PASSENGER CAR SAFETY BEYOND ADAS: DEFINING REMAINING ACCIDENT CONFIGURATIONS AS FUTURE PRIORITIES

Martin Östling
Nils Lubbe
Hanna Jeppsson
Autoliv Research
Sweden

Pradeep Puthan
Autoliv India
India

Paper Number 19-0091

ABSTRACT

New vehicles are increasingly equipped with a variety of Advanced Driver Assistance Systems (ADASs). As these systems have the potential to prevent accidents, accidents of the future will differ from those of today. Predicting the type and characteristics of these future accidents is therefore essential to current research and development in the occupant restraint and new ADAS fields.

In this study, accident avoidance of 15 ADASs was modelled using simple deterministic rules for each, creating both a conservative and an optimistic ruleset to account for current limitations and future possibilities. The rulesets were applied to the US National Automotive Sampling System Crashworthiness Data System data from 1995-2015 and verified through the literature. The residual passenger vehicle to passenger vehicle accidents were analysed, treating all accidents and accidents with at least moderate injuries in modern passenger vehicles (model year 2007 and later) separately.

Many accidents were found to be avoided through such systems, and their combined effectiveness ranged from 51% to 97% depending on ruleset. Electronic Stability Control (ESC), Lane Keep Assist (LKA), and Crossing and Rear End Automated Emergency Braking (AEB) were highly effective, individually preventing over 25% of accidents in the optimistic calculation. Importantly, remaining accidents will have a different distribution across accident types compared to today: rear end collisions will reduce, leaving turning and crossing scenarios to dominate future accidents.

For passenger vehicle to passenger vehicle accidents with at least moderate injuries in modern vehicles, four accident types alone were found to account for 93% of all remaining accidents in the optimistic estimate: Head On, Turn Across Path, Turn Into Path Opposite Direction and Straight Crossing Paths; the latter three are intersection-related and together represent three quarters of all remaining accidents.

The intersection accidents are analysed further for deformation pattern, impact direction, 90% cumulative delta velocity and injured occupant position in order to identify possible new impact conditions to be used when evaluating occupant restraints. The well-established frontal and side impacts will still generate many AIS2+ injuries, while new more oblique impact conditions will also be needed to represent the variety of intersection accidents remaining.

The description of future accidents and impact conditions presented here can serve as a basis for the research and design of future ADASs and occupant restraints. We propose virtual assessment methods with Human Body Models (HBM) based on these impact conditions.

INTRODUCTION

More than six million police-reported motor vehicle accidents occurred in the United States in 2016; of the 37 461 fatalities, 23 714 (63%) were occupants of passenger vehicles [1]. Over recent years, many Advanced Driver Assistance Systems (ADASs) have been introduced to the market, including Automated Emergency Braking (AEB) for rear end collisions and pedestrian impacts and Lane Keeping Assist (LKA), which are estimated to reduce the number of accidents significantly [2-8]. To reduce this number further, additional ADASs, such as AEB for intersections and Evasive Steering Assist (ESA), are under development as a stepwise progression to fully autonomous driving. Society of Automotive Engineers (SAE) describes these steps at five levels [9], where level 0 means no driving automation and level 5 means full driving automation. Most ADASs today are designed for level 2, partial automation, which means that the driver needs to be fully engaged but the vehicle has automated emergency functions like braking and steering. Through monitoring the driver, driving environment and surrounding traffic, these functions intervene to prevent traffic accidents and support safe driving.

With the number of ADASs in the vehicle fleet increasing, the frequency distribution of accident types will change over time. It is of importance to be able to predict which accident types will remain and which will predominate; this is needed not only to guide the development of new or improved driver assistance systems, but also to guide the development of occupant restraints. However, the real-world effect of new ADASs is difficult to determine since they are not yet widely deployed to the market. Attempts to evaluate this may broadly be categorized as either retrospective or prospective, as follows.

Retrospective analyses tell what has happened. This is done by direct comparison of vehicles with and without the ADAS in question. Several researchers have reported on the number of accidents that could be prevented by various ADASs [3, 5, 10-14] using such an approach; however, newer ADASs like ESA, Driver Monitoring Systems (DMS), Traffic Jam Assist (TJA) and Highway Assist (HA) have not yet been evaluated as these have a rather low installation rate, making a retrospective investigation hard to execute. Retrospective analysis is also hard to execute if vehicles are equipped with several ADASs because any of the systems present may have prevented the accident and thus attributing the benefit to a specific ADAS is not clear-cut.

Prospective analyses tell what will happen. Alvarez et al. (2017) define four levels of prospective analyses from level 0, “Use of expert opinion to estimate the potentially addressed situations”, to level 3, “Use of simulation to generate reference situations (RS) and modified situations (MS) from the understanding and characterization of processes” [15]. Prospective analyses take in-depth accident data from accident scenes and then apply an intervention to assess its potential benefit. Such predictions are either made by detailed simulations or by some type of estimation. Simulation is used when a detailed understanding is needed, in which case a thorough set up of the accident boundary conditions is made. The ADAS is then applied to the situation to evaluate whether it prevents the accident or not. When simulating, it is also possible to vary the situation boundaries to evaluate situations that could have happened or to vary the magnitude of the intervention [16-18]. This method is by nature limited to the detailed data available and is time consuming since it requires the creation and validation of a simulation model as well as at least two simulation runs per accident, one reference and one modified with the ADAS. In contrast to this, the use of estimates for given situations gives an overall understanding of the potential of an ADAS [2, 19-21]. Assuming that a range of safety systems will be able to intervene in the future — for example, through the implementation of ADASs — one can model each of these interventions in low detail, apply this to historical crash data, and get estimations regarding future crashes which can be used to prioritize interventions and plan for subsequent ones [22]. This method has been validated for a 10-year time horizon using Swedish fatality data [23]. Although the result is not as detailed as for a simulation, it is nonetheless a significantly faster process.

The objective of this study is to investigate which passenger vehicle to passenger vehicle accident types will remain, and how the impacted vehicles are deformed, in a future when today’s known Level 2 ADASs have been implemented. New impact conditions, guiding the evaluations of occupant restraints, are defined based on these deformations. A prospective approach is taken using estimates to examine the effectiveness of 15 ADASs in avoiding accidents.

METHOD

The method used in this study contains five steps: data collection; definition of ADAS rulesets; verification of ADAS rulesets; accident description; and analysis of the deformation pattern of the remaining impacted vehicles (Fig. 1). First, data regarding passenger vehicle to passenger vehicle accidents and single passenger vehicle accidents were extracted from the National Automotive Sampling System Crashworthiness Data System (NASS CDS). In the second step, two deterministic rulesets, one optimistic and one conservative, were created for today’s known ADASs, 15 in total. The rulesets were then applied to the data to calculate the effectiveness in avoiding accidents of each ADAS alone and in combination. The third step verified the rulesets by comparing the computed effectiveness to the literature for accident avoidance, irrespective of injury severity. In the fourth step, the accidents were analysed in terms of accident scenario and general area of deformation. This analysis was only done for passenger vehicle to passenger vehicle accidents where at least one occupant sustained a moderate injury, i.e. a number equal or higher than two on the Abbreviated Injury Scale (AIS). In the fifth and final step, the accidents still remaining after the optimistic ruleset had been applied were analysed in terms of accident type, delta velocities, corresponding Collision Deformation Classification (CDC) codes and the position of injured occupants.

Definition of terms

Accident scenario: Accident scenarios describe the overall kinematics before and during an impact of both vehicles involved. Accident scenarios are taken as the combination of two NASS CDS variables: crash category and crash configuration [24]. Examples are Same Direction – Rear End, Intersection Path – Straight Path and Vehicle Turning – Turn Across Path.

Accident type: Accident scenarios are divided into specific accident types (crash types in NASS CDS, in which 99 different crash types are described) with each vehicle involved being allocated a type. Examples of accident types are Drive Off Road, Turn Into Opposite Directions and Striking from the Right. An accident having two vehicles is described by a combination: for example, one vehicle is described as "Striking from the Right" and the other by "Struck on the Right".

Deformation pattern: Deformation patterns describe each vehicle's General Area of Damage (GAD), Principal Direction of Force (PDOF), and the Specific Longitudinal or Lateral Location of Deformation [25].

