Heavy Good Vehicle Accident Analysis for the Identification of Potentially Dangerous Situations

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SYNOPSIS

Road accidents are one of the major social problems in Europe since they annually claim more than 40000 lives and leave more than 1.7 million of injuries, representing enormous direct and indirect costs (estimated by the European Community Transport Commission in about 160 billion euro). Heavy Good Vehicles (HGV) are involved in less than 5% of total accidents but their influence on the phenomenon is very significant if it is considered that 25-30% of road deaths in Europe results from crashes involving trucks, due to the high percentage of fatalities in these accidents.

The study reported in this paper has been conducted, within the VERTEC Project funded by the EU (GRD2-2001-50007), aimed at the identification of situations which can be addressed as potentially dangerous when HGV are considered in order to improve road safety and provide a focus for HGV safety strategies.

A first activity has been the definition of a literature review database aimed at identifying the key variables which affect HGV accidents. Then an accident database has been implemented collecting data available from the different countries of the partners involved in this task of the Project (Italy, France, Finland, UK) in a common database.

For the data analysis a set of key variables to be investigated have been identified (severity of the accident, road type, HGV type, road geometry, dry or wet pavement, accident mode etc) and the data have then been split in different "datasets" (scenarios) each of which is represented by a given road type and severity (all accidents, accidents with injuries or fatal and only fatal accidents).

Each different variable has been analyzed in terms of percentage distributions in a given scenario and the HGV accident rates have been also analyzed.

Combining the most frequent conditions for each of the different variables analyzed in each scenario the potentially "most dangerous situations" has been identified (the situations where potentially all the key variables identified as more dangerous occur at the same time).

This result will serve as a basis to concentrate further investigations and simulation efforts in the VERTEC Project on situations identified as "potentially dangerous".

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INTRODUCTION

The study reported in this paper has been conducted within the VERTEC (Vehicle Road Type and Electronic Control Systems) Project, funded by the EU (GRD2-2001-50007), the objective of which is the increase in road vehicle active safety. One of Vertec innovative goal is the development of a fully integrated road-vehicle model for predicting Heavy Good Vehicle (HGV) handling.
Because of the size, weight and the amount of travel, HGVs play nowadays a major role in both the occurrence and consequence of road crashes. Recent European statistics show that HGVs are involved in about 5% of total road crashes in Europe but this percentage raises to 25-30% when only fatal accidents are considered.
So the development of the Vertec model for predicting HGV handling will be useful in order to investigate this problem and analyze the potentially most dangerous situations when trucks are involved.
To identify which are the most dangerous situations to be tackled by the model a specific study was conducted in order to develop a large scale HGV accident analyses at European level. This paper deals with this study aimed at the identification of situations which can be addressed as potentially dangerous when Heavy Gross Vehicles (HGV) are considered.

BACKGROUND

In Europe only few studies have been conducted in order to investigate trucks accidents, and these are mainly at single countries level such as a recent study developed in Italy by Centro Studi Sistemi di Trasporto (CSTT) that highlighted how in Italy in the last years trucks represent about 7-8% of the total vehicle involved in accidents [17]. This analysis have also shown that the most probable type of crash when trucks are involved is a "front side" collision (34%) followed by "front rear" (26%) and "side side" collisions (12%) while runoff and "front front" collisions are less than 10%. The type of vehicle more frequently involved in crashes is a light truck in urban areas and a truck with a weight of more than 35 kN (HGV) in rural context.
The accidents within HGV involved raises to almost 23% considering the 2002 average on the main tollway network provided by the tollway concessionaire. This rate might be related to the traffic composition with high percentage of HGV, in rural highways.

The main lack of European research on the evaluation of the interaction between road safety and Heavy Good Vehicles, is to consider this phenomenon as a continental issue. In order to define a general European analysis the Transport European Commission has recently organized a Community Road Accident Database (CARE) that should collect disaggregated data from all the countries members of the U.E.
A recent study developed in Austria based on CARE accidents data has however highlighted the actual limits of this database due to the different HGV definition of each country and to many data irregularities (CARE currently produces incorrect accidents data for 7 out of 15 countries) [48].

The problem of accidents involving HGV, especially in the last years, has been particularly considered in United States where the Federal Motor Carrier Safety Administration (FMCSA) was established, in January 2000 as a separate administration within U.S. Department of Transportation, with the primary objective of reducing crashes, injuries and fatalities involving trucks and buses.
The 2001 Traffic Safety Facts [32], published by FMCSA, shows that one out of eight traffic fatalities occurred in U.S. is a collision involving a truck, and in particular considering all the fatalities related to HGV accidents, only 14% are occupants of trucks, while 77% are occupants of other vehicles and 9% non occupants. The statistics of this FMCSA study also indicate that most of truck fatal accidents occur in rural areas, during daytime and on weekdays. In terms of accident types trucks result more often involved in a multiple vehicle crash than passenger cars especially in front front and front rear collisions.

The importance of trucks accident occurrence and fatality rates has determined the development of many studies in order to better investigate the phenomenon.

Golob, Recker and Leonard, for example, have analyzed the severity and accident duration of crashes involving HGV. Their analysis highlighted that within different collision types, sideswipe and rear end are the most frequent (43% and 31% respectively) but the most severe accident in term of fatalities resulted to be a bit objects collision followed by rear-end [27].

Most of the literature review focus the attention on specific aspects that may affect accident occurrence or be related to accident consequences. The key studies dealing with different accident analysis aspects are the following:

- a recent brief paper prepared by Office of Motor Carrier and Highway Safety has analyzed driver related factors in crashes involving trucks and passenger vehicles [34]. Results seem to indicate that trucks drivers errors that lead to accidents are less frequent than those of passenger vehicles. In particular in 73% of these crashes the passenger vehicle driver was related to a wrong action while the trucks driver was considered responsible only in 34% of the accidents.
- Accident prediction models have been developed by Daniel and Tsai Chien in order to identify factors that may contribute to truck crashes at particular location [5].
- Occupancy effects in accident severity analysis have been identified in a study conducted by Chang and Mannering in 1998 [7].
- Campbell investigated minimum age for drivers comparing fatal accident involvement rates by driver age [47].
- The speed factor was considered by Raybhandari and Daniel that developed a model that suggested that higher speed limits could be actually related to an increase in monthly crashes involving trucks.
- The influence of road geometry on truck crashes has not been deeply studied. Miaou (1994) investigated the performance of Poisson and negative binomial models in establishing relationship between accidents and geometry of road sections [29].
- A case control study on the role of truck configuration on tractor trailer crashes was conducted in Indiana by Indian University and Insurance Institute for Highway Safety [11].
- A two years study on the effect of HGV mechanical condition on road safety was made in Canada together with the evaluation of an annual mandatory mechanical inspection program.
- Accident rates for heavy trucks-tractor in Michigan were analyzed by Blower and Campbell [28]. In this study the importance of the operating environment (type of road, weather, time of the day) more than of the driver related factors was considered in determining the risk of accident.

The main problem of most of the present studies, even if focused on different aspects, is the limited number of information or the level of accuracy of the data. Because of this lack of reliability in trucks accident information, the U.S. DOT has started in September 2002, a 3 years project, the "Large Truck Crash Causation Study" (LTCCS), conducted by NHTSA and FMCSA, aimed at the collection of the accidents involving trucks, directly on crash location with specialized personnel [21]. The main purpose of this project is to develop a safety national database focusing more on pre-crashes, related factors and causes that lead to the accident and that will allow to conduct deeper and more complete analysis on the phenomenon.

In Australia, during 2002, a large scale analysis on HGV accidents was conducted by the Australian National Road Transport Commission to benchmark trucks safety performance of Australian roads [20]. In this work the trends in the number of fatal truck crashes have been evaluated in Australia and compared to those resulting in United States, Canada, New Zealand, United Kingdom, France, Germany and Sweden. Results highlighted that trucks accidents occurred in urban area are about 40% in Australia but considerably less in other countries (about 20%), that about two-third of fatal crashes involved articulated trucks in Australia, Canada and U.S. but much lower in European countries and that the percentage of single units crashes is everywhere limited between 14 and 20% (and about 25% on Australian roads).

