HIC Evaluation in Teenage Cyclist – SUV Accident

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Abstract: - The study of the crash between normal sedan and teenage cyclist was examined in previous paper, and is here continued analyzing the influence of the front part of the vehicle in the injury caused by the accident. The vehicle is a SUV, with high frontal part. No variation is executed on the model of the teenage cyclist and the bike. The position of the teenage cyclist regard to SUV is the same: three different positions are analyzed: front, rear and lateral position. The injury on the cyclist head is examined by HIC criterion, in the way indicated in the rules. Correlation HIC – AIS is used to calculate the lethality of the injuries. The work is arranged to calculate the damage to the chest by 3 ms criterion, which result is not yet ready. The principal conclusion is done that the injury of the head is more dangerous for the SUV impact than the sedan, but only to the maximum speed (50 km/h). A comparison is executed with the teenage pedestrian concluding that the pedestrian is subjected to greater injury, because the bike absorbs a part of the energy in the front and side crash. The more dangerous injury is the telescoping.

Key-Words: - teenage bicyclist, SUV impact, sedan impact, severe (AIS4+) injury, HIC,

1 Introduction

The energetic systems for the mobility in the automotive field are changed in the last years, like the beginning of this year 2015 have highlighted.
In the field of Internal Combustion Engines, Diesel exceed petrol engines by almost double (55,2% against 31,1%); GPL, CNG, Hybrid and Electric occupy almost 14% of the domestic market (fig. 1).
The phenomenon of the Sport Utility Vehicle occupies 20% of the total sales, while in America this vehicle type has a greater spread (fig. 2).
In the last year in Italy one can count 136,438 accidents with 184,683 casualty and 1,421 deaths of which 250 are cyclists (ANIA 2014).
Many works are found in literature on the impact between vehicle and adolescent [1] [4] or adult pedestrian [2] [3] [5] [10] [19] [24], also numerous are the works that study the impact between the vehicle and the adult cyclist [9] [11] [13] [17] [18] [21] [22] or both cyclist and pedestrian [6] [7] [8] [12] [14] [23], but there is in literature a gap on the accident vehicle - teenage cyclist [15] [16] [20]; other works are not found on this scope.

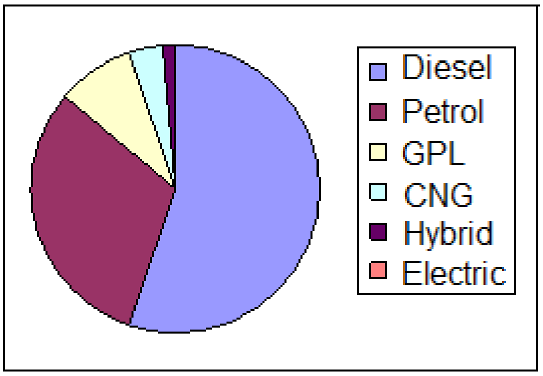

Fig. 1: Italian market for feeding (UNRAE April 2015).

In general numerical simulation multibody is the applied method; the most widely used programs are

MADYMO, Aprosys, PC Crash, while the authors effectively use Visual Nastran 4D.

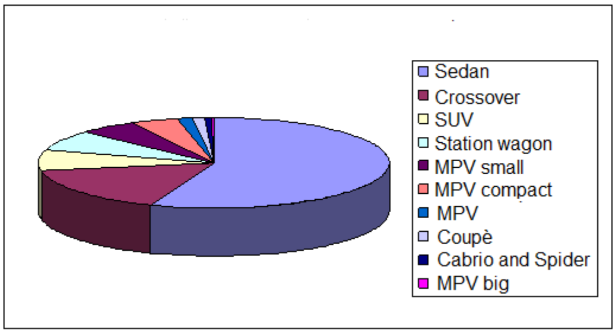

Fig. 2: Italian market for bodywork (UNRAE April 2015).

The studies carried out give an idea of the shape of the front of the vehicle in order to reduce injuries, that may arise due to collision [19], but these works are not frequent in literature. In particular the works [22] [23] [24] also address the crash between SUV vehicle against cyclist or pedestrian.

This paper extends the results already achieved in the works [15] [16] where the damages caused by the energy impact of a teenage cyclist with a sedan car are taken into account and analyzed. Analogous crash is studied in case of vehicle constituted by a SUV instead of a normal sedan, in order to fill the gap in literature: reference is made only to an adult or a child without taking into account the type of vehicle.