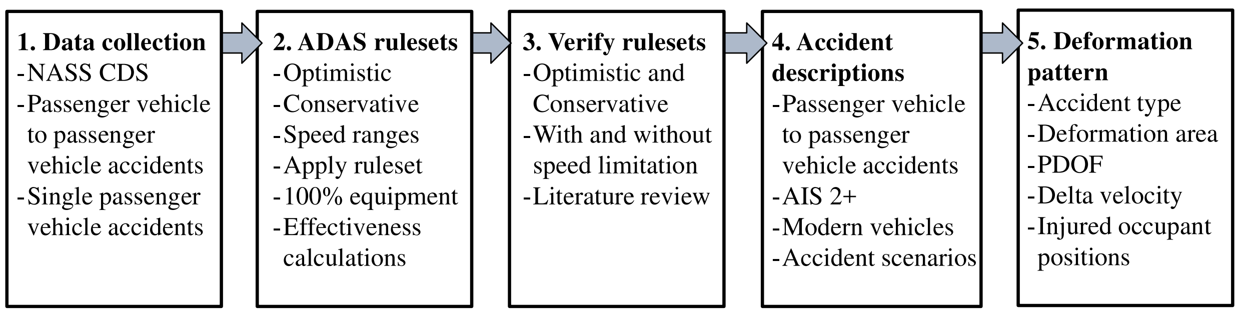


Figure 1. **Description of the five steps used in the study**

1. Data collection

Data regarding passenger vehicle to passenger vehicle accidents and single passenger vehicle accidents were collected from the NASS CDS database, a US nationwide accident data-collection program sponsored by the U.S. Department of Transportation. NASS CDS includes police reported accidents in which at least one involved vehicle is towed away due to damage. Details of around 5 000 accidents are collected every year and consist of accident scene reconstructions, interviews with police and vehicle occupants, medical charts, and detailed information about the vehicles involved. Data are collected on a representative stratified sample of minor, serious, and fatal accidents involving passenger vehicles (passenger cars, pickup trucks, and vans), large trucks, motorcycles, bicyclists, and pedestrians [26].

The data from 1995 to 2015 were extracted on accident level and weighted according to weighting factors provided in the NASS CDS (RATWGT) to compensate for sampling bias. Very heavily weighted accidents (greater than 5000) were removed from the dataset since such cases could influence the results in a disproportionate way [27]. This gave in total 83 038 unweighted and 33 022 646 weighted accidents, of which passenger vehicle to passenger vehicle accidents accounted for 52 462 (63.2%) unweighted and 22 308 978 (67.6%) weighted accidents. Passenger vehicle – Object/Run off/Rollover accounted for 30 576 (36.8%) unweighted and 10 713 668 (32.4%) weighted accidents.

2. ADAS rulesets

Today's known ADASs, 15 in total, were modelled to address a broad range of accident scenarios. Functions were grouped where possible. As an example, Forward Collisions Warning (FCW) and Brake Assist System (BAS) were assumed to be included in the AEB Rear End, and Lane Departure Warning (LDW) included in LKA. A conservative and an optimistic ruleset were created for each ADAS to take into account its limitations and its potentially improved future performance [28]. The conservative ruleset contained limitations which, if present in the accident scenario, would prevent an ADAS from avoiding an accident. These limitations include harsh weather, poor road conditions, including snow and ice on the road, missing lane markings, and unstable vehicle dynamics from skidding or speeding. Each ruleset also has a specific speed range within which the ADAS intervenes. If all the conditions in the rulesets were met, the accident was removed from the dataset, i.e. the ADAS prevented the accident. If the accident scene included a limitation, that specific accident was not avoided in the conservative estimate.

It was assumed that all passenger vehicles in the dataset were equipped with all the ADASs; the rules did not take into account manual overriding. When calculating the effectiveness of all ADASs together, i.e. the combined effectiveness, an accident was only removed once. For example, a lane change related accident can hypothetically be avoided by both Lane Change Assist (LCA) and Blind Spot Detection (BSD), but it will only be counted once. For combined effectiveness, four groups were created, optimistic and conservative with and without speed limitation. The purpose was to identify what limited the effectiveness of the ADASs, i.e. the speed range or the conservative limitations.

Input for speed range and limitations was derived from Euro NCAP assessment procedures [29-30], Euro NCAP test results [31], driver manuals [32-34] and web pages [35-37]. Each ADAS is listed in Table 1 with a brief description of which accident scenario it addresses. A concise description of how the ADAS rulesets were created using NASS CDS variables [25, 38] can be found in Appendix A and B.

3. Ruleset verification and ADAS effectiveness in avoiding passenger vehicle accidents
Rulesets were verified using reference values obtained from literature based on US data only. This was done to keep the conditions as similar as possible to those in the dataset and to minimize noise factors that could affect the result, such as differences in traffic environment or vehicle fleet. Both retrospective and prospective references were used in the verification process to get a range that could be compared to the conservative and optimistic rulesets. Retrospective studies normally give lower effectiveness estimates because they by design include all ADASs limitations. Table 1 lists the 15 ADASs with descriptions and estimates of their effectiveness in avoiding single passenger vehicle and passenger vehicle to passenger vehicle accidents.

4. Accident description
In this step all passenger vehicle to passenger vehicle AIS2+ accidents were selected from the dataset and described by their accident scenario and general area of deformation, where each accident could either be:

- Front–Front, both vehicles had damage to their fronts, coded blue.
- Front–Rear, one of the vehicles had a damage to the front and the other had a damage to the rear, coded green.
- Front–Side, one of the vehicles had a damage to the front and the other had a side damage to left or right side, coded red.
- Other, the accident could be a Side–Side or Rear–Side impact, or be missing such data, coded brown.

Accident scenario and general area of deformation were then combined to give an overview of the accidents (see Fig 3). This was done for this for four groups A–D:

A. All passenger vehicle to passenger vehicle AIS2+ accidents, N = 14 351 accidents, weighted to 2 005 362 accidents.
B. All passenger vehicle to passenger vehicle AIS2+ accidents with model year 2007 and later, N = 1 391 accidents, weighted to 215 184 accidents.
C. The residual of the conservative ruleset with speed limitation of group B, N = 761 accidents, weighted to 117 463 accidents.
D. The residual of the optimistic ruleset with speed limitation of group B, N = 251 accidents, weighted to 42 407 accidents.

5. Analysis of accident type and deformation pattern of the remaining impacted vehicles
To study the optimistic safety potential of the 15 ADASs, the accidents in group D were analysed by accident type to determine the most frequent ones. For the most frequent accident types, the vehicles with an AIS2+ injured occupant were then described in terms of the deformation pattern, 90% cumulative delta velocity, and injured occupant position.

Table 1.
Investigated ADAS, description and its effectiveness

ADAS	ADAS description	Effectiveness from literature
Lane Keep Assist (LKA)	Detects if the vehicle is about to drift beyond the edge of the road or into oncoming or overtaking traffic in the adjacent lane and automatically steers back.	1 - 3 % [2, 4-6]
Lane Change Assist (LCA)	Detects when a is car entering the blind spot while the driver is switching lanes.	Not found
Blind Spot Detection (BSD)	Detects vehicles diagonally behind and to the side of the car, typically when the car is being overtaken by other vehicles.	3% - 7% [2, 10]
Advanced Front Lighting System (AFLS)	Includes special auxiliary optical systems within the vehicle's headlamp housings and measures steering angle and vehicle speed and swivels the headlamps accordingly.	2% [2]
Electronic Stability Control (ESC)	Detects loss of steering control and automatically applies the brakes to help "steer" the vehicle where the driver intends to go. This ruleset was only applied to vehicles with model year earlier than 2010 since newer cars are equipped with ESC due to regulation.	7% - 8% [12, 14]
AEB Rear End	Detects stationary vehicles or vehicles being approached while driving ahead in the same lane. The driver is warned and if does not react, braking is activated.	16% - 21% [2-4]
AEB Reversing	Detects the presence of vehicles or obstructions behind and automatically initiates braking or prevents acceleration while reversing.	0.7% - 2% [11,13]
AEB Crossing	Detects crossing vehicles at an intersection. The driver is warned and if does not react, braking is activated.	2% - 8% [17-18]
Emergency Steering (ES)	Steering assistance upon risk of head-on accident: detects oncoming traffic and intervenes by steering and/or braking within the lane to prevent narrow overlap head-on accidents.	Not found
Driver initiated Evasive Steering Assist (ESA)	Detects oncoming traffic and provides assistance by adding steering torque to support the movement of the steering wheel, swerve or evasive action by driver.	Not found
Driver Monitoring System (DMS	Detects impaired and distracted driving and gives appropriate warning and takes effective action.	Not found
Intelligent speed adaption (ISA)	Detects if the vehicle speed exceeds a safe or legally enforced speed.	Not found
Traffic Jam Assist (TJA)	Detects the vehicle in front of your own vehicle and paces it to automatically maintain a steady following distance. In combination with that it also steers to stay within the lane.	Not found
Highway Assist (HA)	Longitudinal and lateral control on divided roads.	Not found
Alcohol interlock	Prevents the driver from driving when affected by alcohol.	Not found

RESULTS

The results were obtained in a three-step approach corresponding to steps three to five outlined in the method. The first step presents the single and combined effectiveness of each ADAS, with and without limitations, to the full dataset, i.e. to all single passenger vehicle and passenger vehicle to passenger vehicle accidents. It also includes a comparison with the effectiveness found in the literature. In the second step, groups A-D are described regarding accident scenario and impact direction. In the third step, group D accidents are analysed regarding deformation pattern, 90% cumulative delta velocity, and injured occupant position.

