BENEFITS ASSESSMENT OF AUTOMATIC BRAKE ON REAL PEDESTRIAN COLLISIONS

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ABSTRACT

This paper describes the main findings of a coordinated study performed by INSIA-UPM aimed to assess the potential influence of several autonomous emergency braking systems (AEB) in vehicle-pedestrian collisions through reconstruction of real-world accidents occurred in the city of Madrid (Spain).

A total number of 43 vehicle-pedestrian collisions have been in-depth investigated following a common methodology, including on the spot data collection, analysis and reconstruction to estimate the collision speed and the pedestrian kinematics. Every single case has been virtual simulated six times using PC-Crash® software: the first is a reconstruction of the real accident and the following times are simulations in which the operation of AEB systems are emulated. The AEB systems emulated in this paper through computer simulations are based on commercial solutions.

The benefit is assessed in terms of both collision speed and Injury Severity Probability (ISP) by comparing the reduction of their values from the real conditions to the virtual simulations. The pedestrian ISP was estimated, depending on the collision speed and the head impact point, using a specific application to calculate its value based on the results of head form impact laboratory tests. The findings show that a part of the collisions could have been avoided by implementing this systems (around 20% of cases, for Systems 1, 2, 3 and 5; 70% of cases, for System 4); and in most of other cases their consequences would have been reduced in terms of the estimated ISP (these systems reduce the ISP more than 60% in at least 41% of cases). It was also found that in few cases a low reduction of the collision speed would increase the head injury severity.

Further research should include injury information and/or estimation (HIC). Other limitations are the sample size (only one city and frontal collisions) and no unhurt accidents have been included. The injury severity assessment within this study only considers head impacts to the front surface of the vehicle, injuries provoked by subsequent impacts were not taken into account. Hence it can be an interesting subject for further research.

Multi-disciplinary approaches such as this study make the identification of critical parameters easier and simplify the development of practical solutions by quantifying their potential impact on future actions to improve pedestrian safety. The autonomous emergency braking pedestrian systems have a potential benefit in real conditions. It also has limitations so
AEB is actually not intended to fully rely on. It has to act together with other passive features and the driver has to keep aware.

KEYWORDS – Pedestrian safety; autonomous emergency braking system (AEB); on the spot accident investigation; injury severity probability; accident reconstruction

INTRODUCTION

Vulnerable road users' accidents are a main concern nowadays, and among them, those with pedestrian involved. Their special characteristics when interacting in traffic can cause high severity accidents. In year 2013, 371 pedestrians were killed in Spanish roads, 217 of them in urban areas. This incidence has its response in both vehicle manufacturers and Public Administrations, each of them adopting measures to reduce the impact of this kind of accidents. In this way, the technological advances have been focused in secondary safety, but recent developments have as target the collision avoidance. The European parliament and the Council have enacted Regulation (EC) 78/2009 [1], relating to the protection of pedestrian and other vulnerable road users, forcing the manufacturers to equip new cars with a type-approved brake assist system. As a step forward, European safety organization EuroNCAP is introducing a new test to assess the efficiency of Autonomous Emergency Braking systems (AEB) in the detection and protection of pedestrians in case of risk scenarios.

In line with this approach, this paper describes an in-depth accident investigation performed by INSIA-UPM devoted to the evaluation of the potential benefit of 5 different technologies of AEB systems. Data of 43 real frontal pedestrian accidents which took place in the city of Madrid between 2002 and 2006 were collected. Every case has been simulated with PC-Crash® software, and then simulated again emulating the performance of 5 different AEB technologies. These previous simulations conduct to different accident configurations and, thus, different consequences. This process allows the comparison of technologies in both accident avoidance and injury mitigation through Injury Severity Probability (ISP).

METHODOLOGY

The methods presented in this section were developed within the framework of a research project (INSIA et al., 2008 [2]). The methodology was established to encompass into one optimal procedure to investigate on the spot every single accident, to perform reconstructions and simulations, and to analyse the obtained data and the results (Figure 1).

