Objective classification of front-end structures on the basis of impact-related geometric measures in frontal pedestrian accidents

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1 Motivation

The enormous diversity of passenger car models on the market and the conquest of always new niches lead to a variety of most different vehicle front-end-structures. As a result, it becomes more and more difficult to categorize them clearly. Thus, most existing groupings such as the IHRA or APROSYS classifications base on graphical methods (visual allocation of models with similar size and shape) and hence often rely on subjective appraisal. Equally diverging is the way manufacturers allocate models of their own or other brands to the different segments.

In account of that, this study develops a method to objectively classify vehicle models according to their front-end-structure. Therefore, all available models involved in frontal pedestrian accidents in the GIDAS database are measured and categorized by a statistical algorithm.

2 Dataset

The analysis is based on real-world accidents from the GIDAS (German In–Depth Accident study) database, which contains about 14,000 accidents at this time of the study. These are accidents, which happened between 1999 and 2006 in the investigation areas of Dresden and Hanover and involved at least one injured person. Special accident research teams investigate the accidents on the spot and in the hospitals. For each accident, about 3,000 parameters are documented and encoded in the GIDAS database. Furthermore, every accident is reconstructed on the basis of the full-scale accident sketch. Altogether, 9,953 reconstructed accidents are available for the study.

2.1 Creation of the master-dataset

Generally, only vehicle models, which were involved in a frontal pedestrian accident in GIDAS, are considered for the study. For this reason, the relevant accidents and the related vehicles were filtered on the basis of several criteria. At first, all accidents with at least one injured pedestrian are taken into account. A total of 1,305 reconstructed pedestrian accidents are found in the GIDAS database, which makes up 13.1% of all accidents.

In the next step, the collision partner of the pedestrian is considered. As shown in figure 2-1, about 81% of all pedestrians were hit by M1 or N1 vehicles. Nearly 10% of the pedestrians collided with busses and trams and another 10% have had an accident with a two-wheeler. For the further analysis, all pedestrian accidents with M1 and N1 vehicles are chosen. These vehicles are considered to be typical passenger cars (M1) or at least derivates of passenger cars (N1). After that step, 1,056 accidents remain in the dataset.

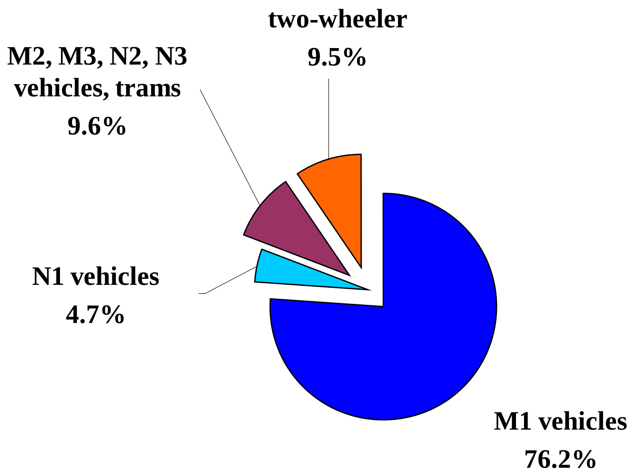


Fig 2-1 Collision partners (vehicle classes) in GIDAS pedestrian accidents (n = 1,305)

In respect of the following classification of front-end structures, the dataset is reduced to accidents with a frontal collision according to the CDC (collision deformation classification) codes calculated during the accident reconstruction. Figure 2-2 shows that this situation is given in two thirds of all considered pedestrian accidents.

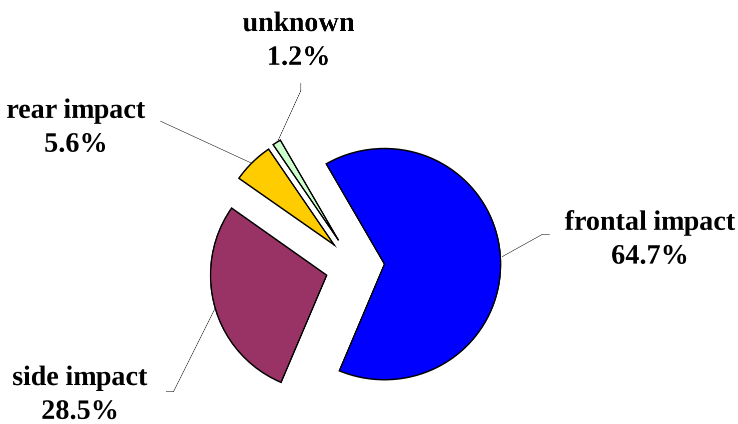


Fig 2-2 Distribution of impact sides in M1/N1 pedestrian accidents (n = 1,056)

The restriction to frontal impacts leaves 683 pedestrian accidents in the dataset. To accomplish the geometric measurement of the vehicle shape for the following classification, only vehicles with an available CAD reference model are taken into account for the analysis. This step excludes another 42 vehicles from the dataset. These are mostly very rare types (e.g. old models from the former GDR) or unknown vehicles.

After applying all filter criteria, the master dataset used for the study finally includes 641 accidents. All parameters relevant for the analysis are then double-checked regarding completeness and plausibility in a single case analysis.

As already mentioned in the title, the classification of front-end structures should be done on the basis of impact-related geometric measures. For this reason, the pedestrian kinematics in frontal accidents has to be considered to extract relevant parameters afterwards.

Generally, the movement of a pedestrian is determined by the combination of the vehicle shape and the collision speed. There are distinctive groups of kinematics. In accidents with passenger cars, the pedestrian is scooped up onto the bonnet if the vehicle was fast enough. At low speeds, the vehicle only hits the pedestrian (without scooping him up) and at high speeds and steep front-shapes, the pedestrian is projected. At very high collision speeds and/or accelerating vehicles, the pedestrian is scooped up and thrown towards the roof. Figure 2-3 shows the distribution of the pedestrian kinematics.

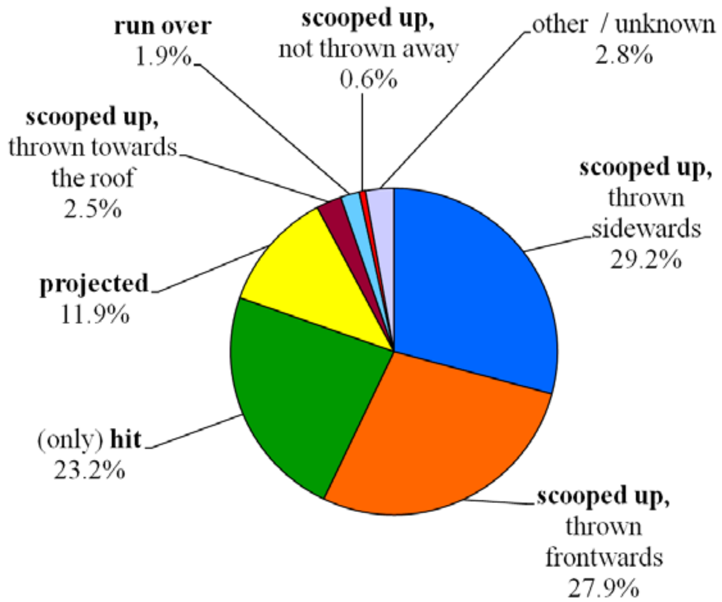


Fig 2-3 Pedestrian kinematics in the considered pedestrian accidents (n = 641)

This kinematics does substantially determine the occurrence of injuries caused by the impact on the vehicle and the secondary impact on the road surface.