Ruleset verification and ADAS effectiveness in avoiding passenger vehicle accidents

Effectiveness in avoiding single passenger vehicle and passenger vehicle to passenger vehicle accidents was calculated for each ADAS (Fig. 2) and, additionally, the combined ADAS effectiveness for the four combinations, the optimistic and conservative rulesets each with and without speed limitation, was assessed. For the optimistic ruleset without speed limitation the combined ADAS effectiveness was 97%. The ADASs with the greatest potential to avoid accidents are AEB crossing (38%), Rear End AEB (24%), Electronic Stability Control (27%) and Lane Keep Assist (27%) (see Fig. 2). However, it was found that the NASS CDS variables that were queried in the ruleset for the ESA and DMS systems included many cases with missing information about the steering before the crash and driver state before the crash, 35% and more than 50%, respectively, which rendered the defined rules inapplicable. This might lead to underestimating effectiveness of these two ADASs in our study.

When the speed limitation was applied to the optimistic rulesets, the combined effectiveness was reduced to 88%. The ADASs most affected by the speed limitation were LKA, AEB reversing and TJA, which saw their effectiveness reduced by 40% to 70% (Fig. 2). Speed limitation was not applied to AFLS, ESC, DMS and Alcohol interlock.

The combined effectiveness for the conservative ruleset without speed limitation was 72%, a reduction of 26% compared to the optimistic ruleset without speed limitation. However, the effectiveness of many of the ADASs was reduced by between 40% and 70%. One exception was ISA whose effectiveness was reduced by 95%, dropping from 8% to less than 1% (Fig. 2). The reason for this substantial reduction was that skidding often occurs in combination with speeding, and as the conservative rule includes the limitation to not prevent the accident if skidding occurs, these accidents are no longer avoided.

Finally, for the conservative ruleset with speed limitations, the combined effectiveness decreased to 51%. The ADASs that were most impacted by this were the same as for the optimistic ruleset, i.e. LKA, AEB reversing and TJA, and, in addition, AEB crossing, LCA and ESA also decreased. The effectiveness of these ADASs was reduced by between 40% and 70% (Fig. 2).

Compared to the reference literature, the optimistic effectiveness truly is an optimistic representation. The ADASs whose effectiveness in the literature reaches these levels were BSD and AEB Rear End. On the other hand, the conservative values were truly conservative, underpredicting effectiveness for BSD, AFLS and AEB Rear End. The effectiveness of LKA, ESC and AEB crossing was overpredicted even with the conservative ruleset. For AEB reversing, the values were in line with the literature. For LCA, Emergency steering, Evasive steering assist, DMS, ISA, TJA, HA and Alco interlock, no reference values were found in the literature.

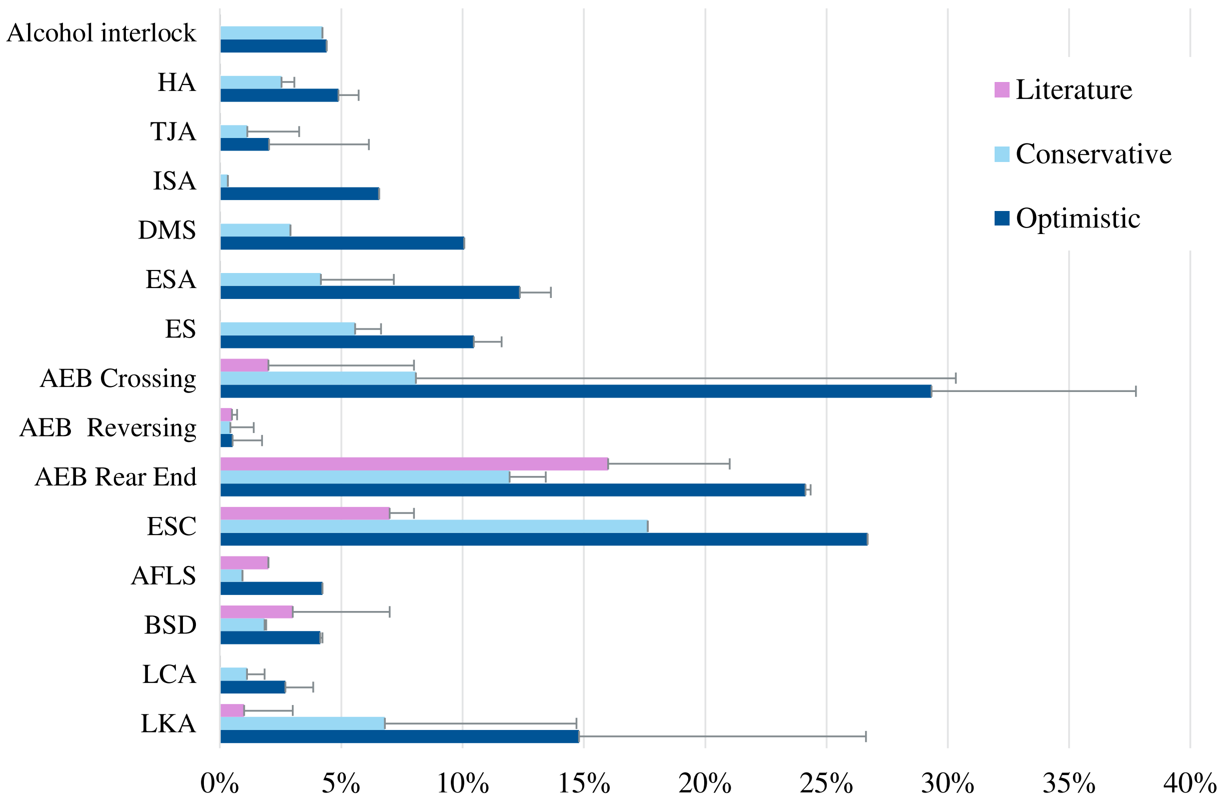


Figure 2. **ADAS effectiveness and reference values from the literature. For conservative and optimistic rulesets, the error bars represent the effectiveness values without speed limitation. For the Literature the error bars represent the upper and lower values found.**

