

PEDESTRIAN KINEMATICS – A DETAILED STUDY FROM THE ASPECSS PROJECT

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ABSTRACT

This study aims at providing insight on pedestrian kinematics during vehicle impact for the following variables: pedestrian size, position and posture as well as vehicle related variables like shape, speed and pre-crash braking. It is part of the work conducted within work package 3 “Injury assessment: data for construction of injury risk curves” of the European project “Assessment methodologies for forward looking Integrated Pedestrian and further extension to Cyclists Safety Systems” (AsPeCSS). The results of this subtask are used within the project to adapt current testing procedures towards more realistic approaches based on changes introduced into accident circumstances by today's smarter car designs.

First, a trend study was carried out using simplified vehicle models based on “Advanced PROtection SYStems” (APROSYS) work in MADYMO using the MADYMO ellipsoid human body models. In a second step, different detailed finite element (FE) and multi body (MB) vehicle models of recent cars were investigated using MADYMO and the MADYMO facet pedestrian model as well as LS-Dyna and the “Total Human Model for Safety” (THUMS) human body models.

Approximately 1700 different simulations were done to study the general effect on head impact speed, angle and wrap around distance (WAD) when varying input parameters like vehicle shape and speed but also pedestrian size, postures and orientations towards the car.

The second study confirmed the trends found with the simplified car models and provided more detailed information on the head and upper leg impact conditions. Moreover, some general effects introduced by simplified models were evaluated and corrected using the results of the detailed vehicle studies. Additional parameter variations as pitching and braking of the car for different initial

speeds or lateral impact position provide a complete picture of pedestrian impact kinematics. It was found, that not only vehicle speed and pedestrian size determined how and where the head of the pedestrian hits the car but also differences in posture or vehicle pitching due to pre-crash braking are influencing the kinematics, the impact conditions as well as the potential injury risk significantly. A running child can hence for example hit a car differently than a walking one. Also, significant differences were found depending on whether the head impact occurs on a bonnet top or the windscreen area.

Combining all three simulation studies the influence of active safety systems on the pedestrian kinematics during car to pedestrian impacts has been estimated. The combined use of generic and actual car models leads to results that are valid for the current and future vehicle fleet. Information on pedestrian kinematics is needed to propose updates to current pedestrian regulations and consumer tests in line with the development of integrated safety systems.

INTRODUCTION

The objective of the AsPeCSS project is to contribute towards improving the protection of vulnerable road users (VRU), in particular pedestrians and cyclists by developing harmonized test and assessment procedures for forward looking integrated VRU safety systems. The outcome of the project will be a suite of test and assessment methods as input to future regulatory procedures and consumer rating protocols. Implementation of such procedures / protocols will enforce widespread introduction of such systems in the vehicle fleet, providing another step forward to further reduction of fatalities and seriously injured among these VRUs.

The work presented in this paper was conducted within the AsPeCSS work package 3 “Injury assessment: data for construction of injury risk curves”. This WP conducts simulation and testing activities generating input data required for the construction of injury risk functions. Pedestrian impact kinematics were studied using human body models (THUMS and MADYMO models) to generate impactor test conditions for the upper legform and head impactor tests. Using these conditions an extensive test program (including virtual testing) will be performed in a next step generating impactor test results representing pedestrian impacts for a range of speeds and conditions for cars with different passive safety protection levels and different types of cars. The data from these impactor tests will then be transformed into injury risk using injury risk functions available in the literature.

SIMULATION MODELS

Human body models (HBMs): For the simulations, 3 different kinds of human body models were used depending on the vehicle models investigated:

- MADYMO ellipsoid pedestrians of different sizes [4] [8] (see *Figure 1*) for the trend study
- MADYMO facet 50th percentile male pedestrian [10] [8] (see *Figure 1*) for the study using a detailed MADYMO car model
- THUMS 6 years old child and THUMS 50th percentile male [12][13][14] (see *Figure 2*) for the study using detailed LS-Dyna FE car models

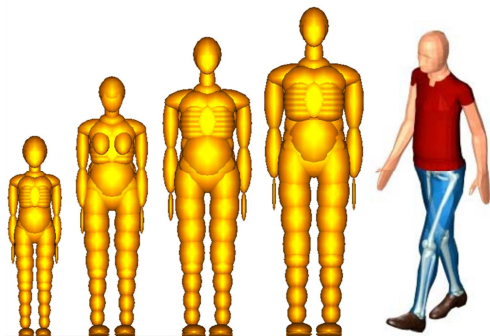


Figure 1. MADYMO ellipsoid pedestrian models. From left to right: 6 year old child, 5th female, 50th male, 95th male. And MADYMO facet pedestrian model in walking position



Figure 2. THUMS FE pedestrian models: 50th male in walking position and 6 year old child in running position

Vehicle models – Trend study: The vehicle models used for the trend study are simplified models (see *Figure 3*) that consist of 8 different planes representing the most important structures of a vehicle front. These models were initially developed within the European 6th framework project APROSYS [2] and further adapted within [11].

The stiffness of the vehicle front and bonnet has been based on the average force - deflection profiles as developed within [2]. The windscreen stiffness has been estimated and adapted based on windscreen impact tests performed at TNO as presented in [11]. All stiffness's are kept the same for all investigated car fronts so the results will not be influenced by a combination of change in geometry and stiffness's, but by change in geometry only. Also no braking or pitching was used. The mass of all vehicle models was set to 1300 kg based on findings from [1] [2].

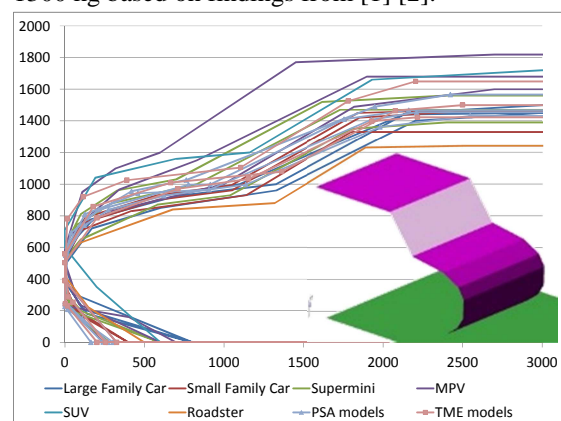


Figure 3: Vehicle contours based on [1], [2] and [11] (left) and example of resulting MADYMO model (right)

In total, 18 vehicle contours were defined for the simulations. These 18 contours define upper and lower boundary as well as median contour of the following vehicle classes:

- Large Family Car (LFC)
- Small Family Car (SFC)
- Supermini (SM)
- Multi-Purpose Vehicle (MPV)
- Sports Utility Vehicle (SUV)
- Roadster (RS)

No RS is used for the detailed model studies.