On-the-Spot in-depth accident database

Virtual reconstruction

Estimation of the head injury severity
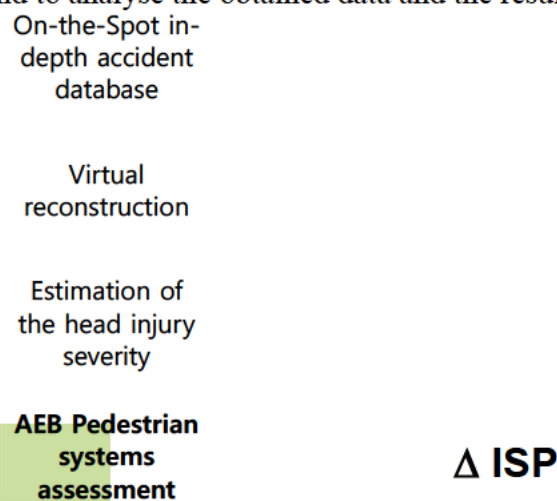
AEB Pedestrian systems assessment

Δ ISP

Figure 1: Methodology of AEB pedestrian systems assessment.

This approach integrates the interaction between collision speed, vehicle frontal design and pedestrian kinematics focused on the estimation of the severity of the pedestrian head impact on real pedestrian collisions. This method deals with the influence of head impact point changes related to changes of the pedestrian impact speed for the AEB pedestrian system benefits assessment.

ACCIDENT INVESTIGATION AND RECONSTRUCTION

A total number of 43 vehicle-pedestrian collisions, occurred in Madrid (Spain), was in-depth investigated by the INSIA-UPM road accidents investigation unit. A multidisciplinary team was created with the support of local police forces, emergency services and hospitals. On the spot accident investigation and data collection was the first step of the process. The INSIA-UPM investigation team in collaboration with the police forces attended the scene to collect all the available information about the scenario, geometry of the roads, visibility, visual evidence such as skid marks and traces, and also vehicle damages, dents and marks. Information about the injuries was obtained from paramedics and hospital data and used in the analysis phase for determining the injury mechanisms.

The sampling was based in three main criteria: first, according to the road characteristics, the selected accidents should occur in urban areas; the second criterion is about the vehicle type, considering only accidents in which the striking vehicle was a passenger car, a SUV or a minivan; the third is related to the accident configuration, only frontal collisions were considered. No restrictions about pedestrian characteristics such us gender, age, height or weight were imposed.

Once the investigation and data compilation phases were finished, the available information was analysed, revised and prepared to be used in the reconstruction using the PC-Crash® software. Next the corresponding vehicle was selected in each case and loaded from the vehicle database available in the computer program; its characteristics were set up according to the real vehicle. The frontal shapes of real vehicles were accurately measured for this purpose.

Finally, the virtual simulations of the accidents were performed using the reconstruction software. Many parameters such as approaching speed (V_0), collision speed (V_k), path, position, pedestrian motion, driver manoeuvres and sequences are slightly modified and tested in different combinations in an iterative process that leads to a reliable reconstruction (Figure 2), matching both the impact points with the visual evidence such as dents or marks and with the injury locations and mechanisms, and the vehicle and pedestrian rest positions.

Some simplifying hypotheses were established so all the simulations were performed from a common approach: 1) the reaction time of the driver was considered to be one second for all cases; 2) the lag for a conventional brake system was 0.25s; 3) the Possible Perception Point (PPP) of the driver was the instant in which the pedestrian stepped onto the pavement and no obstacle covered the driver's field of vision; 4) three intensity levels were established for the pre-collision brake force: no brakes when the evidence show that the driver had no time to react or was completely unaware of the pedestrian presence on the vehicle path, a default medium intensity brake for most accidents and a full brake when evidence such as skid marks leaded to it.

CHARACTERISTICS OF PEDESTRIAN DETECTION SYSTEMS

The systems analysed are based on commercial AEB systems (Hamdane, H. et al, [3]). The field of view of their systems can be larger or smaller depending on the applied technology. It has been considered that the lag time of each braking system is 0.1 seconds and all of them are equipped with ABS. Another assumption is that if the driver is braking and pedestrian enters into the braking area, the system increases brake pressure up to the maximum.

