CHALMERS

Final report

Accident analysis for traffic safety aspects of High Capacity Transports

Date and version
May 2014, v2

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EXECUTIVE SUMMARY

This study was conducted in order to examine the effect of increased vehicle combination length of Heavy Goods Vehicles (HGVs) on traffic safety. It consists of three main parts; the first is a literature study reviewing international experience with Long Combination Vehicles (LCVs, alternatively called High Capacity Transports, HCTs), see Section 1. The second part (Section 2) is an analysis of the crash rates of HGV combinations of different length in Sweden based on national crash data and exposure data. This section also includes analysis of national crash data in Canada on LCVs that was received from Transport Canada. The statistical analysis of national data in Section 2 is then complemented with an in-depth study of fatal HGV crashes in Sweden, presented in Section 3.

It is demonstrated in Section 1 that it is a very complex task to estimate how traffic safety is affected by the introduction of longer truck combinations. Some studies indicate a slightly increased risk of crashes per vehicle kilometre and that the change in risk depends on the vehicle combination. Other studies show that the difference in crash risk in comparison to conventional heavy goods vehicles is small, at least for trucks travelling on larger roads.

It is a general trend in the studies that instead of vehicle combination length, crash data and the exposure data (Vehicle Kilometres Travelled, VKT) are classified by combination type, which makes it difficult to evaluate the potential effect of increasing the maximum vehicle combination length. These considerations were one of the main motivations for conducting a study which, similarly to the regulations on maximum allowed length, directly addresses vehicle combination length.

The resulting study, presented in Section 2 (see also Bálint et al., 2013), constitutes the second main part of this report. This study investigated the rates of fatal and severe crashes per billion VKT for HGVs in different length groups with the aim of comparing crash rates for long Swedish HGV combinations with those of regular European combinations. Note that in fatal or severe HGV crashes, it is typically the occupants of an opposing vehicle that are fatally or severely injured; e.g., passenger car occupants constitute 50% of the fatalities in HGV crashes in the EU in 2009 while the share of HGV occupants is 13% (EC, 2011). Fatal or severe crashes are also called KSI crashes henceforth, where KSI stands for “Killed or Severely Injured”.

The method in the statistical study uses Swedish national crash data and exposure data from the period 2003 to 2012. Unlike most other countries in the European Union where an upper limit of 18.75 metres is in force, vehicle combinations up to 25.25m are permitted in Sweden. The aim is therefore to determine whether “long” truck combinations (with a combination length of 18.76 – 25.25m) have a higher associated rate of KSI crashes per VKT than “medium” (12.01 – 18.75m) or “short” combinations (≤12m).

Several aspects of fatal or severe crashes with the involvement of HGV combinations are analyzed to characterise typical features of KSI crashes in the different length groups. The investigation of the traffic environment reveals that most KSI crashes (60%, 76% and 84% in the “short”, “medium” and “long” groups, respectively) occur

in rural areas. The occurrence of KSI crashes in different seasons per length group is also considered. It is shown that while crashes involving “short” and “medium” combinations have a close to uniform seasonal distribution, KSI crashes with “long” combinations occur substantially more often in the winter (32%) and less often in the spring (18%) than in the other two seasons. Further parameters that are analyzed are road type, posted speed limit, month, and hour of the day.

The crash type distributions in the three length groups are also compared and it is considered to what extent the observed differences can be explained by differences in the exposure data. The crash type distribution for KSI crashes in Sweden involving *“medium”* HGV combinations show a large degree of similarity with Canadian LCV data presented in Section 2.5. The distribution for the “long” group is also similar to Canadian LCV data, but the extent of similarity is much smaller. The reasons behind this phenomenon are not yet explored. In order to understand the relatively large seasonal variability of KSI crashes in the “long” group and the large percentage of crashes in the winter, the seasonal distributions of crashes for each crash type were investigated. High percentages of winter crashes were found for pedestrian crashes, “meeting and overtaking” crashes, rear-end crashes and “other” crashes.

The analysis of crash rates shows that “long” HGV combinations have been involved in less fatal or severe crashes per billion VKT than “medium” or “short” combinations. Since VKT classified by road type or area type was unavailable, it cannot be excluded that this difference is due to that “long” combinations typically travel on safer roads than those in the other two groups. Discussions with experts have also indicated that companies tend to choose their most experienced drivers to drive long vehicle combinations, which might be another non-vehicle related reason behind the better crash statistics in the “long” group. However, it can be concluded from this study that under the usage patterns in the 10-year period 2003 to 2012, including the choice of routes and drivers, “long” combinations that exceed the EU length limit of 18.75m were involved in less fatal or severe crashes per billion VKT than regular EU combinations.

In order to identify trends in the data, the KSI crash rates have also been computed for every year between 2003 and 2012. The KSI crash rates for the “short” group were the highest of the three groups for each year and showed a general downward trend with moderate occasional fluctuations. “Medium” combinations had the second highest KSI crash rate from 2004 to 2011 and showed a more stable decreasing linear trend. “Long” combinations had the lowest rate of all groups in 8 out of the 10 years; however, both in 2003 and in 2012 the rate in the “medium” group was lower than that in the “long” group. In fact, after a downward trend from 2003 to 2008, the KSI crash rate of the “long” group increased every year from 2009 to 2012.

The derivation of current trends does not support a prediction of future KSI crash rates; a prediction would require a much deeper analysis and is not included in the current study. Nonetheless, further investigation may be necessary to identify the reasons behind the increase of the KSI crash rate per billion VKT for the “long” group in the 4-year period starting in 2009.

Finally, in Section 3, results are presented from an in-depth study of fatal crashes with HGV involvement in Sweden in order to analyse whether vehicle combination length has influenced the occurrence and/or severity of these crashes. A method based on objective real-world data collected at the crash scene was designed for determining the potential effect of combination length on the crash. This method, described in detail in Section 3.1, is based to a large extent on the crash configuration (i.e. the positions and angles of the vehicles involved) and the point of impact.

The in-depth data used in this study allowed for the identification of those crashes in which extraordinary circumstances (termed “complicating factors” in Section 3) were present in the crash. Importantly, it is not assumed that the crash is exclusively due to the different complicating factors, except in the case of suspected suicides, where voluntary action is taken by the opposing driver. The detailed analysis of these factors, such as suspected natural death/illness, suspected drowsiness/distraction or alcohol/illegal drug involvement has revealed that they may indeed have influenced crash outcome.

Also, the HGV combination length appears to influence the occurrence and/or the outcome in a crash, showing that an increase in total HGV combination length increases the likelihood of being classified as *possible influence*. However, there is no difference in the ratio of *no influence* to *possible influence* classification in the medium group to the long group.

Finally, the most common crash types and scenarios for fatal HGV crashes were identified in the in-depth study. It was observed that crash type can also affect whether the HGV in the crash receives a *possible influence* or *no influence* categorization. The most frequent crash type in the possible influence category was crashes in longitudinal traffic. However, the ratio of *no influence* to *possible influence* classification for this crash type was lower than the overall average. Illustrations and descriptions of the most common crash scenarios for fatal HGV crashes where the length of the HGV combination may have played a role are given in Section 3.5.

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1 INTERNATIONAL EXPERIENCE

Long Combination Vehicles are already present in certain regions around the globe. Utilizing experience from these regions may be one way of estimating the possible safety consequences of allowing longer combinations in Sweden. The current legal limit for truck combination length in Sweden is 25.25m which exceeds that of most European countries (18.75m). Therefore, in some studies, 25.25m long truck combinations are considered as LCVs. In our terminology, however, LCVs are truck combinations whose vehicle combination length exceeds 25.25m while those up to 25.25m are called HGVs.

The aim of this literature review is to identify studies on truck combinations exceeding 25.25m and summarize the knowledge concerning the following questions:

1. Do LCVs have a larger share of severe and fatal crashes relative to their driven mileage than regular HGV combinations?
2. Which are the most common crash scenarios involving HGVs and LCVs and are there any differences depending on the length of the combination?

These questions will determine the structure of this section. The specification of the LCV types considered in this review (Table 1 below) will be followed by sections summarizing the state-of-the-art knowledge about each of the above questions.

1.1 Common vehicle combinations

Size and weight regulations of HGVs and especially LCVs diverge around the world. Truck combinations with identical names may have different size and weight limitations depending on the local regulations. Similar combinations may also have more than one label even in the same region. An overview of the current weight and length limits for the most common types mentioned in this report is presented in Table 1. The "legal length double" is usually not considered as an LCV but it is included in this table as it has two trailers, which makes it hard to distinguish them from LCVs in many studies.

Table 1 Size and weight limits from http://www.dot.ca.gov, Montufar et al. (2007), Pearson (2000), Schulman (2003) and www.wikipedia.com.

Truck combination	Maximum weight (kg)	Maximum allowed length (m)			
		Total	Trailer 1	Trailer 2	Trailer 3
Rocky Mountain double	47 600 – 63 500	29.0 – 31.5	14.6 – 16.2	7.3 – 8.5	0
Turnpike double	61 200 – 63 500	36.5 – 38.5	14.6 – 16.2	14.6 – 16.2	0
Triple trailer combinations	49 900 – 53 500	33.5 – 38.0	8.5	8.5	8.5
Leagal length double / STAA double		No limit*	8.7	8.7	0
B-double (Australia)	62 500 – 68 000	25 – 27.5	-	-	0

* No national limit in the US, but states may have their own limits (e.g. 22.9m in California)

1.2 Do longer LCVs have a higher rate of severe and fatal crashes per vehicle kilometres driven than regular HGV combinations?

In the LCV literature, most studies are concerned with the determination of the rates of fatal crashes, injury crashes (including all severities) and/or all crashes (including property damage only crashes) per vehicle kilometres travelled (VKT). It has not been possible to find any study in which the rate of severe injuries per VKT is determined for LCVs. Furthermore, in each of the studies, vehicle combination type is considered instead of vehicle combination length. Table 1 above can be used to map combination type to combination length for certain LCV configurations. The studies considering all crash severities are reviewed first, followed by those focusing exclusively on fatal crashes, in approximate chronological order.

A summary of five studies performed between 1980 and 1998 is presented in FHWA (2004), Table VII-7. It has not been possible to access the original studies hence the following points reflect the summary as described in FHWA (2004).

Three of the five studies (Mingo, 1990; FHWA, 1993 and TRB, 1990) derived the rates of injury crashes and fatal crashes per 100 million VKT for single trailer combinations and multiple trailer combinations. In FHWA (1993), the rates were 195.5 and 156.3 injury crashes and 15.2 and 12.9 fatal crashes per 100 million VKT for single and multiple trailer combinations, respectively. The results for the other two studies were different from the first, with slightly lower rates for single trailer combinations (Mingo, 1990; TRB, 1990). However, the results should be interpreted with care as the different studies have used different databases, time frames, methodologies, and the data have different biases.

Two of the five studies (Campbell et al., 1988; FWHA, 1993) compared rural roads versus urban roads and interstate/limited access roads versus other roads. Both studies showed lower crash rates for multiple trailer combinations on interstate/limited access roads in urban and rural areas. On other road types the results are mixed with both higher and lower crash rates for multi-trailer combinations compared to single trailer combinations.

The most recent of these five studies is (Woodrooffe, 2001) in which the number of crashes per 100 million VKT are presented for different HGV and LCV types and crash severities. The investigated crashes in the study are limited to a road network of approximately 2800 km of four- and two-lane highways in state Alberta in Canada. This set of roads, called the “sub-LCV-network,” is part of the road network where LCVs are restricted to operate. The results which are summarized in Table 2 indicate that LCVs have a lower crash rate (16 crashes per 100 million VKT) than straight trucks (187) and tractor-semitrailer combinations (80). The total number of LCVs in this material is only 37, and divided into the existing subgroups of LCVs the numbers are even smaller.

Table 2 Crash rates per 100 million VKT on the sub-LCV-network in Canada for different vehicle types and severities (Woodrooffe, 2001).

Vehicle type	All collision severities	Fatal	Injury	Property damage only	Total number of vehicles
Straight truck	187	4	34	149	715
Tractor-semitrailer	80	3	22	54	918
Multi-trailer	104	5	31	68	418
Rocky Mountain	10	0	2	8	11
Turnpike doubles*	17	2	4	11	20
Triples*	67	0	22	44	6
Personal vehicles	88	1	16	71	19206
All vehicle types	89	1	17	70	21294
All LCV	16	1	4	11	37

In Montufar et al. (2007) the same region of Canada is investigated using data from the years 1999 to 2005, but including the complete LCV network, which is a larger set of roads also including urban roads. The results from this study (see Table 3) point in the same direction as the previous study with fewer collisions per 100 million vehicle kilometres travelled for LCVs as a group (25) than straight trucks (128) and tractor-semitrailer combinations (44).

Table 3 Crash rates per 100 million VKT on the full LCV-network in Canada for different vehicle types and severities (Montufar et al., 2007).

Vehicle Type	All collision severities	Fatal	Injury	Property damage only	Total number of vehicles
Straight trucks and bobtails	128	3	26	100	3825
Tractor-semitrailer	44	2	13	30	2491
Multi-trailer (Legal-length tractor double trailer)	46	2	15	28	983
Rocky Mountain	32	1	6	25	36
Turnpike Doubles	16	2	4	11	21
Triples	62	0	31	31	8
Personal Vehicles	107	1	25	80	59905
All vehicle types	101	2	24	75	67269
All LCV	25				65

Available data on LCVs in the US was investigated in FHWA (2000), concluding that the detailed data needed for determining the safety performance of LCVs was only collected in Utah. It was also concluded that 20 years of data would be needed to produce reliable crash rates on highways and even longer time period for other road types.

However, the study compared the fatal crash rates for single-unit trucks, single trailer combinations and multi-trailer combinations using data from the US Fatality Analysis Reporting System (FARS) between 1991 and 1995. The results showed that the overall crash risk is highest for single trailer combinations, slightly lower for multi-trailer combinations and approximately 50% lower for single-unit trucks, but there is a great variation depending on the road type. It was also concluded that if multiple trailer combinations were unrestricted in their use and their driving patterns were similar to single trailer combinations, then they would be expected to generate an 11 % higher fatal crash rate than single trailer combinations.

