Benchmarking Road Safety:

Lessons to Learn from a Data Envelopment Analysis

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ABSTRACT

Road safety performance indicators (SPI) have recently been proposed as a useful instrument in comparing countries on the performance of different risk aspects of their road safety system. In this respect, SPIs should be actionable, i.e. they should provide clear directions for policymakers about what action is needed and which priorities should be set in order to improve a country's road safety level in the most efficient way. This paper aims at contributing to this issue by proposing a computational model based on data envelopment analysis (DEA). Based on the model output, the good and bad aspects of road safety are identified for each country. Moreover, targets and priorities for policy actions can be set. As our data set contains 21 European countries for which a separate, best possible model is constructed, a number of country-specific policy actions can be recommended. Conclusions are drawn regarding the following performance indicators: alcohol, speed, protective systems, vehicle, infrastructure and trauma management. For each country that performs relatively poorly, a particular country will be assigned as a useful benchmark.

KEYWORDS: road safety, performance indicator, data envelopment analysis, benchmark, target setting, priorities

1. INTRODUCTION

During the past decennia there has been a steady increase in traffic volume, which resulted in continuously increasing traffic problems. Worldwide, an estimated 1.2 million people are killed in road crashes each year and as many as 50 million are injured (World Health Organization, 2004). Due to the human as well as financial suffering caused by crashes there is a continuous effort to improve the level of road safety. In this battle the European Commission set the ambitious aim of halving the number of traffic fatalities between 2000 and 2010 (European Commission, 2001). The 52 500 fatalities in 25 European countries in 2000 has decreased to 41 300 in 2005 (SafetyNet, 2008). It is, however, still a long way to the 25 000 objective for 2010. Several measures exist to this end from which each country needs to select the most effective and appropriate set. Road safety performance information from other countries can help in this respect.

Better insight into the road safety situation can be gained by studying the available data. In this context, a comparison between countries is often made based on crash data. The number of injury crashes and the number of casualties (divided into fatalities, serious injuries and slight injuries) per capita can be used to set up a ranking. In respect to the number of fatalities, Sweden, the United Kingdom and the Netherlands – being referred to as the SUN countries – are seen as an example for other European countries. However, these crash related figures are unable to indicate on which aspects of road safety a country should focus. To select an appropriate set of measures detailed knowledge about the underlying determinants needs to be obtained. Therefore, the concept of road safety performance indicators is recently being elaborated. The

European Transport Safety Council (ETSC) defines a safety performance indicator as "any measurement that is causally related to accidents or injuries, used in addition to a count of accidents or injuries in order to indicate safety performance or understand the process that leads to accidents" (European Transport Safety Council, 2001). One of the main characteristics of an indicator is that it can be influenced by policy measures. This resulted in the definition of a number of essential road safety risk domains on the European level (SafetyNet, 2005), i.e. alcohol and drugs, speed, protective systems, vehicle, infrastructure and trauma management[1,2].

Furthermore, in addition to the development of a set of useful crash related variables on the one hand and road safety performance indicators on the other hand, it would be interesting to create one road safety index (a combination of relevant road safety aspects into one index) enabling an overall comparison across entities (e.g. countries). The multidimensionality is summarised and the total road safety picture can be presented. As already done in other domains like economy, environment and technology (Saisana & Tarantola, 2002) a composite indicator methodology involving several methodological steps needs to be elaborated for the road safety field: a new, challenging and necessary task. The aggregation process resulting in a composite indicator or index consists of two phases. First, the individual indicators per risk domain should be

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[1] The SafetyNet project stresses the importance of daytime running lights as an extra risk domain (in addition to the other six). However, this domain is not considered in this study as, in literature, the importance of this rather small aspect of road safety is less obvious. Additionally, road safety experts consider this as the least important risk domain of all (Hermans et al., 2008a). Some Northern countries constituted a daytime running lights' law a long time ago. Recently, there is no agreement regarding the obligation of daytime running lights on a larger (European) scale as the possible effects are unclear. Moreover, the availability and quality of the data is very poor compared to the other indicators.

