducted for different values of the sensor field of view, since the field of views needed to detect the pedestrians were only known at one second prior to impact. Therefore, these investigations were only conducted for a field of view of 180°.

4. RESULTS

4.1 Empirical Observations

When considering the total sample, comprising 753 cases, we found 38 fatally and 123 severely injured pedestrians. For 32 (105) of the fatally (severely) injured pedestrians, both impact speed and travel speed were known. It was then found that 41% (27%) of the fatally (severely) injured pedestrians were freely visible during the pre-crash phase, but the driver did not brake, and for another 13% (3%) the speed reduction from driver braking was less than 10% of the travel speed.

Restricting to the 243 cases chosen for extended reconstruction, there were 11 fatally and 46 severely injured pedestrians. For the fatally (severely) injured pedestrians, 60% (26%) were freely visible, but the driver did not brake or braked only marginally. These results are close to the corresponding figures for the total sample presented above, and thus provide a check of the representativeness of the sub-sample used for extended reconstructions. We may conclude that an autonomous braking system would have a potential

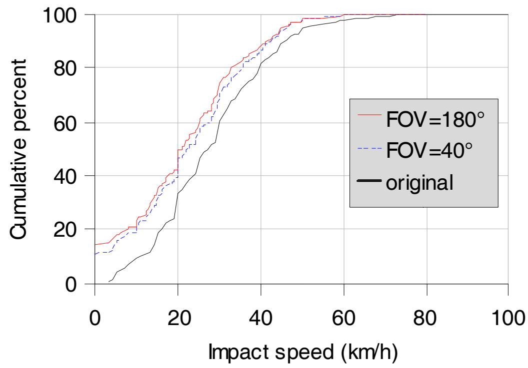

Figure 2. Cumulative impact speed distributions with and without the autonomous braking system.

to largely reduce the impact speed of the car for approximately half of the fatalities and one third of the severely injured pedestrians.

Figures 1a and 1b show the locations of the pedestrians one second prior to impact with different markers for slightly, severely, and fatally injured pedestrians. Since the vehicles typically had higher speeds than the pedestrians, pedestrian locations were more in the centreline of the sensor and farther away from the vehicles the higher the vehicle speed was. The same cases also tended to lead to higher injury severity levels. Finally, from Figure 1a, we see that a sensor with 40° field of view would have detected all but one of the visible pedestrians with fatal or severe injuries.

In total, 69% of the drivers braked, however in many cases the effect of the braking was very small. For the drivers who braked, the mean braking duration was 0.67s. Applying autonomous braking to all cases, regardless of visibility and field of view, the mean braking duration was 1.4s. (Note that activating the brakes one second prior to predicted impact will extend the actual time to impact, since vehicle speed will be decreased.)

In Figure 2, the cumulative distribution of impact speed for the sample is shown together with the corresponding distributions if the vehicles had been equipped with the autonomous braking system with 180° and 40° field of view respectively. The mean impact speed changed from 29 km/h (without the autonomous braking system) to 22 km/h (23 km/h) with a 180° (40°) field of view. Furthermore, 15% (11%) of the accidents would have been completely avoided. The mean travel speed of the cars was 39 km/h. Hence, the drivers achieved, on average, a 26% reduction of travel speed by braking (39 km/h to 29 km/h), whereas the autonomous braking system would have given a 44% (41%) speed reduction for 180° (40°) field of view.

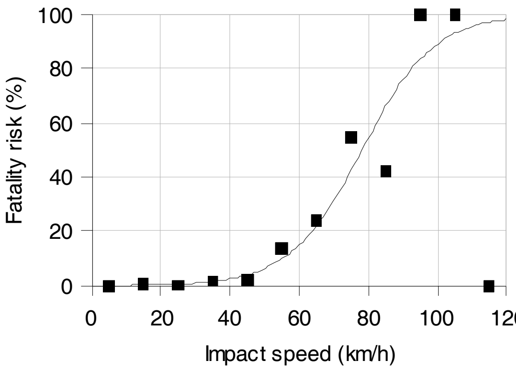

Figure 3. Fatality risk curve and empirical fatality rates (squares).

