ESTIMATION OF THE HEAD INJURY SEVERITY USING THE HEAD IMPACT SPEED BASED ON REAL PEDESTRIAN COLLISIONS

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ABSTRACT

A vehicle-pedestrian impact is a complex phenomenon in which a large number of variables take part simultaneously determining the injury severity of the pedestrian.

Statistical techniques were applied to data from 43 pedestrian accidents that occurred in Madrid, following a similar approach to the one applied in previous publications from authors. In this case, however, the general research objective has been oriented to model the pedestrian head injury severity as a function of the head impact speed instead of the pedestrian impact speed, and a reduced number of independent variables that affect the pedestrian impact kinematic. In previous studies authors have estimated the head injury severity using the pedestrian impact speed. The results of this paper are focused on analyzing variations on head injury severity estimations considering both the head impact speed and the pedestrian impact speed (vehicle speed); and the pedestrian impact kinematic variables influencing these variations.

As a specific objective of this research the previous methodology has been applied to review thoroughly the results about the potential influence of several autonomous emergency braking systems (AEB) estimated in the previous paper of authors.

The vehicle-pedestrian collisions have been in-depth investigated following a common methodology, including on the spot data collection, analysis and reconstruction to estimate the pedestrian impact speed, the head impact speed and the pedestrian kinematics. Every single case has been virtual simulated using the PC-Crash® software. The first is a reconstruction of the real accident and the following are simulations in which the operation of AEB systems are emulated.

For this paper, the methodology used to estimate the head injury severity has been described previously. In summary, from the location of head contact, the collision speed and vehicle characteristics, the probability of suffering a severe (AIS3+) head injury (ISP, Injury Severity Probability) is obtained.

The findings show that the head impact speed is lower than the pedestrian impact speed in the 79% of the cases. Otherwise the Injury Severity Probability considering the head impact speed is lower than the IPS estimated with the pedestrian impact speed in the 68% of the cases due to the influence of the impact area stiffness.

In some cases a low reduction of the pedestrian impact speed due to the AEB systems would increase the estimated ISP (ineffective AEB cases). The interaction among collision speed, vehicle frontal design and pedestrian parameters is more relevant for the severity of the pedestrian head impact than the speed by itself. Considering the head impact speed for the ISP estimation, the number of ineffective AEB cases increases.

Limitations of this research are the sample size (only one city and frontal collisions) and that 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.

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. 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 oriented to model the pedestrian head injury severity as a function of the head impact speed instead of the pedestrian impact speed, and a reduced number of independent variables that affect the pedestrian impact kinematic. In previous studies authors have estimated the head injury severity using the pedestrian impact speed ([2], [3], [4] and [5]). The results of this paper are focused on analyzing variations on head injury severity estimations considering both the head impact speed and the pedestrian impact speed; and the pedestrian impact kinematic variables influencing these variations.

As a specific objective of this research the methodology has been applied to review the results about the potential influence of several autonomous emergency braking systems (AEB) estimated in the previous paper of authors ([5]).

METHODOLOGY

This paper describes an in-depth accident investigation performed by INSIA-UPM intended 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 the 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).

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 analyze the obtained data and the results (See Figure 1).

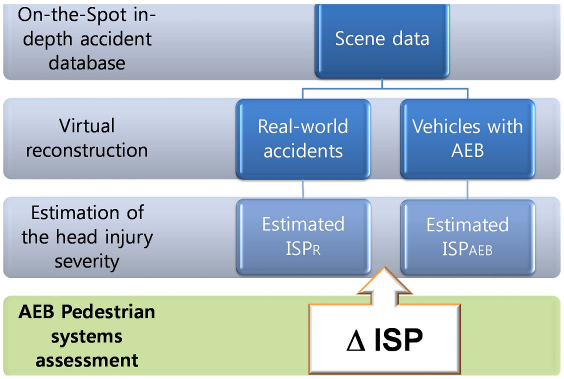

Figure 1. Methodology of AEB pedestrian systems assessment.

