# THE EVOLUTION OF INTERNATIONAL ROAD S AFETY BENCHMARKING MODELS: TOWARDS A ROAD SAFETY DEVELOPMENT INDEX (RSDI)

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*Abstract:* Since the publication of Smeed's model in 1949, the research on road safety benchmarking has progressed nationally and internationally. There are mainly three types of benchmarking: product of safety, practices, and strategic benchmarking. They differ depe nding on the type of indicators that model is trying to compare. It is not relevant to review all literature, however, our focus in this paper is on the background to some of the main benchmarking models that have been used in the past and very recent. In our brief review, we describe the evolution process of benchmarking into four generations of development. The latest generation realised the necessity of combining up all the three types of benchmarking into one index. The Road Safety Development Index (RSDI), as an example, provides a broad picture compared to the traditional (earlier) models in road safety.

*Keywords:* Road safety, RSDI, international comparisons, ranking, composite index, macro - performance indicators

## I. INTRODUCTION

The road safety situation is a complex issue and there are high number of accidents factors and indicators involved. The characteristics between factors and road safety (e.g. exposure versus risk) have been studied at microscopic and macr oscopic levels in several articles and models (i.e. OECD, 1997). Several model have attempted to represent the complexity of road safety problem. For instance the Haddon Matrix (1972) focused on three factors: driver, vehicle, environment (road design) at three different time phases of the crash: pre -crash, crash, and post-crash. Rumar (1999) described the road safety problem as a function of three dimensions: exposure, accident risk and consequences.

Many countries recognise the importance of internationa l benchmarking to measure and compare their own achievements and progress in road safety with other countries. This will allow countries to learn/improve based on existing practices and lessons in other countries.

Benchmarking can identify the strengths an d weaknesses in road safety performance from country to another. This can increase the awareness of the problem among public and policy makers. This will also help policy makers to take appropriate actions to solve their country problems.

A number of benchmarking models are already being developed and they range from relatively simple models to highly complex depending on the number of indicators involved, details of data and complexity of methods used in calculations and analysis.

The model in general depends on what is designed for and how is it designed? In road safety benchmarking between countries, three types of models, which generally used :

1. *Product Benchmarking* is used to compare accident rates.

2. *Practices Benchmarking* is used to compare activities related to human-vehicle-road performance (e.g. seat belts use, crash helmets use, motorways level, etc.)

3. *Strategic Benchmarking* is used to compare National Road Safety Programme (NRSP), management and organisational framework.

The major obstacle in constructing any benchmarking model is the lack of data from different countries, especially in developing countries. To have meaningful benchmarking, it is necessary to have reliable, valid, and available data.

There are several reasons for reducing the number of input variables in most early benchmarking models. These include the simplification needs in the model, reducing the errors, and also reducing the cost and time of the data collection and analysis.

In our perspective, we can describe the evolution of road safety benchmarking models into four stages of generations, which is simplified in the following description and illustration of "generations" in figure 1:

- *The first generation* is characterized with models that compare countries' road safety performance in terms of risk and exposure indicators such as accident rates and motorisation (Product Benchmarking). These models are cross-sectional models, which observed at the same year.

- *The second generation* takes the time into account. Theses models bench mark the road safety product over time series. These models are useful to monitor the trends in road safety in countries and indicate the direction of progress ahead.

- *The third generation* is realized the need for increased integration between product (accident rates) and other indicators in the same model (Product and Practices Benchmarking).

- *The fourth generation* focuses on all three types of benchmarking: Product, Practices and Strategic Benchmarking. One approach is RSDI (Al-Haji, 2005), which integrates much of macro-performance indicators in road safety into a single value.