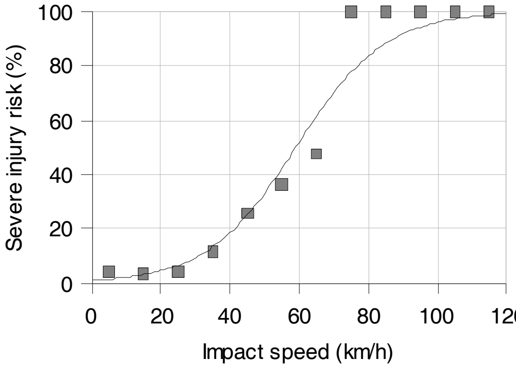

Figure 4. Severe injury risk curve and empirical severe injury rates (squares).

4.2 Injury Risk Functions

Figure 3 shows the fatality rates observed at different intervals of impact speed and the best-fit logistic regression curve. In Figure 4, similar information is given for the risk of sustaining at least one severe injury (MAIS3+). Details of the logistic regression analyses are provided in Table 1, where *a, b* are parameters to the risk function described in equation (1).

4.3 Effectiveness

Figures 5 and 6 show the estimated effectiveness of the autonomous braking system in preventing pedestrians from sustaining fatal and severe injuries for a range of sensor fields of view. For frontal impacts, the effectiveness for fatal (severe) injuries varied between 44% (33%) and 40% (27%) for field of views between 180° and 40°. The left-most category, labelled "All", shows the predicted effectiveness when autonomous braking was applied in all cases regardless of visibility and field of view. This represents the greatest possible level of effectiveness given the unrealistic assumption of perfect information. Figures 5 and 6 also give the effectiveness for the full target population, i.e., when including pedestrians struck by the side of a vehicle. (These results were obtained by a similar analysis as for the frontal impacts.)

Table 1.
Logistic Regression Results.

	a_{fatal}	b_{fatal}	a_{severe}	b_{severe}
Estimate	–7.5	0.096	–4.6	0.078
LL	–9.0	0.067	–5.3	0.059
UL	–5.9	0.13	–3.8	0.096
P-value	<0.0001	<0.0001	<0.0001	<0.0001

Details from the logistic regression analyses. The lower limits (LL) and upper limits (UL) are for a 95% Wald confidence interval.

The effectiveness calculations can be described as follows. The weighted baseline estimates for all 243 cases were 5.07 fatally (29.9 severely) injured pedestrians, which are close to the true values of 5.36 (30.3). Applying the autonomous pre-impact braking in all 243 cases, regardless of visibility, estimated 1.63 (11.8) fatally (severely) injured pedestrians. The effectiveness therefore is $E_{\text{fatal}} = 1 - 1.63/5.07 = 68\%$ ($E_{\text{severe}} = 1 - 11.8/30.3 = 61\%$). Restricting to pedestrians who were visible, the casualties increased to an estimated 2.82 fatalities (20.1 severely injured) and an effectiveness of E_{fatal}=44% (E_{severe}=33%). The results shown in Figures 5 and 6 were generated using parallel calculations for the full range of values for the field of view.

Furthermore, it was found that 75–80% of the saved lives and 65–70% of the reduction of severely injured pedestrians came from cases where the driver had not braked.

For a sensor with 180° field of view, we studied the effectiveness as a function of the time before impact at which the autonomous braking was activated. The results are provided in Figure 7. In this analysis, it was assumed that pedestrian visibility did not change during the pre-crash phase. Naturally, in the statistical model, the effectiveness increased with activation time, since longer braking duration implies lower impact speed and, hence, injury risk. However, in real-life traffic, autonomous braking implies a rather severe intervention in the operation of a driver, which may affect the driver's ability to stay in control of his vehicle (ECE, 1968). This influence is likely larger for harder braking and longer braking durations. Earlier predictions by the system will also increase the uncertainties regarding the intents of other road users, which may lead to higher rates of false activations.