3 Classification of vehicle front-end shapes

After the description of the pedestrian accidents that built the basis of the analysis, the next step will show the classification of the involved vehicles according to their front-end shape. Therefore, all models are measured at specifically defined points first. At first, the method and the used measurement points are described in detail. Based on the measurements, all models are then allocated to groups using a statistical algorithm. The results of the classification are presented at the end.

3.1 Front-shape measurements

The aim of this study is an objective classification of different vehicle models according to their front-end shape. Therefore, geometrical measurements are used that do not rely on a subjective evaluation. Furthermore, clearly defined measurement points are used to allow the equal use of this method for further models.

3.1.1 Measurement method and database

In the first step, the dataset with 641 pedestrians involved in a frontal accident is analyzed regarding different vehicle types. In this analysis, 189 different models can be identified and the lateral view of each model is loaded into a CAD tool. For this study, the models of the AUTOVIEW database (Crash Analyse Ratschbacher GmbH) are used. Afterwards, every measuring point (explained in the following paragraphs) is constructed and measured in the longitudinal vehicle axis from the front (x) and the vertical axis above the ground (y). All measurements are taken from the vehicles median plane. Consequently, lateral profile changes are not considered.

The quality of the results is here for the main part depending on the accuracy and the detailedness of the available CAD models. Due to the used method and the mentioned CAD models, a few model simplifications are necessary. These simplifications do not have an influence on the classification results, but they should be kept in mind for further analyses (e.g. for relations to the impact kinematics and injury causation in the real-world accidents):

- Since there is usually only one CAD outline for each model, differences in the model versions (motorisation, features etc.) cannot be considered. The resulting error will however only be marginal.
- Due to add-on parts like spoilers or skirts, the CAD models might differ slightly from the real vehicles (especially in the area below the bumper).
- The loading situation in the real accident and the typical brake-dive in pedestrian accidents are both disregarded. The latter can actually make up as much as 80mm on the vehicle front (bumper height) and has a decisive influence on the impact kinematics. It is however not relevant for the overall classification of the vehicle shape.

This does also apply for the fact that all models are measured in the mid of the vehicle and will be evaluated independent from the real impact setting. Thus, all models are compared on the basis of their geometrical front-shape in a quasi-static status.

The measurement results in an array of 189 models and the associated 14 measurements (seven measured points with x- and y-values). This shape database is necessary for the classification.

3.1.2 Measuring points

For the choice of the measuring points on the vehicle front, pre-defined positions given in the available pedestrian safety standards (2003/102/EC) are regarded, which underlie fixed guidelines. In addition, characteristic points are defined that are necessary for a specific description of the vehicle front-shape and are presumed to have an influence on the impact kinematics and the injury causation. The following points are chosen:

3.1.2.1 Lower edge of the bumper

This point is defined in the EU Directive 2003/102/EC as the lower most point of contact between a straight edge 700 mm long and the bumper, when the straight edge, inclined forwards by 25°, is traversed across the front of the car, while maintaining contact with the ground and with the surface of the bumper (figure 3-1). This point can however vary for one vehicle model; depending on added parts on the vehicle front and the CAD model (see explanation above).

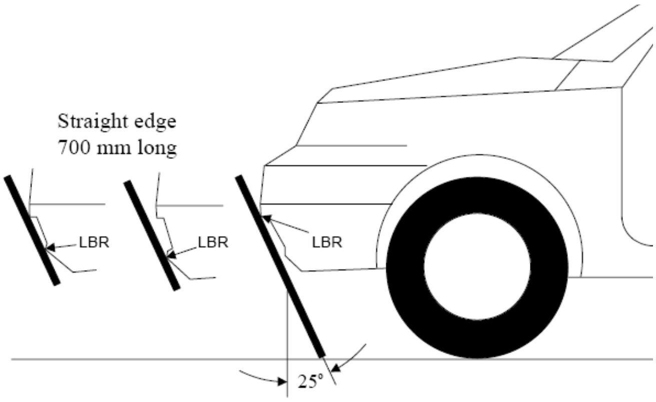


Fig 3-1 Determination of the lower edge of the bumper [from: 2003/102/EC]

3.1.2.2 Upper edge of the bumper

Similar to the lower one the upper edge of the bumper is also defined according to the Directive 2003/102/EC. It is situated directly at the vehicle front (x=0) if the bumper is not rounded too much. It is defined as the upper most point of contact between a straight edge 700mm long and the bumper, when the straight edge, inclined rearwards by 20°, is traversed across the front of the car, while maintaining contact with the ground and with the surface of the bumper [1].

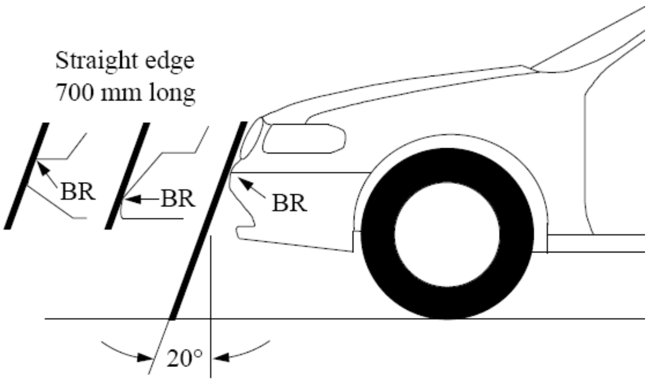


Fig 3-2 Determination of the upper edge of the bumper [from: 2003/102/EC]

This point is important for the impact kinematics because in most of the pedestrian accidents with a frontal impact it is the first contact point of the pedestrian and the vehicle.

3.1.2.3 Bonnet leading edge (BLE)

The third point is the bonnet leading edge. According to the Directive 2003/102/EC, it is defined as the point of contact between a straight edge 1,000mm long and the front surface of the bonnet, when the straight edge, inclined rearwards by 50° and with the lower end 600mm above the ground, is traversed across and in contact with the bonnet leading edge (see figure 3-3). In few particular cases, the bonnet is either too steep or too high so that the determination of the bonnet leading edge point is not feasible according to the specifications in the Directive. These were mostly vans, SUVs and light commercials. In these cases, the first point on the bonnet is used as bonnet leading edge point.

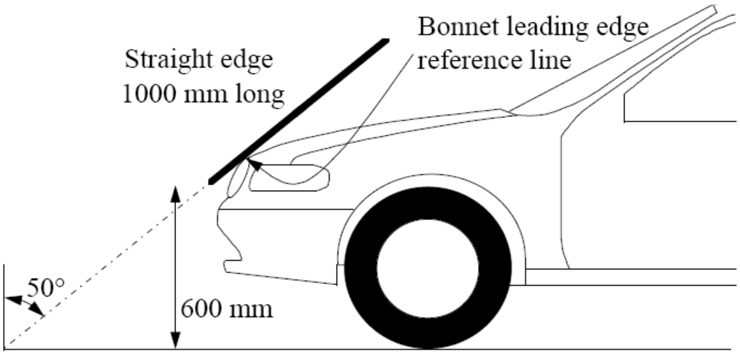


Fig 3-3 Determination of the bonnet leading edge [from: 2003/102/EC]

3.1.2.4 Rear bonnet edge

The rear bonnet-edge point defines the rearmost point of the bonnet in the vehicle median plane. It can be determined easily for almost every vehicle (see figure 3-4) and it can be compared to the points of the bonnet rear reference line of the pedestrian safety policies.

