STUDY REGARDING CYCLIST HEAD INJURY PROBABILITY FOR STANDARDISED IMPACT CONFIGURATIONS USING MULTIBODY SIMULATIONS

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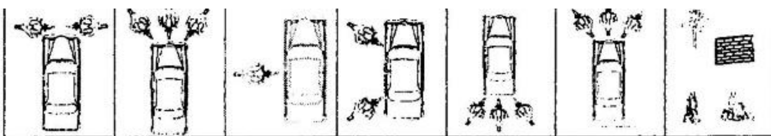
Abstract: *The aim of this paper is to predict head injury probability for cyclists in road accidents using a multibody approach. Cyclist accidents are standardised into seven categories according to the impact configuration. A comparative analysis at identical vehicle and cyclist impact velocities was carried out in order to establish which impact configuration is the most dangerous for cyclists. Simulations in PC Crash software were carried out for each impact configuration at the same impact velocity using a Sedan vehicle. HIC values were calculated using cyclist head accelerations obtained through simulation and the corresponding skull fracture probabilities have been assessed.*
Keywords: *cyclist impact, head injury, skull fracture, impact configuration, PC Crash*

1. INTRODUCTION

Cyclists are vulnerable road users which participate in both urban and rural traffic. Cyclist density varies from one country to another, so do cyclist accident statistics and traffic legislation regarding cyclists. At least 1000 cyclists lose their lives every year in the European Union.[1] The most frequently injured bodyparts for cyclists are the head, the lower and the upper extremities. However, 72% of cyclist fatalities are caused by head injuries alone, which underlines the increased significance of mitigating head injuries for cyclists, whether through improved design and impact behaviour of vehicle frontal profiles or through passive safety equipments.
Road accidents which involve cyclists are classified into seven standardised impact configurations as described in figure 1.[2] Results from an investigation of 876 cyclist accidents recorded in GIDAS and classified according to their corresponding impact configuration have shown that accidents in which the cyclist is hit from the lateral side (collision 1) or frontally (collision 2) are the most frequent and produce the highest number of severe injuries, including head injuries. However, the study does not offer any information about accidents in which the cyclist is hit from the rear (collision 6) and therefore data representativeness is questionable.



collision type	1	2	3	4	5	6	7
classification of collision-angles (degree)	90 ±20 270	180±69	90 ±20 270	180 ±69 0	0 ±69	0 ±69	
bicycle	**24,8%**	**21,6%**	**7,6%**	**10,8%**	**2,2%**	**-**	**32,9%**
MAIS 2+	23,9%	26,4%	17,1%	20,6%	24,4%		20,5%
head AIS 2+	12,9%	15,6%	8,6%	12,5%	12,3%		12,2%
leg AIS 2+	8,8%	9,1%	3,3%	4,6%	8,4%		4,1%

Figure 1: Standardised impact configurations for accidents involving two-wheelers[2]

The ASPECSS project [3] which was carried out by the European Comission over 19172 accident cases involving cyclists offers the most detailed view regarding injury severity for different impact configurations (figure 2., table 1) However, the results shown in ASPECSS do not cover the integrality of cyclist accident typologies and therefore do not allow for a complete analysis of injury severity variations with different impact configurations.

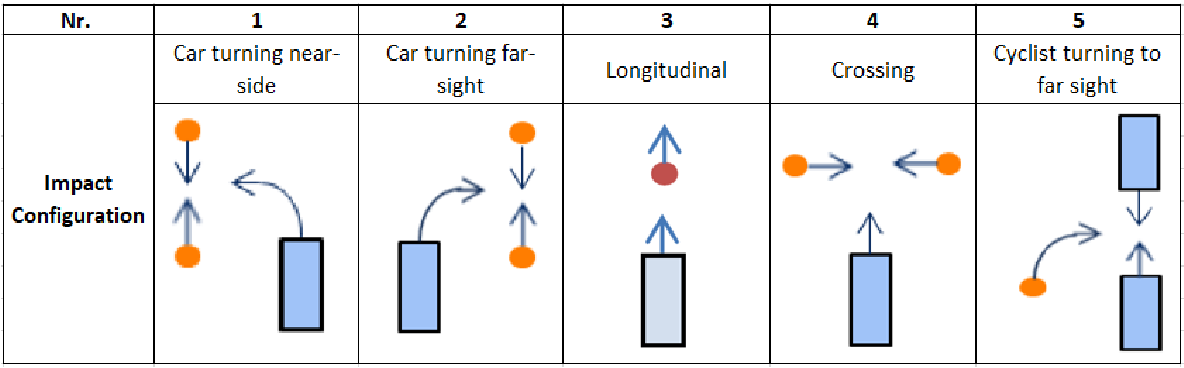


Figure 2: Cyclist impact configurations taken into account in the ASPECSS project[3]