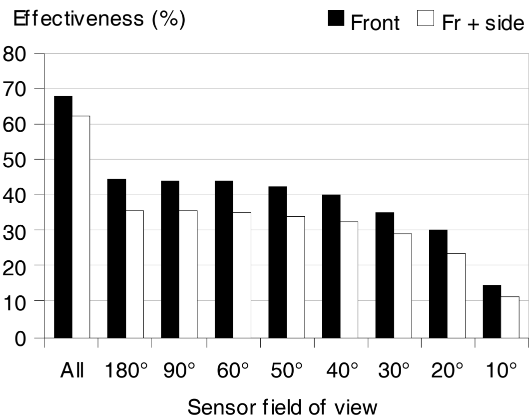

Figure 5. System effectiveness for fatality reduction. The category "All" corresponds to autonomous braking in all cases regardless of visibility and field of view.

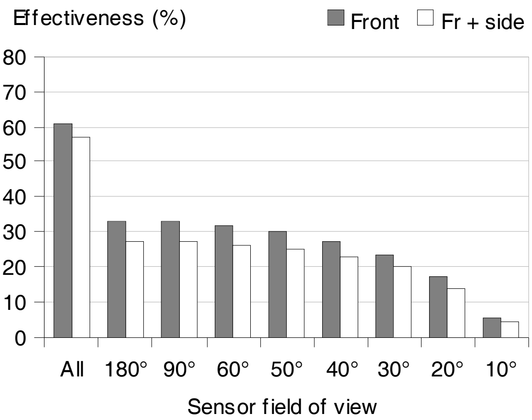

Figure 6. System effectiveness for reduction of severely injured pedestrians.

5. DISCUSSION

The effectiveness of the autonomous pre-impact braking system analysed in this study depends on how many pedestrians would be detected by the sensing system (system accuracy, field of view and detection range) as well as the duration and the level of the applied brake force. We chose to start with an analysis of the relation between sensor field of view and system effectiveness, due to the influence this parameter has on the cost and requirements on the sensing system. Figures 5 and 6 provide the results for a system that activates the brakes one second prior to predicted impact with a maximum braking deceleration of 0.6g. In some cases where the pedestrian was coded as not visible during the pre-crash phase, it is possible that he/she was only partially or temporarily obstructed from view. Even higher system effectiveness may therefore be possible if further development of detection systems and activation strategies leads to reliable detection of these pedestrians. This would decrease the gap between the effectiveness when

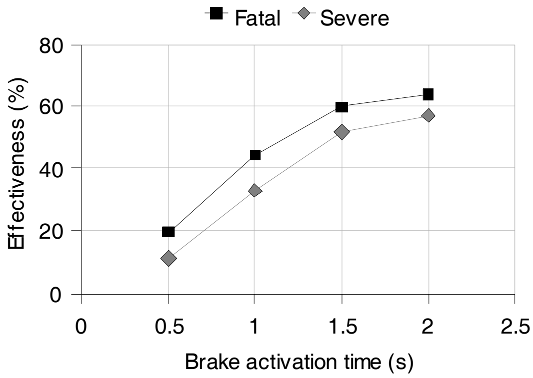

Figure 7. Effectiveness of the autonomous braking system with 180° field of view as a function of the brake activation time to impact.

braking for "All" pedestrians and when braking only for those coded as visible (see Figures 5 and 6).

A natural continuation of this study would be to analyse system effectiveness as a function of braking duration and braking level. Figure 7 provides the results of an initial investigation of this kind.