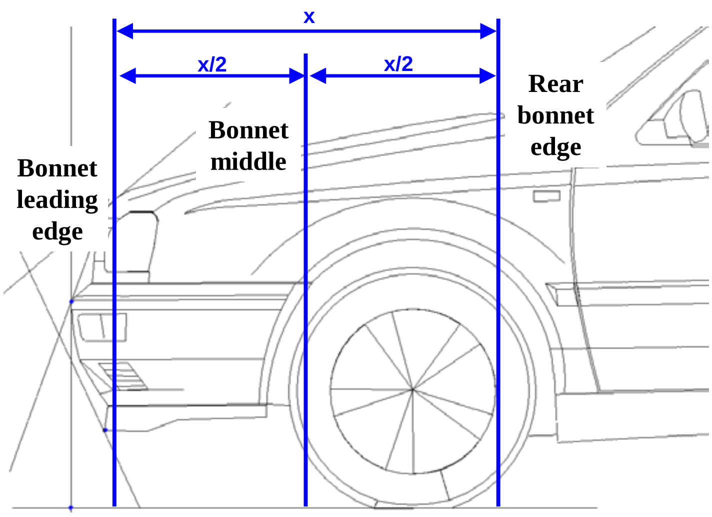


Fig 3-4 Location of bonnet leading edge, bonnet middle and rear bonnet edge

3.1.2.5 Bonnet middle

With regard to the idea to describe the approximate bonnet geometry with the given measurements, the bonnet middle has been defined with the points „bonnet leading edge“ and „rear bonnet edge“. It has the same distance to both reference points in the longitudinal axis and lies on the upper bonnet side on the lateral axis (see figure 3-4).

3.1.2.6 Lower windscreen point

In order to describe the windscreen geometry the lowest (front) point in the vehicle median plane is measured first. Therefore, the lowest visible point of the lateral view of the model is used (see figure 3-5). In some particular cases, this point does not match the lower frame exactly, if the bonnet covers the lower windscreen edge significantly.

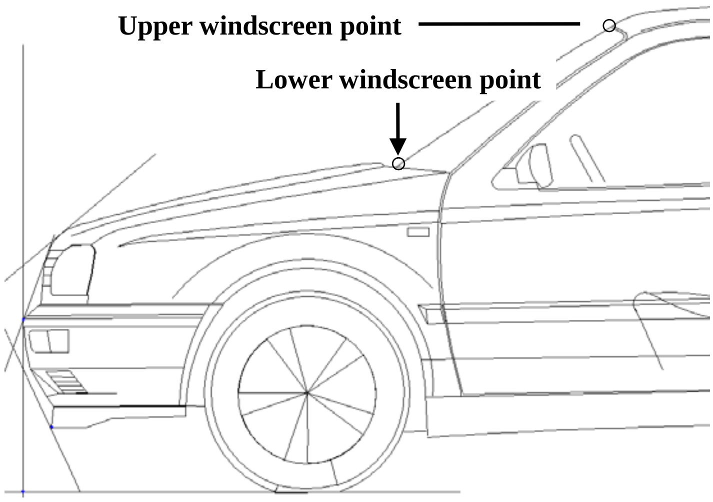


Fig 3-5 Location of the lower and upper windscreen point

3.1.2.7 Upper windscreen point

The farthest point from the vehicle front is the upper windscreen point. This point lies directly at the windscreen frame and determines the average incline of the windscreen together with the lower windscreen line (see figure 3-5).

3.2 Cluster analysis

After the measurement of the 189 models and the preparation of the vehicle-shape database, the main part of the study can be carried out. Here an objective classification of the models according to their geometrical front-shape data is aspired, using a statistical algorithm. At first, the description of the method will be given, and then the results and the description of the calculated groups will follow.

The basis for the analysis are the 1,323 measured points (189 models with seven points each), shown in figure 3-6. In the graphic, the widespread distribution of the single points can be seen that would make it very difficult to create a visual classification for the numerous models.

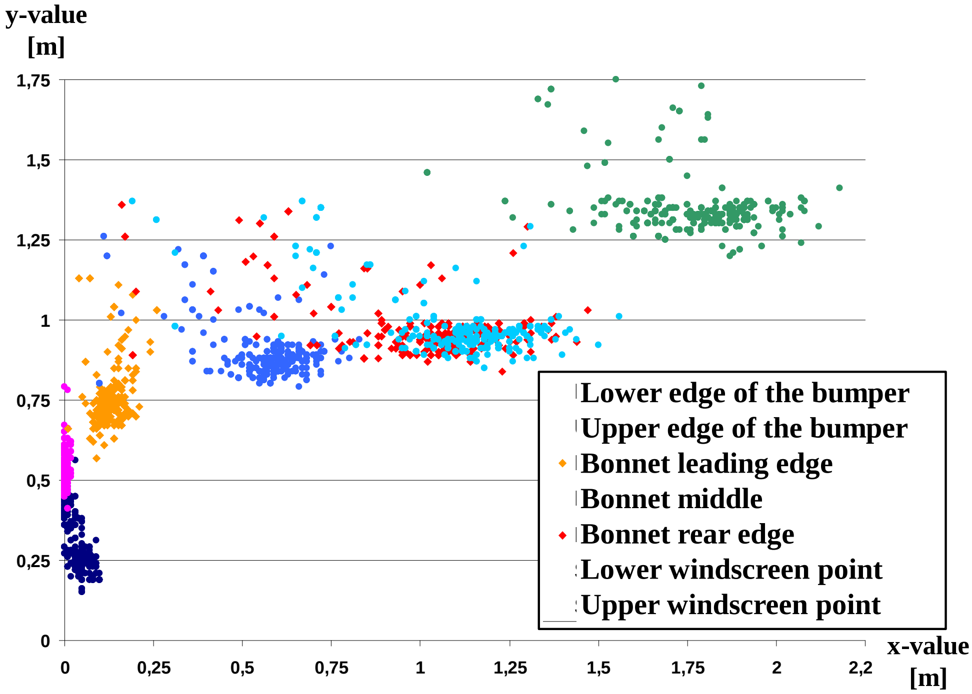


Fig 3-6 Distribution of measured points (n = 189 vehicle models)

3.2.1 Classification method

Statistical algorithms offer different ways to group objects, which are combined in the concept of cluster analyses (also „data clustering“). The common goal is the aggregation of single elements in homogenous subsets with the subsets being as heterogeneous as possible. This is achieved according to the characteristics of the objects that are classified. The analysis considers all characteristics at the same time.

Depending on the question and the database different algorithms are available that do generally have the same approach. In any case, the similarity between the considered objects is determined. For this reason, a certain distance measure is used. Afterwards, the objects are aggregated on the basis of their similarities using a fusion algorithm. In any case, the number of groups (clusters) has to be regarded. She should be neither too small nor too large.

Generally, there are hierarchical and partitional algorithms. Hierarchical algorithms find successive clusters using previously established clusters. The most common hierarchical algorithms can be agglomerative (bottom-up) or divisive (top-down). Agglomerative algorithms begin with each element as a separate cluster and merge them into successively larger clusters. Divisive algorithms begin with the whole set and proceed to divide it into successively smaller clusters.

