FUTURE POTENTIAL OF AUTOMATIC EMERGENCY BRAKING SYSTEMS FOR HEAVY TRUCKS

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Paper Number 19-0088

ABSTRACT

The European Union requires an Automatic Emergency Braking System (AEBS) for all new heavy trucks (N3) since 2015. In case of an anticipated rear-end collision, the AEBS in accordance with EU regulation 347 – 2012 has to provide an adequate two-fold warning cascade and a subsequent emergency braking. After becoming a mandatory system, a strong increase of market penetration of AEBS has been established. However, first analyses in 2017 on German highways showed only minor impact of AEBS in the field [Petersen, E., "Wirksamkeit von Sicherheitssystemen im Straßengüterverkehr", Zukunftskongress Nutzfahrzeuge, Berlin, 08. Nov. 2017]. Identified reasons for the minor impact are, amongst others, overruling of the AEBS by braking / accelerating, a probable system deactivation by the driver, and limited implications of an EU conform AEBS. Concerning the requirements, the EU conform system demands in its current level (effective November 2018), for instance, a deceleration of 20 km/h during an emergency braking on a highway approaching with 80 km/h a standing opponent at the end of a traffic jam– the collision may still occur with up to 60 km/h. Being aware of the limitations of AEBS requirements, BOSCH established top level requirements for a high-performance AEBS assumed to not only mitigate but to prevent most rear-end collisions of trucks.

The present study evaluates the benefit of Automatic Emergency Braking Systems exemplarily for German roads. It comprises of a thorough analysis of rear-end collisions involving N3-trucks, followed by stochastic simulations of a truck assumed to be equipped with either of the systems: the current EU-conform AEBS or a generic high-performance Automatic Emergency Braking System. In the first part of the study, the German in-depth accident study (GIDAS) was used to identify a potential field of effect for AEBS. In the second part, a simulation frame work specifically designed for the stochastic approach was established. It includes a sensor system, various road conditions from on-spot measured data and a simplified truck driver model accounting for driver reaction times and the specific kind of driver reaction.

About 2 300 N3-truck rear-end collisions with casualties per year in Germany can be positively influenced by an AEBS (field of effect for truck AEBS). In the second part of the study, after 2.5 mio stochastic simulations, avoidance potentials of at least 7% for the EU-conform minimum system and up to 84% for the high-performance AEBS were identified (assuming full AEBS penetration in N3 vehicles). These avoidance potentials could scale up to 1 900 collisions with casualties in Germany per year, if each truck would be equipped with the high-performance AEBS. For the remaining accidents the collision velocity would be significantly reduced, too.

In summary, this study reveals that an AEBS applied to and accounting for real-world accident situations can increase the effectivity of an Automatic Emergency Braking System preventing rear-end collisions of trucks

INTRODUCTION

One of the most feared situations for many car drivers is imagining an accident situations on motorways where a heavy truck crashes with almost no speed reduction into a standing car at the end of a traffic jam. This type of accident often results in severe or fatal injuries for the car occupants. At the same time, the car occupants, despite having identified the severity of the situation in advance, have to await their fate helplessly. Severe accidents involving heavy trucks in a front-to-rear-end situation are neither common nor occur often. However, if there is an accident of that type, damages might become catastrophic as well as the medial attention is huge. Furthermore, the motorway is often closed for several hours for rescuing and cleaning the road leading to long traffic jams and thereby to possibly additional economic impact.

To reduce such front-to-rear-end collisions, the European Union requires trucks to be equipped with an Automatic Emergency Braking System (AEBS) [1]. The EU regulation 347 – 2012 is mandatory for middle and heavy trucks (typically >3.5 t, for semi-trailers >8 t) with registration dates after November 2015 (1st level). Three years later, in November 2018, the 2nd level of the regulation became effective. In general, the AEBS should initiate an emergency braking protocol in case of an anticipated collision with a slower or standing vehicle in front of the truck to mitigate or even avoid the collision at all. While the regulation in detail specifies requirements for AEB systems admitted to the European market, the key requirements with respect to physical effectivity of such systems are the ones given in the following. Specifically, the AEBS has to be fully equipped to be able to prevent collisions of constantly moving opponents with velocities larger than 32 km/h (1st level) and 12 km/h (2nd level) being in an in-line constellation. Furthermore, anticipating a collision with a standing opponent, the AEBS has to reduce the truck velocity by at least 10 km/h and 20 km/h for 1st and 2nd level, respectively.