With the availability of the virtual model SUV-teenage cyclist, a campaign of virtual simulations is conducted, in order to quantify the damage caused to the head and chest on the basis of certain criteria such as HIC and 3 ms criterion [15] [16] [25] [26]. In this paper 3ms criterion results are not reported, because they are being developed.

2. Implementation of Virtual Models

The paper [1] is very useful for the study of anthropomorphic model of the human figure of a teenager, understood as a complex of bones, muscles and joints; the book [27] and the paper [28] are very useful for the chassis design and the geometry of the bike

Virtual simulations, performed with Visual Nastran, allowed to quantify the damages in the teenager cyclist – SUV impact on head and chest. Specifically HIC criterion is used regard to head injuries. The dynamics taken into consideration concerns the crash front, side and telescoping.

Difficulties encountered in the study are numerous: CAD implementation of wheels, seat, chassis bonnet and front bumper of the SUV, the geometry of the frame, the vertical position of the center of gravity and the study of the stability of the bicycle.

Instead the implementation of the joints of the human figure, the model of the cyclist and the bike are those already adopted in the works [15] [16]; then the further focus on this topic is not considered appropriate.

The car chosen for the simulations is the SUV Mercedes class M. Information on wheelbase, height, length is provided by the manufacturer.

This type of SUV is chosen for its characteristics: larger structure, monoshell bodywork, the more aggressive mask, and the great mass.

CAD model is obtained by Sketchup software, the model is later imported into Visual-Nastran, inserting the masses, centers of gravity and the inertia moments of the individual components such as wheels, body, chassis, bonnet, front bumper. These parameters are essential for the proper conduct of the simulations and the acquisition of results (Fig. 3).

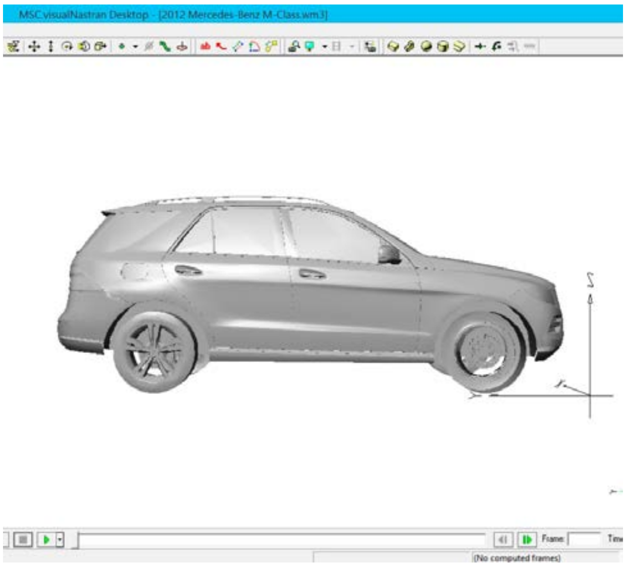

Fig. 3: SUV in Visual Nastran

3. SUV - Cyclist Accident

Visual Nastran allows the reconstruction of the main conditions constituting the dynamic of a teenage cyclist - SUV crash.

In the general case teenage cyclist is placed in a perpendicular position to the longitudinal axis of the road, and goes on the direction perpendicular to the oncoming vehicle at negligible rate. The actions of the vehicle driver has a decisive role in the evolution of the accident.

The most common attitude of the drives is the deceleration by instinct, to reduce the consequences

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of the impact, but it remains to be seen whether the braking of SUV resolves positively or less the accident evolution.
Speed reduction can only cause minor injuries on the cyclist with respect to a constant speed; but despite the perception and reaction times of the driver, the real decrease of SUV speed is often very poor: although the SUV has a braking capacity capable of imposing an average deceleration greater than 0.6g, the effectiveness of braking action is achieved near the instant of impact in most cases.
The teenage cyclist is found in the same three positions examined in the papers [15] [16]. In the first he is positioned as previously described: he is stopped on the roadway with the side facing the overcoming SUV (side impact).
In the second case the cyclist is located in front of the overcoming SUV (front impact), while in the third and last case the cyclist is placed behind the SUV (rear impact or telescoping).

