INFLUENCE OF IMPACT SPEED AND VEHICLE PARAMETER ON INJURIES OF CHILDREN AND ADULTS IN PEDESTRIAN ACCIDENTS

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1. The Importance of Pedestrian Accidents within Automotive Accidents generally

The work done so far in the field of active safety of motor cars has contributed a lot to the reduction of traffic victims world-wide observed. Considering the dominant share of human failure within the reasons of accidents at least the same amount of work will be needed in the future in the field of passive safety (crashworthiness, occupant and pedestrian protection) to reduce traffic victims furthermore. A benefit of safety caused by another structure of the automotive traffic can not be expected in the near future.

Up to now, strongest efforts in the field of passive safety were directed to the problem of occupant protection. This is understandable on behalf of most traffic victims being occupants, followed by pedestrians, cyclists and motorcyclists (see fig. 1). Furthermore, safety measurements for occupant protection were - until now - feasibly with higher benefit/cost-factors than measurements in the area of pedestrian protection. This situation will change when the most effective measurement of the occupant protection , the safety belt, will be introduced and will be worn up to some 80%. In connection with a higher crashworthiness of the car structure, with energy absorbing steering columns, with reinforced door locks and seats, with head rests, and so forth a reduction of occupants deaths of more than 60% can be expected compared to the time before compulsory belt wearing.

Consequently, the efforts in automotive safety are to be directed to the pedestrians and cyclists. Their toll of deaths is, for example, in Germany with 46% only a little less than the toll of deaths for occupants (see fig. 2). From a higher point of view this problem is included in the shifting of the efforts from self protection to partner protection (protection of the weaker partner like small cars, pedestrians, cyclists). The idea of compatibility and nonaggressivity has to be extended to all participants in traffic [1,2] (see fig. 2).

Subject of the presented paper is to make statements on the type, frequency and severity of pedestrian's injuries and their correlation to the impact velocity and car-specific qualities.

The results should be presented, so that later on they may contribute to benefit/cost-analyses in the area of pedestrian protection.

2. Existing results

Compared to investigations on injury patterns of occupants very few results on injury patterns of pedestrians are available. They are based on four investigation methods:

a. Evaluation of records made by the police, possibly completed by questioning [2 to 11]
b. Retrospective investigations, especially of fatal accidents [11 to 14]
c. Accident investigations on scene [15 to 18]
d. Experiments with cadavers [19].

In context with this paper the following results seem to be important:

1. The highest risk for fatality have the groups aged 5, 15 and 75 [4, 11, 15].
2. The frequency of accidents is particularly high at 8, 12, 17 and 25 o'clock [4, 12].
3. The risk for fatal injuries of pedestrians is four times of that of occupants.
4. Running over occurs only with 10% [3] or 2% [11] probability.
5. According to Patrick and experiments made by the Japanese the impact of the head to the pavement is more severe than the impact to a car [5] . In opposite, our dummy tests [20] and accident investigations [15, 17] by the Technical University Berlin show more severe injuries overall and related to the head caused by primary impact than by secondary impact.
6. Fatal injuries are possibly beginning with an impact speed of only 3.3 m/s. In the average, the impact speed for accidents with injuries is 11 m/s for adults [12] and 7.8 [12], 8.9 [1] or 9.2 m/s [15, 17] for children.
7. Frontends with projections and additional parts have no significant influence on the severity of injuries, apart from the side mirror [6, 7, 11].
8. Different front end types like pontoon with high bonnet edge, pontoon with low bonnet edge or slooping hood (V-type) do not produce a significantly different severity of injuries [6 to 8]. In opposite, according to [15], in average there are more severe injuries with the pontoon type than with the V-type.
9. A direct comparison of different car models shows a higher risk for fatal injuries for the Cadillac than for the VW-Beetle, the ratio of injured to cilled pedestrians is 0.046 and 0.038 respectively[5].In opposite, Hall [6, 7] found out a higher risk for death with the VW (Beetle?) than with any other medium sized car (0.085 against 0.053)

10. Mostly pedestrians are suffering from 2.5 injuries per accident [6, 7].
11. Some 12% of injured pedestrians have contact with the windscreen [12].
12. A long hood reduces the injuries of the head [11].
13. The body parts with the highest risk (frequency x severity) are the head, lower extremities, thorax and pelvic [15, 16].
14. Small cars are not so often involved in pedestrian accidents than large cars [9].

3. Method and material of the investigation

Within two years in Hannover and lately also in Berlin some 550 accidents were investigated on scene by an interdisciplinary team.* This includes 150 pedestrian accidents, 80 accidents involving children younger than 15 years and 70 accidents involving adults over 15 years.

4. Statistical data

According to the fact that our investigation teams do not work during the night the share of children (55%) in our data pool is higher than in the federal statistic (45%) of Germany (see fig. 3). One can deduce from a comparison of fig. 2 and fig. 3 that the risk for suffering fatal injuries for the elderly adults (over 65 years) is about eight times higher than for children (under 15 years).

Fig. 4 shows the related frequency of pedestrian accidents versus the curb mass of the involved passenger cars. Also, the related exposure of all cars is to be seen. By dividing, we get the accident frequency related to exposure versus car mass (see fig. 5). We realize that extremely light cars (< 700 kg) and extremely heavy cars (>1400 kg) are relatively seldom involved in pedestrian accidents and medium sized cars (700 - 1400 kg) relatively often. Fig. 6 deals with the correlation of impact speeds, estimated and declared by the drivers (v_d) and computed afterwards (v_c) under consideration of the locking trace. At low and middle speeds the drivers guess - intentionally or not - the impact speed too less. A regression analysis with different functions gave the best correlation for this exponential type:

$$v_c = v_1 \cdot \sqrt{v_d / v_2} \quad \text{with } v_1 = 3.569 \text{ m/s}, \; v_2 = 1.0 \text{ m/s}$$

5. Kinematic data of the pedestrian accident

The mean impact speed (calculated) in nonfatal and fatal pedestrian accidents is 9.4 m/s (34 km/h), in fatal accidents