As commercial vehicles such as heavy trucks have small turn-over cycles, the hope was to reach a state where severe accidents caused by heavy trucks on motorways will significantly reduce. Now, some years later, the share of trucks on motorways equipped with an AEBS should have reached a reasonable level, and first impact of the legislation should be visible. Yet, the situation, especially on German motorways seems to be the contrary [2,3].

Here in this study, we will review the typical accident prior to the AEBS legislation and estimate the impact of a system as demanded by EU regulations, especially for the current 2nd level requirements. In our simulations, we will fully implement a generic three-fold warning cascade with acoustic warning first, followed by partial braking and, in its final stage, an automatic emergency braking. Additionally, we will introduce a generic AEBS based on a high performance system and estimate the maximum in avoidance and mitigation potentials. Based on a comparison with the current status, we will provide insights into how future automatic emergency braking systems could be designed to not only achieve the ambitious aim of EU legislations but also to come close to the maximum with respect to avoidance and mitigation potential of a future AEBS.

STATUS: HEAVY TRUCKS REAR-END COLLISIONS IN GERMANY

For 2017, the Federal Statistical Office of Germany (Destatis) presented in the annual German national accident report a total number of 302 656 accidents with casualties on German roads [4]. In 29 170 accidents of the same year (almost 10%), at least one truck was involved with a total of 32 234 participating trucks [5]. While the official report separates into light trucks (≤3.5t), middle and heavy trucks (>3.5t) and semi-trailers, an individual reporting for heavy trucks (>12t) is not available. However, a trucks with mass >3.5t (middle and heavy trucks as well as semi-trailers) engaged in 15 805 accidents which serves as an upper bound for heavy trucks. Estimating the number of heavy trucks (>12t; N3) being involved in accidents with casualties on German roads will be a first step to assess the field of effect for a heavy truck AEBS.

Evaluating the effect of an AEBS for heavy trucks (>12t) requires a thorough analysis of the present status of the field of effect. For that purpose, the current study is based on in-depth accident data. A more than suitable database is the German in-depth accident study (GIDAS) recording detailed on-spot information about the accident, location and weather conditions, as well as all involved parties in more than 2 000 parameters per accident [6]. GIDAS is by now recording accidents for more than two decades. After recording the accidents, the course of events of each accident is reconstructed. Overall, GIDAS is a database with about 30 000 recorded and reconstructed accidents. By weighting the distributions of accidents, locations and severity to the annual German national accident report, analysis of the GIDAS database is made representative for German roads. By construction, the GIDAS database records accidents with at least one injured occupant – consequently property-damages only incidents are not included in this study.

For the present study, we use a subsample of the GIDAS database containing the years 2005 to 2018 with a total of 28 225 accidents (Fig. 1). Thereof 933 accidents involved a heavy truck (>12t). Refining to an AEBS relevant scenario, defined by a collision of the truck's front with the opponent's rear-end in an in-line constellation, the GIDAS database provides 162 cases. Weighting these cases to German roads, a heavy truck is involved in about 12 500 accidents while the field of effect for an AEBS consists of a total of about 2 300 accidents in Germany.

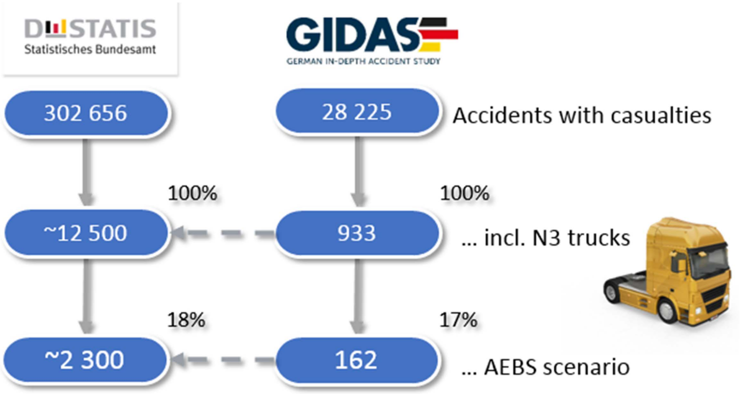

Figure 1: Case selection and basis for the present study, weighted for Germany 2017

In the following paragraphs, we present a thorough analysis of the 162 GIDAS cases – weighted to German roads. As a first result, the location of AEBS relevant crashes for heavy trucks is identified. Every second accident (48%) is found on a motorway, every fourth accident (21%) in rural areas and every third accident (31%) is found in urban areas (Fig 2a). Thereby, the typical road for front-to-rear-end collisions is a straight road – a relevant curve radius <500 m applies in only a marginal 2% of all cases.