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 analyzed, 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), pedestrian impact 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 (See 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.

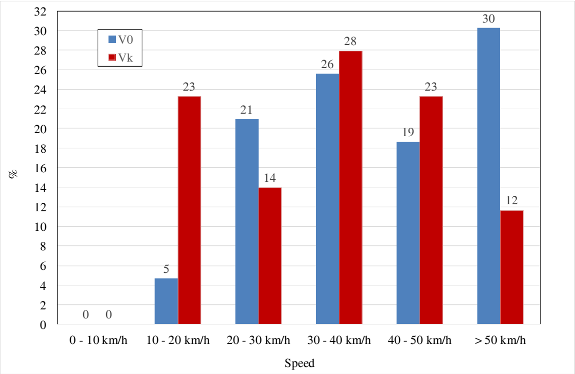

Figure 2. Distribution of vehicle-pedestrian collisions by approaching speed (V_0) and pedestrian impact speed (V_k).

Characteristics of pedestrian detection systems

The systems analyzed are based on commercial AEB systems (Hamdane, H. et al, [6]). The field of view of their systems can be larger or smaller depending on the applied technology. An 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, [6] and commercial data to develop simplified models of operation to be used in reconstruction software (See Table 1).

Table 1.

Characteristics of pedestrian detection systems

System	Maximun accident avoidance speed (km/h)	Maximum Brake Activation Distance (m)	Type	Detection angle	Range (m)
1	25	3.43	Radar Mono Camera	15º 48º	200 60
2	30	4.85	Stereo Camera	30º	87
3	30	4.85	Laser Scanner Stereo Camera	22.5º 44º	200 60
4	50	19.1 5.9	Stereo Camera NIR Camera Mid-Range Radar Short-Range Radar	45º 20º 60º 80º	50 160 60 30
5	30	4.85	NIR Stereo Camera Radar	30º 60º	25 200

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 [7]). For this paper, the methodology used to estimate the head injury severity has been described previously (Badea-Romero et al., 2013 [3], Páez et al., 2014 [4], Páez et al., 2016 [5]). 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.

The aim of these systems (See Table 1) is the avoidance of the impact if possible, or the reduction of the pedestrian impact speed when the accident is inevitable (See Figure 3).

Depending on the system analyzed, the number of accidents avoided or the cases with a reduction on the pedestrian impact speed varies.

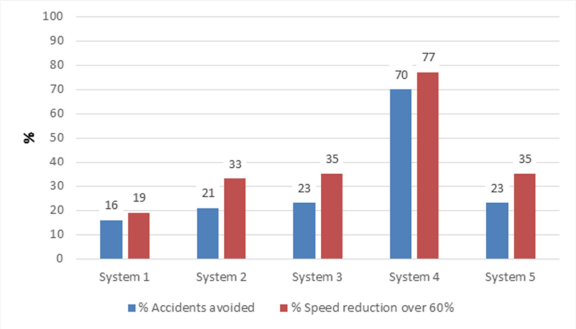

Figure 3. Case distribution by pedestrian impact speed variation.

As it can be observed, system 4 is the most effective avoiding impacts and reducing the pedestrian impact 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.

There is a certain relationship between the pedestrian impact speed (vehicle speed) and the head impact speed. In general, the higher the vehicle speed, the higher the head impact speed. However, when the vehicle speed increases, the difference between them grows too. For the cases studied, the relationship between both speeds is as follows (See Figure 4).

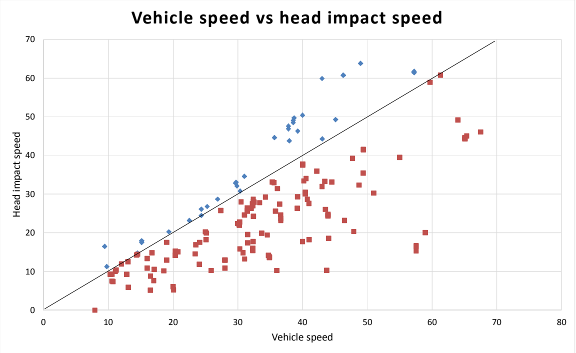

Figure 4. Vehicle speed (pedestrian impact speed) vs head impact speed.