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* Programs sponsored by "Bundesanstalt für Straßenwesen "BAST", Kln

11.8 m/s (42.5 km/h) [14], see fig. 7. The pedestrians are mostly impacted on their side and related to the car nearly uniform over the width with only some more frequent impacts on the fender. The pedestrian strikes the car in different regions dependant on the impact velocity, the front end design of the car and the height of the pedestrian (see fig. 9 and 10). With increasing impact speed and passenger height and a tendency from pontoon to V-contour more areas located in the back are contacted.

contact with	pontoon contour	V-contour
front	17%	-
bonnet 1. part	37%	8%
bonnet 2. part	35%	35%
windscreen	10%	38%
roof	1%	19%
	100%	100%

The throw off distance in driving direction does not depend on the lateral position of the impact point, see fig. 11. The throw off distance increases as the square of the impact velocity is 26% wider for children than for adults and for cars with pontoon contour 29% wider than for cars with V-shape, see fig. 12 and 13.

Fig. 14 deals with the correlation of the lateral throw off distance counting from the impact point and the lateral position of the impact point. On behalf of the lateral velocity of the walking or running pedestrian and the sweep of car shape the lateral throw off wide is zero when the pedestrian is impacted 15% before the middle of the car.

6. Injury severity by car impact and road surface impact for different front end designs

The evaluated data, although not always statistically assured, show an increase of the OAIS from 1 to 6 in a comparatively small range of impact velocity from 7 to 13 m/s (25 to 47 km/h), see fig. 15. The risk for severe injuries is highest for the elderly adults, followed by children and middle aged adults.

The secondary collision produces at all impact speeds less severe injuries than the primary impact. In other words, on a fixed AIS the secondary impact causes this injury level only at higher impact speeds than the primary impact, see fig. 16.

A comparison of different front end designs shows that injuries caused by the primary impact are more severe with the box type contour than with pontoon- or V-contour. Up to AIS = 4 and v = 12 m/s the pontoon car is more dangerous than the V-shaped car, at higher impact speeds the endangering alters, see fig. 17.

In the secondary impact no difference in endangering can be identified by the front end designs, see fig. 18. Fig. 19 shows again in other constellation the lower injury level of the secondary impact and reveals a higher endangering of children up to v = 10 m/s and of adults above v = 10 m/s.

On average, there is no difference in head injuries caused by pontoon contours and V-contours, see fig. 20.

7. Accident frequency and injury severity caused by light and heavy cars

From fig. 5 it is already known that very light and very heavy cars are relatively less involved in pedestrian accidents compared to medium sized cars. Fig. 21 shows the surprising and reflective result that at all impact speeds heavy cars with curb masses > 1000 kg cause more severe injuries than light cars.

8. Injury severity and car size

From recent work in accident research and from dummy tests it was supposed that the length of the bonnet reduces the injuries. From our investigation this presumption cannot be confirmed for cars with pontoon contour neither for the OAIS (see fig. 22) nor for the head-AIS (see fig. 23). Possibly, the differences will be worked out if only the extreme lenghs will be compared. There is almost no difference in the OAIS for V-shaped cars with small and large contour length, see fig. 24.

9. Injuries caused by typical front end types and exterior parts on the car

The frequency and the severity of injuries for children and adults for various body parts under consideration of pontoon, V- and box-shaped cars is shown in fig. 25 and 26. Especially frequent are injuries of the head, abdomen and legs for children, of head and lower legs for adults. The most severe injuries for head and legs are caused by the box type, for abdomen by the pontoon car.

Defining the product of frequency and severity as aggressivity, the most aggressive cars concerning special body parts are:

all types	- concerning the head
box type	- concerning the thorax (adults)
pontoon and box type	- concerning the abdomen (children)
all types	- lower legs

For determinating the sequence of injury producing exterior parts, in fig. 27 and 28 the mean severity, the frequency and the aggressivity of the exterior parts is demonstrated for pontoon and V-contour, differentiating between children and adults.

The most aggressive parts are:

	pontoon contour	V-contour
Children	bumper bonnet edge bonnet 1. part	bumper bonnet 2. part windscreen
Adults	bumper bonnet edge bonnet 2. part	bumper roof panel bonnet 2. part

Children don't reach the area behind the bonnet on pontoon cars. The most severe injuries result from contact with A-pillar, windscreen frame, roof panel, bonnet edge and bonnet 1. part.

Considering the highly nonlinear character of AIS it seems to be more realistic to define the aggressivity as product of frequency and square of AIS. The result, shown in fig. 29, reveals as most aggressive parts:

	pontoon contour	V-contour
Children	bonnet edge bumper bonnet 1. part	bonnet 2. part bumper windscreen
Adults	bumper bonnet edge windscreen frame	bumper roof panel bonnet 2. part

It can be seen that with higher rating of the AIS the aggressive parts don't change drastically, only for children the bonnet proves to be more aggressive than the bumper.

10. Summary

In the past, the measurements of automotive safety were successfully directed to the problem of self-protection. To be consistently, the problem of partner protection has to be accentuated in the future, especially the problem of pedestrian protection.

Although not all results are statistically assured, because of the limited data, our accident investigations show the following trends:

1. Very heavy cars and - in opposite to accidents with injured occupants - also very light cars are relatively seldom involved in pedestrian accidents.

2. Up to some 40 km/h drivers underestimate the impact speed.

3. The mean impact speed in fatal and nonfatal pedestrian accidents is 34 km/h.

4. Pedestrians are impacted almost only by their side.

5. The throw off distance of children is 26% wider compared to adults.

6. The throw off distance for pontoon shaped cars compared to V-shaped cars is 29% wider.

7. In lighter accidents children are more endangered than adults, in severe accidents the elderly adult is more endangered.

8. The secondary road surface impact produces at all impact speeds less severe injuries than the primary car impact.

9. Up to 43 km/h impact speed the pontoon shaped cars produce more severe injuries compared to V-shaped cars, over 43 km/h less severe injuries.