Most of the early models are still in use and being applied in different studies. However, today computers are developing rapidly, which simplifies the work and analysis of a large amount of road safety data that was not available before. This development has made the work in the third and fourth generations become easier and closer to reality.
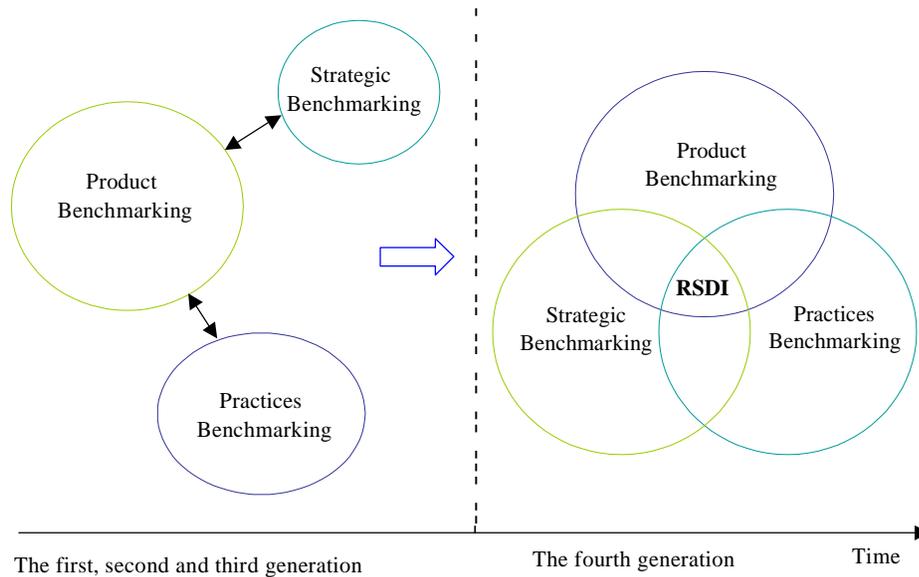
*Figure 1.* *The Road Safety Benchmarking Evolution towards RSDI*

In particular, it was reasonable to start with simplified benchmarking models. Picking up ideas (i.e. performance indicators) from the first three generations was very useful in reaching the fourth generation (i.e. RSDI).

The aim of this paper is to make a selected review of the main benchmarking models in road safety that has been used in the past and very recent.

## II. THE FIRST GENERATION: LINKING MOTORISATION, TRAFFIC RISK AND PERSONAL RISK

An early study in 1949, R.J. Smeed compared twenty countries, mostly European for the year 1938, where he developed a regression model (log-linear model) and he found an inverse (or negative) relationship between the traffic risk (fatality per motor vehicle) and the level of motorisation (number of vehicles per inhabitant). This regression represented the best estimates of the mean values of traffic risk for each given value of motorisation (what is called least square). This shows that with annually increasing traffic volume, fatalities per vehicle decrease (see Figure 2). Smeed concluded that fatalities (F) in any country in a given year are related to the number of registered vehicles (V) and population (P) of that country by the following equation:
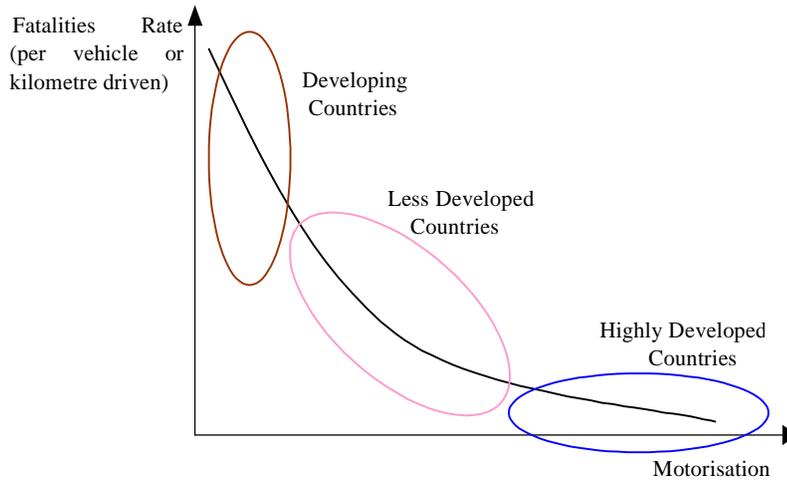
$$F/V = (V/P)^-$$ (1)

Where F = number of fatalities in road accidents in the country

V = number of vehicles in the country

P = population

$= 0.003, \quad = 2/3$

This formula became popular and has been used in many studies. It is often called as Smeed's formula or equation despite some authors preferring to call it a law.



