Injuries to Heavy Truck Occupants – Severity, Patterns and Causation

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Abstract

With the objective to determine the number of killed and injured occupants in trucks with a gross vehicle weight over 12,000 kg (N3 category), consisting of semi-trailers and rigid trucks with and without trailers, a special analysis of the German national statistics was carried out. In 2014, 49 truck occupants were killed and 563 seriously injured in Germany, a considerable number in semi-tractors with foreign registration. Single-vehicle crashes were responsible for one third of the fatalities.

In order to obtain further insight into the prevalent injuries and the collision scenarios causing them, 436 accidents from the German Insurers Accident Database that involved 570 heavy trucks and 594 of their occupants were analysed. Of these, 157 occupants were actually injured, ten of them fatally. Of the 131 persons with detailed injury data, 19 occupants (15%), each, presented MAIS2 and MAIS3+ injury severities. At MAIS2 level, AIS2 injuries were found in the head and face region, in the upper extremities and in the lower legs and feet. MAIS3+ included AIS3+ head, thoracic and abdominal injuries.

Rear-end collisions between heavy trucks, mainly occurring on motorways, were identified as the leading cause for severe injuries or fatal outcomes. The amount of driver cab deformation and its location on the front of the cab appears to determine injury severity more than vehicle deceleration during the crash. Seat belt use could be determined only for a portion of all cases. Belted occupants showed a lower rate of MAIS2+ injuries than those not wearing a seat belt. Driver airbags were installed in 68 vehicles, but only five were documented as deployed.

Keywords Driver cab, heavy vehicle, injury severity, rear-end collision, truck occupant.

I. INTRODUCTION

Many studies have dealt with injuries of car occupants as well as vulnerable road users, but the body of research on injury patterns and severities in occupants of heavy vehicles, particularly heavy trucks, is very limited so far and sometimes dates back to several decades ago.

Reference [1] analysed data from 850 crashes with killed and seriously injured in 1997 in the German state of Bavaria that involved goods vehicles over 3,500 kg gross vehicle weight (GVW). While these accidents claimed 143 fatalities and 691 seriously injured among the crash opponents, 14 truck occupants were killed and 143 were seriously injured. Ten of the killed truck occupants died in collisions with another truck or truck-trailer combination and only two, each, in a crash with a car or in a single-vehicle accident. However, approximately one third of all seriously injured truck occupants resulted from the latter crash type. With 26%, the head was the most frequently affected body region in occupants with MAIS2+ injury severities, followed by the thorax (17%) and lower legs (16%). Head and thorax injuries were attributed mostly to contact with the steering wheel and lower leg injuries were caused by cab intrusions.

Reference [2], in a detailed study of injuries sustained by 78 seriously injured drivers of trucks with 7,490 kg GVW and above in Germany between 1996 and 2001 found the largest proportion of injuries, in general, in the lower extremities (65%), followed by the head region (49%) and upper extremities (42%). However, when looking at the most severely injured body region that determined the MAIS value of each individual, the lower extremities were leading with 42% and the head and the spine came in second with 19%, each. Thorax, abdomen and pelvis injuries displayed the highest AIS values, but were comparably infrequent.

More recent data on truck occupant injuries was provided by [3]. They evaluated GIDAS data on 582 drivers

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of trucks with a GVW of 7,000 kg and above involved in injury crashes in Germany between 2000 and 2011. Altogether, 77 truck drivers (13%) were injured. Similar to previous studies, they reported that the body regions that sustained injuries, irrespective of the injury severity, were the legs (n=36) and the arms (n=32), followed by the head (n=28). MAIS was highest in frontal collisions and although the authors did not analyse driver cab deformation, they hypothesised that injury severity would increase with the degree of deformation.

With trucks covering a wide range of vehicle weights, in general, it is meaningful to discriminate them further by gross vehicle weight when observing their crash involvement. The standard accident statistics report published annually by the German Federal Office of Statistics [4] provides no break-down of goods transport vehicles by GVW, except for delivery vans up to 3,500 kg GVW (N1 category). Therefore, [5] carried out a special analysis of 2015 data from the German national road traffic accident statistics regarding crashes involving heavy trucks, i.e., N3 trucks, with German registration. N3 trucks according to Directive 2007/46/EC of the European Commission [6] are goods transport and service vehicles with a GVW over 12,000 kg which include trucks and semi-tractors, irrespective of whether they operate as single-units, i.e., rigid trucks, or in combination with a drawbar trailer or semi-trailer, respectively. N3 trucks with German registration were involved in 11,261 injury crashes in 2015, the largest share with 37% occurring on motorways. The study reported 14 fatalities and 237 seriously injured in single-vehicle accidents of N3 trucks. In fatal crashes between two parties with at least one of them being a N3 truck, 360 road users died, 22 (6%) of them being N3 occupants. However, it is known that N3 occupant casualties are also found in crashes involving three or more parties, but no data is given in the study of [5] with these regards. Moreover, with Germany seeing a lot of goods transiting on its roads, especially between eastern and western Europe, heavy trucks with foreign registration account for a considerable share of crashes. When truck accident numbers of central European countries are discussed, it is meaningful to consider these as well.

Reference [7] analysed heavy truck crashes in Japan and found that frontal and rear-end collisions were the most common. Injuries to the upper and lower extremities, caused by contact with the instrument panel, were the most frequent, followed by chest and abdominal injuries. The latter were attributed to contact with the steering wheel. The authors proposed to increase the structural strength of the cab in order to reduce intrusion and avoid that the steering wheel tilts up in a frontal impact.

From the U.S., one study [8] dating from 2015 is particularly worth mentioning. Two larger databases, Trucks Involved in Fatal Accidents (TIFA) and a subset of National Automotive Sampling System (NASS), were analysed regarding the crashworthiness of heavy trucks and injuries sustained by their occupants. Trucks for long-distance goods transport were combinations of a semi-tractor and semi-trailer and designed almost entirely as so-called conventional trucks with the engine mounted in front and the sleeper compartment attached to the rear of the driver's cab. Single-unit trucks, on the other hand, featured both conventional and cab-over-engine (COE) designs, the latter mostly on lighter vehicles. More than 750 fatalities annually were reported for heavy and medium trucks. The study found that both types had comparable numbers of occupant injuries, but semi-tractors experienced approximately 100 fatalities more each year. The most harmful events for trucks in all crash severities were rollovers with 233 killed drivers, collisions with hard fixed objects with 122 and collisions with other trucks or buses with 88 killed drivers, on average.