Therefore, the results from these RS profiles are merged together with the SM profile results when being compared to findings from the detailed vehicle model studies. The production year of the car fronts chosen from APROSYS varies from 1994 to 2004 with most cars from 1999 / 2000.

Concerns were raised at the beginning of the project, that these car fronts might be too old to be able to cover the current car fleet on the road properly. Therefore, the centerline of several new car fronts from the different vehicle classes from 2 participating OEMs were checked against the chosen profiles. It was found, that those new car fronts matched the ones based on [2] still reasonably well. It can hence be assumed that the models chosen for this trend study do still cover a wide range of not only older but also recent realistic car fronts.

Vehicle models – detailed study: Two studies were conducted using detailed vehicle models. Study 1 used a facet vehicle model build in MADYMO representing an LFC, whereas in Study 2 simulations were carried out against 3 vehicle models representing an SFC, SM/RS and SUV built in LS-Dyna. All vehicles models used within these two studies were well validated for pedestrian impact and representing actual recent car models.

SIMULATION MATRIX

The parameters chosen for variation as well as their range were based on input retrieved from WP1 “accident analysis” as well as pragmatic considerations like speed limits or availability of models. Within WP1 several sources of accident data to define accident scenarios which are statistically more relevant in EU were analyzed. The most relevant accidents can be characterized as follows:

- Situations where pedestrian was struck by vehicle when crossing road

- Vehicle classes: most representative by European accident data (1. SFC, 2. SM, 3. LFC, 4. SUV and MPV)
- Walking adult and running child pedestrians
- Vehicle speed: covering a range of impact speed, at least from 25 to 40 kph.

Not all these parameters can be described in a statistically meaningful way by investigations conducted in WP1, and some of them cannot be practically addressed by available simulation technology (for example, both driver and vehicle reaction to forthcoming impact).

Some choices were made in terms of parameters setup in T3.1 simulation plan. First of all, the vehicle was assumed to proceed on a straight trajectory with constant speed or constant deceleration at impact, and no driver reaction is following the impact. As for the pedestrian, only standard body types were considered (6YO, AF05, AM50, AM95).

The general simulation set-up and overall parameter variation is presented in *Figure 4*.

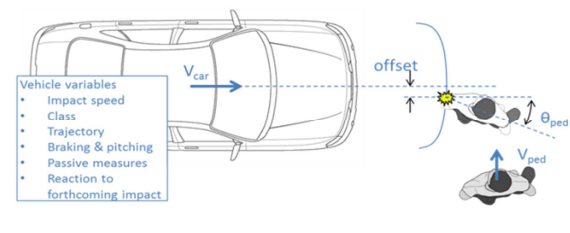


Figure 4: General simulation set-up and overall parameter variation

Trend study: The trend study was conducted in 3 steps with different parameter sets for variation. Due to the simplicity of the car models, runtime for the simulations was low allowing for a large number of simulations. The following parameter variations were considered within the different steps:

Step A: different pedestrian sizes

- 4 pedestrian models (6YO child, 5th female, 50th and 95th male)
- 18 simplified car models (based on [2] and [11])
- 5 car velocities (20 / 30 / 40 / 50 / 60 km/h) and 3 additional car velocities for 6YO child and 50th male (25 / 35 / 80 km/h)
- 1 pedestrian stance (left leg front)
- 1 pedestrian to car orientation (0 degrees = perpendicular to car)

Step B: 50th percentile male

- 1 pedestrian model (50th percentile male)

- 18 simplified car models (based on [2] and [11])
- 5 car velocities (20 / 30 / 40 / 50 / 60 km/h)
- 2 walking pedestrian stances (left leg front / right leg front)
- 3 pedestrian to car orientations (-15 / 0 / 15 degrees)

Step C: 6 year old child

- 1 pedestrian model (6YO child)
- 18 simplified car models (based on [2] and [11])
- 5 car velocities (20 / 30 / 40 / 50 / 60 km/h)
- 3 pedestrian stances (left leg front / right leg front / running)
- 3 pedestrian to car orientations (-15 / 0 / 15 degrees)

This matrix resulted in a total of 1710 simulation runs, of which 1683 could be used for further analysis. The remaining simulations aborted due to numerical instabilities and were neglected for the analysis. The posture used for the running child (see also *Figure 2*) was established based on visual examples of running children found on the internet as no standardized “running child posture” exists so far.

Detailed vehicle model study 1: In this study, only one pedestrian model (MADYMO 50th percentile facet male) and one car model representing a LFC were investigated. The following parameters were varied for a full factorial simulation matrix resulting in 32 simulations:

- Walking stance 50th male pedestrian (struck (left) or non-struck (right) leg front)
- Lateral position of pedestrian (centerline or corner impact)
- Vehicle speed (20 or 40 km/h)
- Vehicle braking (0 or 1g)
- Vehicle pitch (0 or 3deg)

Detailed vehicle model study 2: In this study, two pedestrian models (THUMS 50th percentile male and 6 year old child) and three car models were investigated, based on the priorities from WP1 and the findings from the trend study (e.g. pedestrian orientation not affecting pedestrian kinematics as much as leg positioning). The orientation of the pedestrian towards the car was kept perpendicular and the impact assumed to occur on the centerline of the car for 96 simulations within this study:

- Walking stance 50th male pedestrian (struck (left) or non-struck (right) leg front)
- Running stance 6 year old child (struck (left) or non-struck (right) leg front)
- Vehicle class (Mini / SFC / SUV)

- Vehicle speed (20/30/40/60 km/h)
- Vehicle in constant speed or full braking and pitching conditions

The vehicles chosen for the study account for three clearly different front end shapes. Height of BLE ranges from 710mm in case of SFC, to 757mm of SM, to 854mm of SUV.

