ACEA

What are the most significant safety improvements that can be made to trucks used in urban and rural areas?

It has been advocated that trucks with extended fronts are safer trucks – right or wrong?

AUGUST 2016

Prof Dr Jac Wismans

SAFER Vehicle and Traffic Safety Centre at Chalmers University, Gothenburg, Sweden

Content

1.

Introduction 3

Active and passive safety directives and regulations 3
Increase in maximum allowable length 3
Review of Regulation (EC) No 661/2009 (General Safety Regulation) 4
Objectives 4

2.

Accidents involving Heavy Goods Vehicle Combinations 4

General accident data 4
Distribution of road user groups in HGV accidents 5
Do most HGV accidents happen in urban or rural settings? 5
Collision types 5
Effect of truck mass and length 6
Accident causation 8

3.

Enhanced active and passive safety of heavy trucks 8

Safety systems identified by the Heavy-Duty Vehicles eSafety Working Group 9
Other safety systems 10
Recent effectiveness studies on various active and passive safety systems 11
New data sources for future effectiveness studies 12

4.

Which safety conditions will be best to meet in the event of exemption of vehicle length? 12

Protection of unprotected road users (pedestrians and cyclists) 13
Protection of car occupants and motorcyclists 13

5.

Discussions, conclusions and recommendations 14

Abbreviations and acronyms 17

References 18

ACEA

1.

Introduction

This paper examines the safety of commercial vehicles, focusing on Heavy Goods Vehicles (HGV) mainly used for long-haul and regional deliveries, further referred to here as HGV combinations. In particular, it examines whether HGV combinations with an extended front, which are longer than those currently permitted (16.5m tractor and semitrailer or 18.75m truck and trailer), can be safer. If so, in which accident scenarios in urban and rural areas will greater safety be seen?

In the European Union (EU-27) in 2011, there were 4,252 fatalities from collisions involving HGVs with a weight above 3.5 tonnes and 722 fatalities from collisions with buses and coaches [1]. This represents 18% of the 27,000 people that died on Europe's roads. European accident data available provides no information on fatalities with 16.5m or 18.75m HGV combinations (see also section 2).

The majority of fatalities (more than 70%, see section 2) involving HGV combinations occur outside urban areas. The largest share of the fatalities in HGV collisions, as shown in section 2, is not the truck occupants. Rather, they are other road users; occupants of cars impacting with an HGV and vulnerable road users (pedestrians, cyclists and motorcyclists).

1.1 ACTIVE AND PASSIVE SAFETY DIRECTIVES AND REGULATIONS

EC Regulation 661/2009 deals with the type-approval requirements for the general safety of motor vehicles, their trailers and systems. It specifies amendments to Directive 2007/46/EC concerning safety provisions and refers for the technical requirements to UNECE regulations. The most important UNECE regulations for trucks are summarised in **Table 1**.

There are other regulations (and EC directives) important for safety, such as on lighting, but these are not considered relevant for the scope of this paper.

1.2 INCREASE IN MAXIMUM ALLOWABLE LENGTH

Directive 96/53/EC lays down the maximum permitted dimensions for national and international traffic and the maximum authorised weights for international traffic for trucks. The Directive was revised in 2015 [3] with the aim of introducing more energy-efficient, aerodynamic vehicles by increasing the maximum allowable length beyond the current 16.5m or 18.75m (extended cabs). The revision is based on the assumption that it will improve road safety by increasing the streamlining of the cab, reducing the driver's blind spots, adding an energy-absorbing structure to lessen impact shocks and increasing driver safety and comfort. Article 9a of the revision specifies that [3], "by 27 May 2017, the Commission shall assess the need to develop the technical requirements (within the framework of Directive 2007/46/EC) for type-approval of vehicles equipped with extended cabs taking into account:

(a) improved aerodynamic performance of vehicles or vehicle combinations;
(b) vulnerable road users and improvement of their visibility to drivers, in particular by reducing drivers' blind spots;
(c) reduction in damage or injury caused to other road users in the event of a collision;
(d) safety and comfort of drivers."

Section 4 discusses these four recommendations of the revision. One of the questions discussed is whether there is genuinely a link between improved aerodynamic performance and safety improvements for vulnerable road users in 16.5m or 18.75m long HDV combinations (see section 5).

TABLE 1 **UNECE Regulations dealing with active and passive safety of HGVs**

UNECE REGULATION	SCOPE	PASSIVE/ACTIVE SAFETY
ECE-R13	Brakes	Active
ECE-R16	Safety belts	Passive
ECE-R29	Cabin strength	Passive
ECE-R46	Rear-view mirrors	Active
ECE-R58	Rear Underrun Protection	Passive
ECE-R61	External projections	Passive
ECE-R73	Lateral protection (side guards)	Passive
ECE-R79	Steering	Active
ECE-R93	Front underrun protection	Passive
ECE-R130	Lane Departure Warning System	Active
ECE-R131	Advanced Emergency Braking System	Active

1.3 REVIEW OF REGULATION (EC) NO 661/2009 (GENERAL SAFETY REGULATION)

At the request of the European Commission, TRL conducted a review of Regulation (EC) No 661/2009 (General Safety Regulation) in 2015 [2]. This review aimed to assess the benefits and feasibility of a range of new technologies and unregulated measures in the fields of vehicle occupant safety and protection of vulnerable road users. As far as HGVs are concerned, the report gives special attention to passive safety measures arising from an elongation of the cab (revision of Directive 96/53/EC). Section 3 of this paper reviews the results of the Transport Research Laboratories (TRL) analysis.

1.4 OBJECTIVES

The objectives of this paper are to:

- analyse the main causes of accidents with HGV combinations inside and outside urban areas;
- identify the best way to enhance the traffic safety of such HGV combinations, focusing on active and passive safety;
- identify the best way to meet the safety conditions, considering that an exemption of vehicle length can be applied.

The study was undertaken by the SAFER Vehicle and Traffic Safety Centre at Chalmers University. This is a competence centre where 34 partners from the Swedish automotive industry, academia and authorities cooperate to make a centre of excellence in vehicle and traffic safety. The methodology consisted of a review of a number of reports, papers and other documents covering the scope of the study (see reference list) and discussions with experts from ACEA and SAFER partners, including Volvo Trucks. The limited time available for this study prevented consultation with other truck manufacturers, the European Commission or other stakeholders.

The three objectives above are dealt with in sections 2, 3 and 4 respectively. Section 5 presents a discussion, recommendations and conclusions.

2.

Accidents involving Heavy Goods Vehicle Combinations

This section presents the latest information on accidents resulting in road fatalities and injuries involving HGVs. It examines the crash partners, the most frequently-occurring accident types and the differences between accidents in urban and rural areas and those on highways. It presents differences in outcome between shorter and longer HGVs and the conclusions that can be drawn on accident causation.

The most recent and comprehensive sources available and analysed were the data presented by ETSC in the 2013 7th PIN report [1] and the data presented by Volvo Trucks in their European accident research and safety report 2013 [4]. Volvo Trucks plans to release an updated version of their 2013 report later this year. The Chalmers University analysis of Swedish truck accident data from 2014 [5] was also reviewed, since it includes data on the effect of truck length and differences between urban, rural and highway accidents.

