REAL-WORLD EVALUATION OF DRIVER ASSISTANCE SYSTEMS FOR VULNERABLE ROAD USERS BASED ON INSURANCE CRASH DATA IN SWEDEN

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ABSTRACT

In 2010 Volvo cars introduced advanced driver assistance systems (ADAS) designed to detect vulnerable road users (VRUs) in specific conflict situations. The aim of this study was to evaluate the first generation of the optionally mounted Pedestrian ADAS, which covers car-to-pedestrian collisions, and Cyclist ADAS, which covers car-to-cyclist collisions.

Data from collisions in Sweden between passenger cars and pedestrians or cyclists were collected from 2015-2017. Crashes involving Volvo cars with third-party liability insurance at If P&C Insurance/Volvia were included in the dataset, and cars with these ADAS were compared to crashes involving cars without the systems. A total exposure of 490,000 insured vehicle years was used in the evaluation.

Overall, the number of collisions for cars with the Pedestrian ADAS system was 21% less than the number for cars without it. When studying straight crossing path crashes only, which accounted for more than half of all car-to-pedestrian collisions in Sweden, these were reduced by 36%. However, the results are not statistically significant due to the low number of crashes. For the ADAS, which covers car-to-cyclist collisions, an overview of data available for retrospective performance evaluation is discussed.

One clear restriction in the evaluation of VRU ADAS at this point in time is the relatively low number of cars equipped with the system together with the low rates of car-to-cyclist collisions (≈ 0.0002 per insured vehicle year) and car-to-pedestrian collisions (≈ 0.0001 per insured vehicle year).

This study is the first real-world evaluation of the initial generation of VRU ADAS targeting traffic situations relevant for these technologies. ADAS for avoiding collisions with pedestrians and cyclists have a high traffic-safety potential; recent and future generations of these systems, cover more conflict situations and are thus expected to provide increasing safety benefits.

INTRODUCTION

Globally, pedestrians and cyclists represent 26% of all road traffic deaths [1]. There is a big variation in death rates across regions and countries, with low- and middle-income countries the worst affected. In EU countries, pedestrians and cyclists comprised around 21% and 8% of all road traffic deaths, respectively, in 2015 [2]; in the US the corresponding numbers were 16% and 2.2%, in 2016, [3]. In Sweden, in 2017, 15% of the road fatalities were pedestrians and 8% were cyclists [4, 5]. In many countries, roads still lack separate lanes for cyclists and adequate pedestrian crossings—and motor vehicle speeds are too high [1].

Infrastructure measures, such as the physical separation of motor-vehicle and VRU paths, have proven to be effective in preventing VRU crashes. The expansion of walking and cycling paths in Sweden is a good example: fatal pedestrian and cyclist crashes have decreased from one third of the total road-traffic fatalities in the 1970s to just over one fifth today [4]. Still, VRUs often share the road with motor vehicles, and crashes occur frequently—most commonly in urban areas where walking and cycling are common modes of transport [6].

For car-to-VRU collisions, the distribution of conflict situations in crash databases are used to identify frequent or severe situations to address with traffic safety measures. The majority of crashes are Straight Crossing Path (SCP) situations, i.e. the car is moving straight forward, and the car and the VRU are crossing each other’s paths.

Situations in longitudinal traffic, when the car and the VRU are traveling in the same or opposite direction while sharing the same roadway are not as frequent, but often with more severe injuries for the VRU. Specific situations for car-to-pedestrians are collisons where the car is reversing hitting a pedestrian, and for car-to-cyclists; the cyclist riding into a car door that was being opened by the car driver or a passenger, hereafter called dooring [7-11].

As unprotected road users, pedestrians and cyclists are particularly vulnerable to severe or fatal injuries in case of a crash. One important way to reduce the consequences of a crash is to lower the impact speed [12-14]. To improve the situation where vulnerable road users and motor vehicles share the road, speed limits have been reduced in Swedish cities over the last decade (where appropriate) [15]. Additional speed-reducing measures, such as speed bumps and raised crosswalks and chicanes, have been implemented to achieve better speed compliance [16]. In the work with the Vision Zero initiative, a key indicator measuring the share of safe walking, bike, and moped passages was introduced [17, 18].