RESULTS

Output parameters that were investigated within all three studies related to the pedestrian kinematics were as follows:

- Head WAD / impact location
- Head impact angle
- Head impact speed

In addition to that, also information on the upper leg impact angle as well as speed was gathered for the detailed vehicle study 2.

In general it could be found, that for the head output parameters besides the choice of pedestrian the vehicle speed is most influential parameter.

Trend study: For all pedestrians the head impact location (WAD) rose with increasing vehicle speed. No general influence of the pedestrian orientation towards the car could be found.

The 6 year old child head always hit the bonnet of the car, never the windscreen. The 95th percentile male hit the bonnet in approximately 6% of all simulated conditions but only if the initial speed of the car was 30km/h or less. Two cases were found where this pedestrian hit its head on the car roof, in all other cases the first impact was located on the windscreen.

The 50th percentile male hit a car either on the windscreen, or on the upper bonnet plane. The 5th female results were in-between those of the 50th male and the 6 year old child. As expected it could be seen, that the taller the pedestrian, the higher the head impacted on a car (under similar boundary conditions).

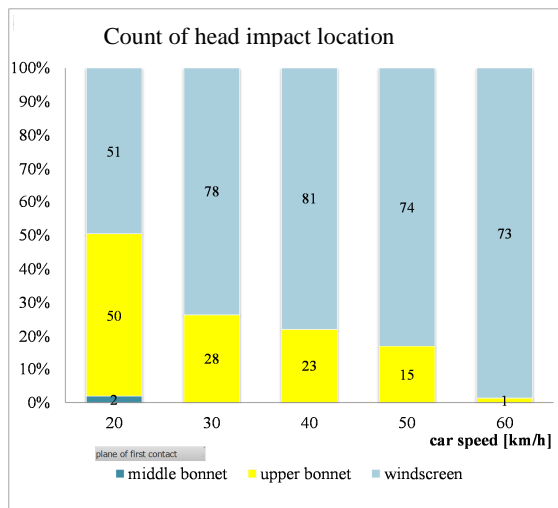


Figure 5: 50th male – head impact location over vehicle speed (Step B results)

When checking the influence of the impact speed on the head impact location for the 50th percentile male, it could be seen that there is a significant increase of impacts on the windscreen when increasing the car speed from 20 to 30 km/h (simulations considered from all vehicle shapes, see Figure 5). When increasing the car speed even further, the portion of hits to the bonnet diminished almost to zero. This indicates that hits on the bonnet are mainly found on the upper most part of the bonnet and proceed over the windscreen base towards the middle of windscreen with increasing speed.

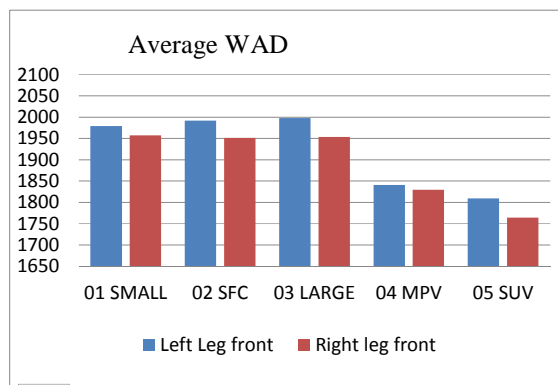


Figure 6: 50th male – influence of stance on average WAD per vehicle class

Though the orientation of the pedestrian towards the car was not found to influence the head impact location significantly, an influence of the pedestrian stance could be found for the 50th percentile male (see Figure 6). If the struck-side (left) leg was positioned to the front, an increase of the average WAD could be seen throughout all defined vehicle classes. Only for the MPV the difference was negligible. For the 6 year old child no influence is found for different walking stances, only for changing the walking to a running stance.

It was found, that a running child would generally hit the bonnet lower than a walking one.

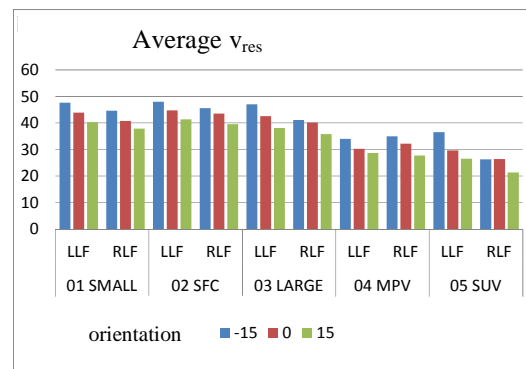


Figure 7: 50th male – influence of stance and orientation on average head impact velocity per vehicle class (Step B results)

The head impact speed is highly influenced by the car speed. The higher the speed of the car, the higher the head impact speed. Also, an influence of the orientation of the pedestrian can be seen when looking at the average resultant head impact speed. From Figure 7 several conclusions can be drawn for the average head impact speed (for the 50th percentile male pedestrian):

- It is higher for small cars compared to larger cars
- It is higher for left (struck-side) leg front compared to right leg front
- It is for both stances highest if the pedestrian is heading under 15 degrees towards the car and lowest if the pedestrian is heading under 15 degrees away from the car.

The difference between the vehicle classes is less significant for the 6 year old child. Also, the average head impact speed is lower for the child compared to the average male.

No head impact below WAD 1000 was observed for any of the car shapes. No child head impact was established above WAD 1500 and no 50th percentile male head impact below WAD 1500. For the 6 year old child and the 50th percentile male pedestrian the current Euro NCAP WADs hence match very well. The 5th female results form a good transition between both pedestrian sizes, though most hits are established in the adult rather than the child area.

The only pedestrians that hit their head higher on a car than WAD 2100 are the 95th percentile male in general and the 50th percentile male for a few cases when the car speed rises above 40 km/h. It can be concluded, that pedestrians up to a size of a 50th

percentile male are well covered within the current Euro NCAP pedestrian test protocol [3] by the chosen WADs.

