External Accident Cost of Heavy Goods Vehicles

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1 Introduction.

In reports on the external cost of road transport, it is often suggested that the accident costs are the dominant cost and that it is highest for heavy goods vehicles (HGVs). It is not always clear if these results are based on some arbitrary allocation of total cost or any other principles. While different principles may exist, we try in this paper to set out a theory of external marginal accident cost; marginal cost in relation to driven kilometre.

Marginal cost of HGVs has previously been dominated by the cost of road wear and tear. This cost increases exponentially with axle weight, the so-called 'forth-power law'. Consequently, road taxes and charges based on marginal cost theory increases generally strongly with axle weight. As the accident cost component becomes more important, the structure of the accident component becomes crucial; does the external accident cost increases with axle weight and reinforce the current structure on taxes or charges or does it decrease with axle weight, i.e. cancelling out the axle dependence of the tax structure. Thanks to two unique databases, one on accidents and one on driven distances, we try to estimate the external marginal accident cost for a number of different weight classes of HGVs.

The paper is structured as follows; Section 2 presents the general theory and Section 3 describes our data sources. The following two sections discuss the key elements in the external cost, the risk and risk elasticity in Section 4, and the relation between internal and external accident cost in Section 5. In section 6 the resulting external marginal accident cost is presented while some conclusions are offered in Section 7.

2 A Theory of External Accident Cost

The number of accidents where HGVs are involved (**A**), is a function of the traffic volume of HGV (**Q**) and other explanatory variables, including the traffic volume of the other categories involved (1). Naturally, **A** should be seen as a vector representing different degree of severity, which also is the case for the cost components; willingness-to-pay of the involved user (**a**), ditto of relatives and friends (**b**) and system external cost (**c**), mainly medical costs paid by the social security system. The marginal cost (**MC**) with respect to the HGV traffic volume (**Q**) follows naturally from the total cost (TC) (2&3). Finally, we derive the external marginal cost as (4) where **PMC** is the private marginal cost already internalised by the HGV user.

$$\mathrm{A} = \mathrm{f}(Q, \ldots\ldots) \tag{1}$$

$$\mathrm{M}C = \frac{\partial \mathrm{A}}{\partial \mathrm{Q}}\,(a+b+c) \tag{2}$$

$$\mathrm{T}C\; = A\left(a+b+c\right) \tag{3}$$

$$\mathrm{M}C^{e} = \mathrm{M}C - PMC \tag{4}$$

This expression of the external cost is equivalent to the well-known congestion externality. However, in congested traffic, all users suffer equally from the congestion, and the private marginal cost equals the average user cost. Not all users suffer from the accident; only the victim in the absence of a liability system. The PMC will therefore not be the same when the HGV user is a victim or when he is an injurer.

We introduce **r** as the accident risk for HGVs (5) and **θ** as the share of total accident costs that fall on HGV users. A victim is assumed to internalise the expected cost related to his value of statistical life expressed by both him and relatives and friends (**a**+**b**) (6). An injurer will not internalise any costs and, consequently, the PMC is zero.

$$\mathrm{r} = \frac{\mathrm{A}}{\mathrm{Q}} \tag{5}$$

$$\mathrm{PM}C_{v} = r\theta\left(a+b\right) \tag{6}$$

The risk, **r** may be affected by an increase in the volume of traffic of HGV. This effect is conveniently written as a risk-elasticity (**E**) (7).

$$\mathrm{E} = \frac{\partial \mathrm{r}}{\partial \mathrm{Q}}\frac{Q}{r} \tag{7}$$

The marginal external cost for HGV users, as an injurer respectively victim follows from (8) and (9) below. The aggregate marginal external cost for the HGV user, both in his capacity as an injurer and as a victim, can be written as (10)[1].

$$\mathrm{M}C_{i}^{e} = r(1-\theta)(1+E)\left(a+b+c\right) \tag{8}$$

[1] An alternative presentation is to start with the average cost of HGV users (i) and the total cost of other categories (ii). The MC can be written as three components, which can be developed to the same expression as above.

$$\mathrm{A}C_{HGV} = r\left(a+b+c\right)\theta \quad \text{(i);} \quad \mathrm{T}C_{k} = A\left(a+b+c\right)\left(1-\theta\right) \quad \text{(ii);}$$

$$\mathrm{MC}^{\mathrm{e}}_{\mathrm{HGV}} = Q\frac{\partial AC_{HGV}}{dQ} + \frac{\partial TC_{k}}{\partial Q} + \theta rc \;= \theta Q\frac{\partial r}{dQ}(a+b+c) + (1-\theta)\frac{\partial A}{\partial Q}(a+c) + \theta rc$$

$$= \theta rE(a+b+c) + (1-\theta)r(1+E)(a+b+c) + \theta rc = r(a+b)\left(1-\theta+E\right) + rc(1+E)\,.$$

$$\mathrm{MC}_v^e = r\theta\,(1+E)\big(a+b+c\big) - r\theta\,(a+b) \tag{9}$$

$$\mathrm{MC}_{i+v}^e = r(1-\theta\;+E)\big(a+b\big) + rc(1+E) \tag{10}$$

The marginal external cost expression (10) is a function of two average costs. First, the average cost of the **a-** and **b**-components {**r(a+b)**} times the probability to hurt another road user in the accident (**1-θ**) and the risk-elasticity (**E**). Secondly, the average cost of the system external component {**rc**} times a risk-elasticity component (**1+E**).

3 Data sources

We have two basic data sources, information on almost 90 000 individual accidents during 1999 from the Swedish National Road Administration (Vägverket) and information on the distance driven during 1999 for 78 000 HGVs above 3.5 tonne from the Swedish Vehicle Inspection Authority (Bilprovningen). The accident database includes almost 70 variables per accident. While this is impressive, it has previously been difficult to use all this information in econometric analysis, as the value on these variables are seldom known when an accident 'did not happen'. The data from *Bilprovningen* gives information on exposure for all individual HGVs and individual vehicle characteristics, such as weight, number of axles, production year etc[2]. However, the information does not give us the possibility to identify road type or geographical area where the HGV has been driving when no accident occurred.

3.1 Accident data.

The accident database is organized as five separate databases linked together with a unique accident number. The *first* database describes the accident with 54 parameters, including information on number of injuries, type of road, speed limit, traffic volume, and time. The *second* database describes the involved vehicles and trailers, which includes detailed information on weight and dimensions due to a link to the Vehicle Registration Authority. The *third* group describes the involved persons; with detailed information on the driver due to a link with the driver licence register. A *forth* group describes the locality of the accident, while the *fifth* group of databases describes unprotected road users and type of game in game accidents.

[2] A further development could be to link this database to the Swedish Vehicle registry, which include more vehicle characteristics.

Table 1: Main accident databases

1	2	3	4	5
Accident information	Vehicle information	Driver and passenger information	Location	Other information
Accident.dat	Motor vehicle.dat	Drivers.dat	Y-ola.dat	Pedestrian.dat
	Trailers.dat	Passenger.dat	Z-ola.dat	Bicyclists.dat
	Other vehicles.dat		Vben-dat	Game.dat

The original accident database consists of all *police reported* accidents in Sweden during the year 1999. This includes information on 580 fatalities, 4 050 severe injuries and 17 935 slight injuries. The motor vehicle database consist of 87 705 vehicles involved in the accidents and the driver database of 85 600 drivers involved.