[2] Road safety outcomes can be decomposed in two main components, i.e. exposure and risk. To fairly compare countries road safety outcomes (e.g. the number of fatalities) are often expressed in terms of exposure (e.g. per number of inhabitants or vehicle kilometres). For these relative outcomes main risk factors are then identified.

aggregated into one indicator per domain. Next, the domain indicators are aggregated in one road safety index. In literature, most attention is paid to the second aggregation. One of the most important aspects in aggregation is the assignment of a correct weight to each indicator. The composite indicators field uses several weighting methods of which budget allocation, analytic hierarchy process, data envelopment analysis (DEA), factor analysis and equal weighting are the most common ones (Nardo et al., 2005; Saisana & Tarantola, 2002). A comparison of these five methods on road safety data revealed that the DEA method resulted in the best fit with the ranking based on the number of traffic fatalities per million inhabitants (Hermans et al., 2008a). These good results of the data envelopment analysis in addition to its interesting characteristics (determination of the most optimal score for each country, consideration of both inputs and outputs, easy incorporation of value judgements to obtain realistic weights, etc) caused the elaboration of a DEA model adapted to and suitable for the specific road safety context. Taking into account relevant road safety information for a large set of countries, the optimization model results in an overall road safety score for each country. The relative position of a country can then be assessed, relevant benchmark countries identified and risk areas requiring urgent policy action assessed.

Data envelopment analysis has already been used in a number of composite indicators (e.g. Cherchye et al., 2005; 2006) to measure the relative performance of countries in terms of efficiency. Different from the original input-output DEA model, a composite indicator DEA model contains only outputs (i.e. indicators). However, the road safety domain consists of both indicators and crash data, enabling a new DEA modeling in the composite indicators field. The broad DEA field offers numerous possible models

(Gattoufi et al., 2004). In the following section we discuss the development of our data envelopment analysis road safety (DEA-RS) model. The data that are used in this study are presented in section 3. The results for the countries are subsequently provided in section 4 based on which policy recommendations are made. In section 5, the main advantages and limitations of the DEA-RS model are discussed and the last section summarizes the most important conclusions of this study.

2 MODEL

Data envelopment analysis developed by Charnes, Cooper and Rhodes (1978) is a performance measurement technique that can be used for evaluating the relative efficiency of decision making units (DMU's). For each DMU – country in our case – the efficiency is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs (Cooper et al., 2000). A score equal to one indicates an efficient country. A set of weights is determined resulting in the best possible score for that country while taking into account a particular set of inputs and outputs. This implies that dimensions on which the country performs relatively well get a higher weight. In the road safety case, the number of crashes and casualties are the outputs while the performance on the underlying risk domains are the inputs (see Figure 1). By defining output and input in this way, the logical relationship of inputs leading to outputs is maintained. For example, an increase in the seatbelt wearing rate results in a reduced number of casualties.

However, as opposed to the economics field, we want a road safety outcome that is as low as possible and indicators that are as high as possible. Therefore, the ratio of the weighted output and the weighted input will be minimized. As a non-linear optimization model is difficult to solve, a linear model is formulated in which the sum over *k* weighted output values of a country *j* is minimized and the sum over *l* weighted road safety indicator values of a country *j* is set equal to one. Algebraically, the DEA model that we will use is presented in (1) and explained below. Input and output weights (v_i respectively w_o) are chosen to optimize the objective value under the imposed restriction of non-negative weights as stated by the final constraint.

$$
\begin{aligned}
RSS_j &= \min \sum_{0=1}^{k} w_o y_{oj} \\
\text{s.t.} \quad & \sum_{i=1}^{l} v_i x_{ij} = 1 \\
& \sum_{0=1}^{k} w_o y_{om} - \sum_{i=1}^{l} v_i x_{im} \geq 0 \qquad \forall m=1,\ldots,n \\
& L_o \leq \frac{w_o y_{oj}}{\sum_{o=1}^{k} w_o y_{oj}} \leq U_o \qquad \forall o=1,\ldots,k \\
& L_i \leq v_i x_{ij} \leq U_i \qquad \forall i=1,\ldots,l \\
& w_o, v_i \geq 0 \qquad \forall o, i
\end{aligned}
\tag{1}
$$

An optimal road safety score (*RSS*) equal to one indicates an efficient country; inefficient countries on the other hand have a road safety score higher than one. The reasoning is that a certain amount of risk (input) results in some level of fatalities and crashes (output). In case the weighted output is equal to the weighted input for a country, the country is highly efficient. Nevertheless, in case the output in terms of fatalities and crashes is higher than what could be expected based on the risk level (in other words, weighted output minus weighted input is larger than zero), the country is inefficient and its road safety score will be larger than the optimal minimum of one. So, the efficient country of two countries with the same level of risk (i.e. the same indicator values) is the one with the lowest number of fatalities and crashes.