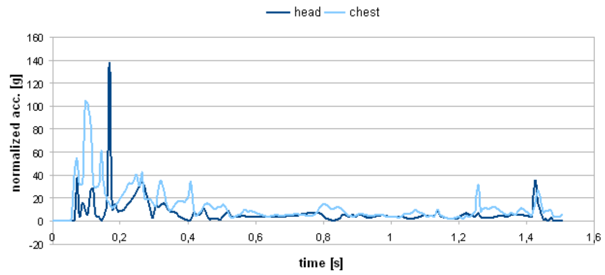

Fig. 4: Head and chest acceleration in the frontal impact at 50 km/h

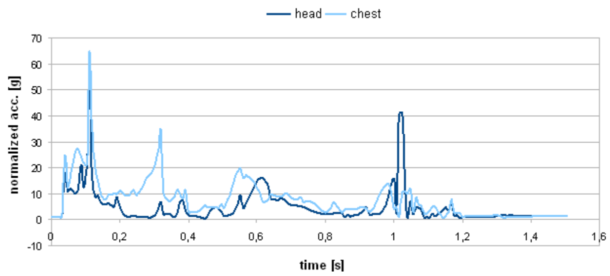

Fig. 5: Head and chest acceleration in the side impact at 30 km/h

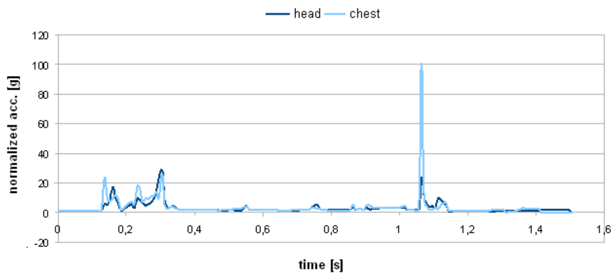

Fig. 6: Head and chest acceleration in the telescoping at 20 km/h

The constraint of Visual Nastran 4D, named "rope", allows that the rider remains upright until an instant before the impact occurs with the SUV.
Since the Highway Code sets the maximum distance of urban land at a maximum speed of 50 km/h, also the crash tests meet this limit. Whereas a speed of 50 km/h can be fatal in the event of impact, crash tests are performed even at the speed of 20 km/h, 30 km/h and 40 km/h for a better study of the problem.

3.1 Numerical Simulation

Measured parameters during the simulations are:
- acceleration of the head gravity center;
- acceleration of the chest gravity center.

Fig. 4, fig. 5 and fig. 6 show the trend of the head and chest acceleration, versus the time for some significant test.

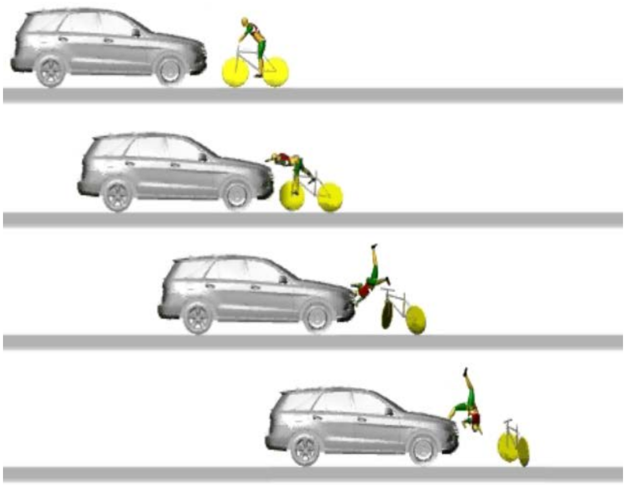

Fig. 7: frontal impact at 50km/h, constant speed.

Events reconstruction in Visual Nastran allows observing the trajectory taken by the adolescent cyclist throughout the collision, by comparing each time the data extracted from the simulation with the frames of the test.
The two sequences represented in fig. 7 and fig. 8 show the different trajectories of the teenage cyclist in function of the different simulation conditions.
Fig. 7 illustrates the dynamic of the frontal impact at 50 km/h; the thrust of the front bumper and the forward projection of the cyclist may be noted.
Fig. 8 depicts the trajectory taken by the cyclist who is invested laterally from the oncoming vehicle at a constant speed of 50 km/h. The thrust forward and the wheeling of the cyclist body may be noted.