*Figure 2.* *Motorisation and fatalities rate internationally (based on Smeed's formula)*

This nonlinear relationship can be translated to a linear one by taking the logarithms o f the two sides:

$$\text{Log } Y = \log \quad + \quad \log X \tag{2}$$

Where Y is F/V and X is V/P

The number of fatalities can be derived from Smeed's formula as: $F = c.V \ .P$ , where c, , are parameters and they are estimated from data by using the least square method . For the Smeed data (year 1938) the formula was:

$$F = 0.0003 \ P^{2/3} \ V^{1/3} \tag{3}$$

Personal Risk (fatalities per population) is obtained by multiplying both sides of Smeed's equation (1) by V/P as follows:

$$F/P = a \ (V/P)^{1-b}$$

$$\text{or } F/P = 0.0003(V/P)^{1/} \tag{4}$$

Since 1949, many studies have discussed Smeed's equation (1) or they made a reference to this equation. Some authors followed the equation of estimating the regress ion parameters ( , ) of the data by calculating the country road safety performance in comparison to other countries; see Jacobs and Hutchinson (1973), Jacobs (1982), Mekky (1985). They found that Smeed's formula can give a close estimation of the actual data and it can be applied to different sample sizes of countries and years with the use of different values of   and  . Jacob and Fouracre

(1977) applied this formula to the same sample of countries used by Smeed for the years 1968 - 1971 and they found that the formula remains stable. Jacobs and Hutchinson (1973) examined the data for 32 developing and developed countries from the year 1968. Mekky (1985) found that the equation significantly captures the relationship between motorisation and traffic risk; h e used cross sectional data for the Rich Developing Countries (RCDs). Al Haji (2001) compared 26 countries around the world with different levels of development. The results from this study support Smeed's view of the relation between motorisation and fata lity rates. The correlation was high, 96% of the variations are explained for the low motorised countries and 93% for the highly motorised countries.

Some authors have tried to develop Smeed's formula and its accuracy further by including several socio-economic variables in the model. Fieldwick (1987) has included speed limits in the same model. The number of registered vehicles has been replaced by the total vehicle kilometre driven in many late studies (e.g. Silvak, 1983). This measure (vehicle kilometre driven) was not available at the time of Smeed's study.

Nevertheless, some other studies have tried to explain why the curve of development (fatality rates) declines downwards as been noted in many countries and shown in Smeed's formula. The studies have analysed the factors and measures that influence the development of the curve of road safety. A review of these studies is reported by (Elvik & Vaa, 2004) and (Hakim, 1991). Besides, Minter (1987) and Oppe (1991b) showed that Smeed's law is a result of a national learning process over time. The development in society at the national level is the result from the developments at the local level. In other words, the individuals (road users) can learn by experience in traffic where they improve their driving ski lls and knowledge, while the whole society can learn by better national policy and action plans. The Figure shown here illustrates these factors on the development curve of road safety.
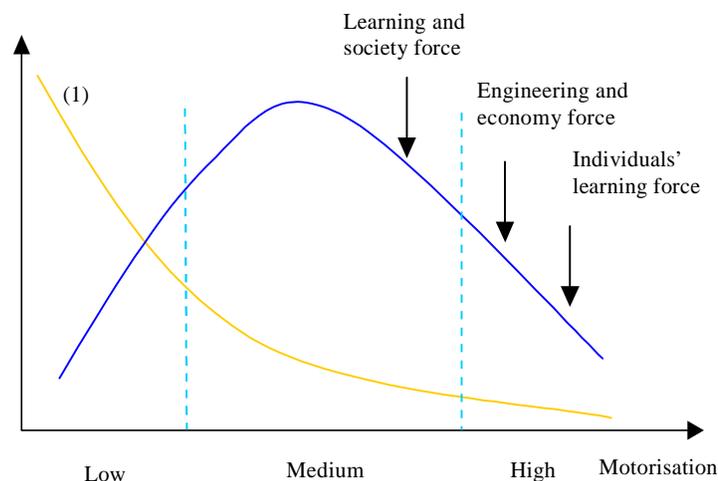


*Figure 3. The influencing factors on the development curve of road safety*

At the same time, many studies have criticised Smeed's model because it only concentrates on the motorisation level of country and ignores the impact of other variables, see (Broughton, 1988), (Andreassen, 1985), (Adam, 1987), where according to Smeed's model, population and vehicles are the only country values, that influence the number of fatalities. This means that road safety measures have no meaning because road fatalities can simply be predicted from population and vehicle numbers in any country and any year. Andreassen (1985) criticised the model's accuracy because there would always be a decline in traffic risk for any increase in the number of vehicles, but generally in non-linear way. Andreassen proposed relating fatalities to $(V)^{B4}$ where $B_4$ is a parameter highly related to each particular country, even to countries with a similar degree of motorisation. Furthermore, Smeed's study analysed data for one year, it was a cross - sectional analysis with no time series analysis (Adam, 1987). Smeed's formula expected the downtrend in fatalities rate but not the number of absolute fatalities, which has occurred in almost most western countries in the seventies (Broughton, 1988). In other words, the trend failed to fit and predict the same as the real figures in HDCs. Broughton has concluded that: *"Smeed's formula has no generally validity"*