The characteristics of the involved vehicles have, for this analysis, been limited to *goods vehicles* with a *total weight above 3 500 kg*. With the unique accident number, we have linked the motor vehicle database with the other databases. The complete HGV database consists of 3 940 accidents including 83 fatalities, 254 severe injuries, and 1 035 slight injuries. This is 5.8% of all the (reported) accidents in Sweden during 1999. In general, HGV accidents seems to be more severe than the average road accident (14% of the fatalities) even if they include less passengers and unprotected users (bicyclist, moped users (1.2%) or pedestrians (2.6%)).

Table 2: Accident Databases

	Original Database	HGV database	Proportion in HGV base
Accidents	68 035	3 940	0.058
Fatalities	580	83	0.143
Severe injuries	4 050	254	0.063
Slight injuries	17 935	1 035	0.058
Involved Drivers	85 600	6 190	0.072
Involved Passengers	6 138	284	0.046
Involved Vehicles	87 705[A)]	*8 858*[B)]	*0.081*
Involved Trailers	2 122	538	0.254
Involved Cycle/Moped users	4 458	54	0.012
Involved Pedestrians	1 902	50	0.026
Game	33 539	1095	0.033
Other	2 635	0	0.000

A) Including 8 152 observations where weights are not recorded.
B) Estimated as total number of involved elements less trailers, cycle-, moped users, pedestrians and game.

The key variables for the accidents and involved HGVs are summarised below (See Table 19 in the Annex). The average HGV accident includes 0.021 fatalities (FATALITY), 0.064 severe injuries (SEVERE) and 0.26 slight injuries (SLIGHT). The average number of involved elements (ANTEL) was almost 2, suggesting a large proportion of collision accidents. The traffic volume was at average 6 986 vehicles (QVEH) of which 718 HGVs (QHGV). Approximately 70% of the accidents occurred in non-urban areas (URBAN). The road was 9.3 metres wide (RWIDTH) with a speed limit of 75 km/h (SPEED).

The average involved HGV was produced in 1992 (YEAR), had a width of 2.53 metre (WIDTH), a length of 8.9 metres (LENGTH) and a total weight of 22.9 tonne (VEHWEIGHT). It had 2.7 axles (AXLE) and an engine of 260 kW (KW). The total vehicle combination included in average 0.18 trailers (TRAILER), the length was for the combination 9.87meter (EKILEN), weight 27.4 tonne (EKIWEI) and had 3.1 axles (EKIAXLE). In 98% of the cases were the HGV insured (INSUR) and all of them where Swedish (NAT).

3.2 Driven distances by Swedish HGVs.

We are looking at the marginal cost in relation to driven kilometre; the relevant measure of exposure is the number of driven kilometre during the period of accident observation. Three possible sources of driven kilometre exists today in Sweden; i) aggregate estimates based on fuel consumption and road counts; ii) detailed road counts on a sample of roads and iii) information from each vehicles road distance meter from the annual inspection.

While it is possible from the first source to find estimates on driven distances by a vehicle subgroup, such as HGV, it is impossible to have a more detailed disaggregating. Nevertheless, this is the most common measure of exposure in risk estimate (e.g. Vägverket(2000)). The second source, the road counts, give us detailed information about driven distance in time and space but does only include a rough disaggregating on vehicle type; '*HGV*' and '*HGV with trailer*' is the common Swedish classification. This source has been used by Winslott (1998). The most promising source for our purpose is the information from the annual inspections, which, since 1999 take place annually for HGVs.

We have asked the Swedish Vehicle Inspection Authority (Bilprovningen) to produce information on the annual inspections for HGVs during 1999 and year 2000. The database consists of information on each HGVs registration number, date for the inspection 1999 and 2000 (Y99,Y00), the measure of the road distance meter in kilometre at each inspection (VMST99, VMST00), the production year of the vehicle (YEAR), the total weight (VEHWEIGHT), number of axles (AXLE), body type (KARKOS) and inspection outcome (UKOD). In addition, Bilprovningen has estimated the average annual distance driven for each vehicle during its lifetime (DISTAV).

We have calculated the annual driven distance during 1999 (DIST99) as the difference between the measure of the road distance meter year 2000 and year 1999 (VMST00-VMST99) adjusted if the number of days between the inspections is different from 365 days (11).

(11) DIST99 = [VMST00-VMST99]*[365/(Y00-Y99)]

The database consists of 76 738 HGVs above 3 500 kg. At the end of the year 1999 75 910 HGVs above 3500 kg were registered[3], which is less than the number of vehicles in our database. This could be because vehicles can be unregistered during a shorter period but cannot avoid an annual inspection.

From Table 3 it follows that the oldest HGV in the dataset is 1951 and the newest HGV is from year 2000. The weight is from 3510 kg up to 159460 kg. This latter huge weight is recorded for only 7 special vehicles. Excluding these, the maximum weight is limited to 60.960 kg. The number of axles is between 2 and 7. The average annual distance during the lifetime of a vehicle is 56 782 km while the driven distance during 1999 at average is 49 239. The average number of days between the annual inspections are 377.

For 99.5% of them we have information on the road distance meter at the inspection year 2000 but for only 52 408 HGVs (68%) have we information for the year 1999. We have calculated a positive driven distance during 1999 for 49 879 vehicles. For 2 091 HGVs we have found negative driven distance, which could depend on manipulated road distance meter or an mistake at the inspection.

[3] Source:SCB TK27 SM0001. Tab 6

Table 3: Database from Swedish inspections of HGVs 1999 and 2000

Variable	Mean	Std.Dev.	Minimum	Maximum	Cases
Y00	36709.4339	106.802677	36527.0000	36890.0000	76738
VMST00	339323.464	248282.746	.000000000	999999.000	76429
Y99	36333.1810	87.1080700	36192.0000	36490.0000	52408
VMST99	331436.255	243206.766	1.00000000	999995.000	52288
YEAR	1989.18485	7.80778548	1951.00000	2000.00000	76720
WEIGHT	18497.9233	8461.17306	3510.00000	159460.000	76738
KARKOD	35.9128333	26.3014236	.000000000	100.000000	76738
AXLE	2.44878297	.543156474	2.00000000	7.00000000	76703
UKOD	2.03243504	2.18280580	.000000000	8.00000000	76738
DISTAV	56782.0341	65670.8965	1000.00000	499480.000	61082
DISTY	377.102084	53.9002877	55.0000000	697.000000	52408
DIST99	49239.7879	62201.9090	1.00000000	1088609.00	49879

All results based on nonmissing observations

3.2.1 Distance by Weight class

The database is restricted to observations where we have calculated a strictly positive distance during year 1999. The HGVs are grouped into 11 weight classes, which basically follow the classes where information on registered vehicles exists.

Table 4: Information by Weight Class

Weight Class	Min. Weight (kg)	Max. Weight (kg)	Registred Vehicles[A)]	Total number of Observations	Observation with DIST99	Mean DIST 99 (km)	Total DIST 99 Mkm [B)]
1	3 510	6 000	8 422	8 900	6 029	17 974	160
2	6 010	10 000	8 531	8 264	5 747	23 787	197
3	10 010	12 000	4 652	4 790	3 064	26 527	127
4	12 010	14 000	..	3 356	2 332	25 907	87
5	14 010	16 000	..	3 066	2 054	20 170	62
6	16 010	18 000	..	6 873	4 673	30 761	211
7	18 010	20 000	..	5 947	3 666	67 425	401
4-7			*18 731*	*19 242*	*12 725*	*39 651*	*761*
8	20 010	22 000	3 489	3 475	2 134	52 899	184
9	22 010	24 000	1 750	1 816	1 201	36 305	66
10	24 010	26 000	15 349	15 204	10 304	69 324	1 054
11	26 010	-	14 986	15 047	8 675	88 313	1 329
Total			**75 910**	**76 738**	**49 879**		**3 877**

A) Source:SCB TK27 SM0001. Tab 6
B) Based on mean DIST99 times total number of observation in weight class.

