GDP, vehicle ownership and fatality rate: similarities and differences among countries

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1. Introduction

In his famous paper, Smeed published his formula for predicting road deaths as an empirical rule relating traffic fatalities to motor vehicle registrations and population (Smeed, 1949).

$$D = 0.0003\ (N*P^2)^{1/3} \qquad (1)$$

where D is the number of annual road deaths, N is number of registered vehicles and P is population.

His paper is mostly cited emphasizing that the increase of vehicle ownership leads to a decrease in fatalities per vehicle.

$$D/N = 0.0003\ (N/P)^{-2/3} \qquad (2)$$

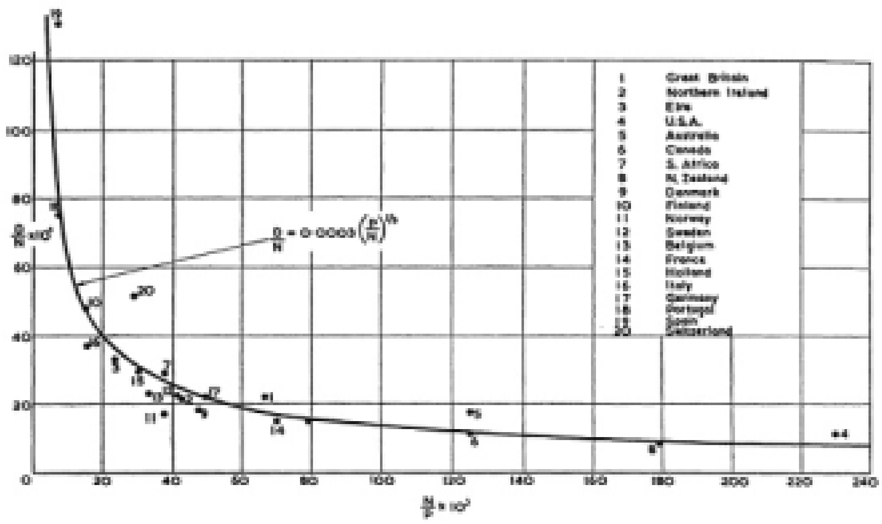


Figure 1/a: Relation between number of deaths per 10 000 registered motor vehicles and number of vehicles per 1 000 population for 1938

Less attention was paid to the other - and less encouraging - interpretation of Smeed's formula, namely that the increase of vehicle ownership leads to an increase in fatalities per population and in the total number of fatalities.

$$D/P = 0.0003\ (N/P)^{1/3} \qquad (3)$$

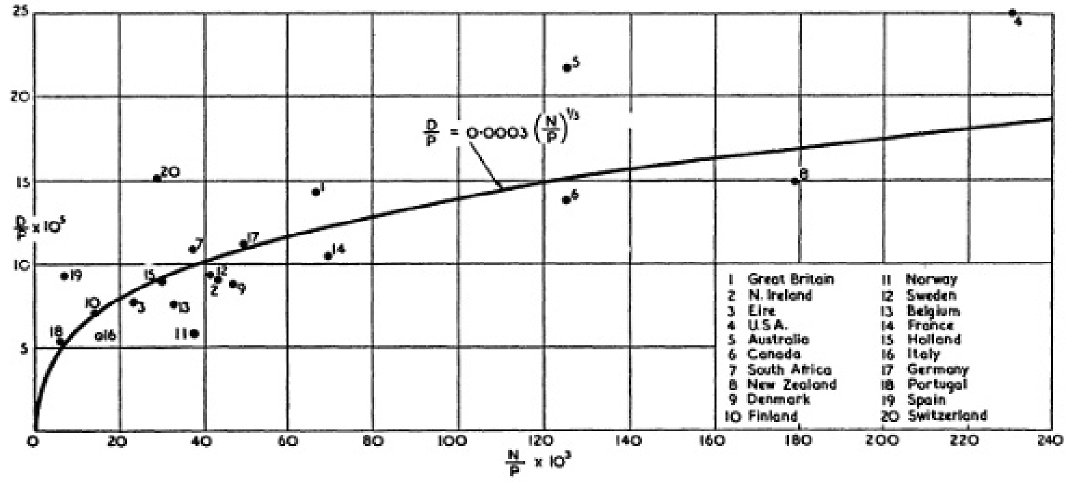


Figure 1/b: Relation between number of fatalities per 100 000 population and number of registered vehicles per 1 000 population for 1938

Later on, other authors tried to validate or update the formula based on newer data. The law was found to be valid with some changes in parameters (e.g. Adams, 1987).

