IS SMEED'S LAW STILL VALID? A WORLD-WIDE ANALYSIS OF THE TRENDS IN FATALITY RATES

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Abstract: Professor R J Smeed published his famous formula for predicting road deaths in 1949. Later on, other authors tried to validate or update the formula based on newer data. Most of these publications emphasized the encouraging finding that the increase of vehicle ownership leads to a decrease in fatalities per vehicle. 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. Fortunately, the increasing trend of the total number of fatalities started to change towards a decreasing trend in some countries from the 60's. The paper analyses GDP, vehicle ownership, population and road fatality data from 139 countries. Relationships between these variables are shown. Using cluster analysis, countries are grouped according to their safety performance trends.

Key Words: Smeed, road safety, vehicle ownership, fatality rate, cluster analysis

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).

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

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 (Figure 1).

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

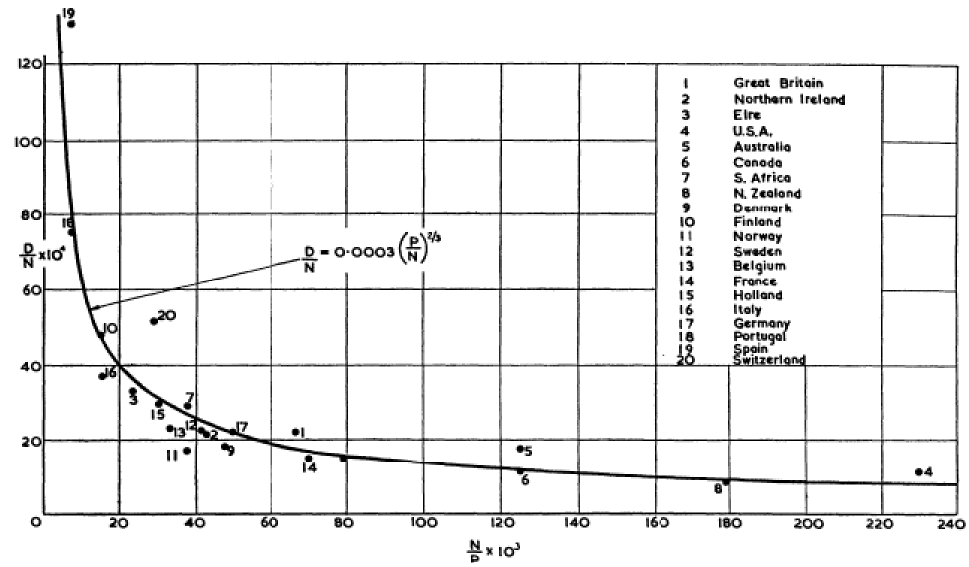

Figure 1. Relation between number of deaths per 10 000 registered motor vehicles and number of vehicles per 1 000 population for 1938

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 (Figure 2).

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

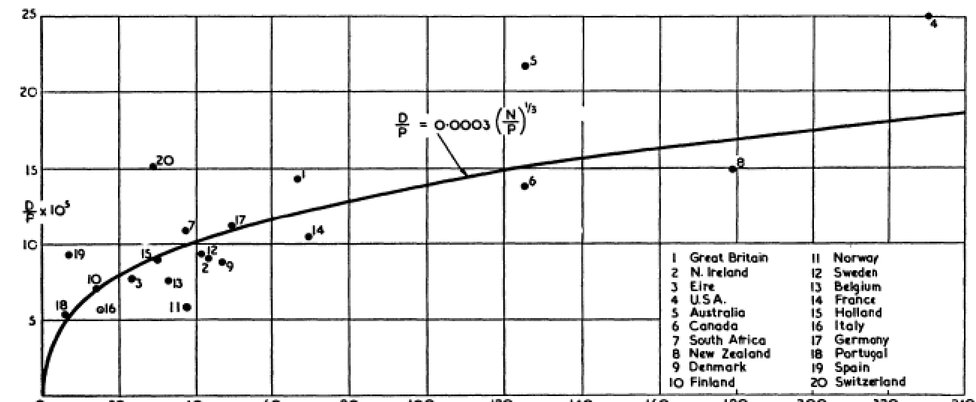

Figure 2. Relation between number of fatalities per 100 000 population and number of registered vehicles per 1 000 population for 1938