For the 95th percentile male, only 23% of all head impacts fall below WAD 2100. If the speed of the car is 30 km/h or higher, the head of this pedestrian is likely to hit the car at more than WAD 2100. It could hence be argued, that in order to cover also pedestrians taller than average, an increase of the maximum WAD beyond WAD 2100 could be beneficial.

From the step A simulations which considered all pedestrian sizes head impact speeds were gathered. From *Figure 8* it can be seen, that for car speeds up to and including 50km/h a head impact speed of 40 km/h covers 92% of the impacts for the 6 year old child. For all adults, the coverage is however much lower (60 to 70%). When looking into this issue in more detail it can be seen, that for the 6 year old child the head impact speed hardly ever rises above the initial car speed. Also, the first contact between head and car is always established on the bonnet for this pedestrian. This is much different for the adult pedestrians which are also able to hit the windscreen.

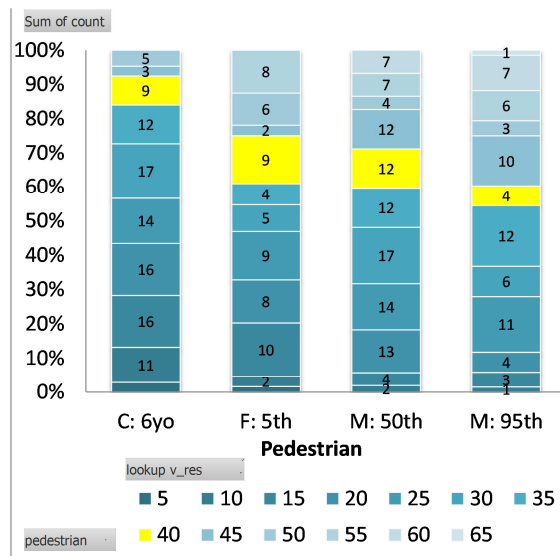


Figure 8: head impact speed distribution per pedestrian, only car speeds up to 50 km/h considered

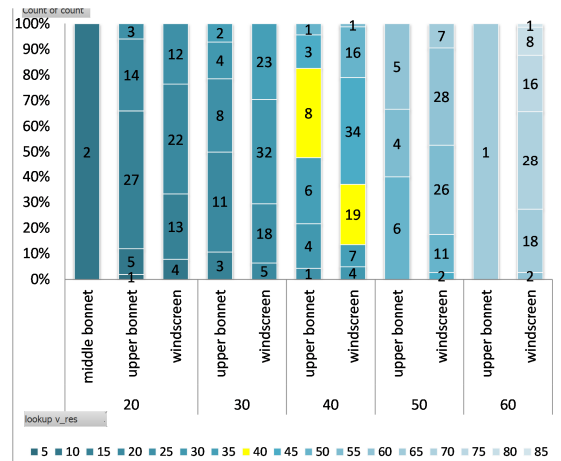


Figure 9: head impact speed [km/h] of 50th percentile male (Step B simulations) over initial car speed [km/h] and first plane contacted by head

Figure 9 shows the head impact speed distribution for the 50th percentile male over the initial car speed. Additionally, the car speeds are split by first head impact location. The following conclusions can be drawn:

- The higher the car speed:
 - the more likely the head impact speed is higher than the car speed
 - the more likely the head hits the windscreen rather than the bonnet
- head impact speeds are higher on the windscreen compared to on the bonnet
- head impacts on the bonnet are well covered with an impact speed of 40 km/h – 99 out of 119 hit the bonnet with an impact speed not higher than 40 km/h. Considering only car speeds up to 40 km/h, a head impact speed to the bonnet of 40 km/h covers even up to 96% of the occurring impacts.
- For head impacts on the windscreen, only 45% (159 out of 357) occur with a speed lower or equal to 40 km/h. Raising the head impact speed on the windscreen to 50 km/h would increase the coverage to 62% (all car speeds considered). Considering only car speeds up to 40 km/h, a head impact speed to the windscreen of 40 km/h and 50 km/h covers up to 75% and 99%, respectively. A higher head impact speed for windscreen impacts could therefore be beneficial to achieve similar coverage as for bonnet impacts.

In literature similar trends can be found for PMHS tests with crash conditions representing a centerline pedestrian impact at 40 km/h. [6], [7] and [9] found that the head impact speed ranged from 68% to 146%, with a tendency for lower values for bonnet impacts compared to windscreen impacts. The hypothesis that was set up in these studies is that an

higher angle of the windscreen results in a higher head impact speed as the neck cannot limit the head motion to the same extend as in a bonnet impact.

Detailed vehicle model studies: From the detailed vehicle studies no results were obtained that were contradicting to what was found in the trend study. For detailed study 1 pitching was investigated separately from braking, i.e. all vehicles in the field will automatically show pitching due to braking, but depending on vehicle suspension stiffness (and other vehicle parameters) the observed level of pitching can vary from car to car. Furthermore, the effect of braking is higher for lower speeds than for higher speeds, whereas pitching is simply changing the vehicle “geometry” for impact independent from speed. By separating the effects of braking and pitching, it can be analyzed whether braking or pitching effect is bigger and how the two compensate each other.

Starting the analysis WAD, the overall picture for different velocities was a bit fuzzy. Especially the effects of braking and pitching were not homogeneous. So, isolated analysis for different speed levels was performed.

Starting at 20 km/h, *Figure 10* shows the pareto chart for WAD at 20 km/h. Only braking, pitching, pedestrian position and pedestrian stance have significant influence on WAD. Comparing decreases with braking and pitching influence at 20km/h it is obvious, that braking is more significant in this case.

In *Figure 10* the influence of the selected input paramteres (vehicle braking, pitching, lateral pedestrian position and pedestrian stance) on the WAD of the 50th percentile pedestrian is shown for 20 km/h. It can be seen, that WAD decreases with braking, but increases with pitching. However, for the 20km/h simulations and for the given pitch angle of 3° braking has more influence than pitching. Therefore, the combined braking+pitching is decreasing WAD. Looking to the other parameters, WAD increases for corner position and for left leg rear (LLR).