In 78,7% of cases the vehicle speed is greater than the head impact speed. The rest (21,3%) is mainly caused by pedestrian kinematics. Because of this, the efficiency of the systems changes according to the speed that has been taken into account.

In general, the number of cases with a speed reduction of 100% (with respect to the real accident) is greater if the head impact speed is used, than if the vehicle speed is used. This is because when the vehicle speed is used, reductions of 100% imply that the accident has been avoided, while when using the head impact speed, reductions of 100% do not necessarily imply that the collision has been avoided, because there may be accidents in which the head of the pedestrian does not hit the vehicle (in these cases the reduction is 100% too).

Cases with speed reductions greater than 60% are kept roughly equal when one or the other speed are used.

However, the cases in which the speed reduction respect the real accident is null or negative are much greater when the head impact speed is used than when the one of the vehicle is used. That is, if the head impact speed is used (instead of that of the vehicle), the efficiency of the systems is penalized. This is because there may be cases in which, although the vehicle speed is less when using the systems, the head impact speed is higher than in the real accident due to the kinematics of the pedestrian during the accident. In average, better reductions are obtained when the vehicle speed is used, as illustrated in the following table (See Table 2).

Table 2. Average values of vehicle speed reduction and head impact speed reduction

System	Vehicle speed (km/h)	Vehicle speed (%)	Head impact speed (km/h)	Head impact speed (%)
1	7,95	32,88	2,81	16,06
2	10,86	41,34	4,87	27,27
3	11,03	42,68	4,76	27,12
4	25,49	81,79	16,99	75,47
5	10,98	42,56	4,79	27,23

An indirect target of these systems is the reduction of the ISP in the accident (See Figure 5), where the pedestrian impact speed is used. 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).

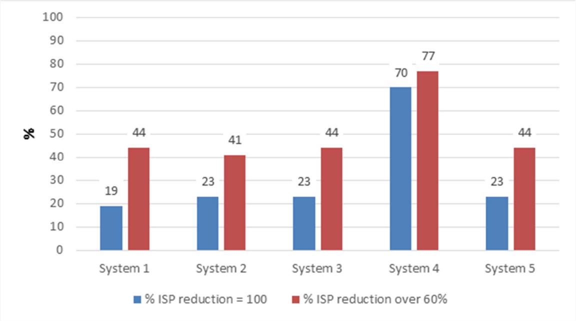

Figure 5. Case distribution by ISP variation, using the pedestrian impact speed.

With the reductions of the ISP something similar happens, since for a case in which the involved pedestrian impact vehicle is the same, and the pedestrian hits in the same zone, the only factor that changes to calculate the new value of the ISP is the speed (pedestrian impact speed vs head impact speed).

For ISP, the cases with reductions of 100% with respect to the real accident remain practically equal when using both speeds. However, cases with a reduction of ISP greater than 60% decrease when using head impact speed instead of vehicle speed. The same is true in cases where there is no ISP reduction, but this is caused because there is an increase in cases where the ISP reduction in relation to the actual accident is negative, that is, a higher ISP value is obtained when using the systems.

Therefore, as with speed, the efficiency of the systems is penalized when using the vehicle speed as reference, rather than the head impact speed. The following table (See Table 3) shows the average reduction values of the ISP when the vehicle speed and when the head impact one are used.

Table 3. Average values for ISP reduction when using the vehicle and the head impact speed

System	ISP for vehicle speed	ISP for vehicle speed (%)	ISP for head impact speed	ISP for head impact speed (%)
1	8,53	36,60	2,47	22,97
2	9,65	42,56	2,33	33,35
3	10,42	44,94	0,2	33,16
4	26,85	74,06	16,25	70,92
5	10,54	43,76	1,94	34,52

Finally, differences between using the vehicle and the head impact speed for ISP calculation will be analyzed by comparing the reduction of each of them with the reduction of vehicle speed (See Figure 6).