10. There is no difference in the injury severity caused by the second collision between pontoon and V-shaped cars.

11. Heavy cars produce at all impact speeds more severe injuries than light cars.

12. The size of the car does not influence the injury severity.

13. The most endangered body parts are:
    for children - head, abdomen, legs
    for adults - head, thorax, pelvis and lower legs

14. The aggressivity of exterior car parts consists in injury frequency and injury severity essentially as a product of both.

15. The design of the front end influences drastically the rank of the most aggressive exterior car part.

16. The most aggressive exterior parts of the car are:
    for children - the bonnet, bumper and windscreen
    for adults - the bumper, bonnet and windscreen frame.

For most of the investigated parameter as impact speed, car shape, car weight, pedestrian size and age, tendencies could be evaluated. Other parameter, like size of car, have to be investigated in the future with refined methods and possibly directly coupled with other parameter like stiffness and shape.

LITERATUR

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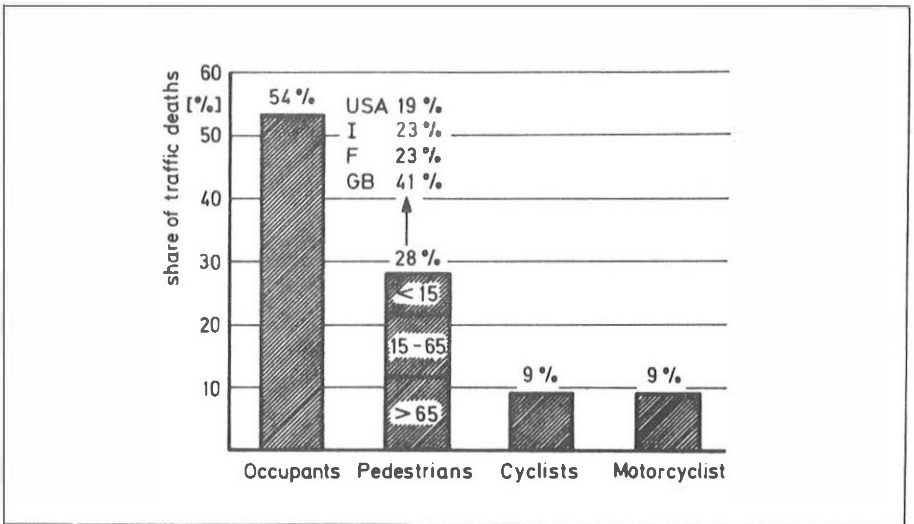

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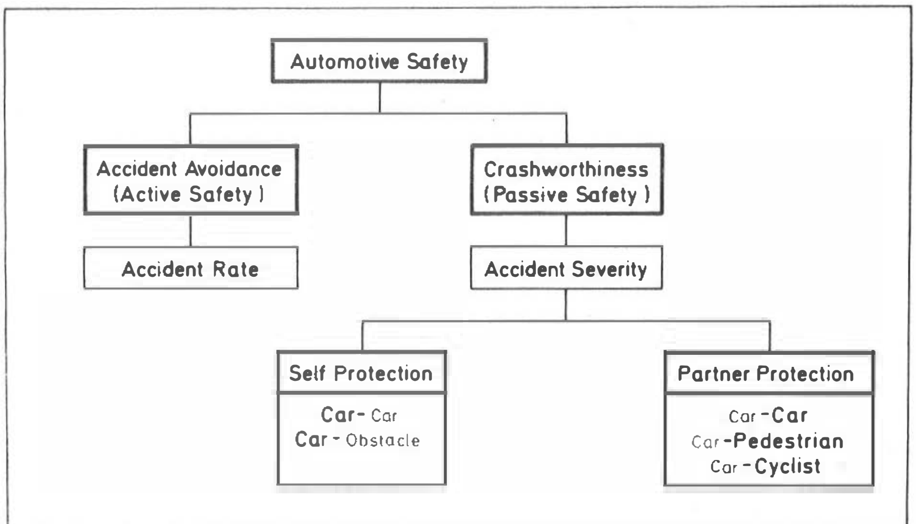

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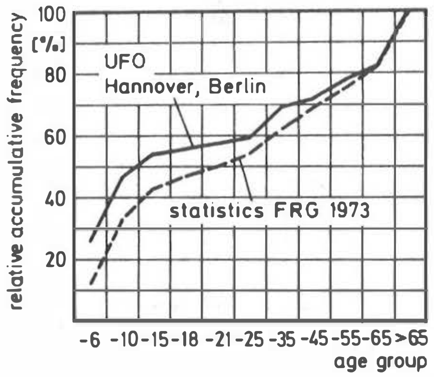

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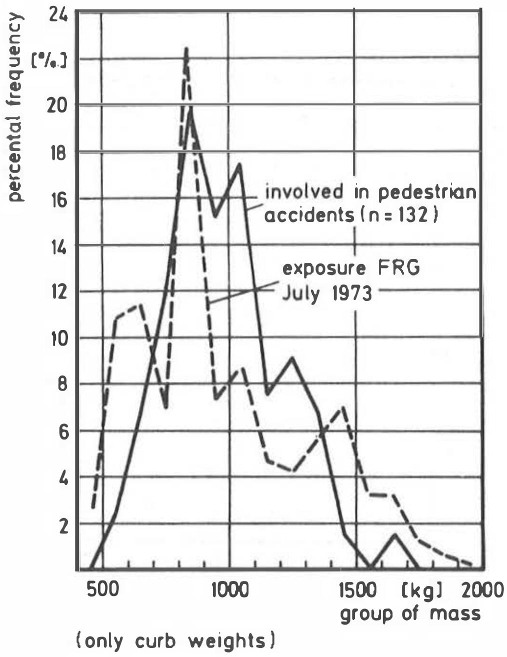
75303