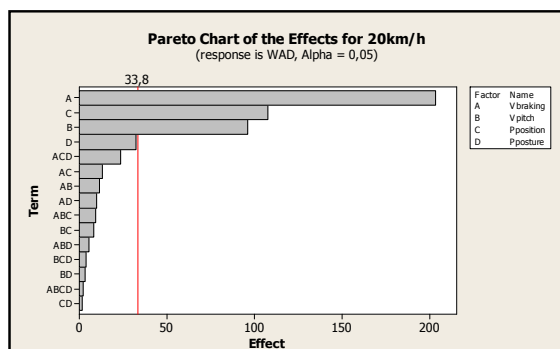


Figure 10: Pareto chart for 50th percentile male head WAD at 20 km/h

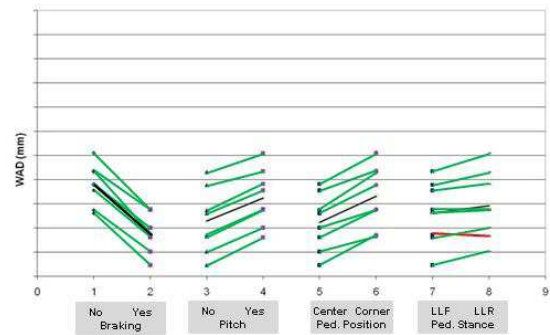


Figure 11: Influence of selected input parameters on 50th percentile male head WAD at 20 km/h

The same analysis for the 40kph simulations shows some significant differences. *Figure 12* shows the pareto chart for 40 km/h, pitching, pedestrian stance, pedestrian position and braking have significant influence on WAD. It is obvious, that the pitching effect is significantly higher than braking here.

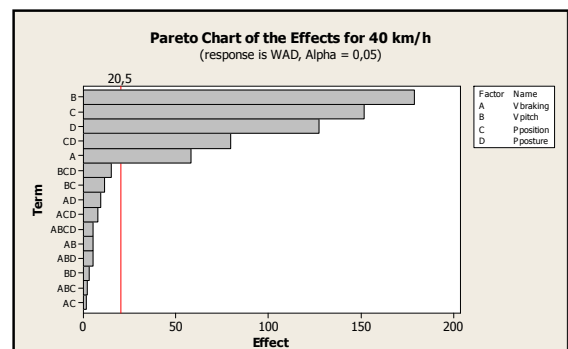


Figure 12: Pareto chart for 50th percentile male head WAD at 40 km/h

Looking to the individual effects in *Figure 13* it can be seen that braking is decreasing WAD whereas pitching is increasing WAD to a higher extend. So, for 40 km/h pitching is more dominant and therefore the overall effect of braking combined with pitching is increasing WAD. Looking to the other parameters in *Figure 13* corner position and LLR are also increasing WAD.

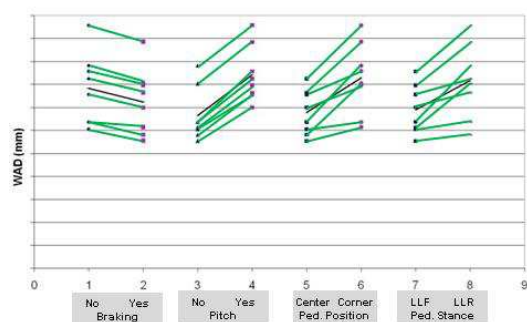


Figure 13: Influence of selected input parameters on 50th percentile male head WAD at 40 km/h

Similar analysis was done for head impact angle and head impact velocity. The general trends as observed in the WAD analysis could also be found there. Besides the impact speed itself, braking and pitching are the most influencing parameters, with pitching being more dominant for increasing speeds.

As the number of simulations conducted in detailed studies is limited and not sufficient to use for statistical trend analysis, the kinematics of pedestrians in detailed models can be used further to confirm the validity of the results from the trend study presented above.

As an example, the kinematics of AM50 impacting small family car (SFC) at 40kph with left leg forward was compared in Figure 14.

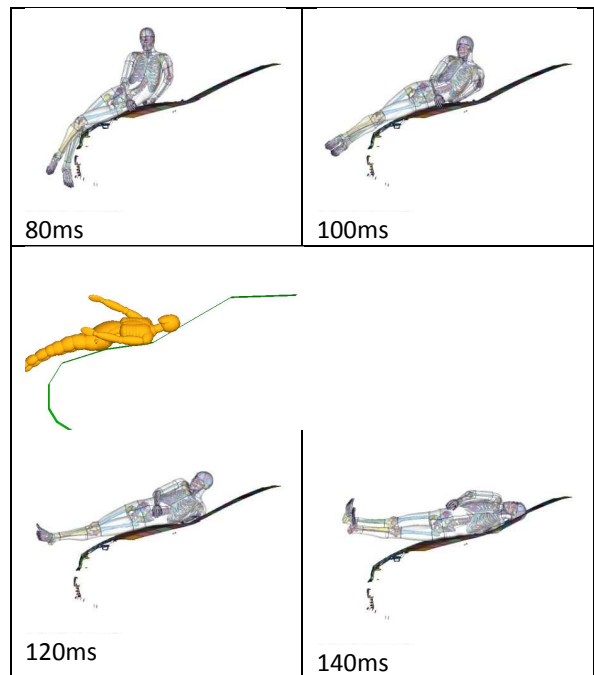
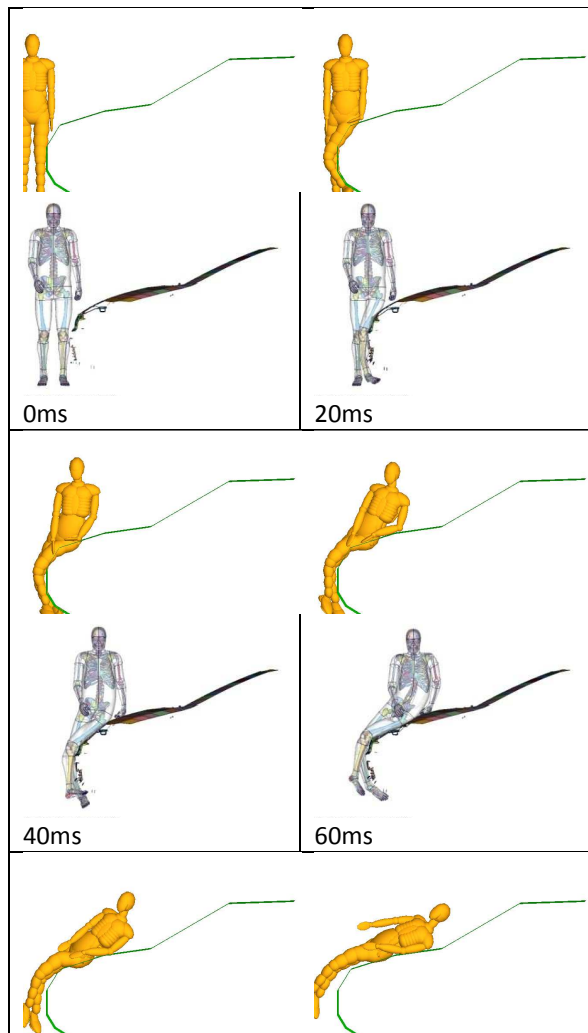