The first inequality constraint guarantees that the difference between weighted output and weighted input is nonnegative for all n countries in the data set in case the optimal weights for the country under study (i.e. j) are filled in. In other words, no country can have a weighted output (i.e. road safety outcomes) lower than its weighted input (i.e. a certain amount of risk). Furthermore, additional restrictions are needed for our model. Total flexibility for the weights has been criticized on several grounds as the weights prove to be inconsistent with prior knowledge or accepted views on the relative values of the inputs and outputs (Allen et al., 1997 ; Pedraja-Chaparro et al., 1997). To obtain realistic and acceptable weights, a multitude of ways to capture value judgements or prior information in DEA are proposed in literature (Allen & Thanassoulis, 2004; Allen et al., 1997). For a country with a very high score on alcohol for example, all input weight could be assigned to this indicator and all output weight to a very low number of fatalities. In that case, only two aspects of road safety are considered which is unacceptable for fairly comparing countries. Here, a distinction is made between the indicators and the crash variables. The contribution of each indicator pie share (i.e. the product of the indicator value and the indicator weight) to the overall weighted input is constrained to lie in the range defined by the minimum and maximum weight obtained from the budget allocation results over all experts (Cherchye et al., 2006). For this case, 11 road safety experts from several European countries were asked to distribute a given budget over a set of risk domains in such a way that spending more on a domain implies that (s)he wants to stress its importance. The experts, participating in the European SafetyNet project and familiar with road safety risk domains and performance indicators, indicated the share of the budget they would spend on alcohol and drugs, speed, protective systems, vehicle, infrastructure and trauma management (Hermans et al., 2008a). For each domain, the minimum (*Li*) and maximum share (*Ui*) over the 11 experts, shown in Table 1, is taken into account by the model. All experts assigned some budget (i.e. more than zero euro) to the six domains implying that all six risk factors are involved in the model. Moreover, the alcohol weight for a country should be chosen in such a way that the product of the alcohol weight and the alcohol value contributes between 7.7 and 38.5% of the weighted input (which is constrained to be equal to one).

In addition, a minimum and maximum bound was given to the share of injury crashes and fatalities in the weighted output (which has to be minimized). The crash share is restricted to the interval [0.1-0.5] while the interval for the fatality share is [0.4-0.8]. These limits guarantee that both outcomes will be used to some extent by the model. Both intervals are rather wide to allow a high level of flexibility. Moreover, the intervals overlap to enable each road safety outcome to get assigned the largest share. However, the interval of the fatality share is higher than the one of the crash share due to the quality of these data (the definition of a road traffic fatality is rather uniform for the different countries, these figures are well (i.e. precisely) collected and are assumed to be the correct ones). In addition, two risk factors, namely protective systems and trauma management are assumed to mainly affect the severity level of an injury and the chance of surviving a crash. Therefore, the casualty domain has a higher share compared to the crash domain. Our final goal is to determine an optimal road safety score for each country that considers all domains presented in Figure 1.

Rather than comparing countries on each road safety aspect separately, the DEA model offers an overall score in which various inputs and outputs are weighted in the best possible way. The simultaneous study of the road safety outcomes and performance indicators offers new insights. In general, the outcomes of a DEA model can be used as follows. An overall ranking of the countries can be made based on their optimal road safety score. Next, for inefficient countries with an index score larger than one, the country-specific weights can identify the sources and the amount of inefficiency in each indicator (Cooper et al., 2000). If the inefficiency of a country is reduced most in case of a better alcohol performance (i.e. that country has a low weight attached to alcohol), this information can be translated in specific alcohol action plans. Additionally, for each inefficient country, another country in the data set can be taken as a benchmark (this is the country for which weighted output is equal to weighted input). Based on the indicator values of the benchmark country and a country-specific adjustment factor, useful targets can be set for the inefficient country and the achievement towards these targets could be monitored in the future. By comparing the current values with the target values domains requiring urgent action can be identified and priorities assigned. These aspects will be illustrated on a road safety data set in section 4. This section is ended with a brief discussion on the target setting approach.