In later years Smeed (in Oppe, 1991a) has commented on some of these remarks that: *"...We must be guided by the data and not by our preconceived ideas...The numb er of fatalities in any country is the number that the country is prepared to tolerate..."*

Also, Haight (in Andreassen, 1985) has referred to Smeed's equation that: "... *When the formula disagrees with the observations we tend to assume that the particular area under investigation is safer or less safe than it ought to be...*"

Regardless of whether one agrees or disagrees with Smeed's model, the fact remains that the model gave a simplified and fairly good representation between traffic risk and motorisation of different parts of the world during the earlier stages of road safety development.

At the same time, there are many other curves developed and presented in different studies in a simple way and with a small number of indicators (motorisation, personal risk an d traffic risk), which can describe the development of road safety in different countries. For instance, Koornstra & Oppe (1992) have suggested the model shown in (figure 4) to describe the long - term development of the number of fatalities over time in hig hly developed countries (HDCs). There is an increasing S-shaped curve with regard to the development of motorisation (referring to the number of vehicle kilometres per year). There is a decreasing curve for the development of the fatality rates per year (traffic risk). Together, by multiplication the values of motorisations and fatality rates, they result in the increase and decline of the number of fatalities that have been noticed in HDCs in recent decades.
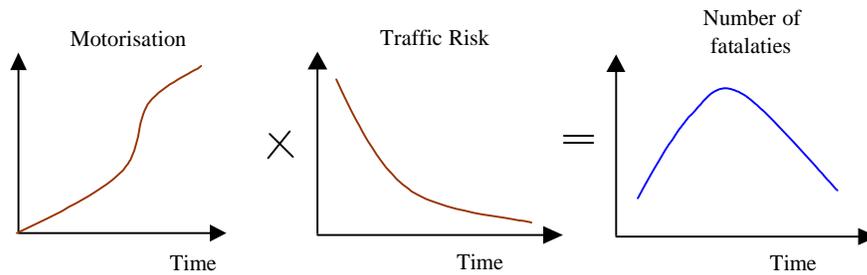
***Figure 4.*** *Road safety development in HDCs (Koornstra & Oppe, 1992)*

Haight (1983) illustrated the development of road safety in developing countries as shown below. The total number of fatalities increases, the fatalities per unit of travel decreases, and the fatality per population remains al most stable or with some decline over time.
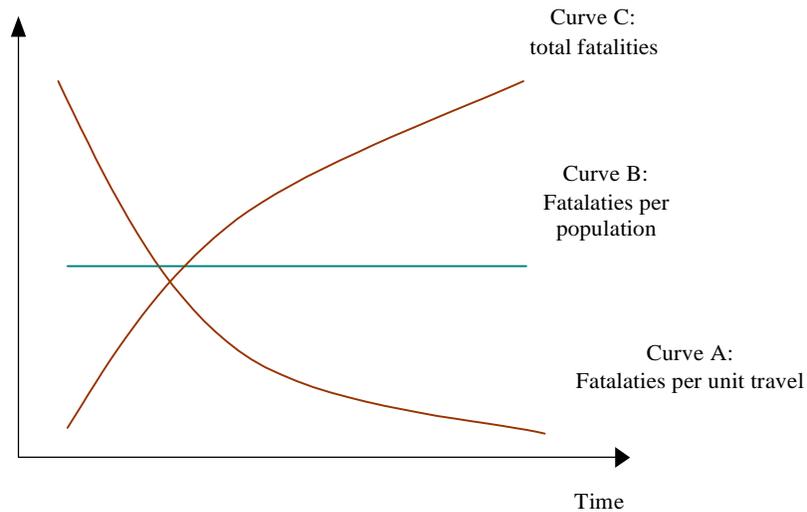


***Figure 5.*** *Road safety development over time for developing countries (Haight, 1983)*

The long-run trends which are shown in (Figure 4) and (Figure 5) based mainly on repeated cross-section surveys from different countries for different years. The objective is to show whether the change (development) of data varies over time.