People-age-groups involved in pedestrian accidents

Ap/St/Go

Fig.3



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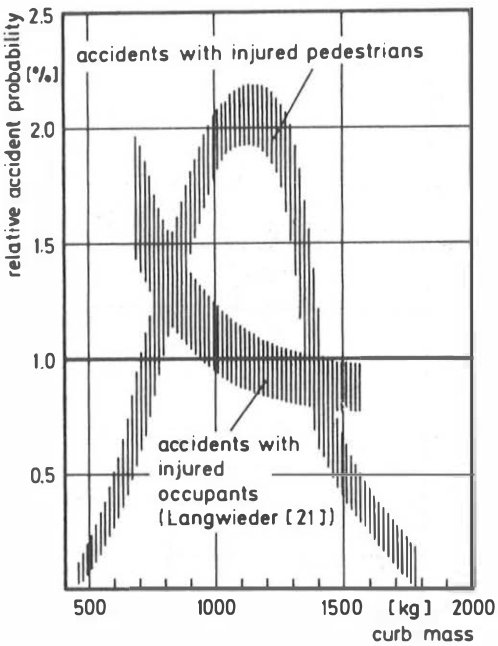
Pedestrian accident involvement rates and exposure of light and heavy passenger cars

Ap/St/Go

Fig.4



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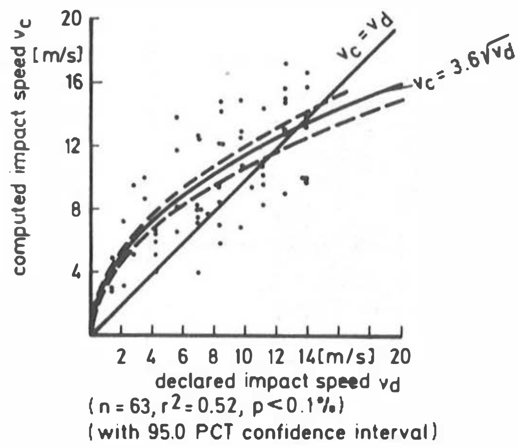
Accident probability related to the exposure of light and heavy passenger cars

Ap/St/Go

Fig.5



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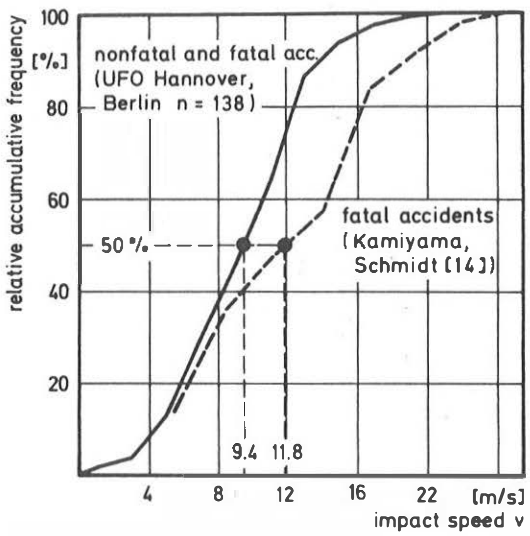
comparison of estimated (driver) and computed impact speed

75306

Ap/St/Go

Fig. 6



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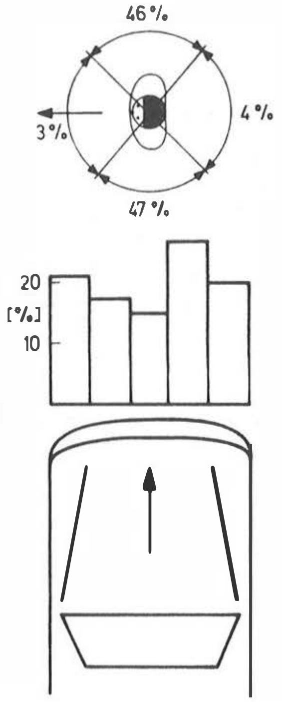
75 307

Relative accumulative frequency of impact speeds for pedestrian accidents

Ap/St/Go

Fig. 7



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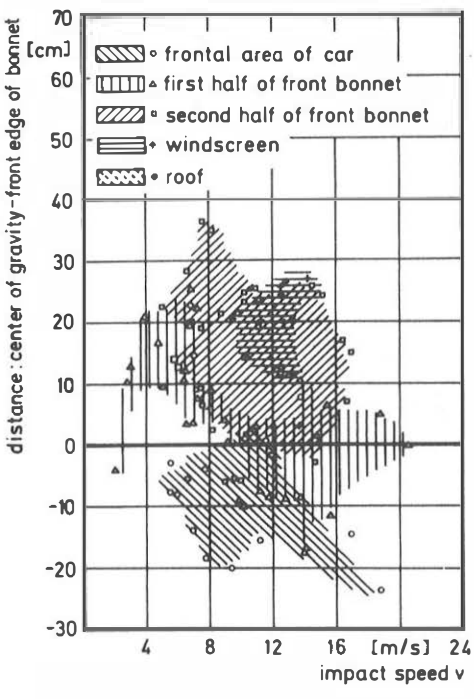
75308

Percental frequency of impact points on human body and vehicle front side

Ap/St/Go

Fig 8



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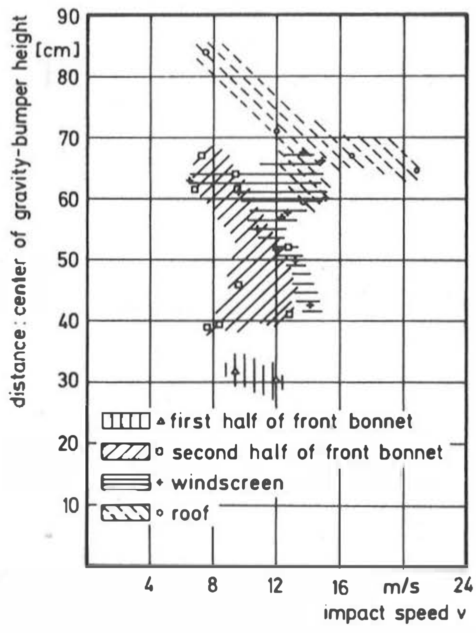
75309