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. SCOPE OF THE PAPER

This paper presents a world-wide analysis that addresses the verification of Smeed's law. Chapter 3 gives an overview of the data used during the analysis. Chapter 4 and Chapter 5 focus on the validation as well as the review of the two interpretations of Smeed's law. In Chapter 5 the authors propose a new function that better describes the evolution of fatality rate per population in the function of level of motorization. In Chapter 6 countries are grouped into 6 clusters according to their GDP, vehicle ownership rate and fatality rate per population based on their 2007 data. In Chapter 7 a detailed investigation of Asian data is provided and finally Chapter 8 summarizes the conclusions.

3. DATA USED IN THE ANALYSIS

For our analyses we used fatality, population, vehicle ownership and GDP figures. The data used in Chapter 4 and Chapter 5 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.

In Chapter 6 dealing with the cluster analysis 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).

In Chapter 7 focusing on Asia the data come from various sources. These were the online database of United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP, 2009), the global report on road safety for the year 2007 (WHO, 2009), the ASEAN Statistical Yearbook (ASEAN, 2005) as well as data rows for China and Thailand from the NICE on RoadS EU-Asia project (Koren & Borsos, 2006).

4. FATALITIES PER VEHICLES

Figure 3 and Figure 4 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 3, 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.

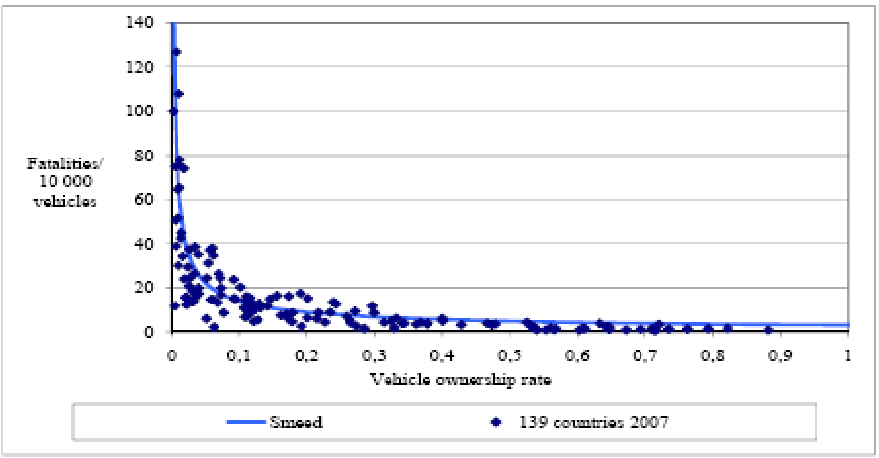

Figure 3. Vehicle ownership and fatality rate per vehicles in 2007 compared with Smeed

However, if we have a closer look of the area below 10 fatalities per 10 000 vehicles (Figure 4, log scale), we see that almost all data lie below the curve, especially for vehicle ownership rates higher than 0.2 which are well out of the range of Smeed's data from 1938. Also the logarithmic scale contributes to the visibility of the differences from the curve.