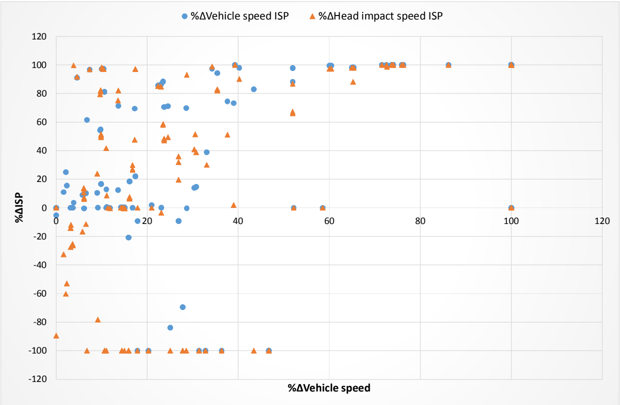

Figure 6. Reduction of ISP calculated according to the vehicle or the head impact speeds versus the reduction of the vehicle speed

The cases of ISP reduction calculated with the vehicle speed are much more dispersed than those calculated with the head impact speed. This is especially true for speed reductions of less than 60%. Also in the when using the vehicle speed there are more atypical values. This is caused because in these cases the only differential factor is the area in which it hits the head of the pedestrian. That is, atypical cases in which there are small speed reductions but large of ISP or in which although there are reductions of the speed, but the reduction of the ISP is negative and very high, are caused by the fact that the pedestrian strikes a worse area of the car.

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 analyze their capacity for severity reduction in pedestrian accidents or even its avoidance.

The analyzed 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.

The head impact speed is minor than the pedestrian impact speed in the 79% of the cases. Otherwise the Injury Severity Probability (ISP) considering the head impact speed is minor than the IPS estimated with the pedestrian impact speed in the 68% of the cases due to the influence of the impact area stiffness. The efficiency of the systems is penalized when using the vehicle speed as reference, rather than the head impact speed.

Limitations of this research 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.

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REFERENCES

[1] The European Parliament and the Council of the European Union. (2009). “Regulation (EC) No 78/2009 on the type-approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users, amending Directive 2007/46/EC and repealing Directives 2003/102/EC and 2005/66/EC.(Official Journal of the EU L 35/1)”. Brussels.

[2] INSIA, Applus IDIADA, CENTRO ZARAGOZA and SERNAUTO. “Investigación industrial en la protección de peatones a partir del estudio en profundidad de accidentes de tráfico en Madrid, Zaragoza y Barcelona. FIT 370100-2007-51 project report” [M]. Madrid, 2008.

[3] Badea-Romero, A., Paez, F.J., Furones, A., Barrios, J.M., de-Miguel, J.L. “Assessing the benefit of the brake assist system for pedestrian injury mitigation through real-world accident investigations” [J]. Safety Science, 2013, 53, p. 193-201.

[4] Páez, F.J., Furones, A., Badea, A. “Simulating the impact of automatic brake on real pedestrian collisions” In proceedings of the FISITA 2014 World Automotive Congress, 2014. (Maastricht, the Netherlands, June 2-6).

[5] Páez, F.J., Sánchez, S., Furones, A., Martínez, F.

"Benefits assessment of automatic brake on real pedestrian collisions" In proceedings of the FISITA 2016 World Automotive Congress, 2016. (Busan, Korea, September 26-30).

[6] Hamdane, H., Serre, T., Anderson, R., Masson, C., Yerpez, J. "Description of pedestrian crashes in accordance with characteristics of Active Safety Systems". In proceedings of the IRCOBI 2014 Congress, 2014. (Berlin, Germany, 10 - 12 September 2014).

[7] Yao, J., Yang, J.and Otte, D. "Investigation of head injuries by reconstructions of real-world vehicle-versus-adult-pedestrian accidents" [J]. Safety Science, 2008, 46, p. 1103-1114.