Fortunately, the increasing trend of the total number of fatalities started to change towards a decreasing trend in some countries from the 60's. For the UK, the Smeed prediction was moving correctly and had approximately the right magnitude until about 1966. Since 1966 the Smeed prediction continues to rise, while the real road deaths have fallen quite reliably. By 2000, the Smeed prediction was about 4 times too high (Safe Speed, 2004).

The models describing the changes in road fatalities are using among others vehicle kilometres travelled and Gross Domestic Product.

Research carried out by Oppe (Oppe, 1991 cited in Elvik & Vaa, 2004, p. 38) found that the long-term development of traffic fatalities in the highly motorised countries follows a law-like pattern determined by the growth of motorisation and the decline of the fatality rate per vehicle kilometre of driving.

The change from the increasing to the decreasing trend could be observed in several countries. Kopits and Cropper have found that the income level at which traffic fatality risk (F/P) first declines is $8600 (1985 international prices), regardless of how the time trends are specified. This is the approximate income level attained by countries such as Belgium, the United Kingdom, and Austria in the early 1970s, South Korea in 1994, and New Zealand in 1968 (Kopits, Cropper, 2005).

2. Data used in the analysis

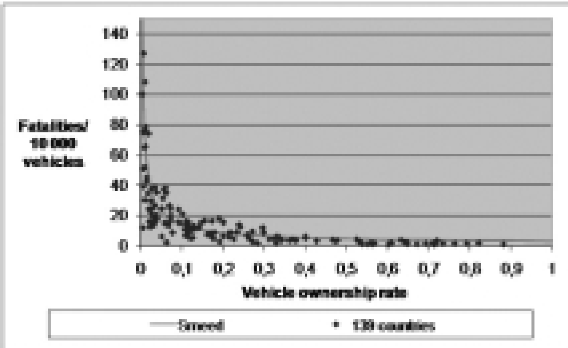
For our analyses we used fatality, population, vehicle ownership and GDP figures. The data used in Section 3 and Section 4 of this paper, namely the number of fatalities, number of registered motor vehicles and population stem from a global report on road safety for the year 2007 (WHO, 2009). Those countries that have less than 100 road deaths were excluded from the analysis, thus 139 countries were considered. The data used in Section 5, time series for Europe, come from the CARE database (CARE, 2009). In Section 6 along with the previously mentioned data the GDP per capita was added. The gross domestic product based on purchasing-power-parity (PPP) per capita was derived from the World Economic Outlook Database of International Monetary Fund (IMF, 2009).

3. Fatalities per vehicles

Figure 2 contain fatality rates per vehicle as well as vehicle ownership rates for the 139 countries in 2007, together with Smeed's relationships.

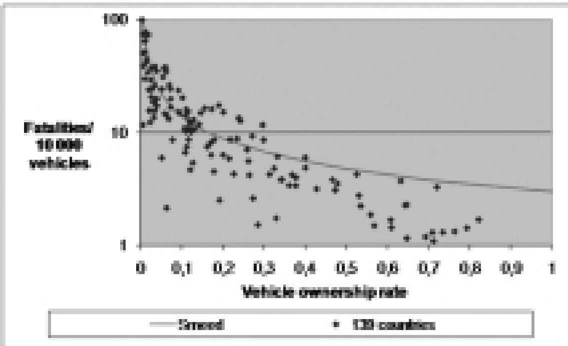
Looking at Figure 2/a, we see that the number of fatalities per vehicles fits well into the trend Smeed found. This is remarkable, considering that the vehicle ownership rates at the time of his study were between 0.01 and 0.23, while some of these figures exceed 0.8 now.

Figure 2/a: Vehicle ownership and fatality rate per vehicles in 2007 compared with the Smeed formula



However, if we have a closer look of the area below 10 fatalities per 10 000 vehicles (Figure 2/b, log scale), we see that almost all data lie well below the Smeed curve.