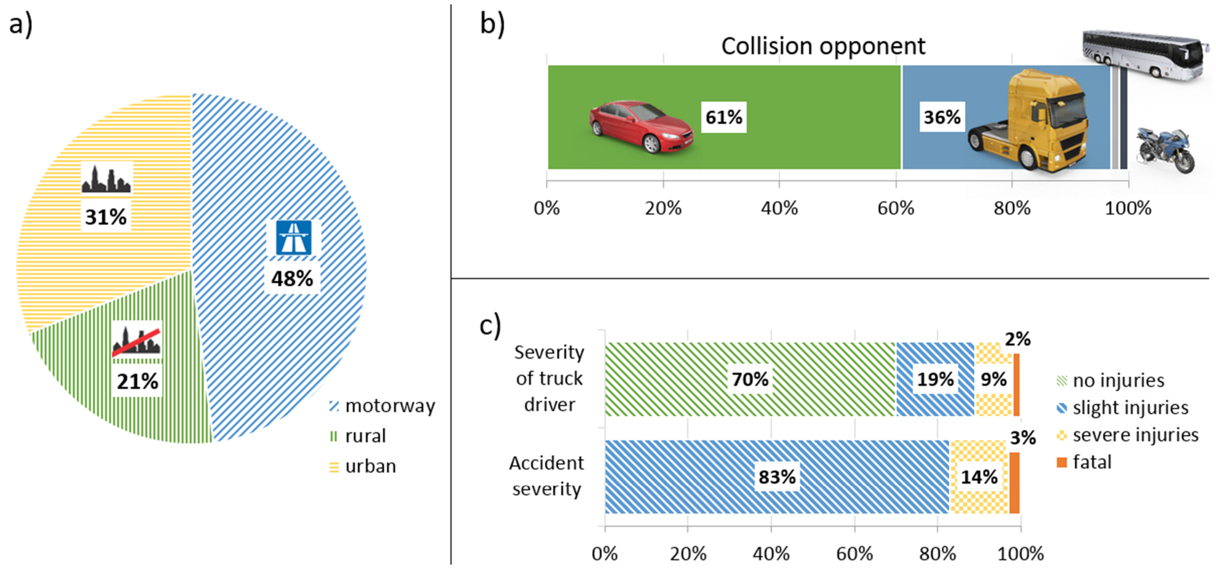

Figure 2: a) Share of collisions on motorways, in rural or urban environments. b) Type of collision opponent. c) Severity of truck driver in comparison to the accident severity. Please note: by construction of GIDAS the accident severity is at least "slight injuries".

Next, collision participants and severity are characterized. In a vast majority of all cases, the collision opponent is a car (61%) or a truck (36%). In the remaining cases, the opponent was a motorcycle or a bus (Fig 2b). The age of the truck at the time of the collision follows approximately the age distribution of trucks in Germany with 80% being younger than nine years. Due to the huge momentum of a heavy truck and a seating position of the truck driver in a height of two and more meters above the road surface, for more than two of three cases (70%) the truck driver was not injured, while the opponent was at least slightly injured (Fig 2c). The truck driver was identified with light and severe injuries in 19% and 9% of all accidents, respectively. Despite the advantages of height and momentum, in 2% of the accidents, the truck driver died. However, one possible reason for the truck driver severity could be the fact that about every 10th truck driver was not belted. For the opponent, the accident severity is typically increased compared to the truck. Accordingly, the accident severity of all AEBS relevant accidents with casualties involving a heavy truck is categorized as “slight” in 83%, “severe” in 14% and “fatal” in 3%.