Table 1: Injury severity for each impact configuration described in the ASPECSS project[3]

Impact configuration	Injury severity			Total casualties	% Killed or Seriously Injured
	Killed	Seriously injured	Slightly injured		
1	1	180	1729	1910	9%
2	3	519	3180	3702	14%
3	41	307	1698	2046	17%
4	27	786	4578	5391	15%
5	16	198	919	1133	19%
Others	116	2699	16357	19172	15%

There is no corroboration between the results from [1] and [2] regarding data afferent to accidents in which the cyclist is hit from the rear or from the lateral. Some studies[3],[4],[5] have shown that accidents during which the cyclist is collided from the lateral side are the most widespread and numerous.
A study[6] carried out over 17930 cyclist accidents recorded in ITARDA database has determined the percentage of each impact direction for cyclist injuries classified in three categories: minor, serious and fatal (figure 3). Results have shown that the ratios for fatal/minor injuries and fatal/serious injuries are the highest for accidents in which the rear part of the bicycle is hit by the frontal profile of the vehicle.

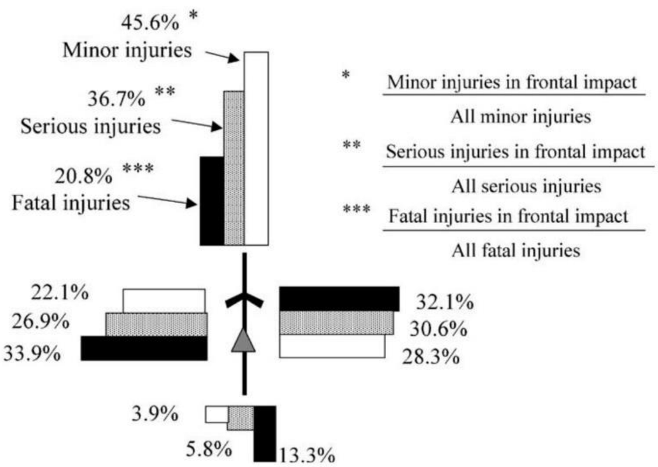


Figure 3: Percentages of impact directions for each degree of injury severity[6]

Although different impact configurations lead to significantly different outcomes regarding cyclist kinematic and dynamic parameters, there is little information in literature regarding the influence of the impact configuration over resulted cyclist injuries.

The purpose of this paper is to determine cyclist head injury severity for each standardised impact configuration for identical impact velocities, in order to establish which impact typologies are the most dangerous. This information can be useful for research purposes regarding future designs of head-protective equipment for cyclists or regarding optimization of frontal profiles for vehicles.