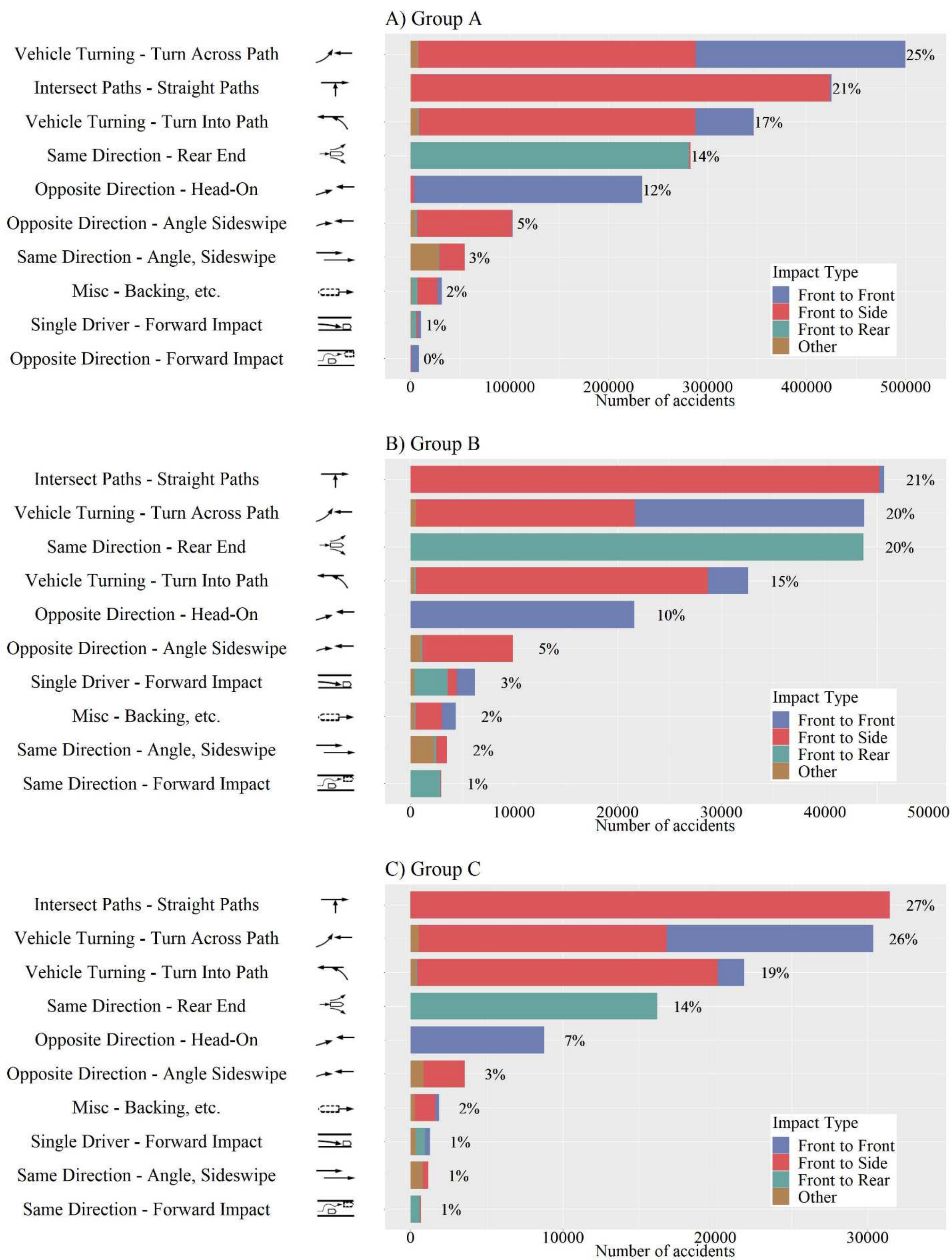
Accident description

Fig. 3 A) illustrates the breakdown of accident scenarios for group A, all passenger vehicle to passenger vehicle AIS2+. The top four accident scenarios are: Vehicles Turning – Turn Across Path, representing 25%; Intersection Path – Straight Path, 21%; Vehicle turning – Turn into path, 17%; and Same Direction – Rear End, 14%.

Fig. 3 B) illustrates this for group B, which is the same as group A but restricted to modern cars, model year (MY) 2007 or later. The same top four accident scenarios remain but with a small variation in percentage and order: as an example, Same Direction – Rear End increases to 20% and Vehicles Turning – Turn Across Path decreases to 20%.

Fig. 3 C) illustrates this for group C, the remaining modern passenger vehicle to passenger vehicle AIS2+ accidents with the conservative ruleset with speed limitations. The top four accident scenarios remain the same but Same Direction – Rear End accidents were reduced to 14% and Intersection Paths – Straight Path and Vehicle Turning – Turn Across Path increased to 27% and 26%, respectively.

Fig. 3 D) illustrates this for group D, which is as group C but with the optimistic ruleset with speed limitations. Same Direction – Rear End accidents are almost eliminated, and Vehicle Turning – Turn Across Path dominate the data. The new top four scenarios are Vehicle Turning – Turn Across Path, Vehicle Turning – Turn Into Path, Intersection Paths – Straight Paths and Opposite Direction Head. Together, these four accident scenarios represent 93% of all remaining accidents, with Vehicle Turning – Turn Across Path accounting for almost half.


A) Group A
Vehicle Turning - Turn Across Path
Intersect Paths - Straight Paths
Vehicle Turning - Turn Into Path
Same Direction - Rear End
Opposite Direction - Head-On
Opposite Direction - Angle Sideswipe
Same Direction - Angle, Sideswipe
Misc - Backing, etc.
Single Driver - Forward Impact
Opposite Direction - Forward Impact
25%
21%
17%
14%
12%
5%
3%
2%
1%
0%
Impact Type
Front to Front
Front to Side
Front to Rear
Other
0
100000
200000
300000
400000
500000
Number of accidents
B) Group B
Intersect Paths - Straight Paths
Vehicle Turning - Turn Across Path
Same Direction - Rear End
Vehicle Turning - Turn Into Path
Opposite Direction - Head-On
Opposite Direction - Angle Sideswipe
Single Driver - Forward Impact
Misc - Backing, etc.
Same Direction - Angle, Sideswipe
Same Direction - Forward Impact
21%
20%
20%
15%
10%
5%
3%
2%
2%
1%
Impact Type
Front to Front
Front to Side
Front to Rear
Other
0
10000
20000
30000
40000
50000
Number of accidents
C) Group C
Intersect Paths - Straight Paths
Vehicle Turning - Turn Across Path
Vehicle Turning - Turn Into Path
Same Direction - Rear End
Opposite Direction - Head-On
Opposite Direction - Angle Sideswipe
Misc - Backing, etc.
Single Driver - Forward Impact
Same Direction - Angle, Sideswipe
Same Direction - Forward Impact
27%
26%
19%
14%
7%
3%
2%
1%
1%
1%
Impact Type
Front to Front
Front to Side
Front to Rear
Other
0
10000
20000
30000
Number of accidents

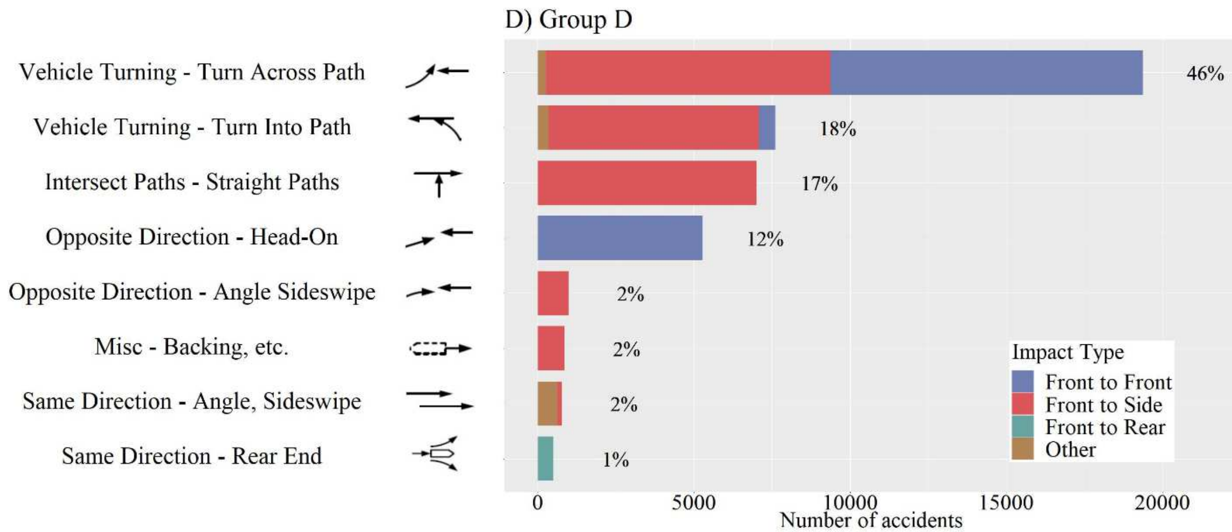


Figure 3. **Top 10 Accident scenarios for AIS2+ passenger vehicle to passenger vehicle accidents with colour code: Blue = Front to Front, Red = Front to Side, Green = Front to Rear, Brown = Other. A) Group A: All passenger vehicle to passenger vehicle AIS2+ accidents, initial population, no ADAS applied, N=2 005 362. B) Group B: All modern passenger vehicle to passenger vehicle AIS2+ accidents, no ADAS applied, N=215 184. C) Group C: Conservative residual with speed limitation of all modern passenger vehicle to passenger vehicle AIS2+ accidents, N=117 463. D) Group D: Optimistic residual with speed limitation of all modern passenger vehicle to passenger vehicle AIS2+ accidents, N=42 407.**

Analysis of accident type and deformation pattern of the remaining impacted vehicles

Accident scenarios are groups of accident types (see above) and breaking down Group D (remaining accidents from the optimistic rule set) further into accident types reveals that four predominate: Head On (12%), Turn Across Path (45%), Turn Into Path Opposite Direction (15%) and Straight Crossing Path (14%). Together these four accident types cover almost 90% of the group D accidents, almost three-quarters of which are intersection accidents.