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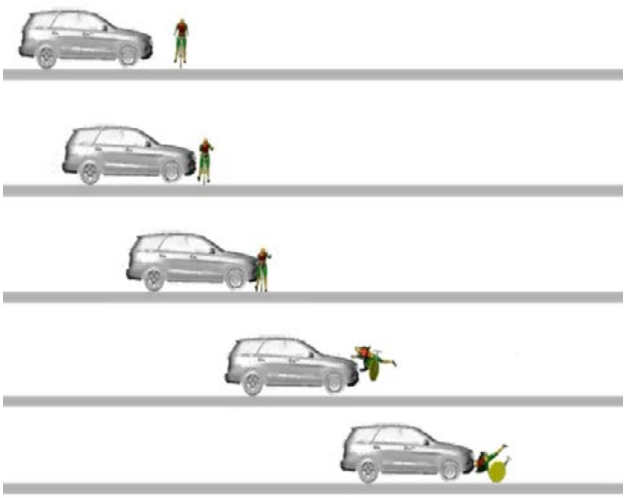

Fig. 8: lateral impact at 50km/h, constant speed.

Table 1: synthesis of the obtained values and HIC.

Test	Position	Vel. [km/h]	$A_{max\ head}$ [g]	HIC
1	Frontal	20	58,51	239,51
2	Frontal	30	67,86	310,16
3	Frontal	40	90,13	569,38
4	Frontal	50	137,84	1453,44
5	Lateral	20	13,52	10,47
6	Lateral	30	54,31	190,30
7	Lateral	40	88,61	565,29
8	Lateral	50	127,51	1317,17
9	Rear	20	28,59	46,80
10	Rear	30	48,68	181,97
11	Rear	40	106,18	823,01
12	Rear	50	154,77	3055,83

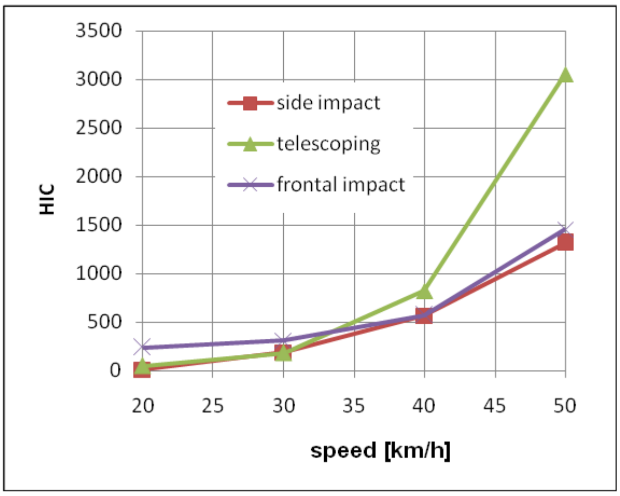

Fig. 9: HIC versus the impact speed.

3.1.1 Test analysis and HIC calculation

Simulations give very useful information for the analysis of the crash effects. Table 1 shows the synthesis of the obtained results in terms of head acceleration and the relative values of HIC. This calculation is executed following the rule, by the traditional formula, assuming a base of time equal to 36 ms.

Fig. 9 shows the trend of HIC versus the impact speed.

3.1.2 HIC-AIS correlation

Table 2 shows the correlation HIC-AIS. HIC data, obtained by the simulations with the injury scale AIS, give the lethality percentage of the event. Fig. 10 shows the procedure: HIC value is reported in the abscissa and the ordinate gives the corresponding percentage of lethality.

The lethality curve of fig. 10 is obtained in previous works i. e. [1] [2] and relative references.

Table 2: lethality percentage by HIC – AIS correlation

Test	Position	Vel. [km/h]	AIS	% lethality
1	Frontal	20	1	0
2	Frontal	30	1	0
3	Frontal	40	2	10-20
4	Frontal	50	4	50-60
5	Lateral	20	1	0
6	Lateral	30	1	0-5
7	Lateral	40	2	10-20
8	Lateral	50	4	50-60
9	Rear	20	1	0
10	Rear	30	1	0
11	Rear	40	2	10-20
12	Rear	50	6	100

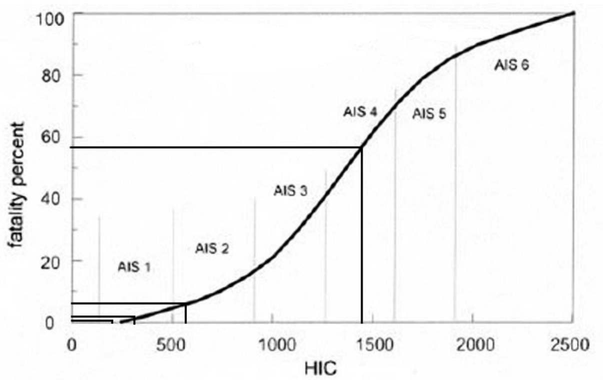

Fig. 10: HIC-AIS correlation (frontal impact at constant speed)

3.2 Considerations on the Results

The simulations are distinguishes in three groups:

1. simulations 1-4 for frontal impact
2. simulations 5-8 for side impacts

3. simulations 9-12 for rear impact.