Figure 14 Kinematics of AM50 adult impacting a Lower medium class (SFC) vehicle at 40kph; comparison of simplified (upper) and detailed (lower) simulation

At the very beginning of the impact, the leg on the struck side is contacting the bumper and the femur starts to rotate to follow the shape of the car (time 0-30ms); this behavior is described in similar manner by simplified and detailed models. At around 40ms, the hip starts contacting the bonnet leading edge area, providing a higher force to the torso, which also starts to move (time 40-60ms); some differences start to appear at this point due to the simplified representation of hood shape and stiffness for the simplified model, which results in a different sliding of the hip over the bonnet compared to the detailed model. As a consequence, the torso of the simplified model rotates more and causes earlier impact of the head to the windshield (time 70-120ms). For the detailed model, the smooth shape of the hood and its realistic deformation allow the legs and hip to slide, which causes later torso rotation and head contact. With this mechanism, the head impact point is occurring at a more rearward position (cf. knee location at 100ms). This difference is expected to be mostly due to the characteristics of the simplified vehicle model, which has a simplified stiffness response and does not change its shape during the impact; the simplified model can be therefore considered as causing a systematic error on the trends which had to be accounted for when summarizing results.

Harmonization of the head impact results In order to identify the best set of input parameters for the impactor simulations and physical tests to be

conducted in the next step, the results of the trend study were combined with the results of the detailed vehicle studies. For this purpose, corridors were established from the trend study for different vehicle speeds evaluating trends by means of weighted averages of the simulation results.

Probability corridors for maximum and minimum values were based on linear fitting of representative maximum and minimum results. These trends were then adjusted with the results from the detailed vehicle studies to account for systematic effect induced by simplified vehicle models.

In *Figure 15* and *Figure 16* the respective corridors can be found for the 50th percentile male as well as for the 6 year old child.

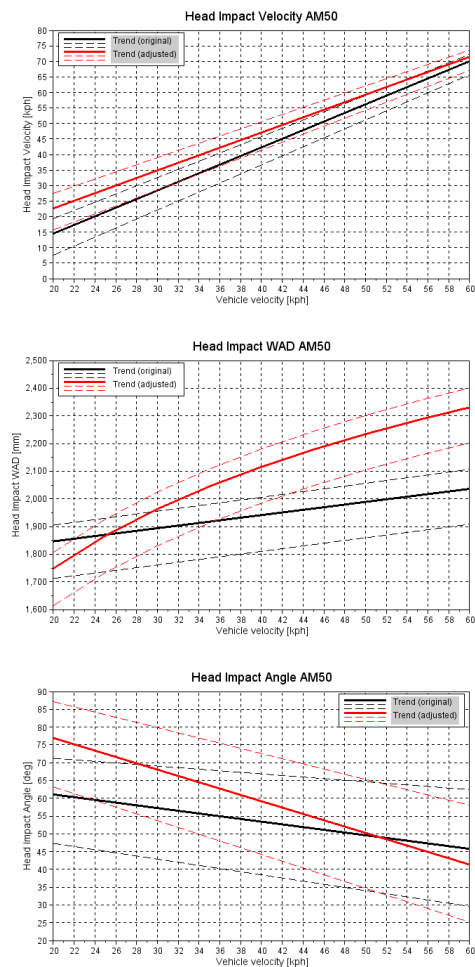


Figure 15: Probability corridors for head WAD, velocity and impact angle from the trend study (black) and adjusted by the detailed studies (red) for the 50th percentile male pedestrian.

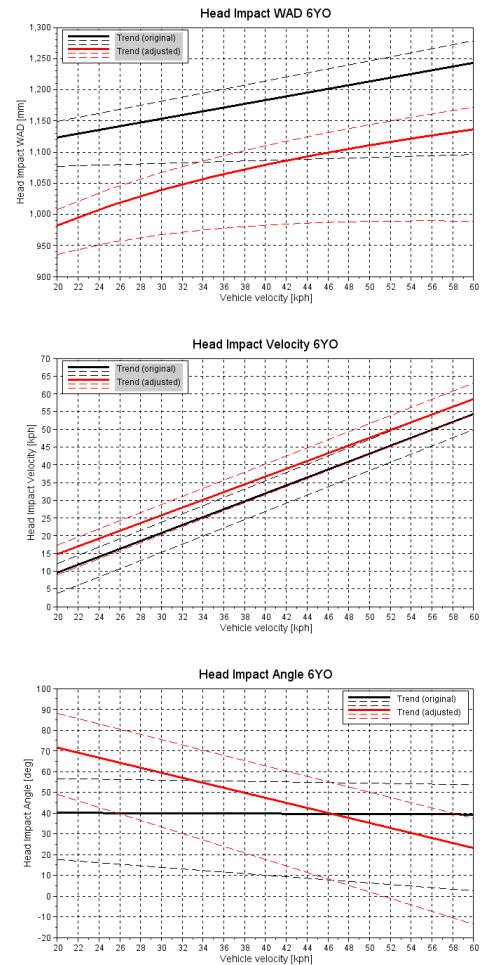


Figure 16: Probability corridors for head WAD, velocity and impact angle from the trend study (black) and adjusted by the detailed studies (red) for the 6 year old child pedestrian.