Throw on wide versus impact speed for passenger cars with pontoon contour

Ap/St/Go

Fig. 9



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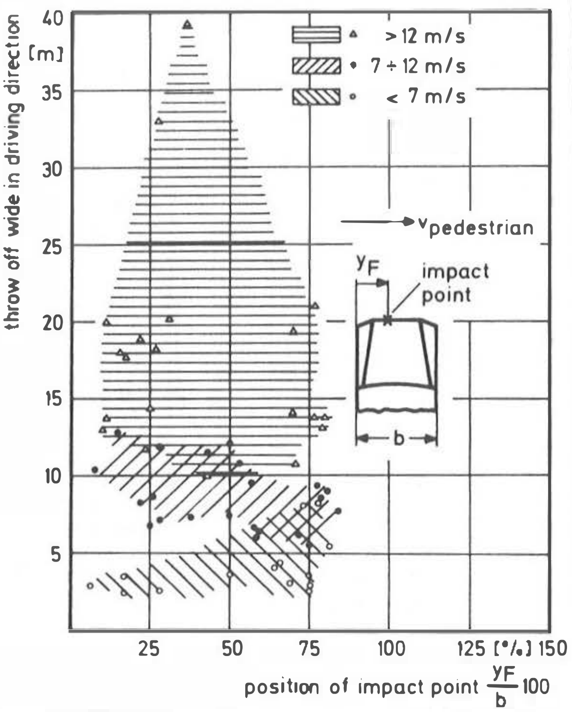
75310

Throw on wide versus impact speed for passenger cars with V-contour

Ap/St/Go

Fig. 10



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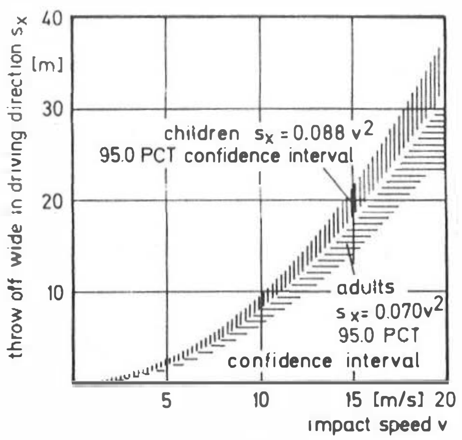
Throw off wide in driving direction versus position of impact point	Ap/St/Go Fig. 11



(impact points don't include the vehicle side edges)

(children : $n = 39$, $r^2 = 0.80$, $p < 1\,\%$)

(adults : $n = 31$, $r^2 = 0.68$, $p < 1\,\%$)

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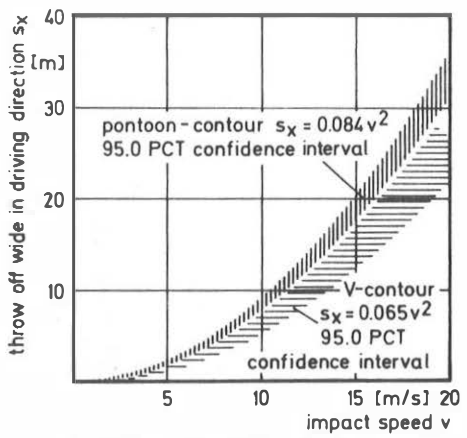
Throw off wide in driving direction versus impact speed for children and adults	Ap/St/Go Fig. 12



(impact points don't include the vehicle side edges)

(pontoon contour: $n = 56$, $r^2 = 0.76$, $p < 1\,\%$)

(V-contour: $n = 11$, $r^2 = 0.69$, $p < 1\,\%$)

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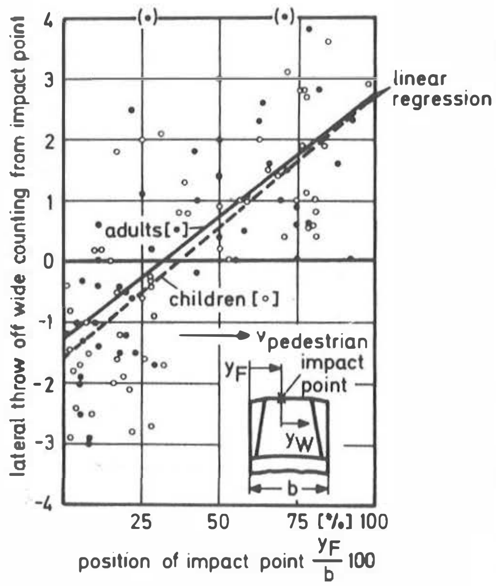
Throw off wide in driving direction versus impact speed for vehicle front contours	Ap/St/Go Fig. 13



adults ($n = 49$, $r^2 = 0.43$, $p < 1\,\%$) $y_W = -1.29 + 0.04\, y_F$

children ($n = 56$, $r^2 = 0.54$, $p < 1\,\%$) $y_W = -1.56 + 0.04\, y_F$

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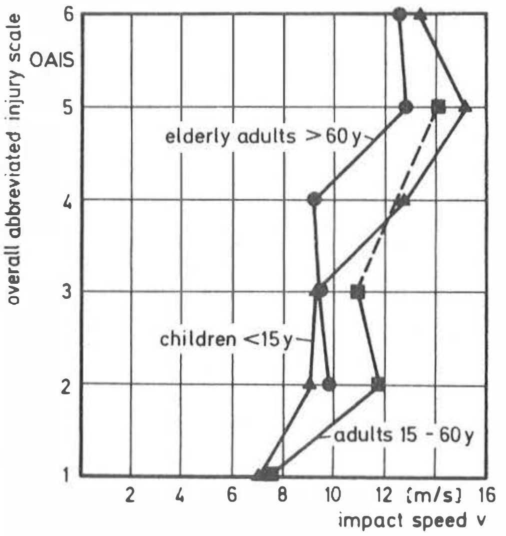
Lateral throw off wide in walking direction versus position of impact point at vehicle	Ap/St/Go Fig. 14