Fig 5 shows that side crash see a series of peaks of acceleration caused by the impact on the lateral plane of the skull against the front of the SUV (bumper and bonnet); in these cases the first contact with the bonnet occurs by the shoulder and, at a later time, with the head. These peaks are repeated generally in the short round of 0.01s due to some rapid rotation of the head around the joint of the cervical neck.

Both front and rear impacts trends are very different one another at different speed. The head, because of the first contact of the teenage cyclist with the bumper of the vehicle, is strongly projected backwards. In this way the center of instantaneous rotation of the cervical varies, by determining a variation of the moment of momentum which results in a substantial increase of the angular acceleration of the whole head. In some cases, there is an overlapping between the impact of the head and the contact of the chest on the bonnet; this gives a considerable increase of the measured accelerations for the chest.

3.2.1 Comparison SUV - sedan

Table 3 shows the difference in percent between the analysis of the impact sedan – teenage cyclist, obtained in [15] [16] [20], and SUV- teenage cyclist, in terms of HIC.

Table 3: comparison of HIC for SUV and sedan

test	Position	Vel. [km/h]	Difference with sedan
			HIC
1	Frontal	20	+1904%
2	Frontal	30	+2240,9%
3	Frontal	40	+2101,8%
4	Frontal	50	+277,6%
5	Lateral	20	-69,9%
6	Lateral	30	-63,5%
7	Lateral	40	-7%
8	Lateral	50	+104,5%
9	Rear	20	-53,3%
10	Rear	30	-42,5%
11	Rear	40	+139,1%
12	Rear	50	+512,2%

Fig. 11, fig. 12 and fig. 13 show the trend and the visual comparison.

The teenage cyclist has lower chance to survive in the front, side and rear impact with the SUV, in the range of speed of 40-50 km/h, because HIC values are consistently greater than the survival values, obtained as in fig. 10.

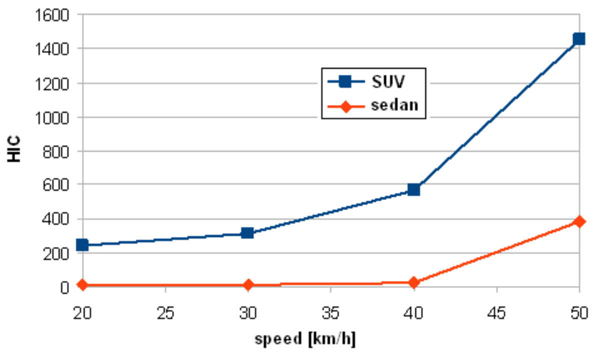

Fig. 3: comparison SUV – sedan for HIC in the frontal impact.

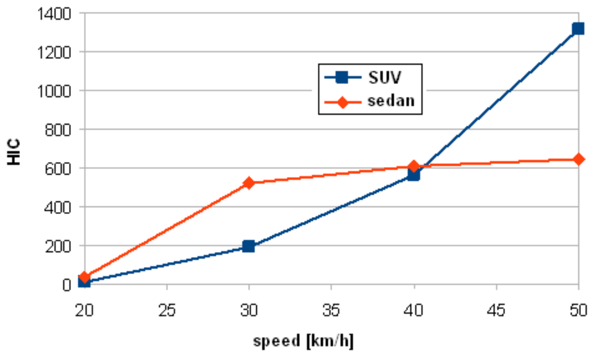

Fig. 12: comparison SUV – sedan for HIC in the lateral impact.

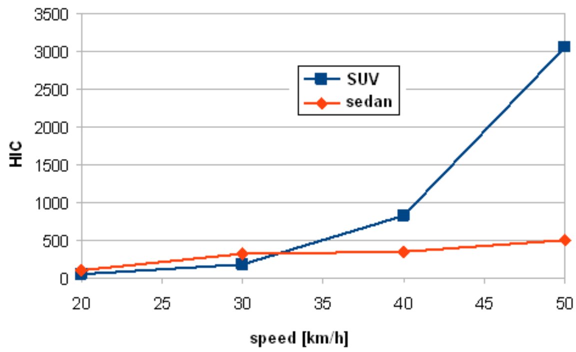

Fig. 13: comparison SUV – sedan for HIC in the telescoping.