In the last decade, vehicle manufacturers have developed countermeasures to reduce the consequences of an impact with VRUs. These involve redesign of the bumper area [19], the hood, windshield, and pillar [20], and introduction of pedestrian airbags [21], and pop-up bonnets [22].

One of the most promising countermeasures presented by the automotive industry is advanced driver assistance systems (ADAS) specifically for pedestrian and cyclist situations. One example is the collision warning with full autobrake and pedestrian and cyclist detection implemented in Volvo car models [23]. Real-world evaluations have shown that autobrake systems are very effective in avoiding (as well as mitigating) car-to-car crashes in rear-end situations [24-33], and test institutes and predictive studies estimate that including pedestrian and cyclist detection will greatly reduce crashes with VRUs [34-38]. In December 2017, HLDI examined pedestrian-related collisions which showed a reduction in the frequency of bodily injury (BI) liability claims, as a result of analyzing an ADAS with a pedestrian detection feature. [39].

The aim of this study was to evaluate the first generation of driver support systems which are intended to detect VRUs, covering car-to-pedestrian- as well as car-to-cyclist collisions, by investigating real-world crashes collected from traffic situations relevant for these technologies.

DATA & METHOD

In this study we used insurance claims data from car-to-pedestrian collisions involving Volvo models with and without Pedestrian ADAS (collision warning with full autobrake and pedestrian detection). Also, car-to-cyclist collisions involving Volvo models with and without Cyclist ADAS (collision warning with full autobrake and cyclist detection) was studied.

To calculate the exposure, information covering all cars registered in Sweden with third-party liability insurance at If P&C insurance/Volvia was used. The analysis was performed using accident and exposure data for the years 2015-2017.

Data collection

Data including both car-to-pedestrian collisions and car-to-cyclist collisions in Sweden are continuously coded and collected in two databases. For cars with third-party liability insurance at If P&C insurance/Volvia, all crashes involving cyclists and pedestrians were coded using information from the claims. This means that a representative set of data, ranging from very low-severity crashes to fatal crashes, is available. These data include crashes sometimes not collected in, e.g. the national crash databases, because they are lower in severity or simply not included in the collection criteria; however, even these situations can result in injuries for VRUs. Two examples illustrate this point: the dooring situation, (defined as a single accident in police-reported accidents in Sweden) and the frequent situation; car reversing hitting a pedestrian, that is not considered at all in official statistics.

In most cases, information about the crash situation was available for both the pre-crash and crash events between car and pedestrian/cyclist. The pre-crash event was described by the conflict situation classification, if available, the driver's estimate of the car's speed just before the accident; and whether the driver's view was restricted. The crash event was described by the point of impact and the impact direction for both the pedestrian/cyclist and the car during the collision. This information was obtained from the claims form and descriptions by the driver and the pedestrian/cyclist. To more fully describe each situation, environmental conditions (light and weather conditions and road status), when (time of day) and where the collision occurred (urban or rural area), and demographics about the driver and the pedestrian/cyclist were recorded. Personal injuries were coded using the Abbreviated Injury Scale (AIS) [40].

Exposure data

Exposure data were calculated for the Volvo car models included in the study, by summing up the number of insured vehicle years (IVY): one car insured for one year is one insured vehicle year, two cars insured for half a year each is equal to one insured vehicle year, etc. Crashes involving cars with the optionally mounted VRU ADAS were identified and compared to crashes involving cars without the systems. For the Pedestrian ADAS detection system, the total exposure was 490,000 vehicle years and for the Cyclist ADAS detection system it was 420,000 vehicle years. For detailed information about the number of selected cases, see Tables 1 & 2.