The differences between registered vehicles by weight class at the end of 1999 and number of vehicles by weight class in our database mirrors the overall pattern discussed above; our database consists of more vehicles than what was registered at the end of 1999. The mean distance during 1999 is higher for the heavier weight classes than for the lighter, although this is not true for every single weight class. It also turns out that the distance driven 1999 is below the average distances driven during the lifetime of each vehicle (Figure 1). This result is surprising as the average transportation distance is reported to have been higher in 1999 than in all other years during the 90's except for 1997[4]. The relative short distances for the weight class 5,6 and 9 can probably be explained by the higher average age in these groups (see Figure 2).

Figure 1: Average distance 1999 and average annual distance during the vehicle lifetime by weight class

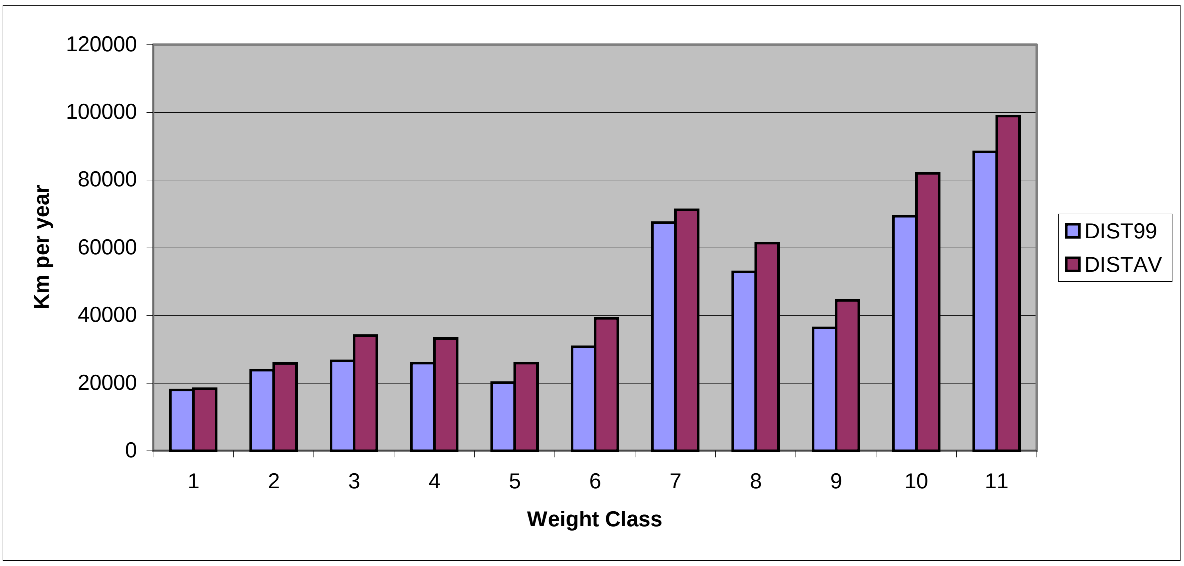
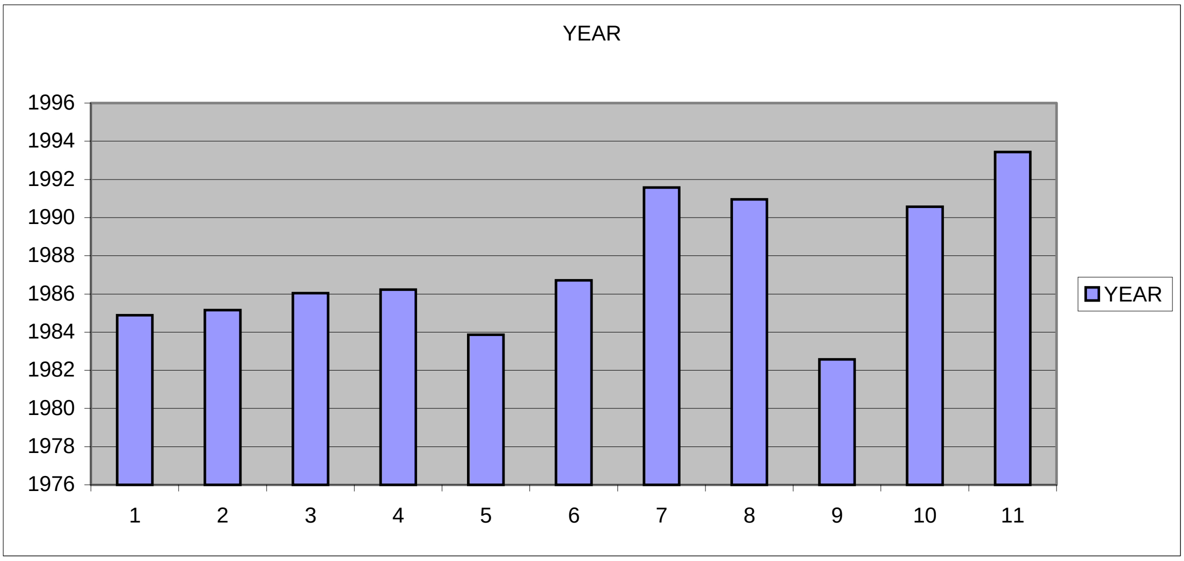


Figure 2: Average production year by weight class



The total driven kilometre during 1999 for the 49 879 HGVs where DIST99 is strictly positive is 2 465 Mkm. Scaled to the total population´, Swedish HGVs were driving 3 792 Mkm during 1999. This is lower than what is reported in other aggregated sources. The total

[4] SIKA Transporter och Kommunikationer, Årsbok 2000/2001, Tab 4.21

distances by all vehicles in each weight class is presented in the last column of Table 4; compared to information from Vägverket this data suggest much longer distances for the heaviest categories and shorter for the lightest[5].

Table 5: Comparison with other sources

Source	Annual distance HGV	Source
Our database	3 792 Mkm	
SIKA		
SNRA	4 260 Mfkm	Vägverket (2000)

4 Accident Risk and Risk Elasticity

The characteristics of HGV accidents are different from passenger car accidents mainly because of the special attributes of HGVs;

1. they are much heavier and larger in dimensions than passenger cars;
2. they have less effective acceleration than passenger cars and have problems to maintain their speed on upgrade, and;
3. they have lower deceleration in response to breaking than have passenger cars.

The result is that HGV accidents often are more serious than other road accidents, especially for the non-HGV road users. The reason *why* HGV accidents should differ from passenger car accidents also means that we should expect a difference in accident rates for different weight classes of HGVs.

However, a survey of the litterature did not result in any conclusive evidence on the relationship between truck configuration and accident risk (see e.g. Braver et.al. (1997) or Nilsson (1996)).

As the number of trucks increases with a *given flow of other vehicles,* we may expect different reactions on the accident probability with different vehicle elements. Jovanis and Chang (1986) reports an effect on overall accidents from truck traffic in a study of the Indiana Toll Road. The total number of accidents increases at a decreasing rate as the truck traffic increases. The overall *accident elasticity*[6] for trucks is around 0.2. Later studies (Joshua and

[5] Vägverket (2000) reports 1 400 Mvkm for HGVs between 3 500 and 16 000 kg and 2 860 Mvkm for HGVs above 16 000 kg while this dataset suggest 632 Mvkm for the lightest and 3 245 for the heaviest.

