

Monetary and Prospective Benefit Assessment Method for Advanced Driver Assistance Systems

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ABSTRACT

Typical effectiveness research into Advanced Driver Assistance Systems (ADAS) based on accident data covers the impact on injured or killed persons. While recent decades have seen a reduction in injuries, accidents with property damage continue to increase. Furthermore, in Germany, they have the highest economic cost. Due to the greater availability of systems that address property damage cases by avoiding or mitigating accidents, it is becoming increasingly interesting for manufacturers, insurers or customers to proactively evaluate the monetary effectiveness of these systems. Avoiding property damage accidents may result in a reduction of insurance premiums or repair costs for customers. This paper discusses a new method for benefit effectiveness evaluation in detail and investigates the most relevant property damage accidents for Germany: parking and maneuvering. Simulation results for an ADAS with fully-automated intervening functions and the hitherto-unknown collision speed distribution for parking and maneuvering accidents based on a naturalistic driving study (SHRP2) are analyzed. The proposal described here is focused on lower collision speed accidents, as property damage accidents are 40 times more frequent in Germany than those resulting in bodily injury. Due to the high claim frequency and expectancy of property damage accidents, various ADAS offer a potential to mitigate or avoid accidents. These benefits need to be evaluated as a prospective, representative and monetary effectiveness method. Thus, a bottom-up approach will be pursued in order to encourage the ADAS installation rate by highlighting its monetary benefit.

INTRODUCTION

Accident research and typical effectiveness evaluations of Advanced Driver Assistance Systems (ADAS) based on accident data primarily cover the impact on injured or killed persons. In recent decades, enhanced safety measures such as improved passive safety and infrastructure have led to reductions in bodily injury in high income countries [1, 75ff]. In particular, active safety systems offer further potential on the way to Vision Zero. ADAS may already interact during the pre-crash phase in order to avoid or at least mitigate the consequences of an accident.

By contrast, property damage accidents in Germany continue to increase. Currently, up to 88 % of all accidents that are officially reported to the police involve property damage – around 2.5 million property damage cases to 0.3 million accidents involving bodily injury in 2015 [2]. Furthermore, only a portion of all real-world accidents appears in the federal statistic. In 2015, 9.251 million claims were filed with German motor insurance companies, with an economic impact and expenditure of 21.9 billion Euros [3, 74ff]. In more detail, around the world – in Australia, Germany, Korea, Japan, Sweden, United Kingdom and the USA – parking and maneuvering accidents are responsible for up to 40 % of all claims and up to 30 % of all insurance claim costs [4].

ADAS, which allow accidents to be avoided or at least mitigated, would offer a monetary benefit to customers and insurers. One advantage of a prospective monetary effectiveness assessment is an ADAS evaluation prior to market penetration. This allows the further monetary impact to be examined, enabling manufacturers to include this evaluation method early on in their product development process for ADAS, to enhance traffic safety by avoiding or mitigating a greater number of accidents, as well as those that are monetarily relevant.

RELATED WORK AND LITERATURE REVIEW

Literature separates the evaluation methods for ADAS based on accident data between a retrospective and prospective approach. Both have the baseline accident database [5–7] in common:

Retrospective Analyses

The basic idea of retrospective analyses is to divide an accident database into at least two groups. One

group has no supporting or intervening ADAS – a baseline group – and the other does have an ADAS – a system group. Comparing injuries, fatalities and claim costs for both groups allows us to investigate the effectiveness of an ADAS. This method has been used for various research analyses for bodily injuries [8, 9] as well for monetary [10–16] ADAS evaluations. Nevertheless, a retrospective analysis is time consuming: firstly, a system has to be developed by the manufacturer, then penetrated in the market and subsequently analyzed within an accident database. It is also problematic that, if an ADAS is a standard piece of equipment among all focused vehicles, then a representative baseline group has to be found – e.g. a similar vehicle or predecessor model. An alternative application would be validation for prospective effectiveness evaluations.