The purpose of the present study is, firstly, to provide an overview of the number of casualties among occupants of N3 trucks including those with foreign registration in Germany and, secondly, to analyse crash data with regards to heavy truck occupant injuries and the typical crash scenarios under which they occur. The scope of this study is limited to accidents involving only a portion of the entire goods transport vehicle fleet in this country. Therefore, the results should be interpreted carefully when transferring them to different countries or continents.

II. METHODS

Two different sources were utilised for the analysis of crash data involving heavy trucks.

For the overview of accident occurrence on German roads, a special analysis of the 2014 national statistics regarding heavy truck crashes was used. This analysis had been commissioned previously at the Federal Office of Statistics specifically for a general study on heavy truck accidents in 2016 [9]. It comprised N3 goods transport vehicles, broken down into rigid trucks, truck drawbar-trailer combinations and semi-trailer combinations like in the 2015 study [5]. In addition, it included also involved foreign registered trucks. While the police are usually not able to determine the exact gross vehicle weight of a foreign truck when filing an accident report, it is possible to discriminate between semi-trailer combinations and other goods vehicles. Since tractors for semi-trailers are almost exclusively rated with a GVW over 12,000 kg it can be safely assumed that foreign semi-tractors would fall in the N3 category. Moreover, semi-trailer combinations are the dominating type of truck for long distance transport in Europe. Thus, it can be assumed that the major portion of foreign N3 trucks involved in crashes on German roadways is represented by semi-trailer combinations.

Data for the detailed evaluation of crash circumstances and injuries sustained by truck occupants came from the German Insurers Accident Database (UDB). This database contains information from samples obtained retrospectively from claim files of German motor liability insurers. Crashes that occurred between 2009 and 2013 were analysed, the majority of them in 2012 due to a larger sample of truck accidents drawn for this year. The time lag between the year that the accident happened and that the case entered the database results mainly from claim processing at the insurer. Cases recruited for the present study involving heavy trucks were required to have estimated claim costs of at least EUR 30,000, covering both personal and property damage irrespective of the actual payments during claim processing and whether the truck driver or another road user was at fault. While some less costly collisions with minor damage to opponent vehicles or slight injuries of their users may be missed with the defined minimum cost threshold, injurious crashes for the truck occupant will likely be captured since major property damage to the truck, its crash opponent or roadside infrastructure can be expected in such cases.

Contrary to the evaluation of the national statistics that is being restricted to German registered N3 trucks and foreign semi-tractors, the analysis of UDB data considers also trucks with a GVW of just below 12,000 kg. The latter are popular particularly as rigid trucks for regional distribution services, often registered with a GVW of 11,990 kg. Formally, they belong to the N2 category according to EC Directive 2007/46/EC [6], but feature chassis frames and driver cabs similar in design and size to those of N3 vehicles (Fig. 1).

Fig. 1. Examples of rigid trucks (above left: 11,990 kg GVW, N2; above right: 32,000 kg GVW, N3), rigid truck (below left: 26,000 kg GVW, N3) with drawbar-trailer, and semi-tractor (below right: 18,000 kg GVW, N3) with semi-trailer.

For this part of the study, goods and service vehicles with a gross vehicle weight starting at 11,900 kg, including their trailers and semi-trailers will be termed *heavy trucks*. Since the data is based on documentation of German liability insurers it pertains primarily to heavy trucks registered in Germany. Nevertheless, the evaluated cases may contain also trucks with foreign registration when several heavy vehicles are involved in an accident. Single-vehicle crashes of heavy trucks which – by definition – do not involve another road user are not captured by liability insurance unless another party, for instance, an injured passenger who was riding in the vehicle, files a claim.

The documentation of crashes usually comprised police reports, witness statements, and sometimes hospital discharge information and post-mortem reports. Several variables were used to characterise the accident site and the actual crash event. These included, among others, the type of road and the type of collision, i.e., whether it occurred as a frontal or rear impact and whether there was a collision opponent or a roadside structure involved.

Injury severity was categorised, on the one hand, according to the definition in German national statistics: killed (deceased within 30 days after the accident), seriously injured (in-patient treatment for at least 24 hours immediately after the accident) and slightly injured (all other injured). On the other hand, individual injuries were coded according to AIS 2005, update 2008 [10], where case documentation was sufficient. Injury severities are then given per body region. Injury severities were grouped into three categories: AIS0-1 for no or only minor injury, AIS2 for moderate injury, and AIS3+ for serious to maximum injury severity. Maximum AIS (MAIS) was determined to describe the overall injury severity of the truck occupant. Where case documentation did not provide the complete injury pattern of occupants with multiple injuries, but described only the major type of trauma, it was assumed that it would also represent the most severe injury sustained by the individual and MAIS was therefore estimated on this basis.

For evaluation of the cause of truck occupant injuries, information on vehicle damage and deformation as well as the use of restraint systems is of interest. These were categorised by location of the main impact (front, left side, right side, rear, top, bottom) and, primarily for the front, whether it pertained to the left, centre or right third of the affected area or a combination of these (Fig. 2). In addition, the degree of deformation (DoD), especially to the driver cab, was classified in five levels based on images of the involved vehicle (Fig. 3).