2.1 GENERAL ACCIDENT DATA

In the European Union (EU-27) in 2011, there were 4,252 fatalities from collisions involving HGVs (weight above 3.5 tonnes) and 722 fatalities from collisions with buses and coaches according to the ETSC analysis [1]. The data provided by Volvo Trucks cover fatalities, as well as serious and slight injuries. This information is shown in **Table 2**. These represent the average for the years 2005-2008. The number of fatalities (7,200) is much higher in that period than in 2011. The ETSC data showed that since 2001, the number of fatalities from accidents involving HGVs has fallen by an average of about 6% per year [1]. ETSC also found that the number of fatalities per distance travelled for HGVs as well as buses and coaches is higher than the average of the whole vehicle fleet [1].

TABLE 2 **Traffic accident casualties in EU-27 (average for 2005-2008)** [4]

	ALL VEHICLES	BUSES >3.5 TONNES		TRUCKS >3.5 TONNES	
		Number of cases	Proportion of all vehicles	Number of cases	Proportion of all vehicles
Fatalities	43,500	1,200	3%	7,200	17%
Seriously injured	298,400	6,500	2%	21,900	7%
Slightly injured	1,386,100	44,300	3%	83,900	6%
All casualities (∑)	1,728,000	52,000	3%	113,000	7%

ACEA

2.2 DISTRIBUTION OF ROAD USER GROUPS IN HGV ACCIDENTS

A large proportion of those fatally or seriously injured in crashes involving HGVs are not the HGV occupants. According to the ETSC study, only 12% of the fatalities in HGV accidents in Europe involve the occupants [1]. The Volvo Truck study showed that of those seriously or fatally injured in an accident, 15-20% are truck occupants. The greatest share of casualties in HGV accidents is car occupants, making up 50% of fatalities according to ETSC [1] and 55-65% of the serious to fatal injuries according to Volvo Trucks [4]. The ETSC study showed that 28% of fatalities in European HGV accidents were unprotected road users, of which 7% were cyclists, 15% were pedestrians and 6% were riders of Powered Two-Wheelers (PTW) [1].

The ETSC data also showed large differences between countries. The Volvo truck study found that 15-25% unprotected road users in HGV collisions suffered serious to fatal injuries. The distribution between cyclists, pedestrians and powered two-wheelers in the Volvo Truck study was analysed for two countries, France and Sweden, and showed marked differences **(Figure 1)**. The percentage of pedestrians involved in HGV collisions is roughly similar; however, the share of motorcyclists is much larger in France.

2.3 DO MOST HGV ACCIDENTS HAPPEN IN URBAN OR RURAL SETTINGS?

ETSC showed that the largest proportion of fatalities in HGV collisions in Europe (58%) occur in rural areas. For urban areas, the figure is 28% and 13% on highways. There are large variations between countries in Europe [1].

The Volvo truck study shows that:

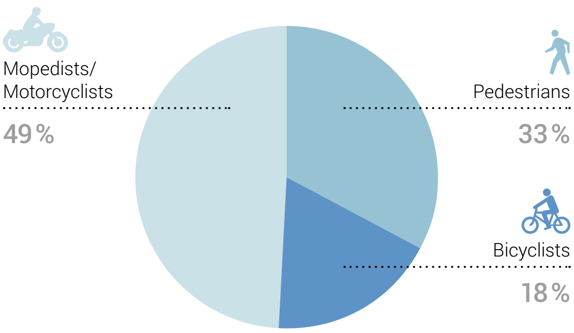
- the majority of accidents resulting in injuries to truck occupants occur in rural areas, on rural roads and on highways, ie roads with speed limits of 70km/h or higher;
- the majority of accidents resulting in injuries to car occupants occur on rural roads and highways;
- 60% of collisions between trucks and pedestrians or bicycles occur in urban areas;
- two-thirds of accidents between trucks and motorcycles occur in rural areas.

The location where an accident happens depends, among other factors, on the length and weight of the truck. This is discussed in section 2.5.

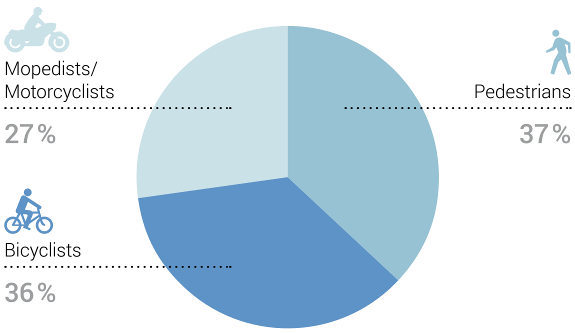
2.4 COLLISION TYPES

Volvo Trucks developed a detailed overview of the accident types involving HGVs that resulted in serious or fatal injuries [4] (see **Figure 2**). The information was based on the analysis by the Lyon and Gothenburg accident research teams as well as external sources. Distinctions were drawn between accident types resulting in injuries to truck occupants, car occupants and unprotected road users.

FIGURE 1 **Proportion of unprotected road users seriously or fatally injured in collisions involving HGVs in France (left, year 2009) and Sweden (right, 2003-2008)** [4]



Killed and seriously injured, France 2009



Killed and seriously injured, Sweden 2003 – 2008

The following observations can be made:

- Around 50% of accidents resulting in truck occupant injuries are single truck accidents (A1 and A2 see **Figure 2**), while 45% of the accidents include a rollover. The front of the truck may be involved.
- Around 30% of accidents involve two trucks (A3 and A4), of which 10% are truck front to truck front accidents and 20% truck front to truck rear.
- Around 65% of truck-car accidents involve the front of the truck (B1, B3, B4 and B5), where the most common severe accident type (35%) is truck front to car front (B1).
- The most frequent accidents with unprotected road users are C3 (25%), unprotected road users that suddenly cross the direction of the truck, for example at a crossing and C4 (20%), truck side when a truck is turning.

The ETSC study showed that nearside turn collisions (C4 in **Figure 2**) do not harm only unprotected road users but also other road users [1]. In the Netherlands, for example, nearly 18% of all fatalities in HGV accidents are nearside turns involving 7% pedestrians, 46% cyclists and 47% other road users. The data clearly indicate the problem of blind spots. There were substantial variations between the nine countries for which data were available.