Prospective Analyses

Various research projects have been conducted to prospectively evaluate the effectiveness of future ADAS in influencing bodily injuries [5, 6, 17–20]. The main difference compared to the retrospective approach is that an accident database is copied. One dataset with collision events is analyzed without an ADAS and one with the focused system. The accidents in the dataset with ADAS are simulated or tested in a real-life scenario. An ADAS intervenes during the pre-crash phase so that collision severity and parameters such as vectorial change of the velocity (Δv) or Energy Equivalent Speed (EES) is determined.

Based on the collision parameters, injury probability functions are used to calculate the probability of different type of injuries. Thus, the two datasets, including the changes by means of an ADAS, are compared and the effectiveness in avoiding bodily injury may be determined. It is important for a representative analysis that the dataset/sample used is valid for federal accidents statistics, for instance. Methods like raking make it possible to achieve representativity [19].

Gschwendtner [21, 22] adopted the method described above for property damages. Compared to the injury risk function, the defined property damage functions to determine the probability of replacing or repairing different outer attachment parts under the influence of EES due to an impact. A potential benefit study for a monetary evaluation of ADAS was performed, and shows that ADAS is highly beneficial in preventing parking and maneuvering accidents.

AIMS AND OBJECTIVE

Retrospective analyses of bodily injuries as well as of monetary effectiveness have been conducted for various ADAS. By contrast, a prospective and representative analysis offers the advantage that an ADAS can be optimized during the product development process, in terms of its hardware and software. Furthermore, this allows customers, insurance companies and manufacturers to be aware of the monetary benefit prior to market start. Firstly, this paper proposes a prospective and representative effectiveness assessment method for an accident-preventing ADAS. The approach also includes real-world ADAS performance evaluated by real tests.

Secondly, the method is applied to parking and maneuvering accidents, which are monetarily relevant in Germany. Test scenarios are analyzed to evaluate real world ADAS performance, as well as naturalistic driving study (NDS SHRP2) results for deriving velocity profiles during parking.

Thirdly, the monetary influence of different low-speed AEB systems is discussed. In addition, the influence of ADAS hardware parameters on parking accidents is shown by means of simulation. Not only are possible means of accident avoidance discussed, but also the monetary influence of different sensor ranges is determined according to the proposed evaluation method.

METHOD AND DATA SOURCE

The general methodology for a prospective monetary assessment is separated into four steps (Figure 1):

1. Accident Database
2. ADAS Performance Evaluation
3. Effectiveness Assessment
4. Monetary Evaluation

Accident Database

Firstly, an in-depth claim database of the Allianz Center for Technology (AZT), consisting of 5,000 Allianz insurance claims, is used as the data source. For a prospective evaluation, existing databases such as German In-Depth Accident Study (GIDAS) are not suitable, as their focus lies on evaluating bodily injuries or federal statistics, without more in-depth information regarding the accidents. Thus, the variables investigated here are different to those in existing databases. In his research, Schatz describes the fundamentals for a prospective monetary database [23].

The database evaluation enables accident types to be clustered with the highest claim expectancy allowing the most relevant and realistic test scenarios to be determined. Due to the in-depth database, further information about severity, damaged parts and moving direction is aggregated to sensor equivalent scenarios for precise knowledge of the pre-crash phase [17], [19].

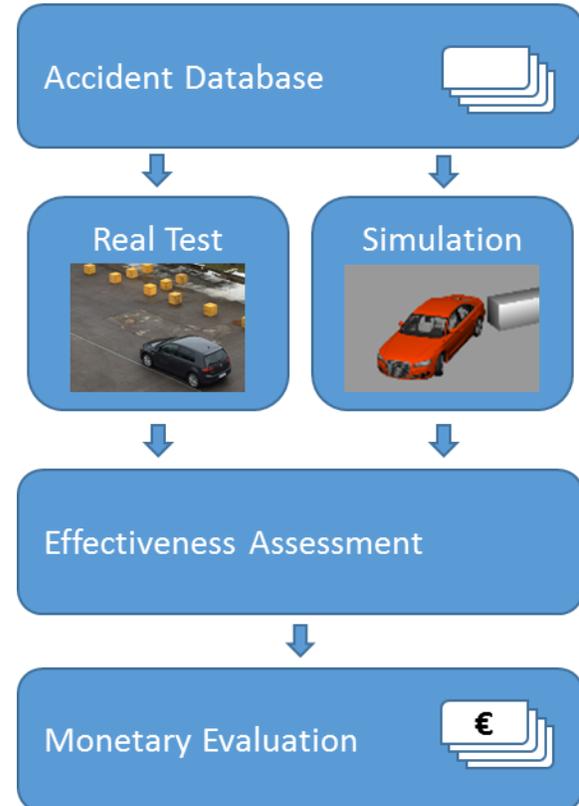


Figure 1. Four Step Method for Monetary ADAS Evaluation.