A closer look on typical velocities reflects the dynamics of a typical AEBS relevant heavy truck collision. The reconstructed initial velocity of the truck before the collision has an average of 61 ± 24 km/h (mean ± one standard deviation, see Fig 3a). The initial state of the opponent was standing for 41% of all accidents (Fig 3b). In the other cases, the opponent was driving with an average of 45 ± 28 km/h, either moving with constant velocity (10%) or moving and braking before the collision (49%). The truck driver behavior prior to the front-to-rear-end collision concerning intensity of braking (with respect to the road condition) was in two of three cases classified as partial braking (66%). In only 10%, the truck driver was decelerating with full braking, while in 20% of all relevant accidents, the truck driver did not show any signs of braking (Fig 3a). The remaining cases (4%) are comprised of an accelerating truck, typically accelerating at traffic lights faster and/or earlier than the collision opponent in front of it.

The distribution of driver reactions prior to the collision reveals the true potential of an AEBS. A warning and subsequent automatic emergency braking could alert the 20% of drivers not braking and could support the 66% of drivers that were only partially braking. Moreover, the 10% of drivers that were fully braking could benefit from an early warning, too: applying the full brake load earlier could further reduce the collision velocity or possible avoid the anticipated collision at all.

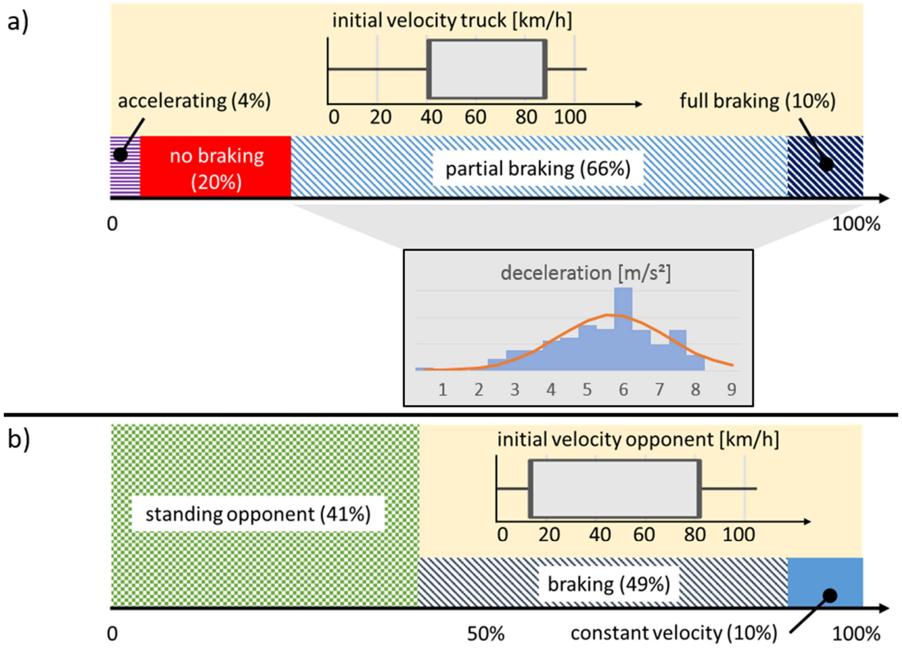

Figure 3: a) Initial truck velocities in a box plot (box equals to mean ± one standard deviation) and type of driver reaction. Inset: reconstructed decelerations for a braking driver as distribution (blue bars) and its Gaussian approximation (orange line). b) Share of standing, constantly moving and braking opponents. The box plot depicts the initial velocity of the opponent.

As reported in the previous section, the GIDAS analysis shows that about 10% of all opponents move with a constant velocity. As an AEBS according to the EU regulation is required to avoid collisions only with constantly moving opponents, the minimal avoidance rates of all EU conform AEB systems is given by the share of accidents with a constantly moving opponent and an initial velocity above the given thresholds of 32 km/h and 12 km/h for 1st and 2nd level, respectively. However, only about 3% of all opponents move with constant velocity and are faster than 32 km/h, while for the 12 km/h threshold the share increases to 7% (data not shown).