ACCIDENT DATA COLLECTION APPROACH

As a result of the literature review a lack of detailed and homogeneous information on HGV accidents can be noticed especially at the E.U. level. In this study, in order to analyze a European representative sample of accidents involving heavy good vehicles, a specific DB has been set up, collecting data from different countries. The database is organized using aggregated data and particularly grouping together a number of accidents having 3 common features: road section, type of HGV and type of accident.

The road section is defined as a portion of road with a given length, description, traffic and typology.

The different **types of roads** considered in this study are:

- rural highways (dual carriageway roads in rural context)
- urban highways (dual carriageway roads in urban context)
- primary (major arterial single carriageway road)
- secondary (secondary arterial single carriageway road)

These four classes do not consider urban context (except for urban highways) since according to experience and most of literature the number and severity of urban accidents involving HGV are not as relevant as rural ones.

The **type of HGV** considered are trucks defined in this study as all commercial vehicles, except buses, with a weight of more than 35 kN.
Trucks are then divided in 3 subclasses (as shown in Figure 1):

- single units
- tractor-trailers
- tractor-semitrailers.

The total truck class have been considered to provide general information on HGV phenomenon while the three trucks subclasses are required in order to supply detailed info on a specific HGV type.

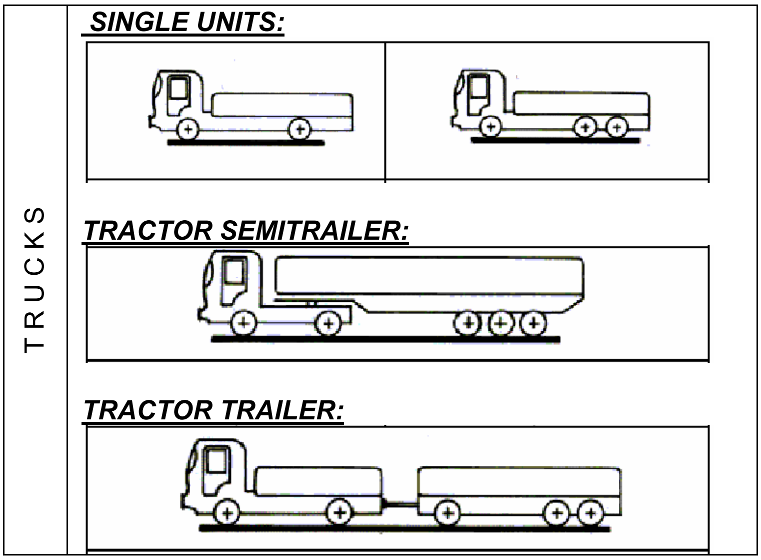

Figure 1: Types of Heavy Good Vehicles considered

The type of accident is defined in order to identify different crash severity classes. Three **types of accidents** have been defined[1]:

- all accidents (including crashes without injuries)
- injuries+fatal accidents (accidents with at least 1 injury or fatality)
- fatal accidents (only accident with at least 1 death).

Each group of aggregated accidents collected in the DB is then described using 4 fixed **key variables**:

- Type of Vehicle involved, that describe how many accidents occurred with only one heavy good vehicle involved (1 HGV), how many with 2 or more HGV (HGV to HGV) and how many accidents involve 1 HGV and other vehicle (1 HGV to other).[2]
- Accident description, that enables to characterize the main cause of a given accident such as Rollover, Front-Rear collisions, Front/side- side collisions[3], Runoff and Other.
- Geometry, that describe how may accidents occur in straights and in curves with different curvatures.
- Weather, that describe how many accidents occur on dry, on wet and on snow or ice conditions.

It has to be highlighted that accidents data collected by U.K. are characterized by a considerable difference in the accident description variable definition in respect to the other dataset. In the U.K. dataset in fact the values of the accident description variable defined before, such as rollover, runoff, rear-end, front-front, front/side-side collisions are descriptive only of 1 or 2 vehicles accidents while crashes with 3 or more vehicles have been anyway located in the 'other' category. So in datasets where accidents provided by U.K. have a great weight, the rate of the 'Other' accident description type might be considerably higher, while analyzing all the categories different from 'Other' they can be considered highly reliable for 1 or 2 vehicles crashes.

[1] It might not be significant to compare data with different accident severity, for example accidents without injuries with fatal accidents.
[2] Accidents involving 2 or more HGVs have been considered as HGV to HGV even if other users are involved.
[3] Front/Side-side collisions are referred to both front-side and side-side collision since in many DB it is difficult to distinguish the exact type of impact between two situations.

HGV ACCIDENT DATABASE IMPLEMENTATION

The goal of this study is the analysis of accidents involving HGV occurred in various European realities, so the database has been implemented with data crashes provided by 4 different countries: France, Italy, United Kingdom, and Finland.
Data collected are not all the accident involving trucks occurred in each country but group of accidents extracted from different national databases that were available within the partners of the Vertec Consortium, representing as much as different situations (in term of different countries, different type of road and of accident severity) as possible.

Italian data have been extracted from two Trunk road Databases (classified as rural highways in this study), covering a period of 7 years and a half, for a total number of 7566 accidents, including crashes without injuries.

France accidents, extracted from the France National Data Files for a period of 3 years from 1999 to 2001, are 456 injuries+fatal crashes, occurred in all different road types defined.

Data from Finland extracted from the Finnish Motor Insurance Database, are 352 fatal accidents occurred between 1997 and 2001 in all national roads.

Data provided by U.K. are more than 20000 injuries+fatal accidents occurred in different types of roads in the period between 1994 and 2000, and extracted from STATS19 and the England Trunk Road Database.

To understand the different data composition provided by each country and in order to develop the analysis, the crashes data collected have been grouped in “Scenarios” that are related to different datasets, characterized by a given accident severity and road type, as shown in Table 1. In the Table for a given type of road and severity class, the number of accidents is given together with the total road length and the countries related to the crashes. In bracket, moreover, the number of accidents related to each country database is indicated, in order to evaluate the weight of each of them in the dataset.

Table 1: Number of TRUCKS accidents recorded in the DB for different types of accidents- and types of road

		ROADS TYPES			
		Highway Rural	**Highway Urban**	**Primary Roads**	**Secondary Roads**
ACCIDENT SEVERTITY	**All**	***Scenario 1*** **7566 accidents** ***498.2 km*** *(Italy)*	-	-	-
	Injuries + Fatal	***Scenario 2*** **15402 accidents** ***4214.2 km*** *(France, Italy, U.K.)* [1356 Italy] [119 France] [13927 U.K.]	***Scenario 4*** **738 accidents** ***214 km*** *(France, U.K.)* [183 France] [555 U.K.]	***Scenario 6*** **5609 accidents** ***2957 km*** *(France, U.K.)* [114 France] [5495 U.K.]	***Scenario 8*** **23 accidents** ***212 km*** *(France)*

	Fatal	***Scenario 3*** **651 accidents** ***4214.2 km + Finland*** *(France, Italy, U.K, Finland)* [130 Italy] [8 France] [506 U.K.] [7 Finland]	***Scenario 5*** **14 accidents** ***214 km*** *(France, U.K.)* [4 France] [10 U.K.]	***Scenario 7*** **698 accidents** ***2957 km + Finland*** *(France, U.K., Finland)* [20 France] [451 U.K.] [227 Finland]	***Scenario 9*** **121 accidents** ***212 km + Finland*** *(France, Finland)* [3 France] [118 Finland]

ANALYSES APPROACH

Two types of analysis are considered in this study, one based on the investigation of the different percentage distributions of the key variables defined in the DB (type of vehicle involved, geometry, weather, accident description) and the other is based on the calculation of an indicator of accident occurrence.

The aim of the first type of analysis is to identify, for a given type of road and severity class, the potentially most probable situations describing accidents involving HGV. To reach this goal, the different key variables have been analyzed independently of the others in terms of percentage distributions. The different percentages have been grouped together. This approach was based on the assumption that the most frequent event can be described by the simultaneously occurrence of each of the most frequent variable singularly. This is equal to suppose that the *real occurrence probability* (P_{REAL}) of a specific event described by a set of values of the key variables, can be related to the *theoretical probability* (P_{THEOR}) given by the product of the single probabilities of the variables describing that accident, and this assumption can be described by the following equation:

- **Eq. 1** $$P_{REAL} = k \cdot P_{THEOR}$$

The assumption of Eq. 1has been tested on Italian accident database where crashes were available also as disaggregated data. In this database each crash event can be described by a set of combination of the 4 different variables whose possible values, described in the Accident Data Collection Approach Section, are summarized in Table 2 .