ADAS Performance Evaluation

Secondly, using either simulations or real tests, collision avoidance capability of ADAS are investigated based on established test scenarios. The maximal initial velocity for accident avoidance by means of an ADAS is determined. Fundamental investigations through simulation of parameters examine the influence of different sensor sets, detection ranges or impact of different acquisition times of algorithms.

Effectiveness Assessment

Thirdly, after a performance evaluation, the effectiveness of an ADAS is analyzed. By this point, a maximum initial velocity is known by step 2. The following step 3 answers the question of how many

accidents within an accident database, clustered to test scenarios, could have been avoided accordingly. Since an ADAS intervenes in the pre-crash phase, initial velocity distribution combines ADAS performance with the assessment of the accidents avoided within the applied database.

Either reconstructed real-world accidents or naturalistic driving studies are used to determine initial velocity profiles of accidents linked to the assessed ADAS operational field.

Strategic Highway Research Program (SHRP2) naturalistic driving data [24, 25], including real-world accidents, are utilized for parking and maneuvering to determine the initial and collision velocity distribution of property damage accidents. The common method when other accident databases, such as GIDAS, are used is accident reconstruction. However, due to lower velocity during parking and fewer traces in low-speed accidents, this would result in a less-precise collision velocity and general accident reconstruction within property damage cases compared to a naturalistic driving data approach with a more precise data acquisition system. This includes information such as video clips prior to crash, velocity tracked by GPS/onboard-diagnostics or steering angle.

Monetary Evaluation

Combining an accident database with knowledge of claim expectancy, the efficacy of simulated or practically-tested ADAS allows the prospective monetary effectiveness of an ADAS to be determined. By step three, the proportion of avoided accidents within the accident database is known, and the repair costs and claim expenditure that have been avoided accordingly may be evaluated through summation of all the events avoided.

RESULTS

In the following section, the proposed method is applied to parking and maneuvering accidents. This type of accident has a high claim frequency and claim expenditure in Germany. The AZT database shows that, for a luxury class vehicle such as an Audi A8 (N=255), up to 50 % of the claim frequency and 40 % of the claim expenditure within motor own damage insurance collisions could be avoided if a 360° low-speed Autonomous Emergency Braking (AEB) system were used. This specification of AEB should protect front, rear and especially the sides of a vehicle due to high repair costs caused by parking and maneuvering accidents. Furthermore,

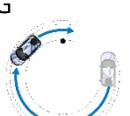
avoided motor own damage claims may also result in third-party liability claims being avoided. This means that a high positive monetary effectiveness is expected for a low-speed 360° AEB. Further information about the accident database evaluation is described by Schatz [23]. According to step 1 in our methodology, test scenarios are derived for these type of accidents. Sensor equivalent scenarios were determined. A test protocol [26] was developed to standardize test environments for real-world ADAS performance or as a basis for simulations. Table 1 shows the eight different scenarios, including the aggregated accident types, claim frequency and claim expenditure within motor own damage collision claims for a luxury model class vehicle.

The scenarios differ between moving direction – forward or backward, steering – straight or cornering – and collision object – cornering inside or outside with different outer attachment parts as a collision zone with a test vehicle.

Step 2 discusses generic low-speed AEB systems. This includes different avoidable collision zones, such as only front and rear or including the sides as well as different maximum avoidable initial velocity. Furthermore, the proposed approach enables a monetary ADAS hardware evaluation according to its performance. For a generic system, the influence of sensor range on crash avoidance and monetary impact is simulated and discussed. This method may be used in a future product development process to evaluate different hardware components.