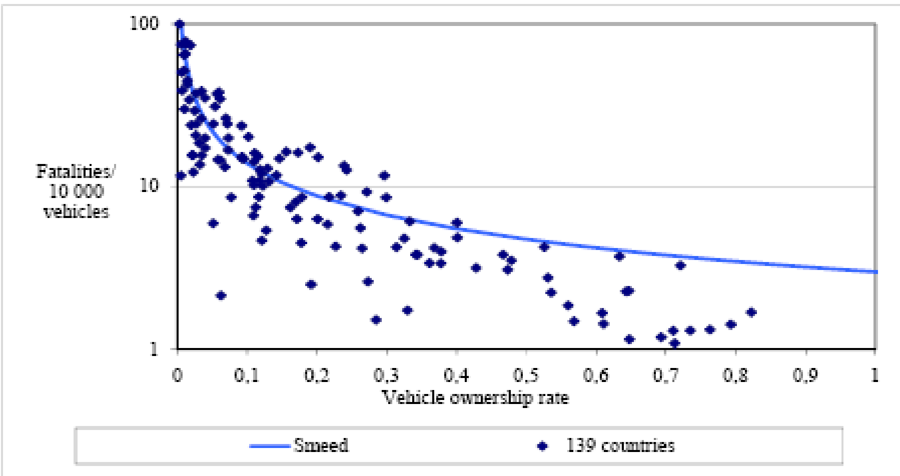

Figure 4. Vehicle ownership and fatality rate per vehicles in 2007 compared with Smeed (log scale)

5. FATALITIES PER POPULATION

As an overall strategic indicator, the most widely used variable to describe the road safety level of a country is the fatalities per population. As it is shown in Figure 5, these data are very much dispersed, the ratio of the highest and lowest values being up to 7:1 for a given vehicle ownership level in 2007. This dispersion is apparently much higher than it was in 1938, with the ratio of about 3:1 between the highest and lowest fatality rates for ownership levels of 0.02 and 0.04. The increase in dispersion is most probably due to the difference in the set of countries studied: Smeed's survey covered a relatively homogenous group of the most developed 20 countries of the world, while the 2007 data come from 139 countries in five continents with huge differences in their economic power, vehicle fleet, road network, social attitude, education and enforcement culture.

Looking at the dispersed "cloud of points" of Figure 5, or trying to find usual regression curves and correlation coefficients, one might come to the conclusion that there is no relationship between vehicle ownership and fatality rates. This is certainly true if we follow the "try several curves until the best fit and then find an explanation" method.

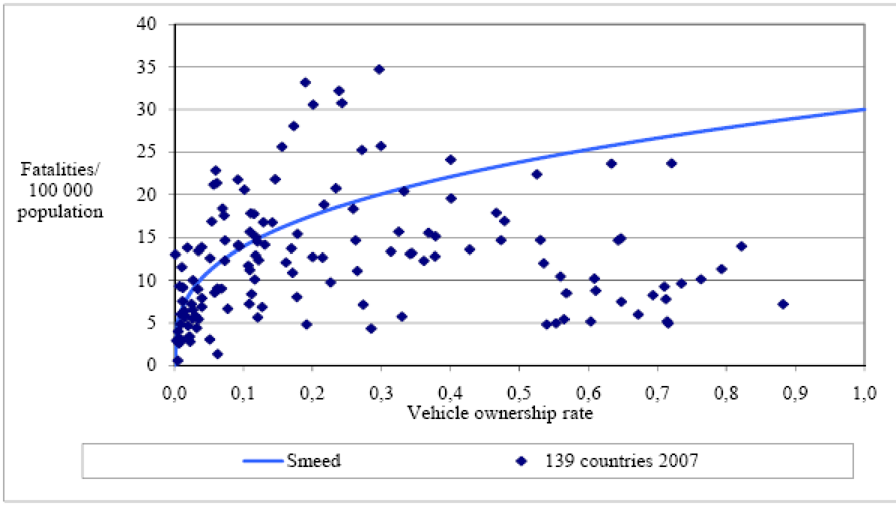

Figure 5. Vehicle ownership and fatality rate per population in 2007 compared with the Smeed formula

The authors followed a different approach: find a formula which explains the phenomenon and then try to fit it. For the description of the relation between vehicle ownership rate and fatalities per population the following formula was used here:

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

The term $a \cdot N/P$ is expressing the growing exposure with the increase of the vehicle numbers. While N/P is very low, $e^{-b \cdot N/P}$ is about 1, so the first part of the formula, i.e. the growth in vehicle numbers is dominant.

The second part of the formula, $e^{-b \cdot N/P}$ is a negative exponential function, expressing that the growth of vehicle ownership generally goes together with the increase in vehicle and infrastructure safety as well as with an improvement in education and enforcement.