System description: Pedestrian ADAS

The pedestrian detection technology (consisting of collision warning and autobrake system) was included in the third generation of Volvo Cars' collision avoidance system, available from 2010 (MY 2011) as an option in the Volvo models S/V60. From MY 2012 it has been available in the V/XC70 and S80 models, and from MY 2013 in the V40. Models introduced from 2015 on, starting with the new XC90, are equipped with the next generation of collision warning and autobrake system as standard. The system uses a combination of a long-range radar and a forward-sensing wide-angle camera that continuously monitors the area in front of the vehicle. For best performance, the pedestrian detection needs a clear view of the person's head, arms, shoulders, legs, and the upper and lower parts of the body—and the person should be moving normally; Figure 1. If large parts of the pedestrian's body are not visible, the system cannot detect it. In the first version of the system, representing all cases included in the study, the capacity for detecting a pedestrian in darkness was limited, but the version introduced in 2015 represents a great improvement. However, some contrast between the pedestrian's silhouette and the background is still needed for detection.

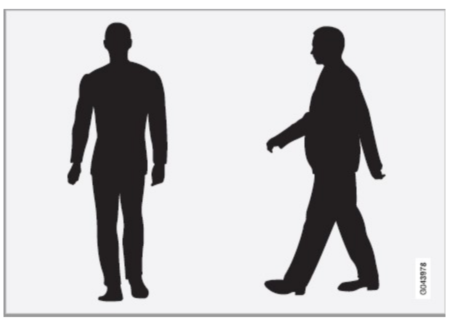

Figure 1. Examples of the clear body contours that the system regards as pedestrians, adapted from [41]

The pedestrian detection system will provide a warning and brake support in some of the situations when there is a credible risk of an accident. If the driver does not intervene after the warning, and the collision threat becomes imminent, intervention braking may automatically be applied to help slow down the car. Up to a speed of 80 km/h, the system may autobrake for a pedestrian, and up to approximately 35 km/h the collision may be avoided completely. In the most recent version, the system is able to reduce speed in up to 45 km/h in some car-to-pedestrian critical situations.

System description: Cyclist ADAS

Cyclist ADAS was an available option in Volvo's collision avoidance system starting in 2012 (MY 2013) in the S/V60, V/XC70, XC60, S80, and V40 models. Like the pedestrian ADAS, this system has been a standard feature in models introduced in 2015 and later, starting with the new XC90.

a) *b)* *c)*

Figure 2. Examples of clear body and bicycle outlines that the system regards as cyclists, adapted from [41-42]

For Cyclist ADAS, the technology is similar to the Pedestrian ADAS. To be able to recognize a cyclist, the system will optimally be able to detect clear, distinct body and bicycle outlines; Figure 2. The first version of the system was able to detect cyclists traveling in the same direction from behind; Figures 2.a & b. In the second generation of the system, introduced in 2015, cyclists can also be recognized from a side view; Figure 2c.

Crash data

Volvo car models V40, S/V/XC60, V/XC70, S80 and S/V/XC90 were selected from the car-to-pedestrian and car-to-cyclist crash databases, starting with the date Pedestrian ADAS and cyclist ADAS respectively were available for these models.

Car-to-pedestrian crash data The car-to-pedestrian crash data contain 12 Pedestrian ADAS cars and 37 non-Pedestrian ADAS cars, collected in Sweden between 2015 to 2017; Table 1.

Of the 12 car-to-pedestrian collisions in which the car was equipped with the Pedestrian ADAS system, six were SCP situations (the pedestrian was crossing the road in front of the car, going straight). The other cases represent a variety of situations: the car turned right as the pedestrian was crossing the road, a young boy was playing beside the road and rolled out onto the road as the car approached, the car was going straight and the pedestrian was standing still beside the road, and the pedestrian ran into the side of the car; in two cases, the car drove over the pedestrian's foot (one in a parking lot and one in a petrol station). In one case the car was reversing.
For cases with information of pre-crash factors, six occurred in daylight and four in darkness. In nine cases the weather was clear, nine cases happened in urban areas and two in non-urban areas. There were two seriously injured pedestrians, the remaining ten have moderate or minor injuries.