No accurate information about operation parameters for each system has been available for the investigation team, so it has been considered information from Hamdane, H. et al, [3] and commercial data to develop simplified models of operation to be used in reconstruction software (Table 1).
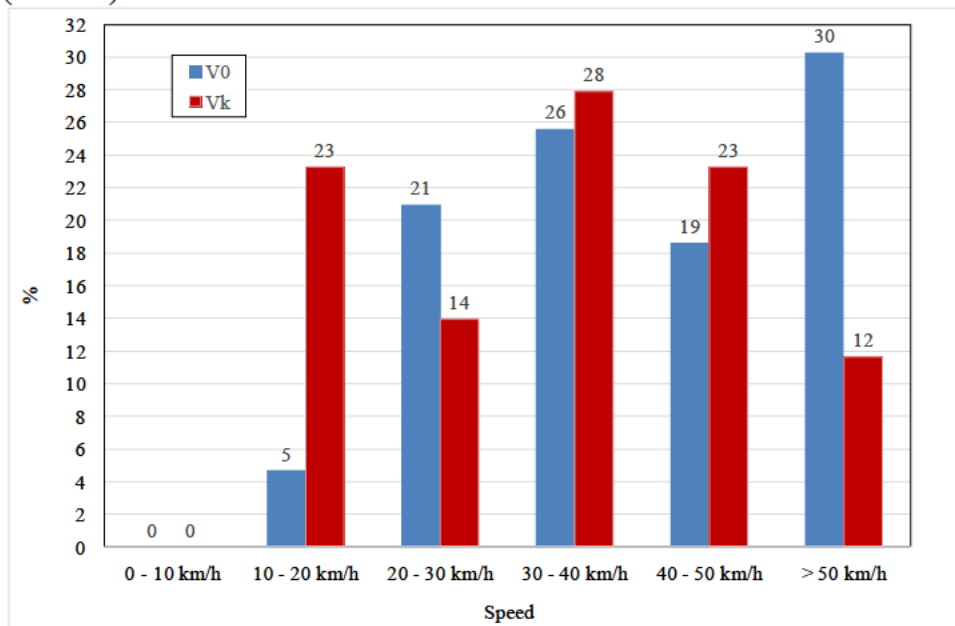

Figure 2: Distribution of vehicle-pedestrian collisions by approaching speed (V_0) and collision speed (V_k).

Systems 1, 2, 3 y 5 have two detection areas (Figure 3): one in which the system detects pedestrians with no further action, and another in which the system brakes (red area). To determine the second zone (maximum brake activation distance), it has been used the speed at which each system avoids the accident according to the manufacturers' information, and simulating a full braking at that speed. This distance determines the limit of the second zone. Therefore, while the pedestrian is outside the braking area, the system can alert the driver with luminous and/or acoustic signals. This area has not been taken into account in the simulations. If the pedestrian gets into the braking area, the system decelerates. The achieved deceleration varies depending on the available road grip.

System 4 is different because of having two braking areas (Figure 3): the first with a medium braking of 4 m/s^2 (orange area), and the second with full braking (red area). To determine the distances, a medium braking sequence has been simulated for one second, as the manufacturer specifies, followed by a full braking. Consequently, two distances have been obtained. Therefore, while the pedestrian is outside the braking area, the system can alert the driver with luminous and/or acoustic signals. This area has not been taken into account in the simulations. If the pedestrian gets into the orange area, the system initiates a medium braking, unless the driver was braking with a higher force at that moment (in this case, it is assumed the deceleration achieved by the driver). When the pedestrian gets into the red area, the system initiates full braking. A summary of the systems is presented in Table 1:

System	Maximun accident avoidance speed (km/h)	Maximum Brake Activation Distance (m)	Type	Detection angle	Range (m)
1	25	3.43	Radar	15°	200

			Mono Camera	48°	60
2	30	4.85	Stereo Camera	30°	87
3	30	4.85	Laser Scanner	22.5°	200
			Stereo Camera	44°	60
4	50	19.1	Stereo Camera	45°	50
		5.9	NIR Camera	20°	160
			Mid-Range Radar	60°	60
			Short-Range Radar	80°	30
5	30	4.85	NIR Stereo Camera	30°	25
			Radar	60°	200