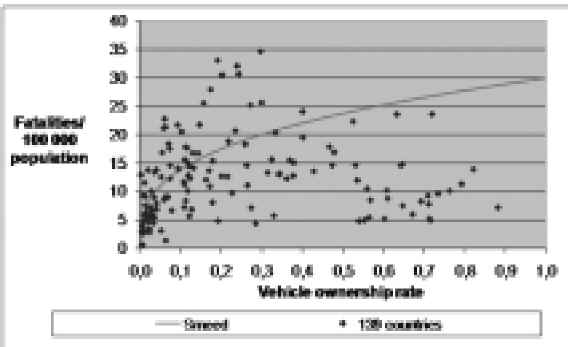
Figure 2/b: Vehicle ownership and fatality rate per vehicles in 2007 compared with the Smeed formula (log scale)



4. Fatalities per population

The most relevant variable to describe the safety of a country is the fatalities per population. As it is shown in Figure 3, this data is also well below the Smeed curve at higher ownership levels.

Figure 3: Vehicle ownership and fatality rate per population in 2007 compared with the Smeed formula



For the description of the relation between vehicle ownership rate and fatalities per population the following formula was used here:

$$D/P = a * N/P * e^{-b*N/P} \qquad (4)$$

The formula was fitted to the 2007 data of 139 countries, finding a and b to minimise the square of differences between actual and expected D/P.

The term *a*N/P* is expressing the growing risk with the increase of the vehicle numbers. While N/P is very low, $e^{-b*N/P}$ is about 1, so the first part of the formula, i.e. the growth in vehicle numbers is dominant. From the data, "*a*" was found to be around 230, which means that for the ownership figure of 0.1 vehicles per person 0.1*230= 23 fatalities per 100 000 population are expected.

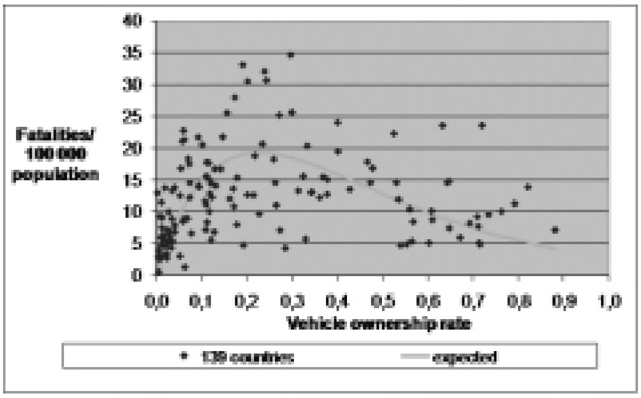
The second part of the formula, $e^{-b*N/P}$ is a negative exponential function, expressing that the growth of motorisation generally goes together with the increase in vehicle and infrastructure safety as well as with an improvement in education and enforcement. From the data, "*b*" was found to be around 4.4, which means that for the ownership figure of 0.1 vehicles per person

the impact of safety improvements is a correction factor of $e^{-4.4*0.1}$ = 0.64, for 0.3 vehicles per person $e^{-4.4*0.3}$ = 0.27, while for 0.6 vehicles per person $e^{-4.4*0.6}$ = 0.07. Thus, with higher motorisation rates the second term of the formula becomes dominant.

The formula used is appropriate to describe the phenomenon that with low motorisation the number of fatalities is increasing. Once reaching a certain threshold, the society will devote and can afford more efforts to turn the previous trends in road safety.

The turning point of the fitted curve is about 0.20-0.25 vehicles per person and 20 fatalities per 100 000 population.

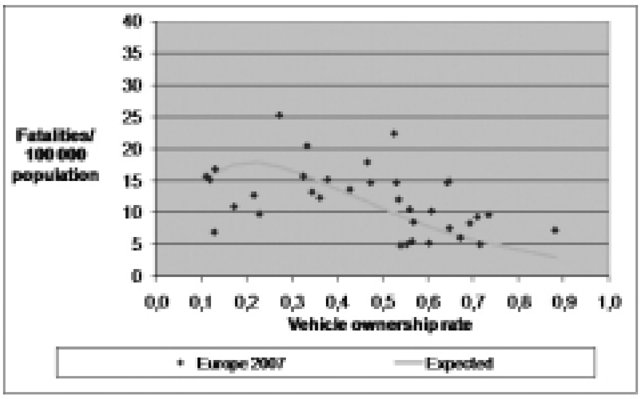
Figure 4: Relationship between vehicle ownership and fatality rate per population for 2007



Apparently there are huge differences among countries as it is shown in Figure 4.