Sources of uncertainty for this study range from the inaccuracy of accident reconstructions in general to the vagary of actual and possible braking levels in particular. Predictive studies, like this one, also depend on the representativeness of the used data set. As described in subsection 3.1, we applied a weighting procedure so that GIDAS data might better resemble the total population of pedestrian accidents in Germany. However, the weighting turned out to have only a slight influence on the derived effectiveness. Like Lawrence et al. (2006), our results were found to be stable against changes in the risk curves. These findings indicate that the applied statistical methods were quite robust.

Lawrence et al. (2006) correctly pointed out that the potential effectiveness of a (non-autonomous) brake assist system is sensitive to the estimated additional deceleration that the system would generate. This is problematic since both the decelerations with and without a brake assist system are difficult to estimate accurately. This difficulty should, however, be largely avoided in this study, since the largest benefit of the autonomous braking system did not come from generating a higher deceleration in cases where the driver had already braked, but from braking when the driver failed to take action. As shown in subsection 4.3, nearly 80% of the fatality reduction came from cases where the driver had not braked. The remaining contribution came mainly from earlier activation of the brakes in cases where the driver had braked only shortly before impact. As shown in subsection 4.1, the average braking duration for drivers that braked was 0.67s, whereas the autonomous braking system had an average braking duration of 1.4s.

The detailed analyses of this study included pedestrians struck by the front of vehicles, with the main results provided in Figures 5 and 6. However, we also included the results of a similar analysis that took into account pedestrians struck by the side of vehicles. In so doing, we were assuming that the risks of fatality or severe injury as functions of impact speed could be derived for all pedestrians struck by the front and side of vehicles by simple logistic regression analysis. However, this assumption is questionable. The risk curves that we obtained (not presented here) were rather flat, since some of the pedestrians struck by the side of vehicles were merely "sideswiped" by the vehicle, or, e.g., hit only by an exterior mirror. Naturally, those pedestrians did not receive much impulse in the crash, and could therefore survive high speed crashes, which had a substantial effect on the risk curve. In other cases, the pedestrian fell over the hood and was struck badly by the A-pillar and windscreen. The flatness of the risk curve implied a lower benefit from braking. It is therefore likely that the effectiveness for pedestrians struck by the front or side of vehicles should be slightly higher than indicated in Figures 5 and 6. However, the results primarily show that the form of the effectiveness plot as a function of field of view did not change when including pedestrians struck by the side of vehicles.

In this study, the system was assumed to operate perfectly in all light and weather conditions, which might be difficult to achieve on the road. Furthermore, the system was assumed to brake for all pedestrians visible within the given field of view one second prior to impact. In real-life traffic, restrictions in system activation strategies may be necessary to gain regulatory and user acceptance.

6. CONCLUSIONS

Enhanced brake assist systems that use forward-looking sensors to predict an emergency situation are now becoming available. The approach taken in this study was to use real-world accident data to estimate the potential reduction of fatally and severely injured pedestrians from an autonomous brake assist system activated by a suitable forward looking sensor. The effectiveness was calculated as a function of sensor field of view for a system that activates the brakes one second prior to predicted impact with a maximum braking deceleration of 0.6g (see Figures 5 and 6).

For a field of view equal to 180°, the effectiveness in preventing fatal and severe injuries was 44% and 33% respectively. The effectiveness remained nearly constant when decreasing the field of view down to approximately 40°. With a field of view of 40°, the effectiveness in preventing fatal and severe injuries was 40% and 27% respectively. Taking into account all pedestrians struck by the front or side of vehicles, the exact figures changed. However, the dependence on field of view was similar.

These findings are in line with the empirical observations that approximately half of the fatally and one third of the severely injured pedestrians were visible to the driver during the pre-crash phase, but the driver did not brake or only braked marginally. Furthermore, a large majority of the visible pedestrians with fatal or severe injuries were within a 30° field of view, and nearly all were within 40°.

Various restrictions will limit the effectiveness in real-life traffic, but the results highlight the large potential in reducing fatal and severe pedestrian injuries with an autonomous braking system and that it is reasonable to limit sensor field of view to 40°.

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