Table 1: Characteristics of pedestrian detection systems
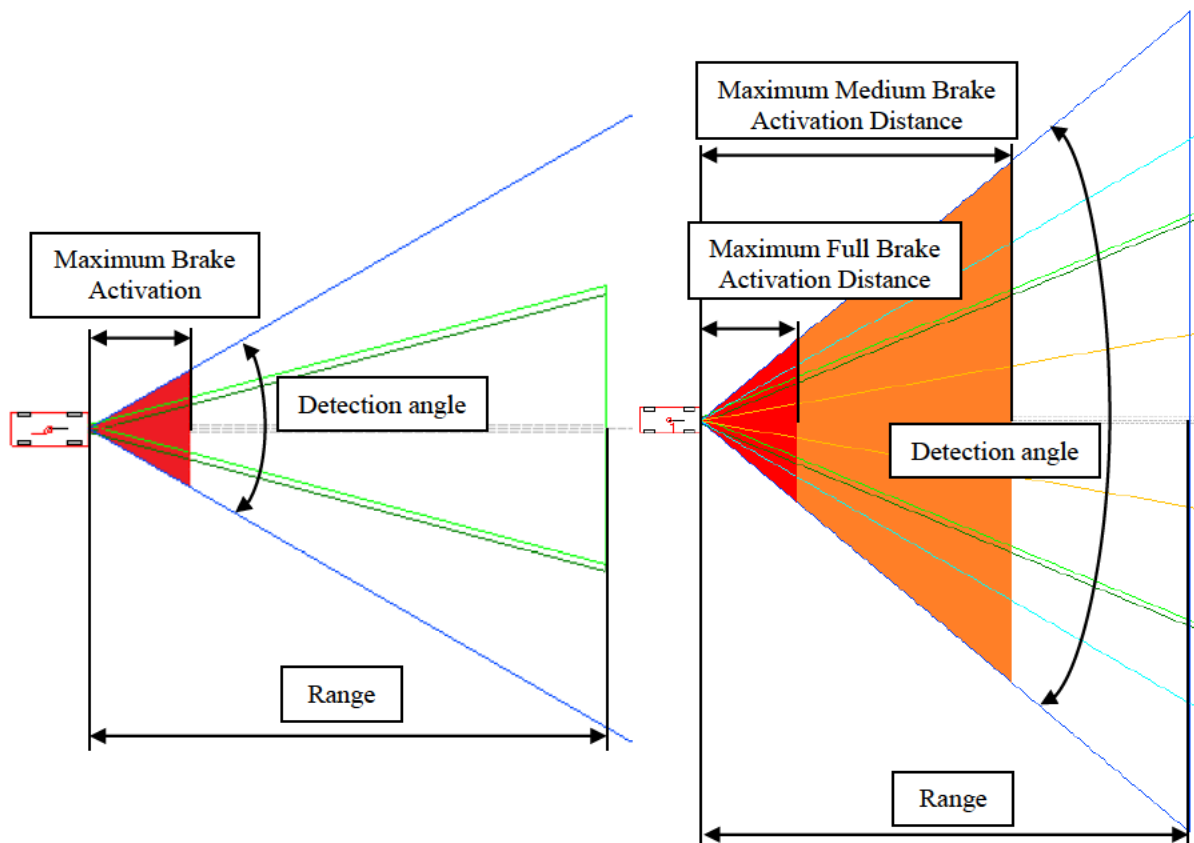
Figure 3: Diagram of systems (system 1, 2, 3 & 5 on the left and 4 on the right)

ESTIMATION OF THE HEAD INJURY SEVERITY

Head injuries are the most life threating injuries suffered by pedestrians when struck by a vehicle (Yao et al., 2008[4]). For this paper, the methodology used to estimate the head injury severity has been described previously (Badea-Romero et al., 2013 [5], Paez et al., 2014 [6]). In summary, from the location of head contact, the collision speed and vehicle characteristics, the probability of suffering a severe (AIS3+) head injury (ISP $_{HIC,H,3}$) is obtained.

RESULTS

43 accidents have been analyzed. Each one has been simulated 5 times, fitting the appropriate sequences related to the performance parameters explained previously.

