Correlation between truck combination length and injury risk

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Abstract

Literature studies show 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.

In the current study, the effect of increased vehicle combination length on the rates of fatal or severe injury crashes by vehicle kilometres travelled is investigated. The method uses Swedish national crash 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 severe or fatal crashes by vehicle kilometres travelled than "medium" (12.01 – 18.75m) or "short" combinations (≤12m).

Different approaches for comparing the number of fatal or severe crashes in the three length groups with the kilometres driven are discussed. The crash type distributions in the three length groups are compared and it is considered to what extent the observed differences can be explained by differences in the exposure data.

Keywords: long vehicle combinations, heavy truck, risk estimates, crash type distribution, crash data, exposure data

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 numbers 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 heavy goods vehicle (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 below), the overall length of the HGV combination was the measure of interest in the current study.

Blower et al. (1993) found small differences in the crash rates comparing combinations with one or two trailers on limited access roads and major roads. A study (Montufar, 2007) on articulated trucks in the Canadian portion of the Canamex trade corridor show that long combination vehicles (LCVs) such as *Turnpike doubles*[1] and *Rocky mountain doubles*[2] have lower crash rate per 100 million vehicle kilometres travelled (VKT) than standard tractor and semitrailer combinations or straight trucks and bobtails.

The results in a study by the Federal Highway Administration (FHWA, 2000) concerning fatal crash rates normalized by vehicle miles travelled point in a different direction. The results are presented relative to the normalized fatal crash rate for single trailer combinations which is set equal to 100%. It was found that the fatal crash rates were 51% for single unit trucks and 97% for multiple trailer combinations.

In Carson (2011) and in af Wåhlberg (2008), the diversity of conclusions in the literature is clearly demonstrated. The latter study gives an overview of how the risk ratios for LCVs vary between 0.15 and 3.3 in different studies compared to regular straight truck or single trailer combinations. Common difficulties for these studies are the availability of detailed crash data containing truck combination lengths and exposure data.

The current study was conducted within a research program (see Acknowledgements) 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 this study 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 in this paper.

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 exposure data.

All HGV combinations considered in this paper 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.

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[1] Turnpike doubles are made up of two 16.2m trailers and a tractor
[2] Rocky mountain doubles are made up of one 16.2m trailer and one 8.5m trailer and a tractor

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 Accident 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.

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.
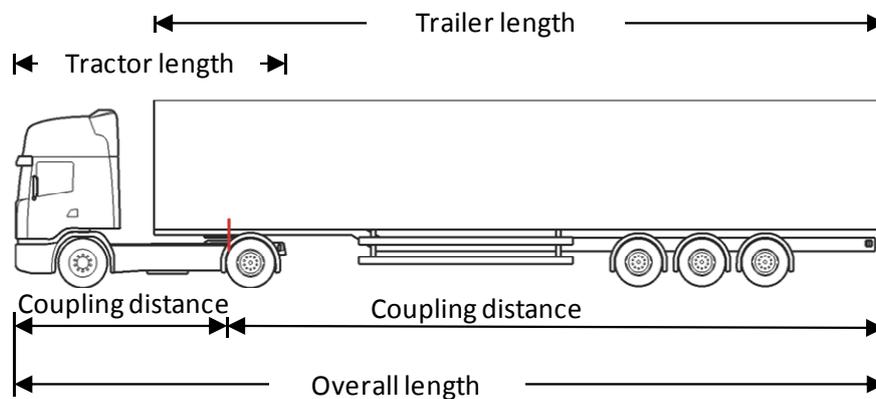
Figure 1

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 tractor or back of trailer to the fifth wheel.

However, for several crashes, coupling distances were unavailable but vehicle lengths 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 and a median difference of 365cm was found. 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 3.

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 3 the length group distribution assumed for these crashes is the same as for those with identified length groups but without crashes where length group was identified on the basis of foreign registration or two trailers (see Table 4).

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 6).

The results in Table 6 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 were computed by dividing the number of crashes in each of the three groups by the corresponding total VKT.