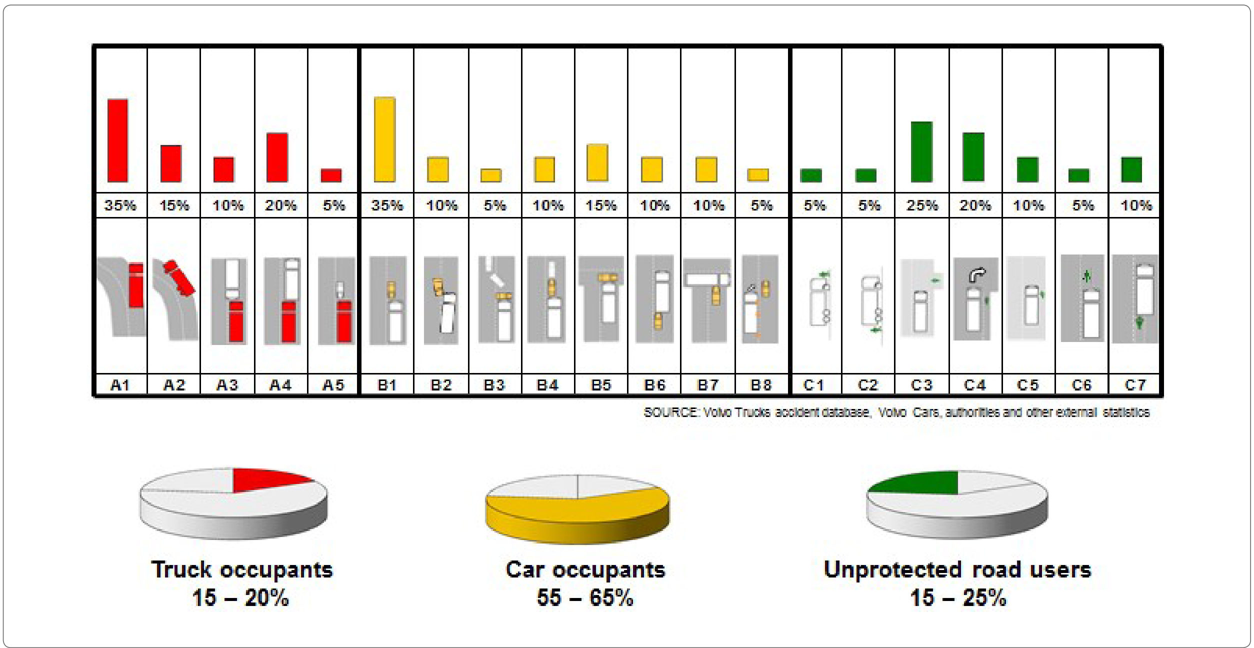
2.5 EFFECT OF TRUCK MASS AND LENGTH

The Volvo Trucks report [4] analysed the difference between heavy-duty trucks (usually above 7.5 tonnes weight) and medium-duty trucks (3.5-7.5 tonnes) involved in accidents, based on Swedish Traffic Accident Data (STRADA) for the period 2003-2007. There were similarities between accidents where both categories were involved; however, there were also significant differences including:

- Unprotected road users were involved in more accidents with medium-duty trucks (22% of those killed and seriously injured) than with heavy-duty trucks (13%).
- Accidents with medium-duty trucks were equally distributed over urban and rural areas while 70% of accidents with heavy-duty trucks occurred in rural areas.
- The majority (55%) of injuries of heavy-duty truck occupants occurred in single accidents compared to 35% for medium-duty trucks.
- In 30% of cases, injuries to occupants of medium-duty trucks involved collisions with cars, more than double the level of accidents involving heavy-duty trucks with cars.
- More than 30% of injuries to car occupants occur in frontal accidents with heavy-duty trucks, compared to 20% in accidents involving medium-duty trucks.

Chalmers University used Swedish data to study the relationship between truck combination length and the

FIGURE 2 **Accident types involving HGVs as defined by Volvo's Accident Research Team** [4]



location of accidents resulting in fatal or serious injuries [5]. Sweden permits vehicle combinations of up to 25.25m length; in most other EU countries, the upper length limit is 16.5m tractor and semitrailer or 18.75m truck and trailer. In this study, trucks reflect the Swedish vehicle combinations and were divided in three length categories:

- Long combinations: 18.76m-25.25m
- Medium combinations: 12.01m-18.75m
- Short combinations: ≤12m

As with the Volvo Truck study, data were derived from the STRADA database and covered a ten-year period from 2003-2012. As shown in **Figure 3**, most accidents resulting in a fatality or a severe injury – known as KSI (Killed or Severely Injured) crashes – occur in rural areas, with long combinations making up the largest proportion. In urban areas, short combinations make up the largest proportion of accidents.

Figure 4 shows a distribution of crash types for the three length categories as defined in the STRADA database. The largest category is meeting/overtaking; the increases with the combination length. In rear-end impacts and cycles/mopeds, the share decreases with truck combination length.

Figure 5 shows the annual rates, over ten years, of KSI crashes per billion Vehicle Kilometres Travelled (VKT) for HGV combinations by length group. Short combinations have a significantly higher KSI crash rate than the longer length groups [5].

Finally, a recent German study focusing on cyclist injuries in HGV turning accidents is worth highlighting [22]. Heavy commercial vehicles were defined as having a weight greater than 7.5 tonnes and light commercial vehicles below 7.5 tonnes. In all relevant incidents in 2012 (n= 2,319), accidents involving heavy vehicles (n= 475) led to 12 fatalities and 62 severely injured cyclists; for light commercial vehicles (n=1,844) there were two fatalities and 186 severe injuries. In other words, the severity of turning accidents involving cyclists is significantly higher in heavy commercial vehicles. A more detailed analysis of the influence of truck length and weight would be valuable.

FIGURE 3 **Location of the accident versus length of the truck combination** [5]

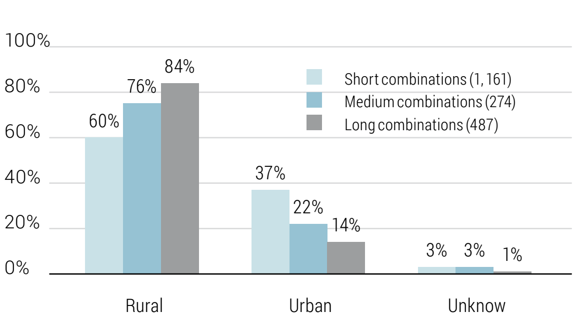


FIGURE 5 **Annual rates of KSI crashes per billion VKT (Vehicle Kilometres Travelled) for HGV combinations by length group**

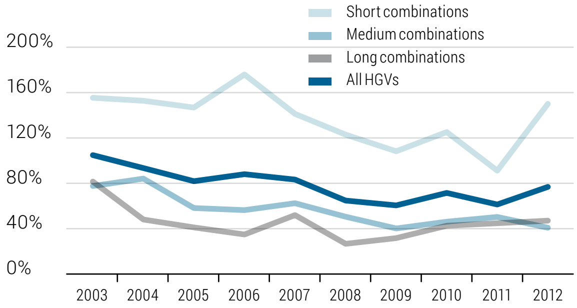
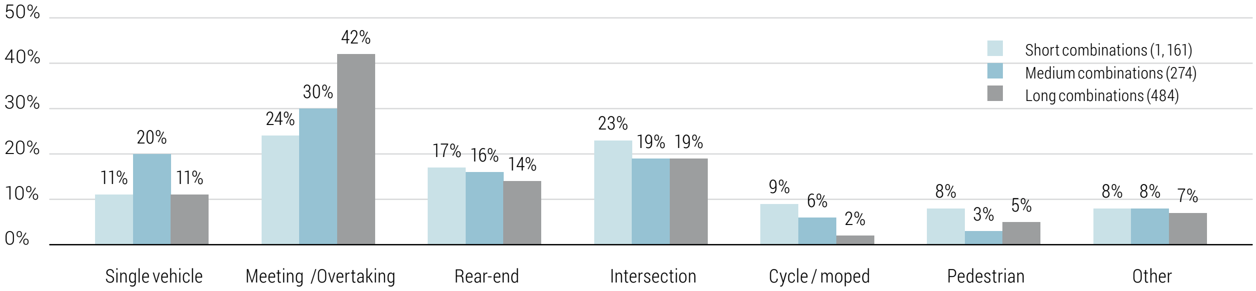


FIGURE 4 **Crash type distribution per length group**



2.6 **ACCIDENT CAUSATION**

A road accident resulting in injuries often results from a combination of factors. Several models have been developed to help analyse the causes of an accident. For an overview of these models, see [6]. The more recent causation models consider an accident as a complex integrated system including the human, and involving both direct and indirect contributing factors. This prevents a focus solely on countermeasures addressing the apparent direct cause of the accident, when in fact there may be other indirect but more efficient solutions available.