In 2004, the fatal crash rate was again investigated (FHWA, 2004) for single and multiple trailers as a more detailed distinction between combination types was not possible in the data. FARS data was used from 13 states for the years between 1995 and 1999 containing a total of more than 2000 involved trucks in 2180 crashes. The result showed a slightly but non-significantly lower fatal crash rate for single trailer combinations.

The TIFA (Trucks Involved in Fatal Crashes) survey is based on FARS but supplemented with more details on the truck configuration. In a detailed comparison of these two databases (Blower and Matteson, 2002) the involvement rate in fatal crashes per 100 million VKT classified by truck length was presented for straight trucks, tractor-semitrailers and double trailer combinations. The peak involvement rates are below 31 feet (<9.45m) for straight trucks, between 61 and 65 feet (18.59-19.81m) for tractor-semitrailer combinations and between 71 and 75 feet (21.64-22.86m) for doubles.

1.3 Which are the most common crash scenarios involving HGVs and LCVs, and are there any differences depending on the length of the combination?

No studies have been found that investigate the relationship between truck combination length and crash type involvement directly but rather, as above, truck combination type is considered instead of combination length. However, the combination type also influences the use of a truck and thereby it also influences the exposure to various traffic environments. Two studies indicating this effect are reviewed first, followed by a discussion on crash types. Finally, studies on crash causation for LCVs are also considered in order to obtain a better understanding of the crash scenarios.

The effect of combination type on traffic environment is indicated by the results in (FHWA, 2000); see Table 4, where normalized rates of fatal crashes are presented for different truck combinations for different roads types. The results are normalized relative to the rate of fatal crashes involving a single trailer combination on a rural interstate which is set as 100 units.

Table 4 Normalized fatal crash rates by truck combination type and road type, where the rate of fatal crashes involving a single trailer combination on a rural interstate is set as 100 units (FHWA, 2000).

	Single-unit trucks	Single-trailer combinations	Multi-trailer combinations
Rural interstate	50	100	114
Other rural arterials	169	386	403
Other rural roads	151	335	497
Urban interstates & other freeways and expressways	64	134	125
Other urban streets	92	206	201

A similar study on FARS data was conducted using data from 13 US states during the years 1995 to 1999 (FWHA, 2004), see Table 5. Differences from the national crash rates were not significant at a confidence level of 95%. The results show a high degree of similarity with the previous study.

Table 5 Rates of fatal crashes per 100 million VKT for FARS data between 1995 and 1999 from 13 US states (FHWA, 2004).

Road functional class	Fatal crash rate per 100 million VKT			
	Number of crashes		Number of trucks involved	
	Single trailer	Multi trailer	Single trailer	Multi trailer
Interstate rural	0.84	1.11	0.93	1.14
Other rural	2.85	3.86	2.94	3.95
Interstate urban	1.15	0.64	1.25	0.86
Other urban	1.75	1.32	1.76	1.32
Total	1.71	1.88	1.79	1.94

Urban versus rural LCV crashes were also investigated in state Alberta, Canada by Montufar et al. (2007) concluding that “single vehicle crashes” is a less common crash type in urban areas with 22% of the crashes compared to the LCV network where 55% of the LCV crashes are single vehicle crashes.

In an attempt to investigate the performance of LCVs, Forkenbrock (2003) investigated 5889 fatal HGV crashes to compare the conditions in which single versus multi-trailer crashes happen. The study is based on data from the TIFA survey (described before) conducted during the years 1995 to 1998. The results show that multi-trailer combinations are overrepresented in crashes with the following conditions: darkness, poor road conditions (snow, slush, or ice on the road surface), involvement of three or more vehicles, and higher-speed facilities with 65 to 75 mph (105 to 121 kph) limits.

As mentioned at the end of Section 1.2, the TIFA survey is based on the Fatality Analysis Reporting System (FARS) file but with supplements and enhancements improving the identification of trucks and supplying a more detailed description of the physical configuration of the trucks involved in the crashes. Details on the information that is found in the TIFA survey are presented in a report (Blower et al., 2002) comparing it to FARS. In this report, the involvement of different truck combinations in fatal truck crashes is presented per crash type. Unfortunately, the details on the involved truck configurations do not allow a distinction between LCVs and shorter combinations presented together with the crash type.

To obtain more detailed information on the most common crash scenarios for truck crashes, the scope of the review has been widened to two studies that contain HGVs only (but no LCVs). The two largest in-depth studies on HGVs were the Large Truck Crash Causation Study (LTCCS, Hedlund and Blower, 2006) performed in the US and the European Truck Crash Causation study (ETAC, EC 2006) performed in Europe.

According to Starnes (2006), the most common general crash types in LTCCS data were rear-end crashes (23%) followed by right roadside departure (10%), same traffic way same direction – sideswipe/angle (10%) and left roadside departure (8%). Somewhat less common crash types are straight intersecting paths (6%), turn across path (5%), same traffic way opposite directions – sideswipe/angle (5%), head-on (3%), turn into path (3%) and single driver – forward impact (2%). More specific crash types are presented in Table 7 in (Starnes, 2006).

ETAC uses a different set of crash types. The most common categories are crash at an intersection (27%), crash in queue (20.6%), crash due to lane departure (19.5%) and crash after overtaking manoeuvre (11.3%). Less common crash types are single truck crashes (7.4%), crash with a pedestrian (6.2%), crash with a vehicle coming from a parking space (3%) and “main crash after first event” (1.8%).

Differences in crash severity and in the categorization of crashes into crash types pose a tangible difficulty when making comparisons between the results of different studies. Similar difficulties have to be faced when analysing crash causation. Again, results from the studies including LCVs are presented first and then these results are complemented with those from LTCCS and ETAC.

During the years 1995 to1998 there were 53 crashes involving LCVs on the roads of Alberta, Canada. Three of these were fatal crashes, 14 were injury crashes and the remaining 36 were property damage only crashes. In the study by Woodrooffe (2001) these crashes are studied in detail to understand the factors contributing to the crashes. In Table 6 the most common factors are presented. None of the crashes on 2-lane undivided roads had overtaking as a contributing factor. There were two crashes on 4-lane divided roads during overtaking manoeuvres, but those crashes were not thought to be caused by the extra length of the LCV.

Table 6 Contributing factors in LCV crashes between 1995 and 1998 in Alberta, Canada (Woodrooffe, 2001). Each crash can have more than one contributing factor.

Contributing factor	Collision location			
	Sub-network			
	4-lane	2-lane	Urban*	Overall
Road surface	8	5	4	17
Animal	4	5	0	9
Weather	5	2	1	8
Configuration-related	3	1	2	6
Intersection	0	0	6	6
Mechanical	0	1	0	1

* Includes 2-lane access routes

In a more recent study of LCV crashes on the LCV network in Alberta, Canada (Montufar et al., 2007) 65 LCV crashes from the years 1999 to 2005 were investigated. Contributing factors that were present more than once were the following: driver condition – fatigue (3), driver action – run-off-road (11), driver action – left of center (2), environmental conditions – raining (5), environmental conditions – snow (11). In total, driver actions (18) and environmental conditions (20) were found to be the most common contributing factors found in LCV crashes.

The study also showed that adverse road conditions were more common for crashes with articulated vehicles including LCVs than those including other vehicles. Another finding was that 9 out of the 65 LCV crashes (14%) involved a struck animal, resulting in a single vehicle run-off-road crash. The corresponding numbers for tractor-semitrailers were 228 out of 2491 (9%), and for legal length doubles, 100 out of 983 (10%).

The LTCCS and ETAC studies also include detailed information on pre-crash characteristics such as critical event and critical reason which has led to the crash. In the ETAC data, a “main crash cause” is identified for HGV crashes, and the top causes for single truck crashes were non-adapted speed according to the situation (20%), fatigue or falling asleep of the truck driver (19%) and loss of road friction (12%). For crashes between a truck and another road user the most common causes varied depending on the scenario. For intersection crashes, failure to observe intersection rules (20%) was the most common main cause followed by non-adapted speed (13%) and improper manoeuvre when turning (8%).

In LTCCS the most frequent “critical reasons” for the single vehicle crashes were too high speed in a curve (22%), falling asleep (13%) and shifting cargo (7%). In most of the multi-vehicle crashes no critical reason was found for the truck. The most common critical reasons found were inadequate surveillance (8%) and too high speed for conditions (5%).

2 CORRELATION BETWEEN TRUCK COMBINATION LENGTH AND INJURY RISK

2.1 Introduction

Regulations limiting combination length for heavy trucks can have a tangible influence on the economy of large regions. For example, a positive socio-economic effect of permitting longer and heavier truck combinations (up to 25.25m, 60 tonnes) in Sweden, than in the rest of the European Union (EU), has been shown in Vierth et al. (2008). It is also shown that the emission costs are reduced since fewer long vehicles are required for the transportation of a certain amount of goods. Decreasing the number of vehicles implies that even if there is a slightly increased crash risk per vehicle the total effect on traffic safety can be positive.

Natural limitations on the length of HGV combinations are posed by the existing infrastructure, most obviously in urban areas. More importantly for the current study, there have been concerns about long HGV combinations having a potential negative effect on traffic safety. However, if longer combination vehicles show an unchanged or positive effect, they can be introduced to a larger extent.

The length and weight regulations for truck and trailer combinations vary around the world. In some countries (e.g. in the United States of America and Australia) the combined length of trailers is regulated, excluding the tractor, whereas in e.g. the European Union the overall length of the truck and trailer combination is regulated. As opposed to most studies in the literature that compare the effects of various combination types (see examples in Section 2 above), the overall length of the HGV combination was the measure of interest in the current study.

The current study was conducted within a research program that was initiated to investigate how introduction of trucks longer than the current limit of 25.25m would affect traffic safety in Sweden. The current limit already exceeds the EU norm of 18.75m therefore it was necessary to examine how traffic safety is affected by this difference.

The aim of the study described in this section is to determine whether “long” combinations (18.76 – 25.25m) have a greater share of fatal or severe injuries in Sweden than “medium” combinations (12.01 – 18.75m) when accounting for VKT in both groups. Combinations that are at most 12m long have a different usage pattern from the other two groups. Therefore, combinations of length ≤12m (“short” combinations) will be treated separately.

2.2 Method

The analysis proceeds in three main steps. First, all crashes that resulted in a severe or fatal injury and involved at least one heavy truck are identified. Secondly, each truck combination is assigned to one of the three length groups. Finally, the rates for severe or fatal injuries in the three length groups are determined by normalizing the number of relevant crashes in each group by vehicle kilometres travelled.

All HGV combinations considered in this section include a rigid truck or a tractor. From this point on, for better readability, these vehicles will be called a “truck” unless the exact type is important for the argument. For similar reasons, trailers and semi-trailers will uniformly be called “trailers” unless it is important to differentiate between them in the given context.

2.2.1 Relevant crashes

The first step in the analysis was the identification of the crashes that are relevant for the current study. These are crashes for which each of the following criteria holds:

a) The crash is included in the Swedish Traffic Crash Data Acquisition (STRADA) system. This criterion implies that the crash occurred on a public road in Sweden and that at least one road user involved sustained an injury.
b) The crash occurred in the 10-year period between 2003 and 2012.
c) At least one person was fatally or severely injured in the crash according to the police report.
d) At least one HGV was involved in the crash.

Vehicle type in STRADA is coded by the police at the scene of the crash, and eventually, police coding is automatically compared with data in the vehicle registry. This coding was used as a basis for the identification of HGVs. However, there are also vehicles which are classified as “unknown goods vehicle” which may in principle be either light goods vehicles (LGVs) or HGVs. In order to identify HGVs as precisely as possible, the following heuristics have been applied:

- If the gross weight of a vehicle combination is known, then this weight is used as a basis for classification. This means that “unknown goods vehicles” with a maximum gross weight above 3.5 tonnes were re-classified as HGV while vehicles that were classified as HGV by the police but had a weight ≤3.5t were re-classified as LGV.
- If gross weight was unknown or missing, then the police-classification as HGV was accepted. However, for those vehicle combinations without a known gross weight that were police-classified as “unknown goods vehicle,” the driver’s license was reviewed. Those vehicles in which the driver was in possession of a license “C” or “CE” (i.e. a license that is required for driving HGV respectively HGV with trailer) were re-classified as HGV.

2.2.2 Determination of length groups

The next step is to assign each HGV combination to one of the defined length groups. The total length of HGV combinations is not coded in STRADA hence length-related data about the truck was combined with similar data for each connected trailer. In STRADA some variables are coded directly by the police (such as the number of trailers) and some are derived from the vehicle registry by synchronisation of the registration number (such as vehicle length).

Knowing the number of trailers enables different methods for determination of length groups for HGV combinations depending on whether the truck has zero, one or at least two trailers. If there are no trailers then the length of the truck equals the combination length. Combinations with at least two trailers were allocated to the "long" group. Since the number of trailers did not exceed two for any crash, this assumption is effectively concerned with the case of exactly two trailers. The other methods described below are concerned with the case of one truck and exactly one trailer.

In case of a tractor and one semi-trailer, the sum of vehicle lengths overestimates combination length because the length of the overlapping parts is counted twice. Therefore, in this case the "coupling distances" were summed which are the distances between the fifth wheel (i.e. the coupling point) and the front of the truck, respectively the back of the trailer, see Figure 1. The sum of coupling distances was used to approximate combination length for rigid trucks with one trailer as well.