Table 2: Key fixed variables possible values in Italian DB

Variable	***Key variables description***	***Possible values***
Variable 1	Type of vehicle	$\overline{Variable1}$: - 1 HGV - HGV to HGV - 1 HGV to other
Variable 2	Accident description	$\overline{Variable2}$: - Rollover - Front-Rear - Front-side/side-side - Runoff - Unknown
Variable 3	Geometry	$\overline{Variable3}$: - Straight - R<500m - 500m<R<1000m - 1000m<R<2000m - 2000m<R<2500m - R>2500m
Variable 4	Weather	$\overline{Variable4}$: - Dry - Wet - Snow/Ice - Unknown

The real occurrence probability of all the possible sets of accidents have been measured in the dataset and compared to the theoretical probability calculated as described in the following equations:

- **Eq. 2** $$P_{REAL}(event) = \frac{Nevent}{Ntotal}$$

- **Eq. 3** $$P_{THEOR}(event) = P(\overline{Variable1}) \cdot P(\overline{Variable2}) \cdot P(\overline{Variable3}) \cdot P(\overline{Variable4})$$

where :

- *event* is an accident characterized by the occurrence of $\overline{Variable1}$, $\overline{Variable2}$, $\overline{Variable3}$, and $\overline{Variable4}$
- *Nevent* is the number of accidents related to the 'event' considered
- *Ntotal* is the total number of accidents
- $P(\overline{VariableX})$ is the probability of the occurrence of a specific value of the variable X (number of accidents characterized by the occurrence of $\overline{VariableX}$ divided by *Ntotal*)

The results have been reported in a diagram P_{REAL} Vs P_{THEOR} and related using a linear correlation factor.

If all accidents (fatal and with or without injuries) are considered (Figure 2) and the linear correlation factor calculated, the statistical results are not very relevant (R^2=0.5464) and this is greatly due to the high dispersion given by sets of accidents that have low measured probability of occurrence. It can be seen, anyhow, that the most frequent event in terms of P_{REAL}, stay the most frequent in terms of P_{THEOR}. Given the fact that the assumption of Eq. 1, is made to analyze the most frequent events, the same analysis has been made considering only accidents with an occurrence probability greater than 0.5% (Figure 3) that correspond to a base of data of 6562 crashes (instead of 7566). In this case the linear correlation shows a good approximation with a R^2 factor of 0.8323.

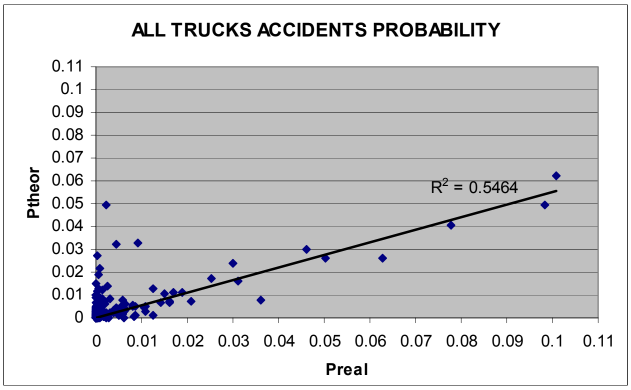

Figure 2: Linear correlation between real and theoretical accident occurrence probability considering all trucks accidents of the dataset

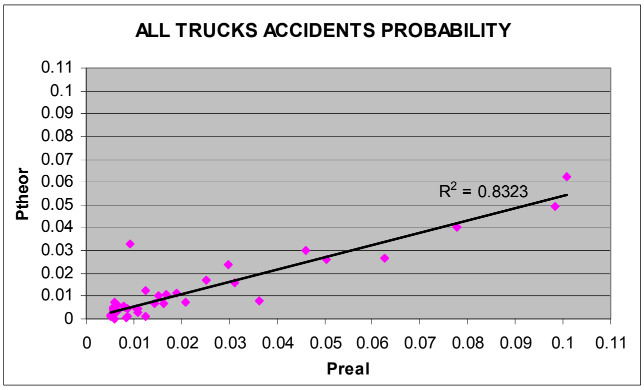

Figure 3: Linear correlation between real and theoretical accident occurrence probability, considering more frequent events (Preal>0.5%) inside the all trucks accidents dataset

The same assumption has therefore been tested only on 'Injuries+fatal' Italian accidents since, as seen earlier these types of accidents are more relevant at European level. In this case considering all sets of accidents (Figure 4) the linear correlation factor is already very good (R^2= 0.8557) and results, again, higher if the accident types with an occurrence probability less than 0.5% are not considered (R^2=0.8876 as shown in Figure 5).

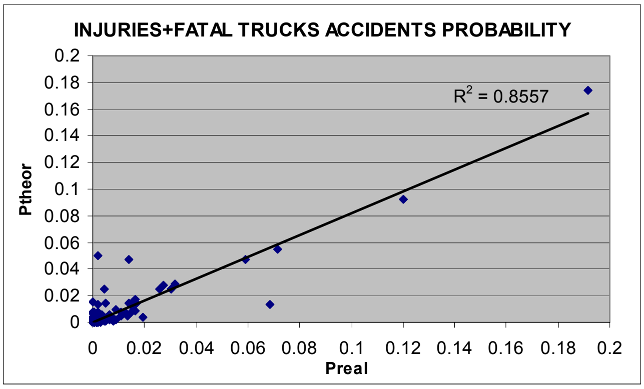

Figure 4: Linear correlation between real and theoretical accident occurence probability considering injuries+fatal trucks accidents of the dataset

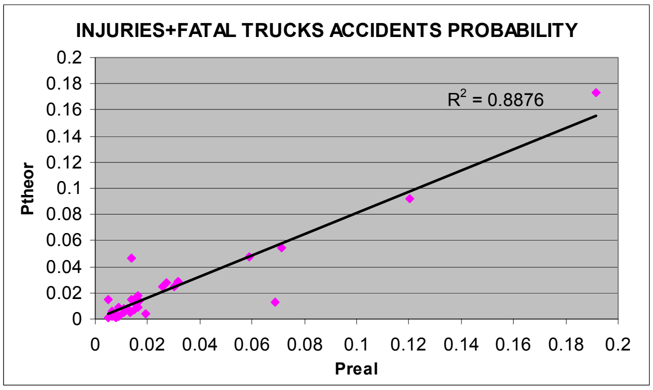

Figure 5: Linear correlation between real and theoretical accident occurence probability, considering more frequent events (Preal>0.5%) inside the injuries+fatal trucks accidents dataset

These results, related to the Italian dataset, have lead to the conclusion that the analysis approach, based on considering the potentially most probable situation as the situation where potentially all the key variables identified as more frequent occur at the same time (assumption of Eq. 1) can be accepted. In fact if the Figure 2 or Figure 3 are considered, the most probable event (Preal=0.10), that is a Front Rear collision involving a HGV and other vehicles (1 HGV to other), occurred in straight and on dry conditions, is also the event with the higher theoretical probability (Ptheor=0.06). In the same way in Figure 4 or in Figure 5 the most probable event (Preal=0.19), that is again a Front Rear collision involving a HGV and other in straight and on dry conditions, is characterized by the highest theoretical probability (Ptheor= 0.17).

A second approach has been followed in order to calculate an accident indicator independent from the specific conditions representing the base of data, that enable a direct comparison between different situations. The indicators used in this study are two:

- The number of accidents per vehicle km referred to as Accident Rate (A.R.) and defined in Eq. 4.
- The number of accidents per HGV km referred to as Heavy Good Vehicle Accident Rate (A.R.(HGV)) and defined in Eq. 5.