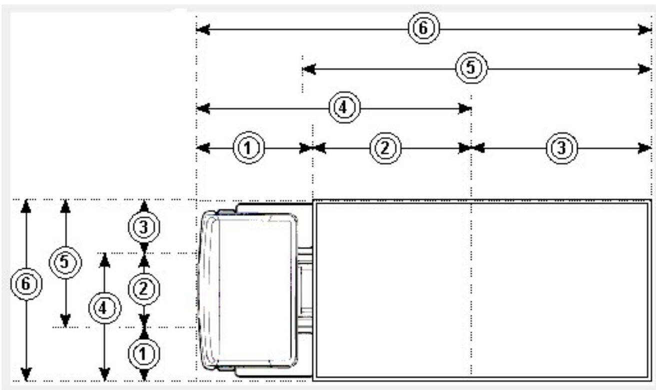

Fig. 2. Scheme to describe the location of impact on the front and the side of the truck.

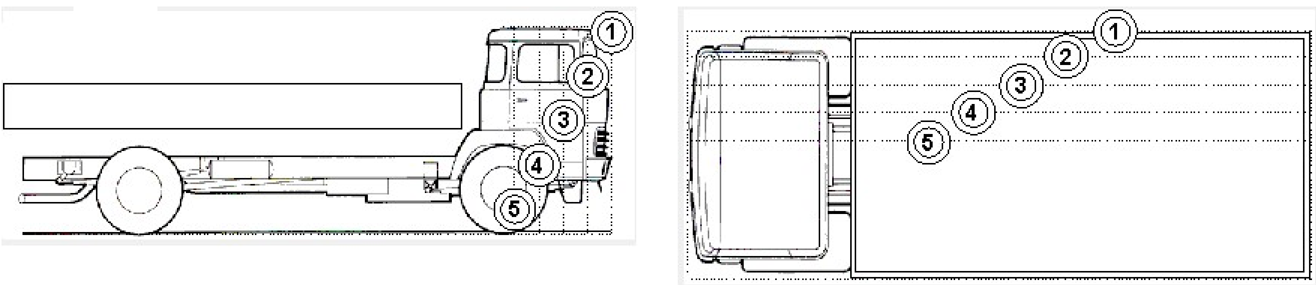

Fig. 3. Scheme to describe the degree of damage (DoD) on the front and the side of the truck.

Seat belt use by the truck occupant was attempted to discern from police reports and other crash documentation, but was often impossible to determine reliably.

The results are provided on the level of the individual person, i.e., the heavy truck occupant, unless otherwise indicated. Therefore, in cases involving more than one occupant the circumstances of the crash or – in case of several occupants in one truck – the characteristics of the vehicle will appear several times in the count, accordingly. For particular aspects, subsets of data are evaluated, i.e., only for injured truck occupants or particular collision scenarios.

Some of the cases had to be excluded from certain analyses depending on the detail and reliability of data. Therefore, percentage values from the data analysis relate to the number of valid cases.

Differences of values based on continuous variables were tested for significance using the t-test, for dichotomous variables the Chi-square test was applied. Statistical significance was assumed at a p-level of 0.05, otherwise the difference was considered non-significant (n. s.).

III. RESULTS

Special Analysis of National Statistics

The results of the special query of the 2014 national statistics regarding N3 trucks and foreign semi-tractors are provided in Table I. In total, 49 occupants of N3 trucks registered in Germany and foreign semi-tractors were killed and 563 were seriously injured. Slight injuries were reported for 1,723 occupants. The largest proportion of killed (n=31; 63%) and seriously injured (n=333; 59%) is found in crashes on motorways. Among fatally and seriously injured occupants in semi-tractors, those in foreign vehicles account for 27% and 35%, respectively. N3 rigid trucks with and without trailers display nearly the same numbers of killed and seriously injured, respectively, but for trucks with trailers the focal point is on motorways whereas the number of casualties in trucks without trailers is on rural roads and in built-up areas, likely due to where they operate primarily.

The share of single-vehicle accidents was available only regarding the number of crashes, but not the number of casualties. According to that, 16 N3 single-vehicle accidents with fatal outcome occurred in 2014. Assuming that not more than one occupant, each, was killed in these vehicles it can be inferred that 16 of the total of 49 fatalities among N3 occupants have to be attributed to these kinds of crashes.

TABLE I
N3 TRUCK CASUALTIES IN GERMANY, 2014

	Motorway			Outside built-up area (excluding motorway)			Built-up area		
	Killed	Seriously inj.	Slightly inj.	Killed	Seriously inj.	Slightly inj.	Killed	Seriously inj.	Slightly inj.
N3 rigid truck w/o. trailer, German registration	-	19	42	3	42	177	4	26	158
N3 rigid truck w/ trailer, German registration	4	54	118	-	21	125	1	7	29
N3 semi-tractor/trailer, German registration	20	144	334	5	85	288	2	24	136
N3 semi-tractor/trailer, foreign registration	7	115	215	3	20	48	-	3	15
other N3 truck	-	1	2	-	1	20	-	1	16
total	**31**	**333**	**711**	**11**	**169**	**658**	**7**	**61**	**354**

Analysis of Insurers Accident Database

For the second part of the study, the German Insurers Accident Database (UDB) provided 436 accidents with at least one heavy truck (GVW of 11,900 kg and above). Altogether, 570 heavy trucks and 594 of their occupants were involved and 157 received injuries. Twenty-six heavy trucks were involved in an accident event, but not in an actual collision, thus, leaving their occupants without injury. For four heavy truck occupants, there was no information as to whether they were injured or not. Of the confirmed 157 casualties, ten were fatally (6.4%), 41 were seriously (26.1%) and 106 were slightly injured (67.5%).

Road infrastructure and environmental conditions: Approximately two thirds of all truck occupants (n=409, 68.9%) were involved in accidents outside built-up areas, including 275 (46.3%) on motorways. Of the 157 injured truck occupants, only 15 (9.6%) were involved in crashes inside built-up areas, the remainder, accordingly, outside of built-up areas including 108 on motorways (68.8%). In particular, eight of the ten fatalities occurred on motorways. The higher rate of injured occupants found in accidents on motorways was statistically significant ($p<0.01$).

The road surface was dry in accidents with known road conditions for 446 occupants (77.0%). Wet road surface was present in 103 cases (17.8%) and slippery or icy conditions were reported only in 30 cases (5.2%). Dry road surface was found in 117 cases (74.5%) among the 157 injured truck occupants and wet roads in 30 cases (19.1%), the difference in proportion of dry roads in comparison to non-injured not being significant (n.s.).