The values of the benchmark country provide useful information in terms of targets for the inefficient country. However, a second factor – a country-specific adjustment factor – is used in the target setting formula in order to assign different targets to countries with the same benchmark(s). Moreover, this adjustment factor can act as a weighting factor for the input and output values of the benchmarks in case more than one country appears to be a benchmark (b=1,…,B). The targets consist more of the values of the first benchmark than the second benchmark if the dual price of the binding restriction (weighted output equal to weighted input) of the first benchmark is larger than the dual price of the second benchmark. The dual price is the rate at which the objective function value will improve as the right-hand side or constant term of the constraint is increased by a small amount (LINDO Systems Inc, 2007). The inefficient country A, having B benchmark countries should aim at the following level of inputs and outputs[3]:

$$\text{Targets}_\text{A} = \sum_{b=1}^{B}\left(\frac{\left|\text{dual price}_\text{b}\right|}{RSS_A} \times \text{values}_\text{b}\right) \qquad \text{with } B = \#\text{ benchmarks} \qquad (2)$$

Equation 2 shows that the target input and output values of a country consider the values of its benchmark(s) and an adjustment factor representing the change in the objective value in terms of percentage. Moreover, multiplying the target values with the optimal set of weights results in a road safety score of one.

3 DATA

[3] More generally, this formula could contain all n countries in the data set, but a simplified version consisting of benchmark countries only is presented here as the dual price of a non-benchmark is equal to zero (the restriction has some slack and is non-binding).

In this study we focus on 21 European countries for which a complete data set could be obtained: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland and the United Kingdom. Six road safety risk domains and two road safety outcome domains are used in this study (Figure 1). More specifically, for the risk domains alcohol and drugs, speed, protective systems, vehicle, infrastructure and trauma management one indicator will be defined even as one outcome variable related to crashes and one for casualties.

The level of road safety between countries is often compared by means of the number of traffic fatalities, normalised by data on the population, the vehicle fleet, or kilometres driven in a country (European Union Road Federation, 2007; SafetyNet, 2008). This information is very useful, but besides focussing on the (fatal) consequence of a crash the occurrence of road traffic crashes with injuries should be considered. An injury crash can result in slightly injured persons, severely injured persons and/or fatalities. Therefore, the number of injury crashes per 100 000 inhabitants is used to indicate the frequency of road traffic crashes in each country. The fatality and crash figures are deduced from the European Union Road Federation (2007) and the population data from the Organisation for Economic Co-operation and Development (2008).

However, as already mentioned in the introduction, one of the main disadvantages of crash related variables is that although they indicate the relative position of a country they cannot offer suggestions on how to reduce the number of crashes and casualties. To this respect, road safety performance indicators are created. The European SafetyNet project (SafetyNet, 2005) develops a framework for possible road safety performance indicators for which information on the European level should be collected uniformly (i.e. by means of the same measurement process). They recommend a number of risk domains having an influence on road safety. Ideally, each domain is represented by a set of appropriate indicators. A number of criteria should be considered in selecting suitable measures of a domain. More specifically, an indicator should be relevant, measurable, understandable, specific, sensitive and have reliable and comparable data available (Hermans et al., 2008b). Especially these latter criteria – reliable and comparable data available – are at this moment difficult to meet as the concept of safety performance indicators is relatively new and no uniform data collection systems are set up yet for a large set of countries. Therefore, in practice, a distinction between best needed indicators on the one hand and best available indicators on the other hand is often made (European Commission, 2005; Ledoux et al., 2005). A best needed indicator refers to an ideal indicator for which the concepts, definitions or data are not yet existing; for which data are existing, but of insufficient or unknown quality; or for which cross-country comparability is limited. A best available indicator is an indicator which can act as a proxy for a best needed indicator and for which the available data are of sufficient quality (i.e. reliable and comparable). Here, the methodology is illustrated on 6 best available domain indicators. Detailed indicator information is provided below. For each indicator, a higher value implies a higher level of road safety. All data, related to 2003, are shown in Figure 2.

The three most important behavioural risk areas relate to alcohol, speed and protective systems. Therefore, the first domain deals with alcohol and drug use. The relative risk of getting involved in a crash starts to increase significantly at a blood alcohol content (BAC) level of 0.04g/dl. For single-vehicle crashes each 0.02% increase in BAC level approximately doubles the risk of ending up in a fatal crash (World Health Organization, 2004). Although the effects of medical and recreational drugs are less understood than those of alcohol, there is agreement that drugs intoxication often goes hand in hand with greater morbidity and mortality (Transportation Research Circular, 2005). As indicator for the first domain, we select the percentage of road users respecting the BAC limit. These data are obtained from the Social Attitudes to Road Traffic Risks in Europe (SARTRE) research (SARTRE 3 consortium, 2004). The second domain – speed – is also considered to be a serious risk factor. In the literature (Elvik, 2005; Kweon & Kockelman, 2005; World Health Organization, 2004) numerous justifications can be found for the fact that excessive or inappropriate speed is one of the main causes of crashes and one of the factors that influences the severity of crashes to a large extent. The percentage of drivers with a driving speed below the maximum speed limit on country roads is the chosen indicator. These data were also derived from SARTRE (2004). Another behavioural characteristic, which is believed to influence road safety is the use of protective systems such as seatbelts, helmets, child's seats, etcetera. These can significantly reduce the consequences in case of a crash (Bédard et al., 2002; World Health Organization, 2004). As a third indicator, we select the percentage of persons wearing a seatbelt in the front seats (with data from the European Transport Safety Council, 2006).