Results

There were 10 196 crashes in STRADA between 2003 and 2012 that involved a HGV combination and 2 290 of these crashes were fatal or severe (i.e. satisfied criterion 'c' for relevant crashes). It is shown in Table 1 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 1
Number of relevant crashes and their share 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. As shown in Figure 2, crashes in rural environment are dominant in all three length groups and this effect substantially increases with increased combination length.
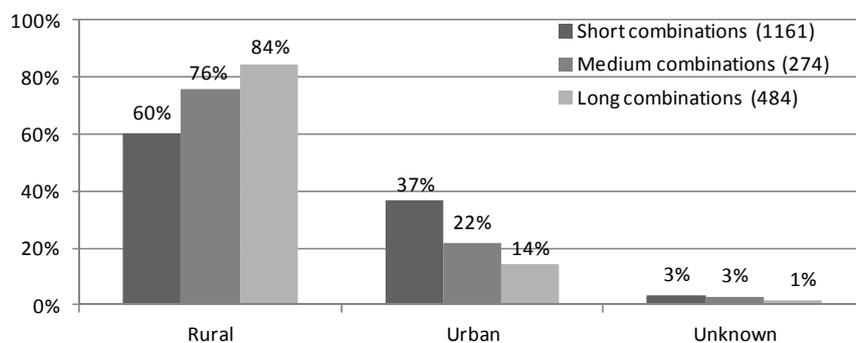
Figure 2
Traffic environment in fatal or severe HGV crashes classified by length group

The crash type distributions in the three length groups using the crash type definitions in STRADA are shown in Figure 3. In this figure, the crash type "Overtaking" was united with "Meeting," while "Turning" and "Intersection" crashes are combined as "Intersection" since a great overlap was observed between these crash types (judged by the detailed crash descriptions).
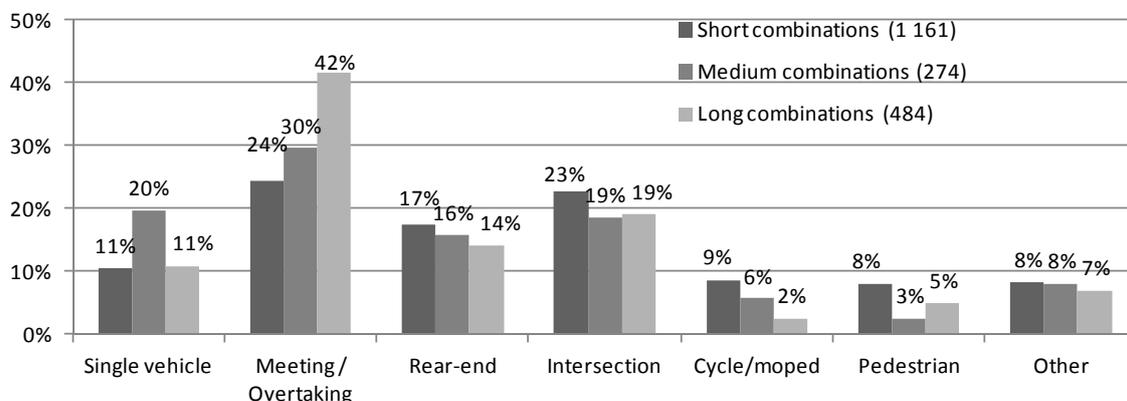
Figure 3
Crash type distribution by length group

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.

The graphs in Figure 2 and Figure 3 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 2. The entry "Sum of vehicle lengths" refers to determination of combination length based on the sum of vehicle lengths with a correction term.

Table 2
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 the "Method" section, 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 3. The corrected number of crashes is shown in the second row of Table 4.

Table 3
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 the "Method" section. 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 4) 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 4
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 registered combinations 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	-

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 5 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 5
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 6.

Table 6
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 6. For countries having the EU length limit of 18.75m, VKT is distributed between the "small" (60%) and "medium" (40%) groups.

Table 7
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 8
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%.

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 Accident 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 2.

The differences in the crash types in the three length groups (Figure 3) can be partly explained by the differences in traffic environment (see Figure 2). "Short" HGV combinations drive more in urban environment than combinations in the other two length groups. Hence, it is expected that the share of crashes with vulnerable road user involvement is the highest in the "short" 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.

Finally, 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 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.

As described before Table 3, 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. 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.

Conclusions

This study determined the rates of fatal or severe crashes in Sweden for the years 2003 to 2012 for HGV combinations in three length groups: "short" (≤12m), "medium" (12.01 – 18.75m) and "long" (18.76 – 25.25m). The rates for the respective length groups were 137, 56 and 44 fatal or severe crashes per billion vehicle kilometres travelled. The derived factors 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 are slightly lower than in the "medium" group while the rate in the "short" group is substantially higher than both. In particular, this study did not find any evidence that "long" combinations that exceed the EU length limit of 18.75m would be less safe than combinations up to 18.75m.

Acknowledgements

References

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

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

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

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.

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.

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 accident risk between long and short truck configurations,* Journal of Risk Research 11, 315-333