The factors contributing to road traffic accidents are usually grouped into three categories; the vehicle, the human and the environment. According to the Volvo Truck study [4], human error is a major contributing factor in 90% of the accidents. **Figure 6** illustrates a number of factors for the three categories. A very important vehicle-related factor is blind spots.

The main blind spots areas are:

- the side of the vehicle, in particular the passenger side during lane changes and turning manoeuvres;
- the rear end when reversing;
- the front of the truck, in particular when starting to move forward [4].

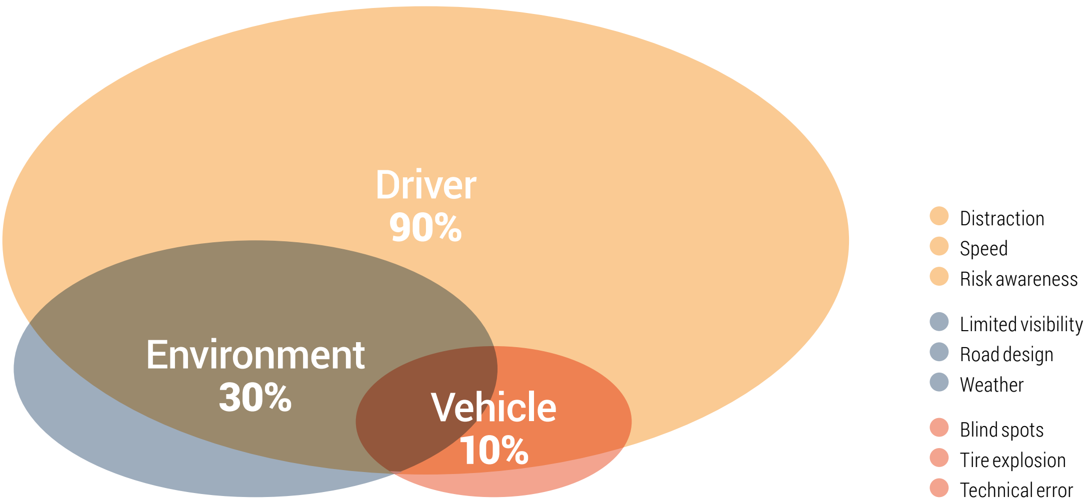
3.

Enhanced active and passive safety of heavy trucks

Probably the first systematic approach to accident and injury prevention strategies was the 'Haddon Matrix', developed by Dr William Haddon in 1968 [7]. This brought about a shift from an almost exclusive focus on trying to improve the driver behaviour to a more comprehensive approach. As well as the three components, human (behaviour and tolerance), vehicle and infrastructure (environment) the Haddon Matrix identified the three phases – pre-event, event and post-event – as sequential phases within a crash event. Measures that help prevent accidents occurring are usually known as 'active safety measures', while measures that reduce the severity of injury (human body protection) in the event that a crash cannot be avoided are called 'passive safety measures'. The most effective example of a passive safety measure for truck occupants is the seat belt.

This approach has led to many successful safety improvements within all elements of the Matrix. However, there are recognised limitations of this model, namely that neither the concept of exposure nor the importance of interactions between Matrix elements are addressed [6]. New approaches, such as the 'Vision Zero' in Sweden [8], view the traffic system more holistically. This requires, among other things, ensuring that the crash energy in an accident is low enough to prevent (serious) injuries and recognising that humans will always make mistakes in traffic. Combining

FIGURE 6 **Major contributing factors in the cause of HGV accidents** [4]



ACEA

active and passive safety systems, often known as 'integrated safety systems', can further increase effectiveness.

3.1 SAFETY SYSTEMS IDENTIFIED BY THE HEAVY-DUTY VEHICLES eSAFETY WORKING GROUP

An important step forward concerning a more systematic approach to addressing safety issues relating to HGVs was the work carried out by the Heavy-Duty Vehicles eSafety Working Group in 2005 [9]. This Group was set up to "review known road safety enhancement measures and approaches specific to heavy-duty vehicles, to evaluate the measures according to the accident figures for heavy-duty vehicles and to formulate recommendations for Member States and the EC on enhanced road safety performance" [9]. Members of the Group included all European original equipment manufacturers (OEMs), a number of leading accident investigation experts, the European Commission and other institutions. The Group defined 'Heavy-Duty Vehicles' as trucks (chassis vehicles) with a permissible total weight exceeding 12 tonnes. However, a number of the recommendations may also apply to lighter trucks and to buses.

Part of the work was an analysis of the accident data available at the time, provided by Volvo, Iveco, Cidaut and Dekra. The method of presenting the findings, using different accident scenarios, was similar to the Volvo Truck approach presented in section 2 and illustrated in **Figure 2**. The global distribution of various crash types appears to be in line with the more recent Volvo Truck findings. One of the recommendations – a research priority – of the Group was: "To ensure the appropriate allocation of future capital investments, a European database for commercial vehicle accidents should be set up" as well as a "European database of reconstructed accidents, since reconstructions are often the only way to identify the action priorities for the further development work on the vehicles". Unfortunately, to date no such European database for truck accidents has been set up.

The Group discussed a list of around 50 technical and non-technical approaches for enhancing road safety performance in heavy-duty vehicles. It divided them into systems already available at the time of the study and the most effective new approaches. The systems were evaluated using four parameters: customer acceptance, effectiveness, system costs and engineering costs. **Table 3** summarises the systems already available in 2005 as well as the most effective new approaches as defined by the Group. Most systems in the table are active systems (including driving support systems) with the exception of X3 and Y4, which are passive safety systems. Seat belt warning X4 is an example of a (simple) integrated safety system.

For those systems already on the market, X1-X4 were rated as medium effective for certain accident scenarios, with costs equal to, or lower than, electronic stability programmes (ESP). These systems are indicated in the table in grey cells. The other systems (X5-X7) that were already available were rated as having low or limited effectiveness. Among the newer systems, Y1-Y7 were all rated as relatively effective (medium to major contribution in an accident scenario).

TABLE 3 **Important safety systems identified by the Heavy-Duty Vehicles eSafety WG** [9]

	SYSTEMS ALREADY AVAILABLE (2005)		EFFECTIVE NEW APPROACHES
X1	ESP for semitrailer rigs	**Y1**	Improving the frictional properties of tyres
X2	Lane Departure Warning	**Y2**	Emergency braking system (3 stages: 1. rear-end, 2. stationary objects, 3. oncoming traffic)
X3	Flexible underrun protection (enhancement of a rigid FUP)	**Y3**	Pedestrian (and cyclist) protection system (warning the driver and intervening if needed)
X4	Seat belt warning	**Y4**	Extended flexible front underrun protection (EFFUP) (focussing on car occupants - compatibility)
X5	Driver alertness monitoring system	**Y5**	Inter-vehicle communication systems
X6	Adaptive cruise control	**Y6**	Infrastructure-supported intersection assistant
X7	Event data recorder	**Y7**	Interactive driver training

Relatively effective according to Heavy-Duty Vehicles eSafety WG [9]
Most likely cost-beneficial according to TRL study [2]

What are the most significant safety improvements that can be made to trucks used in urban and rural areas?