Even though the intersection accidents are defined by accident type, how the vehicles actually impact each other will vary. To understand the deformation pattern for vehicles that had an AIS2+ injured occupant and were involved in an intersection accident, their CDC code was analysed and, based on their general area of deformation, they were divided into having frontal, left or right impacts. It was found that 54% sustained frontal impacts, 25% left impacts, and 19% right (Fig. 4), while 2% of these accidents were missing this type of information. The frontal, left and right cases were further investigated in four regards: the distribution of longitudinal or lateral location of the deformation; principal direction of force (PDOF); 90% cumulative delta velocity; and position of the injured occupant (Fig. 4).

All vehicles with frontal impacts had a distributed deformation involving 75% or more of the front with PDOF of between 11 and 1 o'clock, with the main part, 60%, at 12 o'clock. The 90% cumulative delta velocity is 39 km/h. 76% of the injured occupants are drivers and 23% are front seat passengers (see Fig. 4, left).

For the vehicles with left-side deformation, all vehicles sustained deformation to the part in front of the occupant compartment, i.e. the left wing, with 19% sustaining deformation to this part only. Just above half of the impacts have a PDOF that is perpendicular to the vehicle with the remainder being at 10 and 11 o'clock. The 90% cumulative delta velocity for the left-side impact is 45 km/h. 87% of the injured occupants are drivers and 5% are front seat passengers (see Fig. 4, mid).

Lastly, of the vehicles with right-side impacts, almost all (97%) had an impact that involved the occupant compartment. Most impacts have a PDOF of 2 o'clock. The 90% cumulative delta velocity for the right-side impact is 33 km/h. Of the injured occupants, 92% are drivers and 6% are front seat passengers (see Fig. 4, right).

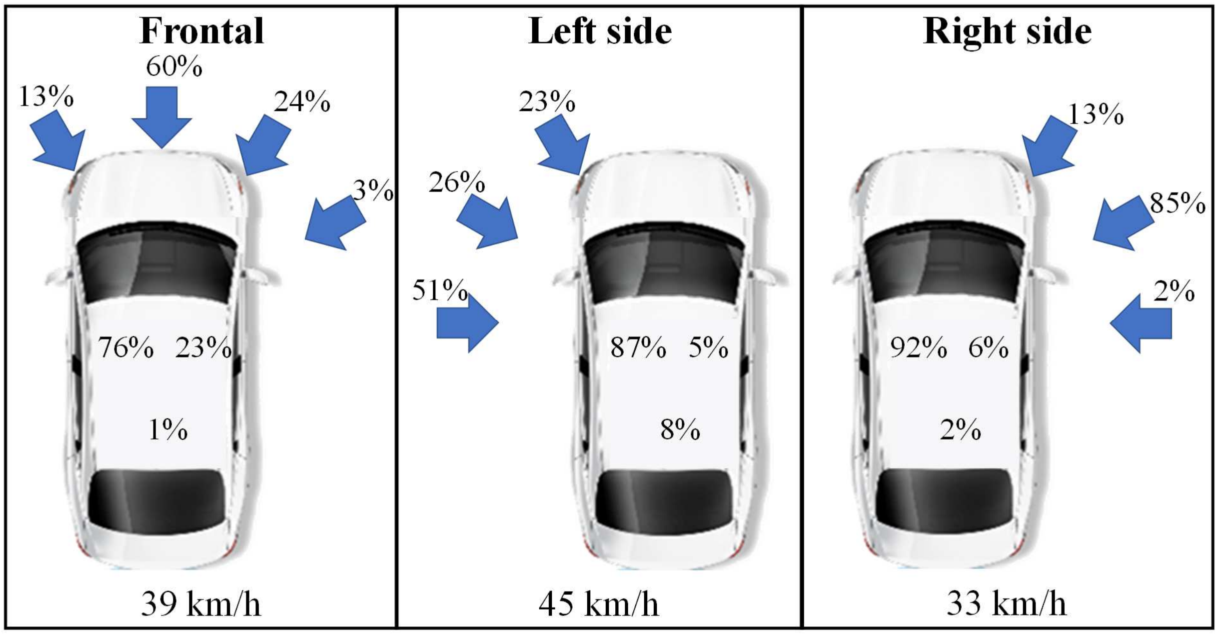


Figure 4. **Longitudinal and lateral deformation area, PDOF, 90% cumulative delta velocity and position of the injured occupant. Left: Frontal impacts. Mid: Left-side impacts. Right: Right-side impacts.**

DISCUSSION

We have presented estimates of the potential for accident reduction of current ADASs, and have included conservative estimates as well as future, optimistic estimates. The use of deterministic rules to create estimates for the effectiveness of an ADAS has a number of limitations but is straight forward, and data from the literature indicate that the calculated values are reasonable and sufficiently accurate for the purpose.

Applying the ADAS rulesets to the AIS2+ passenger vehicle to passenger vehicle accidents shows that to achieve a major change in the accident scenarios, the optimistic ruleset needs to be applied (Fig. 3). With the conservative ruleset, 55% of the accidents would still have occurred, compared to only 20% for the optimistic ruleset, and there is no clear change in the distribution of accident scenarios.

Factors that limit effectiveness

One way to analyse the ADAS effectiveness findings is to figure out what the limiting factor is: the speed range limitation, or the conservative ruleset, in which the limitations stem from either technical limitations of the sensors or vehicle dynamics. It was shown that both factors have a large effect on the total number of accidents avoided, and even more on individual ADAS effectiveness. This indicates that using more generous speed ranges can open the way for improvements in effectiveness, even without technical sensor improvements.

Single ADAS effectiveness and verification of the ADAS rulesets

The four ADASs that address most accidents are ESC, LKA, AEB crossing and Rear End AEB, each having an effectiveness of 25% or above in the most optimistic calculations. ESC has been mandatory in the US since 2010 in passenger vehicles [39] and when comparing accidents involving passenger vehicles older than MY 2010 to those involving newer passenger vehicles, 25% of the older passenger vehicles are coded as skidding prior to the accident compared to 5% of the newer passenger vehicles. This confirms that ESC has a positive effect in reducing accidents. LKA in this study shows an effectiveness of between 7% and 27%. This is much higher than that reported in other studies, which find an effectiveness of 1% to 3% [2, 4-6]. The NASS CDS variable queried here was PREEVENT equals to 10, 11, 12 and 13, which states whether the initial critical pre-crash event was that the passenger vehicle crossed a line (road lane marking) or ran off the road. This seems to be too optimistic a way to simulate LKA, given the findings from previous research, or, alternatively, could be seen as indicating potential for improvement. AEB crossing also gives very optimistic results unless the conservative ruleset with speed limitation is applied, which reduces its effectiveness to a level comparable with findings from the literature. This indicates potential in allowing higher speeds for the AEB crossing. The Rear End AEB gave a result that is directly comparable with the literature with an effectiveness of between 12% and 24%. However, for many of the ADASs there were no references found in the literature and it is therefore hard to evaluate whether a method with a deterministic ruleset is sufficiently accurate.

Need for a new assessment crash test?

When looking at the remaining intersection accidents, and comparing the observed deformation patterns with regulation and consumer ratings [40-41], we see that the full frontal and side impact conditions are well covered by existing crash tests. It is also noteworthy that angled right-side impacts with the driver getting injured represent 17% of the remaining cases, which is a similar impact condition to that of the upcoming Euro NCAP far side crash test [42].

However, it is important to note that both front and side impacts occur at speeds well below the current regulatory and rating speeds yet still generate AIS2+ injuries in the remaining accidents. This indicates that human variations and sensibility to loadings are not fully covered by the current crash dummies, injury criteria and injury thresholds. The remaining injuries are further analysed in terms of occupant characteristics, accident type and injured body region in [43].

We also see oblique front and side impacts remaining which are not covered in current regulation and consumer crash tests. Evaluating these types of impacts would require vehicle dynamics that are hard to replicate in current crash test labs. It is also likely that current crash dummies (developed for pure frontal or side impact) will not respond in a biofidelic way when the load direction is not purely frontal or from the side. New ways of evaluating crashes are therefore required; an alternative might be to use virtual methods and human body models (HBMs). HBMs are by design more valid for omnidirectional loading than current crash dummies. To take this step would require the development of a new virtual assessment method as proposed by [44-46]. Applying these types of impact conditions would most likely also demonstrate a need for new and improved occupant restraints to protect the occupants. Such improved restraint systems are likely to include both pre-crash and in-crash activated components. For example, motorised belts have the potential to keep occupants in position during lateral pre-crash manoeuvres [47] and inflatable shoulder belts have the potential to avoid the shoulder slipping out of the belt, preventing the head and thorax from impacting various components of the vehicle interior [48].