[6] Accident elasticity = dA/dQ Q/A = E+1

Garber (1990), Miaou (1994)) on more general data have supported the conclusion that truck traffic has an influence on the *total number of accidents*.

4.1 Accident Risk by Weight Class

Based on the number of accidents involving HGVs in Sweden during 1999 and the distance database we can calculate an accident risk by weight class.

The average accident risk per registered HGV is 52 police reported accidents per 1000 registered HGVs. This risk is (almost) strictly increasing with weight class. The lightest class has a risk of only 30% of the average risk while the heaviest class has a risk 75% above the average. However, the accident risk per vehicle kilometre does not show the same clear pattern. The average risk is 1.02 police reported accidents per million-vehicle kilometre and the risk for the lightest group is 75% of the average while the risk for the heaviest group is almost the same as the average. The highest risk can be found in WC 4 with a risk 23% above average.

Table 6: Accident risk

WeightClass	Accidents	Accidents per registred vehicle Acc/1000Veh	Accidents per km Acc/Mvkm
1	123.00	14.6	0.77
2	142.00	16.6	0.72
3	136.00	29.2	1.07
4	109.00	..	1.25
5	55.00	..	0.89
6	240.00	..	1.14
7	308.00	..	0.77
4-7	712.00	38.0	0.94
8	194.00	55.6	1.06
9	88.00	50.3	1.33
10	1180.00	76.9	1.12
11	1365.00	91.1	1.03
All HGVs	3940.00	51.9	1.02

This smoothening of the differences in risk when we move from a measure of accidents per vehicle to accident per vehicle kilometre is, probably, due to the difference in the type of exposure. While we do not have information on where the vehicles are driving the information on where the actual accidents occur give some hint on the differences. The accidents involving the heaviest weight class occur in 73% of the cases in non-urban areas while for the lightest class 50% occur in non-urban areas.

Table 7: Characteristics of the environment where accidents occurred, by weight class

Weight Class	Non-urban	Road width	Speed limit	Qveh
1	0.50	8.5	68.9	4 377
2	0.52	9.4	68.4	6 870
3	0.41	9.3	68.0	7 474
4	0.50	9.4	67.3	6 620
5	0.56	8.9	71.2	5 582
6	0.53	9.7	70.1	9 034
7	0.63	9.6	74.9	8 055
8	0.57	9.4	71.9	7 620
9	0.77	9.7	70.2	7 191
10	0.71	9.7	76.8	7 771
11	0.73	9.1	78.2	6 023
All HGVs	0.66	9.3	75.2	6 986

4.2 A HGV accident model

Accidents are a consequence of a number of unlucky coincidences. Most of the vehicles do not get involved in an accident during one year and very few have more than one accident[7]. This structure suggests that we may employ a discrete choice model to explain the accident differences.

The probability (P) that an accident will happen can be written as P=A/Y where A is the number of accidents and Y is the number of registered HGVs. With a logit model this probability can be expressed as (12), were x is the independent variables and β the parameters that will be estimated, $\Lambda(\beta' x)$ indicates the logistic cumulative distribution function.

(12) $$P(A=1) = e^{\beta' x} / 1+ e^{\beta' x} = \Lambda(\beta' x)$$

The risk elasticity can be derived from this model. The marginal effect on the probability can be written as (13) (See Greene (1990)). Let the risk (r) be defined as the number of accidents per kilometre driven (Q) (14). The risk elasticity (E) in relation to the independent variable Q can then be expressed as the marginal effect on the probability with respect to distance (dP/dQ) multiplied by the ratio between distance and probability (Q/P) minus one (15).

(13) $$dP / dx = \Lambda(\beta' x)(1- \Lambda(\beta' x))\beta$$

(14) $$r = A/Q = Y\,P / Q$$

[7] One HGV had two accidents in 1999.

(15) E = dr/dQ Q/r = dP/dQ Q/P - 1

The accident database is linked to the distance database thanks to information on individual registration number (which is subsequently deleted due to privacy reasons). This gives us a database with information; if the HGV was involved in an accident or not (ACC=1/0); the production YEAR of the vehicle and consequently the AGE; the total WEIGHT and the number of AXLES as well as the weight per axle, TPA (= WEIGHT/AXLE). In addition we have information on the distance driven during 1999 (DIST99), a dummy variable which take the value 1 if the vehicle had a *remark* in the last inspection and dummies describing the body of the HGV (see Table 8).

Table 8: Bodytype

Dummy name	Type of Body	Number of HGVs
HGV1	Platform body	14132
HGV2	Delivery body	18531
HGV3	Tank lorry	1618
HGV4	Roll platform	3911
HGV5	Other	11690

Unfortunately, we could not find driven distance (DIST99) for all HGV involved in accidents[8]. The database with individual distances and accidents consists of 49 878 observation and 2047 accidents. The average accident probability is thus 0.041.

Table 9: Descriptive Statistics

All results based on nonmissing observations.

Variable	Mean	Std.Dev.	Minimum	Maximum	Cases
ACC	.412406271E-01	.198848260	.000000000	1.00000000	49878
YEAR	1988.53767	7.37989654	1951.00000	1999.00000	49878
AGE	11.4623281	7.37989654	1.00000000	49.0000000	49878
WEIGHT	18174.0723	8364.84104	3510.00000	55420.0000	49878
AXLE	2.43391156	.538961237	1.00000000	5.00000000	49865
TPA	7205.74104	2495.06572	1200.00000	13333.3333	49865
DIST99	49314.3559	63772.5197	.744897959	2707833.02	49878
INSPOK	.632202574	.482210681	.000000000	1.00000000	49878
HGV1	.283311280	.450610774	.000000000	1.00000000	49878
HGV2	.371506476	.483212268	.000000000	1.00000000	49878
HGV3	.324391515E-01	.177165127	.000000000	1.00000000	49878
HGV4	.784113236E-01	.268820455	.000000000	1.00000000	49878
HGV5	.234311721	.423572113	.000000000	1.00000000	49878

The binary choice model is estimated with the LIMDEP 7.0 software. In this version of the paper we presents only one model, see Table 10.

[8] The characteristics of the vehicles involved in the omitted 700 accidents are similar to the characteristics of the vehicles in the whole database (see Table 21).

Table 10 Estimated Coefficients and Marginal Effects

Multinomial Logit Model	
Maximum Likelihood Estimates	
Dependent variable	ACC
Weighting variable	ONE
Number of observations	49865
Iterations completed	8
Log likelihood function	-7889.953
Restricted log likelihood	-8571.839
Chi-squared	1363.772
Degrees of freedom	5
Significance level	.0000000

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Characteristics in numerator of Prob[Y = 1]				
Constant	-4.197490613	.13540819	-30.999	.0000	
AGE	-.7484687020E-01	.48955427E-02	-15.289	.0000	11.460303
WEIGHT	.3683438678E-04	.50903408E-05	7.236	.0000	18177.110
TPA	.6929778944E-04	.20120438E-04	3.444	.0006	7205.7410
DIST99	.3430510903E-05	.26299470E-06	13.044	.0000	49324.923
INSPOK	.3053785653	.50027574E-01	6.104	.0000	.63230723

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Marginal effects on Prob[Y = 1]				
Constant	-.1167535257	.41208391E-02	-28.332	.0000	
AGE	-.2081871477E-02	.12504915E-03	-16.648	.0000	11.460303
WEIGHT	.1024551314E-05	.14184063E-06	7.223	.0000	18177.110
TPA	.1927523367E-05	.55293212E-06	3.486	.0005	7205.7410
DIST99	.9541992582E-07	.76513972E-08	12.471	.0000	49324.923
INSPOK	.8494128386E-02	.13785474E-02	6.162	.0000	.63230723

The estimated marginal effect and calculated elasticity suggests that the number of accidents increases with the number of driven kilometre by HGV. However, the number of accidents does not increase in proportion to the increase in distance; as the distance increases with 10% the number of accidents will increase with 2%. This means that the accident risk, i.e. number of accidents per kilometre, will decrease; as the distance increases with 10% the risk will decrease with 8%; the risk elasticity is –0.84. This is in line with the elasticity reported by Jovanis and Chang (1986) (E=-0.8).