Of the 37 collisions with non-Pedestrian ADAS cars, 23 were SCP situations, in four cases the car was turning before the collision with a pedestrian crossing the road. In one case the car hit a pedestrian standing still beside the road. In two cases the car was moving forward in a parking lot when hitting the pedestrian, in one case the car skidded before hitting two pedestrians. One case occurred on a motorway in the night. In four cases the car was reversing.
Of the known pre-crash factors 19 of the cases occurred in daylight, 15 in darkness. It was clear weather in 24 of the cases, in two it was raining. The main part, 33 of the collisions, occurred in urban areas. Four of these pedestrian crashes were fatal, one pedestrian had a serious injury, in 11 of the cases the pedestrian had a moderate injury and the rest have only minor injuries.

Car-to-cyclist crash data The car-to-cyclist crash data contains 27 cars with Cyclist ADAS and 56 cars without the system (non-Cyclist ADAS) collected in Sweden between 2015 to 2017, Table2. Of the 27 cars with Cyclist ADAS, only four cars had the updated version of the system where cyclists can also be recognized from a side view.

Of the 27 collisions involving cars with the Cyclist ADAS system, there were one case where the car and the cyclist travelled in the same direction: the handlebar of the bicycle and the side of the car made contact. Of the remaining cases, 19 were SCP situations (the car was going straight when the cyclist crossed the road in front, from either the left or the right). Two of these cases occurred in a roundabout. In six cases, the car was turning right, and in one case the car was turning left, and collided with a cyclist crossing the road.

The majority of the cases occurred in urban areas, during daylight and in clear weather. None of the cyclists were seriously injured.

Of the 56 collisions with non-Cyclist ADAS cars, three cases were same direction situations. Of these three cases two occurred in a roundabout; in one case the car was overtaking the cyclist the handlebar of the bicycle touched the side of the car, in the other case the car was running into the cyclist, diagonally when the cyclist was leaving the roundabout. 31 of the collisions were SCP situations, 13 were situations where the car turned left or right before colliding with a cyclist crossing the road. In eight cases, the car was not moving forward, in three of these cases the car was reversing and five cases were dooring situations. The majority of these 56 crashes occurred in urban areas, during daylight and in clear weather without seriously injured cyclists.

Statistical methods
The rate of car-to-pedestrian collisions was compared per 10,000 IVYs for cars with and without the Pedestrian ADAS system.

The rate of car-to-pedestrian collisions for Pedestrian ADAS cars is defined as

$$\text{Rate}_{\text{Pedestrian ADAS}} = (\text{n}_{\text{Pedestrian ADAS}} / \text{IVY}_{\text{Pedestrian ADAS}}) \qquad (1)$$

where n is the number of car-to-pedestrian collisions. The number of claims can be considered using a Poisson distribution. Exact 95% Poisson confidence limits for the estimated rate were calculated as

$$\text{LCL} = \frac{\chi^2_{2\text{n},\ \alpha/2}}{2}\ , \qquad \text{UCL} = \frac{\chi^2_{2(\text{n}+1),\ 1-\alpha/2}}{2} \qquad (2)$$

The rate and confidence interval of pedestrian and car crashes for non-Pedestrian ADAS cars were defined comparably.

To evaluate the effectiveness of the Pedestrian ADAS technology, Poisson regression was used to compare the car-to-pedestrian collision rates per IVY for Pedestrian ADAS and non-Pedestrian ADAS cars. The calculations were performed with PROC GENMOD (SAS Institute) [42], using a model with a logarithmic link function. Regression models were constructed for the total number of pedestrian and car collisions. Rate ratios (RRs) were provided from the output, together with 95% confidence limits. The system's effectiveness (the reduction in crashes as a percentage) was calculated as $(1 - \text{RR}) * 100$.

RESULTS

Car-to-pedestrian collisions:
The crash database contained 12 car-to-pedestrian cases involving Pedestrian ADAS cars and 37 cases with cars without the system. Six of these cases where car-to-pedestrian straight crossing path (SCP) situations with Pedestrian ADAS cars, and 23 where cars in SCPs without the system; Table 1.

Table 1.
Number of car-to-pedestrian collisions and insured vehicle years for cars with and without the pedestrian detection system Pedestrian ADAS.