The Timo model (1998) shows curves of number of fatalities and total national mileage by time in many eastern and west ern Europe countries according to the development levels of mobility (Figure 6). At the beginning of the growth of motorisation, total fatalities are very high, but decline continuously at a declining rate when mobility increases. When the mobility reaches the saturation level, the decrease in the number of fatalities has slightly stopped or fluctuated.
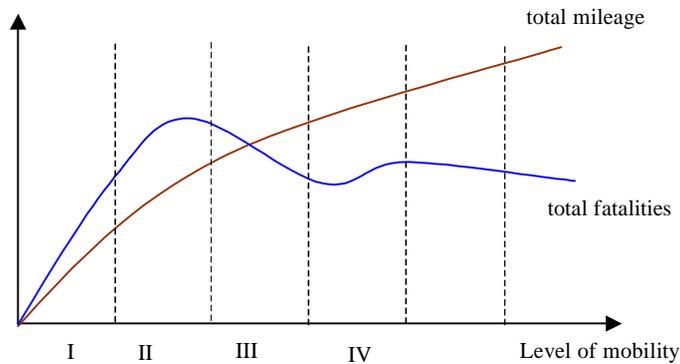
*Figure 6. Total fatalities based on the development of mobility (Timo, 1998)*

The correlation between traffic risk (fatalities per number of ve hicle kilometres) and personal risk (fatalities per number of population) is shown in Figure 7. With a growing number of vehicles per population, countries move from the right to the left across the curve (Fred, 2001). An early level of motorisation, first leads to a growing number of traffic-related deaths, but not necessarily with the same high growth in the number of population-related deaths. However, later at a medium level of motorisation, traffic and personal risks increase and both values are high. At the third higher stage of motorisation, when a country is completely motorised, traffic and personal risks decrease. The change between the three stages is due to better engineering of vehicles and roads and greater understanding of the system by the ro ad users.
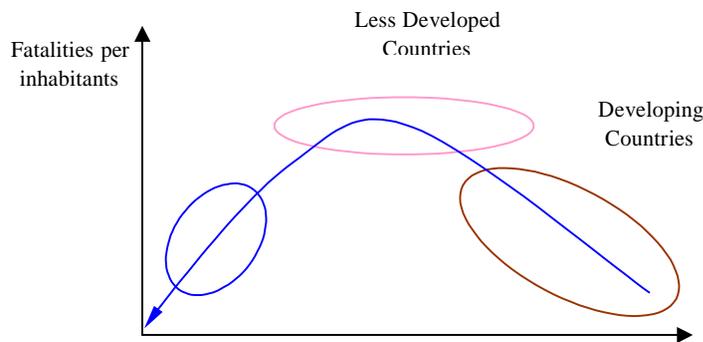


*Figure 7. Traffic risk and personal risk in different countries where countries move*

*from the right to the left across the curve (Adapted from work by Fred, 2001)*

As we discussed earlier, the personal risk is a function of traffic risk  and motorisation. Navin (1994) has converted this function into the following equation (see also Figure 8):

$$T = T_f\, e^{\frac{-M}{M_0}} \tag{5}$$

Where   $M_0$ is the value of motorisation at maximum personal risk,

$T_f$ is the point where the exponential curve meets the T-axis,

T is the traffic risk, fatalities per number of vehicles, and

M is the motorisation, vehicles per population
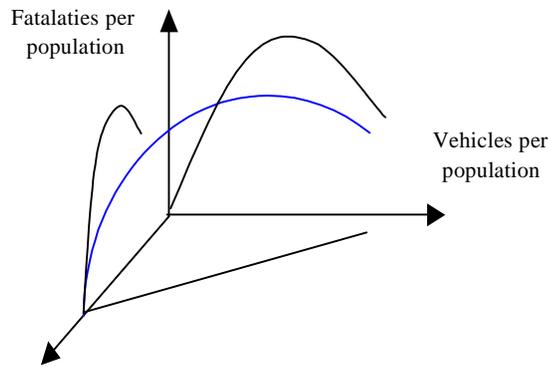


**Figure 8.** *Three-dimension model of motorisation and fatality rates (Navin, 1994)*

The models previously mentioned are in some way based on regression models or multiple regression models or quadratic regression models. They employ more than variables to check the goodness of fit to data from different countries and to find the appropriate related equation(s).