On the extended flexible front underrun protection (EFFUP) Y4, the Working Group (WG) reviewed a system proposed by Scania. It was noted that; "If the front of the truck could be made approximately 300mm longer than the legally permitted maximum length, the survivable differential speed for a frontal collision between a passenger car and a truck would rise from approximately 60km/h to approximately 90km/h (60km/h for the car, 30km/h for the truck)". The Group envisaged such a system being available in 2011. System costs were rated at half those of ESP. However, engineering costs (development costs) were rated as very high, as they would have a major impact on the vehicle design concept. Customer acceptance was rated as low (customers not willing to accept the system in their vehicles). It was also noted in the report that this system, "could make a real contribution to reducing the number of fatalities in passenger car / truck collisions" but that the introduction of such a system would require an increase of the legal permitted length.

The Group identified three development stages for emergency braking systems. The first stage dealt with traffic in front of the vehicle travelling in the same direction, the second with stationary traffic and the third responding to oncoming traffic. The Group noted that in a head-on collision scenario, applying the truck brakes even one second earlier dissipates as much energy as a flexible underrun protection system – Y4 [9]. The last stage is technically the most complicated; reliable systems are not yet available. Note that to date Regulation R131 deals only with the first two development stages.

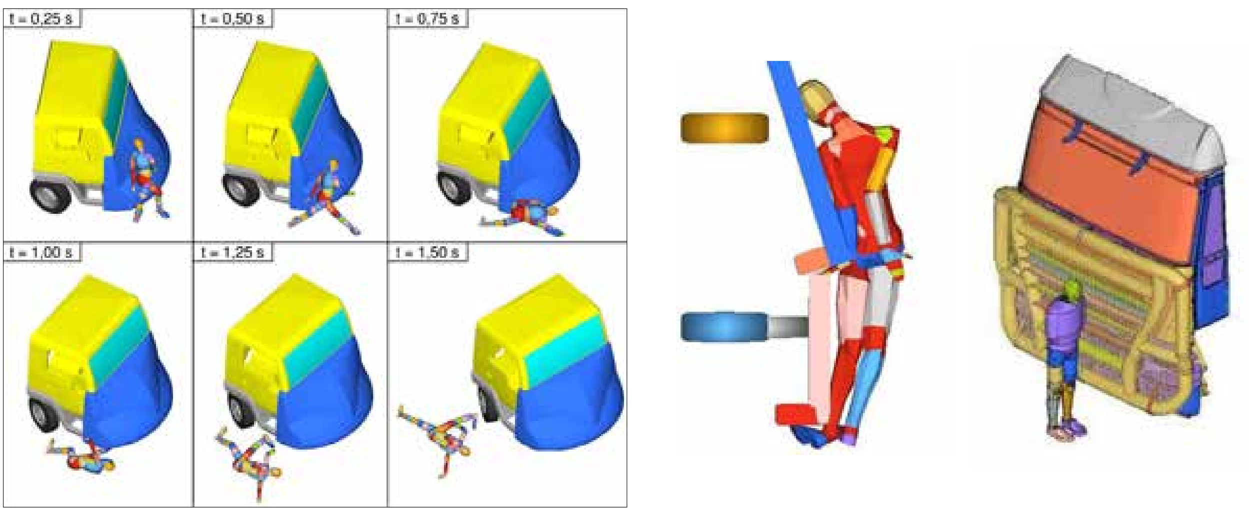
3.2 OTHER SAFETY SYSTEMS

In the APROSYS project, it was shown that an EFFUP, in addition to offering protection to car occupants, could also be beneficial to Vulnerable Road Users (VRUs). Firstly, it influences the motion of the VRU in the event of a collision by reducing the overrun risk and secondly, it reduces the impact forces by offering a softer structure [10/11/12]. The principle of reducing the impact forces requires only limited space; even a few centimetres can significantly reduce the risk of serious head injuries due to impact with the truck front. This additional functionality of an EFFUP is included in Table 4 under Z1. **Figure 7** illustrates these principles.

In their 2013 report, Volvo Trucks identified a number of systems over and above those highlighted by the Heavy-Duty Vehicles eSafety WG [4]. These systems are included in Table 4 (Z2-Z5) [4]. The first three (Z2-Z4) are active safety systems and Z5 is passive. Volvo Trucks also stressed the importance of a number of the systems already identified by the Group, such as the Pedestrian protection system (Y3) and the EFFUP (Y4).

The 2015 TRL review for the Commission of Regulation (EC) No 661/2009 (General Safety Regulation) included two other promising safety systems with the potential to be included in a future regulation; Intelligent Speed Adaption (ISA) and alcohol interlocks (included as Z6 and Z7 in **Table 4**) [2]. In principle, both systems can be applied to all vehicle categories. However, the TRL report made no specific mention of introducing these systems in HGVs.

FIGURE 7 **Illustration of the mechanical principle of influencing motion (left and middle) and occupant contact (right)** [12]



ACEA

TABLE 4 **Other safety systems identified in recent studies**

Z1	VRU protection by an EFFUP
Z2	Lane-keeping support
Z3	Communication support
Z4	Visibility support (aimed at blind spots)
Z5	Rollover protection for truck occupants
Z6	Intelligent Speed Adaption (ISA)
Z7	Alcohol interlocks

■ Most likely to be cost-beneficial according to TRL study [2]

TABLE 5 **Annual fatality reduction potential for EU-27 by an EFFUP by TRL** [2]

	EU-27 annual fatality reduction
Passenger car occupants	128 – 175
HGV occupants	41 – 194
VRUs	104 – 553
of which:	
VRUs (potentially affected by direct vision)	(0 – 553)
VRUs (potentially affected by deflecting front end)	(104 – 263)
Total	**(273 – 922)**

3.3 RECENT EFFECTIVENESS STUDIES ON VARIOUS ACTIVE AND PASSIVE SAFETY SYSTEMS

The TRL study also assessed which safety systems were most likely to be (or become) cost-beneficial. These are indicated in dark grey in **Tables 3 and 4**:

- Enhanced Autonomous Emergency Braking (AEB) with collision mitigation (Y2, Table 3)
- Lane-keep assist (Z2, Table 4)
- Reversing detection and reversing camera systems (part of Z4, Table 4)
- Pedestrian/cyclist detection systems (Y3, Table3)
- Seat belt reminders (X4, Table 3)
- Improved HGV rear under-run guards for compatibility with M1 and N1 vehicles (X3, Table 3)
- Safer HGV front-end design for driver and partner protection
- Intelligent Speed Adaptation (Z7, Table 4)

The importance of AEB is well illustrated in a study by Strandroth et al [23]. In this study, 70 frontal truck accidents with passenger cars (frontal collisions, on-coming traffic) were investigated to estimate the outcome had the truck been equipped with AEB. They showed that in 64 out of the 70 cases, activating AEB on the truck would have reduced the injury outcome. With AEB on the truck, MAIS2+ injuries were reduced by 52%. If the passenger car was also equipped with AEB, a 73% reduction of MAIS2+ was achieved. A study in the USA [24] showed that tractor-semitrailers without an AEB were around twice as likely to be the striking vehicle in a rear-end crash than trucks with the system.