The next domain involves the vehicle. Vehicle techniques and technology have been rapidly evolving. New cars are being equipped with several driving assistance systems, making the age of the vehicle park an indicator of the level of road safety in a country (SafetyNet, 2005). From the United Nations database (2006) the percentage of relatively new cars (i.e. less than 6 years old) is selected. The fifth domain relates to infrastructure. Numerous possible indicators can be considered (European Transport Safety Council, 2001; Evans, 2004; SafetyNet, 2005) but data issues limit the indicator choice. We select the density of motorways in a country, as defined by the total length of all motorways divided by the (surface) area of the country. A high motorway density implies that motorists are rather close to an approach road which enables them to use this safest road type more quickly. Indicator values are deduced from the Eurostat Yearbook (2007). Finally, trauma management influences road safety as a better medical service following a crash can increase the chance of survival. In this study, this dimension is indirectly measured by the share of the gross domestic product spent on health care. The data for this best available indicator are derived from the World Health Organization (Kuszewski & Gericke, 2005).

Six main risk domains and two road safety outcomes are used in the road safety data envelopment analysis model. For the set of 21 countries data for a fatality variable (the number of road traffic fatalities per million inhabitants) and a crash variable (the number of injury crashes per 100 000 inhabitants) have been collected. In addition, for each of the six inputs an indicator has been identified. Several possible indicators have been evaluated on a number of criteria [4] and the best available indicator for each domain at this moment for this set of countries has been selected. Using sound, international data sources (SARTRE research, European Transport Safety Council, United Nations

[4] relevant, measurable, understandable, specific, sensitive and have reliable and comparable data available; see also Hermans et al., 2008b.

database, Eurostat and the World Health Organisation) reliable values are used in this study. However, as we make use of best available rather than best needed (or ideal) indicators, the results presented in the next section should be seen as indicative results based on the data used.

4 RESULTS

Using the road safety data of six inputs and two outputs for 21 European countries, the DEA model (Eq. 1) presented in section 2 yields the following results: a ranking based on the optimal road safety score, identification of relevant benchmarks for each inefficient country, detailed outcomes per country and country-specific road safety priorities. Each aspect is subsequently discussed.

4.1 Ranking based on the road safety score

For each country, the DEA-RS model selects the weights that both respect the imposed restrictions and minimize the road safety score. The minimum score of 1 is obtained by two countries: Denmark and the Netherlands. This outcome can be confirmed by looking at the data presented in Figure 2. A combination of some low crash figures (number of injury crashes and number of fatalities) and several high indicator values (alcohol, speed, protective systems, vehicle, infrastructure and trauma management) can result in an optimal score of 1 in case the weights are respecting all constraints. One characteristic of a road safety score equal to one is that several sets of input and output weights result in the optimal score. Therefore, in the remaining of this section, we focus on the unique, optimal weights of inefficient countries (with a road safety score larger than one). In Table 2 the 21 European countries are shown in increasing order of road safety score.

4.2 Identification of relevant benchmarks

As shown by Table 2, for 19 European countries, the road safety score cannot become one due to a certain binding restriction. More specifically, the optimal weights for the country under study cause the weighted output of another country in the data set to become equal to its weighted input. This country can be seen as a realistic and useful benchmark. Each country is characterized by specific road safety features and every country open for improvement should have its own (set of) country as example to follow. The choice of the benchmark countries is based on the road safety characteristics of the country under study. Table 3 indicates for each of the 19 inefficient countries which country out of the following set – Denmark, Finland, the Netherlands, Sweden – is suitable for comparing their road safety performance to. The benchmark is a country, on the one hand, quite similar to the one under study as the most optimal weights stress the road safety dimensions a country performs on relatively well and, on the other hand, a country that scores better than the country under study on most aspects. This is an explanation for the fact that Estonia should take Denmark as an example while the Netherlands and Sweden are the benchmarks for the United Kingdom.