Daylight was present in accidents with known light conditions for 478 occupants (80.7%), darkness or dusk was reported in 114 cases (19.3%), respectively. Injured occupants crashed under daylight conditions in 118 cases (75.2%) and in darkness and dusk in 39 cases (24.8%). The slightly larger proportion of injured in crashes occurring in darkness or dusk in comparison to non-injured was statistically significant ($p<0.05$).

Truck characteristics, truck occupant demography: Among the 594 occupants in heavy trucks, 346 (58.2%) were in semi-tractors, 115 (19.4%) were in rigid trucks with a drawbar-trailer and 133 (22.4%) in rigid trucks without a trailer. All heavy trucks were cab-over engine (COE) designs, 29 of them being N2 vehicles with a GVW just under 12,000 kg. Injuries were found in 93 (59.2%) occupants of semi-tractors, in 34 (21.7%) occupants of rigid trucks with a drawbar-trailer, and in 30 (19.1%) occupants of rigid trucks without a trailer. The proportion of injured occupants in semi-tractors was not statistically different from that in rigid trucks with and without trailer (n.s).

Vehicle age at the time of the accident could be determined for 528 semi-tractors and rigid trucks, averaging 4.6 years of service (median: 4 yrs.) and ranging between practically new vehicles to 33 years of age for a military truck. There was no difference in age of vehicles in which occupants were injured (average: 4.49 yrs., median: 4 yrs.) as opposed to vehicles where occupants remained non-injured (average: 4.58 yrs., median: 4 yrs.).

The truck occupants consisted of 587 males, among them 21 passengers, and seven females, three of them being passengers. Age was available for 540 of the occupants, averaging 44.6 years (median: 46 yrs.) and ranging from 15 years for a passenger to 74 years for a driver. Injured occupants were slightly older (average: 45.3 yrs., median: 46 yrs.) than non-injured (average: 44.3 yrs., median: 45 yrs.), but not significantly (n.s.).

Police documentation on use of alcohol was available for 413 truck drivers, but merely one of them was actually found being under the influence of alcohol.

Collision scenarios and crash opponents: Because many accidents included multiple collisions for the heavy trucks, crashes were classified into scenarios depending on the presumably most severe collision or impact for the truck occupant. For these, the number of occupants with major injury was determined, discriminated by overall injury severity according to the definition used in national statistics and according to MAIS. Table II provides an overview of the most frequent scenarios that caused major injury (killed and seriously injured; MAIS2 and MAIS3+). Non-injured and slightly injured occupants and those with MAIS0 and MAIS1, respectively, were put in one combined category, each, to separate them from persons with major injury. In this context, it is noteworthy that a few occupants were rated as seriously injured according to national statistics definition, but displayed only MAIS1, whereas some individuals with MAIS2 were rated as slightly injured.

Of the 568 occupants actually experiencing some kind of collision, either in a single-vehicle accident or in a collision with another road user, 134 had an accident with a pedestrian, a bicyclist or a motor-cyclist. None of the collisions with a vulnerable road user (VRU) produced injury in the truck occupant. Similarly, collisions with passenger cars and vans caused MAIS1 injury, at most, in the heavy truck occupant. The focal point regarding scenarios to cause major injury is therefore on single-vehicle crashes and collisions with other heavy trucks, although the entire material included also twelve collisions with buses, trams and trains, and one farm tractor. Table II therefore shows collision scenarios with another heavy truck as the primary crash opponent. Collisions with a motor-vehicle (MV) *travelling in the same direction or stopped* were by far the most frequent in this regard, typically characterised by situations in which one truck rear-ended another on a motorway in slowed-down or stopped traffic. Eight of the ten fatally injured heavy truck occupants and more than half of the MAIS2 and MAIS3+ cases resulted from such crashes.

Some of the rear-end crashes into another truck, particularly when stationary at the end of a traffic jam, resulted in the rear-ended vehicle being pushed into a third truck ahead of it. In such cases, the occupant of the truck that was first struck in the rear and then received a second impact at its front was regarded as an occupant with a – primarily – frontal loading, too. This is a viable assumption in light of the fact that occupants who experienced solely a rear-impact remained non-injured or showed MAIS1, mostly due to cervical spine distortions. By contrast, in trucks with a rear-impact and a subsequent frontal impact, half of the occupants showed also head and facial injuries in addition to spine distortions. Two drivers were MAIS2 injured and one sustained MAIS4 injury in a cab with severe front deformation.

Collisions between a heavy truck and another oncoming vehicle were experienced by 46 occupants, but only two crashes on rural roads with another oncoming truck actually resulted in MAIS3+ injuries for three of the heavy truck occupants. In one of these crashes, both trucks suffered severe cab deformation and one truck driver sustained a MAIS6 neck injury while the driver of the opponent vehicle was injured MAIS3.

Rollovers were documented in 23 cases, altogether. With the exception of two trucks performing a three-quarter turn, all others tipped over on the side, i.e., had a one-quarter turn. Thirteen rollovers were deemed the most harmful events for truck occupants.

Truck fires after a collision were reported in six crashes, but with one exception did no harm, either because the occupant was able to escape from the burning vehicle in time or because the fire could be extinguished quickly.