	Number of collisions all	Number of collisions SCP	Insured vehicle years
Pedestrian ADAS	12	6	142,627
non-Pedestrian ADAS	37	23	347,661

The crash rate for car-to-pedestrian collisions per 10,000 IVYs, all conflict situations included, was 0.84 (95% confidence interval [CI], 0.43, 1.47) for Pedestrian ADAS cars and 1.06 (95% CI, 0.75,1.47) for non-Pedestrian ADAS cars. The rate was 21% lower (nonsignificant) for the Pedestrian ADAS cars (RR = 0.79, 95% CI, 0.41–1.51).

When only SCPs were selected, the rate per 10,000 IVYs was 0.42 (95% CI, 0.15, 0.92) for Pedestrian ADAS cars and 0.66 (95% CI, 0.42, 0.99) for non- Pedestrian ADAS cars. The SCP crash rate was 36% lower (nonsignificant) for the Pedestrian ADAS cars (RR=0.64, 95% CI, 0.26–1.57).

Car-to-cyclist collisions:

For car models XC90, S/V90 and S/V60 (introduced in 2015 and after), the system is now standard mounted with the second generation of the system that is able to recognize cyclists in several conflict situations, see Figure 2. The crash data contain 27 car-to-cyclist collisions involving Cyclist ADAS cars, of which only four have the second generation of the system, and 56 collisions involving non-Cyclist ADAS cars; Table 2.

Table 2.
Number of car-to-cyclist collisions and insured vehicle years for cars with and without the cyclist detection system Cyclist ADAS.

	Number of collisions all	Number of collisions same-direction	Insured vehicle years
Cyclist ADAS	27	1	133,916
non-Cyclist ADAS	56	1	285,012

The rate for all car-to-cyclist collision situations per 10,000 IVYs was 1.98 (95% CI, 1.58, 2.46).

Given that the same-direction conflict situation, targeted by the first generation of the Cyclist ADAS, accounted for only 3 % of all car-to-cyclist crashes [10], no difference could be identified for this type of crash when cars with and without the Cyclist ADAS system were compared.

DISCUSSION

Predictions based on virtual simulations as well as physical testing in specific test scenarios have promised traffic safety improvements from VRU ADAS technologies [34-38]. The present study describes real-world follow-up results in car-to-pedestrian collisions, providing preliminary confirmation of these predictions.

These results, although not significant, indicate that cars equipped with Pedestrian ADAS system reduced car-to-pedestrian collisions by 21% when all types of conflict situations in the data were considered—and by 36% for the SCP situation specifically. This is in line with a predictive estimation of the system's performance made in 2010 that suggested that 30% of the pedestrian crashes could be avoided, and that fatal crashes when the pedestrian is struck by the front of a passenger car could be reduced by 24% [34]. A similar study predicted a reduction in fatally and severely injured pedestrians of 40% and 27%, respectively, for a conceptual AEB system [35].

The performance of Cyclist ADAS in car-to-cyclist collisions was not investigated, since the dataset available mainly covered the first generation of the system only targeting same-direction situations, (Figure 2a-b). This conflict situation was not frequent in the dataset analyzed, nonetheless, the Cyclist ADAS illustrates one small, but important, step towards car-to-cyclist crash avoidance functionalities. In the second generation of the Cyclist ADAS introduced in Volvo car models in 2015, cyclists can also be identified from a side view (Figure 2c). Since more than 40% of all car-to-cyclist collisions in Swedish data [10] are SCP situations, this second generation is expected to perform substantially better.

This study is based on insurance data, covering all levels of crash severity and including situations – that are not always covered in other crash databases with other selection criteria [8]. In general, results from performance estimations depend on the methodology that was applied; how the analysis is implemented, which situations are considered, and the representativeness of the input data. Thus, specific numbers need to be carefully interpreted. For example, in this study, only situations where the car was driving forward are relevant and expected to be reduced.

This is exemplified by the two results presented for Pedestrian ADAS. The overall car-to-pedestrian crash potential consider all types of conflict situations also including crashes where the car was reversing, and taking this total sample into account, 21 % of car-to pedestrian collisions were reduced. On the other hand, a specific evaluation of the SCP situation, one of the target situations of the system, reveals a greater effect (36%), from the Pedestrian ADAS.