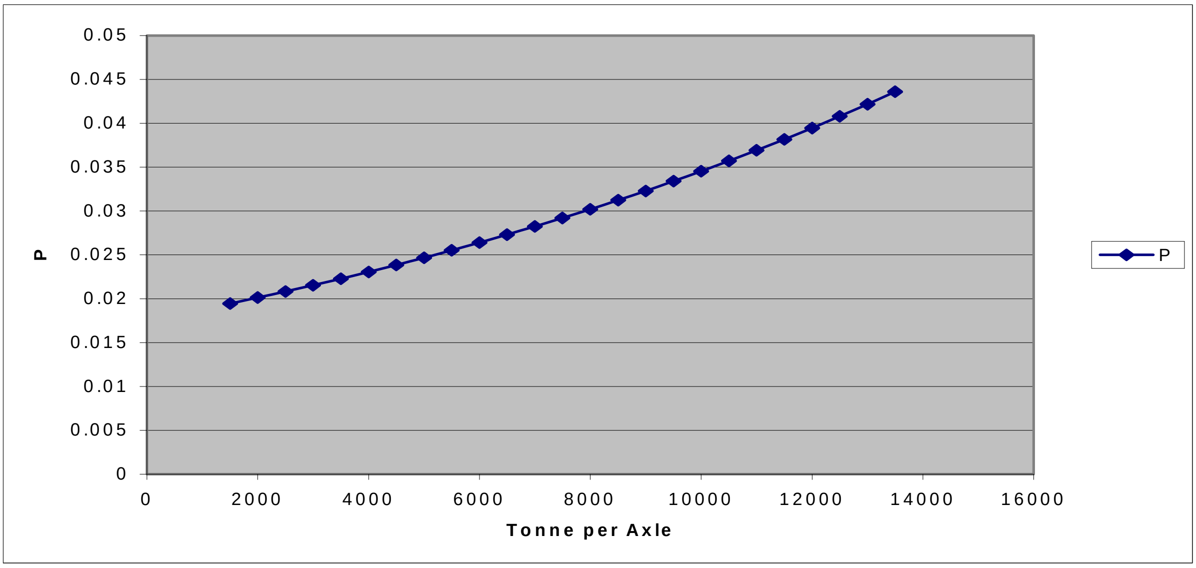
In the table below, the model is employed for each weight class, with the mean value of the variables in each weight class. The predicted probability is between 69% and 112% of the observed probability in each weight class.

Table 11: Predicted probability (P) based on mean values in each weight class compared to observed probability.

WC	CASES	DIST99	AGE	TPA	WEIGHT	INSPOK	P	ACC mean	P/ACC mean
1	6028	17807.2	15.1	2330.2	4674.9	0.59	0.009	0.010	89%
2	5747	23787.0	14.8	4143.7	8287.7	0.63	0.012	0.013	89%
3	3064	26527.3	14.0	5631.5	11278.6	0.59	0.015	0.024	64%
4	2332	25906.8	13.8	6793.0	13611.9	0.61	0.018	0.029	64%
5	2054	20169.9	16.1	7579.6	15211.2	0.49	0.016	0.015	112%
6	4673	30761.2	13.3	8593.2	17217.3	0.62	0.025	0.031	81%
7	3666	67425.0	8.4	9467.0	19025.0	0.57	0.045	0.043	104%
8	2133	52923.4	9.0	10068.0	20667.3	0.59	0.045	0.049	92%
9	1200	36334.9	17.4	7787.4	23381.7	0.77	0.023	0.032	73%
10	10305	69509.6	9.4	8545.9	25639.5	0.71	0.052	0.059	88%
11	8676	88614.7	6.6	9116.6	28420.2	0.66	0.075	0.081	93%
MEAN	49878	49314.4	11.5	7205.7	18174.1	0.63	0.029	0.041	69%

As follows from the model, the accident probability increases with axle weight. In the figure below the mean values of variables has been employed. Although the probability increases with increased axle weight the risk elasticity (E) is almost constant; the elasticity is between –0.83 and –0.84.

Figure 3: Accident probability and axle weight (kg)



5 Internal and external Accident Costs

The theoretical foundation, expressed as equation 6c above, suggests that the distribution of the total accident cost between the HGV and other road users is of crucial importance. From the drivers and passenger databases, we can allocate every personal injury to each participating element in the accident. Table 12 below summarise the result. Only 23% of the killed and injured persons in HGV accidents were HGV drivers or passengers. The majority of the victims were drivers of other vehicles (57%) or passengers in other vehicles (18%). Only 3% were unprotected road users during 1999. For fatalities, the inequality between the HGV and other vehicles are even more striking; only 6% of the killed persons in HGV accidents belonged to the HGV.

Table 12: Killed and injured persons by accident element

	HGV			Other motor vehicle			Unprotected	All	TOTAL
	Driver	Passenger	All	Driver	Passenger	All	users	Non-HGV	
Fatal	5	0	5	61	16	77	2	79	84
Severe	36	5	41	166	47	213	0	213	254
Slight	234	31	265	549	185	734	36	770	1035
Other	3369	8	3377	1770	21	1791		1791	1791

To express the outcome of the accident in one dimension we have applied unit accident cost to fatalities, severe and slight injuries. We have not corrected for underreporting and not included the b-component here. Table 13 summarise the cost we have used, which are based on Swedish official values. See further Lindberg (2000) for the division of the official value on a c-component, external to road users, and a- component, the road users own willingness-to-pay.

Table 13: Unit values (kEuro)

Cost component	Fatality	Severe	Slight	Other
A	1478	238	14	
C	114	48	3	
SUM	1592	286	17	0.00

In total 9% of the accident cost falls on the HGV user, 77% on other motor vehicle users and 2% on unprotected users; 11% is so called system external costs and falls on the society in general, it consists mainly of the hospital and medical costs payed by the general social security system. The total cost of personal injuries from police reported accidents where HGV where involved was 224 Meuro in 1999.