In conclusion, our analysis of the status of front-to-rear-end collisions of heavy trucks shows three major results. First, for a vast majority of collisions, the collision opponent is a car or truck and is prior to the collision in an in-line constellation. Thus, detecting and classifying the anticipated collision becomes possible for most cases. Second, an AEBS could warn 20% of truck drivers not braking prior to the collision and support about 2 out of 3 drivers by applying the maximal brake force. Third, a current EU-conform AEBS avoids only at least 7% of all AEBS relevant collisions involving a heavy truck. Here, even at this stage of the study, a possible benefit of a system beyond EU regulations becomes obvious.

SIMULATION STUDY

Simulation layout

The overall simulation study aims to unravel three main questions:

- What is the avoidance potential of a warning only system in comparison to a high performance AEBS?
- Which share of accidents is mitigated and what is the benefit in reduced collision velocity?
- What is the main advantage of a high performance system compared to a minimal system?

The simulation is designed to fully image the pre-crash trajectory of both main participants in the front-to-rear-end collision. Out of 162 cases in GIDAS identified as AEBS relevant front-to-rear-end collisions involving a heavy truck, a total of 127 cases provide all information necessary to reconstruct the pre-crash trajectories. At the initial state, both participants approach the scene with their respective reconstructed initial velocities. Here, the initial state is assumed to be at least five seconds before the original collision. If applicable, the opponent starts braking as it was reconstructed from the original case. Thereby, we assure to challenge the generic AEBS in the simulations with an opponent behavior as close as possible to the original case. The original truck driver commands are removed and it is assumed the truck driver will only react to AEBS warnings. With these assumptions, the benefit of an AEBS to a cautious truck driver stays beyond the scope of this study. However, the main purpose of the present study is the assessment of the effectivity of an AEBS conform to current EU regulations (2nd level) and the differences between this minimal AEBS and a high performance system.

For each of the 127 GIDAS cases and both types of AEBS specifications, the simulation is performed in three scenarios: first, there is no AEBS present, second, the system generates only an acoustic warning with the truck driver braking and, third, the full AEBS procedure (with acoustic warning, partial braking and in the final step an emergency braking) is applied. The simulation itself is set up as a stochastic simulation with variations in the reaction of the truck driver. In contrast, the reactions of the AEBS are deterministically parametrized as described below. To maintain a statistically stable simulation, a total of 10 000 simulations per GIDAS case are performed. Consequently, for each system involving truck driver reactions, warning only system and full AEBS, a total of 127 x 10 000 = 1.27 mio. runs is performed. The first system (re-simulating the original case without AEBS) is fully deterministic lacking the stochasticity of the other systems and, thereby, assures a proper foundation for a statistical analysis of the simulations.

The technical, yet generic design of the AEBS involves a threefold warning cascade. Upon detection of an AEBS relevant situation, an acoustic signal alerts the driver, followed by initiating a partial braking and finally establishing the emergency braking (see Fig. 4).

Figure 4: Schematic view of AEBS phases

The threefold warning cascade meets the EU regulations if the acoustic warning and the partial braking start at least 1.4 s and 0.8 s, respectively, before the emergency braking phase. While the acoustic warning in the simulation just alerts the truck driver to react and apply the brakes by himself, the partial braking follows a protocol simplified by three steps: (i) system reaction time (no braking), (ii) linear ramp up of the brake force up to the desired deceleration and (iii) holding the maximal constant deceleration of the partial braking phase. Typically, the partial braking phase reduces the velocity of the truck by only a few kilometers per hour and is subsequently followed by an emergency braking phase. After reaching the trigger level for the emergency braking phase, a brake protocol applies again with system reaction time, ramp up of brake force and constant deceleration – up until standstill if necessary. While following the same functional protocol, the individual parametrization is different for both phases. The overall AEBS system parameters are chosen as displayed in table 1, meeting a typical – yet generic – high performance parametrization specific to heavy trucks.

Table 1: Generic AEBS parameter specifications

Category	Value
Start warning phase before emergency braking	1.4 s
Start partial braking phase before emergency braking	0.8 s
System reaction time partial braking	0.4 s
Ramp up gradient partial braking	12.8 m/s^3
Maximal deceleration partial braking	3.5 m/s^2
System reaction time emergency braking	0.15 s
Ramp up gradient emergency braking	10.0 m/s^3
Maximal deceleration emergency braking	8.0 m/s^2

The AEBS reacts to an opponent, if a collision is anticipated. To detect the position and velocity of the opponent, the truck is equipped with a sensor module. In the case of AEBS relevant front-to-rear-end collisions, the opponent is typically in a straight line in front of the truck. Thus, the sensor consists of a list of ranges up to which opponents are detected depending on a generalized radar cross section for motorcycles, cars and trucks. The ranges were chosen to mimic a current state-of-the-art frontal long-range radar, independent of the manufacturer, ranging up to 200m.