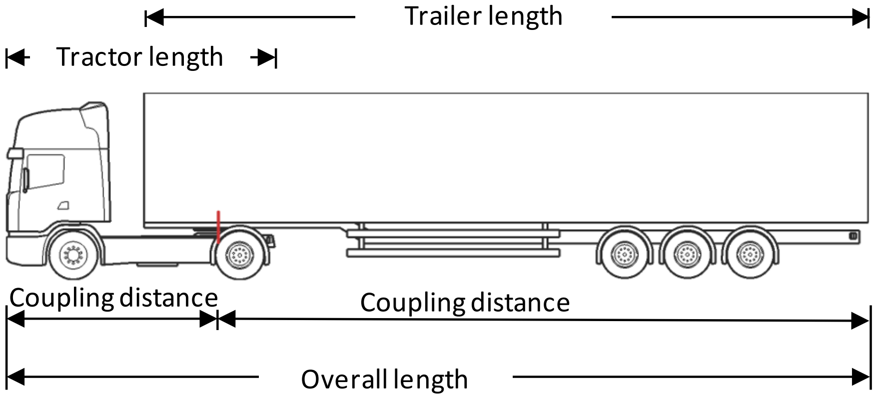

Figure 1 Illustration of length-related variables for a HGV combination consisting of a tractor and a semi-trailer. The arrows above the vehicle represent vehicle lengths while the arrows below represent the combination length and the distances between the front of the tractor or back of trailer to the fifth wheel.

However, for several crashes, coupling distances were unavailable but the lengths of the truck and the trailer were known. In order to deal with these cases, it was investigated how much the sum of lengths overestimated the sum of coupling distances for those crashes where both sums were known. The median difference was found to be 365cm. Therefore, the sum of lengths minus 365cm was used as an estimate for combination length in the crashes with one trailer where coupling distances were unknown or missing.

When neither coupling distances nor vehicle lengths were available for a HGV combination with one trailer, assumptions were made in order to assign the combination to the appropriate length group. For example, length-related data was missing for HGV combinations where both the truck and the trailer had foreign (non-Swedish) registration. However, if the maximum allowed combination length at the time of the crash was 18.75m in the country of registration, the combination was allocated to the "medium" length group. Such assumption was not made for foreign trucks with a Swedish trailer.

For the remaining combinations with one trailer, two simplifying rules were applied, based on consultation with truck experts. Tractors with a semi-trailer were assigned to the "medium" group due to regulations in the European Modular System. Rigid trucks with a trailer were assigned to the "long" group because a truck is normally 8-10m and the trailer is normally between 9-15m long. These rules were used for the assignment of individual crashes to the three length groups, but a refined version, described below, is used to estimate the number of crashes in the three groups (which is necessary for the computation of crash rates).

First, combination length is determined for all truck and one trailer combinations in STRADA for which coupling length is known for both the truck and the trailer. The distributions of tractor and semi-trailer as well as rigid truck and trailer configurations among the three length groups are determined based on this sample. Then, instead of assigning each crash including one of these configurations to one of the length groups, the number of such crashes is distributed among the three length groups according to the derived percentages, see Table 9.

A further step used for the computation of fatal or severe crash rates is the correction for crashes with an HGV combination of unknown length group. Due to the arguments detailed after Table 9 the length group distribution assumed for these crashes is the same as for those with identified length groups but without those crashes where length group was identified on the basis of foreign registration or two trailers (see Table 10).

2.2.3 Exposure data

There is no data available concerning the vehicle kilometres travelled by heavy trucks in Sweden classified by the combination length. However, there are official statistics (Trafa, 2013) of VKT by axle configuration for the following vehicle combination types: tractor only; tractor and semi-trailer; other configurations with tractor; rigid truck only; rigid truck and trailer; other combinations with rigid truck.

STRADA data was used to determine the relative frequencies of the three length groups for given axle configurations within these combination types. The total exposure for the three length groups for the years 2003 to 2012 were determined by first summing VKT in Trafa (2013) for the relevant 10 years for each of the combination types, and then assigning a share of the sums to each group which is proportionate to its relative frequency (see Table 11).

The results in Table 11 are concerned with VKT by Swedish trucks in Sweden. The exposure data for HGV combinations with foreign registration within Sweden is derived from estimates in Trafa (2012) where total VKT is provided for the years 2004 to 2010. For the years 2011 and 2012 it is assumed that the ratio between the VKT by foreign HGVs and Swedish ones is the same as that in 2010 while for 2003 the ratio from 2004 is assumed.

Besides the total VKT, the contributions of individual countries are also available in Trafa (2012) for the years 2006, 2008 and 2010. For HGVs from countries with the same length limit as for HGV combinations in Sweden the length group distribution observed in Sweden is assumed. For countries where the length limit is 18.75m, the exposure is distributed between the "small" and "medium" groups assuming the same proportion between these groups as in Sweden.

Finally, the VKT by Swedish and foreign HGV combinations in Sweden were summed, and the rates of fatal or severe crashes by VKT in the three length groups for the 10-year period 2003 to 2012 were computed by dividing the number of crashes in each of the three groups by the corresponding total VKT. The same procedure was repeated for each year from 2003 to 2012 in order to compute the annual KSI crash rates per length group and identify potential trends.

2.3 Results

There were 10 196 crashes in STRADA between 2003 and 2012 that involved an HGV combination and 2 290 of these crashes were fatal or severe (i.e. satisfied criterion ‘c’ for relevant crashes described in Section 2.2.1). It is shown in Table 7 that crashes involving heavy trucks stand for slightly less than 6% of all crashes and 7% of fatal or severe crashes. This difference is due to the fact that about 18% of all crashes result in a fatal or severe injury but this rate is 22.5% for crashes with heavy truck involvement.

Table 7 Number and share of relevant crashes in Swedish crash data between 2003 and 2012

	All	Involving HGV	Percentage Involving HGV
All crashes	179 913	10 196	5.7%
Fatal or severe crashes	32 499	2 290	7%
Percentage fatal or severe	18.1%	22.5%	-

According to the principles for the identification of length groups described in the previous section, 1161 fatal or severe crashes involved at least one identified “short” HGV combination while 274 and 484 crashes involved at least one “medium” and “long” HGV combination, respectively. There were 75 crashes in which HGV combinations from two length groups are involved; these are counted once for each corresponding length group. There were also 446 crashes for which length group could not be identified. The next section provides results concerning when, where and how these accidents occur, for each length group.

2.3.1 Characteristics of fatal or severe crashes with HGV involvement by length group

In order to examine the main characteristics of KSI heavy truck crashes in Sweden between 2003 and 2012 in different length groups, the following parameters are considered, in the order described here:

- crash location-related parameters such as traffic environment, road type, posted speed limit;
- time distributions with respect to season, month and hour of the day;
- crash type distribution.

In each case, it is analyzed whether there are general trends in the data and whether crash distributions in specific length groups deviate from the general trends.

As shown in Figure 2 below, crashes in rural environment are dominant in all three length groups. This effect substantially increases with increased combination length to the extent that, on average, slightly more than 5 out of 6 KSI crashes with the involvement of “long” HGV combinations occur in rural environment.

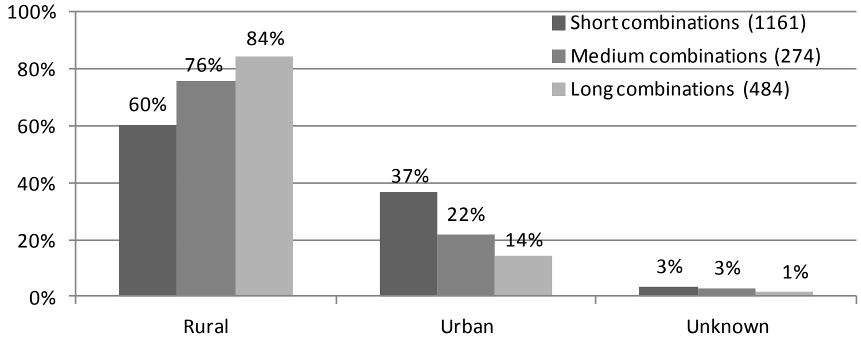

Figure 2 Traffic environment in fatal or severe HGV crashes classified by length group

The analysis of road types was based on the road type values included in the STRADA database (see Figure 3). The largest percentage of KSI crashes occurred on “other public roads” with the relevant percentages ranging from 46% to 66%, with increasing figures for increased group length. On the contrary, the shares of intersection crashes decrease from 21% in the “short” group to 13% in the “long” group, and crashes on streets decrease from 8% to 2%. There are smaller differences between the shares in different length groups for crashes on motorways and separated expressways (“motortrafikled” in Swedish).

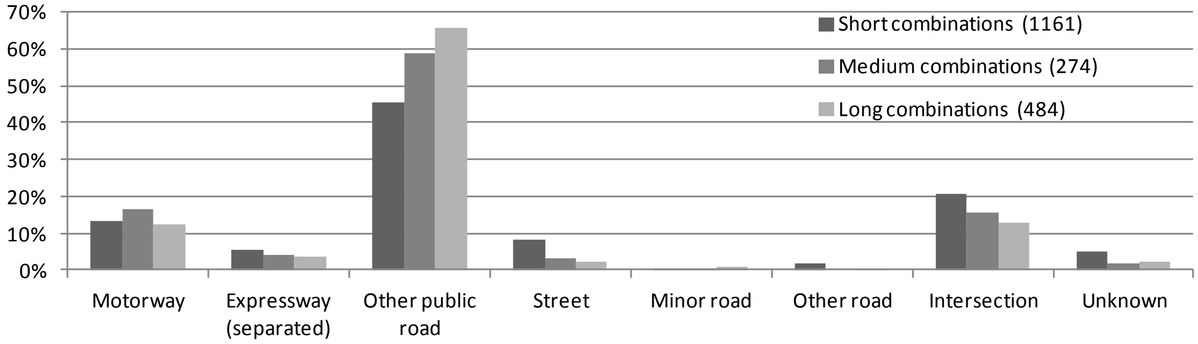

Figure 3 Road types in fatal or severe HGV crashes classified by length group

The posted speed limits on the roads where KSI truck crashes occurred are shown in Figure 4. For crashes that occurred in intersections of roads with unequal posted speed limits, the higher posted speed limit was considered in the analysis. Posted speed limits below 20 kph and above 150 kph were disregarded in the analysis in order to avoid mistyped values. A tendency of clustering around the values 50, 70, 90 and 110 kph can be observed on Figure 4; in fact, more than half of KSI truck crashes (58%-66%, depending on the length group) occur at posted speed limits of 70 or 90 kph.

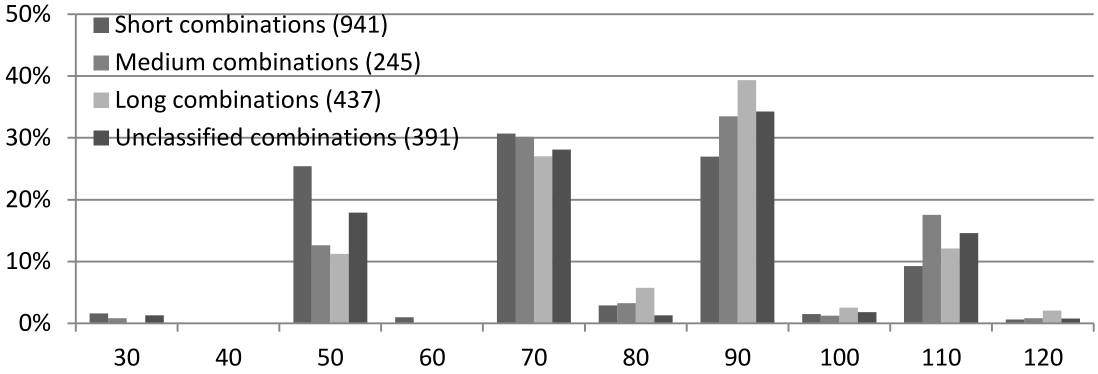

Figure 4 Posted speed limits (kph) at the scenes of fatal or severe HGV crashes classified by length group

A difference between length groups is that while 25% of KSI crashes with “short” HGV combinations occur at a speed limit of 50 kph, the corresponding percentages are 13% and 11% in the other two groups. Conversely, at 90 kph the shares of length groups increase from 27% (“short”) to 39% (“long”). Finally, while slightly more than 1 out of 6 KSI crashes with “medium” combinations (18%) occur at 110 kph, the relevant ratios are approximately 1 out 8 for “long” combinations (12%) and 1 out of 11 for “short” combinations (9%).

For a further quantification of the differences between the three length groups, the main features of the resulting distributions are compared; namely, the sample mean: $\overline{x}$, the sample median: *m*, and the corrected sample standard deviation: *s*, all given in kph. The results reinforce that the KSI crashes involving “short” HGV combinations ($\overline{x}=74.3$, *m=70, s=19.98*) occur typically at lower posted speed limits than those with “medium” combinations ($\overline{x}=81.96$, *m=90*, *s=19.28*) or “long” combinations ($\overline{x}=82.84$, *m=90, s=17.67*), but the variability of the posted speed limits is the largest for “short” combinations.

Time distributions of KSI truck crashes are considered next. The chart in Figure 5 indicates that KSI crashes with “short” and “medium” HGV combinations have similar seasonal patterns with each season having a share of 25±3% of the crashes. Conversely, almost 1 out of 3 KSI crashes with “long” HGV combinations (32%) occur in the winter and slightly less than 18% occur in the spring; the values for summer and autumn are close to 25% for the “long” group as well. All length groups have the smallest percentage of KSI crashes occurring in the spring.