For the study, the Ward clustering method is used. This is an agglomerative hierarchical algorithm and it is commonly used for a variety of applications in biology, market research or medicine. The chosen cluster algorithm is here used for the classification of geometrically similar vehicle front-shapes. The measured x- and y-values of the seven points represent the relevant characteristics necessary for the evaluation of similarity and the allocation of the groups.

The numerical realisation of the cluster analysis is done with the statistical software SPSS®. For the calculation of the proximity values, the quadratic Euclidean distance is used. In addition to that, the single values are weighted to the array [-1;1] to prevent an over-representation of points with a large range (e.g. x-value of the upper windscreen point) towards points with a small range (e.g. bumper height). The weighting process is schematically shown in figure 3-7.

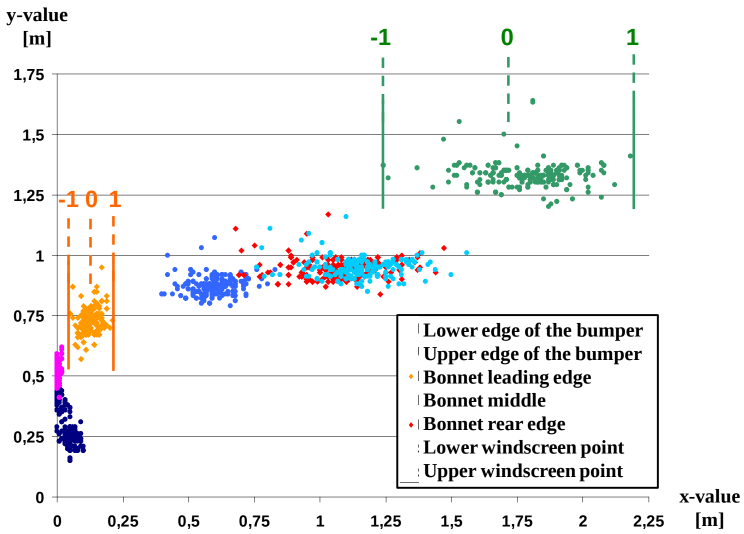


Fig 3-7 Weighting of measuring points to the array [-1 …1]

3.2.2 Development of the model

Using the method explained above, the dataset is now analysed regarding similar geometric models. At first, the absolute x- and y-values are used for the cluster analysis. In several steps, versions with different measuring points and different numbers of cluster are calculated. At that, measuring points that have redundant or negligible information (e.g. the x-value of the upper edge of the bumper) are excluded from the considerations. Furthermore, the cluster number is modified. The aim is to find a compromise between manageability (preferably low cluster number) and homogenous groups (preferably high cluster number).

The process shows that the increase of the number of clusters does often only separate one cluster into two groups with similar models while the other clusters are not changed. Above a certain number of clusters, there is no improvement in the quality or validity of the results anymore. The results of the first groupings do generally show that there is partially not enough selectivity between the groups. Furthermore, some model allocations are not classified in a sufficient manner (following logical considerations).

Generally, there is one problem evident after the first steps of the analysis that results from the formal independence of the individual points. The related x- and y- values cannot be defined as pair of values in the SPSS® calculation. If every value is handled as a separate characteristic, then the fundamental relation of the values of one measuring point is lost. In addition, the consideration of vectors between the measuring points is not feasible, because it would also separate the corresponding length and angular information.

Due to that a new approach is developed, which does connect the individual points and allows the derivation of characteristic parameters that are particularly relevant for the pedestrian impact and have an influence on the impact kinematics. Using the measurement data, relevant values are extracted and characteristic parameters are calculated:

- the height of the upper edge of the bumper
- the height of the bonnet leading edge (BLE)
- the angle around the bonnet leading edge (= angle between the points „upper edge of the bumper“ and „bonnet middle“ around the BLE)
- the angle towards the bonnet leading edge (= angle between a horizontal line and the BLE at the upper edge of the bumper)
- the bonnet length (= distance between the points „BLE“ and „rear bonnet edge“)
- the (average) bonnet angle (= angle between a horizontal line and the line between the points „BLE“ and „rear bonnet edge“)
- the height of the rear bonnet edge
- the (average) windscreen angle (= angle between a horizontal line and the line between the lower and upper windscreen point)

An overview of these parameters is given in figure 3-8.

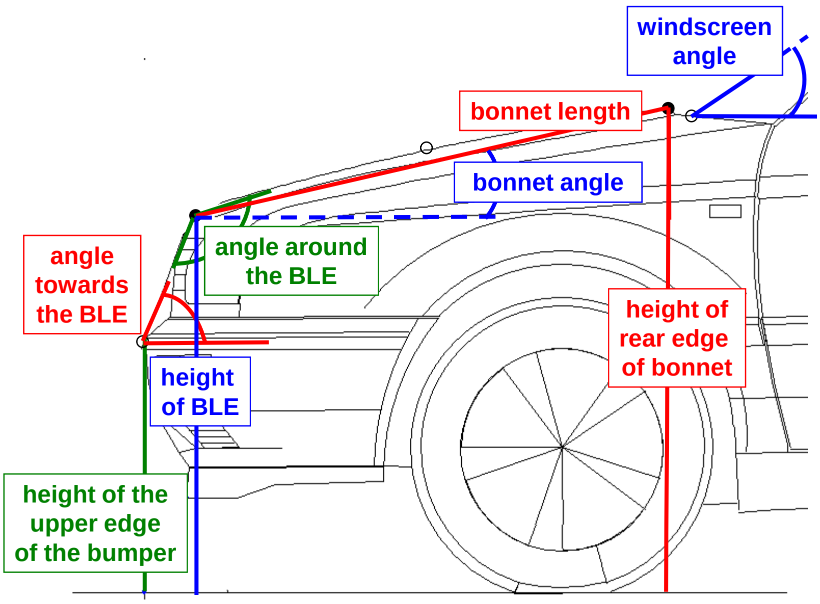


Fig 3-8 Used parameters for the cluster analysis (final model)

The cluster analysis is repeated with these eight parameters explained above. The analysis shows that a solution with five clusters is the most reasonable one. After the aggregation using statistical methods, a logical review of the clusters has to follow on the basis of the included models. The solution that was found can be accepted as convincing from both a statistical and a logical point of view and will be described in detail.

3.2.3 Results of the cluster analysis

The 189 vehicle models were grouped into five clusters. For their graphical illustration the seven original measuring points of each model are connected. The outer contours depict the upper and lower boundaries of the cluster. The connection of the measuring points does not perfectly represent the real vehicle geometry; it does however give a good approximation. Some characteristics that are specific for the clusters can already be seen in this graphics. The following pictures show the outlines for every cluster with all upper and lower limitations for the models and the explanation of the characteristic specifications. Furthermore, every cluster is characterized by one specific model that represents the middle of the cluster and that is illustrated besides the graphic.

3.2.3.1 Cluster 1

In the first cluster, 123 of the 189 models can be found. Figure 3-9 shows all included outlines and a representative vehicle image. Looking at the models only passenger cars can be found in this cluster. The specific characteristics for Cluster 1 are the relatively round and less steep bonnet leading edges (angle around the BLE) and the slightly steeper bonnets.