TABLE II

OVERVIEW OF COLLISION SCENARIOS AND INJURY SEVERITIES OF HEAVY TRUCK OCCUPANTS

		Heavy truck occup. injury severity (national stats.)			**Heavy truck occup. injury severity (Maximum AIS)**			
	No . of involved occup.	Non-/ slightly injured	Seriously injured	Killed	MAIS 0-1	MAIS 2	MAIS 3+	MAIS n/a
Heavy truck rollover	13	7	6	-	7	3	3	-
Collision with obstacle	11	9	2	-	9	1	1	-
Collision w/ VRU (pedestr., bicyclist, motor-cyclist)	134	-	-	-	-	-	-	-
Collision w/ turning MV	60							
Of these: collision w/ another truck	*16*	*15*	*1*	*-*	*15*	*1*	*-*	*-*
Collision w/ oncoming MV	46							
Of these: collision w/ another truck	*17*	*11*	*4*	*2*	*8*	*1*	*3*	*5*
Collision w/ MV travelling in same direction or stopped	225							
Of these: collision w/ another truck	*132*	*103*	*21*	*8*	*96*	*11*	*11*	*14*
Other type of collision or run-off road	79							
Of these: collision w/ another truck	*32*	*28*	*4*	*-*	*24*	*2*	*1*	*5*
Total	**568**	***173***	***38***	***10***	***159***	***19***	***19***	***24***

Presence and use of occupant restraint systems: Reliable information on seat belt use was available only for a comparably small number of cases. For nine injured occupants, among them two fatalities, it was documented that they were not wearing the seat belt. Seat belt use was reported for 67 injured occupants, one of them was killed. However, a large proportion of that information was self-reported and therefore possibly biased towards belt use. Belt use was completely unknown for 81 injured occupants, including seven fatalities.

According to the documentation of vehicle equipment, a driver airbag was installed in 68 of the heavy trucks involved in an accident and 369 vehicles had no airbag. Information on airbag equipment was missing for 133 vehicles. Only five driver airbag deployments were documented based on photos of the accident scene and from vehicle appraisals. These included two fatalities, both in conjunction with severe to massive cab deformation.

Truck occupant injury patterns and related collision scenarios: MAIS could be determined or at least reliably estimated for 131 of the total of 157 heavy truck occupant casualties. MAIS1 was found in 93 occupants, MAIS2 in 19 occupants and MAIS3+ in another 19 occupants, the latter including seven of the ten fatalities.

For the most important crash scenarios and broken down by seat belt use, Annex I and Annex II provide the number of heavy truck occupants documented with the respective levels of MAIS as well as AIS by body region, including the non-injured. The following evaluation focuses on these scenarios, i.e., frontal impacts into another heavy truck and collisions with roadside obstacles or rollovers.

Frontal impacts in collisions with another heavy truck (Annex I) were the cause for the majority of occupants with moderate (MAIS2) or serious to maximum injury severity (MAIS3+). In 84 cases, the first collision – often being the only collision for the heavy truck – was a frontal impact and represented the main collision in terms of harm to the occupant. In 23 cases, the frontal impact was the secondary collision for the truck occupant and likely responsible for his or her injury severity. Regardless of seat belt use, injury severities were lower, in general, when the frontal impact was the secondary collision. This scenario is typical of a truck being rear-ended first and receiving a frontal impact subsequently. The frontal impact will then likely involve less kinetic energy in comparison to frontal impacts that represent the first or the only collision.

While 83% of the 30 occupants with known MAIS who were reported as belted had no or minor injuries (MAIS0-1), all eight occupants who were reported as unbelted were at least MAIS2 injured. Though based on small numbers, the unbelted occupants displayed a larger proportion of AIS3+ injuries than belted occupants in the head/face, thoracic and abdominal area as well as in the lower extremities.

With thirteen occupants experiencing a rollover and eleven involved in a collision with a roadside obstacle (Annex II), these events represented the second most frequent collision scenarios with the potential to injure a truck occupant. In the rollovers, three occupants, each, displayed MAIS2 and MAIS3+ injury patterns. These included AIS2 spinal and extremity fractures and AIS3+ thoracic injuries, among other injuries. Collisions with obstacles like trees, guard rails or tunnel walls resulted in only one case of AIS2 spinal fracture and one case of severe burn injury after a truck had hit a passenger car and then crashed into a tree and caught fire. A breakdown of the 24 occupants by belt use yielded too few cases to assess the effect of the restraint system in rollover and run-off road scenarios.

Sixteen occupants of trucks that received solely a rear-impact by another heavy truck, nearly all of them occurring on motorways, remained non-injured or sustained only MAIS1 injuries, usually consisting of spine distortions or bruises to the head or thorax.

Truck occupant injury severity and cab deformation: Because of the large proportion of truck occupants with frontal impacts the amount of driver cab deformation on the front was studied further. Sufficient documentation on cab deformation from a frontal impact – regardless of the type of collision object – and MAIS was available for 208 occupants, among them 134 without injuries. Maximum depth of longitudinal cab deformation was classified into five degrees of damage (DoD) as explained in the Methods section.

For 74 injured occupants in trucks with a frontal impact, Fig. 4 shows the distribution for MAIS1 to MAIS6, depending on cab DoD. MAIS1 injuries can be found up to DoD 4, while the large majority of them are present at DoD 2 to DoD 3. With one exception, MAIS3+ injuries occurred at DoD 3 and onwards which includes intrusions of the cab interior. It is worth mentioning that in some crashes with large overlap the entire truck cab was shifted rearwards on the chassis frame by more than one metre upon impact, thus, reducing the crash energy acting on the cab and probably sparing it from additional deformation.

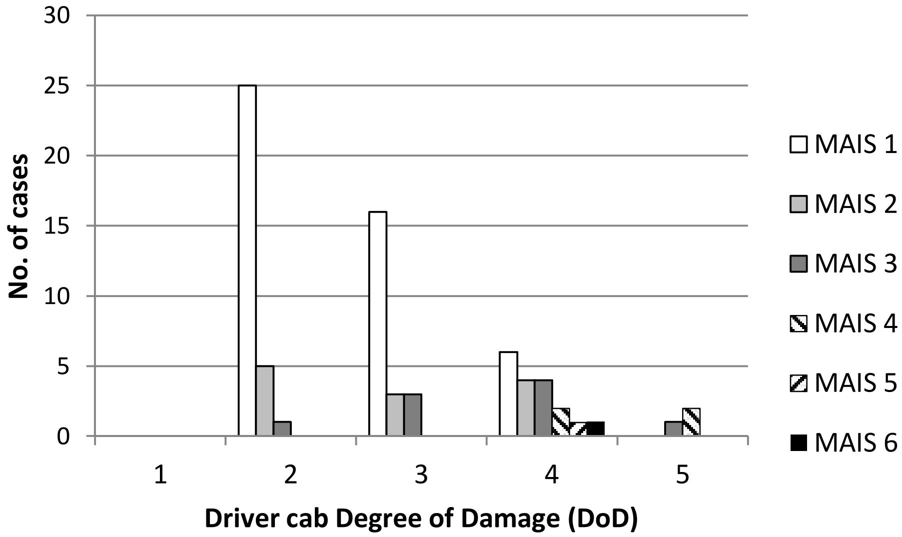

Fig. 4. MAIS and related driver cab degree of damage (DoD) for 74 injured occupants in a frontal impact.