Table 14: Total accident costs of police reported accidents in Sweden 1999 (MEuro)

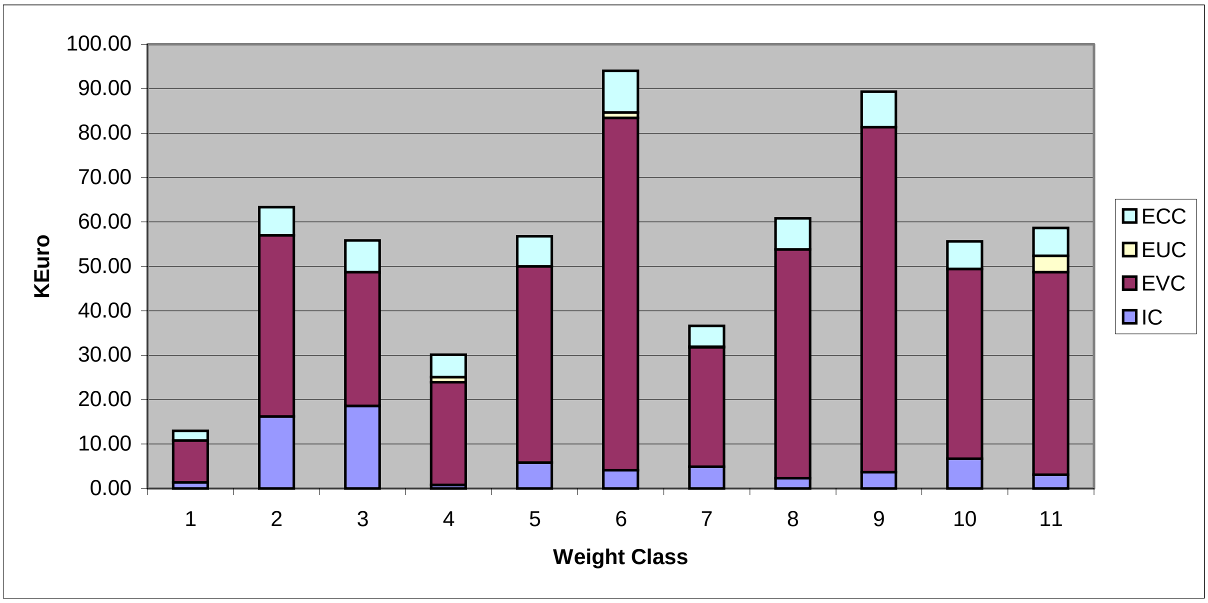
	Cost	Percentage
Intern	20.9	9%
Ext-veh	172.8	77%
Ext-unpr.	5.5	2%
Extern-c	24.6	11%
Extern	202.9	91%
Total	223.7	100%

The average cost of a HGV accident was 57 000 Euro with 13 000 Euro for weight class 1 and 94 000 for weight class 6. The proportion internal cost has been calculated in relation to the total cost excluding the system external cost (θ=IC/(TC-ECC)). The proportion of internal cost is between 0.03 and 0.62 for different weight classes. However, the proportion of internal cost does not show any clear relationship with weight class. Even if it could be expected that heavier vehicles protect the HGV user better, this is not mirrored in the result.

Table 15: Internal and External Cost per HGV accident in Sweden 1999 by weight class (kEuro/Accident)

Weight Class	Internal Cost IC (kEuro)	External Cost - other vehicles EVC (kEuro)	External Cost – Unprot. user EUC (kEuro)	System External cost ECC (kEuro)	Total External Cost TEC (kEuro)	Total Cost TC (kEuro)	PROP (•)
1	1.36	9.45	0.00	2.18	11.63	12.99	0.14
2	16.23	40.79	0.00	6.30	47.09	63.32	0.40
3	18.59	30.12	0.00	7.10	37.22	55.81	0.62
4	0.77	23.12	1.15	5.04	29.32	30.08	0.03
5	5.85	44.18	0.00	6.74	50.92	56.77	0.13
6	4.14	79.26	1.22	9.39	89.87	94.01	0.05
7	4.91	26.89	0.14	4.64	31.67	36.58	0.18
8	2.31	51.48	0.00	7.04	58.51	60.82	0.04
9	3.66	77.68	0.00	8.03	85.71	89.37	0.05
10	6.71	42.70	0.01	6.21	48.93	55.64	0.16
11	3.12	45.62	3.65	6.24	55.50	58.62	0.06
TOT	5.29	43.85	1.38	6.26	51.49	56.79	0.12

Figure 4: Internal Cost (IC), External cost of other vehicle users (EVC, unprotected users (EUC and System external cost (ECC) for an average accident by weight class, 1999 in Sweden.



We have grouped the data into 8 axle weight classes starting at 1.5 tonne with steps of 1.5 tonne. Table 16 below summarise the internal and external cost for these classes. The proportion internal cost decreases with axle weight, although this is not true for the lightest axle weight class. It is also indications that the cost per accident increases with axle weight.

Table 16: Internal and External Cost per HGV accident in Sweden 1999 by axle weight class (kEuro/Accident)

Axle weight class	TpA Mean (kg/axle)	Cases	Internal Cost IC (kEuro)	External Cost - other vehicles EVC (kEuro)	External Cost - Unprot. user EUC (kEuro)	System External cost ECC (kEuro)	Total External Cost TEC (kEuro)	Total Cost TC (kEuro)	PROP (•)
1	2305.37	123	1.36	9.45	0.00	2.18	11.63	12.99	0.13
2	3959.80	102	22.32	34.88	0.00	6.11	40.99	63.31	0.39
3	5514.80	182	14.12	35.32	0.23	6.97	42.52	56.64	0.28
4	7029.06	155	2.62	33.74	0.81	6.30	40.85	43.47	0.07
5	8621.70	2181	5.06	46.66	0.39	6.45	53.50	58.56	0.10
6	9602.77	1162	3.77	44.87	3.82	6.13	54.82	58.59	0.07
7	11225.21	20	0.70	122.23	0.00	15.52	137.76	138.45	0.01
8	12617.86	14	0.00	1.00	0.00	0.20	1.20	1.20	0.00

6 External Marginal Cost

The theory in section 2 gives a clear expression on the external marginal accident cost. The cost is based on four key elements; *first* the accident risk (**r**), *secondly* the proportion of internal accident cost (**θ**), *thirdly*, the risk elasticity (**E**) and *fourthly*, the cost per accident (**a, b** and **c**). In section 4 and 5 these variables have been discussed and many of them presented by weight class. In Table 17 below the result are summarised.

The cost per accident is presented in two parts, the a-component, i.e. users willingness-to-pay, and the c-component, the system external cost. The first component is a sum of the HGV users internal cost (IC) and External cost of other vehicles (EVC) and unprotected users (EUC) as presented in Table 15. The second component is presented as System external cost (ECC) in the same table. To include the willingness-to-pay of relatives and friends, the b-component, the presented a-component should be increased with 40%. An estimate with the b-component is presented in Figure 4 below.

The risk elasticity has been set to –0.8 for all of the weight classes. All presented external marginal costs are based on mean values per weight class for the year 1999.

Table 17: External Marginal Cost by Weight Class

WC	Accident risk	Cost per accident (a-component)	Proportion internal cost	Risk elastcicty	Cost per accident (c-component)	External Marginal Accident Cost
	r	A	•	**E**	C	**MC**
	(Acc/Mvkm)	(kEuro/Acc)	(IC/(TC-ECC))		(kEuro/Acc)	**Euro/1000vkm**
1	0.77	10.81	0.14	-0.8	2.18	0.4
2	0.72	57.02	0.40	=	6.30	-9.1
3	1.07	48.71	0.62	=	7.10	-22.6
4	1.25	25.04	0.03	=	5.04	5.0
5	0.89	50.03	0.13	=	6.74	2.2
6	1.14	84.62	0.05	=	9.39	12.1
7	0.77	31.94	0.18	=	4.64	0.0
8	1.06	53.79	0.04	=	7.04	7.7
9	1.33	81.34	0.05	=	8.03	14.0
10	1.12	49.42	0.16	=	6.21	1.3
11	1.03	52.38	0.06	=	6.24	6.2
Tot	**1.02**	50.53	0.12	=	**6.26**	3.2