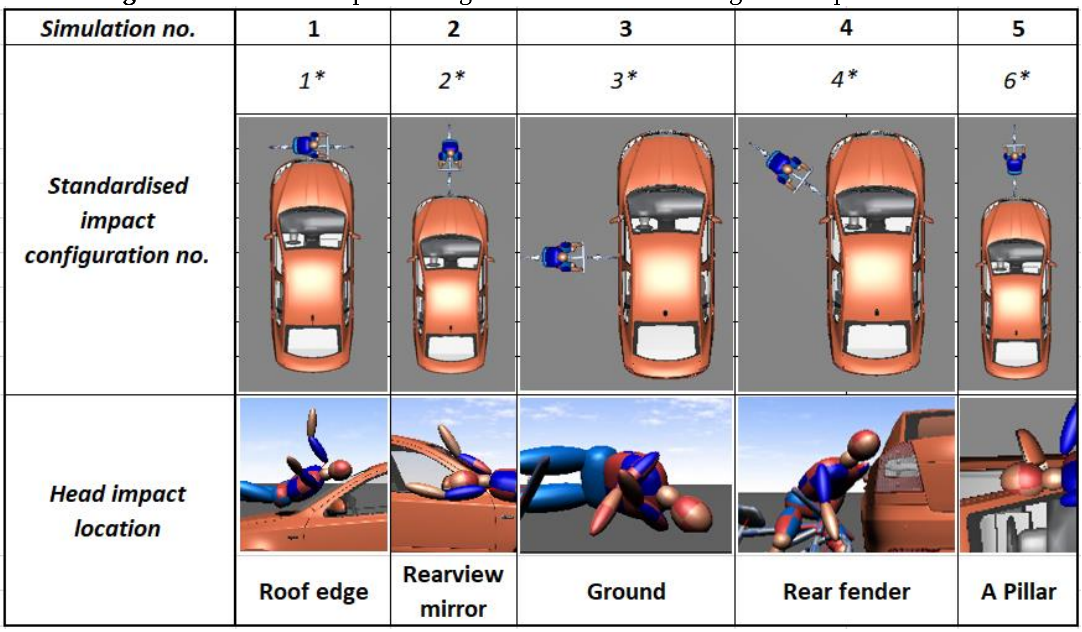
2. METHODS

Multibody simulations were carried out in PC Crash for each of the standardised cyclist impact configuration using a Sedan vehicle (Skoda Octavia). The cyclist/bicycle impact velocity was set to 15km/h, vehicle impact velocity was set to 50km/h and vehicle deceleration was set to 7m/s2 in all simulations. However, the comparative analysis required in order to evaluate head injury severity was not carried out for impact configurations 5 and 7, for the following reasons:

- Collision 5 characterizes accidents in which the cyclist hits the rear profile of the vehicle. This impact typology can take place in the following types of situations: when the cyclist is travelling at a higher velocity than the vehicle, the vehicle is moving in reverse, or both. It is evident that these types of situations do not concur with the set initial conditions in this study.
- Collison 7 characterizes accidents in which the cyclist hits various obstacles. There is virtually an infinity of possible cyclist-obstacle accidents depending on the form and the mass of the obstacle, directly influencing the outcome of the head impact for the cyclist. Therefore, it is not feasible to compare these types of accidents with the vehicle-cyclist impacts described through impact configurations 1-6.

The impact configurations used in the simulations and the head impact locations for each configuration are presented in figure 4.

Figure 4: Simulated impact configurations and the resulting head impact locations



The multibody model in PC Crash was configurated in accordance with the 50th percentile male anthropometry. For increased kinematic accuracy, the angular stiffness values for all cyclist joints (Table 2) were configurated in accordance with validated data from a study regarding cyclist multibody system optimization in PC Crash.[7]

Table 2: Defined angular stiffness values for cyclist joints [7]

Joint	Stiffness [Nm/˚]
Torso-Hip	0.8
Torso- L/R upper arm	0.2
Femur L/R - lower leg L/R	0.2
Upper arm L/R - Lower arm L/R	0.2
Torso - Neck	0.5
Hip - Femur L/R	0.5

Lower leg L/R - Foot L/R	0.2
Neck - Head	0.5

Cyclist head accelerations obtained through simulation were processed (with a CFC 60 filter) and the corresponding HIC values were calculated with the formula:

$$HIC = \left\{ [\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt]^{2,5} (t_2 \text{-} t_1) \right\}_{max} \quad (1)$$

where a is the resulting head acceleration for the cyclist in g;

t2-t1 ≤ 15ms / 36ms is the time interval corresponding to the maximum HIC value.

Obtained HIC values were used to determine the corresponding skull fracture probability using the variance relationship existent in literature.

3. RESULTS

Cyclist head accelerations obtained through simulation are presented in figure 5. The maximum value for head acceleration is recorded at 79g for Simulation 5, which is almost double the second highest head acceleration of 40g recorded for Simulation 1. The time at which the cyclist head impact takes place is almost the same in all impacts during which the cyclist is hit by the frontal profile of the vehicle (lateral-Sim 1; frontal – Sim 2; longitudinal – Sim 5). For impact configurations in which the cyclist hits the lateral profile of the vehicle (Sim 3 and Sim 4), the time of the head impact is higher and the head may only impact the ground and not the vehicle (Sim 3).