For 85 cases in which the front of a heavy truck struck another heavy vehicle or a roadside obstacle and MAIS for the driver was available, the location of the cab deformation was evaluated. While 49 drivers were exposed to frontal impacts that affected the entire width of the cab, the remainder had an offset collision which loaded primarily either the driver-side or the passenger-side portion of the cab front. The driver-side front, including full overlap crashes, was affected in 60 cases whereas the impact occurred off-side from the driver, i.e., in the centre or the passenger-side portion, in 25 cases. The injury severities between frontal collisions that resulted in deformation on the driver-side (full overlap or driver-side overlap; areas 1, 4 or 6 on the front, respectively, in Fig. 2) and those merely in the centre or on the passenger-side (areas 2, 3 or 5 on the front, respectively, in Fig. 2) were compared. MAIS2+ injuries were sustained by 21 (35%) of the 60 drivers in cases where deformation involved the driver-side front, opposed to three (12%) among the 25 drivers where the deformation occurred mainly off-side. While the number of MAIS2+ among the latter is too small to perform a Chi-square test, a significant difference can be suspected, yet.

For rear-end collisions between two heavy trucks, the differences in speed of the crash opponents and the related MAIS values of the occupants in the striking vehicles were evaluated. Respective data was available for 22 events, primarily from analog or digital tachograph readings and in some cases from accident reconstruction or reliable witness statements. The differences in speed should not be confused with the change in velocity for the vehicles as, for instance, in small overlap crashes, collapsing structures and jack-knifing may cause rather side-swiping collisions than collinear impacts.

Fig. 5 demonstrates that MAIS2+ injuries did not appear below differential speeds of 50 kph. MAIS4+ injuries were found from approximately 70 kph onwards. In cases of MAIS1 or MAIS2 which were still seen at high differential speeds, the effect of a small overlap opposite of the occupant position may have saved the driver-side from large deformation and at the same time may have contributed to moderate vehicle decelerations.

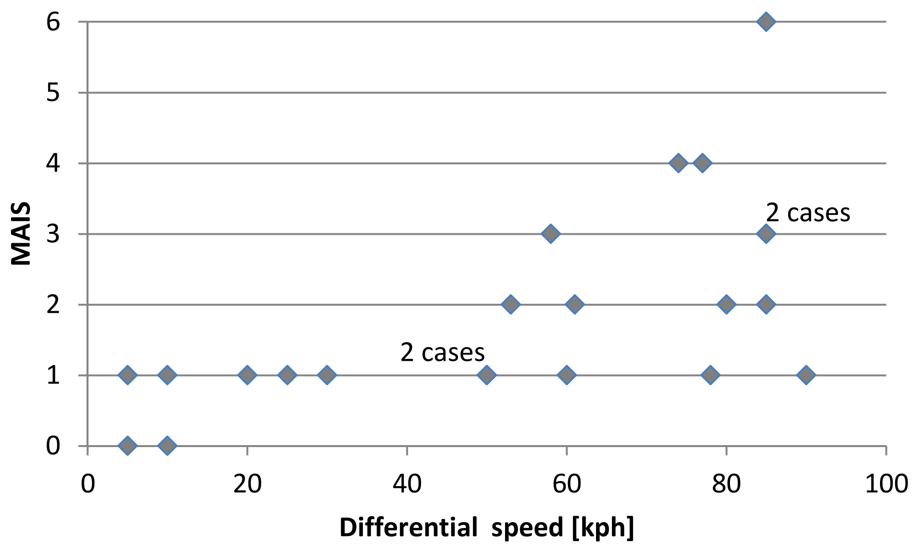

Fig. 5. MAIS and related differential speed between two heavy trucks from 22 rear-end crashes.

IV. Discussion

The present study aims at providing insight into the number of casualties among heavy truck occupants in Germany and their injury situation as well as identifying the major scenarios responsible for them. These figures are not readily available from the standard reports of the German Federal Office of Statistics and research projects into accidents of goods transport vehicles, in general, and heavy trucks and their occupants, in particular, are not carried out on a regular basis. An additional difficulty arises from the fact that goods transport vehicles encompass a large range of possible vehicle concepts and weights. For this reason, we limited our study to heavy trucks that meet the definition of N3 vehicles according to EC definition [6], but included also trucks from the top range of gross vehicle weights (GVW) of N2 vehicles which, in principle, covers trucks from over 3,500 kg to 12,000 kg GVW. Thus, our material and analysis captures trucks and their trailers over 11,900 kg of GVW used for regional as well as long distance freight transport and construction and other specialty trucks that were involved in crashes with personal injury in Germany.

Fatalities and serious injuries of heavy truck occupants account for only a small proportion of casualties in Germany. The special analysis of the national statistics that was geared solely at accidents involving N3 trucks provided 49 fatally and 563 seriously injured occupants in such vehicles for 2014. In comparison to 3,377 killed and 67,732 seriously injured road users in Germany altogether during this year [4], N3 truck occupants represent only 1.5% and less than 1% of them, respectively. Nevertheless, truck drivers are professionals and injuries – including psychological trauma caused by an accident – must be considered a potential risk that they cannot continue with their job. Moreover, road transport has increased over the years not only in Germany, but most of Europe, and measures against equally rising accident figures are therefore necessary.