## III. THE SECOND GENERATION: LINKING TRAFFIC RISK, MOTORISATION AND PERSONAL RISK WITH TIME

In this generation, many benchmarking models have been developed to describe and predict safety development between countries on the basis of time serie s models and theories. They relate the variables to a function of time to determine the long run change in safety level over time either in a monthly form or annually. These models attempt to find the smoothed curves to the time series data.

Koornstra (1992) has shown that motorisation is considered to be dependent on time, and the relationship between deaths and population should include time. To measure the correlation between the output and input variables, one should take into account the trends in the model. He found the following formula for approximating the number of fatalities for a country in a particular year:

$$F_t = z V_t^x V_{t-k}^w \left( (\frac{V_{max}}{V_{t-k}})^c - 1 \right)^y \qquad (6)$$

Where     $F_t$ is the number of fatalities for a country in a year t,

$V_t$ is the number of vehicle kilometres travelled in the year t,

Vmax is the maximum number of vehicle kilometres,

k is the time lag in years, and

x, w, z, y, and c are constants

Oppe (1989) assumes that fatality rates follow a negative exponential learning function in relation to the number of vehicle kilometres and time. This method has been found to be most effective when the components describing the time series behave slowly over time as follows:

$$\ln (F_t/V_t) = \ln (R_t) = \ t +$$

Or, equivalently:

$$R_t = e^{\ t+} \qquad (7)$$

Where     the ln function is the natural logarithm,

$F_t$ is the number of fatalities for some country in a year t,

$V_t$ is the number of vehicle kilometres travelled in that year,

$R_t$ is $F_t/V_t$ and

,    are constants

This means that the logarithm of the fatality rate decreases (sign of improvement) if    is negative proportional with time. This model is called the negative exponential learning model, where    is supposed to be less than zero. Both    and    are the parameters to fit.

Oppe (1991a) assumes that the amount of vehicle kilometres per year is related to time and it is assumed that traffic volume will develop over time by a logistic function of a saturation model. This assumption indicates that the growth rate of traffic volume is a percentage of the ratio between the traffic already existing and the remaining percentage of Vm as follows:

$$\ln(\frac{V_t}{V_m - V_t}) = \ t +$$

Or, equivalently:

$$V_t = \frac{V_m}{1 + e^{-(\ +\ )}} \qquad (8)$$

Where $V_t$ is the number of vehicle kilometres travelled in that year, and

$V_m$ is the maximum number of vehicle kilometres

This formula shows that countries with a large   should have a fast growth in traffic. The traffic volume will increase quickly first and at the end it will reach its saturation level, which differs from country to country.

Oppe has applied the two formulas (7 and 8) to data from six highly motorised countries over the time period 1950-1985. He found that both models describe the data fairly well. He concluded that the development in road safety is a result of the development (learning) of the traffic system in the country, which is more or less similar to Smeed's conclusions. However, Oppe's theory in estimating the remaining growth of traffic is questionable, particularly when we know that many European countries are currently discussing the possibility t o stop or reduce the increase rate of motorisation. It is uncertain whether the number of fatalities can be predicted simply from the fitted curves or from the number of vehicle -kilometres. The question is therefore whether this decreasing equation (7) ass umes that the fatality rate reduces to zero in the end or not, and in this case what is the predicted year for one particular country according to its current level of mobility? Besides, what will happen to the expected number of fatalities if the country's trend becomes fully motorised to 100%.

Adams (1987) has stated a similar relation between fatalities (F) and vehicle kilometres (V), which was presented:  $Log (F/V) = a + b*y$ where y = year  – 1985. Broughton (1988) has tested this logarithmic model on d ata from Britain between 1950 and 1985 and the results fitted well. In the same study Broughton applied the same model to data from four western countries: U.S.A (1943-85), West Germany (1965-85), Norway (1947-85) and New Zealand (1948-83). He found that this model describes the data pretty well.

(Broughton 1991) and (Oppe, 2001a) they developed another technique, the 'singular value decomposition method', in comparing road safety trends between different countries. This technique investigates the similarities and dissimilarities between different groups of countries regarding fatality trend. They compared various time series of data of countries jointly to investigate the correlation between these series. This technique is useful in classifying the countries that are similar (accidents patterns) to each other.