4.3 Detailed model outcomes

The data envelopment analysis leads up to country-specific outcomes. Within the bounds of the equality and inequality constraints the most optimal weights are chosen creating a road safety score as close to one as possible. The model output can be interpreted and translated in useful road safety enhancing recommendations. Since each country has its own story, we will illustrate the approach here only for the first country in the data set, Austria. In section 4.4, a brief overview of the road safety risk domains requiring extra attention is given for all inefficient countries.

The output of applying the DEA-RS model to Austria is presented in Table 4. For each input and output the optimal weight is given. These weights should not be compared against one another because the raw values were used, having a different scale. It is better to look at the shares which are the products of the weight and the corresponding value. The input restriction of the model implies that the sum of the six indicator shares equals one. The sum of the crash share and the fatality share is equal to the road safety score of the country. For Austria, the final score is 1.977. This, and not 1, is the best possible score under the imposed restrictions. The indicators speed and trauma management contribute most to the final score. Figure 2 shows that Austria scores above-average on these two dimensions so more weight is given to these factors.

Another piece of useful information is related to the input and output restrictions. There are binding constraints for four inputs and one output. As we aim to minimize the road safety output (in terms of crashes and casualties), more weight is given to the output dimension Austria scores on better. In this case, the severity of the crash (or the fatality share) makes up 80% of the weighted output. The reason for this is that Austria has an average number of traffic fatalities per million inhabitants and a very high number of injury crashes per 100 000 inhabitants. The weighted input (which has to be equal to one) needs to consider all six indicators to some extent. The minimum and maximum indicator shares were determined using the opinion of road safety experts and were presented in Table 1. From Table 4 we can deduce that the maximum share of the indicator in the overall input is obtained by speed and trauma management. At the same time, the minimum share is binding for the protective systems and the vehicle domain. This implies that policy attention is especially needed for these two aspects of road safety.

The results for Austria already give some useful insights. However, information from other, best performing countries is also available. Using the set of weights given in the second column of Table 4, the weighted output or road safety score for the Netherlands respectively Sweden becomes equal to its weighted input; this is a binding restriction. Therefore, a combination of the Netherlands and Sweden can be taken as an example. The dual price associated with the binding restriction for the Netherlands (-0.583) and for Sweden (-1.441) offer valuable information as well. We will specify targets that consider both the values of the benchmark countries and the corresponding adaptation factor related to the inefficient country under study (see Eq. 2). That way, Austria and for example Belgium will have different targets, despite the fact that they share the same benchmarks. For Austria, the values to aim at result from the ratio of the absolute value of the dual price of the binding restriction for the Netherlands and the road safety score for Austria (i.e. 0.583/1.977 = 0.29) multiplied by the input and output values of the Netherlands plus the ratio of the absolute value of the dual price of the binding restriction for Sweden and the road safety score for Austria (i.e. 1.441/1.977 = 0.73) multiplied by the input and output values of Sweden. Although Austria has two benchmark countries, it can be noted that Sweden has a larger impact on the targets than the Netherlands does. As can be seen from the fifth column in Table 4, impossible values are sometimes put forward as an example (the alcohol indicator is represented by a percentage, which has a maximum of 100). However, these target values result in an efficient road safety score of 1.

In this respect, it is useful to compare the aimed values with the current Austrian situation and quantify the effort that is needed to attain the goals in terms of percentages. As measures should be taken on the input side, thereby aiming to reduce the output in terms of crashes and fatalities, we focus on the risk domains here. Priorities for the road safety indicator domains can be set based on the information in the last column. For Austria, the main priority is to enhance the percentage of persons wearing protective systems in traffic. Higher enforcement on the one hand and directed sensibility campaigns on the other hand are effective measures in this respect (SUPREME, 2007). Beside that, the performance on the vehicle domain needs amelioration. This can be done by promoting new(er) cars (e.g. by means of a change in tax policy). Furthermore, the alcohol and infrastructure domain require an increase of 4.5% to aim at. Finally, a negative value of the change needed for an indicator (in this case for the speed and the trauma management domain) does not imply that the effort should be reduced for this domain. It simply indicates that the current value exceeds the target.

4.4 Road safety priorities per country

For each country, a similar approach can be followed to obtain useful policy results. In Table 5 we indicate the priority domains that each inefficient country should work on in order to increase its relative road safety performance level. The most urgent road safety aspect is assigned score 1, the second most important score 2 and so on. Only a value is given in the table in case the aimed indicator value (based on the adjustment factors and the indicator values of the benchmark countries) is 10% higher than the current indicator value for a country.