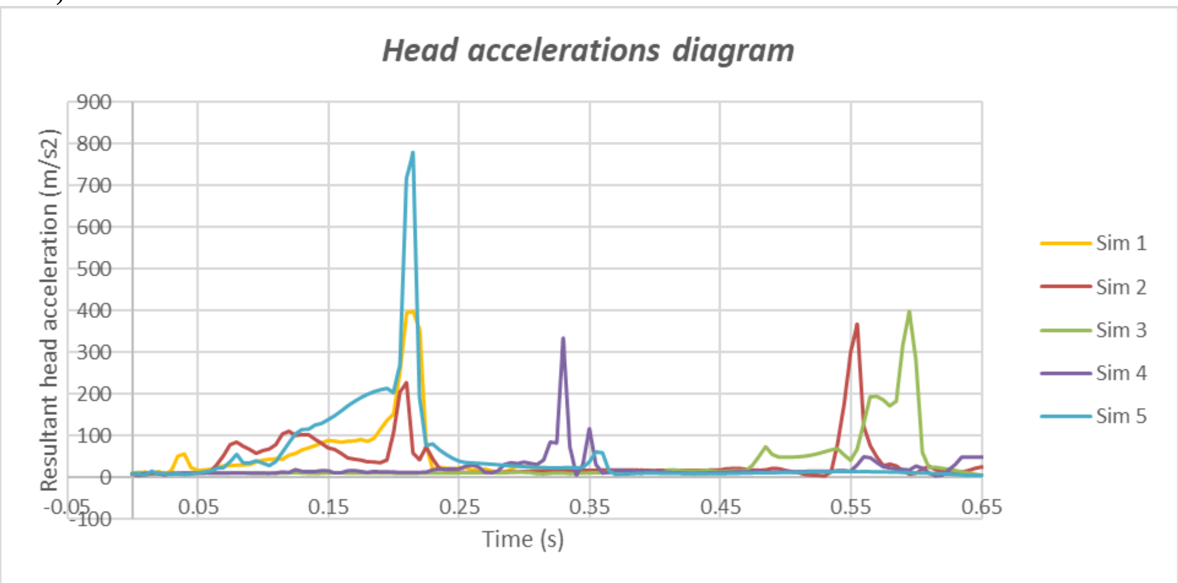


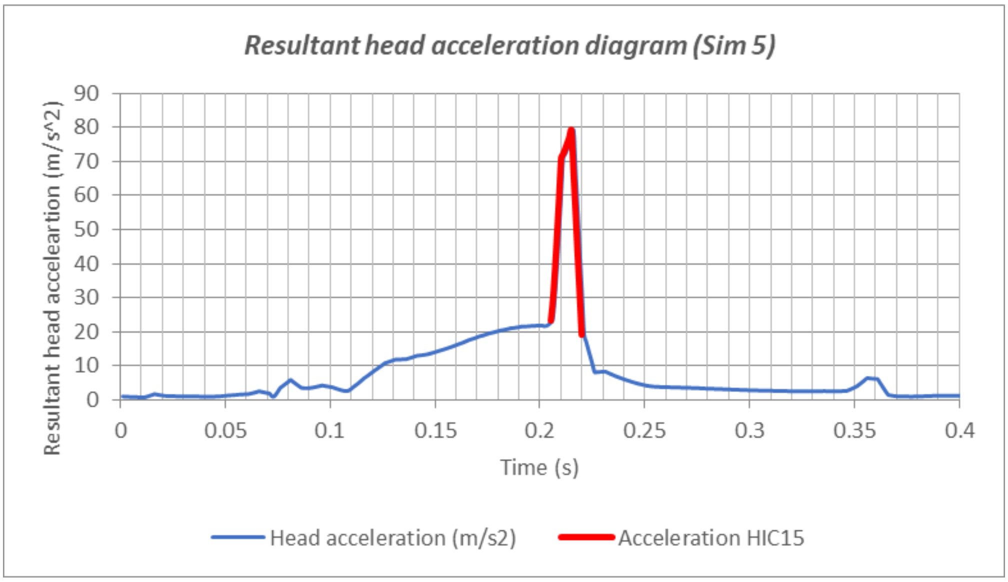
Figure 5: Cyclist head accelerations diagram obtained through simulation

HIC 15 and HIC 36 values were calculated after data filtration for each impact configuration and are presented in table 3.