First, three different situations can be distinguished according to the way the pedestrian moves relative to the car or if there is an obstacle: the system do not work because the pedestrian does not get into the automatic brake area, the system works late because the pedestrian gets into the automatic brake area at a distance lower than its highest avoindance capability, and finally the system works at the programmed distance because the system detects the pedestrian far enough.
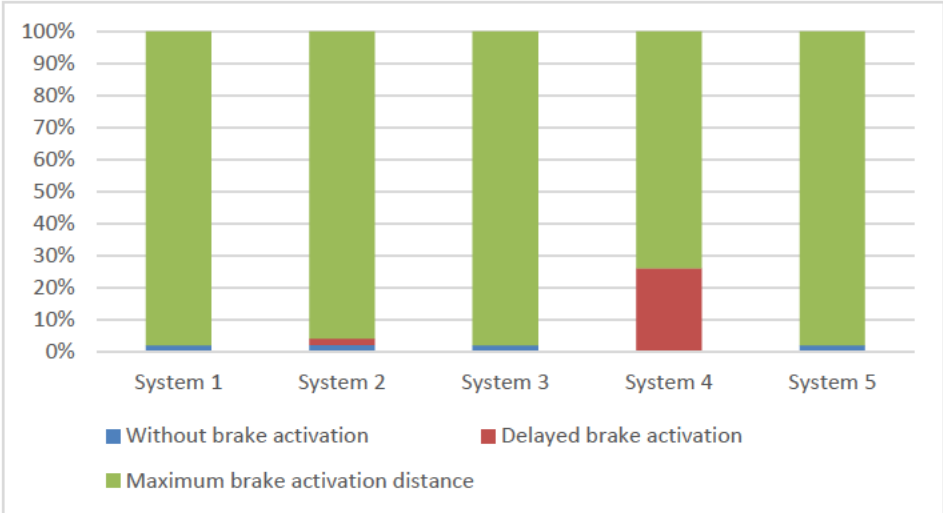

Figure 4: Case distribution by brake activation distance

System 4 works in all cases due to having the largest actuation area, therefore, it is easier for the system to detect the pedestrian. But in 26% of cases it works late due to obstacles on the roadside or because the car was turning.

In the rest of the systems there is a case in which it does not work, corresponding to an accident in which a child crosses the road between two parked cars. Furthermore, for system 2, there is another accident in which the system detects too late due to its narrower detection angle. In the rest of the cases, the systems always work.

The combination between the action of the system and the driver reaction can be grouped in 4 different situations (Figure 5): no system performance (the same as above), the system works before a driver action, the driver brakes before the system operation, and with medium braking, and finally when the driver brakes before the system and with severe braking.
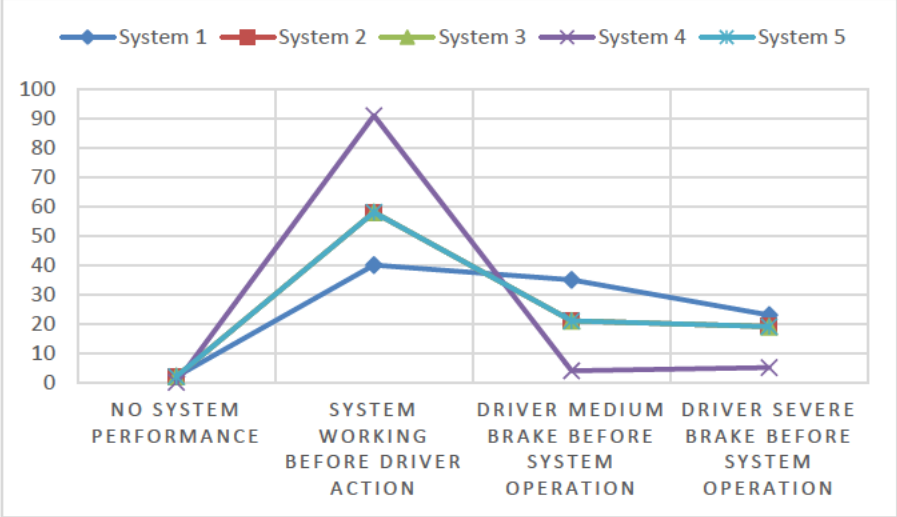

Figure 5: Case distribution by driver reaction

System 4 stands out from the others because in most cases it anticipates the driver action. In systems 2, 3 and 5 the driver brakes before the AEB operates in more than half of the cases. In addition, the proportion of cases of driver action with slight and severe braking are similar. System 1 anticipates the driver action in less than half of the cases. Also, the cases of driver action with slight braking are more than the cases with severe braking.