▲ < 15 y : n = 67 ; p < 1 %. ; V = 14.3 m^2/s^2

■ 15 - 60 y . n = 32 ; p < 1 %. ; V = 9.9 m^2/s^2

● > 60 y : n = 28 ; p > 5 %. ; V = 11.3 m^2/s^2

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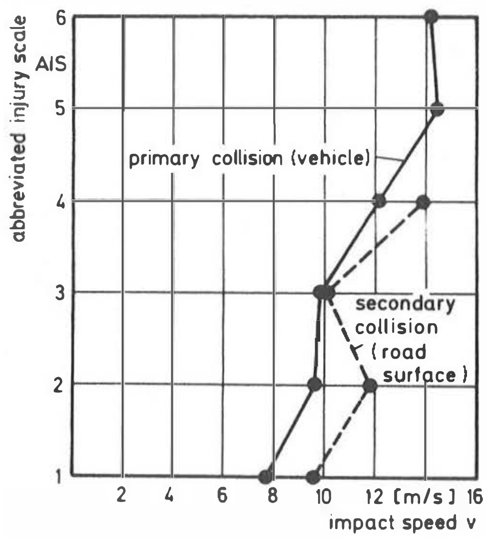
Injury severity versus impact speed for main groups of pedestrians	Ap/St/Go Fig. 15



primary collision : p < 1 %. ; V = 13.9 m^2/s^2

secondary collision : p > 5 %. ; V = 14.0 m^2/s^2

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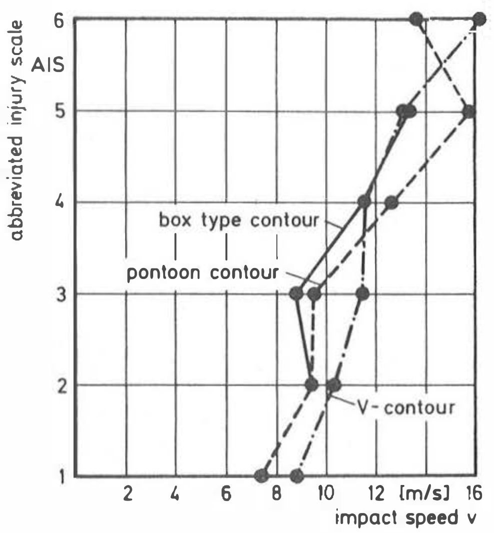
Injury severity versus impact speed for primary and secondary collision	Ap/St/Go Fig. 16



box type contour : p > 5 %. ; V = 11.1 m^2/s^2

V - contour : p > 5 %. ; V = 6.5 m^2/s^2

pontoon contour : p < 1 %. ; V = 15.7 m^2/s^2

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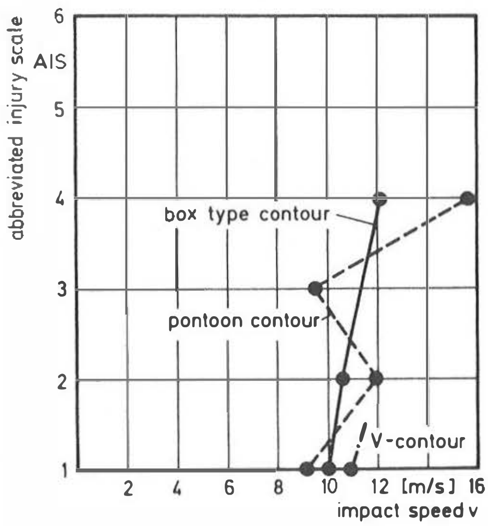
Injury severity versus impact speed in primary collisions for different front contours	Ap/St/Go Fig. 17



box type contour: p > 5 %. , V = 3.2 m^2/s^2

V - contour : — V = 6.4 m^2/s^2

pontoon contour : p > 5 %. , V = 16.4 m^2/s^2

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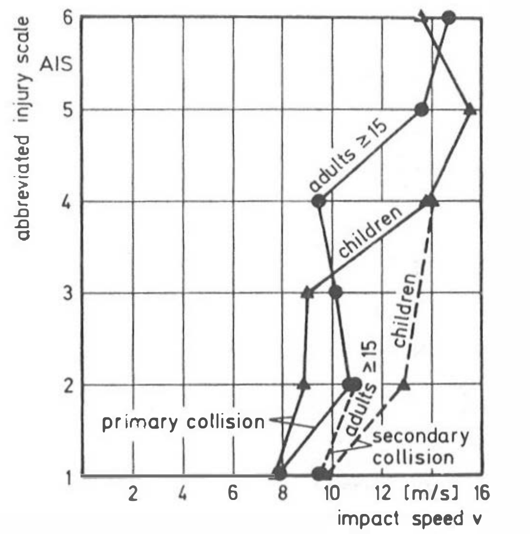
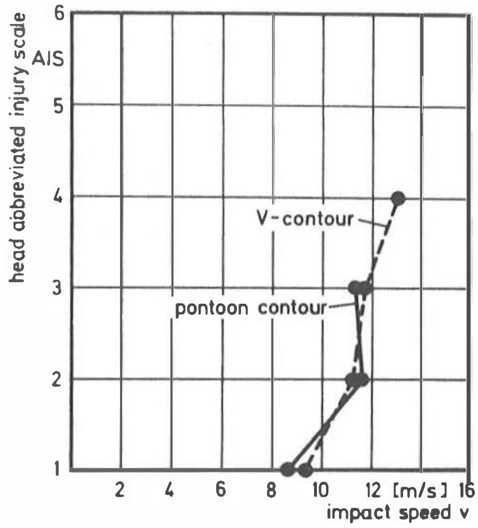
Injury severity versus impact speed by secondary collision for different front contours	Ap/St/Go Fig. 18



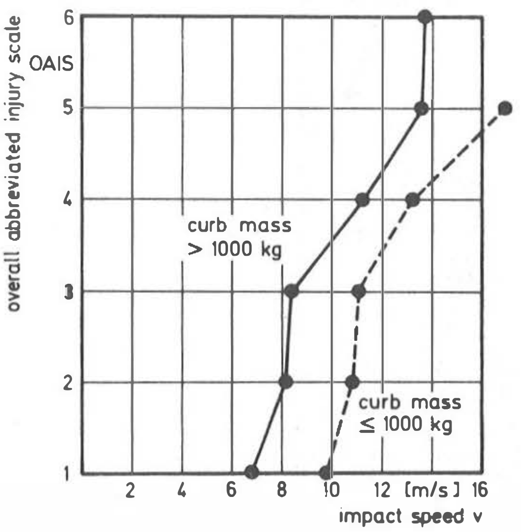
primary children : $p < 1‰$, $V = 15.5 m^2/s^2$
primary adults : $p < 1‰$, $V = 12.6 m^2/s^2$
secondary children : $p > 5‰$, $V = 16.6 m^2/s^2$
secondary adults : $p > 5‰$, $V = 11.3 m^2/s^2$