Limitations

The estimations were based on the NASS CDS database which contains data from accidents occurring in the United States. Accident distributions may therefore not be representative of other areas where the driving environment and vehicle fleet differ. In addition, the database may include some degree of misclassification of the key variables used, or omit pertinent data, or may not include sufficient details to determine the true conditions. One such variable is vehicle speed, which is often not reported. In this study, the speed limit of the location was used if the vehicle speed was not reported. This could be one reason for the relatively low level of effectiveness obtained for Intelligent Speed Adaptation (ISA) as the speed may, in the real event, have been higher.

Using deterministic rulesets has some inherent limitations. In our implementation, an accident can only be prevented or not. In reality, accidents that are not prevented can still be mitigated. When analysing accidents with AIS2+ injuries, this is important because reducing the impact speed might also reduce the injury severity. This cannot be captured in this study.

Another example of an inherent limitation is that an ADAS can intervene in driving through braking or steering, thereby affecting the trajectory of the vehicle, and in consequence may not only avoid accidents but also cause new types of accident or modify deformation distributions; again, this cannot be accounted for in this study.

For some of the level 2 ADASs, drivers need to accept and use the information given by the system and respond appropriately. Drivers may, in fact, switch the system off, not trust it or, in a critical situation, be overwhelmed by the information and not take appropriate action, thus reducing the effectiveness of the ADAS from its potential [49-50]. This can also be seen in the literature, with retrospective analyses often giving a more conservative response than prospective studies. The method used here does not take into account inappropriate driver action.

Implementation rate

This study has assumed that all passenger vehicles in the vehicle fleet are equipped with all ADASs. In reality, it takes a long time for high implementation rates of a given ADAS to be attained [51]. However, the implementation rates of new systems might speed up in the near future through software updates during a vehicle's lifetime. This can be done if a vehicle is equipped with sensors that recognise the driving conditions and driving environment and has the computing power to take the sensor data and make decisions [52].

CONCLUSIONS

The benefit of ADASs in reducing the number of passenger vehicle accidents is impressive. Still, even with a 100% implementation in passenger vehicles of the systems in use or under development today, accidents will occur. Occupant restraints, therefore, will still be needed to mitigate occupant's injuries into the future.

After applying today's known ADASs, 15 in total, to modern passenger vehicle accidents with severe injury outcome, almost 90% of the remaining accidents were found to fall into four accident types: Head On, Turn Across Path, Turn Into Path Opposite Direction and Straight Crossing Paths. The latter three are intersection accidents and represent as much as three quarters of all remaining accidents.

The detailed analysis of these remaining intersection accidents presented here indicates a need for new oblique impact conditions targeting lower impact speeds. These oblique impacts are a necessary complement to the existing and still relevant frontal and side crash tests to reduce the number of AIS2+ injuries. The impact conditions may be evaluated in virtual assessments with HBM and can guide the development of tomorrow's occupant restraint systems.

ACKNOWLEDGEMENTS

The work was partly carried out at SAFER, the Vehicle and Traffic Safety Centre, at Chalmers, Sweden. We thank Vinnova, the Swedish Energy Agency, the Swedish Transport Administration and the Swedish vehicle industry for funding parts of this work through the strategic vehicle research and innovation (FFI) program for the project 2017-01945 Assessment of Passenger Safety in Future Cars. We also thank Dr Helen East for her help with language revisions.

REFERENCES

[1] Traffic Safety Facts DOT HS 812 494, NHTSA 2018. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812494

[2] Jermakian, J. 2011. "Crash avoidance potential of four passenger vehicle technologies." Accident Analysis and Prevention 43, 732–740

[3] Cicchino, J.B. 2017. "Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates." Accident Analysis and Prevention 99, 142–152

[4] Kusano, K. and Gabler, H.C. 2015. "Comparison of Expected Crash and Injury Reduction from Production Forward Collision and Lane Departure Warning Systems." Traffic Injury Prevention 16, S109–S114

[5] Cicchino, J.B. 2017. "Effects of lane departure warning on police-reported crash rates." Insurance Institute for Highway Safety

[6] Kusano, K. and Gabler, H.C. 2014. "Potential Occupant Injury Reduction in the U.S. Vehicle Fleet for Lane Departure Warning–Equipped Vehicles in Single-Vehicle Crashes." Traffic Injury Prevention 15, S157–S164

[7] Edwards, M., Nathanson, A. and Wisch, M. 2014. "Estimate of potential benefit for Europe of fitting Autonomous Emergency Braking (AEB) systems for pedestrian protection to passenger cars." Traffic injury prevention 15, pp.S173-82

[8] Rosén, E. 2013. "Autonomous Emergency Braking for Vulnerable Road Users." In Proceedings of IRCOBI conference. Gothenburg, Sweden, pp. 618–627.

[9] Society of Automotive Engineers International. 2016. "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems." J3016-SEP2016, https://www.sae.org/standards/content/j3016_201609/preview/

[10] Cicchino, J.B. 2017. "Effects of blind spot monitoring systems on police-reported lane-change crashes." Insurance Institute for Highway Safety

[11] Cicchino, J.B. 2017. "Effects of rearview cameras and rear parking sensors on police-reported backing crashes." Traffic Injury Prevention 18:8, 859-865.

[12] Dang, J.N. 2007. "Statistical Analysis of the Effectiveness of Electronic Stability Control (ESC) Systems." Evaluation Division; National Center for Statistics and Analysis National Highway Traffic Safety Administration Washington, DC 20590. DOT HS 810 794.

[13] Flannagan, C.A., Kiefer, R.J., Bao, S., LeBlanc, D. J. and Geisler, S.P. 2014. "Reduction of Backing Crashes by Production Rear Vision Camera Systems." Journal of ergonomics S3:8

[14] Farmer, C.M. 2004. "Effect of electronic stability control on automobile crash risk." Traffic Injury Prevention 5(4):317–325, doi:10.1080/15389580490896951.

[15] Alvarez, S., Page, Y., Sander, U., Fahrenkrog, F., Helmer, T., Jung, O., Hermitte, T., Düring, M., Döring, S. and op den Camp, O. 2017. "Prospective Effectiveness Assessment of Adas and Active Safety Systems Via Virtual Simulation: A Review of the Current Practices." Proceedings of 25th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Detroit, USA.

[16] Sander, U. 2017. "Opportunities and limitations for intersection collision intervention—A study of real world 'left turn across path' accidents." Accident Analysis and Prevention 99, 342–355.

[17] Scanlon, J.M., Sherony, R. and Gabler, H.C. 2017. "Injury mitigation estimates for an intersection driver assistance system in straight crossing path crashes in the United States." Traffic Injury Prevention 18:S1, 9–17

[18] Scanlon, J. M., Sherony, R. and Gabler, H.C. 2017. "Preliminary Effectiveness Estimates for Intersection Driver Assistance Systems in LTAP/OD Crashes." Proceedings of Fourth International Symposium on Future Active Safety Technology: Toward zero traffic accidents (FAST-zero), Nara, Japan.

[19] Bahouth, G.T., Murakhovsky, D., Zuhurudeen, M., Asada, H., Fukaya, T., Maeda, M., Liers, H. and Wagner, M. 2017. "Potential Safety Benefit of ADAS Technologies In the US and Germany." Proceedings of Fourth International Symposium on Future Active Safety Technology: Toward zero traffic accidents (FAST-zero), Nara, Japan.

[20] Puthan, P., Östling, M., Jeppsson, H. and Lubbe, N. 2018. "Passive Safety Needs for Future Cars: Predicted Car Occupant Fatalities in the USA." Proceedings of FISITA World Automotive Congress, Chennai, India

[21] Lubbe, L., Jeppsson, H., Ranjbar, A., Fredriksson, J., Bärgman, J. and Östling, M. 2018. "Predicted road traffic fatalities in Germany: The potential and limitations of vehicle safety technologies from passive safety to highly automated driving." In Proceedings of IRCOBI conference. Athena, Greece.