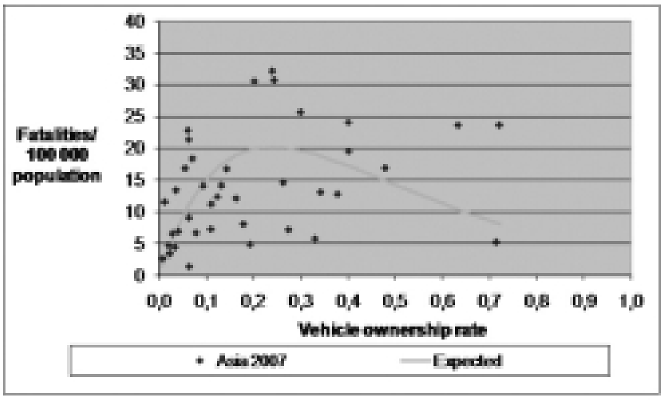
In Europe, most of the countries are already beyond the "hump" but the upward trend is still visible in the 0.1-0.2 ownership range (Figure 5). Some countries lie already at the 5 fatalities per 100 000 population level.

Figure 5: Relationship between vehicle ownership and fatality rate per population for Europe



The upward trend is valid in most of the Asian countries, but the downward section is also significant (Figure 6). In some countries the fatality rate is over 30 per 100 000 inhabitants. The difference in fatality rates between countries is quite high, and also the ownership levels have a very wide range. The latter is due to the high share of two-wheelers in several countries.

Figure 6: Relationship between vehicle ownership and fatality rate per population for Asia



In Africa, almost all countries are still in the upward section of the curve (Figure 7). In some countries the fatality rate is over 30 per 100 000 inhabitants. The turning point seems to be located at higher ownership and higher fatality rate than in other continents.

Figure 7: Relationship between vehicle ownership and fatality rate per population for Africa

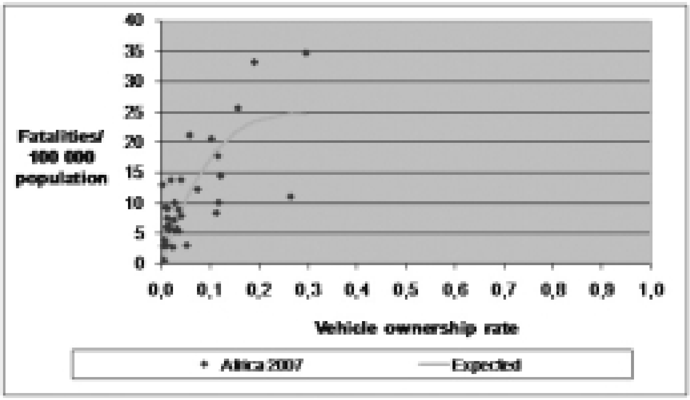


Figure 8 contains the countries in America and in Australia. These countries are divided in two groups. One is that of the low-medium ownership countries in the upward and top section of the curve. The other group has very high ownership levels with lower fatality rates. However, the USA with its highest ownership level has quite bad fatality figures.

Figure 8: Relationship between vehicle ownership and fatality rate per population for America and Australia

