Prospective evaluation of the collision severity L7e vehicles considering a collision mitigation system

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Abstract

SEV (small electric vehicle) is one of the future solutions for urban mobility, since these cars show a small environmental footprint due to their lightweight design for optimizing the range. Due to the low number of SEVs in real accidents it is difficult to judge the collision severity of these vehicles, especially if such vehicles are equipped with ADAS (Advanced Driver Assistance Systems) in order to avoid accidents or mitigate injury severity.

The objective of this study is to analyze the collision severity of SEVs in real accidents to assess the injury severity of the occupants. Further the effectiveness of a collision mitigation system (CMS) that aims to reduce impact speeds or, if possible, avoid collisions of passenger cars is evaluated.

The method used in this study refers to the virtual pre-crash simulation. In a first simulation (called the baseline simulation) the original vehicles were successively replaced by an L7e so that collisions between original cars and L7e cars are considered. In a second simulation (system simulation) it was assumed that the L7e vehicles are virtually equipped with a CMS. Certain characteristics of the CMS such as sensor range or opening angle and various response strategies were varied. The response strategies under investigation are:

a) warning to the driver at 2.6 s TTC (time to collision) and fully braking after 0.8 s reaction time,
b) braking with 50% brake force at 1.6 s TTC and fully braking at 0.8 s TTC,
c) braking with 50% brake force at 1.6 s TTC and finally
d) fully braking at 0.8 s TTC.

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Occupants of L7e vehicles generally have a higher risk to suffer MAIS3+ injury than in M1 vehicles. The analysis showed a reduction of the risk to suffer a MAIS3+ injury up to 65% when involved in an accident situation in an L7e vehicle for CMS with sensor system 1 and up to 87% with sensor system 2.

Keywords: advanced driver assistance system; collision mitigation system; L7e; lightweight; small electric vehicle

1. Introduction

Within the next ten to 15 years the number of SEVs (and alternative drive train) will increase. The latest results of the Automotive Landscape study states that, "small vehicles will grow fastest across the globe" by 2025 (Fig. 1) (Kalmbach et al., 2011). The figure shows the growth rates of the different vehicle segments. A/B segment indicates smaller cars. In 2020 SEV sales are projected with 3% up to 6% (Pike et al. 2011), which means approximately 0.36 to 0.72 million vehicles according to overall vehicle sales in Europe of 12 million in 2012 (ACEA, 2013). A higher future market share of SEV is expected. In Austria the market share is even lower. At the moment small vehicles have a share of 0.25% on average between 2006 and 2014 (Statistics Austria).

Small vehicles due to weight, engine power, etc. are considered in the EC regulation 2007/46/EG (European Parliament and Council, 2007) which defines the vehicle class “L”. According to the regulation 2002/24/EG (European Parliament and Council, 2007) the “L“ class vehicles are further split into e.g. “L7e“. The weight of L7e vehicles will not exceed 450 kg, excluding battery pack. In case of an accident, the passenger of an L7e vehicle is usually exposed to a higher injury risk than in a M1 vehicle. One reason is that the compact design of SEVs only allows for less robust structures, thereby offering less potential for energy absorption, i.e. smaller crush zones. Furthermore, the weight difference between SEVs and a typical M1 vehicle can often be larger than 50%, which leads to the result that the lightweight vehicle is more affected by the impact force during a crash than the heavier vehicle.

Since the share of L7e vehicles in traffic is comparatively small, only little data on real accidents involving such vehicles is available, making a retrospective statistical assessment of their safety difficult. Especially in the case of in-depth accident databases such as CEDATU (Central Database for In-Depth Accident Study) (Tomasch and Steffan, 2006; Tomasch et al. (2008)) or GIDAS (German In-Depth Accident Study) with highly detailed information but small sample size compared to national statistics with high number of cases but fairly low in their detail. Thus an assessment of the performance of L7e vehicles is very difficult.

A study was prepared within the German collaborative research project, Visio.M, which focused on the development of a Visionary Mobility concept car to meet tomorrow’s electro mobility needs. The analysis made use of conventional vehicles on the market that corresponded to possible electric vehicles in terms of their dimensions. In general, these are vehicles in the Golf category or below (SafeEV D1.2, 2013). Compared to the vehicle class M1 the Visio.M vehicles are more involved in urban areas and at junctions. The collision speeds do not seem to be different. The energy equivalent speed (EES) for Visio.M vehicles tends to be higher than the EES of M1 vehicles. However, the change of velocity (delta-v) wasn’t evaluated.

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Fig. 1. Car sales index by 2025 (The vertical axis shows the percentage whereby 2005 means 100% and the horizontal axis are the years in five years steps) (Kalmbach et al., 2011).

Within the EU funded project MATISSE (Modelling and Testing for Improved Safety of key composite Structures in alternatively powered vehicles) a stochastic approach was used to assess the injury severity of occupants in SEV (MATISSE Deliverable D1.1, 2013). The weight of the SEV was limited to 500 kg. It was assumed that the SEV was equipped with a generic Collision Mitigation System (CMS) – no real algorithm was implemented. The collision speed in general was reduced with a CMS but the change of velocity was increased compared to a M1 vehicle.