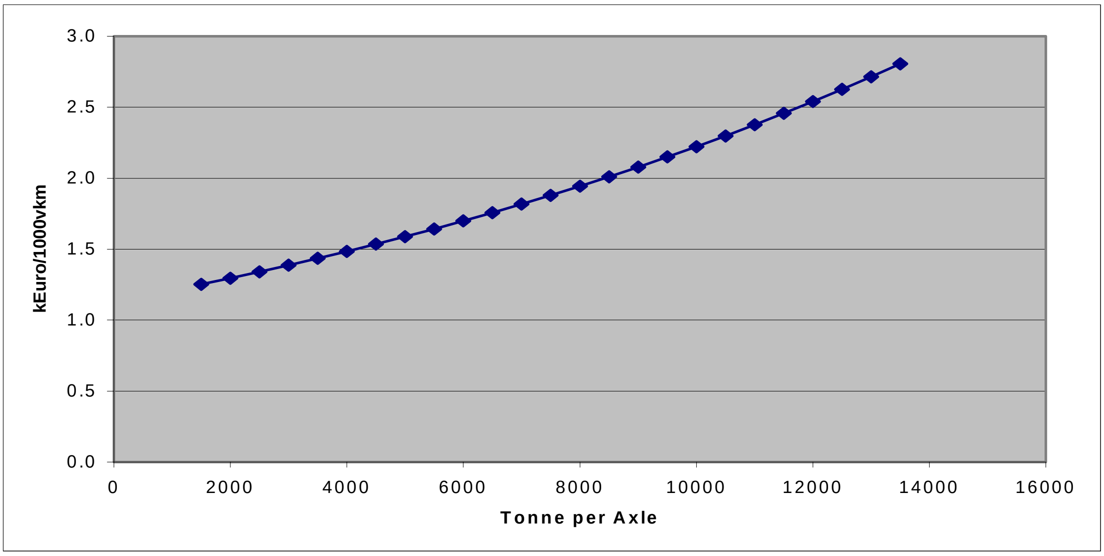
The external marginal accident cost, based on data for 1999, is in Sweden 3.2 Euro/1000 vkm for an average HGV. For the lightest weight class (WC 1), both the risk and the cost per accident are below the average and the proportion internal cost is higher then average. The external marginal cost for this group is only 0.4 Euro/1000vkm. The opposite is true for WC 9. This group has an external marginal cost of 14 Euro/1000vkm. Weight class 2 and 3 has a very high proportion internal cost, 40% and 62%. This means that the external cost is negative.

The current estimate of the elasticity may be subject to criticism. In Figure 5 below, the external marginal cost with an elasticity of –0.5 is presented in addition to an example with the b-component included. The average cost increase to 23 Euro/1000 vkm in the first case, and to 4.1 Euro/1000 vkm in the last example, i.e. E=-0.8 and b-component.

Figure 5: Sensitivity test of external marginal accident cost

With mean value on the cost per accident and proportion internal cost, we have calculated the external marginal cost by axle weight. The marginal cost increases as expected with axle weight (see Figur 6).

Figur 6: Marginal external cost by axle weight (Kg/axle)



7 Conclusion

We have estimated the external marginal accident cost for HGVs in Sweden. The estimates are based on information for year 1999. It is clear that our estimate on 3.2 Euro/1000 vkm for an average HGV is far below other estimates on the external accident cost. Even if we include the b-component, willingness-to-pay of relatives and friends, the marginal cost will be low, 4.1 Euro/1000 vkm. Basically, this is a result of the low elasticity we have estimated. The number of accidents increases as the number of driven kilometre by HGV increases, but the number of accidents increases not in proportion to the increase traffic. This means that the accident risk decreases.

We have found a positive relationship between the accident probability and axle weight. This relationship reinforce the ‘forth power law’, used for estimates of marginal infrastructure cost, even if the accident relationship is not as progressive as the marginal infrastructure cost.

We have in this paper not estimated any model to explain the average accident cost or the proportion internal cost. However, it exists indications that the average accident cost may increase with axle weight, and the proportion internal cost decreases with axle weight. This would strengthen the relationship between axle weight and marginal external accident cost.

If the external marginal cost based on the theory presented in this paper is internalised we would ensure an optimal level of traffic volume; an optimal level of activity. However, the aim has not been to correct any externalities in the decision on the level of care taken. We can have an optimal traffic volume with users that do not take the optimal level of care, e.g. speed level. While, an internalisation of this external marginal accident cost would improve the overall efficiency of the transport system it would not be enough.

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Table 18: Database limited to vehicles where DIST99 is strict positive

	Mean	**Std,Dev,**	**Minimum**	**Maximum**	**NumCases**
Y00	36710	91,7498	36528	36889	49879
VMST00	369016	245490	136	999923	49879
Y99	36333,2	87,221	36192	36490	49879
VMST99	318649	229923	1	998884	49879
YEAR	1988,54	7,38005	1951	1999	49879
WEIGHT	18173,6	8364,85	3510	55420	49879
AXLE	2,43392	0,538925	2	5	49866
UKOD	2,07117	2,16529	0	8	49879
USEDY	32628,9	2583,26	4225	36649	49877
DISTAV	57689,2	67788,3	1000	499480	44726
DISTY	376,818	53,4391	55	697	49879
DIST99	49239,8	62201,9	1	1,09E+06	49879

Table 19: Key variables for Accidents

	Mean	Std.Dev.	Skewness	Kurtosis	Minimum	Maximum	NumCases
YEAR	1992.52	5.37749	-0.96529	4.20876	1962	1999	3919
TRAILER	0.217513	0.415672	1.42219	3.18827	0	2	3940
INSP	0.0840102	0.49089	5.70328	33.6624	0	3	3940
VEHWIDTH	253.937	9.66161	-3.40047	17.7167	188	266	3939
FUEL	2.99238	0.1232	-16.1102	260.538	1	3	3939
EKILEN	1013.51	420.024	2.50784	8.74677	500	2552	3613
EKIWEI	28400.2	15464	1.40803	5.18092	3510	132500	3940
INSURANC	0.986548	0.115214	-8.44601	72.3349	0	1	3940
NATION	0	0	0	0	0	0	3940
LENGTH	896.874	144.184	-0.599724	2.67392	500	1330	3940
KW	264.437	81.327	-0.56152	2.91101	53	800	3939
TJWEIGHT	10526.2	2806.08	-0.332648	4.46611	2080	23870	3940
TOTWEIGH	23056.4	6645.28	-0.988599	4.06424	3510	48600	3940
VEHSTATU	1.0868	0.298219	3.46701	14.9633	1	3	3940
AXLE	2.70558	0.526157	-0.167818	2.39115	2	4	3940
EKIAXLE	3.24727	1.46961	1.62051	4.60234	2	8	3939
IC	5.29248	59.0353	21.1169	512.805	0	1533.93	3940
ECV	43.8545	275.571	15.4111	374.198	0	8868.69	3940
ECU	1.38447	71.068	61.6563	3843.36	0	4434.34	3940
ECC	6.25503	28.9945	15.4899	440.825	0	1027.19	3940
EC	51.494	345.048	22.5982	804.92	0	14330.2	3940
TC	56.7865	352.765	21.369	739.526	0	14344.2	3940
PROP	0.812816 958	0.334755	-1.32966	2.86677	0.0714942		1
WC	8.70076	2.90338	-1.30002	3.51167	1	11	3940
HGV1	0.288325	0.453041	0.934464	1.87297	0	1	3940
HVG2	0.111168	0.314379	2.47365	7.1187	0	1	3940
HGV3	0.0411168	0.198585	4.62152	22.3582	0	1	3940
HGV4	0.343147	0.47482	0.660683	1.43625	0	1	3940
HGV5	0.216244	0.411735	1.37835	2.89958	0	1	3940
ANTEL	1.9698	0.657606	2.38308	22.6982	1	10	3940
QVEH	6986.29	9449.78	3.03178	13.9697	1	90000	2815
QHGV	717.539	859.449	2.39923	9.92135	0	5590	2804
FATALITY	0.021066	0.207288	24.6344	940.776	0	9	3940
SPEED	75.2425	20.084	0.0580822	1.93661	30	110	3773
SLIGHT	0.26269	0.759323	12.8534	363.036	0	26	3940
TIME	1202.12	573.934	-0.0193386	2.34649	0	2359	3856
DAY	3.21777	1.66175	0.331245	2.26317	1	7	3940
SEVERE	0.064467	0.295359	5.50273	39.7424	0	4	3940
URBAN	1.66103	0.473422	-0.680263	1.4625	1	2	3900
WIDTH	93.711	29.4619	0.589322	2.98951	27	217	2900
MONTH	6.70431	3.61798	-0.0574558	1.69142	1	12	3940
TPA	8414.41	1674.04	-2.08575	7.83559	1755	13000	3940