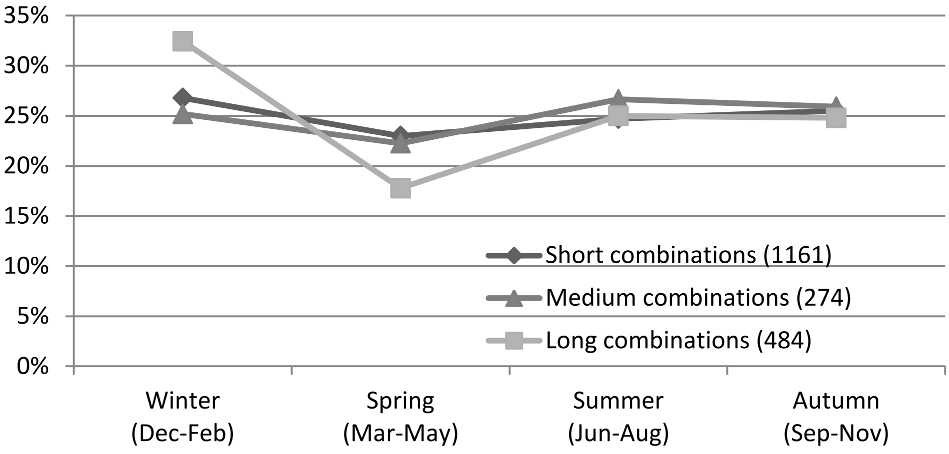

Figure 5 Seasonal distribution of fatal or severe HGV crashes classified by length group

The month distribution of KSI truck crashes by length group (Figure 6) shows that KSI crashes with “short” HGV combinations show the smallest monthly variability throughout the year: all values are in a 3% wide corridor. On the contrary, the percentages in the “medium” group range from 4.74% (May) to 11.68% (December and March) and in the “long” group from 4.75% (May) to 11.57% (February) resulting in differences close to 7%. Generally, the different length groups have similar percentages of KSI accidents in the months from April to December with differences smaller than 2.75%, while the largest differences between length groups for the months January to March are around 4%.

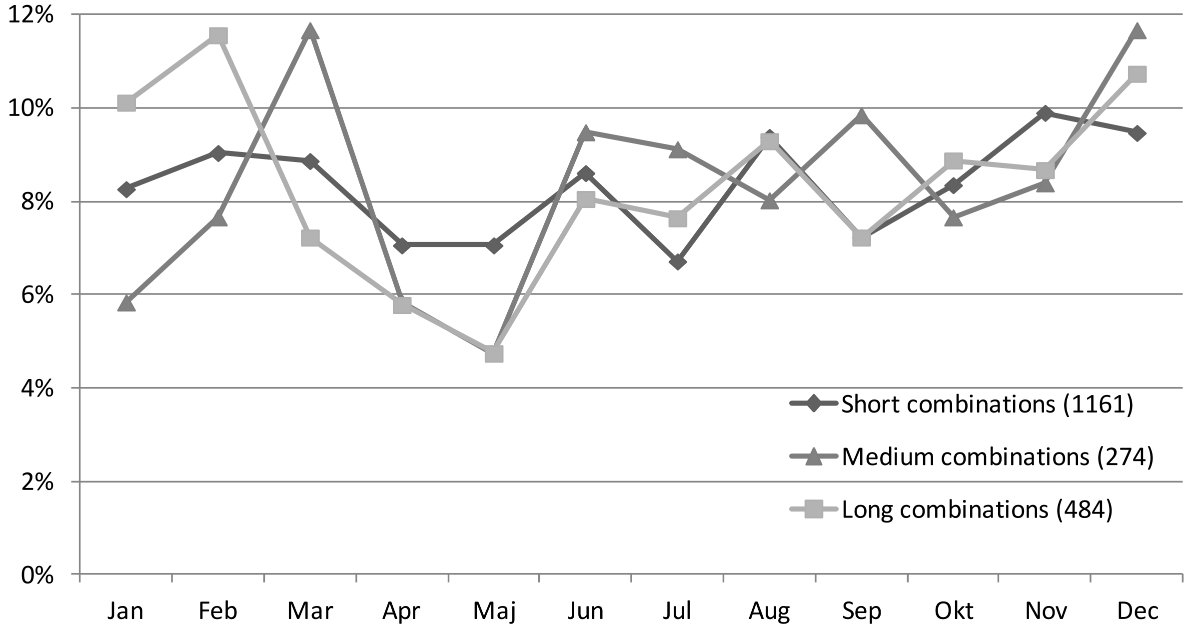

Figure 6 Month distribution of fatal or severe HGV crashes classified by length group

The last time distribution chart in Figure 7 shows that the largest percentage (87-93% depending on the length group) of KSI crashes occur during daytime (from 6am to 10pm). In the “short” group, all hours between 7am and 4pm have percentages between 6% and 9% while in the “long” group it is only the hours between 10am and 2pm that have shares higher than 6%. However, in the “long” group all hours between 5am and 8pm have shares above 3%, showing that KSI crashes with "long" combinations have a greater spread than those with "short" combinations. The crashes with "medium" combinations show larger fluctuations than the other two length groups, with the peak hours (>6% share) being 10am-11am and 1pm-6pm.

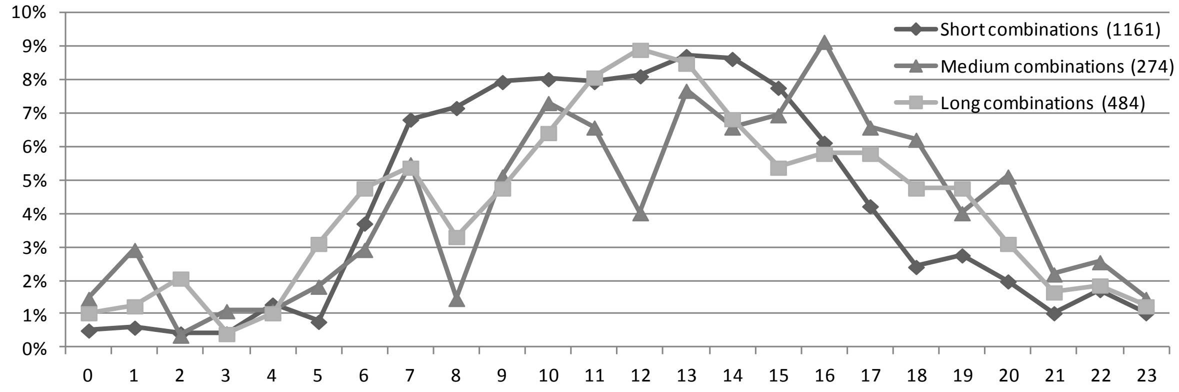

Figure 7 Hour of the day distribution of fatal or severe HGV crashes classified by length group

The crash type distributions in the three length groups using the crash type definitions in STRADA are shown in Figure 8. In this figure, the crash type "Overtaking" was united with "Meeting," while "Turning" and "Intersection" crashes are combined as "Intersection" since an overlap was observed between these crash types (judged by the detailed crash descriptions).

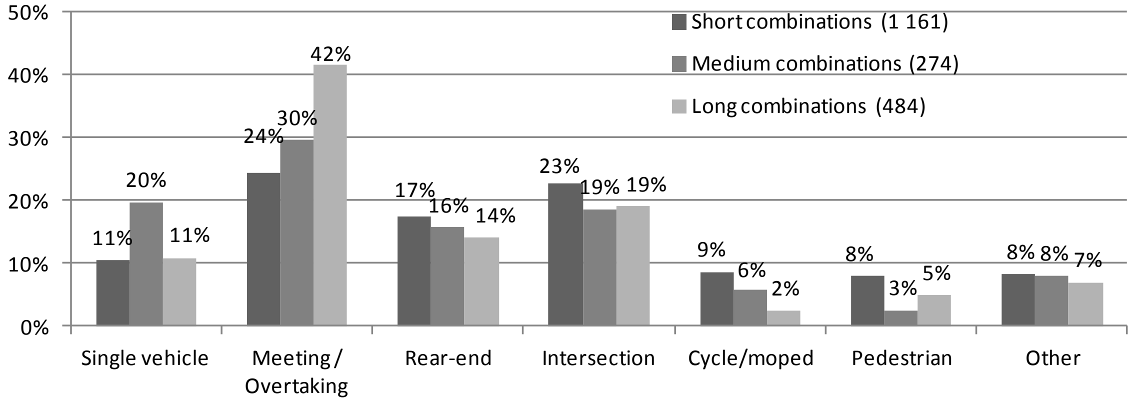

Figure 8 Crash type distribution by length group

A comparison of crash type distributions in the three length groups reveals that the shares of meeting and overtaking crashes within the length groups increase with increased combination length while the shares of rear-end and cycle/moped crashes decrease. Single vehicle crashes have a much higher share among "medium" length combinations than in the other two length groups.

It was mentioned before Figure 5 that the seasonal distribution of crashes with "long" combinations shows larger deviations from 25% than the seasonal distributions in the other two length groups. Therefore, for each crash type, it was investigated what percentage of crashes with "long" HGV combinations occurred in the different seasons, see Figure 9.

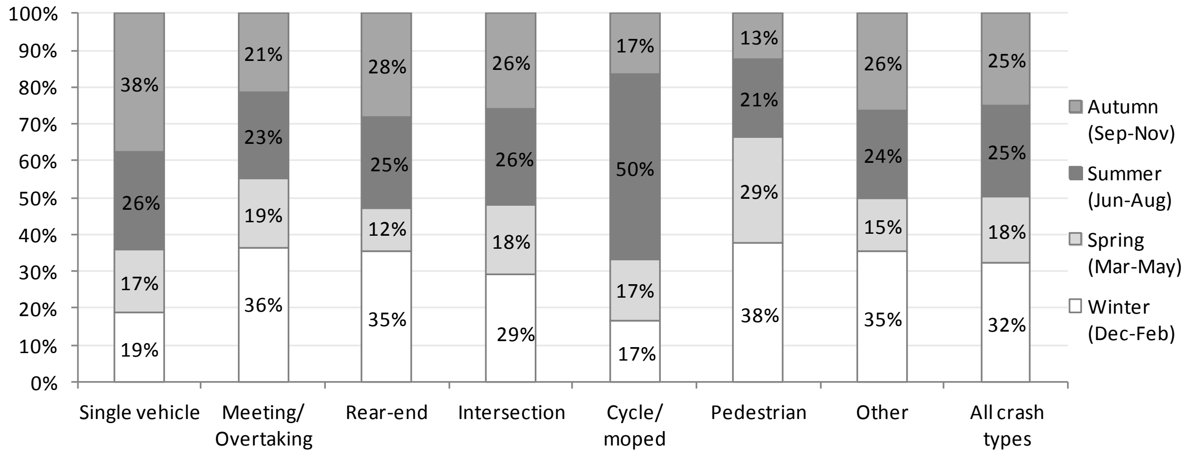

Figure 9 Seasonal distribution of KSI crashes with "long" combinations per crash type

The results show that 36% of meeting and overtaking crashes occurred in the winter while 19% occurred in the spring. Since “meeting and overtaking crashes” was the most common crash type according to Figure 8 (having a 42% share of all KSI crashes with “long” combinations), a difference within this crash type largely affected the overall seasonal distribution. Further crash types that had a higher percentage of winter crashes than the 32% overall share of winter crashes were pedestrian crashes, rear-end crashes, and “other” crashes. Note in particular that there were three times as many KSI rear-end crashes with “long” combinations in the winter than in the spring. This includes crashes where the HGV was the striking vehicle as well as those where the HGV combination was struck. 50% of the KSI crashes with cycles or mopeds occurred in the summer; while this was the highest percentage for any season and any crash type, it had a minor effect on the overall seasonal distribution because of the low relative frequency (2%) of this crash type (Figure 8). Finally, 38% of KSI single vehicle crashes with a “long” HGV combination occurred in the autumn.

2.3.2 Misclassification rates and corrected number of KSI crashes

All graphs from Figure 2 to Figure 8 are based on the crashes where the length groups were identified using the principles and assumptions described in the “Method” section. The error rates and the resulting expected misclassifications are estimated in Table 8**.** The entry “Sum of vehicle lengths” refers to determination of combination length based on the sum of vehicle lengths with a correction term.

Table 8 Estimated extent of misclassifications

Number of Trailers	Assumption	Error Rate	Crashes Affected	Expected Number of Misclassifications
1	Sum of vehicle lengths	13%	137	18
1	Foreign registration → “medium”	-	84	0
1	Tractor + semi-trailer → “medium”	25%	76	19
1	Rigid truck + trailer → “long”	28%	284	80
2	Two trailers → “long”	0%	11	0
Total		-	592	117

The two assumptions about length group based on configuration type (the last two assumptions with one trailer) have the highest error rates and are responsible for

85% of all expected misclassifications. As described in Section 2.2, the number of crashes in the three length groups will be corrected by using refinements of these assumptions. These refinements use the distribution of length groups for the relevant configuration types which is determined on a sample where precise information of combination length is assumed, see Table 9. The corrected number of crashes is shown in the second row of Table 10.

Table 9 Distribution of length groups for two configuration types with one trailer

Configuration Type	Short	Medium	Long
Tractor + semi-trailer	18%	75%	7%
Rigid truck + trailer	1%	26%	72%

Besides the classified crashes, there are 446 crashes in total where the length group could not be identified using the principles and assumptions described in Section 2.2. In all these crashes, the number of trailers is registered as zero or one, which implies that there will not be any HGV combinations that are assigned to the “long” group because of the presence of two trailers. Therefore, it cannot be assumed that unknown crashes have the same distribution as those whose length groups have been identified.

Similarly, there is sufficient information available for all unclassified crashes concerning the nationality of the truck and the trailer, thus there will not be any medium length HGV combinations identified on basis of nationality. Therefore, those crashes are counted where length group was identified without the assumptions on two trailers (T) or foreign registration (F) (see row 3 in Table 10) and the corresponding length group distribution is given in row 4. This length group distribution is assumed for crashes with HGV combinations of unidentified length group. The resulting number of fatal and severe crashes is shown in row 5.

Table 10 Fatal or severe crashes in the three length groups. The entries in the last row are obtained by summing the corrected numbers and the shares of unknown crashes prescribed by the distribution in the fourth row. Without T&F means that combinations with two trailers and foreign registration are excluded.

Combination Length	Short	Medium	Long	Unknown
Crashes identified	1 161	274	484	446
Corrected number	1 178	330	411	446
Without T&F	1 178	246	400	446
Distribution assumed for unknown	65%	13%	22%	-
Number of crashes	1466	390	509	-

2.3.3 Exposure data and KSI crash rates per length group

After obtaining the fatal or severe crashes in the three length groups, it is necessary to estimate the exposure data in order to determine crash rates. This is based on data from Trafa (2013) and STRADA using a process that is demonstrated below.