Our study has some limitations. With the chosen threshold of EUR 30,000 estimated claims cost, some accidents with minor damage to the vehicle, yet with injury to the occupants may have been missed. This may explain why the proportion of killed and seriously injured among the 157 casualties in our database is slightly higher (32%) than that determined in our special analysis of 2014 data from national statistics (26%). The insurers accident database under-estimates the number of single-vehicle crashes because it is based on liability insurance data. The results from the special analysis of national statistics suggest that approximately one third of fatally injured truck occupants have to be attributed to crashes that involve only the N3 truck alone. Our in-depth material of 157 injured occupants includes a number of crashes that are likely characteristic of single-vehicle accidents, but involve some minor damage or injury to a third party, for instance, because cargo from an over-turned truck spread over the highway and hit another road user. Therefore, injury patterns found in rollovers of trucks in the in-depth cases may possibly reflect those in single-vehicle rollover events, in general. However, this hypothesis would require more data to confirm it.

Regarding the injuries in detail, it can be stated that – despite severe cab deformation seen in several cases – serious and critical injuries in truck occupants are surprisingly rare. Apparently, the cab deformation and the resulting intrusion of interior structures – not the deceleration of the driver cab – often determine the overall injury situation. While the MAIS1 injury patterns consisted of bruises and spinal distortions, MAIS2 was characterised mainly by head injury and simple fractures of the upper and lower extremities in our study. Only in MAIS3+ cases, usually in conjunction with either severe cab deformation or a rollover, skeletal injury to the thorax, serious head and abdominal injury was seen. In that respect, it is surprising that [3] did not report a single thoracic injury in their material of 77 injured while the extremities and the head were leading in frequency of AIS2+ injuries. More injury data would have been desirable, especially for truck drivers who were killed in the accident. However, post-mortem examinations are not a standard procedure in Germany after fatal crashes.

Another weak point is that the study data could provide information on the use of the seat belt only in a small number of cases. Similar problems with regards to reliably reporting seat belt use have been mentioned in [8]. Nevertheless, the small number of cases in our database with information about belt use indicates that belted truck occupants are less likely to sustain severe injuries than those not wearing a seat belt. Reference [8] noted a considerable portion of unbelted occupants in the U.S. who were ejected from their truck, particularly in rollover events. The fact that few rollovers were seen in our material, often at low collision speed when they occurred, may explain why ejection does not appear to constitute a major problem in Germany.

In line with data from [7], crashes into other heavy vehicles or into roadside obstacles appear to be the most challenging scenarios in our study both for the structural integrity of the truck cab and its restraint system. Airbags are offered in Europe only as optional equipment, if available at all, and seat belt pretensioners are rarely included, mostly in connection with an airbag. Since the frontal loading on a person in a truck is apparently more determined by intrusion and the resulting contact forces than by deceleration, modern restraint systems cannot fully leverage their potential under these circumstances as they do in modern cars. In this context, ensuring that the steering column and the steering wheel remain in their position during a crash seems crucial.

Although a significant number of trucks in our material were equipped with driver airbags only a very small number of them were reported as deployed. It is known that the threshold to activate an airbag in a truck is even higher than in passenger cars, but it should be discussed if deployments at a lower threshold might prevent some of the head injuries, at least.

Our study adds to the knowledge about truck occupant injuries particularly with regards to crashes between heavy vehicles. Reference [8] ranked rollovers number one, followed by crashes into fixed objects, which suggests that single-vehicle accidents are the leading cause of injuries on U.S. roads whereas our analysis of in-depth data found crashes between heavy trucks to represent the most frequent reason for severe injury. This finding is endorsed by results from other European studies and the figures from the 2014 special analysis that suggests a proportion of one third of single-vehicle crashes among N3 fatalities. Reference [3] presented data, also from Germany, according to which higher MAIS values were found in collisions with other trucks. They pointed out that fatal injury occurred only in conjunction with crashes between trucks which is seen in the ten fatalities in our material, too. Very likely, the busy traffic on motorways in densely populated central Europe is one factor promoting the frequent occurrence of rear-end collisions as seen in our data. The longer stretches of highways with comparably little traffic and the greater distances travelled between destinations in North America may lead to more single-vehicle crashes. In this context, it would be interesting to investigate in retrospect whether the mandatory installation of lane-departure warning on N3 trucks which came into force a couple of years ago in Europe has had a positive effect on these kinds of truck accidents.

V. CONCLUSIONS

Due to their large mass and raised seating position, crashes of heavy trucks pose a relatively low risk of serious or fatal injury to their occupants. In Germany, and probably in other parts of central Europe as well, collisions between two heavy trucks are the most dangerous scenarios for truck occupants, especially in rear-end collisions on motorways. Therefore, the enhancement of emergency braking systems and their mandatory installation in trucks should be first priority in efforts to reduce the number of casualties among truck occupants and their crash opponents.

Nevertheless, improvement of the passive safety of heavy trucks is necessary, too. Airbags and seat belts currently do not provide the level of protection like they do for car occupants. Until now, the structural strength and the crush zone of a typical COE driver cab have been very limited because of length restrictions of truck-trailer combinations in Europe. Structural enhancements, possibly by modestly extending the front of the cab, would offer considerable improvement in passive safety in frontal crashes, but would likely require new vehicle concepts.