- **Eq. 4** $$A.R. = \frac{10^6 \cdot Nacc(HGV)}{365 \cdot Nyears \cdot \overline{AADT} \cdot \cdot length}$$
- **Eq. 5** $$A.R.(HGV) = \frac{10^6 \cdot Nacc(HGV)}{365 \cdot Nyears \cdot \overline{AADT} \cdot HGV\% \cdot length}$$

where:

- *Nacc(HGV)* is the number of accidents occurred in the reference period on the given road section.
- $\overline{AADT}$ is the Annual Average Daily Traffic on the given road section [4]
- *Length* is the length of the road section considered
- *Nyears* is the number of years in the reference period considered.
- *HGV%* is the percentage rate of HGV in the traffic composition of the considered road portion

The accident key variable distributions used to determine probable crash situations, are referred to a specific set of data, the Accident Rate (A.R. or A.R.(HGV)), on the contrary, is a reliable general indicator of danger since, taking in consideration traffic conditions and road lengths, is not related to the specific conditions of the dataset . Unfortunately the A.R., as seen, needs complete and specific information associated to accidents to be calculated, so the approach followed in this study is to analyze all simple variable percentage distributions to calculate the potentially most probable situation involving HGV and then calculate the A.R. and A.R.(HGV) when data are available, in order to compare the risk of accident in different types of roads.

[4] If different AADT values can be applied to one given road section a weighted average can be considered where the weight is the length of each subsection with a given AADT.

DATA ANALYSIS

The first part of the data analysis is devoted to defining the situations where HGVs are more likely to occur. This is based on the probabilistic distribution approach described before. An independent analysis has been conducted for each of the scenarios defined in Table 1, and then compared considering all the scenarios referred to the same road type.

Identification of trucks most probable accident situations

RURAL HIGHWAYS

As described earlier trucks accidents occurred in rural highways collected in the database, have been grouped in 3 datasets each one related to a defined severity class (‘All’, ‘Injuries+Fatal’ and ‘Fatal’).

If the trucks accidents of each dataset are considered and the distributions of the key variables analyzed, the results lead to the following considerations:

- In all the datasets the most frequent accident condition (Figure 6) results a truck involved with other users. Single HGV are relatively frequent if all accident are considered but almost negligible in severe accidents. Beside this the analysis on accident description (Figure 7) shows that front-rear are the main situations describing crashes in all the datasets while runoff appear rather limited especially if severe accident are considered.
- Accidents occurred on wet (Figure 8) are approximately 15% but this rate is considerably higher when severe accidents are considered (20 to 30%). Since the percentage of accidents occurred on dry conditions is quite similar in the 3 scenarios the different distributions on wet might be due to the high number of ‘Unknown’ accidents in the ‘All’ dataset (scenario 1). This lack of information in the dataset is probably related to the fact that accidents without injuries and fatalities are collected and described with less accuracy.

  Anyway since these data are related to the different weather of each country to better investigate the accident-weather relation the actual number of raining days in one year should be considered.
- The influence of road geometry (Figure 9) highlights that the greatest part of ‘injuries+fatal’ and ‘fatal’ accidents occur on curves with radii contained between 500 and 1000 meters (35-40%). If ‘All’ accidents are considered the distribution is very different with more than 60% of accidents occurring on straights. In comparing these two indications it should be kept in mind that the road network over which the three scenarios are considered are different. Therefore the number of elements with a given curvature can be different from the scenario 1 to the scenarios 2 and 3 (where only sever accidents are considered). Even considering a single scenario it is important to consider that accident might occur more frequently on a type of element (as the straight in scenario 1) only because this is the most frequent geometric condition. To solve this problem this variable could provide more reliable indications if considered with reference to the Accident Rate and not to the total number of accidents occurred, but the required data to evaluate this indicator in each geometric class were available only in the ‘All’ accidents dataset. Based on this analysis the highest Accident Rate was identified on radii between 500m and 1000m as shown in Figure 10. According to these considerations and to the results of the analysis of severe accidents (with injuries or fatal) curves with radii between 500m and 1000m can be identified as the most probable for rural highways accident occurrence.

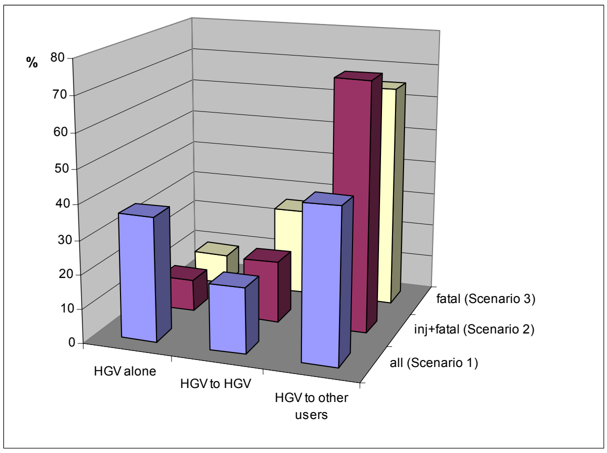

Figure 6: Accidents-Vehicles involved distribution

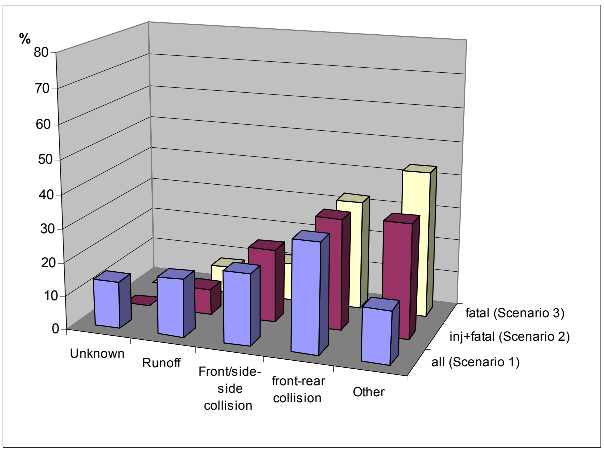

Figure 7: Accident description distribution

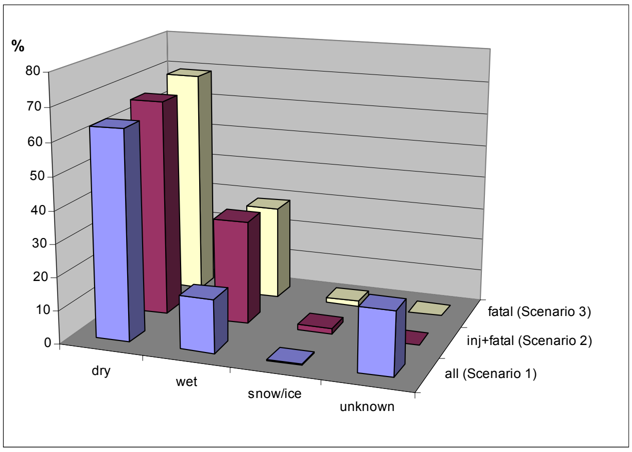

Figure 8 : Accident weather distribution

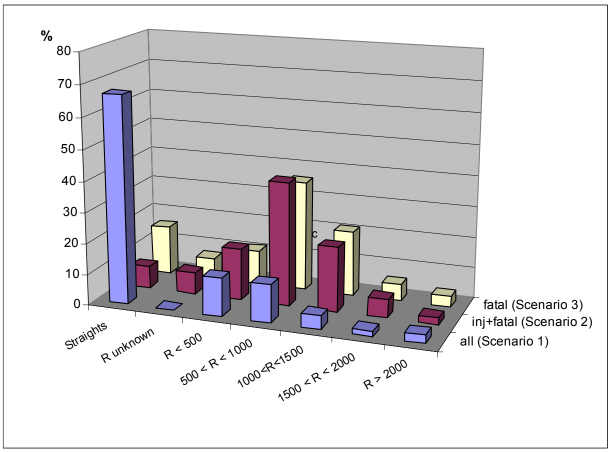

Figure 9: Accident Geometry distribution

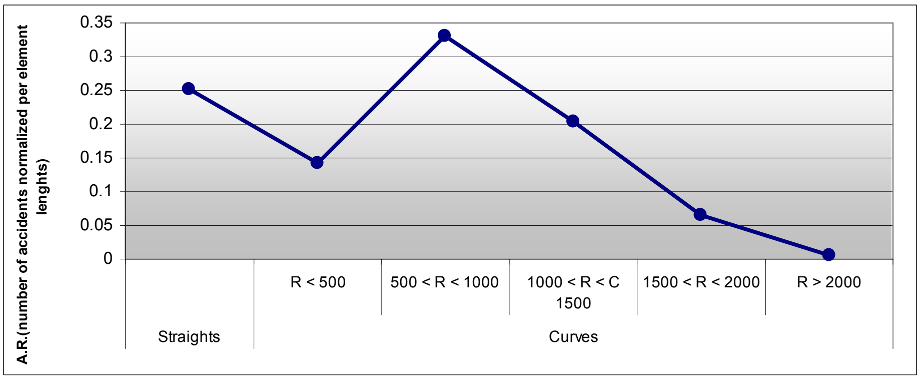

Figure 10: Geometry variable distribution based on Accident Rate for Scenario 1

In conclusion under the assumption discussed earlier that the most likely accident situation is the one where all the variables assume the most probable value (cfr. Eq. 1), the situation where most likely HGV accidents occur in **rural highways** appears to be:

- a front rear accident involving a truck with another user *(that can be likely associated to a braking manouvre)* on curves with radii between 500m and 1000m on dry or wet surfaces (the first condition is more frequent but the second is more severe).