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.

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.

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 $e^{-4.4 \cdot 0.1} = 0.64$, for 0.3 vehicles per person $e^{-4.4 \cdot 0.3} = 0.27$, while for 0.6 vehicles per person $e^{-4.4 \cdot 0.6} = 0.07$. Thus, with higher motorisation rates the second term of the formula becomes dominant.

Though the least square method was used to find the best fit, the curve should not be considered as a regression line and therefore no correlation coefficients are given here.

The formula used is appropriate to describe the phenomenon that with low motorization 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 6). Apparently there are huge differences among countries. These differences are mainly due to the considerable variations between countries' characteristics such as geographical features, economic and political background.

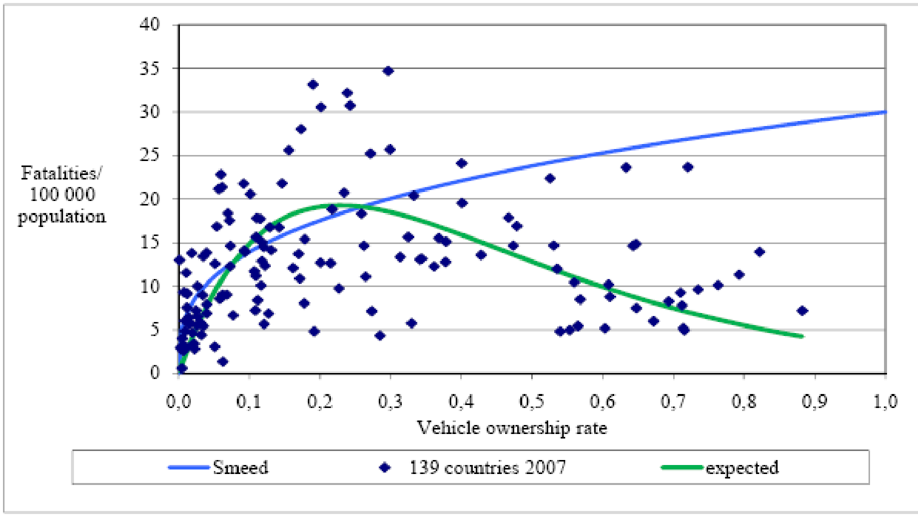

Figure 6. Relationship between vehicle ownership and fatality rate per population for 2007

Although the above data represent a cross-section from one year, the relationship between vehicle ownership and fatalities can be also explained as a change over time (see also section 7.3).

The change in the number of fatalities per population is influenced by the following driving forces:

- Increase in vehicle ownership rate goes together with an increase in accident exposure.
- Increase in vehicle ownership rate goes together with economic growth and technological development (better infrastructure, better equipped cars, better emergency services etc.).
- Social attitude against road safety changes (evaluation of accident costs, acceptance of restrictions etc.).

The combined impact of the three driving forces leads to three stages of development:

- Declining road safety situation

Increasing fatality rate per population dominates due to growing traffic volume and exposure, the economy is weak, and there is no social attention to road safety.

- Turning point

The road safety situation is quite bad; however, the economic performance makes the change possible, if there is adequate social and political will.

- Long-lasting improvement

The pace of economic and technological development as well as the change in social attitude is higher than the growth in traffic volume.

It has to be mentioned here that the number of vehicles is far from being a perfect measure of accident exposure. Vehicle kilometers travelled on a countries road network would describe the exposure much better. In the above explanations the term "vehicles" could be replaced by "vehicle kilometers" as well. Probably the dispersion of the points in the figures would be considerably less. Similar studies were performed earlier for cases when there is a good data set of vehicle kilometers. This is usually possible for individual countries with consistent vehicle kilometer data over the years (e.g. Safe Speed, 2004). Unfortunately, the international statistical data collections contain vehicle kilometer data only for a very limited number of countries and even for those countries which provide such data, the difference in definitions and calculation methods reduces the possibility of international analyses.