3.2.2 Comparison with other results

Impact simulations SUV - teenage pedestrian are executed in [24], by the multibody software MADYMO. The teenager is in frontal/rear position regard to SUV; no distinction is made between frontal or rear position, so that fig. 14 shows the comparison with Visual Nastran 4D results of the rear position only, given that the difference with the frontal position is very small. Fig. 15 shoes the analogous comparison for the lateral position; the fact that the comparison is between teenage

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pedestrian (MADYMO) and teenage cyclist (VN 4D) has to be remarked.

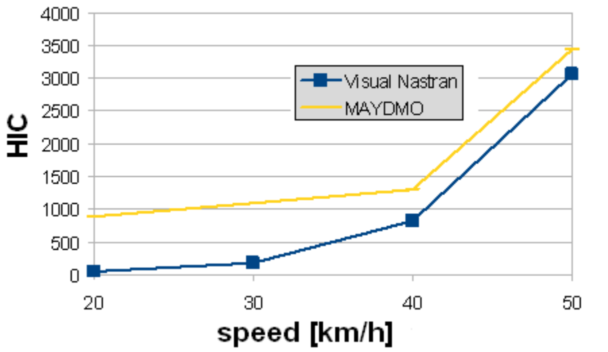

Fig. 14: comparison HIC for frontal/rear simulations in Visual Nastran and MAYDMO environments.

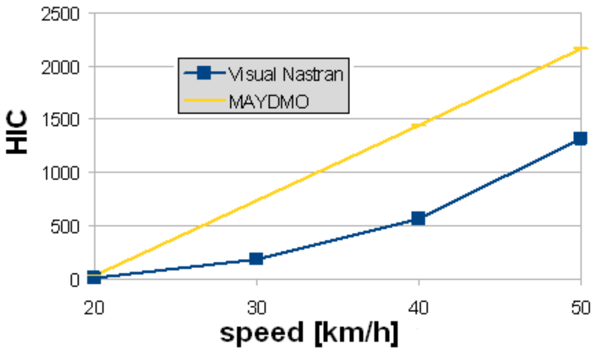

Fig. 15: comparison HIC for lateral simulations in Visual Nastran and MAYDMO environments.

Some considerations can come from this comparison:

- Front/rear and side simulations show that teenage cyclist has a greater chance to survive regard to a teenage pedestrian, as the HIC values are consistently below the survival values;
- Part of the impact energy is absorbed by the chassis of the bike with the same impact velocity SUV – teenage pedestrian in the front and side simulations.

3.3 Impact points location

Figure 16 shows the areas of the bonnet involved when the subject head hits the front of the SUV during the impact. The marking of the vehicle for identifying the areas (WAD) is done according to the directives EURONCAP.

Impact point dispersion is localized in all cases in the area of the WAD 1500 except for impacts at 20 km/h (WAD 1000). The dispersion of the points in the case of rear impact involves a larger area than the other cases. Furthermore, the analysis of the contact points allows obtaining a new confirmation of the accuracy of the values. The acceleration peaks, even very intense, generally are due to a collision against a rigid wall of the vehicle front.

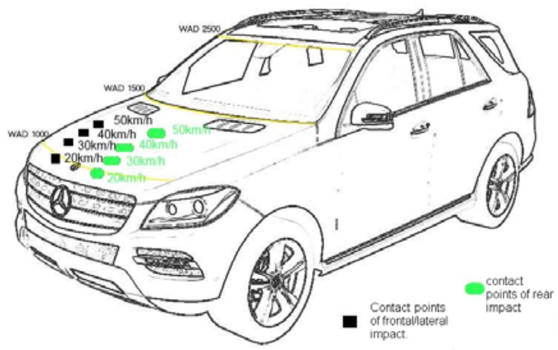

Fig. 16: Contact points head-SUV in the frontal, rear and lateral impact.

4 Conclusion

The aim of this work is not only to assess the damage caused in the event of accident, by analyzing the impact dynamic between SUV and bike. Above all the aim is to try and suggest possible improvements and solutions to increase the safety and limit the damage by the weaker person.

Simulations, and the results comparison with other analysis, show the importance of certain key elements such as: the height of the rider, the front profile of the SUV, the ground clearance, and the rigidity of the parts that come in contact with the cyclist at the moment of impact.

Simulations show like the position of the cyclist at the time of the accident can affect the outcome of the impact: telescoping is more dangerous than the frontal impact; in fact HIC values obtained from simulations are higher than the frontal impact, because the head of the cyclist hits immediately the bonnet of the SUV. It overwhelms the cyclist and not the bike, so that the bike does not absorb the shock, unlike what happens in the other cases.