Main differences were found in **WAD evaluation**, where simplified models seem to underestimate the AM50 impact location for speeds greater than 25kph, when vehicle deformation tends to be significant. This mechanism has been explained above. The opposite effect was found in case of 6YO, but it should be remarked that detailed simulations were only considering running posture. The simplified 6YO simulations results are averaged with those from child pedestrians in walking conditions which were found to result in higher WAD. Moreover, in case of WAD, a significant improvement of trend fitting was observed when using logarithmic fitting rather than linear (R^2 correlation increased from 68.7% to 79.6% in case of AM50 results); that fitting suggests a tendency of head impact location to change much more at lower than higher impact speed.

Some difference can also be found for the trends of the head impact angle for the 6 year old child. The adjusted corridors are much more defined compared to the corridors from the trend study which are quite wide and basically showing not much influence of the vehicle speed at all. This can be explained when looking into the vehicle shapes. For the trend study 18 different contours were considered compared to 3 for the detailed vehicle studies.

From the trend study it can be seen, that the contour of the vehicle can have a major influence on the **head impact angle**. For vehicles with a high car front the impact angle can be almost 90 degrees as the head is not yet bending towards the car upon impact. For cars with a lower car front trends are similar as for an adult, though the absolute head impact angles are in general more shallow as can be seen exemplarily in *Figure 17*. This effect results in less pronounced corridors for the trend study and is much less apparent in the detailed study due to the limited amount in variation of the car fronts.

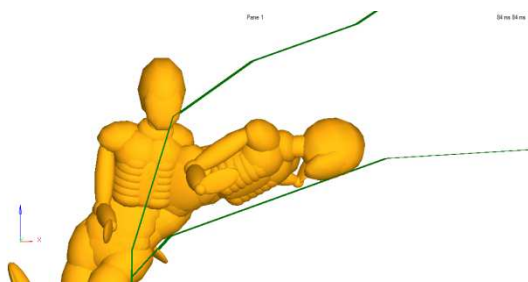


Figure 17: Example of the position of the head for a 6 year old child on different car fronts under similar boundary conditions

Trends found for **impact velocity** are quite consistent between simplified and detailed simulations, considering that the average results from detailed simulations almost fall in the probability corridors evaluated in the trend study.

Upper leg impact conditions Results for upper leg impact conditions were extracted from detailed study 2 only, therefore there was no need for harmonization; on the other hand, they depend on the actual vehicle used, and it is difficult to use them to define general trends. Setting impactor conditions equivalent to results from human body model simulation is not trivial due to femur configuration which is changing during the impact, see *Figure 18* and *Figure 19*. BLE impactor, on the other hand, has fixed impact location and angle, depending on vehicle BLE height and bumper lead [3].

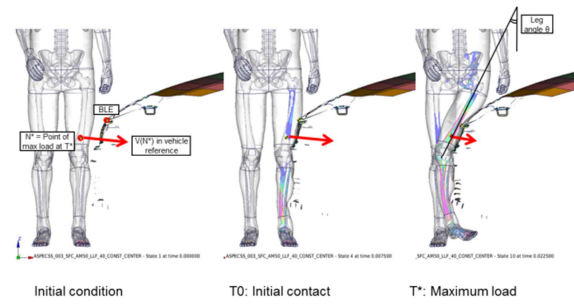


Figure 18 Upper leg impact kinematics; N^* is the point on femur subject to highest load; T_0 is time of first contact of N^* to the vehicle; T^* is time when N^* reaches maximum load.

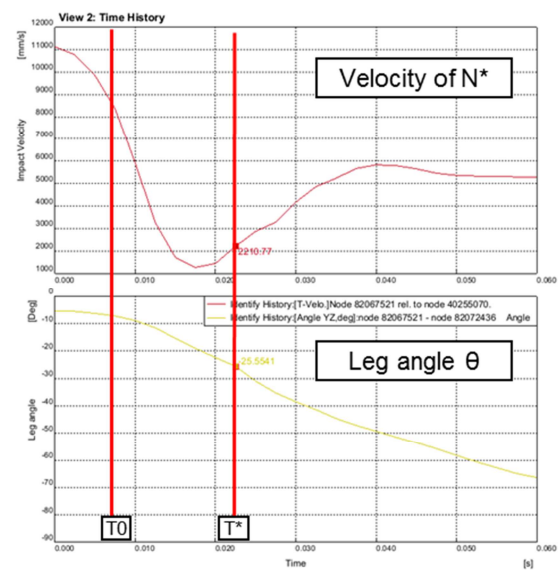


Figure 19 Time-histories of velocity of femur point with maximum load N^* (in vehicle reference) and femur angle θ

Taking into account the suggestions from [12] and [15], the criteria set to analyze parameters effect were:

- Velocity, which is set at initial impact conditions at time T_0
- Angle, which is set at femur maximum load
- Position, which should depend on vehicle geometry and location of maximum load on the femur

Setting equivalent impactor mass over the speed and impact conditions considered is still an issue. Euro NCAP suggests some energy criterion, which is based on 40kph impact speed [11]. On the other hand, some authors suggest to use just a fixed equivalent mass of 7.5 kg for the femur [12].

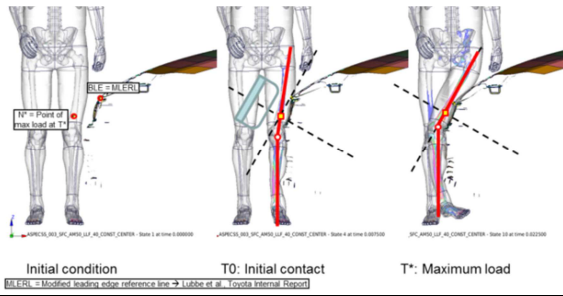


Figure 20 Proposed conditions for upper leg impactor setup in case of AM50 impacting SFC at 40kph.