2. Objective

The first objective of the present study is the assessment of the injury severity of the occupants in small vehicles i.e. L7e vehicles. The second objective is the injury severity assessment in L7e vehicles equipped with a CMS.

3. Material

The in-depth database CEDATU (Central Database for In-Depth Accident Study) was the source for the basic data on real accidents which were then analyzed (Tomasch and Steffan, 2006; Tomasch et al. (2008)). Each individual traffic accident was reconstructed using the traffic accident reconstruction program PC Crash and saved on CEDATU with all accident related data. Information on initial speed, run-off-road or collision speed, run-offroad angle, reaction times, travel times and vehicle trajectories etc. were calculated on the basis of accident reports which consist of reports such as police reports and medical reports, attached photos and photogrammetric analyses of the accident site.

The data field basis of CEDATU is the STAIRS protocol (Standardisation of Accident and Injury Registration System) (Vallet G. et al. 1999) which was developed over the course of an EU project with the same name. Building on the STAIRS protocol, data fields were developed using information from the EU projects PENDANT (Pan-
European Coordinated Accident and Injury Databases) (Thomas P et al. 2006), RISER (Roadside Infrastructure for Safer European Roads) (RISER 2006) and ROLLOVER (Improvement of rollover safety for passenger vehicles) (Gugler and Steffan 2005). Furthermore, the data fields from national statistics were integrated to enable a direct connection to the latter (Statistics Austria 2007).

4. Method

Many active safety systems aiming to reduce collision velocities or even avoid imminent collisions are already in use in modern cars. They are known among others by names such as “Forward collision mitigation” (Mitsubishi Outlander), “Collision mitigation brake system” (Honda Civic) or “City Safety” (Volvo XC60). Each of these systems is designed to work in specific conflict situations. In the present paper, such systems shall simply be referred to as “Collision Mitigation Systems” (CMS).

4.1. Virtual simulation of the pre-crash phase

Due to lack of sufficient accident numbers with L7e vehicles, a two-step approach of the virtual simulation of the pre-crash phase was used (Zauner 2014). Real world accidents of the CEDATU database were reconstructed and simulated at least twice in a virtual forward simulation. As a first step, one of the involved M1 vehicles in the reconstructed scenario was replaced by a L7e vehicle, assuming a weight of 550 kg (maximum allowed weight of 450 kg plus battery pack and one occupant). The scenario was simulated and the altered collision parameters like collision velocity and delta-v were calculated. Those simulations shall be called “baseline” simulations. In a second step, the L7e vehicles were virtually equipped with a CMS system, which are called “system” simulations. Again, the same set of collision parameters are being calculated as in the baseline simulation. By comparison of the baseline and system simulations, the effectivity of the CMS can be evaluated.

For the virtual simulation of the pre-crash phase, the in-house tool X-Rate (Extended Effectiveness Rating of Advanced Driver Assistance Systems) (Vehicle Safety Institute, TU Graz) is used. X-Rate uses PC-Crash (DSD) as a solver for the simulation of driving dynamics, thus parameters relevant for accident analysis can be computed. Due to the capability of PC-Crash to simulate driving dynamics of vehicles, the pre-crash phase can be evaluated as well.

4.2. Collision mitigation intervention strategies

Four different intervention strategies were investigated for the CMS system. Basis for triggering an action is the time to collision (TTC). The following strategies were considered:

a) TTC = 2.6 s: The driver reacts with a reaction time of 0.8 s to a warning signal. Full brake performance without lag time, is available and is utilized by the driver to decelerate the vehicle until standstill or the collision.
b) TTC = 1.6 s: The system starts to decelerate the vehicle with 50% of the available brake force. The driver reacts with a reaction time of 0.8 s to the warning braking of the system. The remaining 0.8 s until collision are used by the driver to decelerate the vehicle with full brake force down to standstill or the collision.
c) TTC = 1.6 s: The system decelerates with 50% of the available brake force, but the driver does not react. The system continues to decelerate with 50% of the available brake force.
d) TTC < 1.6 s: No reaction by the driver. Upon reaching a TTC = 0.8 s the system starts a fully autonomous emergency brake until standstill or collision.
4.3. Sensor integration

The vehicles were virtually equipped with LiDAR sensors in order to detect collision opponents. For that purpose, the specifications of two recent LiDAR-sensor models were used (Winner, 2015). The first simulated sensor (system 1) is the “gen3” by Omron with a horizontal opening angle of 30° and a range of 100 m (Fig. 3). The second sensor (system 2) is the “ScaLa” by Ibeo which features a horizontal opening angle of 145°, an angular resolution of 1° and a maximum range of 150 m.