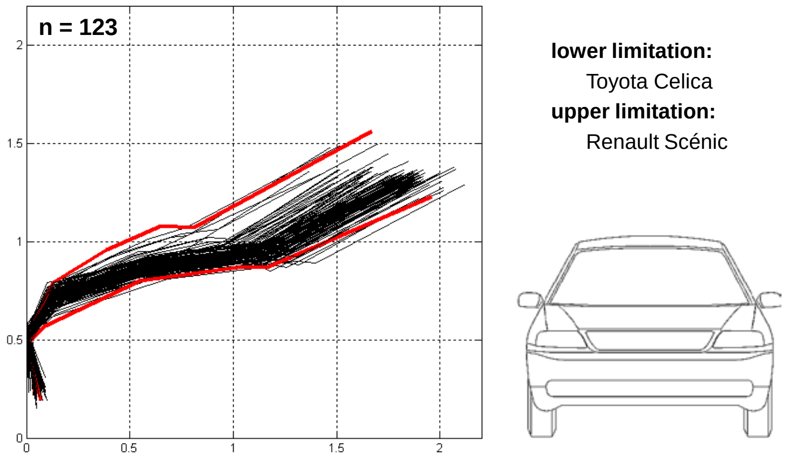


Fig 3-9 Models in Cluster 1

3.2.3.2 Cluster 2

Another 40 models are assigned to Cluster 2. These are also vehicles that fit the label „typical passenger car“ without models from the newer vehicle sectors (e.g. SUV, MPV). The bonnet leading edge has a sharper edge and the incline towards the BLE is steeper than in Cluster 1.

Furthermore, the bonnets are flatter and the windscreens are slightly steeper. The height of the upper edge of the bumper shows no notable differences between Cluster 1 and Cluster 2 (see figure 3-10).

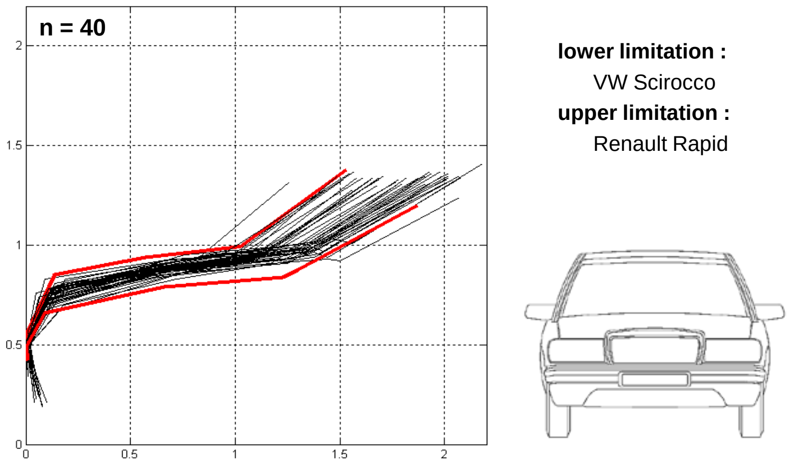


Fig 3-10 Models in Cluster 2

3.2.3.3 Cluster 3

The third cluster makes up the smallest group with only seven models. The outlines of the cluster do not overlap with other clusters (except for the bumper area). The included models are especially transporters and often types of older vehicle generations (e.g. MB 100, VW T3). The outlines of the seven models are given in figure 3-11. The models in this cluster do all have a high BLE, very steep bonnets and windscreens and have particularly short bonnets.

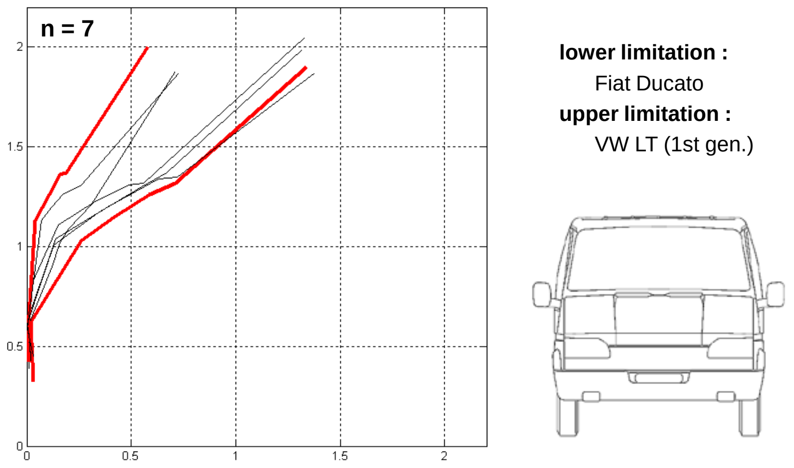


Fig 3-11 Models in Cluster 3

3.2.3.4 Cluster 4

The eleven outlines of the fourth cluster lie between Cluster 1 and Cluster 3. The group includes models with less prominent bonnet leading edges and shorter and steeper bonnets than the models in Cluster 1 and Cluster 2 (see figure 3-12).

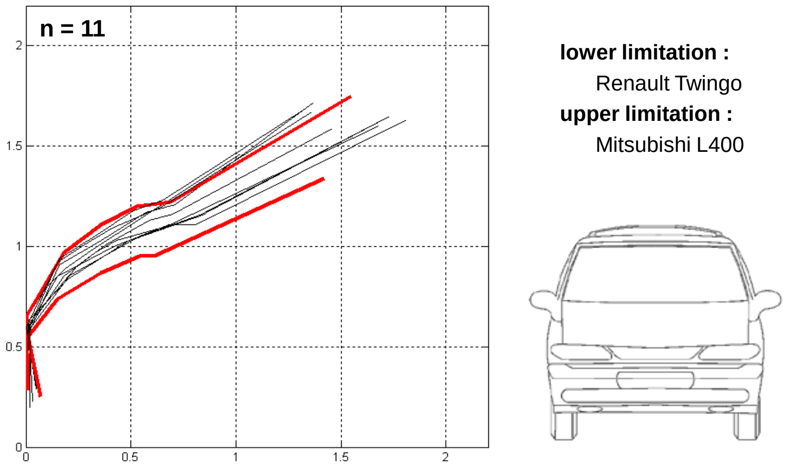


Fig 3-12 Models in Cluster 4

3.2.3.5 Cluster 5

The fifth cluster includes eight models that show particularly edged shapes. Especially the steep or almost perpendicular incline towards the bonnet leading edge and the angle around it towards the often flat bonnet are characteristics for this cluster. Furthermore, the models within this group have very steep windscreens (see figure 3-13).