Some limitations in this study should be mentioned. It was not possible to find any significant safety benefits attributable to the ADAS systems in this study. The number of cars in traffic equipped with this functionality was low in the first years after its introduction. Further, the accident rates of pedestrian and bicycle crashes with cars are relatively low in Sweden, so it takes time before there are enough data available to study. As a comparison, approximately 50 rear-end-frontal collisions occur per 10,000 IVYs—compared to one car-to-pedestrian and two car-to-cyclist collisions for the same exposure. This was obvious when the collision warning and autobrake systems were evaluated in 2016; there was only one crash for the cars equipped with the pedestrian detection feature, and no crashes for the cars equipped with cyclist detection [32]. The possibility of achieving reliable performance estimations will increase, since the systems are now standard features in all new Volvo models. Given the higher frequency of VRU crashes in other regions of the world [1], it is suggested that research on the effectiveness of advanced driver assistance systems also be performed in other countries.

This study did not evaluate a mitigation effect, i.e. when the system was activated and the speed (and thus the crash severity) was reduced, but the crash was not completely avoided. In car-to-VRU crashes even slight reductions in impact speeds have a large effect on the injury outcome for pedestrians and cyclists [12], so it is therefore suggested that crash mitigation be included in future studies.

In this study, we found a clear indication that the first generation of Pedestrian ADAS is effective in reducing car-to-VRU crashes, and it was suggested that more recent generations of both Pedestrian- and Cyclist ADAS will be even more efficient in terms of traffic safety improvements for VRUs. Other countermeasures to reduce or mitigate car-to-VRU injuries have been implemented, including: infrastructure measures [15, 44], consumer rating tests on vehicles [36, 37], protective gear for cyclists [45], and motor-vehicle measures [19-23]. All of these initiatives should be considered in order to maximize a long-term decrease in VRU injury rates.

CONCLUSIONS

To our knowledge, this is the first study to analyze real-world crash data in relevant situations to evaluate ADAS systems targeting car-to-pedestrian and –cyclist collisions. Car-to pedestrian collisions were reduced by 21% when all conflict situations were considered, and by 36% in the specific straight-crossing path conflict situation, for cars equipped with Pedestrian ADAS. For Cyclist ADAS, the target situation in the first generation of the system only cover a low share of car-to-cyclist collisions, and no performance estimation was made. Our results, albeit nonsignificant, indicate that as more data become available, further improvements are foreseen in crash reduction and mitigation for the vulnerable road users that share the road with motor vehicles.

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REFERENCES

[1] GLOBAL STATUS REPORT ON ROAD SAFETY 2018, WHO Available at: https://www.who.int/violence_injury_prevention/road_safety_status/2018/en/ Downloaded 20190123.

[2] Annual Accident Report 2017, European Road Safety Observatory: Available at: https://ec.europa.eu/transport/road_safety/specialist/observatory/statistics/annual_accident_report_en Downloaded 20190123.

[3] Traffic Safety Facts, 2016; Report DOT HS 812 554. NHTSA, U.S. Department of Transportation; May 2018.

[4] Vägtrafikskador, 2017: Available at https://www.trafa.se/vagtrafik/vagtrafikskador/ Downloaded 20190123.

[5] IRTAD, International Transport Forum. Road Safety Annual Report 2018. Available at: https://www.itf-oecd.org/road-safety-annual-report-2018. Downloaded 20190215.

[6] Pedestrian and Cyclists 2015, European Road Safety Observatory: Available at: https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/ersosynthesis2015-pedestrianscyclists25_en.pdf Downloaded 20190123.

[7] Isaksson-Hellman, I. 2012. A study of bicycle and passenger car collisions based on insurance claims data. In: Proceedings of the Ann. Adv. Automot. Med., vol. 56, pp.3-12.

[8] Isaksson-Hellman I and Werneke J. 2017. Detailed description of bicycle and passenger car collisions based on insurance claims. Safety Science. 92:330-337.

[9] Lindman, M., Jakobsson, L., Jonsson, S. 2011. Pedestrians interacting with a passenger car; a study of real world accidents. IRCOBI Conference Proceedings. No. IRC-11-61.

