ASPECTS REGARDING THE INJURY SEVERITY IN VEHICLE-PEDESTRIAN COLLISIONS

Bogdan Benea*, Dorin Dumitrascu

Transilvania University of Brasov, Romania

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ABSTRACT - Worldwide, the road traffic accidents resulted injuries represent one of the top major factors to reduce life expectancy. Statistical analysis reports show that, while the general trend in some industrialized regions is to reduce the effects of traffic accidents by the means of imposing programs involving the car manufacturers, the research institutions and the society (i.e. APROSYS and PReVENT for E.U.), for the regions under development there is room for improvement in this area.

INTRODUCTION

Road traffic accidents make up for a financial cost of about anywhere between 1% and 2% of a country's GDP – less for underdeveloped countries and more for industrialized countries. DALY figures show that traffic accidents resulted injuries, situated in the top of factors responsible to reduce life expectancy on 9th place, are estimated to rise up to 3rd place towards 2020. According to the last WHO/World Bank report on this matter, globally, traffic accidents represent the 2nd death cause for children and youth between 5 and 29 years old and 3rd for the adult age group (30-44 years old). The figures on victims of road traffic accidents sum about 1.2 million persons per year, while for injured, up to 50 million persons. Resumed as a daily report, the number surpasses 3000 deaths, about ¾ of which found in countries under development.

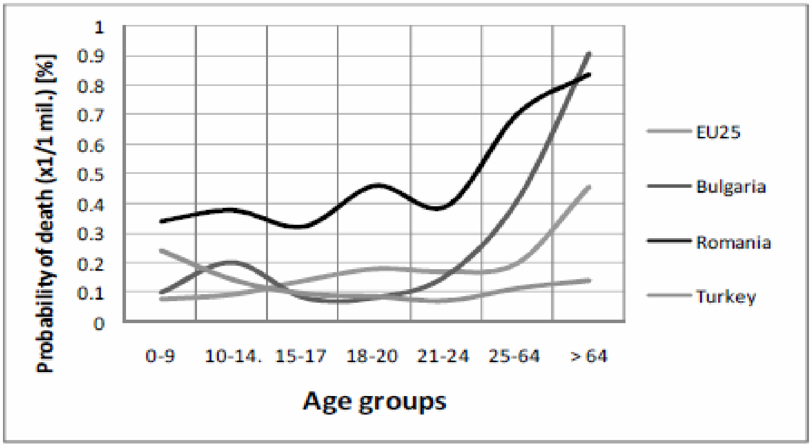


Figure 1: Probability of death by car accident as pedestrian

COLLISION KINEMATICS

The kinematics of pedestrian in then vehicle to pedestrian collision depends on several factors such as vehicle shape, initial position of pedestrian and collision velocity. A clear schematic view, based on a typical Haddon matrix, of the factors and collision phases of a vehicle-pedestrian collision analysis outlines the frontal body profile at the intersection of vehicle as factor and main collision as phase.

During such a collision, the resulted movement of the pedestrian body, due to the initial impact, can be divided into three phases:

- Contact phase
- Flight phase
- Sliding phase (ground contact phase)

The first phase is the contact phase, where one or more body parts of the pedestrian have contact with the vehicle and the pedestrian is accelerated. High contact forces can be observed during this phase, these forces being blamed for the main causes of injuries.

The second causes for pedestrian injuries are determined during the ground contact phase, so both phases contribute to the injuries and injury severity.

The most frequent kinematics behavior for the contact phase is the following: the front bumper hits the pedestrian's leg in the area of calf and knee, after which the pedestrian's thigh or pelvis is hit by the bonnet leading edge. At this point, the pedestrian rotates about the leading edge until arms, head and chest hit the bonnet top or windscreen.