In Table 11 the relative shares of length groups for rigid trucks without a trailer are given, classified by axle configuration (which is the number of axles on the rigid truck in this case). For example, the percentage values for 3 axles are derived by considering all rigid trucks in STRADA without a trailer and with 3 axles whose length is known. The length is at most 12m for 2740 such trucks, it is between 12m and 18.75m for 56 trucks and there are no trucks for which the length is between 18.75m and 25.25m; therefore, the relative frequencies of short, medium and long groups are 98%, 2% and 0%, respectively.

The column “Total” contains exposure data obtained from Trafa (2013) summarized for the years 2003 to 2012. This amount of VKT is distributed according to the relative frequencies derived as described above, resulting in estimates for VKT in the three length groups.

Table 11 Estimated VKT for rigid trucks without a trailer, registered in Sweden, for the 10-year period 2003 to 2012

Rigid Truck	Relative Frequencies			Vehicle Kilometres Travelled (billion km)			
	Short	Medium	Long	Total	Short	Medium	Long
2 axles	99.6%	0.4%	0%	3.68	3.67	0.02	0
3 axles	98%	2%	0%	3.26	3.19	0.07	0
4 axles	86%	13.7%	0.3%	0.42	0.36	0.06	0
Other number of axles	0%	0%	0%	0	0	0	0

Similar tables are prepared for the following vehicle combinations: rigid truck and trailer; other combinations with rigid truck; tractor only; tractor and semi-trailer; other configurations with tractor. Summing the results yields the VKT for each length group, see Table 12.

Table 12 Exposure data for Swedish HGV combinations from 2003 to 2012 (billion VKT)

Towing Vehicle	Vehicle Kilometres Travelled (billion km)			
	Short	Medium	Long	Total
Tractor	0.45	2.21	0.32	2.98
Rigid truck	7.38	2.91	10.65	20.94
Overall	7.83	5.12	10.97	23.92
Share	33%	21%	46%	100%

Exposure data for foreign HGV combinations will be derived from data in Trafa (2012) as follows: VKT for combinations from countries with the same length limit for HGV combinations as in Sweden is distributed between the length groups using the percentage values in the last row of Table 12. For countries having the EU length limit of 18.75m, VKT is distributed between the “small” (60%) and “medium” (40%) groups.

Table 13 Vehicle kilometres travelled in Sweden between 2003 and 2012 for HGV combinations by length group and country of registration (billion km)

Combination Length	Short	Medium	Long	Total
Swedish registration	7.83	5.12	10.97	23.92
Foreign registration	2.89	1.89	0.72	5.5
Total	10.72	7.01	11.69	29.42

The crash rates for fatal and severe crashes in the three length groups can be computed at this point by dividing the number of crashes by the total VKT in each group.

Table 14 Crash rates for HGV combinations by length group

Combination Length	Short	Medium	Long
Number of fatal or severe crashes	1 466	390	509
VKT (billion km)	10.72	7.01	11.69
Crash rate	137	56	44

Setting the crash rate for “medium” length HGV combinations to 100%, the rate for the “long” group is 78% while the rate for the “short” group is 246%. Note that the crash rates here are given per billion VKT. The rates per 100 million VKT, which is more commonly used in Section 1, can be computed by dividing the rates in Table 14 by 10; i.e. the rates for the “short”, “medium” and “long” groups are 13.7, 5.6 and 4.4 fatal or severe crashes per 100 million VKT, respectively.

2.3.4 Annual crash rates and trends

The same methodology as described above has been applied in order to calculate the KSI crash rates for every year between 2003 and 2012 and identify trends in the data. Figure 10 below shows the corrected numbers of KSI crashes in each length group, and the VKT per length group is shown in Figure 11.

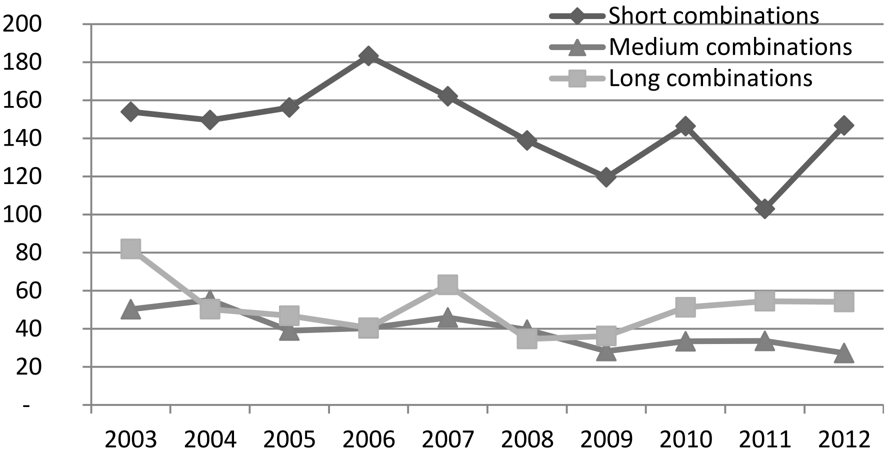

Figure 10 Corrected numbers of KSI crashes by length group

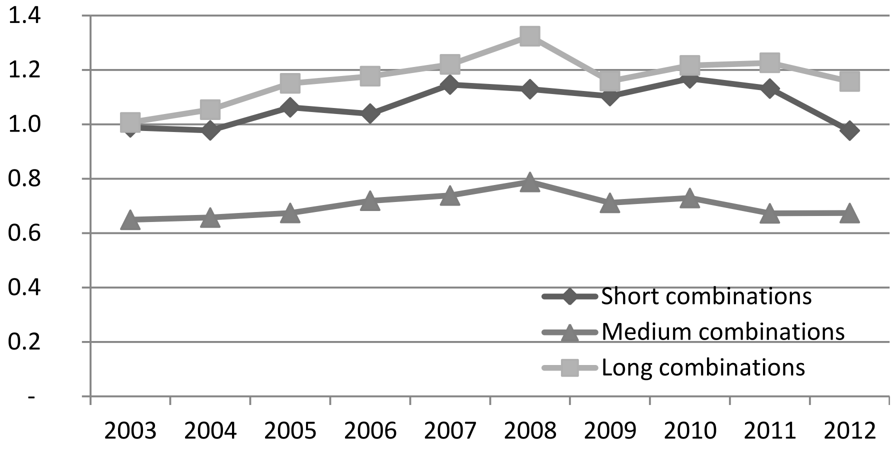

Figure 11 Vehicle kilometres travelled in Sweden by length group (billion km)

Dividing the corrected numbers of crashes by VKT yields the KSI crash rates in the three length groups, see Figure 12. Besides the results by length group, the overall crash rates for all heavy goods vehicles are also provided in this figure.

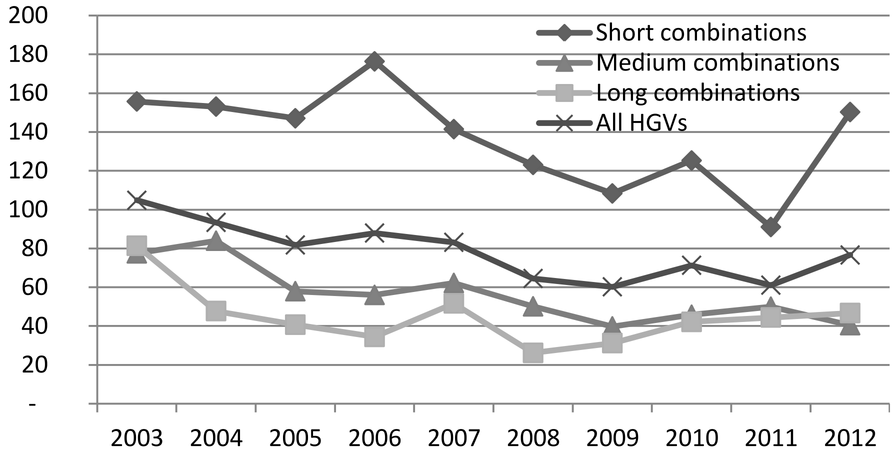

Figure 12 Annual rates of KSI crashes per billion VKT for HGV combinations by length group

“Short” HGV combinations consistently had the highest KSI crash rate of the three length groups. The crash rates in this group show a general downward trend with occasional deviations; most remarkably, while the rate in 2011 is the lowest, the rate in 2012 is one of the highest in the considered 10-year period. The trend line is described by the equation y= -4,9357x+164,28 and has a coefficient of determination of R² = 0.35.

“Medium” combinations had the second highest KSI crash rate in 8 out of the 10 years and show a more stable decreasing linear trend at y= -4,1945x+79,461 with R²= 0.74. “Long” combinations had the lowest rate of all groups from 2004 to 2011; however, both in 2003 and in 2012 the KSI rate in the “medium” group was lower than that of the “long” group. The graph of the “long” group had a low coefficient (R²= 0,194 for the line y= -2,2001x+56,764) for linear trend fitting; therefore, a polynomial trend of order 2 was fitted and the equation $y= 1,369x^2-17,259x+86,881$ indeed gives a higher R² value of 0,6746.

The KSI rates for all length groups combined show a downward trend that can be approximated by the equation y= -3,8428x+99,607; the coefficient of determination for this line is $R^2 = 0,6335$.

2.4 Discussion and limitations

The current analysis was based on Swedish national crash data for the years 2003 to 2012 hence the derived conclusions reflect the state of HGV traffic in Sweden between 2003 and 2012. The study used police-reported data stored in the Swedish Traffic Crash Data Acquisition (STRADA) crash database complemented with data from the vehicle registry. Police-reported data is potentially subject to differences in the individual judgement and knowledge of police officers regarding e.g. injury severity and a number of other variables (such as the coding of the number of trailers).

The identification of crashes with HGV involvement was based on data from the vehicle registry when such data were available. However, the identification of HGVs among vehicles with unknown or missing weight based on driver's license included potential sources of error. Note, however, that length data was missing for all HGVs classified this way hence these vehicles have only a very small effect on the results. In particular, there were 132 fatal or severe crashes that included such a HGV (5.8% of all fatal or severe crashes) and in 6 crashes it was possible to assign a length group to the HGV combination.

STRADA contains limited information about the total vehicle length and therefore several approximations and assumptions have been made in order to perform the analysis. As a result, misclassifications of length groups may be present; the estimated overall error rate for classifications is 6.1% (117 out of 1 919 classifications), see Table 8.

In Section 2.3 where various features of KSI crashes are analyzed, several factors are dependent on each other. In particular, many other results are affected by the fact that the majority of KSI crashes (increasing from 60% in the "short" group up to 84% in the "long" group) occur in rural traffic environment (see Figure 2). One consequence is that the share of crashes on "streets" (which are related to urban environment) is below 10% of the KSI crashes in each length group, and most crashes occur on "other public road" (see Figure 3). The "short" group has a higher share of urban KSI crashes than the other two groups. It is presumably for this reason that the KSI crashes involving "short" HGV combinations occur typically at lower posted speed limits than those in the other two length groups (Figure 4).

The differences in the crash types in the three length groups (Figure 8) can again be partly explained by the differences in traffic environment. Due to the relatively larger share of urban crashes in the "short" group it is expected that the share of crashes with vulnerable road user involvement is the highest in this length group. Greater exposure to urban conditions could also explain differences for rear-end crashes and intersection crashes. The differences for meeting or overtaking crashes, however, seem too large to be exclusively explained by the traffic environment and require further investigation.

A factor influencing the proportion of single vehicle crashes in the "medium" group is the presence of HGV combinations that were assigned to this group on the basis of foreign registration. For Swedish truck combinations, the relative frequencies of fatal or severe single vehicle crashes in the "short", "medium" and "long" groups are 11%, 13% and 11%, respectively.

The graph about the seasonal distributions of KSI truck crashes in different length groups (Figure 5) shows that comparatively many KSI crashes with “long” combinations occur in the winter (32%) and few in the spring (18%). All other seasonal shares in each length group are in the range 25±3%. It is shown in Figure 6 that the largest differences between the length groups are in the months from January to March. Both these results suggest that winter conditions might affect the safety performances of vehicles in different length groups differently. In order to have a better understanding of the seasonal variability of crashes in the “long” group, the seasonal distributions have been computed for each crash type, see Figure 9. High percentages of winter crashes were found for pedestrian crashes, “meeting and overtaking” crashes, rear-end crashes and “other” crashes.

Finally, the hour distribution of KSI crashes (Figure 7) may be related to typical usage patterns of HGVs in the different groups. “Short” HGV combinations are often used as delivery trucks which partly explains why most KSI crashes in this group occur in usual working hours (from 6am to 5pm). On the other hand, “long” combinations often travel greater distances which may require extended operational hours; this might be one reason why each hour from 5am to 8pm has a higher than 3% share of KSI crashes in the “long” group. The hour distribution of KSI crashes with “medium” HGV combinations is also related to work hours but has much greater fluctuations than the other two groups, possibly due to the smaller sample size.

As described before Table 10, a correction of the number of crashes in different length groups is applied. Note, however, that this correction cannot be used for the characterization of crashes involving HGVs from the three length groups by various aspects (e.g. seasonal distribution or crash type) since it does not enable the identification of individual crashes that were misclassified. However, it does correct the number of crashes in each length group and improves the preciseness of the rates of severe or fatal crashes per VKT in the three length groups.

Exposure data was not available for total vehicle combination length but rather for combinations with a given axle configuration. The VKT in different length groups was approximated from Trafa (2013) using the distribution of the three length groups in STRADA data with the prescribed axle configuration. Approximations were also used to obtain the VKT data of foreign HGV combinations in Sweden by length group. Although the derived shares were deemed reasonable by truck experts, further research to obtain enhanced exposure data is required to corroborate the findings.