In the simulation the area visible by the sensor (the area in which other objects can be detected) is represented by a cone, with its origin at the installation position of the sensor and a given opening angle and range. The sensor could be positioned at any place within the car. For the simulation in the study the position at the top of the windscreen nearby the rear-mirror was chosen.
4.4. Assessment function

The evaluation is done by comparing the baseline with the system simulation based on accident mitigation potential reduction of delta-v. In the case of a collision when a vehicle is equipped with a CMS, the evaluation is done using MAIS3+ injury risk functions. Delta-v is in many cases an indicator for the risk to suffer an injury, in this case a MAIS3+ injury. With increasing delta-v, also the risk of MAIS3+ injuries rises (Augenstein et al., 2003, Gabauer and Gabler 2006, Viano and Parenteau, 2010). Such injury risk curves are available for various collision situations and regions of the human body.

5. Limitations

For the baseline simulation it was assumed that the driver keeps his driving behavior even if he drives an L7e vehicle.

Within the assessment of L7e and CMS only accidents at junctions are considered.

In the virtual simulation no obstructions e.g. houses, bushes, garden fences, etc. are considered. It was assumed that the sensor is able to work within the full sensor angle and range.

The original M1 vehicles were successively replaced by L7e vehicles without considering the payload and number of occupants.

The CMS detects the opponent vehicle within a cone and an appropriate latency time. A real detection algorithm is not considered.

In order to detect possible collisions it was assumed that each object continues to move in the same direction as at the last moment when it was detected, with constant velocity.

The effectivity of the CMS was studied by considering traffic situations that led to accidents.

6. Results

Among the investigated crossing scenarios, those appearing most often in the national statistics were chosen (Fig. 4). The most common one is an intersection accident where both parties involved in the accident try to cross the intersection in a straight line (32%). Accidents with one of the participants turning left and the other participant coming from that direction make up 28% and are the second most common. Furthermore, accidents where one participant intends to turn left and the other comes from the oncoming direction have a relative share of 22%.

Fig. 4. Investigated accident scenarios under the assumption that at least one colliding vehicle is a L7e vehicle.
The differences between the strategies a), b) and d) regarding avoidable accidents or change of delta-v (Fig. 5) were rather small (only around 1% in avoidance or 1 km/h in change of delta-v), while strategy c) stood out as less effective in general. Obviously the baseline vehicle – L7e – has higher delta-v compared to the vehicles in the reconstructed real accident. At average the delta-v for the vehicles in the original accident was calculated to 35 km/h and for the baseline vehicles (L7e) delta-v was at about 46 km/h. In the calculation of the average, avoided accidents were included with a delta-v of zero.

![Fig. 5. The average change of delta-v for four different intervention strategies and two different sensor systems, compared to the baseline. For accidents that were avoided, the delta-v was set to zero.](image)

![Fig. 6. Cumulated relative share of accidents for the baseline and L7e vehicles equipped with two different CMS.](image)
Around 47% of all considered accidents can be avoided with sensor system 1 (range of 100 m and opening angle of 30°) and 66.5% with sensor system 2 (range of 150 m and opening angle of 145°) (Fig. 6). For the cases not avoided with the CMS an in-depth investigation of the simulation were undertaken. All of these non-avoided accidents are referred to “reduced baseline”. Fig. 6 clearly shows the overall effectiveness of the CMS, as well as the superiority of the higher range and larger opening angle of sensor system 2.

Fig. 7. For each configuration (Sensor system combined with a specific strategy), the average delta-v is in non-avoidable accidents is calculated (blue bars). The red bars display the average delta-v of the reduced baseline (baseline without accidents that are avoidable by a specific configuration).

Fig. 8. The risk of suffering a MAIS3+ injury for M1 vehicles, L7e vehicles without CMS and L7e vehicle with CMS (two different sensor systems).
In Fig. 7, the average delta-v of accidents that were not avoidable (“reduced baseline”) in the system simulation by a specific combination of sensor system and strategy is displayed as blue bars, compared to the average delta-v of the baseline containing only the non-avoidable accidents for a specific configuration (red bars). If the average delta-v for a configuration is higher in the system simulation than in the baseline, it is assumed (not proven by investigating a case-by-case analysis) that the human driver performed better than the CMS. A conclusion could be that the non-avoidable accidents are traffic situations that are not covered by the CMS.

Among the analyzed intersection accidents, an average delta-v of 35 km/h was identified in the original accident situation for M1 vehicles. If one of the vehicles in the original accident situation is replaced by an L7e vehicle and the baseline calculated, the average delta-v is 46 km/h resulting in an increase of the load on the occupants by approximately 31%.

Looking at the two different systems the change of velocity was decreased to 25.8 km/h at average with system 1 and to 16.2 km/h with system 2 (Fig. 8) when including avoided accidents in the calculation of the average with a delta-v of zero. The black line shows the risk to suffer a MAIS3+ injury in the case of an accident for a specific delta-v (Augusteine et al., 2013). The risk to suffer an MAIS3+ injury in the original accident with M1 vehicles is at 59%. The risk for L7e vehicles (baseline) in the same accident situations would be 86%. The overall risk of MAIS3+ injury for an L7e vehicle equipped with a CMS would be approximately 30% for system 1 and approximately 11% for system 2.

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