INSTITUT FUR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITAT BERLIN	75 319
Injury severity versus impact speed by primary and secondary collision for different age groups	Ap/St/Go Fig. 19



pontoon: $p < 1‰$, $V = 13.2 m^2/s^2$
V-contour: $p > 5‰$, $V = 8.0 m^2/s^2$

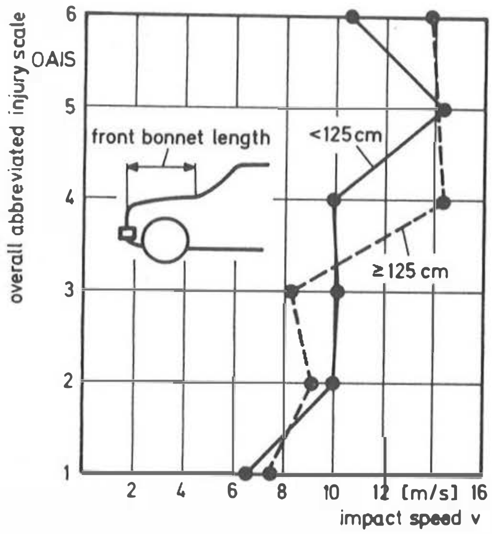
INSTITUT FUR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITAT BERLIN	75320
Injury severity of the head versus impact speed for different contour types	Ap/St/Go Fig. 20



(only pontoon contours)

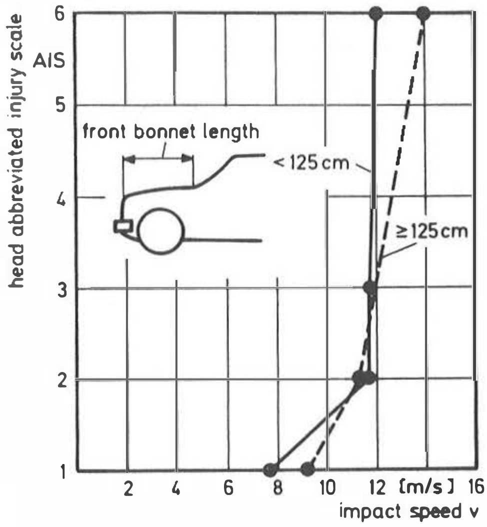
≤1000kg : $p < 1‰$, $V = 11.7 m^2/s^2$
>1000 kg : $p < 1‰$, $V = 13.9 m^2/s^2$

INSTITUT FUR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITAT BERLIN	75321
Injury severity versus impact speed for different curb masses	Ap/St/Go Fig. 21



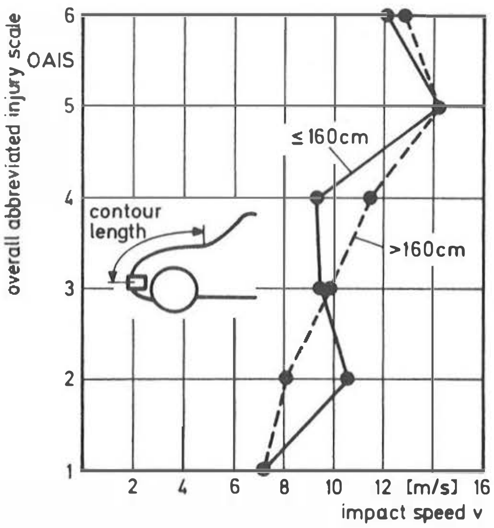
< 125 cm : $p < 1‰$, $V = 15.0 m^2/s^2$
≥ 125 cm : $p < 1‰$, $V = 12.4 m^2/s^2$

INSTITUT FUR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITAT BERLIN	75322
Injury severity versus impact speed for different front bonnet lengths	Ap/St/Go Fig. 22



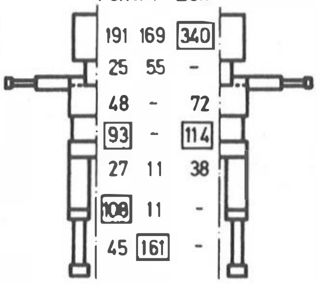
< 125cm : p<5%, V = 8,5 m^2/s^2
≥ 125cm : p>5%, V = 12,5m^2/s^2

INSTITUT FUR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITÄT BERLIN	75 323
Injury severity of the head versus impact speed for different front bonnet lengths	Ap/St/Go Fig. 23



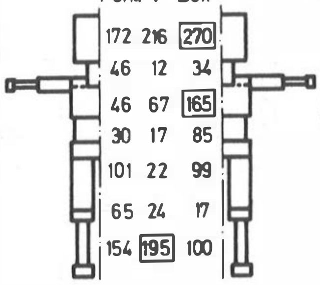
≤ 160cm: p<1%, V = 13.2 m^2/s^2
> 160cm: p<1%, V = 12.7 m^2/s^2

INSTITUT FUR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITÄT BERLIN	75324
Injury severity versus impact speed for different contour lengths	Ap/St/Go Fig. 24