The data allowed the computation of the KSI crash rates per billion VKT for each year between 2003 and 2012 and the fitting of trend lines. However, the identified trends should not be used as a prediction of future crash rates according to the general principle that extrapolation beyond the range of the sample should be avoided (Chiang, 2003). The prediction of future rates would require a much deeper analysis and is not included in the current study. Nonetheless, further investigation may be necessary to identify the reasons behind the fact that the KSI crash rate per billion VKT of “long” HGV combinations has increased every year in the 4-year period starting in 2009; in particular, while the VKT in the “long” group in 2012 was at the level of 2009 (Figure 11), the corrected number of KSI crashes in this group has substantially increased in this period (Figure 10).

2.5 Australia and Canada

In the previous sections, no information was presented about LCV data in Australia. Although it was not possible to directly access and analyse LCV data from Australia, relevant information could be found in an Australian report (Driscoll, 2013) which, among other results, compares the involvement of different truck combinations in crashes with their share of the freight task.

Rigid trucks with trailer and multi-trailer combinations, excluding B-doubles, are shown to have a crash involvement share proportional to their share of the freight task. On the other hand, tractors with semitrailers have a much larger share (38%) of the crashes compared to their part of the freight task (21%) while B-doubles have a much smaller crash share (24%) than their freight share (45%).

It is important to note that these results are not concerned with the whole LCV population in Australia but rather a subset which is insured by a specific insurance company. However, the underlying company insures a large percentage of LCVs and has a wide coverage throughout Australia.

Conversely, there were several studies mentioned in Sections 1.2 and 1.3 where Canadian data was analyzed. Those results are not repeated here but the focus in this section is on new data analysis. On our request, Transport Canada has agreed to query data from the National Collision Database (NCDB) in Canada and re-code NCDB’s collision configurations to the crash types used in the study in Section 2 (which are in turn based on the crash types from the Swedish national crash database STRADA). The data from Transport Canada is concerned with the years from 2006 to 2010. The definition used for LCV excludes what NCDB calls “Unit Trucks > 4536 kg GVWR” which may or may not have a trailer.

The results for those combinations that have at least two semi-trailers are presented in Table 15 below. According to discussions with truck experts, each combination here has a total length of at least 16.5m, and with the exception of combinations consisting of two twin trailers connected with a draw bar, they are longer than 18.75m. Note that the Canadian term “road train” is different from Australian road trains which are longer than 31m.

Table 15 Road train data from the National Collision Database in Canada for the years 2006-2010 using STRADA crash types; queried and re-coded by Transport Canada.

Trailer Type	Single vehicle	Meeting/ Overtaking	Rear-end	Intersection	Cycle/ moped	Pedestrian	Other	Total
2 Semi, A Train	2	2	1	4	0	0	3	12
2 Semi, B Train	2	25	3	11	4	0	14	59
2 Semi, C Train	1	7	1	0	0	0	0	9
2 Semi, unk. connctr	41	50	23	33	6	3	23	179
3 Semi	3	3	3	1	0	3	3	16
Total	49	87	31	49	10	6	43	275

These results were then related to those described in Section 2 regarding Swedish HGVs classified in three length groups: “long” combinations (18.76 – 25.25m), “medium” combinations (12.01 – 18.75m) and “short” combinations with a total length less than 12m. The comparison is presented in Figure 13 below.

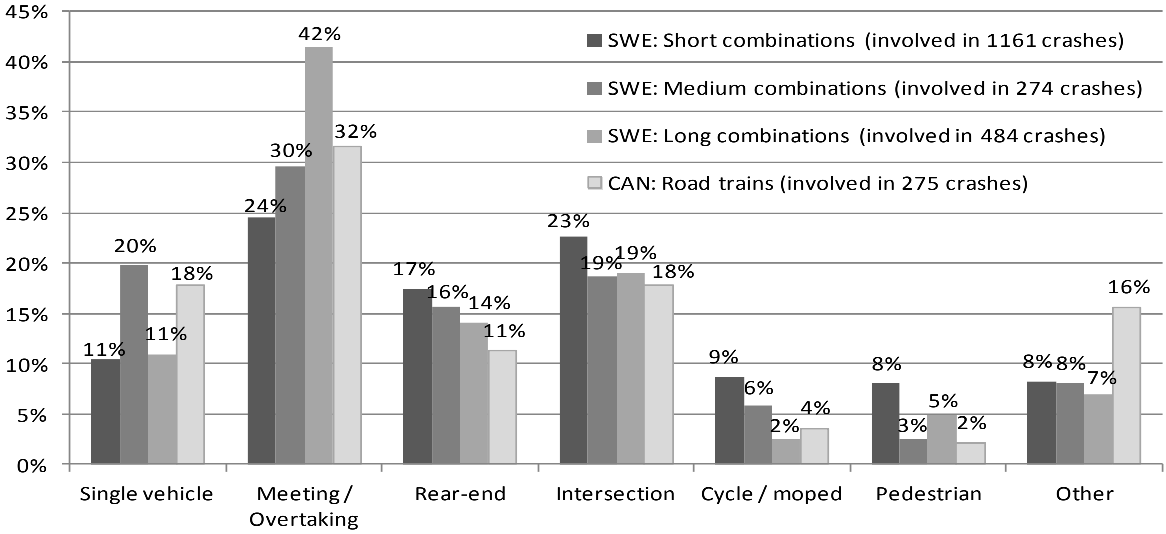

Figure 13 Comparison of crash types in fatal or severe crashes with HGVs in different length groups in Sweden (2003-2012), respectively road trains in Canada (2006-2010).

In Figure 13 it is shown that the Canadian LCV data shows a good match with the “medium” group in the Swedish data. It is also similar to the crash type distribution for the “long” group but to a smaller extent. The larger share of the “Other” crash type in the Canadian data is to a large extent due to the fact that the Swedish crash type classification was used for the analysis and hence certain crash types that are specified in NCDB were re-classified as “Other”.

3 IN-DEPTH ANALYSIS OF FATAL TRUCK CRASHES IN SWEDEN

The aim of the in-depth analysis presented in this section was to determine whether the combination lengths of heavy goods vehicles have had an effect on either the occurrence or outcome of fatal HGV crashes in Sweden. For this purpose, data from the Swedish Traffic Accident Data Acquisition database (STRADA) and the Swedish national in-depth fatal crash database was used. Thereby, the statistical analysis presented in Section 2 is complemented by in-depth analysis of fatal HGV crashes in order to achieve a better understanding of the influence of combination length.

STRADA was already mentioned in Section 2.2. The in-depth database for fatal crashes was initiated by the Swedish government in 1997, with the aim of improving the understanding of all phases of fatal crashes in Sweden. The electronic database currently contains in-depth data from 2004 and onward, while earlier crashes have not yet been digitalized. The total number of crashes in the database from Jan-2004 to Dec-2012 is 3481.

The STRADA database was queried for fatal crashes occurring between 2004 and 2012 with the involvement of at least one HGV. From these crashes a selection was made based on the STRADA crash type in order to address the most common crash types in which HGV combination length could possibly play a role. The selected crash types for this study were Meeting, Intersection, Turning, Single vehicle, Overtaking and Rail vehicle crashes (M, K, A, S, O and J category crashes) while the categories Bicycle, Pedestrian, Rear-end, Other, Crashes with animals and crashes with No Motor Vehicle involved (C, F, U, W, V and G category crashes) were removed.

Vehicle length was not a variable in the in-depth crash database; however, for some crashes the HGV specifications were recorded. Where the specifications were missing, the length of the HGV was extracted from the vehicle registry database when possible. Where only a separate truck (rigid or tractor) without any trailer was identified in a crash, the length corresponds to the vehicle length. In the cases where at least one trailer was identified, the total HGV combination length corresponds to the sum of the coupling lengths of the individual truck, trailers and dollies. The same three length groups for HGV combinations were considered as in Section 2 (namely “short”, “medium” and “long” HGV combinations corresponding to combination length ≤12m; 12.01 – 18.75m and 18.76 – 25.25m, respectively).

The query in STRADA resulted in 538 fatal crashes prior to the selection based on STRADA crash type was applied and 379 crashes remained after the selection. The length of the HGV combination could be identified in 237 crashes, while in the remaining cases the length of at least one element comprising the HGV combination was unknown. One crash was excluded because the collision with the HGV was a secondary crash, following a crash with an animal.

3.1 Categorizing crashes based on influence from HGV combination length

The crashes were categorized into two groups based on the assessed likelihood that the HGV combination length has contributed to the crash occurrence (i.e. that the two vehicles have collided, irrespective of the severity of the crash) or the crash outcome (i.e. that at least one person was killed in the crash). These categories were *no influence* or *possible influence* from HGV combination length in crash.

Categorization was based on the crash configuration and the point of impact on the HGV. The crash configuration and the point of impact on the HGV combination were determined based on the following data:

- Detailed description by the in-depth investigators of the crash;
- Police or investigator sketches;
- Police, rescue service or investigator photographs from on-scene or follow-up investigation.

A necessary condition for assessing that a crash has been influenced by vehicle length was that the impact point was located at least an approximate car-length behind the front of the truck. The motivation for this requirement is that it indicates that if the HGV had been replaced by a passenger car the crash would not have happened. For example, a verified frontal, head-to-head crash was assessed not to have had any influence from HGV combination length.

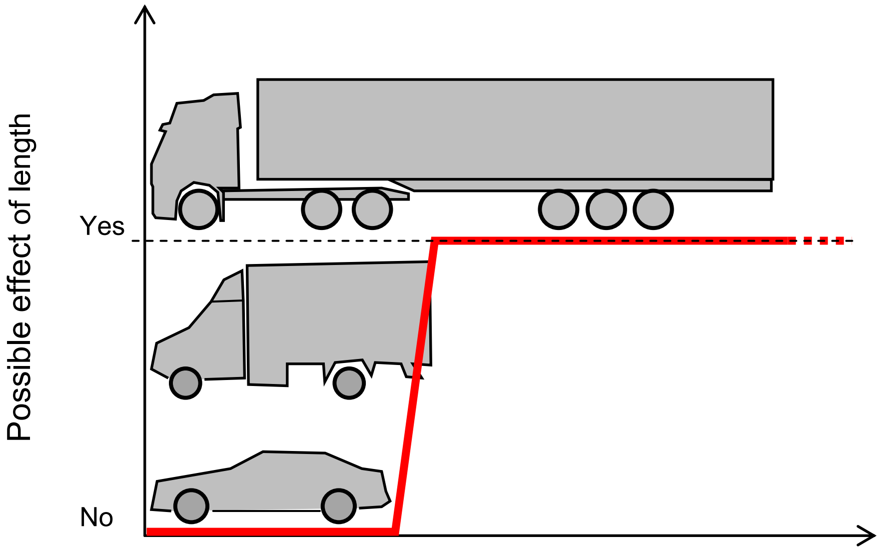

Figure 14 Determination of potential effect by combination length

The graph illustrates how the influence from HGV length in the occurrence or outcome of a crash was estimated. The horizontal axis indicates the point of impact on the heavy goods vehicle.

3.2 Factors influencing the crash

Four factors which can be attributed to human errors or influences, believed to have been able to affect or change the crash outcome, were registered in the in-depth database. These factors, henceforth referred to as *complicating factors*, were; *suspected suicide*, *suspected natural death/illness*, *suspected drowsiness/distraction* or *other factors* such as alcohol or illegal drug involvement, vehicle banned from driving due to failed inspection, or driver lacking an appropriate driving license. A complicating factor is defined to be present in a crash if it applies to at least one driver (which can be the truck driver or the driver of another vehicle involved in the crash).

Data regarding the first three factors were filled in by the in-depth investigators, or extracted from the detailed crash description, categorized as *Y* (yes), *U* (unknown) or *N* (no) or empty (which presumably indicates the absence of the corresponding factor). The last factor (related to the presence of "other factors") was inserted where it was identified and verified in the in-depth material. Cases with suspected suicide were removed but those with any of the remaining factors were kept in the data set. The prevalence of complicating factors is shown in Table 16.

Table 16 Frequency of complicating factors among fatal HGV crashes.

Complicating factor	Whole dataset (n=379)		Length-categorized dataset (n=236)	
	Yes	Unknown	Yes	Unknown
Suspected suicide	65	33	44	18
Suspected natural death/illness	18	14	12	9
Suspected fatigue/distraction	60	65	42	46
Other factors	58		34	

The remaining 192 crashes after the removal of the 44 suicides from the length categorized data were used for the analysis.

3.3 Results

The HGV combination length in each crash was judged to have no or possible influence utilizing the approach described in Section 3.1 to categorize influence; this showed that in 166 crashes HGV combination length could be considered as having *no influence* in crash and 26 crashes categorized as *possible influence* from HGV combination length. The distribution of trucks among the three length groups can be seen in Figure 15. The graph shows that the *no influence* category is most common in the "short" group, and second most common in the "long" group. The HGVs where a *possible influence* was identified are most common among the "long" combination vehicles, and the frequency was decreasing with decreasing HGV length.

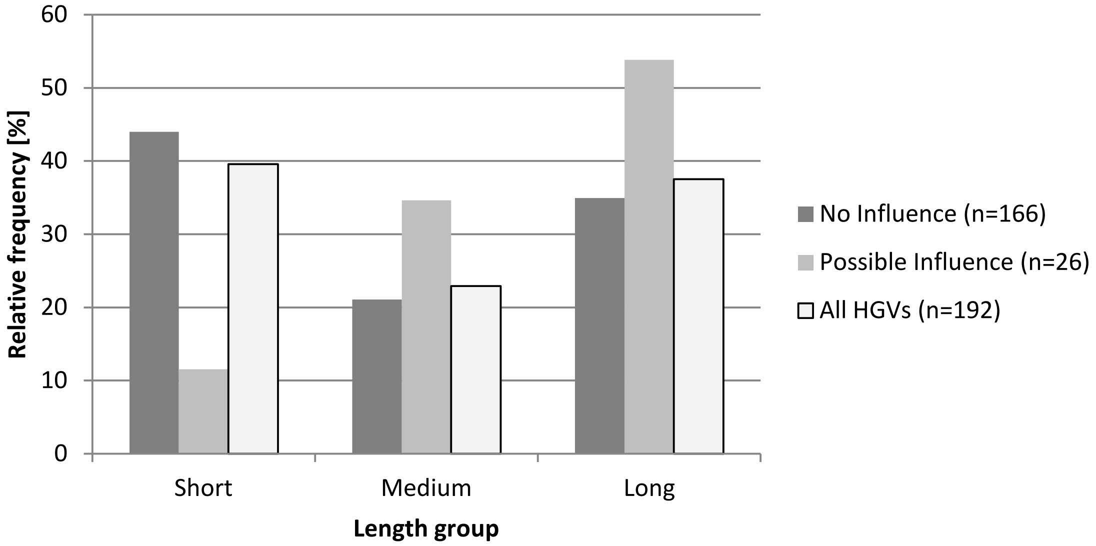

Figure 15 Distribution of HGV length groups classified by crash influence

The distribution with respect to influence in the three length groups are shown in Figure 16. The relative frequencies of the *possible influence* crashes are similar in the “medium” and “long” HGV length groups, representing approximately 20% of all crashes in these groups, while it is only 4% in the “short” group.