Alerting the driver and intervening if required in the potential event of collisions in turning accidents with pedestrians and cyclists (Y3) is expected also to be an effective active system, given the large number of fatalities involved (section 2). The UNECE Working Party on General Safety Provisions (GRSG) is currently discussing a regulation based on the use of advanced sensing (including video systems) [22].

On improving the extended flexible front underrun protection (EFFUP), TRL noted that; "Further work is needed to define suitable requirements, which will affect costs and alternative active safety systems should also be investigated to ensure that the best benefit is delivered for a given cost" [2]. TRL also made an estimate, based on the 2011 ETSC fatality values, of the group that potentially would benefit from an improved EFFUP. The resulting estimates are: for truck occupants, 317-511 fatalities; for car occupants, 1276-1595 fatalities; VRU benefitting from direct vision improvements, 298-727 fatalities; and VRU potentially effected by an EFFUP, 357-417 fatalities [2]. These fatalities represent the maximum numbers where a benefit in fatality reductions might be possible. However, in reality many fatalities are often unavoidable, as the actual crash speed often will be too high. TRL evaluated a number of sources for their estimate, including the work done in VC-Combat [13], the 2011 FKA 'Design of a Tractor for Optimised Safety and Fuel Consumption' study [14] and national data from the UK [15]. This resulted in the indicative range of fatalities prevented across EU-27 shown in **Table 5**. There was no estimate available for the reduction of seriously or slightly injured casualties.

The ranges in this table are broad; for passenger car occupants, estimates are partly based on an energy absorbing front underrun protection device (comparable to X3 in **Table 3**), rather than a device that is extended in front of the vehicle front. Therefore, a further analysis of these estimates would be beneficial.

3.4 NEW DATA SOURCES FOR FUTURE EFFECTIVENESS STUDIES

New data sources for investigating the performance of safety systems are now available from Naturalistic Driving Studies (NDS) such as EuroFOT, DriveC2X, and UDRIVE (see www.eurofot-ip.eu, www.drive-c2x and www.udrive.eu). These studies contain information on how to support benefit estimates of active and passive safety systems through different analysis procedures, such as that developed by Bärgman [25]. Also relevant is a study by Chalmers University and Volvo Trucks, due for completion this year. The aim is to develop a generic safety evaluation framework, integrating relevant data sources, methods and tools into a structured process for evaluating commercial vehicle safety systems and services [26].

4.

Which safety conditions will be best to meet in the event of exemption of vehicle length?

This section covers only extended fronts for trucks. It does not deal with active safety alternatives and accident configurations where an extended truck front has no effect (eg bicycle accidents in turning manoeuvres, etc). Section 1.2 showed that the European Commission will assess the need to develop technical requirements for type-approval of vehicles equipped with extended cabs by 27 May next year. This will take into account:

- improved aerodynamic performance;
- visibility of VRU's by reducing of drivers blind spots;
- damage and injury reduction to other road users;
- safety and comfort of drivers.

A truck design study carried out by FKA in 2011 considered these four areas [14] and showed – primarily based on simulation methodologies – that in principle it is possible to combine the four requirements in a single design.

Although the topic of improved aerodynamic performance is outside the scope of this study, it does warrant some remarks. The simulations and wind tunnel tests carried out by FKA demonstrate that fuel economy savings are possible with an extended cab length. This is of considerable interest to the truck industry and its customers. Implementing a length increase would allow manufacturers to improve fuel economy for competitive advantage. However, optimising aerodynamics is a standard part of any (re)design and is probably not suitable for a regulatory approach. There is a challenge in assessing improvements in aerodynamic performance of specific components of a vehicle, as testing takes place on complete vehicles or vehicle combinations. A truck manufacturer principally sells incomplete vehicles for completion by third parties for specific uses. Thus there should be no need to define technical requirements on aerodynamics. It is worth pointing out that a front extension of the cab is only one way to improved aerodynamics; for example, other options include replacing rear view mirrors with cameras.

On improving visibility of VRUs by reducing drivers' blind spots, UNECE Regulation 46 regulates the design of the mirror to cover the blind spots in the front and at the passenger side of the trucks. This regulation was recently updated to minimise the blind spot on the right-hand side of trucks. It now requires greater coverage by the class V close proximity mirror and allows for replacement with a camera, opening the possibility for an active safety solution. It is also mandatory to have a close proximity mirror in the front of the truck to cover the blind spot. Several studies have shown reducing blind spots at the front is feasible if the front of the cab is elongated.

Currently, there are no technical requirements for direct vision of truck drivers. According to a 2014 discussion by a working group set up by DG MOVE, the existing German requirement (StVZO §35), dealing with 180 degrees forward vision of truck drivers, could offer a suitable baseline for developing such a requirement for European trucks[21]. Direct vision requirements may become part of the General Safety Regulation and consequently apply for all trucks types (ie not only those with extended fronts). There is an ongoing discussion on whether to request direct vision of the driver or sensor-based detection systems. This will be part of an ongoing study carried out by TRL, with results expected later this year. Note that lowering the cab, often thought to improve direct vision, is not necessarily beneficial in long haul, where a higher driver position improves the overview of the road.

Concerning damage and injury reduction to other road users – ie partner protection – several studies have shown that introducing an energy-absorbing front improves protection. Partner protection can be distinguished in protection of unprotected road users (discussed in 4.1) and protection of car occupants (discussed in 4.2). Given that the speeds involved in motorcycle collisions with trucks, which mainly occur in rural areas, are comparable with collisions with passenger cars, motorcyclist protection is discussed together with protection of car occupants.

For the safety and comfort of truck drivers, the FKA study (and others) has shown that extending truck length increases protection, assuming that a seat belt is worn. A number of manufacturers have developed in-house procedures for assessing the safety of occupants of their trucks in the event of a crash, for example Volvo for impacts with the rear of a semi-trailer. If the length extension is included in the EC regulatory system, a number of truck manufacturers will use this extra space to increase the comfort and safety of truck occupants, providing a potential competitive advantage. Therefore defining technical requirements for the safety and comfort may not be needed and not be efficient. It would be beneficial to establish a harmonised test procedure that provides an objective comparison of the safety protection offered to the truck occupants in the event of a crash. Note also that UNECE Regulation 29.03 (see **Table 2**, dealing specifically with survival space in a cab) recently became mandatory in Europe with regard to protecting commercial vehicle cab occupants.

4.1 PROTECTION OF UNPROTECTED ROAD USERS (PEDESTRIANS AND CYCLISTS)

In accident configuration C1 (**Figure 2**), the truck speed is too low for an energy-absorbing front to be effective. The target group for protection in accident configuration C4 (turning accidents) concerns around 20% of the VRU involved in truck collisions. An extended front will have no benefit here.

Extended fronts may be beneficial in accident configuration C3 (crossing VRUs), which concern around 25% of the VRU in truck collisions. There are currently no passive safety requirements for protecting VRUs in the event of a collision with the front of an HGV (N2 and N3 vehicles). However, for passenger cars (M1) such measures do exist (UN R 127 and Euro NCAP test procedures, which only differ slightly). They consist of a number of impactor tests (representing different body parts, such as the head), which have to be undertaken on the front structure of the car. Further investigations to apply such a test method for truck fronts may prove worthwhile.