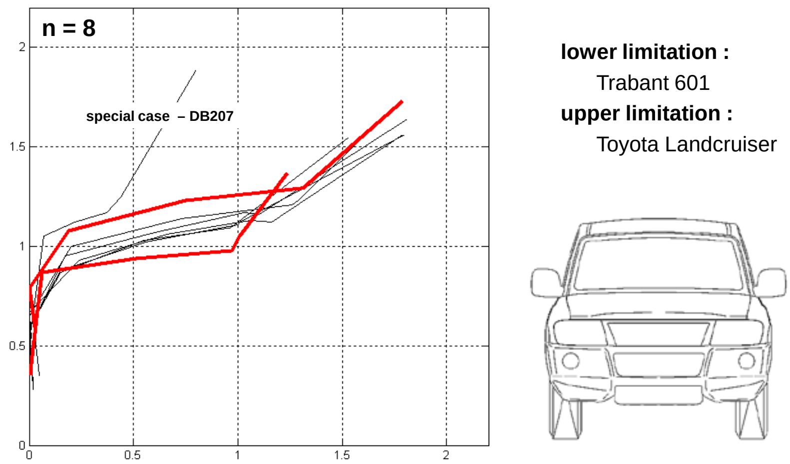


Fig 3-13 Models in Cluster 5

Looking at the included models this cluster is the most heterogeneous one (including especially SUVs and MPVs). Except for the special case of the Mercedes DB 207, which has also been included in this cluster due to its edged and almost perpendicular geometry, all other models lie between the upper and lower outline.

3.2.3.6 Summary of the cluster formation

The classification of the models according to their geometrical characteristics, using statistical methods led to the five clusters explained above. To compare their specific positions, figure 3-14 shows the upper and lower outlines of all clusters. The graphic shows that the clusters overlap in some parts. This is easily comprehensible because the shapes of almost all passenger car models lie within a certain range (especially the absolute height). As the cluster formation is however based on geometrical characteristics, also overlapping outlines can be classified.

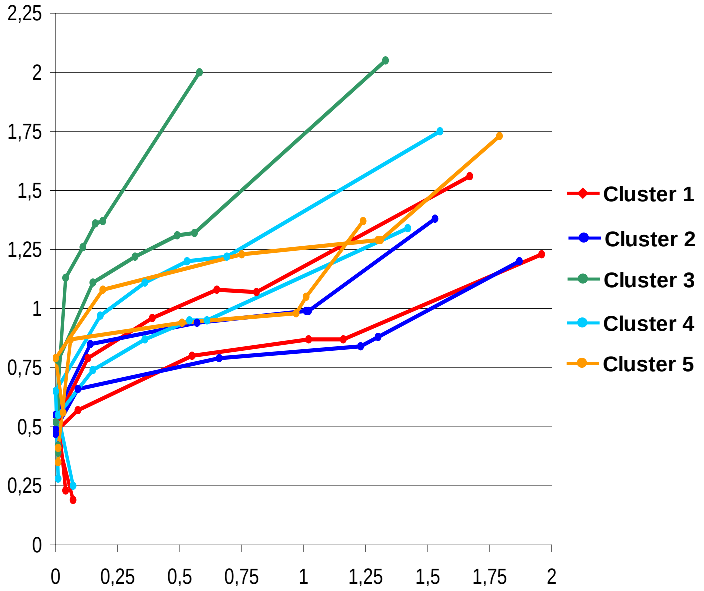


Fig 3-14 Summary of all clusters

To estimate the quality of the cluster analysis according to logical facts, the different production series of one vehicle model can be considered. Cluster 2 for example includes the models VW Golf I, II and III and the older production series of the BMW 3-series (E30, E36), while the newer models (VW Golf IV, BMW 3-series E46) are assigned to Cluster 1. This separation is found for all vehicles with more than one production series in the dataset.

Generally, it can be stated that the clusters do partly include models from very different vehicle classes. One example is Cluster 4 that includes vans (Ford Galaxy, VW Sharan) together with lower-class cars (Renault Twingo, MCC Smart) and the transporter-like Mercedes Vito, which are aggregated according to their geometrical shape. Due to that, there cannot always be a universal label found for each cluster and the clusters will be referred to by their numbers in the following chapters instead of a specific name.

3.2.4 Descriptive statistics of the clusters

After the visualization of the clusters and the formal description of their characteristics, a numerical description according to statistical measures is done. Therefore, the arithmetic mean, the minimum value, the maximum value, and the standard deviation are used. The graphics in the following paragraphs contain this information as follows:

- arithmetic mean ➔ (red) horizontal line
- (arithmetic mean) ± standard deviation ➔ (blue) bar
- range between minimum and maximum value ➔ (black) vertical line

At first the assumption is tested, that the vehicles in the Clusters 1 and 2 that are all passenger cars are modern or older models. Therefore, the year of market introduction is analysed for the models in the five clusters and depicted in figure 3-15.

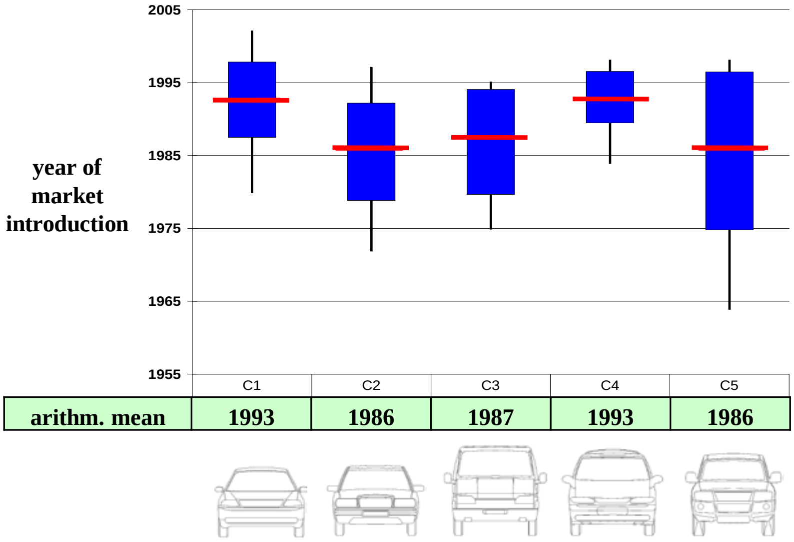


Fig 3-15 Statistical information - Year of market introduction

The figure shows that the rounded shapes in Cluster 1 are seven years younger than the vehicles in Cluster 2 on average. It can be stated that the development of vehicle front-end shapes is reflected in the cluster formation. The vehicles in Cluster 4 do mostly have the same age as the vehicles in Cluster 1. Considering the single models this fact seems plausible as van-like shapes entered the market at the beginning of the 1990s and more and more vehicles of special niches (e.g. MPV) have been introduced into the market since that time.

The special progress in the passenger car area can be seen in the following analyses of the statistical measures. Here you can see the obvious differences and similarities between the clusters and the variety of the evaluated measures. All following results refer to the comparison of the calculated mean values.

Considering the height of the upper bumper edge (figure 3-16), only a small difference can be found between Cluster 1 and Cluster 2. The other clusters approximately have the same level.

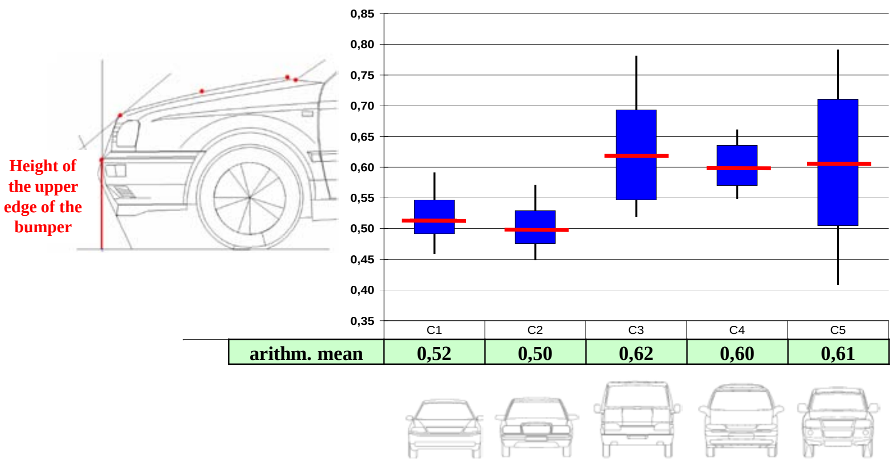


Fig 3-16 Statistical information - Height of the upper edge of the bumper

The height of the BLE (figure 3-17) is slightly lower for Cluster 1 in comparison to Cluster 2. Together with the slightly higher bumpers, this fact leads to an averagely smaller distance between the upper bumper edge and the BLE in Cluster 1.