URBAN HIGHWAYS

The analysis of crashes occurred in urban highways have been developed only on 'injuries+fatal' accidents (Scenario 4) since the 14 fatal accidents showed in Table 1 for scenario 5, are not significant enough to characterize this type of severity.

The analysis results show that:

- The condition of crashes with HGV involved with other users is very frequent (almost 90%) and even higher than the rate seen in rural highways, indicating that in urban area trucks accidents are more probably caused by interactions with other users (Figure 11).
- The main trucks accident situation (Figure 12) is a front/side-side collision (35%) and since urban highways are double carriageway roads this event is more likely a side-side collision. Front-rear are still very frequent situations (about 25%).
- The weather influence (Figure 13) shows that about 25-30% of accidents occur on wet conditions similarly to what happen in rural highways[5].
- Accidents Vs Geometry distribution shows that accidents occurred in small radii (R<500m) curves are more than 40% and another 20% occur in curves with radii contained within 1000 meter (Figure 14). If compared to the results obtained with reference to rural highways, in urban highways accidents in

[5] It was not possible to evaluate the severity of wet accidents as only 'Injuries+fatal' data are available for this type of road.

proximity of smaller radii seem to be more frequent and this is probably related to the fact that small radii curves are more diffused in road design geometry.

According to these distributions the most probable situation for **urban highways** appear to be:

- a side-side collision *(that can likely be associated to a lane change manouvre)* involving a truck and another user in sharp curves in dry conditions.

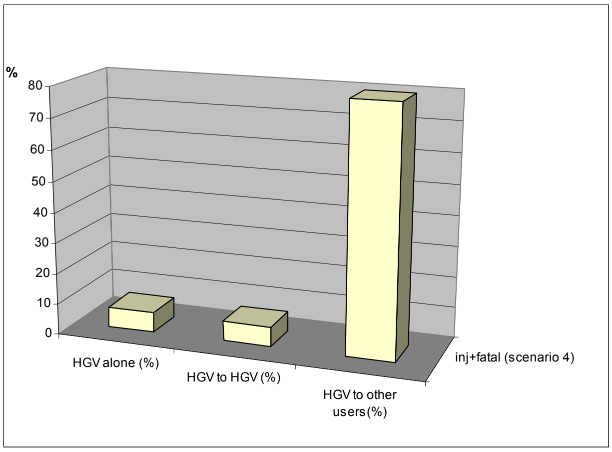

Figure 11: Accidents-Vehicles involved distribution

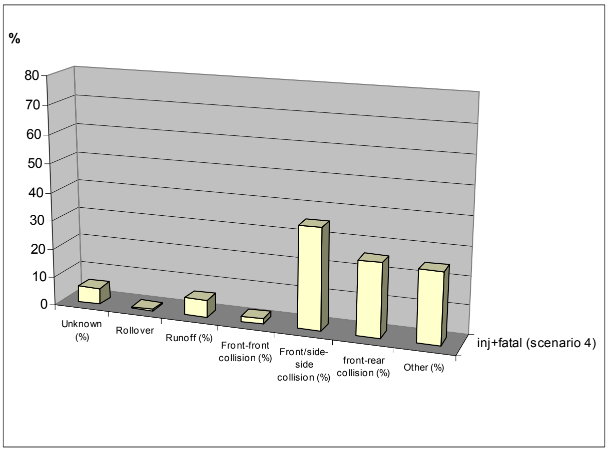

Figure 12: Accident description distribution

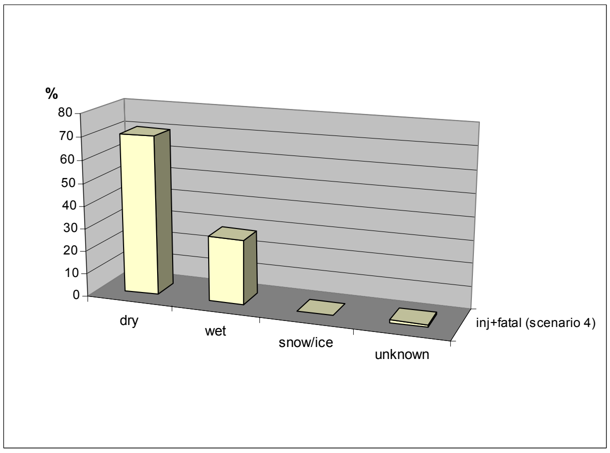

Figure 13: Accident weather distribution

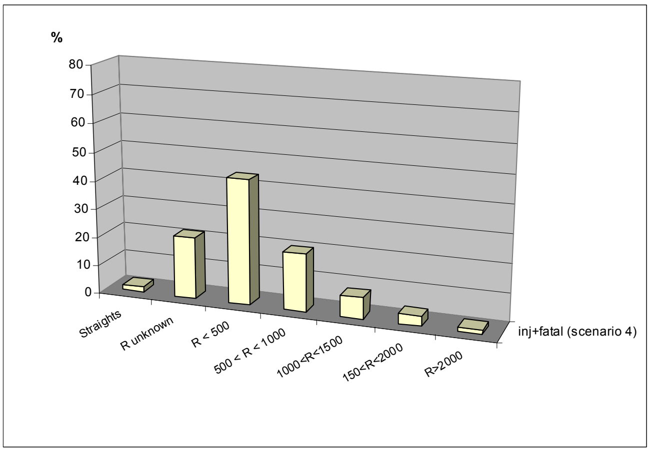

Figure 14: Accident Geometry distribution

PRIMARY ROADS

For this road type two different scenarios have been considered: the injuries+fatal accidents (scenario 6) and the fatal ones (scenario 7).

The analysis of the defined key variables distributions lead to the following considerations:

- The vast majority of accidents (80%) involve again a truck with other users (Figure 15). Single vehicle accidents, especially fatal, are characterized by very low frequency.
- The accident description analysis highlights that majority of events (over 30%) is located in the 'other' category (Figure 16). This result, that might lead to the conclusion that the definition of accident description categories are not appropriated, can instead be explained considering that, as described in the 'HGV Accident Database Implementation', all accidents involving more 3 or more vehicles occurred in U.K. (that have a great weight in the datasets) have been located in the 'other' category. So analyzing all the categories different from 'Other', that can be considered highly reliable for 1 or 2 vehicles crashes, front/side-side collision are characterized by higher frequency. For primary road these type of accidents are more likely associated to a front-side collision since side-side are usually connected with 2 carriageways. Front-rear collision are highly probable (20%) in "injuries+fatal' dataset but less in fatal accidents.
- Accidents occurred in wet conditions are about 40% in 'injuries+fatal' dataset and 30% considering only fatal crashes (Figure 17). This difference is related to an increase of rate of accidents on dry and on snow/ice. On one hand the high number of fatal accidents occurred on snow/ice might be explained

considering that the dataset of scenario 7 contains additional data from Finland (where snow is evidently more frequent then in other European countries considered), not present in scenario 6 (injuries+fatal); on the other hand the higher rate of fatal accidents occurred in dry conditions if compared to injuries+fatal ones, might be related to higher speed in good weather conditions and more severe consequence for the persons involved in crashes (a similar trend can be noticed also in rural highways (Figure 8)).

These data show anyway that accident on primary roads seem to be more frequently characterized by critical surfaces (wet or snow) than those occurred on highways.