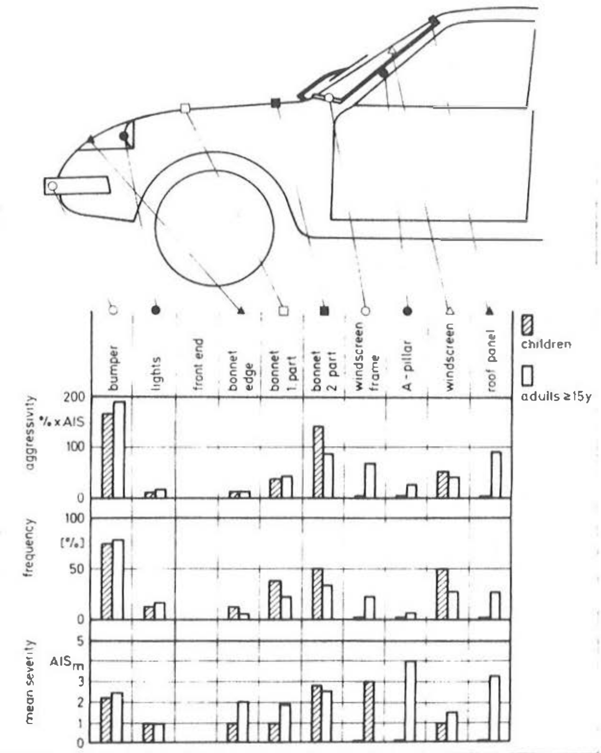
injury frequency (%.)			(%. x AIS)			abbreviated injury scale (AIS)		
Pont.	V	Box	Pont.	V	Box	Pont.	V	Box
91	89	100	191	169	340	2.1	1.9	3.4
13	22	-	25	55	-	1.9	2.5	-
19	-	38	48	-	72	2.5	-	2.0
32	-	38	93	-	114	2.9	-	3.0
17	11	25	27	11	38	1.6	1.0	1.5
54	11	-	108	11	-	2.0	1.0	-
28	67	-	45	161	-	1.6	2.4	-
frequency			aggressivity			severity		

INSTITUT FÜR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITÄT BERLIN	Frequency and severity of injuries of child-pedestrian for various body parts	75325	Ap/St/Go Fig. 25

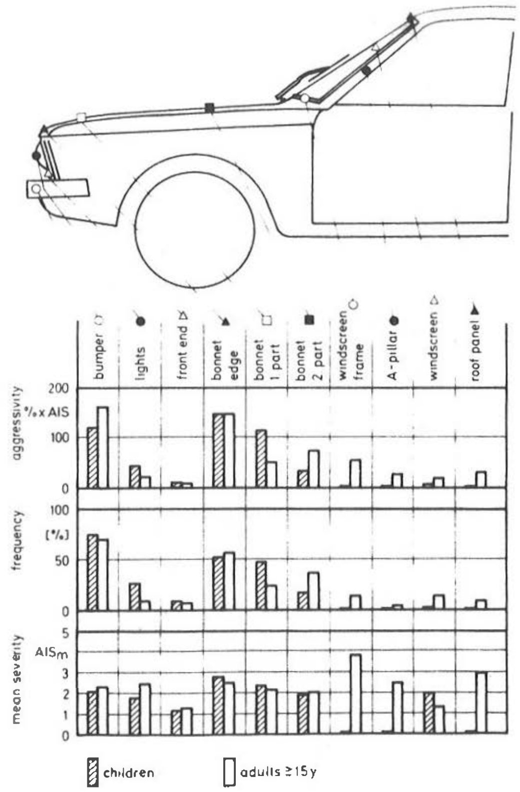


injury frequency (%.)			(%. x AIS)			abbreviated injury scale (AIS)		
Pont.	V	Box	Pont.	V	Box	Pont.	V	Box
86	94	100	172	216	270	2.0	2.3	2.7
19	6	17	46	12	34	2.4	2.0	2.0
14	28	50	46	67	165	3.3	2.4	3.3
7	11	50	30	17	85	4.3	1.5	1.7
36	11	33	101	22	99	2.8	2.0	3.0
38	17	17	65	24	17	1.7	1.4	1.0
67	78	50	154	195	100	2.3	2.5	2.0
frequency			aggressivity			severity		

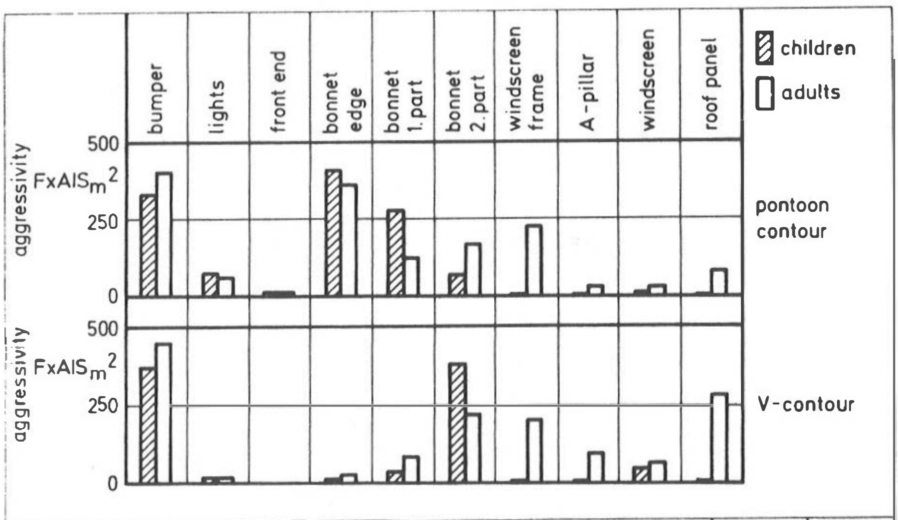
INSTITUT FÜR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITÄT BERLIN	Frequency and severity of injuries of adults ≥15y for various body parts	75326	Ap/St/Go Fig. 26



INSTITUT FÜR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITÄT BERLIN | Aggressivity of exterior parts V-contour | 75 327 | Ap/St/Go Fig 27



INSTITUT FÜR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITÄT BERLIN | Aggressivity of exterior parts pontoon contour | 75 328 | Ap/St/Go Fig 28



INSTITUT FÜR LANDVERKEHRSMITTEL TECHNISCHE UNIVERSITÄT BERLIN | Aggressivity $F \times AIS_m^2$ of exterior parts | 75329 | Ap/St/Go Fig. 29