The aim of these systems is the avoidance of the impact if possible, or the reduction of the impact speed when the accident is inevitable (Figure 6). Depending on the system analyzed, the number of accidents avoided or the cases with a reduction on the collision speed varies.
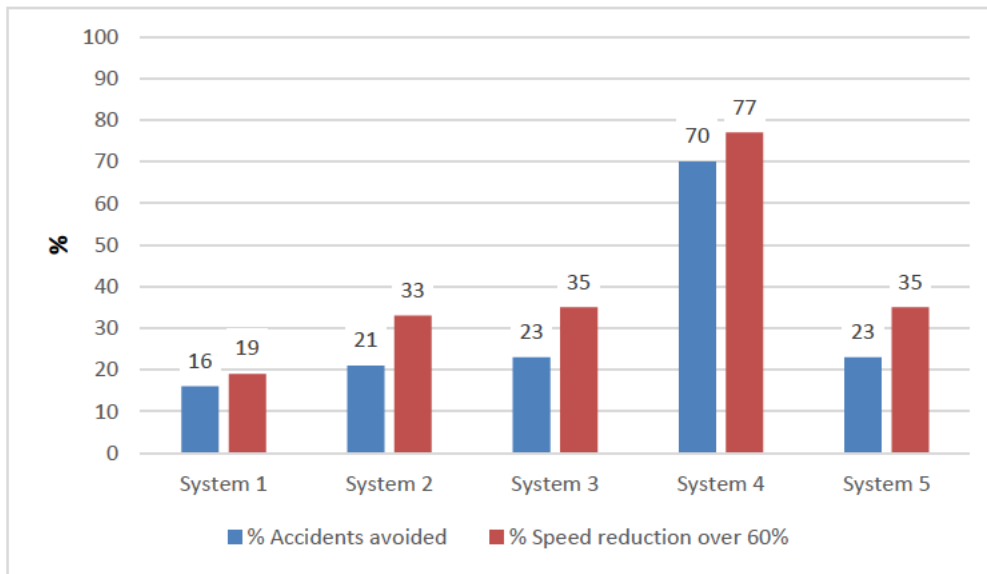

Figure 6: Case distribution by speed variation

As it can be observed, system 4 is the most effective avoiding impacts and reducing the collision speed in more than 60%. This is because it brakes before the rest of the systems. Systems 2, 3 and 5 are less effective (the cases where the impact is avoided do not reach a quarter of the total). Finally, system 1 is the most limited because of the short braking distance it uses.

An indirect target of these systems is the reduction of the ISP in the accident (Figure 7). Cases with 100% ISP reduction includes accidents where the car stops before the impact and those where even having collision, the ISP is reduced completely (those cases in which the pedestrian head does not hit the car, i.e. accidents with low speed or very cornered).
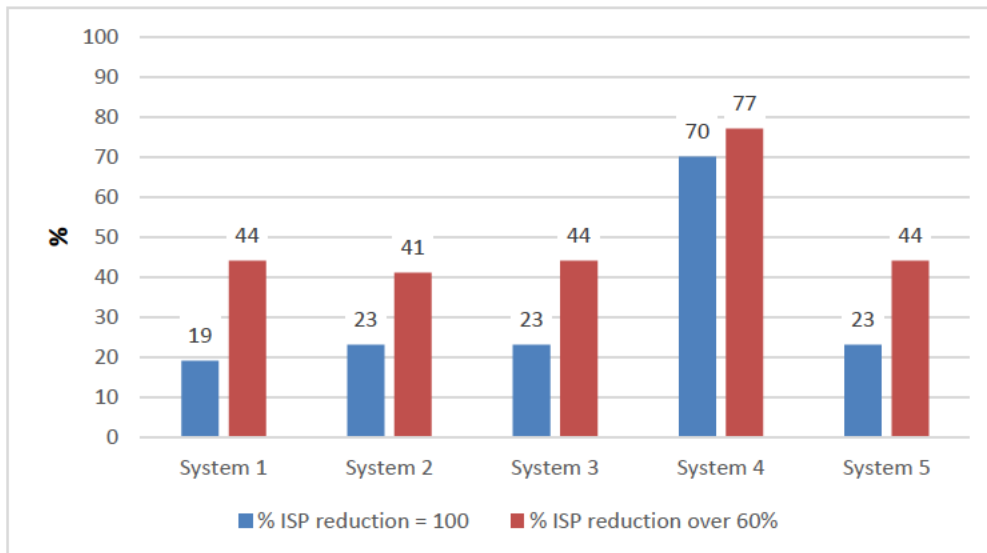
Figure 7: Case distribution by ISP variation