- A great part of 'injuries+fatal' accidents occur in small radii curves (R<300) while crashes occurred on straight are less than 2% (Figure 18). Even if this could be related to a reduced lengths of straights if compared to highways, on this type of road there is clearly a bigger problem with manouvres in sharp bends. When more severe accidents are considered, the most probable geometric elements where fatal accidents occur are great radii curves (R>500m) while small radii, and straights, occur in about 20% of accidents.

  Given the fact that the dataset referred to scenario 7 (fatal accidents) contains also data from Finland, which are not represented in scenario 6, it was necessary to check if this shift of the most dangerous situation from small radii (for injuries+fatal accidents) to high radius values (for only fatal accidents) was biased by this change in the dataset. The same analysis has therefore been conducted comparing scenario 6 (U.K. and France databases) with a subset of its dataset where only fatal accidents have been included (again only from U.K. and France). From the results shown in Figure 19 the same effect of shifting the dangerous conditions to high radii has been observed confirming the results of the evaluations based on scenario 7.

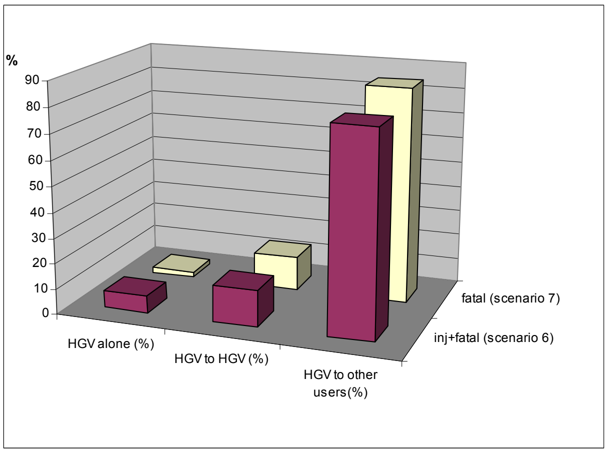

Figure 15: Accidents-Vehicle involved distribution

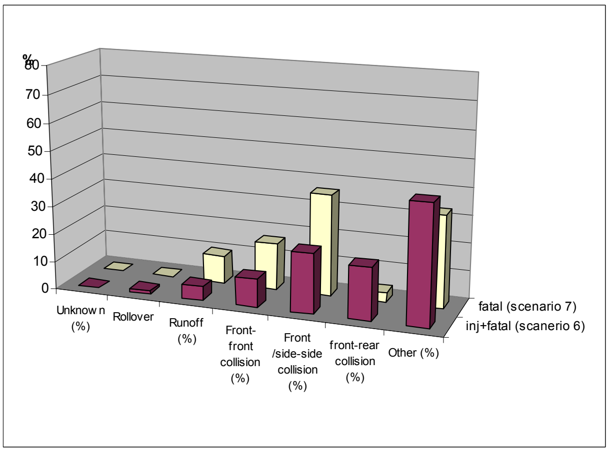

Figure 16: Accident description distribution

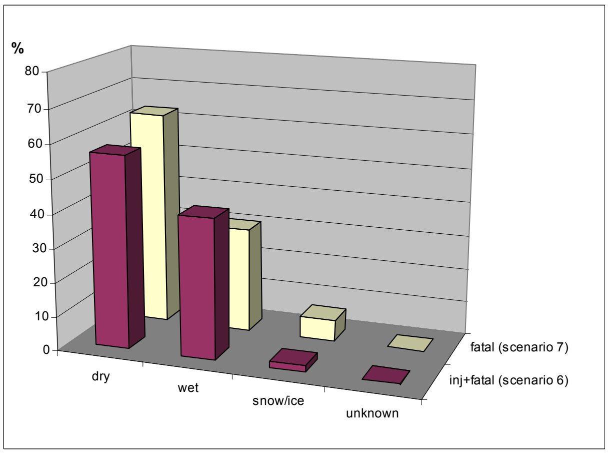

Figure 17: Accident weather distribution

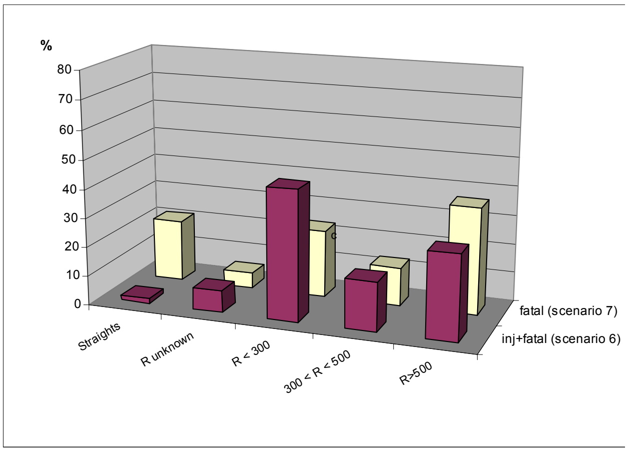

Figure 18: Accident Geometry distribution

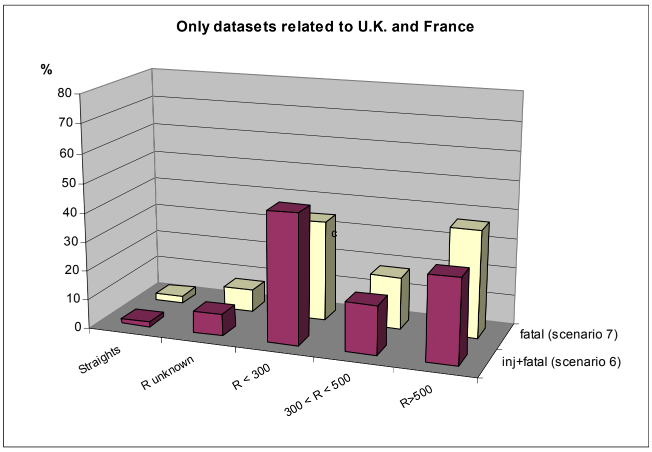

Figure 19: Accident geometry distribution referred to scenario 7 and scenario 8 based on the scenario 7 dataset (only accidents occurred in U.K. and France)

In conclusion for **primary roads** the most probable situation appear to be:

- a front-side collision *(likely an avoiding obstacle manouvre)* involving a truck and other users on wet surfaces. As far as geometric is concerned, small radii seem to be more critical considering all accident severities but larger ones lead to higher probability of fatal events, probably due to higher speeds.

SECONDARY ROADS

Accident data referred to secondary roads available in the database are only 'Fatal' accidents mainly occurred in Finland (97.5% of the dataset), so they are not highly representative of different countries situations. For this reason the preliminary results described below should be further investigated. Based on the available data it can be highlighted that:

- The most frequent accident condition (Figure 20) is again a truck involved with other users (almost 80%) but the rate of accidents with only 1 HGV involved is higher than in all the other types of road.
- The most probable situation (Figure 21) is a front/side-side collision (55%) and very frequent (35%) are also runoffs that might be related to the described higher frequency of single vehicle crashes. In this case, being a secondary arterial with a single carriageway road, the front/side-side accident is more likely a front-side event even though the information in the available data do not enable to confirm this assumption.
- Trucks accident occurred in wet conditions are about 10% of the total (Figure 22), considerably less than what resulted on highways and primary roads. This data can be explained considering that snow/ice influence is very relevant and this is evidently due to the fact that this dataset is strongly composed by accidents from Finland where snow on road surfaces is more frequent than in other countries involved in the study.
- About 50% of trucks accidents occur on straights (Figure 23), while the most dangerous curves are those with large radii (R>300m).