VI. References

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VII. APPENDIX

APPENDIX I

INJURY SEVERITY OF HEAVY TRUCK OCCUPANTS BY BELT USE IN FRONTAL IMPACTS INTO OTHER TRUCKS

			Occupants w/ MAIS level [2]		No. of occupants w/ AIS level by body region [3]					
Belt use	Main collision/ impact location [1]	MAIS/AIS level	No. of occup.	Percent. of known MAIS	Head/ face	Spine	Thorax	Abdo-men	Upper extr.	Lower extr.
Yes	1st/front (n=28)	(M)AIS0-1	18	60%	21	20	19	21	21	21
		(M)AIS2	3	10%	1	1	2	-	1	-
		(M)AIS3+	2	7%	-	-	1	1	-	-
		(M)AIS n/a	*5*		*6*	*7*	*6*	*6*	*6*	*7*
	2nd/front (n=7)	(M)AIS0-1	7	23%	7	7	7	7	7	7
		(M)AIS2	-	0%	-	-	-	-	-	-
		(M)AIS3+	-	0%	-	-	-	-	-	-
		(M)AIS n/a	-		-	-	-	-	-	-
Subtotal of occupants w/ known (M)AIS			**30**	**100%**	**29**	**28**	**29**	**29**	**29**	**28**
No	1st/front (n=6)	(M)AIS0-1	-	0%	1	4	2	1	4	2
		(M)AIS2	1	14%	-	1	1	1	1	1
		(M)AIS3+	4	57%	4	-	2	3	-	2
		(M)AIS n/a	*1*		*1*	*1*	*1*	*1*	*1*	*1*
	2nd/front (n=2)	(M)AIS0-1	-	0%	-	2	2	2	2	2
		(M)AIS2	2	29%	2	-	-	-	-	-
		(M)AIS3+	-	0%	-	-	-	-	-	-
		(M)AIS n/a	-		-	-	-	-	-	-
Subtotal of occupants w/ known (M)AIS			**7**	**100%**	**7**	**7**	**7**	**7**	**7**	**7**
n/a	1st/front (n=50)	(M)AIS0-1	26	51%	32	32	31	35	31	30
		(M)AIS2	7	14%	4	2	3	1	6	5
		(M)AIS3+	8	16%	3	2	4	-	-	3
		(M)AIS n/a	*9*		*11*	*14*	*12*	*14*	*13*	*12*
	2nd/front (n=14)	(M)AIS0-1	9	18%	9	8	8	8	8	8
		(M)AIS2	-	0%	-	1	1	-	1	-
		(M)AIS3+	1	2%	1	-	-	1	-	1
		(M)AIS n/a	*4*		*4*	*5*	*5*	*5*	*5*	*5*
Subtotal of occupants w/ known (M)AIS			**51**	**100%**	**49**	**45**	**47**	**45**	**46**	**47**

[1] Frontal impacts are distinguished between being the primary (*1st/front*) or the secondary (*2nd/front*) collision.
[2] Columns titled *Occupants w/ MAIS level* show absolute numbers and percentage of occupants with corresponding level of maximum injury severity (MAIS).
[3] Columns titled *No. of occupants w/ AIS level by body region* show absolute numbers of occupants with corresponding AIS level in body region, without consideration of level of maximum injury severity.

Numbers of occupants with missing injury data are shown in italics.

APPENDIX II

INJURY SEVERITY OF HEAVY TRUCK OCCUPANTS BY BELT USE IN ROLL-OVERS AND COLLISIONS WITH OBSTACLES

			occupants w/ MAIS level [2]		no. of occupants w/ AIS level by body region [3]					
Belt use	Type of collision	MAIS/AIS level	No. of occup.	Percent. of known MAIS	Head/ face	Spine	Thorax	Abdo- men	Upper extr.	Lower extr.
Yes	Tip-over/ rollover (n=7)	(M)AIS0-1	4	57%	6	5	5	6	5	5
		(M)AIS2	1	14%	1	1	-	1	2	1
		(M)AIS3+	2	29%	-	1	2	-	-	1
		(M)AIS n/a	-	-	-	-	-	-	-	-
subtotal of occupants w/ known (M)AIS			**7**	**100%**	**7**	**7**	**7**	**7**	**7**	**7**
No	Tip-over/ rollover (n=1)	(M)AIS0-1	-	-	1	-	1	1	1	1
		(M)AIS2	1	100%	-	1	-	-	-	-
		(M)AIS3+	-	-	-	-	-	-	-	-
		(M)AIS n/a	-	-	-	-	-	-	-	-
Subtotal of occupants w/ known (M)AIS			**1**	**100%**	**1**	**1**	**1**	**1**	**1**	**1**
n/a	Tip-over/ rollover (n=5)	(M)AIS0-1	3	60%	5	5	3	5	5	4
		(M)AIS2	1	20%	-	-	-	-	-	1
		(M)AIS3+	1	20%	-	-	1	-	-	-
		(M)AIS n/a	-	-	-	-	*1*	-	-	-
Subtotal of occupants w/ known (M)AIS			**5**	**100%**	**5**	**5**	**4**	**5**	**5**	**5**
Yes	Collision w/ obstacle (n=2)	(M)AIS0-1	1	50%	2	1	2	2	2	2
		(M)AIS2	1	50%	-	1	-	-	-	-
		(M)AIS3+	-	-	-	-	-	-	-	-
		(M)AIS n/a	-	-	-	-	-	-	-	-
Subtotal of occupants w/ known (M)AIS			**2**	**100%**	**2**	**2**	**2**	**2**	**2**	**2**
No	Collision w/ obstacle (n=0)	(M)AIS0-1	-	-	-	-	-	-	-	-
		(M)AIS2	-	-	-	-	-	-	-	-
		(M)AIS3+	-	-	-	-	-	-	-	-
		(M)AIS n/a	-	-	-	-	-	-	-	-
Subtotal of occupants w/ known (M)AIS			**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
n/a	Collision w/ obstacle (n=9)	(M)AIS0-1	8	89%	9	9	9	9	9	9
		(M)AIS2	-	-	-	-	-	-	-	-
		(M)AIS3+	1[1]	11%	-	-	-	-	-	-[1]
		(M)AIS n/a	-	-	-	-	-	-	-	-
Subtotal of occupants w/ known (M)AIS			**9**	**100%**	**9**	**9**	**9**	**9**	**9**	**9**

[1] One driver with severe burn injury on legs, *External* body region with AIS4 due to burn injury not shown.

[2] Columns titled *Occupants w/ MAIS level* show absolute numbers and percentage of occupants with corresponding level of maximum injury severity (MAIS).

[3] Columns titled *No. of occupants w/ AIS level by body region* show absolute numbers of occupants with corresponding AIS level in body regions, without consideration of level of maximum injury severity.

Numbers of occupants with missing injury data are shown in italics.