INJURY SEVERITY EVALUATION. THE ABBREVIATED INJURY SCALE (AIS)

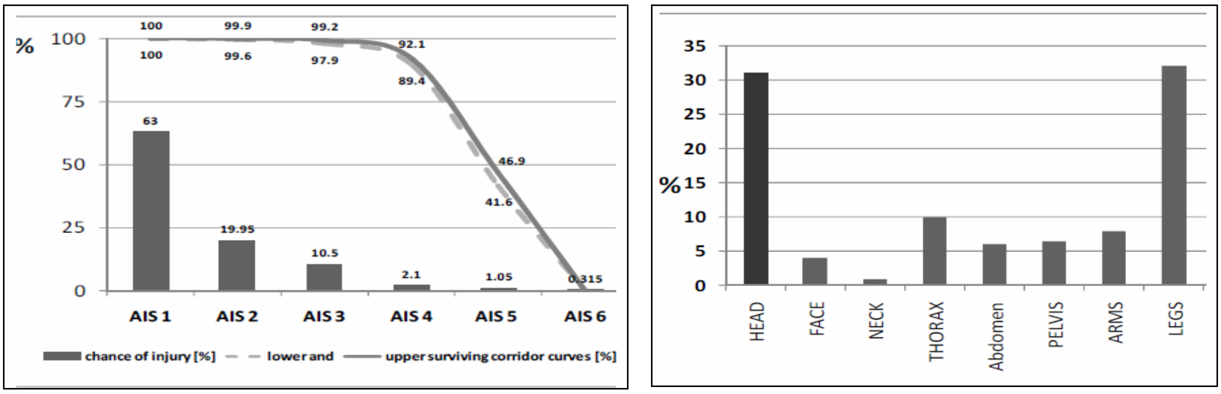
In order to evaluate the degree of injury for the human body, several classification criteria have been used, for the body as a whole, or specialized for different regions, criteria such as AIS or HIC. For AIS (Abbreviated Injury Scale) any injury level is evaluated on a scale from 1 to 6, as it can be seen in the table below. The same table describes the relation between AIS and head injury.

Table 1: AIS, head injury related [3]

AIS code. Injury level	Fatality probability	Injuries
1. Minor	0%	Light brain injuries with headache, vertigo, no loss of consciousness, light cervical injuries, whiplash, abrasion, contusion;
2. Moderate	0.1-0.4%	Concussion with or without skull fracture, less than 15m minutes unconsciousness, corneal tiny cracks, detachment of retina, face or nose fracture without shifting;
3. Serious	0.8-2.1%	Concussion with or without skull fracture, more than 15 minutes unconsciousness without severe neurological damages, closed and shifted or impressed skull fracture without unconsciousness or other injury indications in skull, loss of vision, shifted and/or open face bone fracture with antral or orbital implications, cervical fracture without damage of spinal cord;
4. Severe	7.9-10.6%	Closed and shifted or impressed skull fracture with severe neurological injuries.
5. Critical	53.1-58.4%	Concussion with or without skull fracture with more than 12 hours unconsciousness with hemorrhage in skull and/or critical neurological indications
6. Survival unsure		Death, partly or fully damage of brainstem or upper part of cervical due to pressure or disruption, Fracture and/or wrench of upper part of cervical with injuries of spinal cord.

As apparent in table above, the injury severity does not rise linearly with the AIS categories; it rises exponentially. From an AIS equal to three, the severity of injuries rises steeply.

The graphs below show the AIS distribution across AIS level and pedestrian body.



a) b)

Figure 2: a) Likelihood of injury severity and survival corridor based on AIS for a pedestrian hit by a vehicle; b) Localization of injuries for a pedestrian hit by a vehicle [Source: GIDAS Database, Germany]

THE HEAD INJURY CRITERION (HIC)

The human head is a system composed of the following:

1. Bones: the skull with the cranial and facial bones;
2. Tissue: skin and other soft tissue covering the skull also known as the SCALP. The Scalp is composed by Skin, Connective Tissue, Aponeurosis (Galea), Loose connective tissue and Periosteum layers;
3. Organs and systems: the contents of the skull. Most notably the brain, but also including the brain's protective membranes (also known as meninges) and numerous blood vessels (see figure below).