Different thing happens in the frontal and side impact. In these cases SUV affects primarily the bike that absorbs the shock. Impact point is highlighted in the vicinity of the wheel and the cyclist falls in a different way, since he is located at a few greater distance (seemingly irrelevant).

In all the simulations, HIC values are lower than 1000 (limit imposed by the rules); this is possible because a good part of the impact is absorbed by the bicycle and not by the body of the cyclist. The speed of 50 km/h can be considered critical, given that HIC assumes very high values.

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However the principal result of this paper is that the front shape of the vehicle has great importance to limit the injury to the cyclist that is the more weak part in the impact.

The use of multibody virtual method as the for the simulations is beneficial, given that it implements numerous adaptations, especially if one considers that the prototypes existed only as CAD drawings. In this way, the study of SUV, which must necessarily pass imposed tests of approval, is certainly easier and can lead to reliable results, reducing also the excessive costs.

This kind of simulation has not only an impact on costs, but also on the safety, thanks to tests of the effectiveness of passive and active devices for a better performance.

Deformable bumpers improve the protection of the cyclist because they mitigates the violence of the impact on the legs; protection increases if the shock is applied to the lower part of the leg, away from the knee, and if the crash forces are spread over a greater length of the leg. It occurs in the lateral crash.

Front edge of the bonnet can be improved by eliminating all the unnecessary rigid structures. Finally, the ability of the bonnet to rise during the crash improves the protection of the cyclist (or pedestrian) head; this can be implemented by leaving greater space between the bonnet and the engine block.

Finally, making use of proximity sensors, the presence of a cyclist on the trajectory of the vehicle can be determined more effectively and rapidly in communicating the data to a control unit that provides to implement a braking in closer times than those obtainable from human reflexes, in order to reduce more effectively the speed at the instant of the crash.

References:

[1] G. Virzi' Mariotti, S. Golfo, Determination and analysis of the head and chest parameters by simulation of a vehicle–teenager impact, *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*; Vol 228(1), 2014, 3–20

[2] G. Bellavia, G. Virzi' Mariotti, Multibody Numerical Simulation For Vehicle – Pedestrian Crash Test, *Ingegneria dell'autoveicolo ATA* Vol. 62, 11/12, 2009, pp 40-49 ISSN: 0001-2661;*XXI Science and Motor Vehicles 2007, JUMV international Conference with Exhibition*, 23-24 April 2007, Belgrade, Serbia, ISBN 978-86-80941-31-8

[3] G. Bellavia, G. Virzi' Mariotti, Development of an Anthropomorphic model for Vehicle – Pedestrian Crash Test, *Ingegneria dell'Autoveicolo,* vol. 62, n. 3/4 marzo aprile 2009, pag. 48-56; *XXI Science and Motor Vehicles 2007, JUMV international Conference with Exhibition,* 23-24 April 2007, Belgrade, Serbia, ISBN 978-86-80941-31-8

[4] A. F. Williams, J. Tison, Motor vehicle fatal crash profiles of 13-15-year-olds, *Journal of Safety Research*, 43, 2012, 145-149

[5] M. Kleinberger, E. Sun, R. Eppinger, S. Kuppa, R. Saul, Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems, *National Highway Traffic Safety Administration*, September 1998

[6] J W Watson, Investigation of Cyclist and Pedestrian Impacts with Motor Vehicles using Experimentation and Simulation, *PhD thesis*, Cranfield University, feb. 2010

[7] Y. Peng, Y. Chen, J. Yang, D. Otte, R. Willinger, A study of pedestrian and bicyclist exposure to head injury in passenger car collisions based on accident data and simulations, *Safety Science* 50 (9), 2012, 1749-1759

[8] Q. Chen, Y. Chen, O. Bostrom, Y. Ma, E. Liu, A comparison study of car-to-pedestrian and car-to-E-bike accidents: Data source: The China in-depth accident study (CIDAS), *SAE Technical Paper* 2014-01-0519, 2014, doi:10.4271/2014-01-0519.

[9] M. X. Xu, Reconstruction analysis of car-electric bicycle side impact accident based on PC-Crash, *Journal of Chang'an University (Natural Science Edition),* ISSN: 1671-8879, 33, 1, 2013, 85 - 88+99

[10] N. Chaurand, P. Delhomme, Cyclists and drivers in road interactions: A comparison of perceived crash risk - *Accident Analysis and Prevention* 50, 2013, 1176–1184

[11] G. Milne, C. Deck, N. Bourdet, (...), R. P. Carreira, R. Willinger, Assessment of bicyclist head injury risk under tangential impact conditions, *2013 IRCOBI Conference Proceedings - International Research Council on the Biomechanics of Injury*, pp 735-746.

