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Real life safety benefits of increasing brake deceleration in car-to-pedestrian accidents: Simulation of Vacuum Emergency Braking

Hanna Jeppsson[*], Martin Östling, Nils Lubbe

Autoliv Research, Wallentinsvägen 22, 447 83, Vårgårda, Sweden

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ABSTRACT

The objective of this study is to predict the real-life benefits, namely the number of injuries avoided rather than the reduction in impact speed, offered by a Vacuum Emergency Brake (VEB) added to a pedestrian automated emergency braking (AEB) system. We achieve this through the virtual simulation of simplified mathematical models of a system which incorporates expected future advances in technology, such as a wide sensor field of view, and reductions in the time needed for detection, classification, and brake pressure build up.

The German In-Depth Accident Study database and the related Pre Crash Matrix, both released in the beginning of 2016, were used for this study and resulted in a final sample of 526 collisions between passenger car fronts and pedestrians. Weight factors were calculated for both simulation model and injury risk curves to make the data representative of Germany as a whole. The accident data was used with a hypothetical AEB system in a simulation model, and injury risk was calculated from the new impact speed using injury risk curves to generate new situations using real accidents.

Adding a VEB to a car with pedestrian AEB decreased pedestrian casualties by an additional 8–22%, depending on system setting and injury level, over the AEB-only system. The overall decrease in fatalities was 80–87%, an improvement of 8%. Collision avoidance was improved by 14–28%.

VEB with a maximum deceleration in the middle of the modelled performance range has an effectiveness similar to that of an "early activation" system, where the AEB is triggered as early as 2 s before collision. VEB may therefore offer a substantial increase in performance without increasing false positive rates, which earlier AEB activation does.

Most collisions and injuries can be avoided when AEB is supplemented by the high performance VEB; remaining cases are characterised by high pedestrian walking speed and late visibility due to view obstructions. VEB is effective in all analysed accident scenarios.

1. Introduction

Pedestrian fatalities and injuries are frequent: according to the World Health Organisation (2015), 270,000 pedestrian fatalities account for 22% of a total 1.25 million road traffic fatalities. This frequently cited report might underestimate the true size of the problem. Bhalla et al. (2014) for example estimate that 460,000 pedestrian fatalities account for 35% of a total 1.33 million road traffic fatalities. In the European Union (EU), 5621 pedestrian fatalities comprised 21% of all road fatalities in 2014 (European Commission, 2016). In Germany, 537 pedestrian fatalities (16% of total road traffic fatalities) and 31,073 non-fatal pedestrian casualties (8% of total non-fatal road traffic casualties) were reported for 2015 (Bundestag, 2016).

Better protection of pedestrians in road traffic has been called for, specifically through reduced driving speeds, improved vehicle design with more forgiving car fronts, and greater traffic flow separation (World Health Organisation, 2015). EU initiatives to improve road safety (European Commission, 2010) resulted in an overall reduction in fatalities of 22% between 2010 and 2013, but of only 11% for pedestrians. Further actions to improve the situation were proposed, such as encouraging safe roadway infrastructure and assessing the effectiveness of emergency brake systems with pedestrian detection (European Commission, 2015). Germany reports figures in line with those of the EU, with a below-average fatality reduction for pedestrians in the mid-term evaluation of the 2011–2020 targets, and has called for a greater focus on pedestrian safety (BMVI, 2015).

The EU is advanced in pedestrian protection. The European Enhanced Vehicle-Safety Committee (EEVC) published test methods and requirements for pedestrian protection in the 1990s (European Enhanced Vehicle-Safety Committee, 2002). These formed the basis for

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[*] Corresponding author.
E-mail address: hanna.jeppsson@autoliv.com (H. Jeppsson).

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the pedestrian protection measures mandated for new vehicle types in the EU since 2005, which require vehicle manufacturers to comply with a set of tests to ensure forgiving car fronts in case of collision (EC directive 2003/102). The European New Car Assessment Program (Euro NCAP) has tested and published results using similar but more stringent tests since 1997 to provide consumers with a safety rating (van Ratingen et al., 2016). These ratings have been shown to correlate with real life benefits: higher rated vehicles have been observed to cause fewer pedestrian injuries (Strandroth et al., 2011; Pastor, 2013).

Euro NCAP has recently gone further, introducing in January 2016 a rating for automated emergency braking (AEB) for pedestrian protection which evaluates a car's ability to reduce speed to mitigate or avoid collisions with pedestrians crossing in front of it (Schram et al., 2015). Pedestrian AEB is predicted to have great potential in reducing pedestrian casualties, both when implemented on typical levels of car-front-forgiveness (Rosén et al., 2010; Rosén, 2013; Lindman et al., 2010) and when used in combination with pedestrian airbags (Fredriksson and Rosén, 2012; Edwards et al., 2015).

AEB is more effective in reducing speed the more reliably it activates (dependent upon sensor accuracy and cover area, time delays in detection, and classification of event), the earlier it activates (dependent upon sensor and system delays), and the harder it decelerates (dependent upon brake activation delay, brake pressure build-up, and maximum deceleration).