[10] Lindman, M., Jonsson, S., Jakobsson, L., Karlsson, T., Gustafson, D., Fredriksson, A. 2015. Cyclists interacting with passenger cars; a study of real world crashes. IRCOBI Conference Proceedings. No. IRC-15-10.

[11] Op den Camp, O., Ranjbar, A., Uittenbogaard, J., Rosén, E., Fredriksson, R. and de Hair, S. 2014. Overview of main accident scenarios in car-to-cyclist accidents for use in AEB-system test protocol. Proceedings of: International Cycling Safety Conference, Gothenburg, 2014.

[12] Rosén, E., Sander, U., 2009. Pedestrian fatality risk as a function of car impact speed. Accid. Anal. Prev. 41, 536-542.

[13] Kim, J.-K., Kim, S., Ulfarsson, G.F., Porello, L.A. 2007. Bicyclist injury severities in bicycle-motor vehicle accidents. Accid. Anal. Prev. 39, 238–251.

[14] Bíl, M., Bílová, M., Müller, I. 2010. Critical factors in fatal collisions of adult cyclists with automobiles. Accid. Anal. Prev. 42, 1632A–1636A.

[15] Isaksson-Hellman I. and Töreki J. 2018. The effect of speed limit reductions in urban areas on cyclists' injuries in collisions with cars. Presented on International Cycling Safety Conference ICSC Barcelona.

[16] Gustafsson, S., Jägerbrand, A., Grumert, E. Hastighetsdämpande åtgärder, En litteraturstudie med fokus på nya trafikmiljöåtgärder och ITS-orienterade lösningar. 2011. VTI 17-2011. Available at: www.vti.se/publikationer. Downloaded 20190215.

[17] Swedish transport administration, Trafikverket This is vision zero. Available at: https://www.trafikverket.se/en/startpage/operations/Operations-road/vision-zero-academy/Vision-Zero-and-ways-to-work/. Downloaded 20190220.

[18] Swedish transport administration, Trafikverket. Trafiksäkerhetsmål och indikatorer. Available at: https://www.trafikverket.se/for-dig-i-branschen/samarbete-med-branschen/Samarbeten-for-trafiksakerhet/tillsammans-for-nollvisionen/mal-och-indikatorer/. Downloaded 20190220.

[19] Ahmed, S., Patil, G. 2013. Bumper Shape Optimization for Pedestrian Safety. International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 1, January - February 2013, pp.1724-1732.

[20] Hu, J., Klinich, K. D. 2012. Toward designing pedestrian-friendly vehicles. Int. J. Veh. Saf. 2012, 8, 102873.

[21] Jakobsson, L., Broberg, T., Karlsson, H., Fredriksson, A., Gråberg, N., Gullander, C., Lindman, M. 2013. Pedestrian airbag technology – a production system. 23rd ESV Conference; 2013; Soeul, Korea. Paper No. 13-0447.

[22] Lee, K. B., Jung, H. J., Bae, H. I. 2007. The study on developing active hood lift system for decreasing pedestrian head injury. 20th ESV Conference; 2007; Lyon, France. Paper Number 07-0198.

[23] Coelingh, E., Eidehall, A., Bengtsson M. 2010. "Collision Warning with Full Auto Brake and Pedestrian Detection - a practical example of Automatic Emergency Braking" 13th International IEEE Annual Conference on Intelligent Transportation Systems Madeira Island, Portugal.

[24] Isaksson-Hellman I, LindmanM. 2012. The effect of a low-speed automatic brake system estimated from real life data. In: Proceedings of the Ann. Adv. Automot. Med. vol; 56: pp. 231–240.

[25] Rizzi, M., Kullgren, A., Tingvall, C. The injury crash reduction of low-speed autonomous emergency braking (AEB) on passenger cars. 2014. IRCOBI Conference Proceedings. No IRC-14-23.

[26] Highway Loss Data Institute. 2015. Volvo city safety loss experience—a long-term update. HLDI Bull. 2015;32(1):1–24.