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 1. Clusters were numbered according to their growing GDP/P means. Except for Clusters 5 and 6, the Vehicles/P means are growing parallel to the GDP/P means. The Fatalities/P means generally follow the findings before; they are low at low and high vehicle ownership rates, while the highest fatality rates were found for medium ownership figures. In

Figure 7 clusters are illustrated with different markers in the vehicle ownership – fatality rate coordinate system.

Table 1. 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)

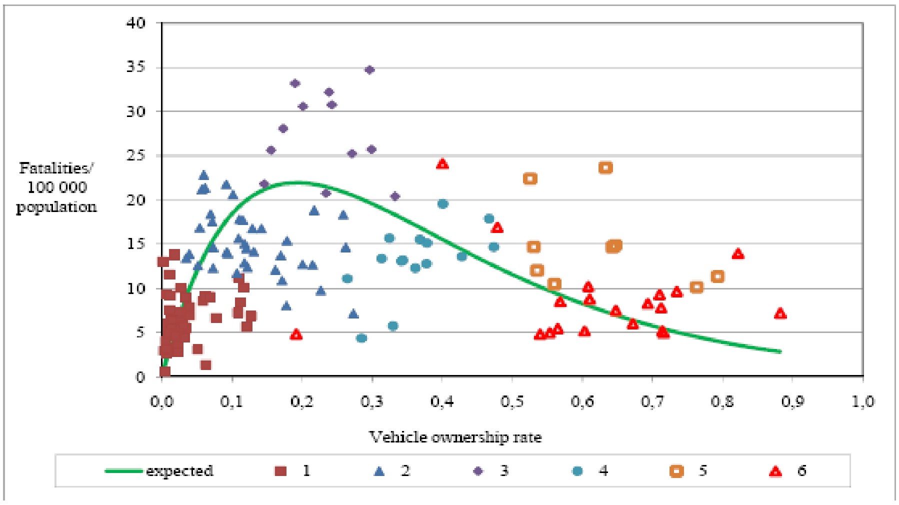

Figure 7. Clusters of countries according their GDP, ownership and fatality rates

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.

Cluster 5 is an outlier in some sense. Here 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 (or the other way round: their GDP is lower than it would be expected from their vehicle fleet). Probably this discrepancy leads to the result that fatalities per person in these countries are 1.2 times of 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 2 shows the first ten countries in each cluster closest to the cluster centre

Table 2. The first 12 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	UK
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
Malawi	Moldova	Guyana	Korea	-	Switzerland
Congo	Honduras	Saudi Arabia	Thailand	-	Japan

7. ANALYSIS OF ASIAN TRENDS

7.1 Fatalities per vehicles – 2007 data

In order to have a better view on Asia we collected the 2007 data for the Asian countries.

As far as the fatalities per vehicles are concerned, the countries are quite dispersed along the Smeed curve due to their different vehicle ownership rates.