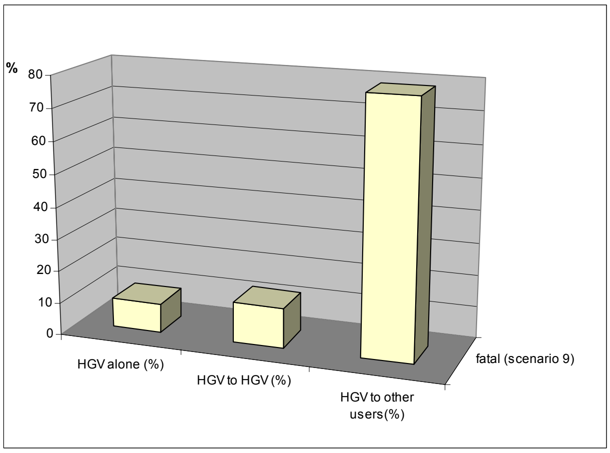

Figure 20: Accidents-Vehicles involved distribution

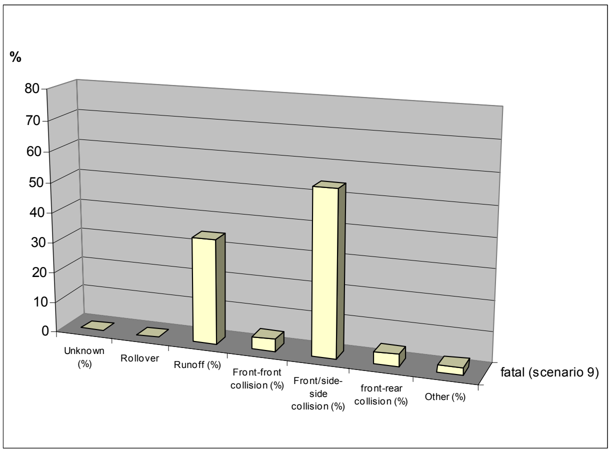

Figure 21: Accident description distribution

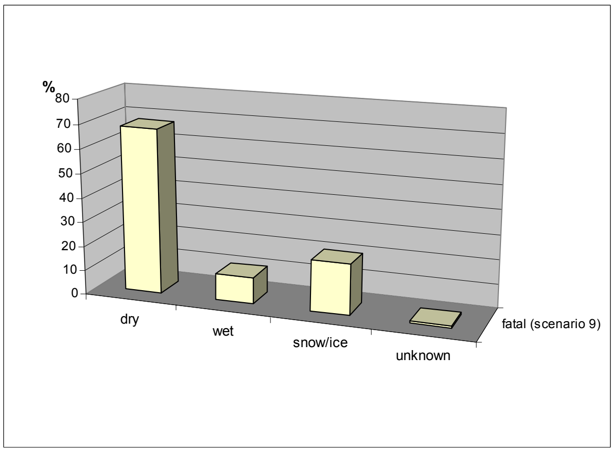

Figure 22: Accident weather distribution

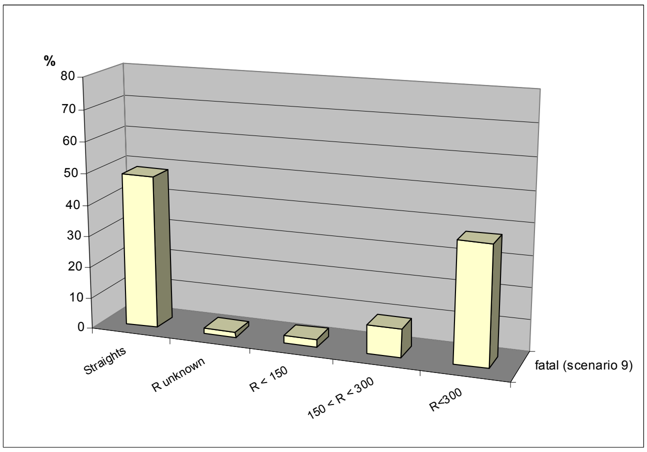

Figure 23: Accident Geometry distribution

When **secondary roads** are considered the most probable situation appears to be:

- a front-side collision (that is more likely than a side-side event on single carriageways where no lane change is allowed) *(avoiding an obstacle manouvre)* involving a truck with another user vehicle on dry surfaces on curves with radii wider than 300m.

Analysis of different types of HGV

The analysis described previously for trucks accidents have been developed also for all the single trucks typologies: single units, tractor-semitrailer and tractor-trailers. Results do not highlight great differences in the fixed variables distributions between trucks and the defined trucks types the so the analysis lead to the same conclusion in term of potential probable accident situations.

It is interesting to analyze how the different truck types are involved in accident occurrence considering different types of roads.

On rural highways single units are the HGV type more frequently involved in 'All' accidents but tractor-semitrailer are more probably involved in crashes considering 'Injuries+fatal' and 'fatal' datasets (Figure 24). This different distribution can be related to the different base of data and especially to Italian database (that is the only one related to the 'All' accident dataset) where the rate of crashes involving single units is considerably higher than in all other countries. Considering that accidents with higher severity are more relevant and related to more different countries, tractor-semitrailer can be considered the most probable type of HGV involved in a severe crash occurred in rural highways.

Also in urban highways (Figure 25) the most frequent type of vehicle involved in accident results to be a tractor-semitrailer (almost 50%).

On primary roads single units are the trucks most frequently involved in 'Injuries+fatal' accidents but tractor-semitrailer are the most likely in fatal ones (Figure 26) . In this distribution it is also possible to notice that the tractor-trailer rate increases considerably from 'Injuries+fatal' dataset to 'Fatal' one, and this is related to the weight of Finnish data in the dataset that are characterized by a high percentage of tractor-trailer accidents. So, in primary roads, tractor-semitrailer can be considered the type of HGV most frequently involved in severe accidents but a deeper analysis based on traffic distribution should be done in order to better investigate the issue.

Finally for secondary roads the distribution of accident with the type of vehicle highlights that single units and tractor-semitrailer are involved in crashes with very similar rate (about 45% as shown in Figure 27).

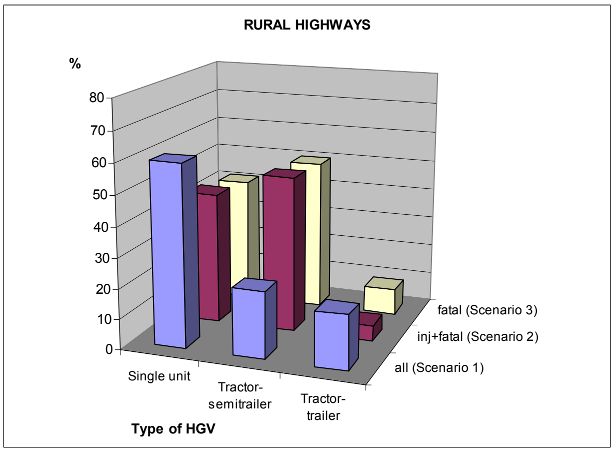

Figure 24: Distribution of accidents involving different type of HGV occurred on rural highways

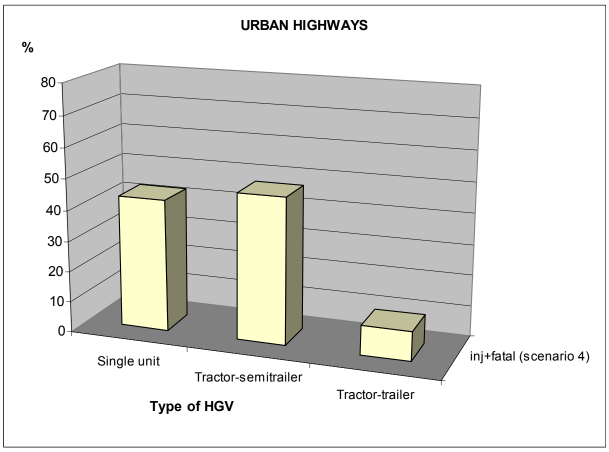

Figure 25: Distribution of accidents involving different type of HGV occurred on urban highways

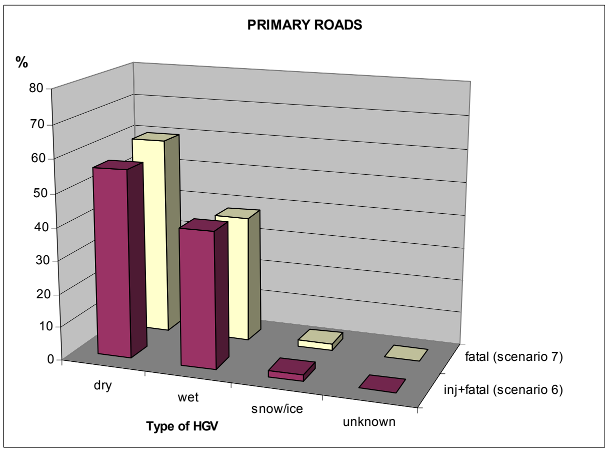

Figure 26: Distribution of accidents involving different type of HGV occurred on primary roads