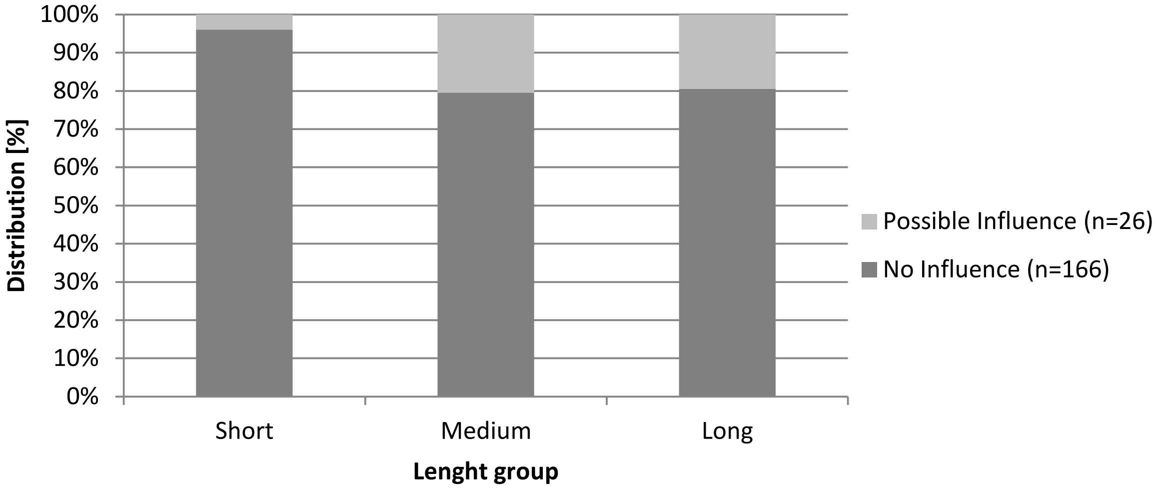

Figure 16 Distribution of influence in the three length groups of HGVs.

3.4 Crash types

The crash types were verified using the material available in the database and re-categorized into the crash types as described in the DaCoTA project (which are available online at http://dacota-investigation-manual-eu.ita.chalmers.se/English/41). The DaCoTA crash types are retrieved from the German In-Depth Accident Study (GIDAS) and are used in other European crash databases. The primary crash types are shown in Figure 17.

The percentages show that crashes in longitudinal traffic (which refers to conflicts between road users moving in the same or in the opposite direction including head-on collisions) are the most frequent of all crash types in this study. Longitudinal crashes comprised 66.3 % and 53.8 % respectively of all “no influence” and “possible influence” crashes (110 and 14 crashes, respectively). These were followed by 20 plus 5 crashes in the second largest group of turning in/crossing crashes (12.0% and 19.2% for no influence and possible influence, respectively). For turning off crashes, which was the third largest group, the relevant percentages are 6% and 23.1% which correspond to 6 and 10 crashes respectively.

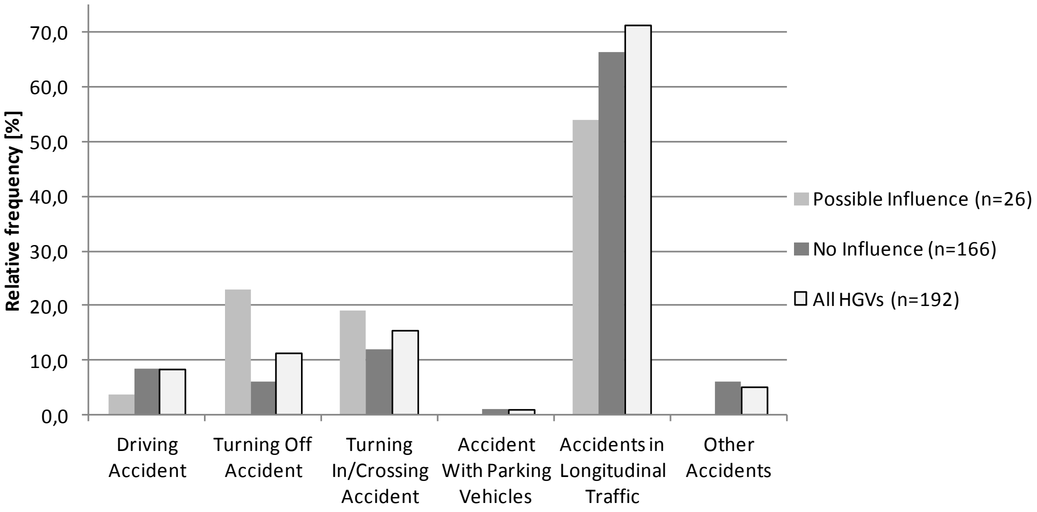

Figure 17 Distribution of crash types for possible influence and no influence category crashes.

While driving accidents (which are crashes without the involvement of other road users) have only slightly smaller share of all crashes than turning off accidents do, their share of “possible influence” crashes is much smaller. In fact, the distribution of influence classified by crash type (see Figure 18) indicates that turning off crashes have the highest fraction of fatal crashes in which the length of the HGV combination has possibly influenced the occurrence or outcome of the crash. The turning in/crossing crashes also had a higher than average rate of “possible influence”.

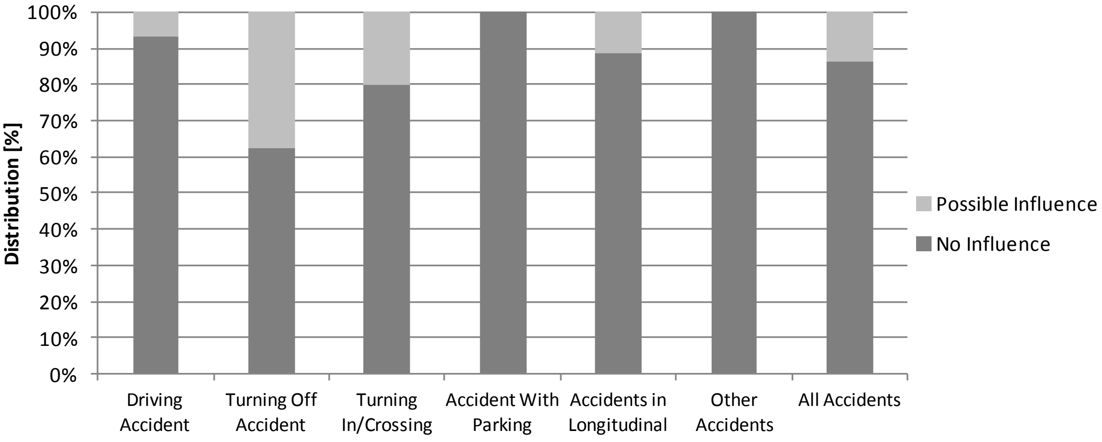

Figure 18 Distribution of influence per crash type in the selected data set.

3.5 Typical events in fatal crashes with possible influence from combination length

This section includes illustrations of events identified as typical for fatal crashes where the HGV combination length was found to possibly have influenced the crash occurrence or outcome. These crashes were found in four of the above mentioned crash types, namely crashes in longitudinal traffic, turning off crashes and turning in/crossing crashes, and driving crashes (see Figure 17). The illustrations show a passenger car as the opponent vehicle to the HGV which may in real life have been any other vehicle such as an HGV, bus or a motorcycle; the motivation is that passenger cars were the opponents in the majority of the cases considered.

3.5.1 Crashes in longitudinal traffic

Fatal HGV crashes in longitudinal traffic in which the length of the HGV combination had a possible influence on the outcome include nine loss of control crashes and five overtaking crashes. In the loss of control scenarios, either the HGV driver had lost control over the entire vehicle or just the trailer (Figure 19) or the counterpart driver had lost control (Figure 20). In these crashes the trailer became the primary counterpart in the crash.

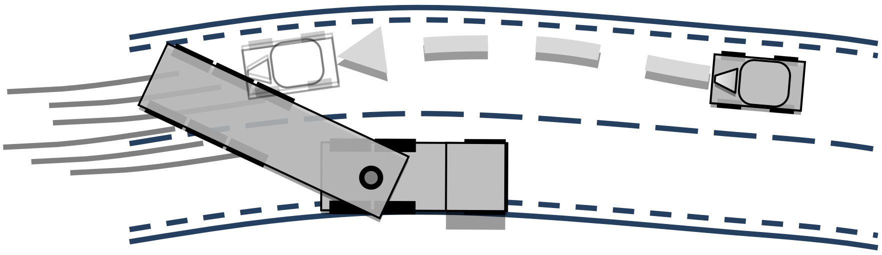

Figure 19 Loss of control scenario 1: HGV driver loses control of vehicle or trailer.

The second loss of control crash scenario may involve maneuvering of the HGV. When the opposing vehicle has lost control or for unknown reason drifts over towards the oncoming traffic, the HGV tries to avoid the crash which causes the trailer to become the primary counterpart in the crash.

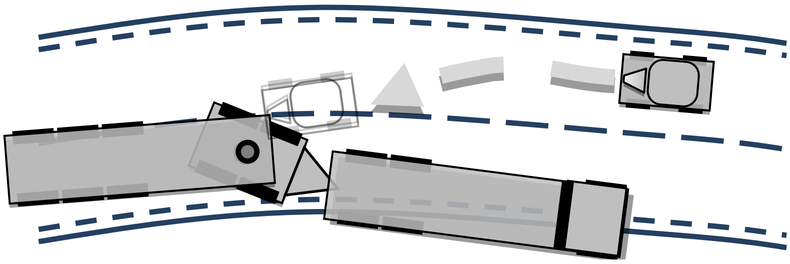

Figure 20 Loss of control scenario 2: HGV counterpart loses control, possibly with attempted avoidance manoeuvring of HGV.

The characteristics of the five overtaking crashes possibly influenced by length (Figure 21 below) are that an overtaking vehicle misjudges the oncoming traffic, tries to brake and return to the right lane and collides with the HGV combination.

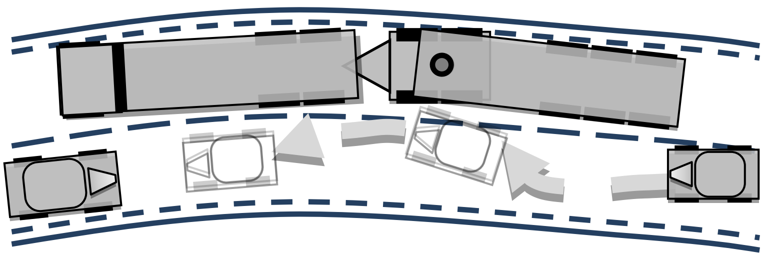

Figure 21 Overtaking crash in longitudinal traffic.

3.5.2 Turning off crashes

Crashes involving turning off from a main road were identified in two different scenarios, representing almost a quarter (6) of all crashes where the HGV combination length possibly had an influence in the crash. The first scenario was for HGV turning off to a road on the left, while a vehicle catches up, crashing into the rear of the trailer of the HGV (Figure 22).

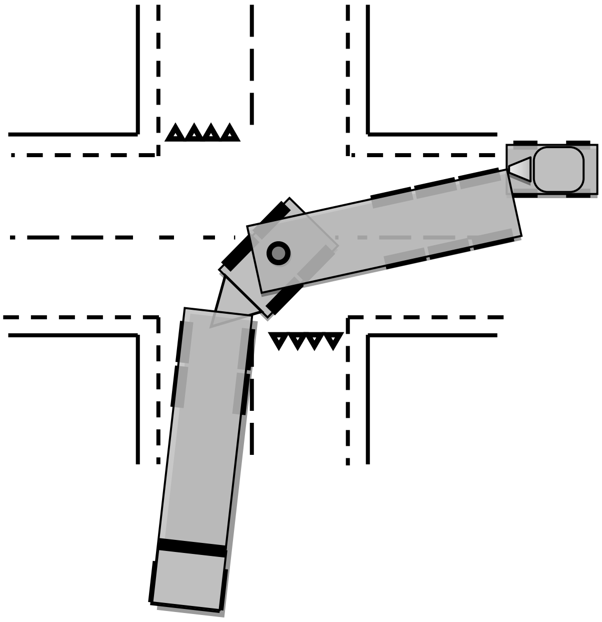

Figure 22 Turning off crash scenario 1: HGV turning off to the left, with opponent vehicle catching up.

The second type involve right turning HGV crossing the middle road marking to allow for the HGV combination to enter the narrower road. Consequently, the full width of the main road is occupied, and the following vehicle has crashed into the right side or the rear of the trailer (Figure 23 below).