Skin injuries may be categorized as superficial or deep, and include contusion (bruise), laceration (cut), and abrasion (scrape).

Injuries to the brain and associated soft tissue are the result of either head impact or abrupt head movement (e.g., deceleration injury) or some combination of the two. Injuries may be due to the skull fracturing and being pushed inward (a depressed fracture), or from the brain impacting the interior of the skull, or from internal stressing of the brain (i.e., shear, tension and/or compression). The complexities of the head and brain system are reflected in the rather bewildering array of head injury consequences.

Three various methods are used to categorize brain injuries [2]:

1. The cause of injury, (contact or non-contact);
2. The type of injury, (primary or secondary):
   a. Primary in which the injury occurs at time of initial injury producing event;
   b. Secondary in which the injury results from some injury producing event but does not develop until somewhat later (through an intermediate process such as a metabolic effect);
3. The type of injury, either focal versus diffuse:
   a. Focal (i.e. fairly localized);
   b. Diffuse (rather distributed).

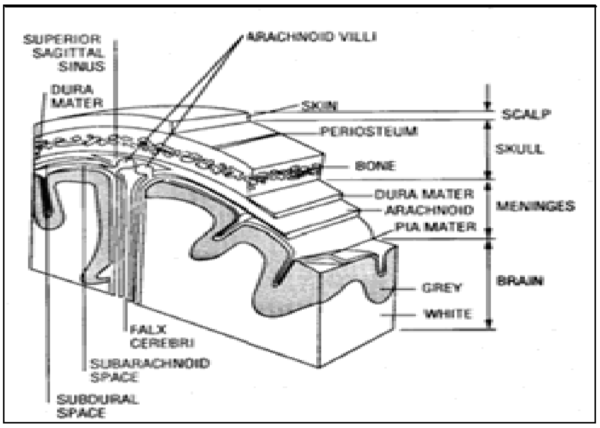


Figure 3: Head section

In injury producing events, there are generally 3 collisions which occur [2]:

1. The "first collision" is that in which the injury producing event occurs, e.g. the vehicle strikes the pedestrian and as a result the pedestrian is rapidly accelerated and/or rotated.

2. The "second collision" is the movement of the pedestrian and the subsequent contact with the vehicle frontal structure.

3. The "third collision" is when the internal organs of the pedestrian collide and/or move within him.

This index is used with head-on impacts. A HIC greater than 1000 is basically declared as the threshold value from which high occupant injuries are expected [2]. Recent research by NHTSA related to Improved Injury Criteria have included reviewing the existing regulations which specify a HIC for the 50th percentile male ATD. As of 2000, the NHTSA final rule adopts limits which reduce the maximum time for calculating the HIC to 15 milliseconds (HIC15) versus the prior HIC36 and revising the limits for different sizes of dummies as shown below [2]:

Table 2: Head Injury Criteria values for NHTSA dummy sizes

Dummy type	Large size male	Mid-size male	Small size	6-Year old child	3-Year old child	1-Year old child
HIC_{15} limit	700	700	700	700	570	390

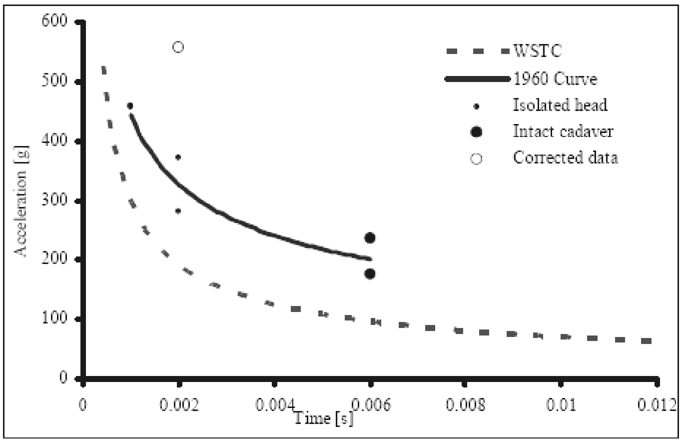
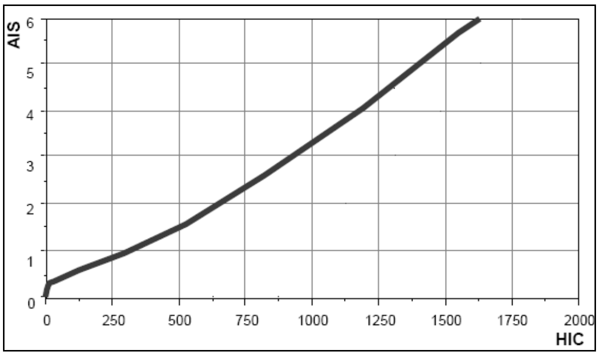