Again, system 4 is the most effective. Furthermore, cases with high ISP reduction correspond to cases with high speed reduction. In the rest of the systems, cases with 100% ISP reduction are practically the same as those avoided. However, cases in which the ISP is reduced more than 60% are more numerous than cases in which speed is reduced more than 60%, this difference is more significant for system 1.

This fact is explained because the ISP does not depend only on the speed: there may be cases where although collision speed using a system is greater than the collision speed using another one, the ISP is reduced.

This can be seen in the next graphics (Figures 8, 9 & 10). There are two areas: one in which speed reductions are high and other in which speed reductions are low or medium. In the first area, there is a relation between speed reduction and ISP reduction. This means that if speed is greatly reduced, the ISP will follow the same trend. On the contrary, cases with low or medium speed reductions will not always have low or medium ISP reductions. It depends on other factors, such as the location the head hits the vehicle and vehicle shape.
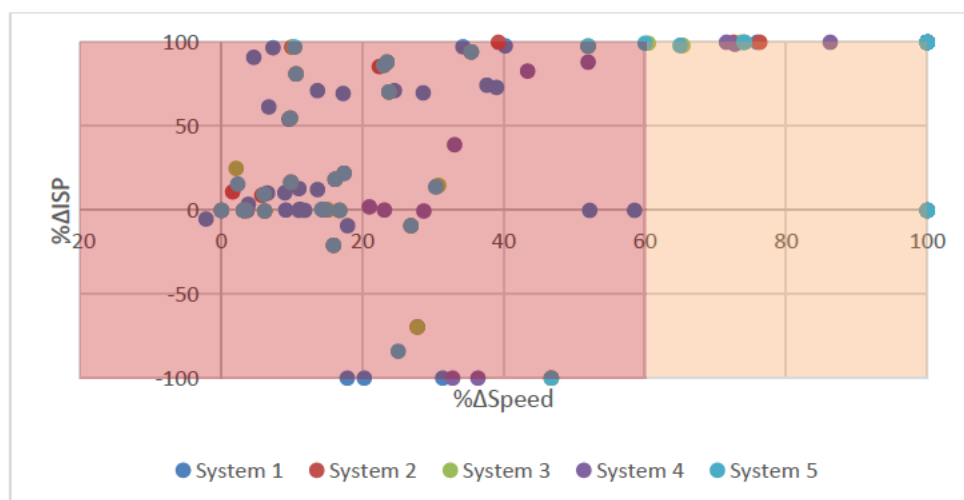

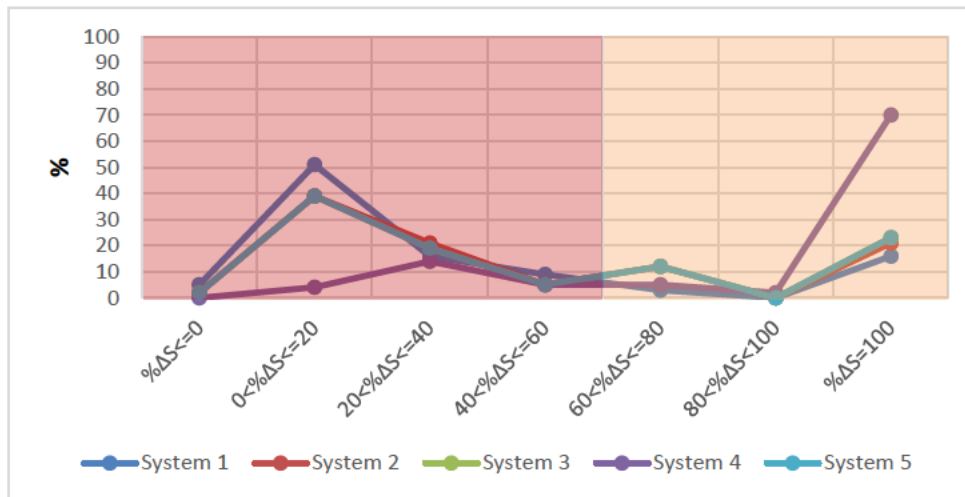Figure 8: Correlation between speed and ISP variation