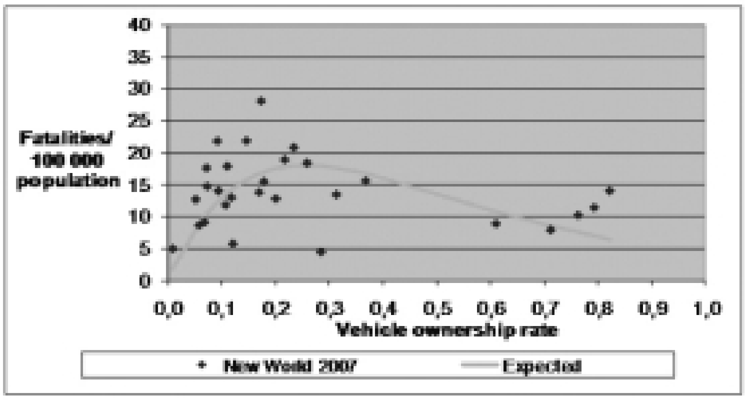


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Table 1 contains the coefficients of equation (4) for the continents and for the total of 139 countries. They show some differences: Africa with the steepest growth of fatalities with the increase of motorisation (a=250) and Europe with the highest exponent (b=4.8) which is some kind of "dumping" factor of fatalitiy figures with the increase of car ownership.

Table 1: Coefficients of equation (4) for the continents

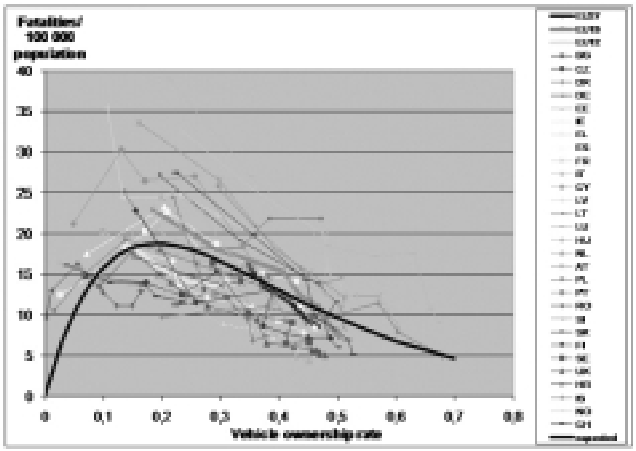
Continent	a	b
Europe	232	4.8
Asia	230	4.2
Africa	250	3.7
America + Australia	195	4.0
World	230	4.4

5. Time series for Europe

For European countries the time series of cars per population and fatalities per population between 1970 and 2007 were analysed. The overall picture is similar to the previous cross sectional figures but in Fig. 10 the changes for each country can be observed. The same curve was fitted to the data. The coefficients of the best fitted curve are slightly higher than the ones from the cross-sectional analysis: a=260, b=5,3.

It can be observed that the upward section of the curve has a limited amount of data as the turning point in many of the European countries was reached before 1970. However, the upward section for some countries, like Greece, Poland, Portugal, Spain is well visible.

Figure 9: Relationship between car ownership and fatality rate per population (EU 27 1970-2007)



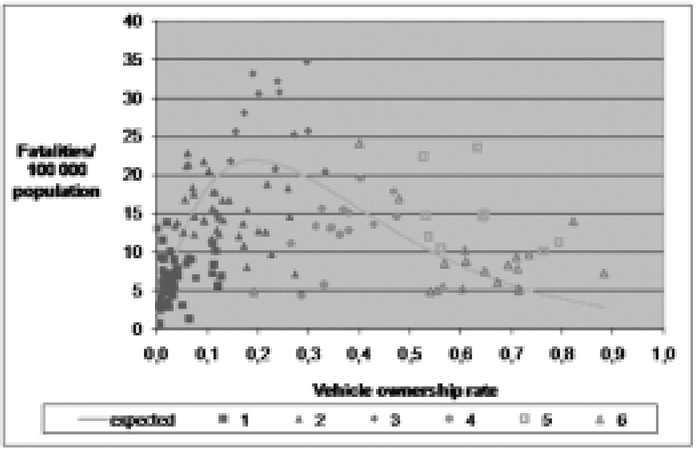
6. Cluster analysis

In order to arrange countries by their 2007 data into clusters, three variables were chosen: GDP per population, vehicles per population and fatalities per population. Because of their different magnitudes, all variables were normalized, i.e. their values were divided by their respective means. Then the countries as cases were clustered according to the three variables using K-Means Cluster Analysis in SPSS software. Among others tables of cluster membership and distance from cluster centre were produced as outputs. After several runs it was found that the choice of 7 clusters gives a reasonable description of each cluster. The number of cases (countries) in each cluster and the cluster means of the three variables are shown in Table 2. In Fig. 10 clusters are illustrated with different markers in the vehicle ownership - fatality rate coordinate system.