Based on real-world evaluated ADAS or on simulations, the maximal avoidable initial velocity for parking and maneuvering crashes are determined in step 2. Step 3 analyzes a hitherto-unknown collision velocity distribution for parking and maneuvering accidents. The effectiveness of an evaluated ADAS for parking and maneuvering is evaluated by real-world crashes within the NDS SHRP2 data. Neither a representative in-depth property damage accidents database (including reconstructed non-bodily injury cases) is available nor does the common approach of deriving accident and initial velocity distributions for effectiveness assessments of ADAS by reconstructed crashes enable due to the expected tolerance the use of low-speed accident reconstructions. NDS studies with a data acquisition system including velocity and video data during the pre-crash phase allow more precise evaluations to be performed.

Table 1.
Test scenarios for parking and maneuvering, as well as claim frequency and relative claim expenditure within motor own damage collisions for an Audi A8 (N=255, AZT Database).

| Test scenarios [26] | Included accident types, according to [27] | Claim frequency | Relative claim expenditure |
|---|--|-----------------|----------------------------|
| A  | 811, 831, 851. | 4.7 % | 5.0 % |
| B  | 711, 712, 821, 841, 861. | 11.0 % | 6.9 % |
| C  | 702, 706, 812, 814, 832, 834, 871, 873, 875, 877. | 11.4 % | 7.4 % |
| D  | 701, 707, 813, 815, 833, 835, 872, 874, 876, 878. | 3.9 % | 2.6 % |
| E  | 816, 817, 836, 837, 856, 857. | 10.2 % | 8.7 % |
| F  | 826, 827, 846, 847, 866, 867. | 4.3 % | 2.1 % |
| G  | 705, 822, 824, 842, 844, 862, 864, 881, 883 885, 887. | 1.2 % | 1.1 % |
| H  | 704, 823, 825, 843, 845, 863, 865, 882, 884, 886, 888. | 3.1 % | 2.3 % |

The NDS SHRP2 data used includes more than 4,300 years of driving, around 3,400 participants and 3,300 participant vehicles [24]. For our research, 1,465 crashes and 2,710 near-crash events were available [28]. The data consists of time series data, like vehicle velocity or brake application, manually-coded event data and forward-looking videos for crash and near-crash events. The available crash events were clustered based on the proposed test scenarios above (step 1 of our methodology). 172 of 1,465 accidents – including low risk tire strikes – remained. Due to our research focus, for a low-speed AEB system preventing collisions with objects or vehicles, 37 usable cases remained. Finally, 37 accidents that occurred while entering or leaving a parking position (25 in a forward and 12 in a backward direction) are available for an effectiveness assessment of a low-speed 360° AEB discussed in this paper.

Therefore, velocity distributions were analyzed for different sensor-measured Time To Collisions (TTC). A TTC equal to zero is collision velocity and the example 0.5 s means that a sensor would have detected a possible collision within that TTC. A distinction was made between forward and backward driving. Due to a sampling rate of 10 Hz within the time series data, a velocity distribution is available every 100 ms. Figure 2 uses boxplots to show three different sample TTC velocity distributions (left: forward moving direction; right: backward). It is clear that the initial velocity, which is relevant for an ADAS intervening in that period of an accident, is higher than the collision velocity for forward as well as backward collisions (TTC = 0 s). Furthermore, backward velocity tends to be slower than forward. Within a sensor-measured TTC less than 1 s, 25th percentile is 3.9 km/h forward and 3.4 km/h backward, median 5.9 km/h and 3.7 km/h, 75th percentile 8.6 km/h and 5.2 km/h and maximum velocity is 14.4 km/h and 8 km/h. In addition, Figure 3 shows the cumulative velocity curves for TTC = 1.0 s for forward and backward collisions.

Step 3 answers the following question: How many accidents may be avoided by means of a low-speed ADAS? If a system enables avoidance up to 10 km/h for test scenarios according to the proposed test protocol and needs to intervene due to system/brake delay and decelerating phase at a TTC = 1 s, up to 85 % of forward scenarios (A, C, D, E) and all backward (B, F, G, H) may be avoided. The relevant TTC is achieved directly by a velocity plot of

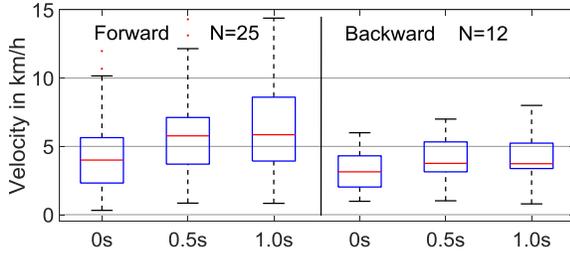


Figure 2. Velocity distribution for forward and backward parking and maneuvering accidents within different time to collisions.