Like Austria, Belgium, Italy, Slovenia and Switzerland should focus their road safety efforts in the first place on the seat belt wearing behaviour of its drivers. Cyprus, the Czech Republic and Portugal should try to invest more in vehicle technology and promoting new(er) cars to its inhabitants. Trauma management is the major bottleneck in the United Kingdom while Estonia, Finland, France, Greece, Hungary, Ireland and Poland could gain from policy actions inspired on infrastructure to enhance road safety. Ten countries have one main priority (i.e. for one risk domain their current situation is more than 10% worse than what they should aim at) while six countries (Cyprus, Czech Republic, Estonia, France, Greece and Hungary) are urged to focus on three of the six dimensions. Finally, for Germany and Spain the target values do not differ significantly from the current values on any of the dimensions.

5 ADVANTAGES AND LIMITATIONS

Having developed and applied a data envelopment analysis model for the road safety context, the evaluation in terms of advantages and limitations is discussed now. Road safety is complex and several relevant outcome variables as well as risk indicators can be considered to express the performance of a country in terms of road safety. Data envelopment analysis is a technique in which multiple inputs and outputs can be incorporated, making it a useful technique for the road safety context. Taking into account the input and output data for a large set of countries the most optimal road safety score is calculated for each country. To guarantee consistency with prior knowledge and accepted views from experts, restrictions with regard to the share of each input and output can be added. Countries can be ranked in terms of efficiency and areas of underperformance can be determined.

Since each country has its own characteristics, the identification of one or more country-specific benchmark countries can be justified. Taking these countries as an example for improving the performance, useful targets can be set, even as priorities for policy action. That way, needful risk domains are tackled and relevant measures can be taken. This makes DEA valuable for the road safety context.

However, like any technique, DEA is based on a number of assumptions and characterised by some limitations that should be taken into account when interpreting the results. First, DEA compares the performance of a country to the performance of the other countries in the data set (Anderson, 2006). This approach only measures efficiency relative to best practice within the sample and a change in the data set (e.g. an extra country) may imply other outcomes. Moreover, the results produced by DEA are particularly sensitive to measurement error, input and output specification and sample size (Steering Committee for the Review of Commonwealth/State Service Provision, 1997). Therefore, reliable data sources should be consulted, appropriate inputs and outputs selected and as much countries as possible considered to enable a fair performance evaluation.

As shown earlier, valuable information can be gained from the DEA-RS model. However, this is mainly the case for inefficient countries. On the contrary, for efficient countries, several sets of weights result in an optimal score of 1. Therefore, not much attention should be given to the set of weights presented in the output. In addition, as the efficient countries are the best performing countries in terms of road safety within this data set, it is impossible to identify a benchmark country or set challenging targets based on the data of the other countries. Apart from efficient countries, the model appears to be unable to produce clear policy information for a country performing relatively well on all dimensions (like Spain). In the future, adaptations to the model can be made in order to render the data envelopment analysis road safety model of value for all countries. In case data are available over time, this information could serve for target setting and identification of priorities.

6 CONCLUSIONS

In order to further reduce the level of crashes and casualties an efficient road safety policy is required. In this respect, policymakers need to select an optimal set of measures. In this study, a methodology has been developed able to assist in prioritising actions based on the safety performance of other countries. Policymakers are supported as the model shows which of the following risk domains – alcohol, speed, protective systems, vehicle, infrastructure, trauma management – and road safety outcomes – crashes, fatalities – are good and bad aspects of the road safety system of a country. In addition, based on the performances of other countries, it is possible to set targets for each domain.

The data envelopment analysis model presented here introduces new insights in the composite indicators field as it has been adapted to the specific road safety context. First, besides indicator values, crash and fatality data are used. In other words, both road safety outcome and risk information is taken into account by the model. Secondly, we defined a minimization problem in which the indicator values should be as high as possible while the outcomes (i.e. crashes and fatalities) should be minimized. Moreover, the model results in the best possible score based on eight relevant road safety variables for each country, thereby respecting the opinion of experts regarding the share of e.g. alcohol in the overall risk score.

The model has a number of limitations. The country-specific results depend on the countries in the data set; therefore, as many countries as possible should be incorporated to make a fair comparison. Furthermore, countries that obtain a road safety score of one are highly efficient in terms of road safety; however, no policy recommendations are made for these countries. Finally, the conclusions are affected by the inputs and outputs used in the model. For each road safety aspect or domain possible indicators should be listed and evaluated on a number of criteria. Best available indicators (i.e. the most ideal indicators for which reliable and comparable data are available) are to be preferred.