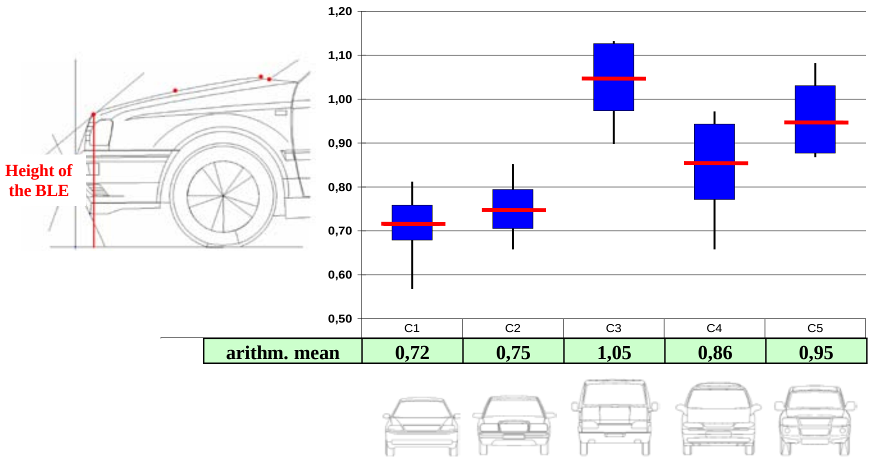
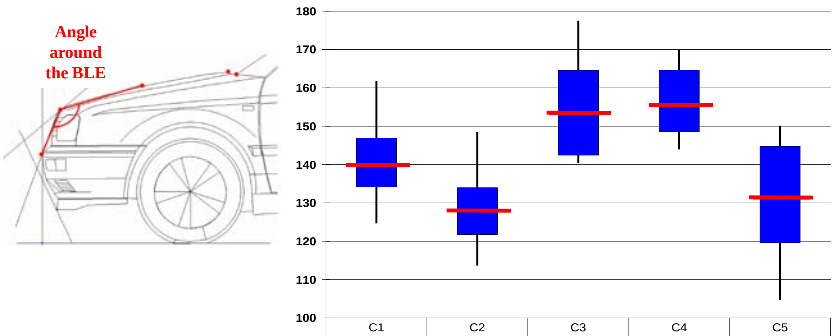


Fig 3-17 Statistical information - Height of the BLE

The models in Cluster 3 have an extremely high BLE. Here a distinctive difference to Cluster 4 can be found. Cluster 4 does indeed also include vehicles with so-called „box-shapes“; it does however differ in the vehicle classes. The mean value of Cluster 5, which includes three off-road vehicles, is situated between Cluster 3 and Cluster 4.

The angle around the BLE (figure 3-18) is an important measure concerning frontal pedestrian accidents because it is usually the second contact point of the pedestrian after the primary contact on the bumper. The BLE is the main center of rotation during the pedestrian impact (especially on typical passenger car structures) and its radius and angle are crucial for the kinematics of the person. The value does thus allow a first estimation of more or less „impact-friendly“ shapes for the area of the pelvis and the lower extremities.

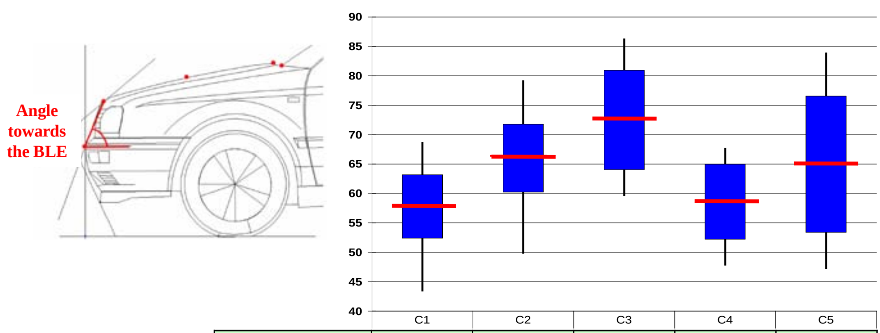


arithm. mean	140,5	127,9	153,5	156,6	132,2

Fig 3-18 Statistical information – Angle around the BLE

The vehicles in Cluster 1 and Cluster 2 have a difference of twelve degrees in the considered angle. The characteristic, which was called „edged BLE“ yet, can now be described numerically as well. The vehicles in Cluster 5 are similarly edged, too. While the values of the height of the BLE differ substantially between Cluster 3 and 4, the considered angle is almost identical.

In the next, the angle towards the BLE is considered (see figure 3-19).



arithm. mean	57,8	66,0	72,5	58,6	65,0

Fig 3-19 Statistical information – Angle towards the BLE

A difference between Cluster 1 and 2 can again be derived here. The front-shapes in Cluster 2 are about eight degrees steeper than in Cluster 1 on average. Furthermore, this parameter can also be used as differentiation criterion between Cluster 3 and 4. For the fifth cluster, the variance does not allow valid assumptions.

The characteristic analyzed next is the bonnet length (figure 3-20). Here the results show that the more modern models in Cluster 1 do statistically have shorter bonnets than the vehicles in Cluster 2. The difference, taking into account the arithmetic mean within the clusters, is 13cm. The bonnets of the vehicles in Cluster 3 and 4 are yet shorter, as both clusters include mostly box-shapes. The smallest average value can be found in Cluster 3 with only 36cm.

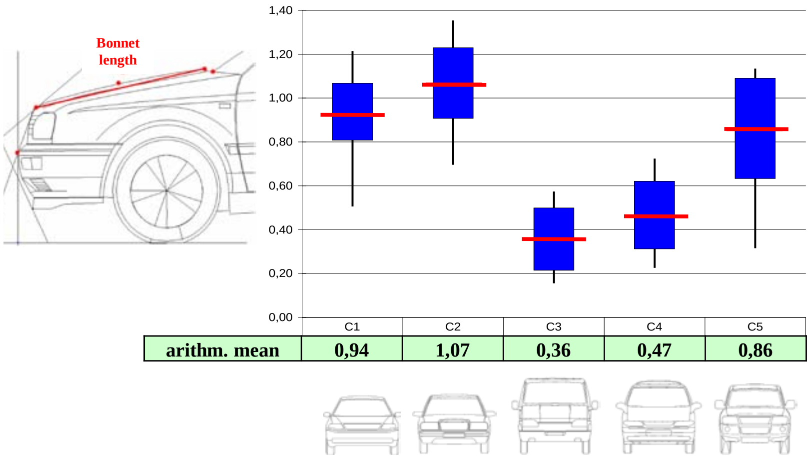


Fig 3-20 Statistical information – Bonnet length

Similar results can be found for the bonnet angle (figure 3-21).