As it can be observed from the sample case of AM50 impacted by SFC at 40kph (Figure 20), the location of most severe load might be quite different from BLE. That is a purely geometric descriptor, and it does not consider the actual properties of the vehicle front end. The proposed equivalent setup for the BLE impactor is summarized in Figure 21, where 511mm is the distance between knee and ground in THUMS 50th percentile adult model.

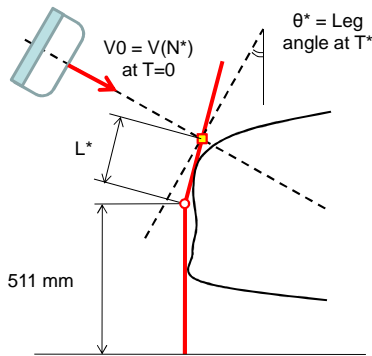


Figure 21 Proposed impactor setup

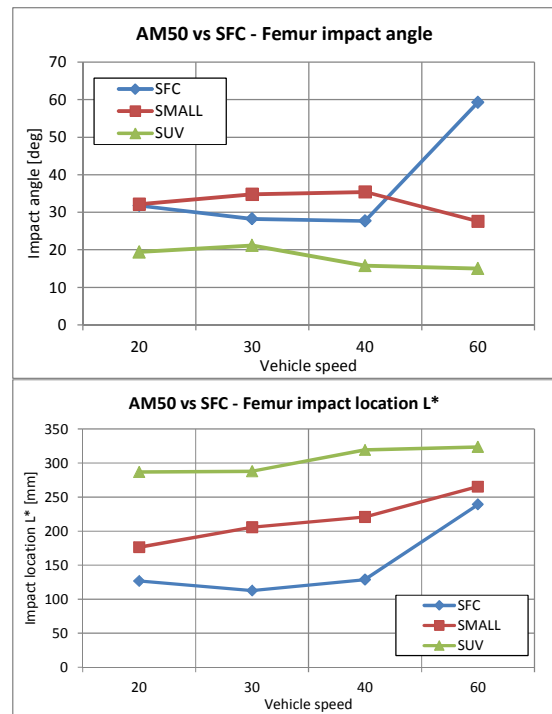
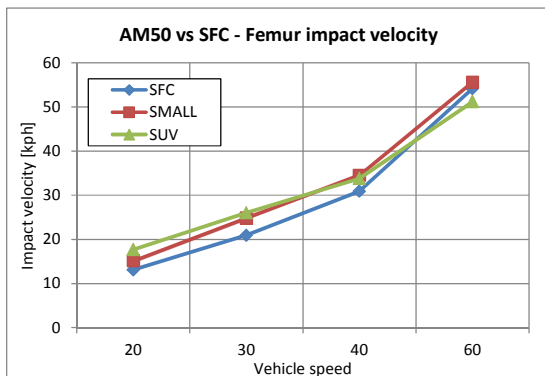


Figure 22 Upper leg impact conditions: impact velocity, angle and location of point N*

The results obtained from detailed simulations with AM50 model were summarized in Figure 22. Charts show a clear trend for impact velocity, but do not show clear trends for impact angle and location with vehicle velocity. The impact location seems to depend on BLE height, but the impact angle is not proportional to this geometrical descriptor, due to femur loading being dependent on actual front end stiffness. An interesting result comes from the case of SFC at 60kph: impact angle and location seem changing completely from results at 40kph and lower impact speeds. This effect can be explained by the actual vehicle behavior: bonnet deforms enough at 60kph to cause femur to contact a hard point in the car (Figure 23, condition 2) at a different location than the bumper in 40kph impact (Figure 23, condition 1).

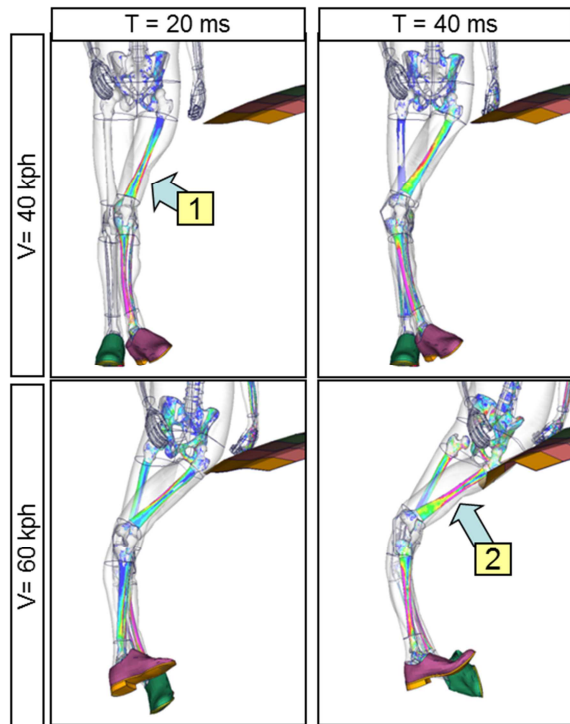


Figure 23 Different mechanism causing maximum load on the femur when impacting SFC at 40kph and 60kph (actual vehicle structure not shown).

CONCLUSIONS

This study addressed the need to investigate impact conditions for a range of vehicle types, impact speed and pedestrian types, while considering the scatter caused by other parameters, such as the pedestrian posture or the vehicle braking.

A large number of parameters was studied by combining a trend study with simplified models and detailed studies with detailed vehicle models to confirm the trends. Results harmonization was also established by means of a comparison of the pedestrian kinematics to confirm a systematic effect from assumptions in the simplified models on the head impact conditions.

With regards to 50th percentile male and 6 year old child, the results for the head impact conditions also confirm the general validity of the current Euro NCAP setup, which is based solely on a vehicle impact speed of 40kph.

The results from this study will be utilized in a next step with in the AsPeCSS project to set up impactor tests addressing a range of impact speeds and representing conditions due to vehicles involved in pedestrian accidents in Europe, also considering new active and passive safety measures for VRU.

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methodologies for forward looking Integrated Pedestrian and further extension of Cyclist Safety Systems) no. 285106

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