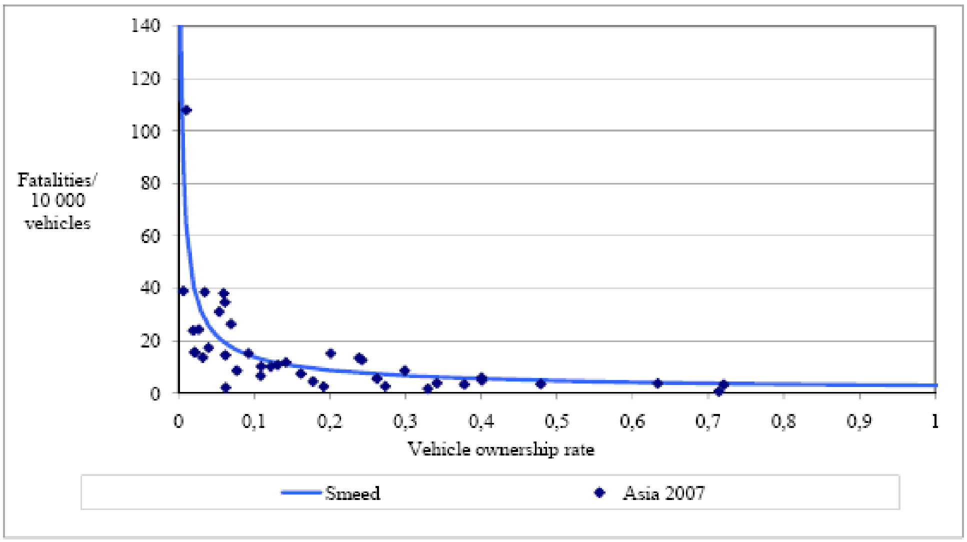

Figure 8. Relationship between vehicle ownership and fatality rate per vehicles for Asia

7.2 Fatalities per population – 2007 data

From the point of view of the fatalities per population even stronger differences can be perceived among Asian countries. Most of them are still in the upward trend, but the downward section is also significant (Figure 9). The high dispersion of fatality rates between countries is due to the fact that Asia is the most divergent continent: countries with low, medium and high income, with widely different geographic conditions, road networks, vehicle fleets and social systems can be found here.

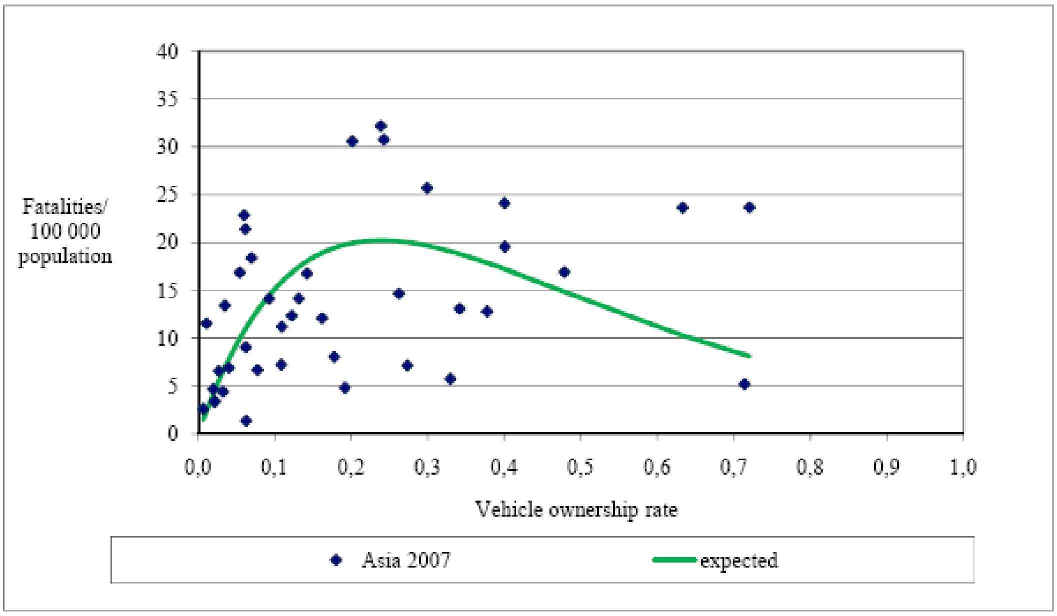

Figure 9. Relationship between vehicle ownership and fatality rate per population for Asia

Unfortunately, in some countries the fatality rate is over 30 per 100 000 inhabitants. Oman, Kazakhstan, Iran are the worst-performing countries with a motorization level of 200~300 and a fatality rate higher than 30 fatalities per 100 000 population. On the contrary there are some well-performing countries, such as Singapore (4,82 fatalities per 100 000 population, 191 vehicles per 1 000 population) or Japan with quite high level of motorization (5,18 fatalities per 100 000 population, 714 vehicles per 1 000 population).

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.