For a simulation study of a driver assistance system, supporting the driver in his reactions, a truck driver model is needed. As a matter of fact, no released model for a truck driver is currently available. Thus, a generic model was set up. For the present comparative study, the truck driver is not initiating the emergency braking by himself but reacts only to an acoustic warning of the AEBS. The generic driver is modelled by a probability to react to the acoustic warning, a reaction time and a maximal deceleration. For this study the parameters were chosen as described in table 2 with reaction time and maximal deceleration being modelled as normal distributions with mean and standard deviation. Here, the probability to react to the acoustic signal is in accordance with recent finding [7] and mean and standard deviation for reaction time follow acknowledged data of the field [7-9]. In contrast, the maximal deceleration is motivated by the findings of the GIDAS analysis itself as presented in Fig. 3 a.

Table 2: Truck driver parameter specifications

Category	Value
Probability to react to acoustic warning	80%
Reaction time – mean	1.4 s
Reaction time – standard deviation	0.5 s
Maximal deceleration – mean (according to GIDAS)	5.7 m/s^2
Maximal deceleration – standard deviation (according to GIDAS)	1.5 m/s^2

In total, the simulation setup is well defined and allows for a stochastic simulation study of real-world accident data. Again, the driver assistance system AEBS is fully deterministic, while the truck driver is modelled by probability distributions for the main characteristic and, thereby, a stochastic approach is suitable.

Simulation results

An obvious parameter for an AEBS being of enormous interest is the avoidance potential. However, the simulation provides more than just the avoidance potential. First, the distances to the opponent at the time of initiating the emergency braking is analyzed. Second, avoidance potentials of the warning only and the full AEBS are highlighted. Here, an avoidance potential of an AEBS fulfilling the minimal EU requirements is estimated, too. Finally, the share of mitigated collisions and corresponding collision velocities as well as the velocity difference at the time of the collision is evaluated.

Analyzing the start of the emergency braking phase is most straight forward: given the AEBS parameters, as well as the position and velocities of both participants, the start of the emergency braking phase is calculated by the distance needed for braking the truck's velocity to the opponent's velocity. Here, the AEBS is neither triggered nor limited by thresholds of the variable "time to collision". In contrast, the chosen procedure to determine the start of emergency braking allows for a target braking. At the start of the emergency braking phase, the truck has a distance of 20.0 ± 12.8 m (mean ± standard deviation) to its opponent with larger distances in cases of a standing opponent. These distances correspond to times of 1.8 ± 1.1 s before the collision (for a detailed distribution see Fig 5a). For acoustic warning and partial braking, the respective phase is initiated 1.4 s and 0.8 s earlier, as required by EU regulation 347 – 2012.