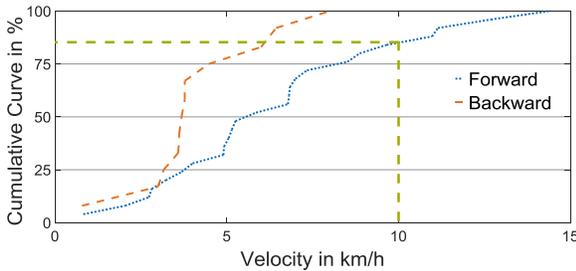


Figure 3. Cumulative velocity curve for a sample time to collision of 1.0 s.

real tests or simulations, or by equations of motion used in accident reconstructions.

Therefore, values for parameters such as sensor/brake delay and maximum possible deceleration are used from literature to compute a TTC for system actuation in order to achieve crash avoidance. Interpolation can be used to determine a velocity distribution between our sampling rate of 10 Hz (each 100 ms).

Finally step 4: the effectiveness of each test scenario is calculated by the velocity distributions in step 3. The monetary assessment is conducted by means of summation of the numerically-ordered accident cases clustered to each group of test scenarios. Thereby, following our example, it was analyzed that 85 % of forward scenarios could have been avoided with an ADAS fulfilling the eight test scenarios up to 10 km/h. Each real-world case within our accident database labeled by forward scenarios – A, C, D and E – is ordered numerically according to claim expenditure. Summing up the claim expenditure of the first 85 % of claims for each forward test group allows us to evaluate the monetary benefit for this specific real-world tested ADAS. The same process is used for backward scenarios – B, F, G and H – with an effectiveness determined here of 100 %.

The assumption for the numerical order is used because for one test scenario it is expected that a

higher collision velocity, and accordingly higher energy equivalent speed, causes higher repair costs. For practical reasons, in a secondary survey insurance claims database each individual case is not available in reconstructed form, which means that this approach is used to sort higher claim expenditure according to higher impact velocity.

System and Parameter Variation for Monetary Effectiveness Assessment of Low-Speed AEBs for Parking and Maneuvering

In this section, different operational fields of low-speed AEBs for parking and maneuvering-related crash avoidance are discussed. Firstly, the effectiveness for systems avoiding different initial velocity according to the proposed test protocol and scenarios are determined. By means of our methodology, monetary effectiveness is also assessed. Furthermore, ADAS hardware parameters such as sensor range are evaluated according to their monetary benefit. Therefore, a parameter variation is simulated in order to determine maximal avoidable initial velocity within test scenarios, and accordingly the sensor range may be linked directly to monetary assessment.

Six different systems and operational fields are discussed in the following part of this paper. This differentiation includes moving direction (forward/backward), straight or cornering and initial crash avoidance velocity. E.g. system 1 is able to avoid forward collisions:

- System 1: A
- System 2: A, E
- System 3: B
- System 4: B, F
- System 5: A, B, E, F
- System 6: all scenarios

Figure 4 shows claim frequency reduction within motor own damage collisions due to different low-speed AEB systems (for parking and maneuvering). The analysis conducted is based on German motor own damage collision claims insurance database of AZT for the claims years 2013 and 2014 for a luxury class vehicle model, such as Audi A8. The figure below reveals the claim frequency reduction under the influence of avoidable initial velocity within test scenarios. Firstly, a 360° low-speed AEB for parking and maneuvering accidents has an effectiveness of up to 50 % of all motor own damage collision claims. Furthermore, it can be seen that a system operating only forward (system 1) has a lower

effectiveness than backward (system 3) because more parking-related accidents occur while reversing within our database. In addition, preventing graze or side collision leads to an even higher effectiveness (system 3, 4 and 5). Nevertheless, adding to the operational field side collisions due to cornering the claim frequency potential rises to 30 % (system 5 compared to system 6). Backward operating systems show a performance increase of up to 7 km/h and forward up to 13 km/h. The reason for this result is caused by the velocity profile derived from the SHRP2 NDS.