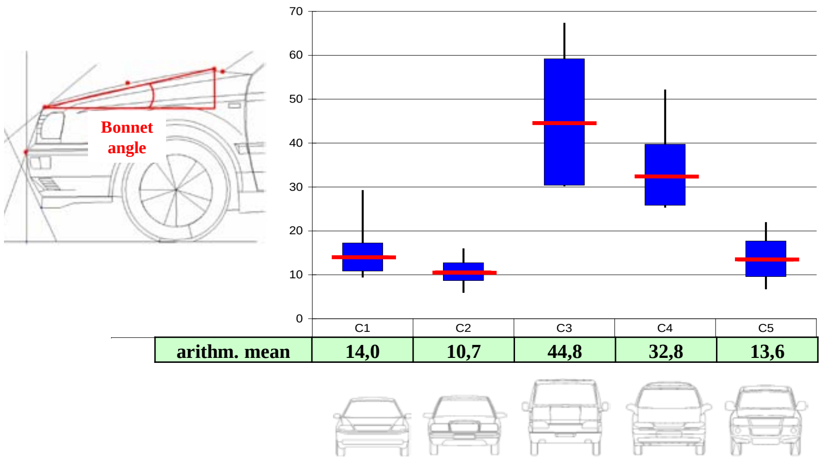


Fig 3-21 Statistical information – Bonnet angle

Here, the values of Cluster 1 and 2 are relatively close. Compared to Cluster 2 (older vehicles), Cluster 1 shows a slight trend towards steeper bonnets. The values in Cluster 5 are also similar. The vehicles in Cluster 3 and 4 (mostly box-shaped vehicles), do naturally have very steep bonnets, with Cluster 3 showing the highest values. The analysis of the bonnet geometry does not include the concavity. It is however very similar for most of the vehicles in all clusters.

The height of the rear edge of the bonnet is shown in figure 3-22. The results do hardly show any differences between Cluster 1 and Cluster 2. Only the models in Cluster 3 show very high values and thus delimitate from Cluster 4.

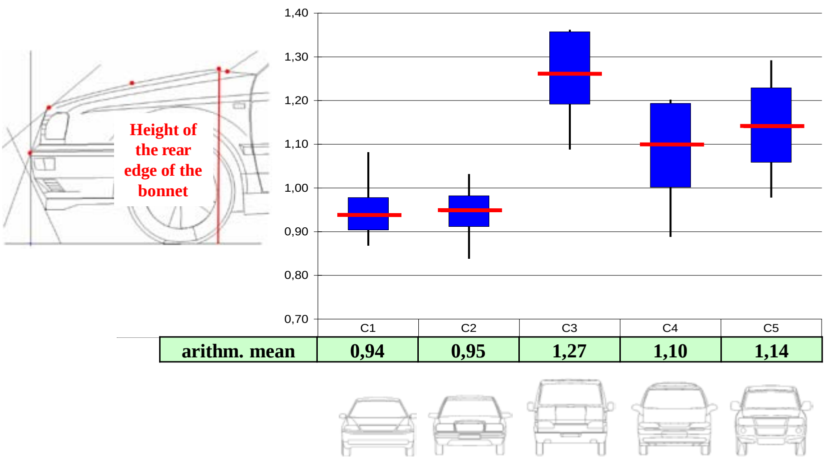


Fig 3-22 Statistical information – Height of the rear edge of the bonnet

Finally, the (average) windscreen angle is analyzed (see figure 3-23).

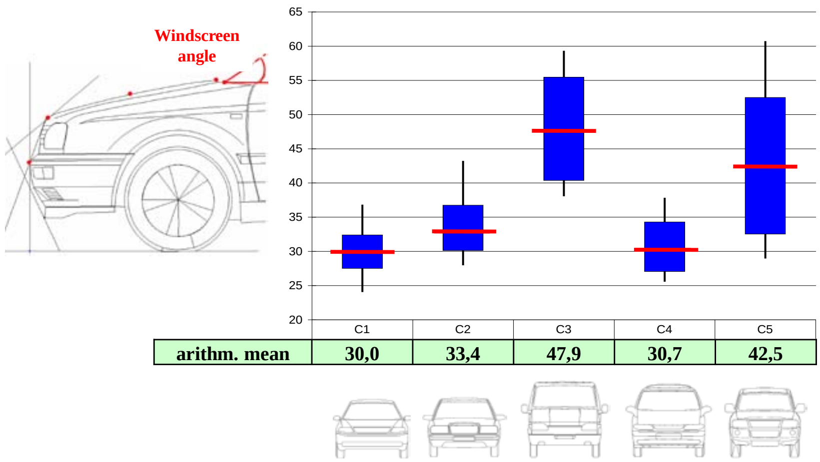


Fig 3-23 Statistical information – Windscreen angle

Here, slight differences (three degrees) can be found between Cluster 1 and Cluster 2. More important is the fact that the models in Cluster 3 have significantly steeper windscreens than the vehicles in Cluster 4. The models in Cluster 4 do therefore have a similar shape to the typical passenger cars in Cluster 1 after the steeper bonnet. The models in Cluster 5 have partially very steep windscreens, while regarding the broad range of values. In combination with the steep front-shapes and the flat bonnets, this fact leads to the very edged shape explained above.

3.2.5 Summary of the cluster analysis

The statistical analysis of the considered parameters shows that all clusters differ in several characteristics. Thus, the separation of passenger cars into two clusters and the separation of the box-shaped vehicles can now be described numerically. Beside the formation of the clusters, another result can be drawn out of the comparison of Cluster 1 and 2. Some trends in the development can be derived from the data, resulting in the different construction periods. Compared to Cluster 2, the more modern vehicles in Cluster 1 are statistically characterized by:

- slightly higher upper edges of the bumper
- slightly lower and a lot rounder bonnet leading edges
- less steeper vehicle front-shapes
- shorter and steeper bonnets
- slightly flatter windscreens

It can also be seen that the summarization of all box-shaped vehicles in one group (e.g. in the IHRA corridors) is not useful. The significant differences between Cluster 3 and 4 regarding the height of the BLE, the angle towards the BLE and the windscreen angle assure this fact.

It can be stated that the classification of front-end shapes, using a cluster analysis with impact-related parameters, can be performed successfully; leading to sensible and reproducible results.

4 Summary and Outlook

It was the aim of the study to develop an objective and statistically proper method for the classification of vehicle front-end shapes. Therefore, vehicles involved in frontal pedestrian accidents in the GIDAS database were analyzed. After the geometrical measurement of 189 CAD models, they were classified into five groups using a cluster analysis. After that, the calculated clusters were statistically described and compared, leading to the result that the formation of logical and at the same time statistically comprehensible groups is possible. The classification can be repeated with more or less models at any time.

The crucial advantage of this method is the fact that there are no visually based algorithms used for the classification and that there is no subjective evaluation involved as it has been in former classifications. The use of the cluster analysis would also be possible for further geometrically based analyses (visibility relations, vehicle classifications etc.). In addition, a three-dimensional evaluation of front-end shapes would be possible.

Furthermore, analyses can be done concerning the influence of the vehicle shape on the actual injury severity of the pedestrian in the real-world accident.