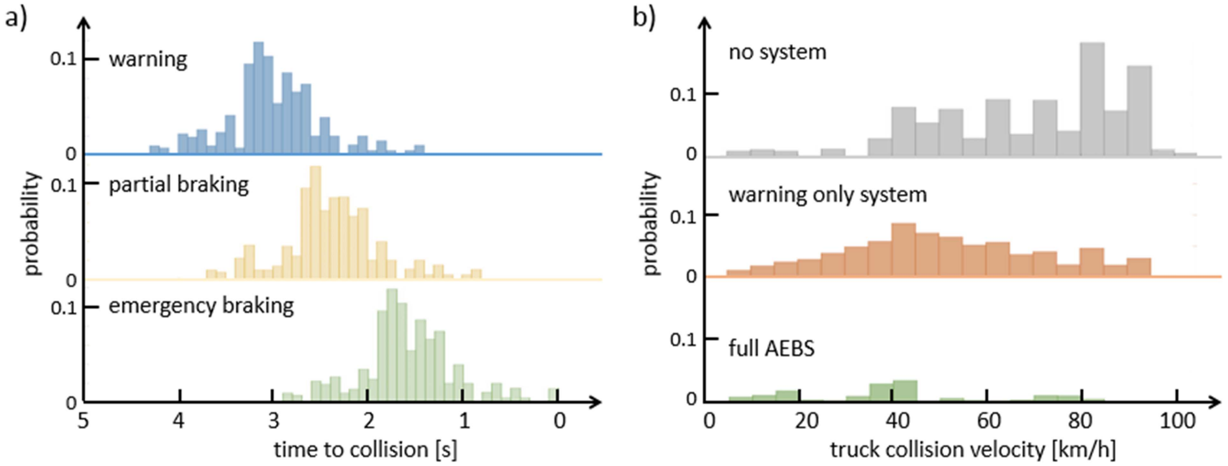

Figure 5: Simulation results: a) start of warning phase (top), partial braking phase (middle) and emergency braking phase (bottom) b) Truck collision velocities.

The most desired effect of an AEBS is its ability to avoid collisions. Given by the EU regulations effective since November 2018, an AEBS has to avoid a collision with an opponent moving with a constant velocity above 12 km/h. Thus, the minimal avoidance potential for any AEBS operating within the EU is given by the 7% of cases where the opponent fulfills the given requirement. However, there are three additional categories of opponent behavior: (i) standing opponent (41%), (ii) constantly moving opponent with v<12 km/h (3%), and (iii) moving but braking opponent (49%). While an advanced high performance AEBS would avoid collisions with any standing or constantly moving opponent (together 51% within the field of effect), a braking opponent is challenging as the opponent is actively decreasing the remaining distance between truck and opponent. In cases where a truck equipped with a high performance AEBS is approaching a braking opponent, two out of three collisions could be avoided (66%). Given the large share of 49% of all cases involving a braking opponent, the maximal share of avoided collisions for a high performance AEBS sums up to 41%+10%+66%x49% = 84% for a standing, a constantly moving and a braking opponent, respectively (Figure 6). In contrast, the minimal avoidance potential for a minimal AEBS is estimated by the share of accidents with a constantly moving opponent with velocity above 12 km/h, i.e., 7%. Under the assumption, the minimal AEBS is performing equal or worse than the high performance system if the opponent is braking, the upper bound for the avoidance potential of a minimal AEBS is set by 7%+66%x49% = 40%. Compared to the maximal avoidance potential of 84% of a high performance system, a substantial increase in avoidance potential is still possible.

After analyzing the benefit of a full AEBS system, the avoidance potential of a warning only system is addressed. Here, the simulations show an avoidance potential of about 23%. However, the avoidance potential for this system is strongly dependent on the particular truck driver parametrization and large deviations become possible by changing the driver parametrization. For a rough estimate, we identify about one out of four collisions avoided by a warning only system, while more than four out of five collisions could be avoided by an advanced high performance system.

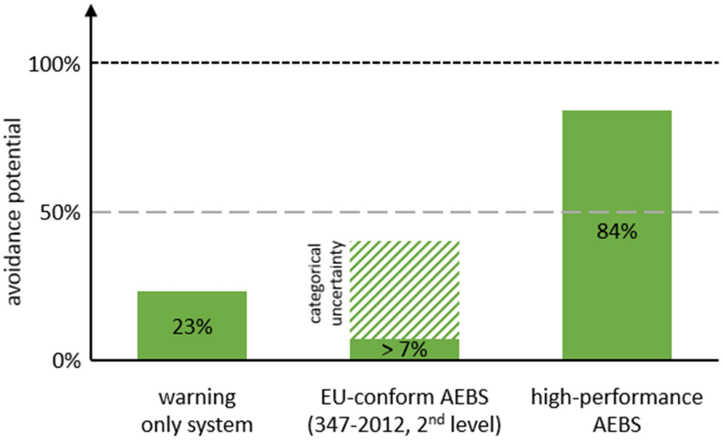

Figure 6: Simulation results: avoidance potentials for a warning only system vs EU-conform AEBS vs high-performance AEBS

In cases where avoidance stays out of reach, the collision velocity and the difference in velocities at the time of collision become important. Here, we compare three systems as described earlier: (i) cases without any intervention, (ii) warning only system and (iii) full AEBS. A weighted distribution of the truck collision velocities for the respective system is shown in Fig. 5b. Obviously, braking reduces the collision velocity drastically. In terms of means and standard deviations, for a warning only system the collision velocity is about 52 ± 22 km/h, while for the full system the mean becomes 43 ± 22 km/h. However, especially for the full AEBS, most cases are avoided and the reported mean and standard deviations of collision velocities are comprised of only few cases.