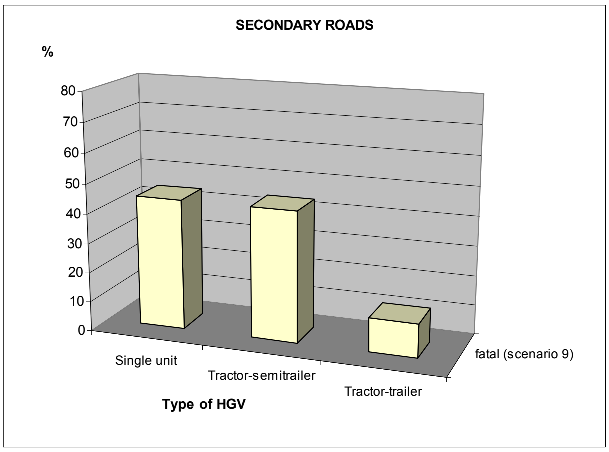

Figure 27: Distribution of accidents involving different type of HGV occurred on secondary roads

Accident risk comparison on different types of roads

The accident rate (A.R. and A.R.(HGV)) calculated for different types of roads and accident severity classes are given in Table 3 and shown separately in Figure 28 (A.R.) and in Figure 29 (A.R.(HGV)). The available data do not allow to consider secondary roads in this analysis since information available in the database are not completely in terms of road lengths and of traffic values for this types of roads.

Table 3: A.R. and A.R.(HGV) calculated for different types of roads and of accident severity classes

	A.R. (accidents per million Vehicles km)	***A.R.(HGV)*** (accidents per million HGVs km)
All accidents:		
Highway Rural	0.251	0.994
Highway Urban	- (**)	- (**)
Primary Roads	- (**)	- (**)
Injuries+fatal accidents:		
Highway Rural	0.495·10-1	0.217
Highway Urban	0.624·10-1	0.427
Primary Roads	0.114	0.715

	A.R. (accidents per million Vehicles km)	A.R.(HGV) (accidents per million HGVs km)
Fatal accidents:		
Highway Rural	0.215·10-2	$0.931 \cdot 10^{-2}$
Highway Urban (*)	0.120·10-2	$0.847 \cdot 10^{-2}$
Primary Roads	0.568·10-2	$0.43512 \cdot 10^{-1}$
(*) Not very significant because referred only to 14 accidents (**) Accidents Data Not Available in the database		

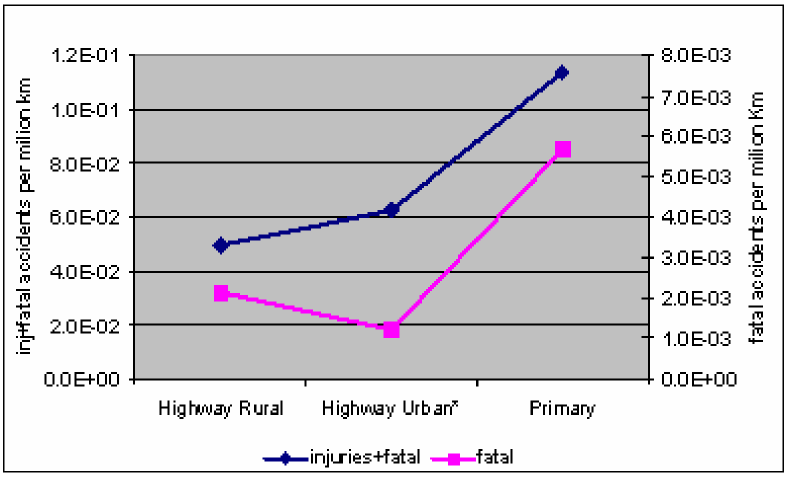

Figure 28: Accident Rate (A.R.) comparison for different type of roads

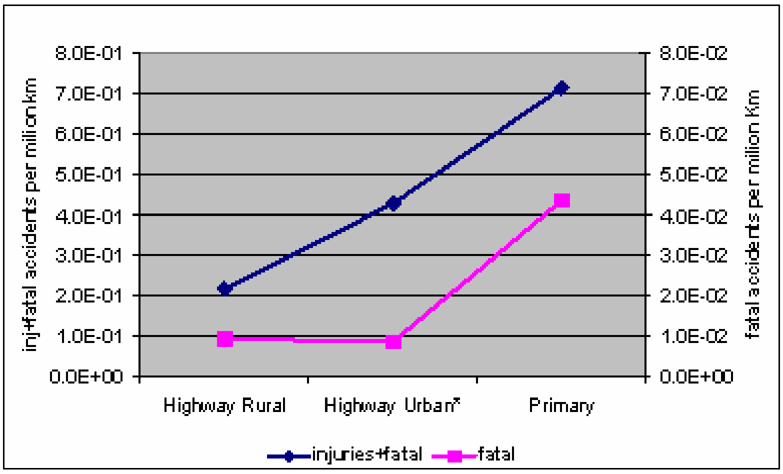

Figure 29: Accident Rate based on HGV (A.R.(HGV))comparison for different type of roads

A comparison between the data in Figure 28 and in Figure 29 highlights that accident rate based on the heavy vehicle traffic distribution (A.R.(HGV)) increase the difference between different types of road and this because HGV traffic distribution is different for different types of roads. A.R.(HGV) indicator seems to be more realistic than simple accident rate (A.R.) in an HGV accident rates comparison for different types of road because gives a direct relation between accidents and roads without being influenced by the traffic composition that instead affects A.R..

Using A.R.(HGV) indicator (Figure 29) this analysis highlights that primary roads if compared with rural highways, have an accident rate more than 3 times greater for 'injuries+fatal' accidents and almost 5 times greater for 'fatal' accidents, while if compared with urban highways have an accident rate about 1.7 times greater for 'Injuries+fatal ' accidents. Moreover urban highways have an 'injuries+fatal' accident rate almost double than rural highways but it should be kept in mind that a very limited 'fatal' accidents dataset was available.

CONCLUSIONS

This study has been conducted to identify the situations which can be addressed as potentially dangerous when HGV are considered. Further detailed studies will then be performed with simulation tools to analyze these specific situations.

The investigation has been made organizing an accidents database, collecting accidents from Italy, France, United Kingdom, and Finland, and then analyzing them all together.
HGV accidents analysis has been focused on trucks and on 3 different trucks subclasses, Single Units, Tractor-Semitrailer and Tractor-Trailer. Different situations characterized by different accident severity and road types, have been analyzed through the percentage rate of defined key variables.

This study highlighted that the truck type more frequently involved in a severe (with injuries or fatal) HGV accident is a tractor semitrailer. Severe accidents usually involve other users together with a HGV (almost 80% of events in any dataset).

For each specific road type, assuming that the most frequent events can be described by the situations where potentially all the key variables identified as more probable occur at the same time (assumption tested on the Italian database), the most probable situations have been identified as follows:

- <u>for rural highways:</u> a front rear accident involving a truck with another user (likely a breaking manouvre) on curves with radii between 500m and 1000m on dry or wet surfaces (the first condition is more frequent but the second is more severe).
- <u>for urban highways</u>: a side-side collision (likely due to a lane change manouvre) involving a truck and another user in sharp curves (with radii lower than 500m) in dry condition but it is anyway recommended to investigate both wet and dry conditions.
- <u>for primary roads:</u> a front-side accident (likely an “avoiding an obstacle” manouvre) involving a truck and another user on wet surfaces. Small radii seem to be more critical but larger ones lead to higher probabilities of fatal events so the two conditions of R<300m and R>500m should both be investigated.
- <u>for secondary roads</u>: a front-side accident (likely an “avoiding an obstacle” manouvre) involving a truck with another user on dry surfaces on curves with radii wider than 300m.

The analysis done is characterized by a consistent number of events for rural highways and primary roads while the significance of the investigation on urban highways and on secondary roads should be verified with deeper investigation since results might be affected by the limited base of data (both for number of accidents and for the number of different countries represented) available in the database.

The comparison between different type of roads in terms of accident rates based on HGV traffic distribution (A.R.(HGV)) have highlighted that primary roads, if compared with rural highways, results 3 times more dangerous for Heavy Vehicles considering ‘injuries+fatal’ accidents and almost 5 times considering ‘fatal’ accidents, while if compared with urban highways the danger is almost double considering ‘injuries+fatal ‘ accidents.

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