The more detailed time series data have led to advanced and sophisticated ways of fitting a curve to data, especially with the current use of computer packages. For example, auto -regressive integrated moving average (ARIMA) techniques are used to fit and forecast the time series that are changing fairly quickly. ARIMA models should be stationary; otherwise we need to transform the data to make them stationary.  The first part of the model is the auto -regressive (AR). This means that the Y factor is a relation of past values of Y. The second part is the moving average (MA). This means that the Y factor is a function of past values of the errors; see Frits et al. (2001). For instance Scott (1986) has appli ed this method to model the accidents in England (seasonal and annual data). Oppe (2001b) has applied this method to a model that predicts the accident data from Poland (1980 -2010).

## IV. THE THIRD GENERATION: THE NEED FOR INCREASED INTEGRATION WITH MANY VARIABLES INVOLVED

Most early development efforts for international road safety development have focused on one or a few indicators by means of risk indicators (accident rates), which are few and isolated. The third generation has realised the need for increased integration between product (accident rates) and other indicators in the same benchmarking model.

Page (2001) has compared safety situations and trends in the OECD countries from 1980 to 1994. He developed a statistical model using pooling cross-sectional time series. The model gives a rough estimate of the safety performance of a country regarding some variables such as: population levels, vehicle fleet per capita, percentage of young people, and alcohol consumption. Based on this model, countries that are showing the best levels are Sweden, the Netherlands and Norway.

Bester (2001) has developed a model by means of stepwise regression analysis. The criteria will indicate the variables that should be added or removed in the model. The study used collected data from different international sources and the variables used are: national infrastructure and socio-economic factors (e.g. GDP per capita).

(Elvik & Vaa, 2004) has used techniques for evaluating the effectiveness of various road safety measures (output) in different countries by using what is called the "before and after study" evaluation technique. Similar techniques might be used to show the effectiveness of road safety measures that countries have taken.

(Asp & Rumar, 2001) developed the 'Road Safety Profile (RSP)'. It includes all possible quantitative and qualitative variables that may have been important in describing, explaining and comparing road safety situations in different countries. This technique illustrates the development in a country over time in a quick and easy illustration. RSP uses both types of quantitative and qualitative indicators. The quantitative data obtained from international sources. The qualitative indicators are derived from a survey of questionnaires to experts in each country. Respondents' countries were asked to answer questions regarding key road safety issues. The answers are used to measure the RSP level for each country.

The countries were divided into three different groups of motorisation (low, medium and high). The RSP technique includes more than 20 direct and indirect road safety indicators. Each indicator is normalised on a scale from +2 to –2. Then the results are illustrated as a profile (see Figure 9). This made the comparisons between countries simpler and easier. The Road Safety Profile was seen as a successful tool for identifying the problems in the country where actions are needed.
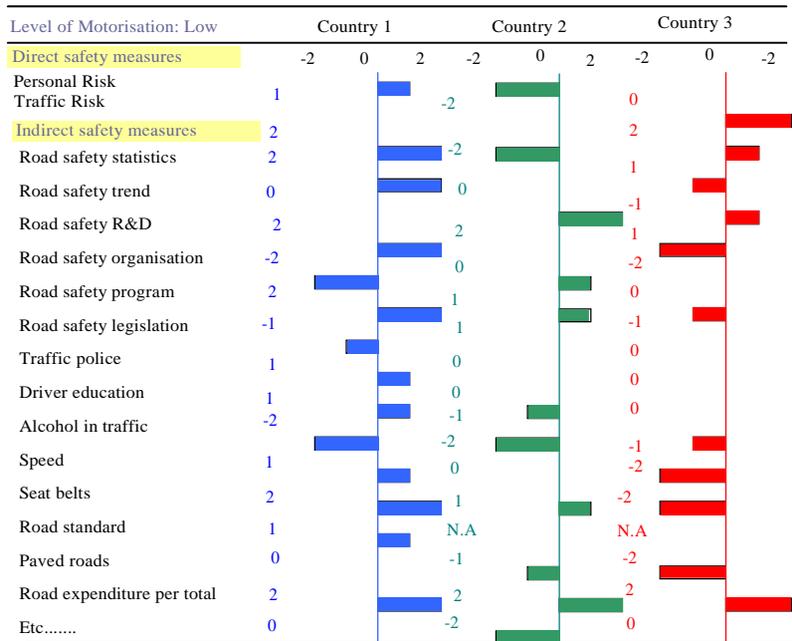
**Figure 9.** *Illustration of Road Safety Profiles (Asp & Rumar, 2001)*

The Globesafe database (Asp, 2004) is pre sently being constructed by means of IT and Internet. It facilitates the illustration of Road Safety Profile across countries.