While for the EU conform AEBS (2nd level) the minimal avoidance rate is at least 7% for the collision velocity an upper bound is found: for all standing opponents, the collision velocity is reduced by at least 20 km/h. This results in a weighted mean collision velocity of maximal 53 km/h. Due to a further reduction of velocity of individual systems prior to a collision with a standing opponent or reducing the collision velocity with a braking opponent, the mean collision velocity of a current EU conform system is assumed to be reasonably smaller than 53 km/h.

Whether limitations of the sensor restrict the avoidance potential is another question that was addressed by the simulations. Here, we analyzed additional to the finite sensor ranges discussed above the avoidance potential of a system with a sensor of infinite range. However, the improvement of avoidance potentials by an infinite sensor is virtually not present: the avoidance potential with an infinite sensor is at the same rate as with the finite sensor. The reason is mainly that a combination of the generic sensor set with ranges up to 200 m with the restricted velocities of a truck is sufficient to not restrict avoidance potentials of an AEBS.

CONCLUSIONS

The present study reveals various insights of front-to-rear-end collisions in an in-line constellation for heavy trucks. First, an AEBS could address up to annually 2 300 accidents on German roads. More than every second collision was found on a motorway with typical opponents being other trucks or cars. Due to the large share of motorway incidents, the initial velocity of trucks is rather large with 61 ± 24 km/h. Additionally, due to heavy masses of large trucks and often very demanding conditions for truck drivers, 3% of all AEBS relevant accidents were fatal, and in an additional 18% the accident was classified as severe. Consequently, to avoid collisions with standing opponents, a large reduction in velocity is necessary which – in turn – demands highest requirements for such a system. On the other hand, the analysis showed the true potential of advanced automatic emergency braking systems: in two out of three reconstructed collisions, the truck driver was only partially braking before the collision. Here, an AEBS could support the driver and further reduce the collision velocity.

Our stochastic simulations estimated minimal and maximal benefits of AEB systems. For an AEBS conform to current EU regulation 347 – 2012 (2^{nd} level) the benefit was estimated to:

- minimal avoidance rate of at least 7%
- reduced collision velocity for all mitigated collisions smaller than 53 km/h

For a high performance, yet generic AEBS the benefit could become:

- maximal avoidance rate up to 84%
- reduced collision velocity for the few remaining mitigated collisions 43 ± 22 km/h

The main limitations of the EU conform AEBS are given by requiring only for avoidance with constantly moving opponents faster than 12 km/h. For standing opponents, a speed reduction of at least 20 km/h is requested. Including full avoidance of all constantly moving as well as all standing opponents could boost the effectivity of truck AEBS with respect to avoidance from at least 7% up to 51% and more. Yet, improving sensor quality to secure a reliable detection of standing opponents is a key challenge for further improving future automatic emergency braking systems.

Given the enormous avoidance potentials of up to 84% within the field of effect, a strong decline in front-to-rear collisions of heavy trucks should be visible soon – even with only few systems on the street. However, recent studies on German motorways were yet not able to detect any decline in accident numbers at all [2,3]. Mostly a combination of AEBS penetration rates in truck stock and low avoidance rates required by the EU regulation could explain why a study of 2017 was not able to detect any impact of AEBS. On the other hand, the expected decline in accident numbers could result from small datasets and statistical outliers: with a hypothetical assumption of a market penetration of 50% only a little more than one year after AEBS became mandatory, an AEBS would address little above 500 accidents with casualties on German motorways (field of effect: 2 300 accidents with casualties in Germany; hypothetical market penetration: 50%, share of all accidents on motorways: 48%). Assuming the minimal avoidance potential (7%) for the 2^{nd} level of EU regulation the system would avoid only less than 50 accidents with casualties on German motorways. Thus, from a statistical point of view, it is very challenging to detect effects due to AEBS. Nevertheless, often attributed and partially speculated reasons [2,3], e.g., truck drivers manually overriding the AEBS, could still play a role for explaining not-declining front-to-rear accident numbers involving heavy trucks and casualties.

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