Figure 4: Acceleration responses from embalmed human cadaver tests and the original and revised tolerance curves [1]

AIS – HIC CORRELATION

On the basis of a lot of post mortal experiments (experiments with dead bodies) [6] a correlation between HIC and AIS has been developed. It should be noted that the following correlation is based on only head-on impact tests [3].

Figure below shows the probability of injury (AIS 4+) as a function of HIC. The head injury risk from real-world data (National Automotive Sampling System, NASS database) at the two speeds falls on the probability curve [1].



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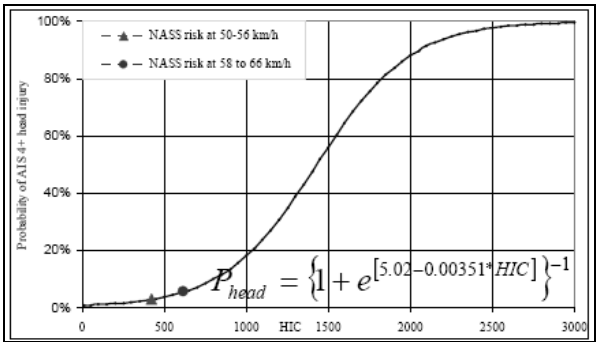

b)

Figure 5: a) Correlation between AIS and HIC [3]; b) Probability of head injury as measured by HIC for MAIS = 4 in frontal impacts. Solid circle and triangular symbols show the risk of head injury based on NASS analyses [1]

SIMULATION

PC-Crash 8.0 has been used for simulating the impact behaviour and collision mechanics. Several tests have been conducted in order to determine the influence of vehicle speed and shape over the impact mechanics. The resulted acceleration graphs of the multi-body system components simulate for the real human body parts movement.

1. First test. Testing the influence over AIS and HIC parameters, when considering the impact velocity of the same vehicle.

Parameters:

- initial car speed: 40km/h;
- braking: pedal position: 100%, brake factors: 101.9 on both axles;
- vehicle: one vehicle used;
- pedestrian position: side impact;
- pedestrian parameters: default PCCrash pedestrian values;
- pedestrian regions analyzed: torso, hip, femur, lower left leg, head, left knee.