Figure 5 combines the effectiveness assessment conducted with a monetary benefit determined according to the proposed method in this paper. Whereas a low-speed 360° AEB enables a reduction of up to 40 % in claim expenditure for motor own damage collisions. Again, avoidance of cornering accidents concerning vehicles sides significantly increases the monetary benefit of an ADAS by 15 %. Backward operating systems (excluding grazing collisions) are still more effective for avoiding monetary claims than forward. However, due to the higher repair costs involved with front collisions the difference in reduction is smaller than for claim frequency.

The reason for this result is that optional equipment (such as LED headlights or radar sensors for

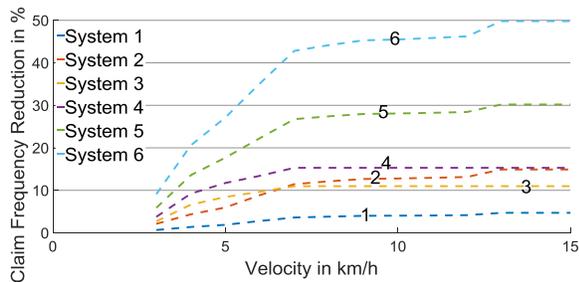


Figure 4. Claim frequency reduction within motor own damage collisions for six sample low-speed parking AEB systems.

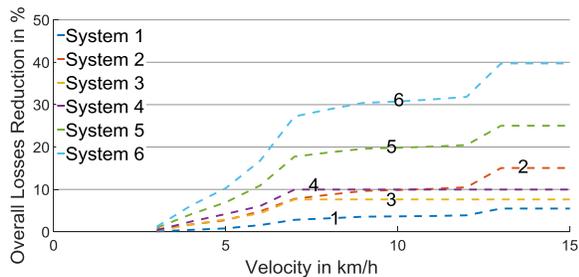


Figure 5. Claim expenditure reduction within motor own damage collisions for six sample low-speed parking AEB systems.

adaptive cruise control) increase repair costs due to the installation position for front crashes during parking and maneuvering than reversing collisions. A possible further reason could be that the forward collision velocity is determined to be greater than backward, and repair costs are accordingly higher. In the next chapter of this paper, specific ADAS are simulated in order to evaluate sensor range and its claim expenditure reduction potential. Therefore, system 5 is simulated with rateEFFECT. This software tool has already been used in different research analyses [29–31]. System 5 includes forward and backward collision avoidance without cornering. Therefore, an ultrasonic-based ADAS has been designed with four sensors in the front and four in the back, which is what most parking assist systems consist of. The system and simulation layout is described in Figure 6. Based on ultrasonic sensor measurement in combination with a TTC estimator, the AEB algorithm is triggered. If a measured TTC is below the activation threshold – modeled by a relay for each sensor – brakes were fully applied (simple algorithm) and actuators influence vehicle dynamics in order to avoid a possible collision. Furthermore, the following system parameters were used (Table 2).

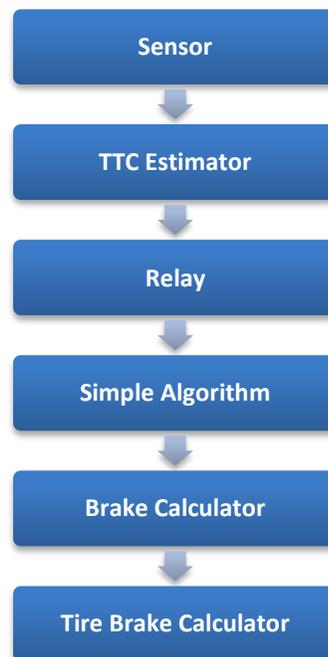


Figure 6. Low-speed AEB system algorithm design.