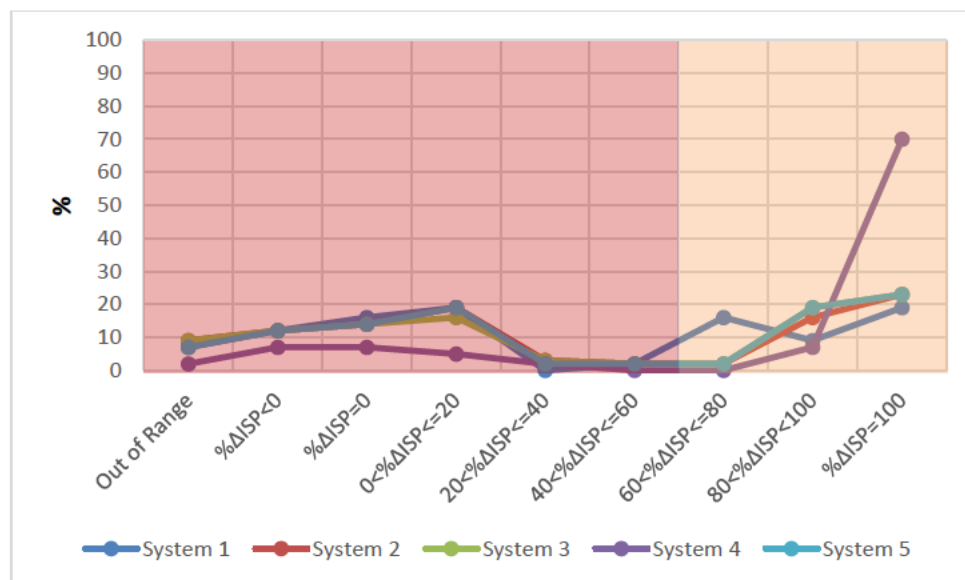Figure 9: Case distribution by speed reduction ranges

Figure 10: Case distribution by ISP variation ranges

CONCLUSIONS

Multi-disciplinary approaches such as this study make the identification of critical parameters easier and simplify the development of practical solutions by quantifying their potential impact on future actions to improve pedestrian safety.

Using this methodology, a database containing 43 pedestrian accidents was created, including in detail information of the vehicle, person (anthropomorphic variables, injury codification); scene and pedestrian kinematics. Reconstructions of these accidents were performed using advanced techniques to accurately estimate multiple parameters from the collision, the pre- and post-impact phases.

The gathered information has been used for the evaluation of the effectiveness of the 5 different AEB technologies based on commercial solutions. The performance of these systems has been simulated in the reconstructions, so it was possible to analyse their capacity for severity reduction in pedestrian accidents or even its avoidance.

The analysed systems proved to be efficient for reducing severity of pedestrian accidents in most of the studied cases, especially the System 4. The findings show that a part of the collisions could have been avoided by implementing this systems (around 20% of cases, for Systems 1, 2, 3 and 5; 70% of cases, for System 4); and in most of other cases their consequences would have been reduced in terms of the estimated ISP (these systems reduce the ISP more than 60% in at least 41% of cases).

In some cases a low reduction of the collision speed due to the simulated systems would increase the estimated ISP. The interaction between collision speed, vehicle frontal design and pedestrian parameters –height, weight, speed – is more relevant for the severity of the pedestrian head impact than the speed by itself, because it determines the head trajectory, acceleration and impact point. Thus, these primary safety systems should be combined with other secondary safety devices, such as the pop-up bonnet or the windscreen airbag.

ACKNOWLEDGEMENTS

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