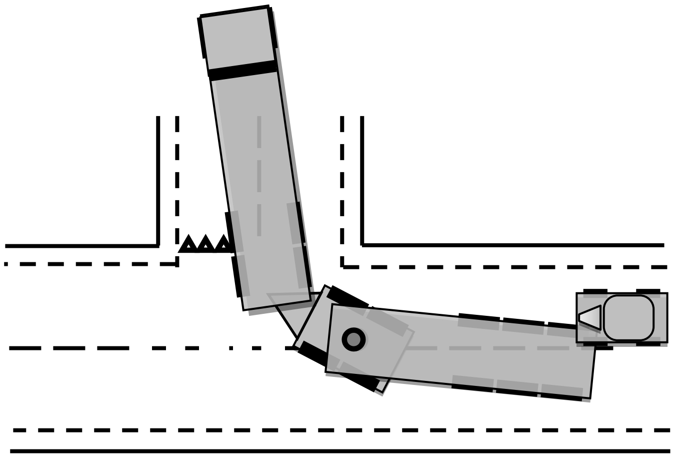

Figure 23 Turning off crash scenario 2: HGV in a right turn occupies the road to be able to make the right turn, while a vehicle catches up and crashes into the rear of the HGV.

3.5.3 Turning in/crossing crashes

The five turning in/crossing crashes with possible influence from HGV length involve two different scenarios. The first one (Figure 24) involves a vehicle which must give way to crossing traffic, but fails to see the HGV and enters the intersection striking the side of the HGV.

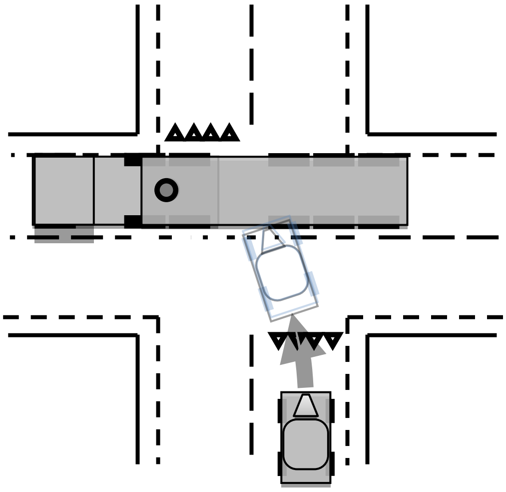

Figure 24 Turning in/Crossing crash scenario 1: a vehicle tries to turn in/cross a main road before the HGV has cleared the road.

The second turning in/crossing scenario (Figure 25 below) is a situation when the HGV has started crossing or turning in to the main road and a vehicle with the right of way sees the HGV too late to stop.

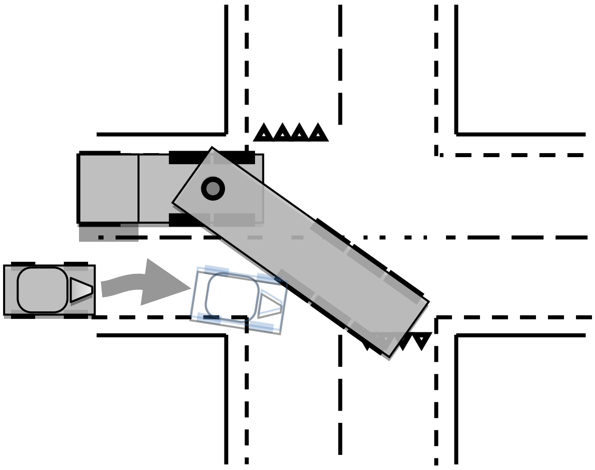

Figure 25 Turning in/Crossing scenario 2: an HGV turns into or crosses a main road and a vehicle with the right of way sees the HGV too late to stop.

3.5.4 Driving crash

According to the definition, driving crashes happen without the involvement of other road users. In the single driving crash that was classified to have “possible influence” from HGV combination length (not illustrated), it was judged that the length of the HGV combination caused the driver to lose control of the vehicle.

3.6 Analysis and discussion

The in-depth study of the 379 fatal crashes involving HGVs included 65 crashes classified as suicides all of which were head-on collisions. These crashes were considered to have been caused by conscious human intervention, and as such, they were not included in the analysis regarding the influence from HGV combination length in a crash.

The information stored in the in-depth database formed the basis for the judgment regarding influence of HGV combination length in the occurrence or outcome of the crash. Although there was an element of subjectivity in the assessment of the crash scenario, the judgment of influence was done by a well-defined procedure using objective information, described in Section 3.1.

Table 16 shows the frequencies of the different complicating factors both for the full dataset and for the dataset where the length of the HGV combination could be identified. Crashes with complicating factors were kept in the dataset used for the analysis since the effect of these factors on the crash outcome was unknown. It cannot be excluded that certain factors, such as alcohol involvement, have affected the crash outcome; however, even so it is possible that the crash would not have occurred or would not have been fatal if the HGV combination had been shorter.

Figure 15 indicates that more than half of *possible influence* crashes include “long” HGVs; about one third include “medium” HGVs and only about 10% include “short” HGVs. However, it is shown in Figure 16 that in the selected set of crashes, there was essentially no difference in the ratio of *no influence* to *possible influence* crashes in the “medium” and “long” HGV groups. Based on this it cannot be concluded that the “long” HGVs give rise to fatal crashes influenced by length more frequently than the HGVs in the “medium” group. On the other hand, the “short” group had a much lower ratio of *possible influence* compared to the *no influence* crashes.

The graph in Figure 17 shows that the most common crash type was crashes in longitudinal traffic, followed by turning off crashes and turning in/crossing type crashes. Furthermore, more than 50% of crashes with possible influence occurred in longitudinal traffic. However, studying the ratio of *possible influence* to *no influence* crashes in each crash type (Figure 18) shows higher than average rates for the turning off and turning in/crossing crashes, but not for the crashes in longitudinal traffic.

The characterization of typical events in fatal crashes with influence from HGV combination length has revealed that 14 of the 26 relevant fatal crashes occurred under the following circumstances:

- loss of control or other unknown reason for leaving lane;
- misjudgment of oncoming traffic during overtaking.

The main characteristics of the six turning off crashes and the five turning in/crossing crashes are also analyzed in detail, see Sections 3.5.2 and 3.5.3.

4 CONCLUSIONS

The statistical study presented in Section 2 determined the rates of fatal or severe crashes per billion vehicle kilometres travelled in Sweden for the years 2003 to 2012 for HGV combinations in three length groups. The three groups were defined in terms of the total length of the HGV combination: “short” (≤12m), “medium” (12.01–18.75m) and “long” (18.76–25.25m) combinations were differentiated. The main conclusions were as follows.

- For the 10-year period from 2003 to 2012, the rates for the “short”, “medium” and “long” HGV combinations were 137, 56 and 44 fatal or severe crashes per billion vehicle kilometres travelled, respectively.
- The derived rates need to be interpreted with caution due to difficulties in the identification of the HGV combination length and the exposure data in the three length groups. The study indicates, though, that the rates in the “long” group were slightly lower than in the “medium” group while the rate in the “short” group was substantially higher than both.
- Under the usage patterns in the relevant 10-year period, “long” combinations that exceed the EU length limit of 18.75m were involved in less fatal or severe crashes per billion vehicle kilometres travelled than regular EU combinations.
- It cannot be excluded from this study that the lower rate mentioned in the previous bullet point is due to that ”long combinations” travelled on safer roads and/or were driven by more experienced drivers.
- While the rates of fatal or severe crashes including “medium” combinations show a relatively stable decreasing linear trend, the corresponding rates for the “long” group increased every year from 2008 to 2012.

These results were complemented by an in-depth study of fatal HGV crashes in Sweden (Section 3). It was investigated whether the combination lengths of heavy goods vehicles have had an effect on either the occurrence or the outcome of these crashes, and crash types with a high frequency of “possible influence” crashes were identified. The main conclusions from the in-depth study are summarized below.

- An increase in total HGV combination length increases the likelihood of being classified as *possible influence*. However, there is no difference in the ratio of “*possible influence”* to “*no influence”* crashes between the “medium” group and the “long” group. For the “short” group, this ratio was smaller than in the other two length groups.
- The most frequent crash type in the possible influence category was “crashes in longitudinal traffic”. However, the ratio of “*possible influence”* to “*no influence”* crashes in this crash type was lower than the overall average.
- The highest ratio of “*possible influence”* to “*no influence”* classification was found for “turning off” crashes. Another crash type with a high portion of possible influence crashes relative to no influence crashes was “turning in/crossing” crashes.

ACKNOWLEDGEMENTS

This study is part of the research and innovation program “Traffic safety effects of HCT and suggestions for compensatory measures” established at Safer – Vehicle and Traffic Safety Centre at Chalmers, Sweden. This study is funded by the Research and Development Program at the Swedish Transport Administration. The project managers are Anders Berndtsson, Petter Åsman and Thomas Asp.

We thank Owen Driscoll (National Transport Insurance in Australia) and Dan Blower (UMTRI) for valuable discussions. We are grateful to Peter Burns, Victor Johanson, Michael Marth and James Kelley at Transport Canada who supported us both with data and information on LCV combinations and combination lengths in Canada.

Two experts from AB Volvo, Anna Wrige and Karsten Heinig, have been consulted on several occasions during the project. Discussions about their previous studies, vehicle combination length and our preliminary results have been very valuable and have increased the quality of our results. Finally, we want to thank Jesper Sandin (VTI) for comments on an earlier version of this report, and Mikael Östlund (Scania) and Alexander Kärkkäinen (Chalmers) for the illustration in Figure 1.

REFERENCES

Bálint, A., Fagerlind, H., Martinsson, J., Holmqvist, K. (2013), *Correlation between truck combination length and injury risk,* 2013 Australasian College of Road Safety Conference – "A Safe System: The Road Safety Discussion", Adelaide.

Blower, D., Campbell, K., Green, P. (1993), *Crash rates for heavy truck-tractors in Michigan*, Crash Analysis & Prevention, 25(3), 307-321.

Blower, D., Matteson, A. (2002), *Large trucks in FARS and in TIFA,1999,* Center for National Truck Statistics, University of Michigan Transportation Research Institute UMTRI-2002-17

Campbell, K.L., Blower, D.F., Gattis, R.G., Wolfe, A.C. (1988), *Analysis of Accident Rates of Heavy-Duty Vehicles*, Final Report, University of Michigan Transportation Research Institute, Ann Arbor.

Carson, J.L. (2011), *Directory of significant truck size and weight research,* National Cooperative Highway Research Program (NCHRP) Project 20-07, Task 303.

Chiang, C.L. (2003), *Statistical methods of analysis*, World Scientific, ISBN 981-238-310-7.

Driscoll, O. (2013), *Major accident investigation report*, National truck accident research centre, National Transport Insurance, Brisbane.

EC (European Commission) (2006), *ETAC, European Truck Accident Causation – Volume 1, Final Report*, European Commission, Directorat General for Energy and Transport, Brussels. Available at: http://ec.europa.eu/transport/roadsafety_library/publications/etac_final_report.pdf

EC (European Commission) (2011), *Traffic Safety Basic Facts 2011, Heavy Goods Vehicles and Buses*, European Commission, Directorat General for Energy and Transport, Brussels. Available at: http://ec.europa.eu/transport/road_safety/pdf/statistics/dacota/bfs2011_dacota_intras_hgvs.pdf

FHWA (Federal Highway Administration) (1993), *Larger Dimensioned Vehicle Study – Final Report*, FHWA-PL-94–00, Washington, Department of Transportation.

FHWA (Federal Highway Administration) (2000)*, Comprehensive Truck Size and Weight (CTS&W) Study*, FHWA-PL-00-029 (Volume III, Chapter VIII).

FHWA (Federal Highway Administration) (2004), *Western Uniformity Scenario Analysis: A Regional Truck Size and Weight Scenario Requested By the Western Governors' Association*, Washington. Available at: http://www.fhwa.dot.gov/policy/otps/truck/wusr/wusr.pdf.

Forkenbrock, D. (2003), *Fatal Crash Involvement by Multiple-Trailer Trucks* 37, no. 5. Transportation Research Part A: Policy and Practice: 419 – 433, doi:10.1016/S0965-8564(02)00034-4.

Hedlund, J., Blower, D. (2006), *Large Truck Crash Causation Study (LTCCS) Analysis Series: Using LTCCS Data for Statistical Analyses of Crash Risk,* US DOT, Publication #: FMCSA-RI-05-037.

Mingo, R. D., et al. (1990), *Safety of Multi-Unit Combination Vehicles.* Association of American Railroads, Washington, D.C.

Montufar, J., Regehr, J., Rempel, G., McGregor, R.V. (2007), *Long Combination Vehicle (LCV) Safety Performance in Alberta: 1999-2005*. Final report Alberta Infrastructure and Transportation Policy and Corporate Services Division.

Pearson, B. (2000), *National review of B-double length – final report,* Pearsons Transport Resource Centre, Report to VicRoads.

Schulman, J. F. (2003), *Heavy Truck Weight and Dimension Limits in Canada*, The railway association of Canada.

Starnes, M. (2006), *Large-Truck Crash Causation Study: An Initial Overview*, National Center for Statistics and Analysis National Highway Traffic Safety Administration U.S. Department of Transportation, Rep.nr. DOT HS 810 646

Trafa (Trafikanalys) (2012), *Utländska lastbilstransporter i Sverige 2009-2010*, reports available for years 2007-2008 and 2004-2006, at http://www.trafa.se/ [12 Aug 2013]. In Swedish, summary in English.

Trafa (Trafikanalys) (2013), *Swedish national and international road goods transport*, reports available for years 2003 to 2012, at http://www.trafa.se/ [12 Aug 2013]. In Swedish, summary in English.

TRB Transportation research board (1990). *Special Report 225 Truck Weight Limits.* National Research Council, Washington, D.C.

Vierth, I., Berell, H., McDaniel, J., Haraldsson, M., Hammarström, U., Reza-Yahya, M., Lindberg, G., Carlsson, A., Ögren, M., Björketun, U. (2008), *Långa och tunga lastbilars effekter på transportsystemet*, Statens väg- och transportforskningsinstitut (VTI) Report No. 605. In Swedish, summary in English.

af Wåhlberg, A.E. (2008), *Meta-analysis of the difference in crash risk between long and short truck configurations,* Journal of Risk Research 11, 315-333

Woodrooffe, J. (2001), *Long Combination Vehicle Safety Performance in Alberta 1995 –1998*. Woodrooffe & Associates