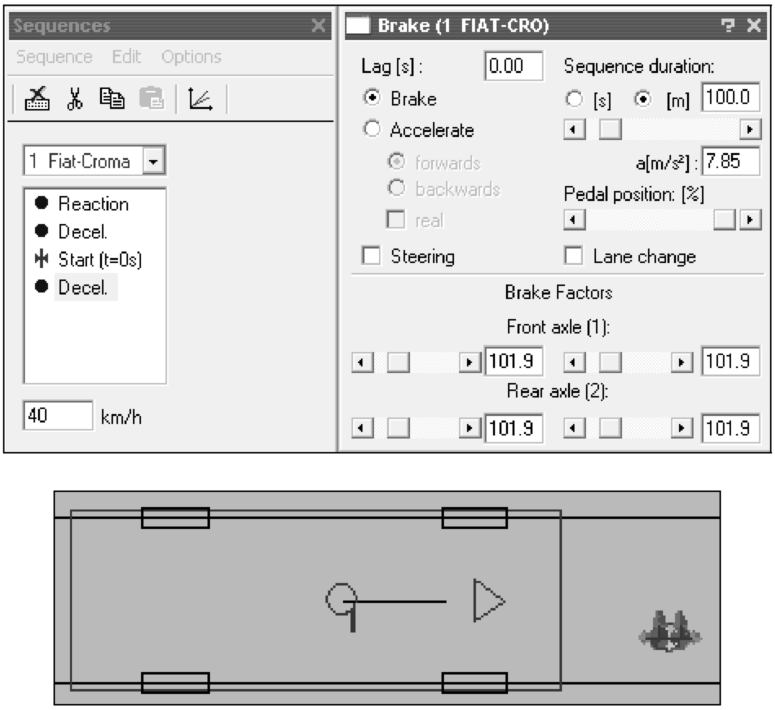

Figure 6: Setting up the impact sequences and parameters

2. Second test. Testing the influence of the pedestrian distance towards the median plane, when also taking into consideration the shape of frontal structure of the same vehicle.

Parameters:

- initial car speed: 40km/h;
- braking: pedal position: 100%, brake factors: 101.9 on both axles;
- vehicle shape: one vehicle used for a selected shape type;
- pedestrian position: four positions have been used, a) near the center b) intermediate 1 c) intermediate 2 d) centred on the wheels;
- pedestrian parameters: default PC-Crash pedestrian values;
- pedestrian regions analyzed: torso, hip, femur, lower left leg, head, left knee.

3. Third test. Testing the influence of the vehicle shape for different geometrical corridors.

Parameters:

- initial car speed: 40km/h;
- braking: pedal position: 100%, brake factors: 101.9 on both axles;
- vehicle shape: vehicles used for the 6 different shape types;
- pedestrian position: the second pedestrian position of the previous test was used;
- pedestrian parameters: default PC-Crash pedestrian values;
- pedestrian regions analyzed: torso, hip, femur, lower left leg, head, left knee.

4. Fourth test. Testing the influence of the vehicle shape for different vehicles of the same geometrical corridor.

Parameters:

- initial car speed: 40km/h;
- braking: pedal position: 100%, brake factors: 101.9 on both axles;
- vehicle shape: different vehicles used for the most common shape type;
- pedestrian position: same as above;
- pedestrian parameters: default PC-Crash pedestrian values;
- pedestrian regions analyzed: torso, hip, femur, lower left leg, head, left knee.

VALIDATION

For the validation tests, a specially constructed dummy was placed in front of a vehicle, simulating a road crossing. The impact took place in the tibia region, right below the knee. The vehicle impact speed was close to 29 km/h, the dummy hitting the vehicle between the first third and the median line of the bumper.

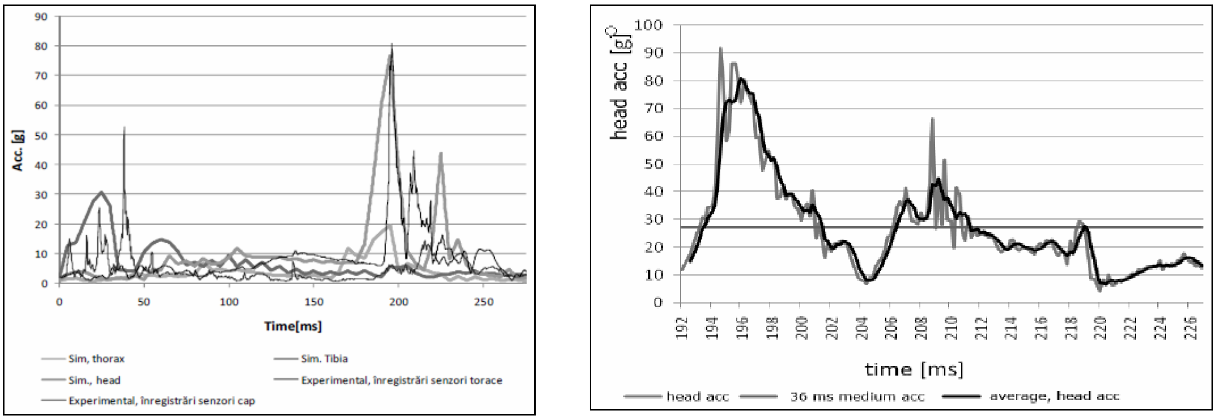

Figure 7: Overlap of simulation and real tests accelerations (left) and HIC36 results (right)