Table 20Average weight for HGV involved in accidents respectively all HGV

WC	Acc	All
1	4610.73	4675
2	8435.21	8288
3	11444.63	11279
4	13777.34	13612
5	15313.64	15211
6	17411.38	17217
7	19166.56	19025
8	20585.41	20667
9	23345.57	23382
10	25707.18	25639
11	28360.69	28420
Tot	**23056.39**	18173.6

Table 21: Drop-out

	HGV	HGV not	Dist
Observations	3940	695	0.176
YEAR	1992.52	1989.42	0.998
TRAILERS	1.01	1.01	1.000
WIDTH	254.13	254.04	1.000
INSP	2.93	2.99	1.019
WEIGHT	23056.39	22430.12	0.973
INSURANCE	1.00	1.00	1.000
LENGTH	896.87	881.99	0.983
KW	264.62	256.44	0.969
AXLE	2.71	2.68	0.991
STATUS	1.09	1.32	1.217

Table 22: Contents of databases in group 1, 2 and 3.

OLYCKA.DAT		MOTORVEHICLE		DRIVER	
Fältnamn	Klartext	Fältnamn	Klartext		
OLYCKSID	olycksidentitet	OLYCKSID	olycksidentitet	OLYCKSID	olycksidentitet
ANTELEMENT	antal trafikelement	TRAFELEMT	trafikelementnummer	TRAFELEMENT	trafikelementnummer
ATRAF_AXP	trafikflöde [axelpar per årsdygn]	AARSMODELL	årsmodell	AALDER	ålder [år]
ATRAF_FORDON	" --- [fordon per årsdygn]	ANTPERS	4 antal personer	BEHOERDATUM	ursprungligt utfärdandedatum för körkortsklass vid olyckstillfället
ATRAF_TUNG	" --- [tunga fordon per årsdygn]	ANTSLAEP	antal släp	BEHOERIGHET	körkortsklass vid olyckstillfället
BELYSNING	vägbelysning	BESIKTNDATUM	besiktningsdatum	KOEN	kön
BROOLYCKA	broolycka	BESIKTNSTAT	besiktningsstatus	KOERKORTINDR	körkort indraget, datum
DELSTRAAKNR	delstråknummer	BREDD	fordonsbredd [cm]	SKADEGRAD	skadegrad
DOEDADE	antal dödade personer	DRIVMEDEL	drivmedel	(TRAKTORKORT	traktorkort – termen har utgått)
EJSVAENG	vänstersvängsförbud	EFFEKTNORM	motoreffektnorm	UTBYTTUTL	utbytt utländsk körkort
	följdolycka			VARNING	9 körkortsvarning, datum
FOELJDOLYCKA					
HASTIGHET	hastighetsbegränsning [km/h]	EKIPAGELGD	ekipagelängd [cm]	TAXIBEHOER	taxiförarlegitimation utfärdad, datum
KOMMUN	kommun [kod]	EKIPAGEVIKT	ekipagevikt [kg]	FOERARHEMV	förarhemvist [postnummer] (vid hämtningstillfället)
KONFLIKTTYP	konflikttyp	FABRIKAT_TYP	fabrikat och typ	PASSPLATS	placering - för förare alltid förarplats (1)
KORSNTYP	korsningstyp	FAERG	färg	INSTRUKTOER	instruktör
KVAEGKAT	vägkategori för anslutande väg	FOERSBETALD	försäkring betald	HANDLEDGOD	handledargodkännande
LISKADADE	antal lindrigt skadade personer	FORDONAEGARE	fordonsägare	U_BEHOERIG	1:a körkortsklass exklusive traktorbehörighet
LJUS	ljusförhållande	FORDONNATION	fordonsnation	U_BEHOERDAT	1:a körkort ursprungligen utfärdat, datum
MBREDD	mittremsebredd [dm]	FRVBNR	frånvägbensnummer	INNEHAVSTID	körkortsinnehavstid [månader]
OLANDRDATUM	ändringsdatum, ÅÅMMDD	KAROSSERIKOD	karosserikod	TRAFKAT	trafikantkategori
OLKLOCKSLAG	klockslag	KOPPLINGAVST	kopplingsavstånd (cm)		
OLPLATSTYP	platstyp	LAENGD	fordonslängd [cm]		
OLREGDATUM	registreringsdatum, ÅÅMMDD	LEASINFORDON	leasingfordon		
OLVECKODAG	veckodag	MAXPASS	maxantal passagerare		
OLYCKSDATUM	olycksdatum, ÅÅÅÅMMDD	MODELLKOD	modellkod		
		MOTOREFFEKT	motoreffekt [kW]		
OLYCKSTYP	olyckstyp	ROERELSETYP	rörelsetyp		
ORT	ort / stadsdel	PRIMELEMENT	primär- / sekundärelement		
POLISDNR	polisens diarienummer	STULET	stöldanmält fordon		
POLISDISTR	polisdistrikt	TIVBNR	tillvägbensnummer		
SLITLAGER	slitlager	TJVIKT	tjänstevikt [kg]		
STOPP	stoppskyldighet	TOTALVIKT	totalvikt [kg]		
STRAAKNUMMER	stråknummer	TRAFELEMTYP	trafikelementtyp		
STRAAKTYP	stråktyp	UTRYCKNING	utryckningsfordon / taxi		

SVSKADADE	antal svårt skadade personer	VAEXELLAAD	växellåda
TRAFIKBEBYGG	bebyggelsetyp	YRKESTRAFKOD	yrkestrafiktillstånd
TRAFIKSIGNAL	trafiksignal	FORDONSTATUS	fordonsstatus
TUNNELOLYCKA	tunnelolycka	CYLINDERVOLYM	cylindervolym (cm3)
VAEDER	väderlek	AXELANTAL	axelantal
VAEGARBETE	vägarbete	EKIPAGEAXL	ekipageaxlar fordon + släp
VAEGHAALLARE	väghållare	GRUPPKOD	gruppkod
VAEGKAT	vägkategori	KROCKKUDDE	krockkudde för framsätespassagerare
VAEGLAG	väglag	HANDIKAPPANP	handikappanpassat fordon
VAEGNR	vägnummer		
VAEGTYP	vägtyp		
VAEJNING	väjningsskyldighet		
VBREDD	vägbredd [dm]		
VILTSTAENG	viltstängsel		
LAEN	län		
REGION	väghållningsregion		
SVAARIGHET	svårhetsgrad		
OLMAANAD	månad		
OLAAR	år		
POLISOMRÅDE	polisområde (vid uttagstillfället)		
VINTVAEGHALL	vinterväghållningsstandardklass		