However, these impactor tests only deal with reducing injury risk in the event of contact between the body part and the front structure; they do not deal with overrun protection. For M1 cars, there is no regulatory performance-based requirement to control the motion of the pedestrian following the initial contact. In principle, it would be possible to develop a method for controlling pedestrian – and cyclist – motion, based on virtual testing. However, this would require considerable committee work and possibly further R&D to develop an acceptable regulatory method. The work undertaken in the APROSYS project on the Heavy Vehicle Aggressivity Index and particular run-over aggressivity [10] may be relevant here. Using a pedestrian dummy in crash-test methodology, as suggested by ETSC [16], is not recommended, given issues such as limited biofidelity, lack of suitability for cyclists and the fact that only a single dummy size is available.

4.2 PROTECTION OF CAR OCCUPANTS AND MOTORCYCLISTS

The target groups here are car occupants in B1 (truck front - car front) and, to a lesser extent, car occupants in B3, B4 and B5 in **Figure 2**, plus motorcycle accidents. Compatibility is an important issue and there has been considerable work in the VC COMPAT project to develop test procedures, etc that mainly focus on truck front - car front. A number of possibilities were evaluated, including virtual testing, moving deformable barrier tests and full-scale tests. However, the project has not delivered a final acceptable proposal for a test methodology and it appears there has been little new R&D work carried out in this area since then. The FIMCAR project (www.fimcar.eu) has continued working on car-car compatibility issues and has emphasised the importance of structural alignment in vehicles.

Given the differing accident configurations involved and considering that virtual testing (simulation methodology) has improved significantly since the end of the VC COMPAT project in 2007, virtual testing is probably the best method to pursue. General guidelines on implementing virtual testing procedures were developed in the IMVITER project and finalised in 2012[18]. Such an approach could be complemented with relatively simple experimental tests, such as a moving deformable barrier or – simpler still – a rigid impactor test similar to those used for the truck cab front in ECE-R 29 (see **Figure 8**). Ultimately, regulatory requirements may be limited to the simple test procedure(s).

Figure 8 **ECE-R 29 pendulum on test front**

5.

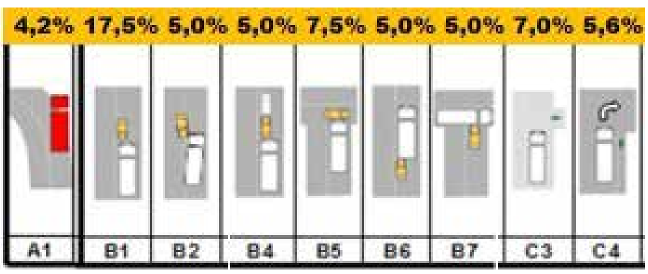
Discussions, conclusions and recommendations

In the European Union (EU-27) in 2011, there were 4,252 fatalities from collisions involving HGVs with a weight over 3.5 tonnes. This represents 18% of the 27,000 people that died in road accidents in Europe. The largest share of HGV-related casualties was car occupants impacting a truck, followed by vulnerable road users (see section 2). Truck occupants constitute the lowest category of fatalities.

The first objective of this paper was the analysis of the main causes of these accidents. The types that cause most fatalities (around 4% or more of the total) are summarised in **Figure 9**, where the 'A' accidents are those causing deaths in truck occupants, the 'B' deaths in car occupants and the 'C' deaths in vulnerable road users (pedestrians, cyclists and motorcyclists). This distribution is based on an in-depth analysis of accidents conducted by Volvo Trucks (see section 2 for details). Percentages of deaths relate to the 4,252 fatalities in 2011 (5% represents around 200 fatalities). The majority of accidents resulting in fatal and serious injuries occur in rural areas, with the exception of those involving pedestrians and cyclists. Around 60% of these occur in urban areas. Human error is the main factor contributing to accidents (both truck drivers and the other road users).

The second objective of this paper was to identify the best way of improving the safety of HGV combinations. An overview of various available systems has been provided in section 3, focusing on the most effective and those likely to offer a cost-benefit (see **Table 3 and 4**). According to the 2005 Heavy-Duty Vehicles eSafety WG, emergency braking

Figure 9 **Overview of most frequent accident types**



ACEA

systems, pedestrian (and cyclist) protection systems that warn the driver and intervene where needed and extended flexible front underrun protection (focusing on car occupants compatibility) were considered relatively effective. These are also the most likely to offer cost-benefits, according to a recent TRL study. The same study also identified lane-keeping support, visibility support (aimed at reducing blind spots) and Intelligent Speed Adaption (ISA) as the most likely to provide cost-benefits. Improving safety in truck accidents demands an integrated approach that takes into account the cost-benefit of active and passive safety systems. Certain accident types require safety systems that can avoid or lessen the damage (injuries) caused by a collision.

It is important to note at this point that safety systems, whether passive or active, require cab space, as will potential improvements to aerodynamics. Increasing cab length offers the opportunity to package these systems efficiently.

Aerodynamic improvements are indirectly linked to safety improvements, given that greater cab space offers the potential for both for aerodynamic and safety improvements. Aerodynamics are most important in rural areas; in urban settings, speeds are too low to make aerodynamic changes effective. Urban and rural settings produce different accident types; most accidents resulting in fatal and serious injuries occur in rural areas, particularly those involving HGV combinations. Improved aerodynamics do not automatically imply improved safety. Similarly, passive safety improvements do not automatically deliver aerodynamics improvements. However, sufficient available space can allow both improved aerodynamics and improved safety. The research findings presented here show that vulnerable road users need safety systems in urban areas, although low speeds mean that aerodynamic changes have no effect.

An important accident category – where energy-absorbing fronts offer no benefit – are turning accidents. UNECE Regulation 46 was recently updated to minimise the blind spot on the right side of trucks. The German delegates at UNECE (GRSG) recently announced they were preparing a proposal for a new regulation for HGVs on the mandatory equipment of driver assistance systems to address blind spot issues in turning accidents [22]. TRL is investigating direct and indirect vision issues as part of an ongoing study dealing with other active and passive safety issues (including crashworthiness). TRL should include the German proposal to UNECE in their study. Currently, TRL lacks data on the costs of these systems and would welcome data from OEMs for their study. The report from this TRL study is expected later this year.

By 27 May next year, the European Commission will assess the need to develop technical requirements for type-approval of vehicles equipped with extended cabs, taking into account:

- improved aerodynamic performance;
- visibility of VRU's by reducing of drivers blind spots;
- damage and injury reduction to other road users;
- safety and comfort of drivers.

All of these requirements should be technologically neutral and not prescribe any solution. In other words, legislation should encourage, rather than hinder, innovation. Any requirements should also be as transparent and simple as possible, as well as cost-effective.

Current data on truck accidents involving trucks are limited; in-depth data are largely related to specific countries such as Sweden. Specific accident data as well as exposure data for HGV combinations with maximum lengths (16.5m tractor and semitrailer or 18.75m truck and trailer) are also lacking. In addition, definitions differ for long combinations between countries (eg the Volvo accident database versus the German database). This highlights the need for a comprehensive system of European truck accident data, both nationally and in-depth, as recommended by the Heavy-Duty eSafety WG in 2005. This is essential for monitoring progress and assessing future priorities for both active and passive safety measures and determining their cost-benefit. Such a system could, for example, build on the existing collaborative activities in the Initiative for the Global Harmonisation of Accident Data (IGLAD) (www.iglad.net).