[22] Strandroth, J., Sternlund, S., Tingvall, C., Johansson, R. Rizzi, M. and Kullgren, A. 2012. "A new method to evaluate future impact of vehicle safety technology in Sweden" Stapp Car Crash Journal, Vol. 56, October, pp. 497-509

[23] Strandroth, J. 2015. "Validation of a method to evaluate future impact of road safety interventions, a comparison between fatal passenger car crashes in Sweden 2000 and 2010." Accident Analysis and Prevention 76. 133–140

[24] U.S. Department of Transportation National Highway Traffic Safety Administration. 2015. "National Automotive Sampling System — Crashworthiness Data System 2014 Coding and Editing Manual." DOT HS 812 195

[25] SAE J224: Collision Deformation Classification. 2011. SAE International, reaffirmed 2011-05-18, Detroit USA.

[26] National Center for Statistics and Analysis National Highway Traffic Safety Administration. 2012. National Automotive Sampling System (NASS), Washington

[27] Kononen, D.W., Flannagan, C.A.C., and Wang, S.C. 2011. "Identification and validation of a logistic regression model for predicting serious injuries associated with motor vehicle crashes." Accident Analysis and Prevention 43(1):112–122, doi:10.1016/j.aap.2010.07.018.

[28] Depth-sensing imaging system can peer through fog http://news.mit.edu/2018/depth-sensing-imaging-system-can-peer-through-fog-0321

[29] European New Car Assessment Program (Euro NCAP) Test Protocol – Lane Support Systems Version 2.0.1 November 2017, https://www.euroncap.com/en/for-engineers/protocols/safety-assist/

[30] European New Car Assessment Program (Euro NCAP) Test Protocol – AEB systems Version 2.0.1 November 2017, https://www.euroncap.com/en/for-engineers/protocols/safety-assist/

[31] Test result published at https://www.euroncap.com/en

[32] Mercedes-Benz USA. 2016. "S-Class Operator's Manual." Stuttgart, Germany: Daimler AG

[33] Volvo Car Corporation. 2017. "Volvo XC60 Owner's Manual." Gothenburg, Sweden

[34] Audi. 2016. "Audi Q7 Owner's Manual." Germany

[35] http://www.lexus.com/models/LS/safety

[36] https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/propilot.html

[37] https://www.audi-technology-portal.de/en/electrics-electronics/driver-assistant-systems/audi-q7-turn-assist

[38] Radja, A.G. 2016. "National Automotive Sampling System – Crashworthiness Data System, 2015 Analytical User's Manual." DOT HS 812 321

[39] FMVSS No. 126 Electronic Stability Control Systems

[40] European New Car Assessment Program (Euro NCAP) Assessment protocol – Adult Occupant Protection, Version 8.0.3, October 2018. https://cdn.euroncap.com/media/41746/euro-ncap-assessment-protocol-aop-v803.201811061520101516.pdf

[41] National Highway Traffic Safety Administration. 2012. "Laboratory Test Procedure For New Car Assessment Program Frontal Impact Testing. "

[42] European New Car Assessment Program (Euro NCAP) Far Side Occupant Test and & Assessment Procedure Version 1.1, November 2018. https://cdn.euroncap.com/media/41765/euro-ncap-far-side-test-and-assessment-protocol-v11.201811091249031149.pdf

[43] Östling, M., Puthan, P., Jeppsson, H., Lubbe, N. and Sunnevång, C. 2018. "Future passive safety needs: Predicted injury patterns and possible countermeasures." International Symposium on Sophisticated Car Safety Systems - airbag 2018, Mannheim, 26-28 November 2018

[44] http://osccarproject.eu/

[45] https://projectvirtual.eu/

[46] Ratingen, v. M. 2016. "Saving Lives with Safer Cars: The Past, Present and Future of Consumer Safety Ratings." In Proceedings of IRCOBI conference. Malaga Spanin.

[47] Holt, C., Douglas, E., Graci, V., Seacrist, T., Kerrigan, J., Kent, R., Balasubramanian, S. and Arbogast, K. 2018. "Effect of Countermeasures on Adult Kinematics during Pre-Crash Evasive Swerving." In Proceedings of IRCOBI conference. Athena, Greece.

[48] Edwards, M.A. and Nash, C.E. 2017. "Inflatable Shoulder Belts and Inboard Upper Anchor Shoulder-belt Geometry in Far-side Oblique Impacts." In Proceedings of IRCOBI conference. Antwerp, Belgium.

[49] Kidd, D.G., Cicchino, J.B., Reagan, I.J., and Kerfoot, L.B. 2017. " Driver trust in five driver assistance technologies following real-world use in four production vehicles". Traffic Injury Prevention, 18:sup1, S44-S50, DOI: 10.1080/15389588.2017.1297532

[50] Reagan, I.J. and McCartt, A.T. 2016. "Observed activation status of lane departure warning and forward collision warning of Honda vehicles at dealership service centers." Traffic injury prevention, 17, No 8, 827-832

[51] Highway Loss Data Institute. 2017. "Predicted availability and fitment of safety features on registered vehicles." IIHS Bulletin Vol. 34, No. 28, September

[52] Automotiv World January 2018. Special report:ADAS - a stepping stone to autonomous driving? https://www.automotiveworld.com/?s=ADAS+-+a+stepping+stone+to+autonomous+driving%3F

APPENDIX A

Table 2.
ADAS accident prevention conservative rulesets

ADAS	Ruleset using NASS CDS variables	Ruleset in text
LKA, Lane Keep Assist Typical accident scenarios that can be avoided are running off the road, drifting into oncoming vehicle and side swipes.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREEVENT == (10,11,12,13) LANES != 99999 WEATHER == 0 or CLIMATE == (16,18,19) PREISTAB == 1 SURCOND != (3,4) PREEVENT !=5 PREEVENT != 6 TRAVELSP>= 60	Passenger vehicle Initial critical pre-crash event No missing lane marks No precipitation No skidding prior to accident No ice or snow on the road Good road condition No speeding Speed > 60 km/h
LCA, Lane Change Assist Typical accident scenarios that can be avoided are side swipes and rear end accidents when changing lane.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREMOVE == 15 LANES != 99999 WEATHER == 0 or CLIMATE == (16,18,19) PREISTAB == 1 SURCOND != (3,4) PREEVENT !=5 PREEVENT ! =6 speeding TRAVELSP >= 60)	Passenger vehicle Pre-event movement: Changing lane No missing lane marks No precipitation No skidding prior to accident No ice or snow on the road Good road condition No speeding Speed > 60 km/h
BSD, Blind Spot Detection Typical accident scenarios that can be avoided are side swipes and rear end accidents when changing lanes or merging.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREMOVE == (15,16) WEATHER == 0 or CLIMATE == (16,18,19) PREISTAB = 1 SURCOND != (3,4) PREEVENT != 5 TRAVELSP >= 10	Passenger vehicle Pre-event movement: Changing lane or merging accident No precipitation No skidding prior to accident No ice or snow on the road Good road condition Speed > 10 km/h
AFLS, Advanced Front Lighting System Typical accident scenarios that can be avoided are running off roads in dark conditions	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") LGTCOND == 2 ALIGNMNT == (2,3) WEATHER == 0 or CLIMATE == (16,18,19) PREISTAB == 1 PREEVENT != 6	Passenger vehicles Light condition equal to dark Curve to right or left No precipitation No skidding prior to accident No speeding
ESC, Electronic Stability Control Typical accident scenarios that can be avoided are skidding accidents.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREISTAB == (2,3,4) MY =< 2010 SURCOND ! = (3,4) PREEVENT != 5 PREEVENT != 6.	Passenger vehicles Skidding prior to accident Model year earlier than 2010 No ice or snow on the road Good road condition No speeding
AEB Rear End, Autonomous Emergency Braking Rear End	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == "R"	Passenger vehicles General Area of Damage equal to rear