[27] Doyle, M., Edwards, A., Avery, M. 2015. AEB real world validation using UK motor insurance claims data. Paper presented at: 24th ESV Conference; 2015; Gothenburg, Sweden. Paper Number 13-0058.

[28] Isaksson-Hellman I, Lindman M. 2015. Real-world performance of city safety based on Swedish insurance data. Paper presented at: 24th ESV Conference; 2015; Gothenburg, Sweden. Paper Number 15-0121.

[29] Fildes, B., Keall, M., Bos, N., et al. 2015. Effectiveness of low speed autonomous emergency braking in real-world rear-end crashes. Accid Anal Prev. 2015; 81:24–29.

[30] Isaksson-Hellman, I. and Lindman M. 2015. "Evaluation of rear-end collision avoidance technologies based on real world crash data. Paper presented at: 3rd International Symposium on Future Active Safety Technology Towards Zero Traffic Accidents; Gothenburg, Sweden.

[31] Isaksson-Hellman, I. and Lindman, M. 2016. Evaluation of the crash mitigation effect of low-speed automated emergency braking systems based on insurance claims data, Traffic Inj. Prev. 2016; 17:sup1, 42-47.

[32] Isaksson-Hellman, I. and Lindman, M. 2016. "Using insurance claims data to evaluate the collision avoidance and crash-mitigating effect of CWB+ACC." Paper presented at IEEE, IV'16; 2016; Gothenburg, Sweden.

[33] Cicchino, J. 2016. Effectiveness of Volvo's City Safety Low-Speed Autonomous Emergency Braking System in Reducing Police-Reported Crash Rates. Insurance Institute for Highway Safety.

[34] Lindman, M., Ödblom, A., Bergwall, E., Eidehall, A., Svanberg, B. and Lukaszewicz, T. 2010. "Benefit Estimation Model for Pedestrian Auto Brake Functionality". ESAR, Hanover, Germany.

[35] Rosén, E., Källhammer, J.E., Eriksson, D., Nentwich, M., Fredriksson, R. and Smith, K., "Pedestrian injury mitigation by autonomous braking". 2009. Paper presented at: 21st ESV Conference; Stuttgart, Germany, 2009. Paper Number 09-0132.

[36] Euro NCAP TEST PROTOCOL – AEB VRU systems. Version 2.0.2. November 2017

[37] IIHS Pedestrian Autonomous Emergency Braking Test Protocol (Version 1). December 2018.

[38] Kovaceva, J.,Balint, A., Schindler, R., Schneider A., Stoll, J., Breunig, S., Bräutigam, J.,Jaussein, M., Bruyas, M-P., Puente guillen, P., large, D., Perlet, K., Petersson, M., Esquer, A. Prospect, proactive safety for pedestrians and cyclists. 2018. European Commission Eighth Framework Programme Horizon 2020 GA No. 634149. Assessment of the PROSPECT safety systems including socioeconomic evaluation, D2.3.

[39] HLDI. 2017. Effect of Subaru EyeSight on pedestrian-related bodily injury liability claim frequencies. Bulletin Vol. 34, No. 39.

[40] AAAM (Association of the Advancement of Automotive Medicine), 2005. The Abbreviated Injury Scale (AIS), 2005 Revision. AAAM, Des Plaines, IL, USA.

[41] V70/XC70 owner's manual. Available at: https://carmanuals2.com/get/volvo-v70-2016-agarmanual-61589. Downloaded 20190123.

[42] XC90 owner's manual. Available at: https://carmanuals2.com/get/volvo-xc90-201x-agarmanual-52988. Downloaded 20190123.

[43] SAS Institute. PROC GENMOD. SAS: Statistical Software [computerprogram]. Version 9.4. Cary, NC: SAS Institute Inc. Available at:https://support.sas.com/documentation/cdl/en/statug/63033/HTML/default/viewer.htm#genmod_toc.htm.

[44] Lu, M. 2006. Modelling the effects of road traffic safety measures. Accid. Anal. Prev. 38, 507-517.

[45] Høye, A. 2018. Bicycle helmets – To wear or not to wear? A meta-analyses of the effects of bicycle helmets on injuries. Accid. Anal. Prev. 117, 85-97.