The relationship between these parameters and estimates of AEB effectiveness has recently been explored. Edwards et al. (2014) quantified the increased monetary benefits in Germany and the UK of three hypothetical AEB systems, representing future advances in technology, when time delays for detection, classification, and brake pressure build up, were decreased. A maximum deceleration of 10 m/s^2 for dry road and 8 m/s^2 for wet roads was used for all systems. Rosén et al. (2010) showed that AEB effectiveness in reducing severe and fatal injuries increased when sensor field of view (FoV) was increased, when maximum brake deceleration was increased from 2 m/s^2 up to 10 m/s^2, and when brake activation delay was reduced. Rosén (2013) quantifies the expected real life consequences of further system limitations such as deactivation of the AEB system above 60 km/h driving speeds and during night time. However, none of these studies investigated the benefits of increasing maximum brake deceleration to levels above 10 m/s^2, possibly because it seemed unlikely that such deceleration levels could be achieved and sustained.

Increasing the rate of deceleration would be expected to deliver significant safety benefits, but achieving this is challenging. A brake airbag has been proposed which can increase brake deceleration levels from 10 m/s^2 to 20 m/s^2 for up to 0.1 s, after which deceleration levels drop below 10 m/s^2 (Mellinghoff et al., 2009). Overall, it takes longer to come to a standstill with the brake airbag than with continued conventional braking at 10 m/s^2. Activation, therefore, needs to be timed carefully and the safety benefit appears to be limited.

We here propose and model the safety benefits of a Vacuum Emergency Brake (VEB), also called the Torricelli Brake (Lang, 2015). The VEB can produce a sustained increase in deceleration. The new system is described below, and the remainder of this paper presents research to quantify the expected safety benefits of adding the VEB to an AEB system.

The VEB consists of a vacuum tank with opening valve, a release mechanism, linkage to the vehicle and rubber plate for the ground contact (Fig. 1a). On activation, a release mechanism shoots the unit towards the ground, and 0.07 s later, when the unit hits the ground, a valve to the vacuum tank is opened. The atmospheric pressure presses the unit toward the ground and the linkage transmits force both in the driving direction (friction force) and upwards against the vehicle (normal force). The force level is dependent on the plate area acting on the ground, while the force duration is dependent on the rubber sealing and the size of the vacuum tank. With a plate area of 0.36 m^2, the peak deceleration increased by a factor of 1.8 against baseline in tests with a road friction coefficient of 0.9. This translates to an increase of maximum vehicle deceleration from 9 m/s^2 to 16 m/s^2. The VEB is best mounted behind but close to the center of gravity of the vehicle. Due to conflicts with surrounding parts in the test vehicle, it was positioned close to the rear wheel axis in our tests (Fig. 1b).

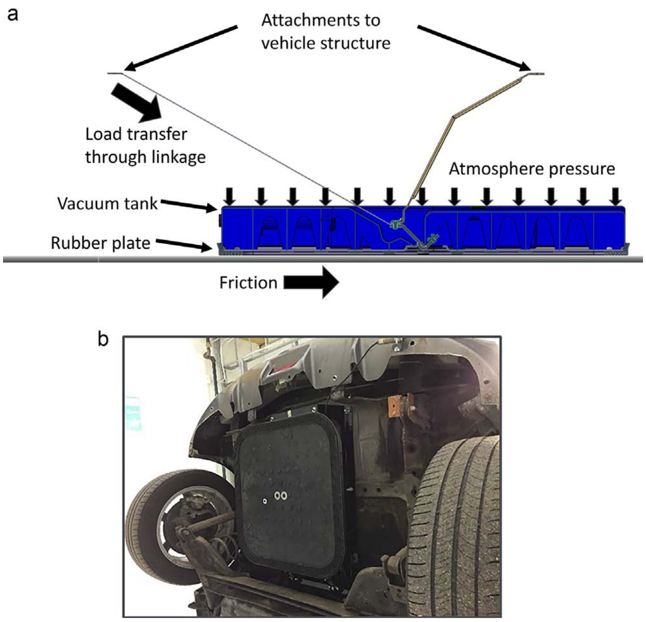

Fig. 1. (a) VEB components. (b) VEB installation in test.

While it is clear that pedestrian protection will increase when using VEB, as achievable speed reduction is always larger than that achievable without VEB, the exact real-life benefit of a realistic and sustained maximum deceleration of more than 10 m/s^2 is uncertain.

The objective of this study, therefore, is to predict the number of casualties avoided in accidents through virtual simulation of simplified mathematical models of a VEB added to a pedestrian AEB system. The system modelled incorporates future advances in technology, such as short delays for detection and classification, a reduction in the time needed for brake pressure build up (Edwards et al., 2014), and a wide sensor field of view. An analysis of benefit sensitivity to road friction levels and system settings, alongside a characterization of casualties not prevented (remaining cases), concludes this analysis.

We denote this as “real-life benefits” as we predict the effect on injuries and fatalities in the real world as opposed to “test benefits” where one predicts the effect on impact speeds in a limited set of test scenarios. One should take these estimates with due care, they are approximations, and need to be confirmed with retrospective studies once sufficient real-world data becomes available.

This paper is structured as follows: Section 2 reviews and discusses existing methods to evaluate safety benefits of pedestrian AEB systems. Section 3 details the methods employed in this study to quantify the real-life benefit of VEB. Section 4 presents the results, and is followed by discussion in Section 5 and the conclusion in Section 6. We limit the description of the simulation model in Section 3.4 to the essentials; details on system parameter settings are presented in Appendix A. Appendix B gives confidence intervals for the injury risk curves which are omitted from Fig. 4, Section 4.1 for clarity and brevity. Appendix C presents a model fit assessment for the injury risk curves.

2. Review of existing safety benefit evaluation methods

Predicting real-life safety benefits of new vehicle safety technology can be carried out in many ways. Here we review methods for the prospective assessment of safety benefits offered by vehicle-based