[12] T. Maki, J. Kajzer, K. Mizuno, Y. Sekine, Comparative analysis of vehicle–bicyclist and vehicle–pedestrian accidents in Japan, *Accident Analysis & Prevention,* Volume 35, Issue 6, 2003, 927–940

[13] J. Ki Kim, S. P. Kim, G. F. Ulfarsson, L. A. Porrello, Bicyclist injury severities in bicycle–motor vehicle accidents, *Accident Analysis & Prevention* 39, 2, 2007, 238–251

[14] Y. Peng, Y. Chen, J. Yang, D. Otte, R. Willinger, A study of pedestrian and bicyclist exposure to head injury in passenger car collisions based on accident data and simulations, *Safety Science* 50, 9, 2012, 1749–1759

[15] F. Carollo, G. Virzì Mariotti, E. Scalici - Injury Evaluation in Teenage Cyclist-Vehicle Crash by Multibody Simulation - *WSEAS Transactions on Biology and Biomedicine*, ISSN/E-ISSN: 1109-9518/2224-2902, Volume 11, 2014, Art. 26, pp. 203-217

[16] F. Carollo, G. Virzi' Mariotti, E. Scalici - Biomechanics Parameters in the Vehicle-Cyclist Crash with Accident Analysis in Palermo – *Recent Advances in mechanical Engineering, NAUN Conference ECME'14*, Firenze 22-24 November 2014, pp 139-148, ISBN: 141 978-960-474-402-2.

[17] M. van Schijndel, S. de Hair, C. Rodarius, R. Fredriksson, Cyclist kinematics in car impacts reconstructed in simulations and full scale testing with Polar dummy, *IRC-12-85 IRCOBI Conference* 2012, pp 800-812

[18] R. Fredriksson, E. Rosén, Priorities for Bicyclist Protection in Car Impacts – a Real life Study of Severe Injuries and Car Sources, *IRC-12-85 IRCOBI Conference* 2012, pp 779- 786

[19] D. T. Detweiler, R. A. Miller, Development of a sport utility front bumper system for pedestrian safety and 5 mph impact performance. *Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles*, Paper Number 01-S6-W-145, Amsterdam, The Netherlands, June 4-7, 2001.

[20] F. Carollo, Analisi di alcuni parametri biomeccanici nello studio d'impatto auto bici, *graduate thesis*, Palermo, 2014

[21] E. van Hassel, R. de Lange, Bicyclist safety in bicycle to car accidents: an inventory study *TNO report 06.OR.SA.031.1/RDL*, August 17, 2006.

[22] S. Mukherjee, A. Chawla, D. Mohan, M. Singh, R. Dey, Effect Of Vehicle Design On Head Injury Severity And Throw Distance Variations In Bicycle Crashes - *Proc. of TRIPP conference*, New Delhi Paper no: 07-0467

[23] O. Fanta, K. Jelen, H. Purš, Interaction between Cyclist and Car during Broadsideand Confrontation with Pedestrian Throw Formulas Multibody Simulation -*Transactions on Transport Sciences* V. 3, N 3, pp. 99-106. DOI: 10.2478/v10158-010-0014

[24] C. K. Simms, D. P. Wood, Pedestrian risk from cars and sport utility vehicles – a comparative analytical study, *Proc. ImechE Part D J. Automobile Engineering*, Vol. 220 (8), 1085-1100 (2006)

[25] K. U. Schmitt, P. F. Niederer, M. H. Muser, F. Walz, *Trauma Biomechanics: Accidental injury in traffic and sports*, Springer London, 2007

[26] A. M. Nahum, J. W. Melvin, *Accidental Injury: Biomechanics and Prevention*, Springer, London, 2001

[27] S. Battaglia, I. Damiani, G. Virzi' Mariotti, *La bicicletta sportiva. Caratteristiche geometriche ed inerziali. Simulazione dinamica*, ISBN 88-548-0801-6, Aracne, Roma, 2006.

[28] F. Giannitrapani, G. Virzi' Mariotti, Dynamic Analysis of Motorcycle Behaviour on the Road with Steering Plate Structural Optimisation, *EAEC Conference*, Belgrade, 30th May – 1th June 2005