## V. THE FOURTH GENERATION: LINKING PRODUCT, PRACTICES AND STRATEGIC BENCHMARKING- RSDI AS AN EXAMPLE

The latest generation realise d the necessity of having a systematic way to add up all the potential indicators of human, vehicle, road, environment, and regulation combined with weights into one index. This will give a broad picture of benchmarking and not focus on one or few particular aspects.

RSDI, as an example, combines all three types of benchmarking together: Product, Practices and Strategic Benchmarking. This will be useful to tell success from failure in a country. RSDI is capable to compare the road safety level and progres s across a large number of countries and regions worldwide

Each benchmarking type is a sum of indicators and dimensions. There will be as balanced and important indicators within each dimension as available of data as possible.

The following figure shows the main components involved in RSDI where each component comprises a number of indicators:
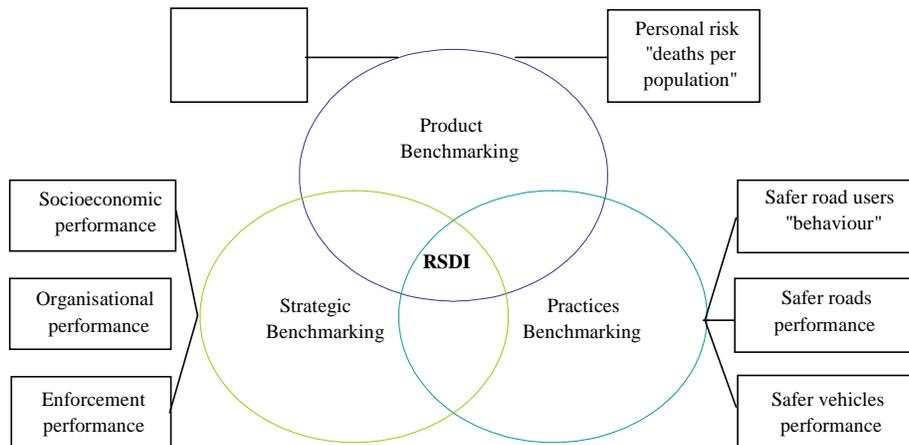
*Figure 10.* RSDI conceptual framework (overall road safety performance)

The major steps used in the process of constructing RSDI are the following (Al -Haji, 2005):

- Finding the key indicators and dimension,

- Normalising (standardising) the indicators,

- Weighting the indicators,

- Combining the chosen indicators into (RSDI) by using different techniques,

- Applying RSDI for a sample of countries and performing an a nalysis of the results, and finally

- Testing the uncertainty and comparing the methods used with the obtained results.

The composite index of RSDI takes the form:

$$RSDI = \frac{\sum_{i=1}^{n} w_i X_i}{\sum_{i=1}^{n} w_i}$$

Where:    $X_i$: normalised indicators for country i

$w_i$: the weights of the $X_i$

n number of dimensions

The weights ranged from 0 to 1 and the sum of weights is one.

The RSDI ranged from 0 till 100. The higher values indicate a higher level of safety in the country. The lower values indicate the worst performance in country in term s of road safety level and vice versa. The target value of RSDI is 100 and it shows how far the country has to be developed to provide safer roads.

## VI. CONCLUSIONS

International benchmarking models in road safety are in the interest of most countries and international bodies since they will show the scale of the problem. This paper has reviewed in brief the development of the benchmarking models and how they have been used.

Road safety is a complex issue and there are a high number of performance indicator s that can be used for benchmarking. However few of these indicators were generally included in the earlier modelling process (generation one and two).

There are mainly three types of benchmarking: product of safety, practices, and strategic benchmarking. They differ depending on the type of indicators, which the models are trying to compare. The literature review has shown the importance of having a large number of factors involved in the benchmarking model. The road safety level in a country is a result of the whole development in society (e.g. health, education, enforcement, engineering, etc.).

The RSDI seems to provide a broader picture compared to the traditional early models in road safety.

Today computers are developing rapidly, which simplifies th e work and analysis of cross-sectional data and time series data, which was not available before (e.g. to Smeed in 1949). This development has made the work in the third and fourth generations become easier and closer to reality.

### Acknowledgement

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