Table 2.
Applied simulation parameters.

| Parameter | Value |
|-----------------------------------|----------------------------|
| Sensor range | Variable |
| Sensor angle | 120° [32] |
| Coefficient of friction (assumed) | 0.8 |
| Acquisition time sensor (assumed) | 0.15 s |
| System delay | 0.1 s [19] |
| Brake system delay | 0.05 s [33] |
| Brake gradient | 28.6 m/s ³ [19] |

According to the simulations conducted under the influence of sensor range for each sensor set, the maximal avoidable initial velocity for each test scenario is determined – for system 5 layout, the scenarios A, B, E, F. By means of the methodology presented, the claim frequency reduction and claim expenditure for a luxury class within motor own damage insurance collision claim cases is evaluated (Figure 7). The analysis reveals that there is a significant increase in claim frequency and expenditure reduction up to a sensor range of 1.3 m (avoidable velocity of 7 km/h).

The reason for the following saturation is that backward collision within the velocity distribution we have used occurs up to this velocity range. A system offering a guaranteed sensor range up to 2.6 m increases the claim expenditure reduction by a further 8 %. Therefore, different sensor sets and expected installation costs may be discussed in the product development process. For ultrasonic sensors in particular, a high fidelity range of up to 2.6 m may be challenging, which means that for sensor fusion, a camera system with additional system and development costs could be necessary. The significant increase in claim expenditure reduction compared to claim frequency around a 2.6 m sensor range occurs because with a greater sensor range, collision with higher initial velocity and accordingly repair costs may be avoided.

DISCUSSION AND LIMITATIONS

The analyses conducted are limited to German insurance data derived by AZT. The claims occurred in the years 2013 and 2014. Within motor own damage insurance, only collisions (not vandalism, theft, explosion, etc.) where an ADAS could have intervened were considered. Furthermore, the vehicle class is limited to luxury models

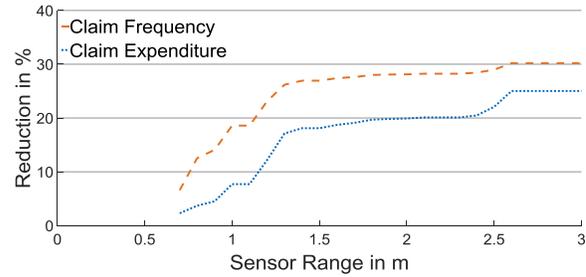


Figure 7. Claim frequency and claim expenditure reduction under the influence of sensor range for system 5.

such as an Audi A8. Nevertheless, the same procedure proposed here may be used for other vehicle classes. Further influencing parameters such as surface condition or lighting were not conducted but can be directly implemented in our methodology by changing the maximum avoidable initial velocity. The velocity curves are also derived from SHRP2 data within USA and of limited sample size.

CONCLUSION AND OUTLOOK

This paper described a prospective monetary ADAS effectiveness assessment. This includes the possibility of evaluating real tested ADAS based on test scenarios. The main steps in this approach are a monetarily-representative database, ADAS performance evaluation, effectiveness assessment and, finally, monetary evaluation.

In particular for low-speed accidents – parking and maneuvering related – a high monetary effectiveness for customers and insurance companies can be determined. A 360° low-speed AEB system, vehicle front, back and side protection – offers a reduction in claim frequency of up to 50 % for motor own damage collisions and a up to 40 % of claim expenditure for a luxury class vehicle. Based on a prospective evaluation method, these investigations can be conducted before an ADAS enters a market. Furthermore, as early as in the product development process it is possible to evaluate not only sensor hardware due to accident avoidance capability but also monetary effectiveness due to customers' avoided repair or insurance costs.

The next steps are to offer a sensitivity analysis of the conducted effectiveness assessment for parking and maneuvering by evaluating surface and lighting conditions for low-speed AEB systems, including real tested parking-relevant ADAS.

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Philip Feig (corresponding author) initiated and implemented this paper. Julian Schatz contributed to database evaluation of this paper and critically revised the manuscript. He is also working on the research project. Dr.-Ing. Klaus Gschwendtner contributed to a critical discussion of the proposed methodology. Marcel Borrack supported database acquisition. Prof. Dr.-Ing. Markus Lienkamp made an essential contribution to the conception of the research project. He critically revised the paper for important intellectual content. Mr. Lienkamp gave final approval for this version to be published and agrees to all aspects of the work. As a guarantor, he accepts responsibility for the overall integrity of the paper.

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