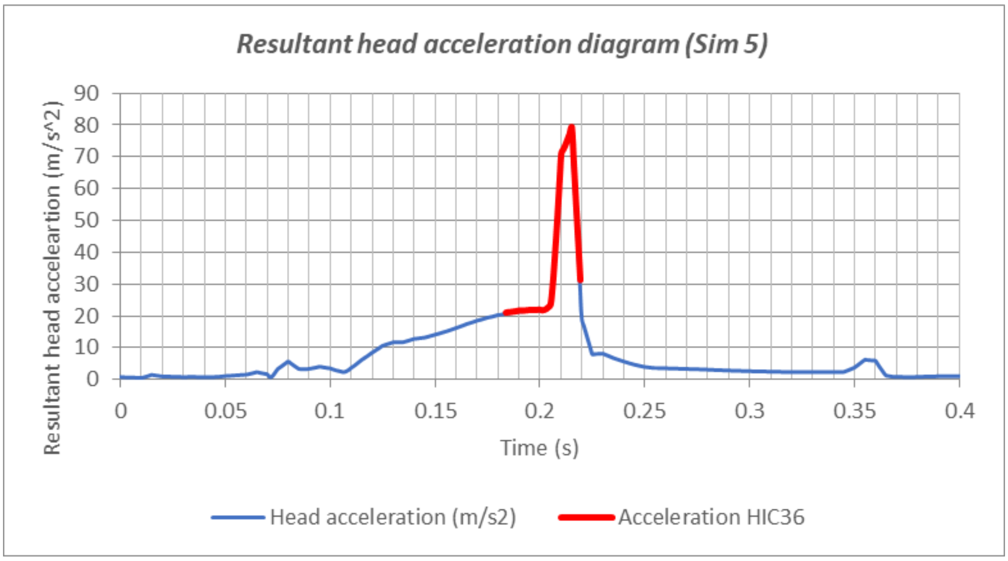
Table 3: HIC values calculated for each simulation/impact configuration

Simulation no.	1	2	3	4	5
Standardised impact configuration no.*	1*	2*	3*	4*	6*
HIC 15	129	61	85	26	359
HIC 36	116	39	103	23	282

Results show that for the impact configuration 6 (Sim 5) during which the cyclist is hit from the rear presents the highest HIC values compared to the rest of the scenarios: the HIC 15 (figure 6.a) and HIC 36 (figure 6.b) values account for 278% and respectively 243% of the second highest values which were recorded for lateral impacts (Sim 1).



6.a.



6.b.

Figure 6: HIC 15 and HIC 36 for Simulation 5

HIC values presented in Table 4 were used to determine the corresponding skull fracture probability using the relationship[8],[9] presented in fig 7. Interval limits for skull fracture probability are defined accordingly to the calculated HIC 15 and HIC 36 values.

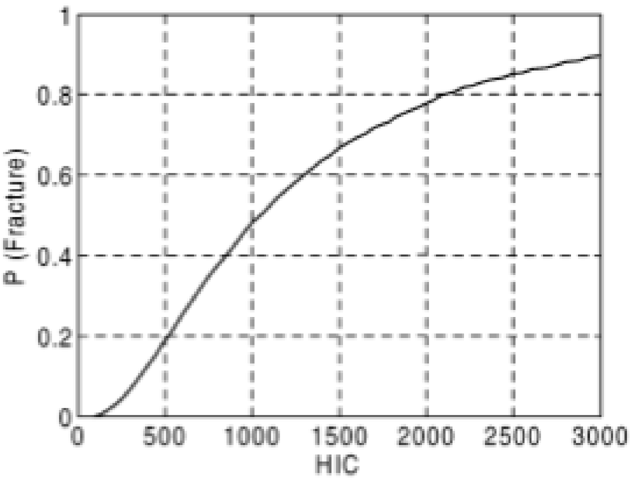


Figure 7: - Skull fracture probability variance with HIC values[8],[9]

Table 4: Skull fracture probability for each simulation/impact configuration

Simulation no.	1	2	3	4	5
Standardised impact configuration no.*	1*	2*	3*	4*	6*
Skull fracture probability	1 - 2%	0%	0%	0%	12 -13%

4. CONCLUSION

Results of the carried out simulations indicate that impact configuration 6 (Simulation 5) is the most dangerous typology regarding head injury severity. The maximum head acceleration, maximum HIC values and the maximum skull fracture probability of all the simulations were identified in Simulation 5.
There is a significant difference between head injury probability for impact configuration 6 (the most dangerous in accordance to the calculated injury criteria) and impact configuration 1 (the second most dangerous). This proves that accidents during which the cyclist is hit from the rear constitute the most dangerous impact typologies for cyclists, which corroborates with the interpretations of Maki [6].
This type of accidents occur on roads shared by both vehicles and cyclists, their genesis being heavily influenced by visibility conditions. One consecrated method of eliminating the main causal factor of this type of accidents is the implementation of cycle tracks, which effectively separate the trajectories followed in traffic by vehicles and cyclists with the exception of road intersections. This stresses the importance of this road safety measure in mitigating cyclist head injuries, through a direct manner by separating vehicles from cyclists in traffic and through an indirect manner by eliminating the main causal factor of the most dangerous impact configuration for cyclists.

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