Table 2: Main data of the clusters

Cluster No.	Number of countries	Cluster means		
		GDP/P	Vehicles/P	Fatalities/P
1	44	0.15	0.15	0.53
2	38	0.50	0.53	1.22
3	12	1.04	0.96	2.21
4	15	1.26	1.51	1.06
5	9	1.73	2.59	1.20
6	20	2.99	2.58	0.70
(7)	(1)	(6.66)	(2.99)	(1.20)

Figure 10: Clusters of countries according their GDP, ownership and fatality rates



Cluster 1 contains the poorest countries. Their vehicle fleet is similarly low. Fatalities per person in these countries are half of the average of all countries. Most of these countries are in Africa but other countries like Tajikistan and Afghanistan belong also to this group.

In Cluster 2 the average GDP is higher but still only half of the average of all countries. Their vehicle fleet is closely proportional to their income. Despite their relatively low vehicle fleet, fatalities per person in these countries are 1.2 times the average of all countries. Countries in this cluster are distributed on 4 continents.

Only 12 countries belong to Cluster 3 which contains the most dangerous ones. Their GDP and vehicle fleet is around the average of all countries, but their fatalities per person figure is 2.2 times more than the average of all countries. Also 4 continents are represented in this group and in several of these countries a large number of population is exposed to a high risk (Russia, Kazakhstan, Iran, Mexico, South Africa, Venezuela).

Cluster 4 contains countries with slightly higher income than the average. Their vehicle fleet is higher than it would be expected from the GDP figures. Fatalities per person in these countries are around the average of all countries. Besides some new EU member states (Bulgaria, Hungary, Poland, Slovakia) countries like Argentina, Korea, Thailand, Uruguay belong to this group.

In Cluster 5 the average GDP is 1.7 times higher than the average of all countries and their vehicle fleet is much higher in proportion to their income. Fatalities per person in these countries are 1.2 times the average of all countries. Countries in this cluster are the lower income old EU member states (Greece, Portugal) some higher income new member states (Czech Republic, Estonia, Slovenia) as well as three other countries from three continents.

Cluster 6 contains the 20 most developed countries with a GDP three times than the average. Their vehicle fleet is slightly lower than it would be expected from the GDP figures. Fatalities per person in these countries are only about 70% of the average of all countries. Most of the old EU member states as well as Australia, Canada, Japan and the USA belong to this group.

Cluster 7 has only one element, this outlier is Qatar with its very high GDP and moderately high fatality rate.

Table 3: The first 10 countries in each cluster closest to the cluster centre

1	2	3	4	5	6
Tajikistan	Albania	Russian Fed.	Hungary	Estonia	Canada
Sudan	Tunisia	Kazakhstan	Croatia	Portugal	Belgium
Benin	Turkmenistan	Botswana	Argentina	Slovenia	Austria
Afghanistan	Jordan	Iran	Trinidad	Czech Rep.	Sweden
Cameroon	Georgia	Mexico	Lebanon	Greece	France
Tanzania	Azerbaijan	South Africa	Slovakia	New Zealand	United Kingdom
Burkina Faso	Jamaica	Venezuela	Bulgaria	Lithuania	Australia
Ghana	Namibia	Libya	Poland	Puerto Rico	Germany
Mali	Paraguay	Montenegro	Belarus	Malaysia	Ireland
Chad	Armenia	Oman	Latvia		Netherlands

7. Conclusions

For the description of the relation between vehicle ownership rate and fatalities per population a formula was found combining a linear function with the growth of vehicle ownership with a negative exponential function explaining the improvements in safety level.

The formula can be used both for cross sectional data of a given year to describe difference between countries and for time series of given countries.

The range of fatality figures between countries for a given car ownership level is quite large. These differences underline the fact, that the trends found are not like laws of nature. A country will not automatically follow the trend, but a lot has to be done to follow it; it is a result of many efforts in vehicle design, infrastructure safety, enforcement and education.

The cluster analysis identified 6 clusters of countries with similar fatality rates, car ownership and GDP levels within each cluster but huge differences between clusters. Countries within the same cluster should preferably follow similar road safety strategies.

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