7.3 Fatalities per population – time series

For some Asian countries time series of cars per population and fatalities per population were analyzed. For seven out of eight countries the number of registered vehicles (ASEAN, 2005), in case of Japan the passenger cars in use (UNESCAP, 2009) were used. Owing to lack of data the length of these time series differs, the following list gives an overview of the years included in the analysis:

- China: 1994-2003, 2007
- Malaysia: 1997-2003, 2007
- Myanmar: 1997-2000, 2007
- Philippines: 2003, 2007
- Singapore: 1997-2003, 2007
- Thailand: 1994-2003, 2007
- Lao People's Democratic Republic: 1997-1999, 2007
- Japan: 1990-2002, 2007

The overall picture is similar to the previous cross sectional figures but in Figure 10 the changes for each country can be observe.

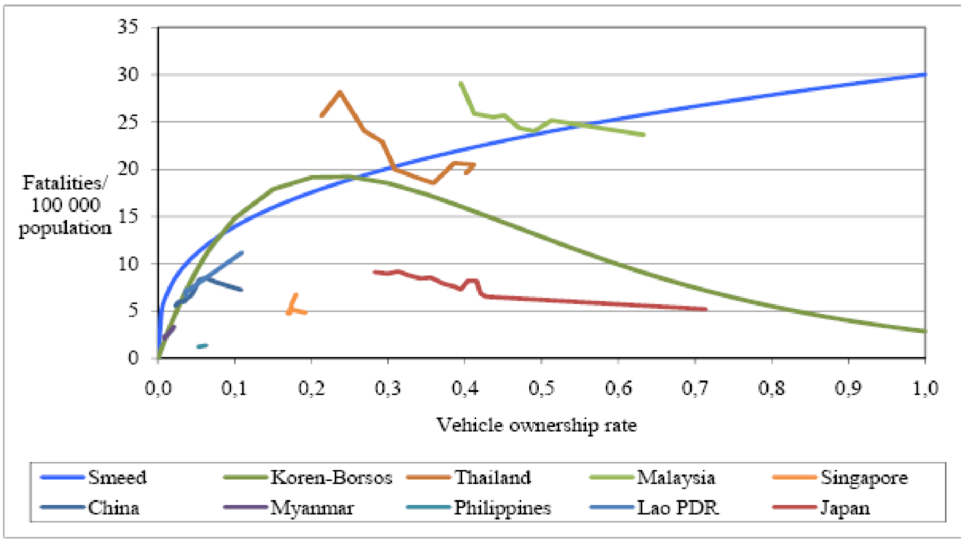

Figure 10. Changes of fatality rates versus vehicle ownership in some Asian countries

Some countries in the lower motorization phase have low fatality numbers but these figures have steadily been increasing in the last decade (China, Myanmar, Philippines, Lao PDR). Some others (Malaysia, Thailand) suffer from much higher fatality rates but these rates are decreasing, especially in Thailand. The low Japan fatality rates show a further decrease.

Fatalities of low vehicle ownership countries (e.g. China, Philippines, Myanmar) are still low but unfortunately rapidly increasing. Countries with medium vehicle ownership (like Thailand, Malaysia) have quite high fatality rates but these are decreasing remarkably. In these countries, the high share of two-wheelers contributes to the high fatality figures. Japan's data are very much similar to that of the high income countries in Cluster 6.

8. CONCLUSIONS

It was found that Smeed's formula is describing reasonably well the changes (increase) in fatalities up to the 0.2-0.3 vehicles/person ownership level, whereas above this level the formula is too pessimistic, the fatalities are fortunately tending to decrease in reality.

For the description of the relation between vehicle ownership rate and fatalities per population a new formula was found combining a linear function showing 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.

In terms of road safety, three stages of development can be identified all over the world. In the first phase the road safety situation is declining. At a second phase, countries come to a turning point. The third phase can be a lasting improvement.

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 six 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.

The Asian countries show a very much dispersed picture in terms of fatality rates and their trends.

Many of them are in a declining road safety situation, where an increasing fatality rate per population due to growing traffic volume dominates, and there is not enough social attention to road safety.

Some other countries are around the turning point, their road safety situation is quite bad, and however, the economic performance makes the change possible, if there is adequate social and political will. There is also the chance for a long-lasting improvement, if the pace of economic and technological development as well as the change in social attitude is higher than the growth in traffic volume.

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