CONCLUSIONS

The nonlinear increase of AIS severity is clearly supported by the virtual and real tests.

The 40km/h impact score the best results for the lower body parts. An impact velocity producing head acceleration above 60g would develop a HIC36 above 1000, which is connected to AIS levels 3+.

As the tests show, it can be seen that the pedestrian distance towards the median plane has a clear impact on the event mechanics.

The third test shows the influence of the shape type for different shape types. Different values and numbers for maximal values for the different body parts evolved clearly illustrate the difference of influence each shape type has on the car-pedestrian impact.

The fourth test shows the influence of the shape type for different vehicles, of the same shape type: trapezoidal shape with shallow bonnet.

For most graphs, it can be seen that the head acceleration maximal values are between 40 g and 90 g, while the lower body parts accelerations maximal values go anywhere from 100 g to 250 g.

Analyzing the collision at head level, it was possible to observe that the head to windscreen impact lasted for about 90 ms, with a maximum acceleration value of 810 m/s2, a HIC15 value of 133,35 for a medium acceleration of 379,81 m/s2, and a HIC36 value of 139,32 for a medium acceleration of 272,32 m/s2.

The optimization of the analyzed parameters can lead to a greater impact in the decreasing of the collision speed influence on the pedestrian injury level, most notably quantified with HIC, thorax acceleration and other means.

ACKNOWLEDGEMENT

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REFERENCES

[1]. YOGANANDAN,N., & others, Biomechanical aspects of blunt and penetrating head injuries, IUTAM ;

[2]. MCHENRY,B., Head injury criterion and the ATB, 2004;

[3]. SHOJAATI,M., Correlation between injury risk and impact severity index ASI, STRC2003;

[4]. http://catalog.nucleusinc.com;

[5]. DSD, A Simulation program for Vehicle Accidents. Example Manual, Technical Manual, Dr. Steffan Datentechnik, Austria, 2001;

[6]. MOSER &others, The Pedestrian Model in PCCrash. The Introduction of a Multi Body; System and its Validation, SAE technical paper, 1999;

[7]. MOSER , Validation of the PC –Crash Pedestrian Model, SAE technical paper, 2000;

[8]. SVOBODA,J., Cizek,V., Pedestrian – vehicle collision: vehicle design analysis, SAE technical paper, 2003;

[9]. E/ECE TRANS/WP.29-GRSP-36-1 Proposed draft Global Technical Regulation (GTR) on Pedestrian protection, 7-10 Dec. 2004;

[10]. REPORT, TA for Road Safety Measures Implementation – Final Report, Europe Aid/114414/D/SV/RO, 2004;

[11]. Document, WHO (2004), World Report on Road Traffic Injury Prevention, Geneva;

[12]. Document, APROSYS (2006), AP-SP31-007R, „The generalized geometry corridors, generic shapes and sizes of the vehicle fleet covering cars, MPV's and SUV's”.

[13]. SOICA,A., LACHE,S., Theoretical and Experimental Approaches to Motor Vehicle - Pedestrian Collision, 3rd WSEAS International Conference on APPLIED and THEORETICAL MECHANICS - MECHANICS'07, Tenerife, Spain, December 14-16, 2007;

[14]. OKAMOTO,Y. And others., „Pedestrian Head Impact Conditions Depending on the Vehicle Front Shape and Its Construction-- Full Model Simulation”, AAAM, Traffic Injury Prevention, 3/2007;

GLOSSARY: WHO: World Health Organisation