A detailed analysis of the German In-Depth Accident Study (GIDAS) and the UK in-depth accident databases would be a solid first step towards a European truck accident database. The aim would be to study accident configurations in these countries and compare them with the data in the Volvo accident database and national data such as STRADA in Sweden. In addition, the accident cases could be used to study the effectiveness of various safety systems, by assessing the potential outcome of an accident if a specific safety system had been incorporated in the vehicles under investigation Such an approach has already been applied in various studies, including the study by Strandroth et al [23] on AEB effectiveness discussed in section 3.

New data sources for studying the performance of safety systems are now becoming available from Naturalistic Driving Studies (section 3.4). Also of relevance is a generic safety evaluation framework that integrates relevant data sources, methods and tools into a structured process for evaluating commercial vehicle safety systems and services. This will become available this year (section 3.4).

Abbreviations and acronyms

ABS	Anti-lock Brake System (vehicle system)
ACC	Adaptive Cruise Control (vehicle system)
AEB(S)	Autonomous Emergency Braking System
ADAS	Advanced Drives Assistance System (vehicle system)
AEB	Autonomous Emergency Braking (vehicle system)
APROSYS	Advanced Protection Systems (EU research project)
EC	European Commission
ECE	Economic Commission for Europe
ERTRAC	European Road Transport Research Advisory Council
EFFUP	Extended Flexible Front Underrun Protection system
ESC	Electronic Stability Control
ESP	Electronic Stability Program
ETSC	European Transport Safety Council, Brussels
EuroNCAP	European New Car Assessment Programme
FIMCAR	Frontal Impact and Compatibility Assessment Research (EU research project)
FKA	Forschungsgesellschaft Kraftfahrwesen mbh Aachen, Germany
FUP	Front Underrun Protection
GTR	Global Technical Regulation
HGV	Heavy Good Vehicle
IMVITER	European Project on Implementation of Virtual Testing Procedures in Regulation
ISA	Intelligent Speed Adaption
ITS	Intelligent Transportation System
KSI	Killed or Severely Injured
LDW	Lane Departure Warning (vehicle system)
LKA	Lane Keeping Assist (vehicle system)
MDB	Moving Deformable Barrier test
PIN	Road Safety Performance Index
PTW	Powered Two-Wheelers
SAFER	Vehicle and Traffic Safety Centre at Chalmers, Gothenburg Sweden
STRADA	Swedish Traffic Accident Data
TRL	Transport Research Laboratories, UK
UNECE	United Nations Economic Commission for Europe
VRU	Vulnerable Road User
VC-COMPAT	European project on Vehicle Crash Compatibility
VKT	Vehicle Kilometres Travelled
WG	Working Group

References

1 7th Road Safety PIN Report. Brussels: European Transport Safety Council (ETSC), 2013.

2 D Hynd, M McCarthy, J Carroll, M Seidl, M Edwards, C Visvikis, M Tress, N Reed and A Stevens, "Benefit and Feasibility of a Range of New Technologies and Unregulated Measures in the fields of Vehicle Occupant Safety and Protection of Vulnerable Road Users", TRL Final Report for the European Commission, March 2015.

3 Directive (EU) 2015/719 of the European Parliament and of the Council of 29 April 2015.

4 European Accident Research and Safety Report, Volvo Trucks, 2013.

5 András Bálint, Helen Fagerlind, Jan Martinsson and Kristian Holmqvist: "Accident analysis for traffic safety aspects of High Capacity Transports", report Chalmers University of Technology, 2014.

6 Pete Thomas et al, "Identifying the causes of road crashes in Europe", 57th AAAM Annual Conference, Annals of Advances in Automotive Medicine, September 22-25, 2013.

7 Haddon Jr., W. (1968), "The changing approach to the epidemiology, prevention, and amelioration of trauma: the transition to approaches etiologically rather than descriptively based", American Journal of Public Health, 1968, 58:1431–1438.

8 Jeanne Breen, Eric Howard and Tony Bliss: An independent review of road safety in Sweden, Swedish Road Administration, September 2008.

9 Final report of heavy-duty vehicles safety Working Group, Brussels, 2005.

10 Bovenkerk J (2006). APROSYS SP2 - Strategies for enhanced pedestrian and cyclist friendly design - AP-SP21-0062. Aachen: RWTH Aachen.

11 Feist F and Faßbender S (2008). APROSYS SP 2 - Demonstration of truck front design improvements for vulnerable road users - AP-SP21-0088. Aachen: RWTH Aachen.

12 Faßbender S (2008), Demonstrator module for new design concepts D2.1.3, Final Deliverable, APROSYS, AP-SP21-0077, Aachen: RWTH Aachen.

13 Gwehenberger J, Bende J, Knight I and Klootwijk C, VC-COMPAT - Collection of Existing In-depth Accident Cases and Prediction of Benefit on Having Front and Rear Underrun. GDV, Insurance Institute for Traffic Engineering (2004).

14 Welfers T, Ginsberg S, Funcke M, Hamacher M, Matheis R, Wohlecker R, Design of a Tractor for Optimised Safety and Fuel Consumption. Aachen: Forschungsgesellschaft Kraftfahrwesen mbH (FKA), (2011).

15 Robinson BJ, Knight I, Robinson T, Barlow T and McCrae I, Safer aerodynamic frontal structures for trucks: final report. Published Project Report PPR533, TRL, 2010.

16 ETSC. Briefing - Weights and dimensions of heavy goods vehicles - maximising safety. Brussels: European Transport Safety Council (ETSC).

17 Edwards M.J. et al, VC-COMPAT - Final technical report. TRL/TNO, 2007.

18 Imviter.com.

19 Andersson Anna-Lena, Svensson Kenneth: Fatalities in road traffic: A result of accidents or suicides, 17th International Conference Road Safety On Five Continents (RS5C 2016), Rio de Janeiro, Brazil, 17-19 May 2016.

20 European Motor Vehicle Parc, ANFAC, 2014.

21 Aerodynamics for the front of trucks, working document of the European Commission DG MOVE (final draft March 2015).

22 Informal document GRSG-109-19 (109th GRSG, 29 September – 2 October 2015 agenda item 15).

23 Johan Strandroth, Matteo Rizzi, Anders Kullgren and Claes Tingvall: Head on collisions between passenger cars and heavy goods vehicles: Injury risk functions and benefits of Autonomous Emergency Braking, Paper Irc 12-42, Ircobi 2012 Conference.

24 John Woodrooffe et al.: Performance Characterization and Safety Effectiveness Estimates of Forward Collision Avoidance and Mitigation Systems for Medium/Heavy Commercial Vehicles, Report UMTRI-2011-36, The University of Michigan Transportation Research Institute, August 2012.

25 Jonas Bärgman: On the analysis of naturalistic driving data, Licentiate thesis, Chalmers University of Technology, 2015.

26 http://www.vinnova.se/sv/Resultat/Projekt/Effekta/2009-02186/Analysis-Framework-for-Safety-Systems-and-Services/.

European Automobile Manufacturers' Association

Avenue des Nerviens 85
B – 1040 Brussels
T +32 2 732 55 50
info@acea.be
@ACEA_eu

WWW.ACEA.BE