Typical accident scenarios that can be avoided are impacts to rear end of vehicle in same lane.	GADEV2 == "F" WEATHER == 0 or CLIMATE == (16,18,19) SURCOND != (3,4) PREEVENT != 5 PREISTAB == 1 (TRAVELSP-TRAVELSP_OPP) <= 70	General Area of Damage equal to front No precipitation No ice or snow on the road Good road condition No skidding prior to accident Relative speed < 70 km/h
AEB reversing, Autonomous Emergency Braking Reversing Typical accident scenarios that can be avoided are impacts to another vehicle when reversing.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") ACCTYPE == (92, 93, 98, 99) WEATHER == 0 or CLIMATE == (16,18,19) TRAVELSP<= 30	Passenger vehicles Backing accidents No precipitation Speed < 30 km/h
AEB Crossing, Autonomous Emergency Braking Crossing Typical accident scenarios that can be avoided are crossing and turning at intersections.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREEVENT == (15,16,17,65,66,67,68) WEATHER == 0 or CLIMATE == (16,18,19) SURCOND != (3,4) PREEVENT !=5 PREISTAB == 1 TRAVELSP <= 30.	Passenger vehicles Initial critical pre-accident event crossing scenarios No precipitation No ice or snow on the road Good road condition No skidding prior to accident Speed < 30 km/h
Emergency Steering (ES) upon risk of head-on accident Typical accident scenarios that can be avoided are head on scenarios where the driver is not performing any maneuverer.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == "F" ? SHL == (“L”,”R”) MANEUVER != (6-9,11,12) WEATHER == 0 or CLIMATE == (16,18,19) SURCOND != (3,4) PREEVENT != 5 PREISTAB == 1 TRAVELSP <= 100 & TRAVELSP >= 40	Passenger vehicles General Area of Damage equal to front Specific longitudinal or lateral deformation location equals to left or right Driver is not initiating a maneuverer No precipitation No ice or snow on the road Good road condition Not skidding prior to accident 40km/h < Speed < 100 km/h
Driver initiated Evasive steering assist Typical accident scenarios that can be avoided are head on scenarios where the driver is not steering enough to avoid the accident.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == "F" MANEUVER == (6-9,11,12 WEATHER == 0 or CLIMATE == (16,18,19) SURCOND != (3,4) PREEVENT != 5 PREISTAB == 1 TRAVELSP <= 70 & TRAVELSP >= 20	Passenger vehicles General Area of Damage first vehicle equal to front Driver is initiating a manoeuvre No precipitation No ice or snow on the road Good road condition No skidding prior to accident 20km/h < Speed < 70 km/h
DMS, Driver drowsiness/distraction monitoring	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") DRIVDIST == 11 PREEVENT ! = 6	Passenger vehicles Driver sleepy No speeding

All types of accidents where driver is distracted can be addressed.		
ISA, Intelligent Speed Adaptation Accidents where the cause is speeding can be addressed	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREEVENT == 6 WEATHER == 0 or CLIMATE == (16,18,19) SURCOND != (3,4) PREEVENT !=5 PREISTAB == 1	Passenger vehicles Speeding accident No precipitation No ice or snow on the road Good road condition No skidding prior to accident
TJA, Traffic jam assist Typical accident scenarios that can be avoided are low speed side swipes and rear end impacts.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == ("F", "L", "R") TRAFFLOW == (1, 2, 3) RELINTER == (0, 3) WEATHER == 0 or CLIMATE == (16,18,19) SURCOND != (3,4) PREEVENT != 5 PREISTAB == 1 TRAVELSP <= 65	Passenger vehicles General Area of Damage first vehicle equal to front, left or right Divided road with and without barrier Traffic way not related to junction No precipitation No ice or snow on the road Good road condition No skidding prior to accident Speed < 65 km/h
HA, Highway Assist Typical accident scenarios that can be avoided are high speed side swipes and rear end impacts on highways.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == ("F", "L", "R") SPLIMIT > 50mph (80km/h) RELINTER == (0, 3) TRAFFLOW== (1,2,3) WEATHER == 0 or CLIMATE == (16,18,19) SURCOND != (3,4) PREEVENT !=5 PREISTAB == 1 PREEVENT != 6 TRAVELSP >= 80	Passenger vehicles General Area of Damage first vehicle equal to front, left or right Speed limit > 50 mph Traffic way not related to junction Divided road with or without barrier No precipitation No ice or snow on the road Good road condition No skidding prior to accident No speeding Speed > 80 km/h
Alcohol interlock Prevents the driver from driving when affected by alcohol.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") DRINKING == 1 ALCTEST > 8 & ALCTEST< 200	Passenger vehicles Police reported alcohol presence Alcohol test result

APPENDIX B

Table 3.
ADAS accident prevention optimistic rulesets

ADAS	**Ruleset using NASS CDS variables**	**Ruleset in text**
LKA, Lane Keep Assist Typical accident scenarios that can be avoided are running off the road, drifting into oncoming vehicle and side swipes.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREEVENT == (10,11,12,13) TRAVELSP>= 60	Passenger vehicle Initial critical pre-crash event Speed > 60 km/h
LCA, Lane Change Assist Typical accident scenarios that can be avoided are side swipes and rear end accidents when changing lane.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREMOVE == 15 TRAVELSP >= 60)	Passenger vehicle Pre-event movement Changing lane Speed > 60 km/h
BSD, Blind Spot Detection Typical accident scenarios that can be avoided are side swipes and rear end accidents when changing lanes or merging.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREMOVE == (15,16) TRAVELSP >= 10	Passenger vehicle Pre-event movement Changing lane change or merging accident Speed > 10 km/h
AFLS, Advanced Front Lighting System Typical accident scenarios that can be avoided are running off roads in dark conditions	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") LGTCOND == 2 ALIGNMNT == (2,3)	Passenger vehicles Light condition equal to dark Curve to right or left
ESC, Electronic Stability Control Typical accident scenarios that can be avoided are skidding accidents.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREISTAB == (2,3,4) MY =< 2010	Passenger vehicles Skidding prior to accident Model year earlier than 2010
AEB Rear End, Autonomous Emergency Braking Rear End	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == "R" GADEV2 == "F"	Passenger vehicles General Area of Damage equal to rear

Typical accident scenarios that can be avoided are impacts to rear end of vehicle in same lane.	(TRAVELSP-TRAVELSP_OPP) <= 100	General Area of Damage equal to front Relative speed < 100 km/h
AEB reversing, Autonomous Emergency Braking Reversing Typical accident scenarios that can be avoided are impacts to another vehicle when reversing.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") ACCTYPE == (92, 93, 98, 99) TRAVELSP<= 30	Passenger vehicles Backing accidents Speed < 30 km/h
AEB Crossing, Autonomous Emergency Braking Crossing Typical accident scenarios that can be avoided are crossing and turning at intersections.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREEVENT == (15,16,17,65,66,67,68) TRAVELSP <= 60	Passenger vehicles Initial critical pre-accident event crossing scenarios Speed < 60 km/h
Emergency Steering (ES) upon risk of head-on accident Typical accident scenarios that can be avoided are head on scenarios where the driver is not performing any maneuverer.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == "F" ? SHL == (“L”,”R”) MANEUVER != (6-9,11,12) TRAVELSP <= 140 & TRAVELSP >= 40	Passenger vehicles General Area of Damage equal to front Specific longitudinal or lateral deformation location equals to left or right Driver is not initiating a manoeuvre 40km/h < Speed < 140 km/h
Driver initiated Evasive steering assist Typical accident scenarios that can be avoided are head on scenarios where the driver is not steering enough to avoid the accident.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == "F" MANEUVER == (6-9,11,12 TRAVELSP <= 100 & TRAVELSP >= 20	Passenger vehicles General Area of Damage first vehicle equal to front Driver is initiating a manoeuvre 20km/h < Speed < 100 km/h
DMS, Driver drowsiness/distraction monitoring All types of accidents where driver is distracted can be addressed.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") DRIVDIST == 3-8,11,12,13	Passenger vehicles Driver distraction

ISA, Intelligent Speed Adaptation Accidents where the cause is speeding can be addressed	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") PREEVENT == 6	Passenger vehicles Speeding accident
TJA, Traffic jam assist Typical accident scenarios that can be avoided are low speed side swipes and rear end impacts.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == ("F", "L", "R") TRAFFLOW == (1, 2, 3) RELINTER == (0, 3) TRAVELSP <= 65	Passenger vehicles General Area of Damage first vehicle equal to front, left or right Divided road with and without barrier Traffic way not related to junction Speed < 65 km/h
HA, Highway Assist Typical accident scenarios that can be avoided are high speed side swipes and rear end impacts on highways.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") GADEV1 == ("F", "L", "R") SPLIMIT > 50mph (80km/h) RELINTER == (0, 3) TRAFFLOW== (1,2,3) TRAVELSP >= 80	Passenger vehicles General Area of Damage first vehicle equal to front, left or right Speed limit > 50 mph Traffic way not related to junction Divided road with or without barrier Speed > 80 km/h
Alcohol interlock Prevents the driver from driving when affected by alcohol.	BODYTYPE == ("Cars","SUV","Van","Pickup_Truck") DRINKING == 1 ALCTEST > 8 & ALCTEST< 200	Passenger vehicles Police reported alcohol presence Alcohol test result