For each domain, based on the benchmark values and some adjustment factor, a value to aim at was obtained and compared to the current indicator score. The domains urgently needing action were ranked. The following insights were gained based on this research. Austria, Belgium, Italy, Slovenia and Switzerland should focus their road safety efforts in the first place on the seat belt wearing behaviour of its drivers. Cyprus, the Czech Republic and Portugal should try to invest more in vehicle technology and promoting new(er) cars to its inhabitants. Trauma management is the major bottleneck in the United Kingdom while Estonia, Finland, France, Greece, Hungary, Ireland and Poland could gain from policy actions inspired on infrastructure to enhance road safety.

The data envelopment road safety model has proven valuable. In the future, more aspects should be investigated. First, more inputs and outputs could be used to describe road safety, for example helmet wearing and the number of seriously injured persons. At the same time, the number of countries considered by the model should be increased. Secondly, this model is valuable for a disaggregated analysis as well in which relevant road safety inputs and outputs are compared for certain age classes (e.g. young persons), transport modes (e.g. motorcyclists) or on a more regional level. Thirdly, a sensitivity analysis could reveal the impact of a change in the weight boundaries provided by experts or the impact of incorporating another indicator. Fourthly, the data envelopment analysis is suitable for country comparisons over time as well. In case data are available for at least two periods, the progress towards the objectives and the benchmark country could be quantified. Finally, the policy actions in the benchmark country could be inventoried, so a country has some ideas about possibly efficient measures.

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OVERVIEW OF THE TABLES AND FIGURES

TABLE 1 Minimum and maximum indicator shares

	Li	*Ui*
Alcohol	0.077	0.385
Speed	0.145	0.515
Protective systems	0.071	0.362
Vehicle	0.014	0.154
Infrastructure	0.014	0.308
Trauma management	0.015	0.246

TABLE 2 Road safety scores

	Road Safety Score
Denmark	1.000
Netherlands	1.000
United Kingdom	1.059
Sweden	1.117
France	1.123
Ireland	1.150
Finland	1.189
Switzerland	1.263
Germany	1.352
Estonia	1.595
Greece	1.670
Spain	1.740
Hungary	1.770
Italy	1.886
Belgium	1.957
Poland	1.969
Austria	1.977
Czech Republic	2.009
Slovenia	2.052
Cyprus	2.132
Portugal	2.228

TABLE 3 Benchmark countries for the inefficient countries

	Denmark	Finland	Netherlands	Sweden
Austria			X	X
Belgium			X	X
Cyprus	X	X	X	
Czech Republic	X	X	X	
Estonia	X			
Finland			X	
France	X			
Germany			X	X
Greece	X			
Hungary	X			
Ireland			X	
Italy			X	X
Poland			X	
Portugal		X	X	X
Slovenia			X	X
Spain	X	X	X	
Sweden			X	
Switzerland			X	X
United Kingdom			X	X

TABLE 4 Data envelopment analysis outcomes for Austria

	Weights	Share	Binding restrictions	Aim	Current value	% change needed
Alcohol	0.001362	0.1327		101.83	97.4	+4.5 (3)
Speed	0.005787	0.5150	Upper	88.05	89	-1.1
Protective systems	0.000922	0.0710	Lower	92.43	77	+20.0 (1)
Vehicle	0.000398	0.0140	Lower	40.22	35.14	+14.4 (2)
Infrastructure	0.010663	0.0213		2.09	2.0	+4.5 (3)
Trauma management	0.024117	0.2460	Upper	9.46	10.2	-7.2
Crashes	0.000739	0.3954		207.17	535	-61.3
Fatalities	0.013753	1.5816	Upper	61.59	115	-46.4
Road safety score		1.9770	NL: -0.583 & SE: -1.441			

TABLE 5 Road safety priorities per inefficient country

	Alcohol	Speed	Protective systems	Vehicle	Infra-structure	Trauma mngment
Austria			1	2		
Belgium			1			
Cyprus	3			1		2
Czech Republic			2	1		3
Estonia				2	1	3
Finland					1	
France	3			2	1	
Germany						
Greece			2	3	1	
Hungary			3	2	1	
Ireland					1	
Italy			1			
Poland					1	
Portugal				1		
Slovenia			1			
Spain						
Sweden					1	
Switzerland			1			
United Kingdom						1

FIGURE 1 Overview of road safety variables

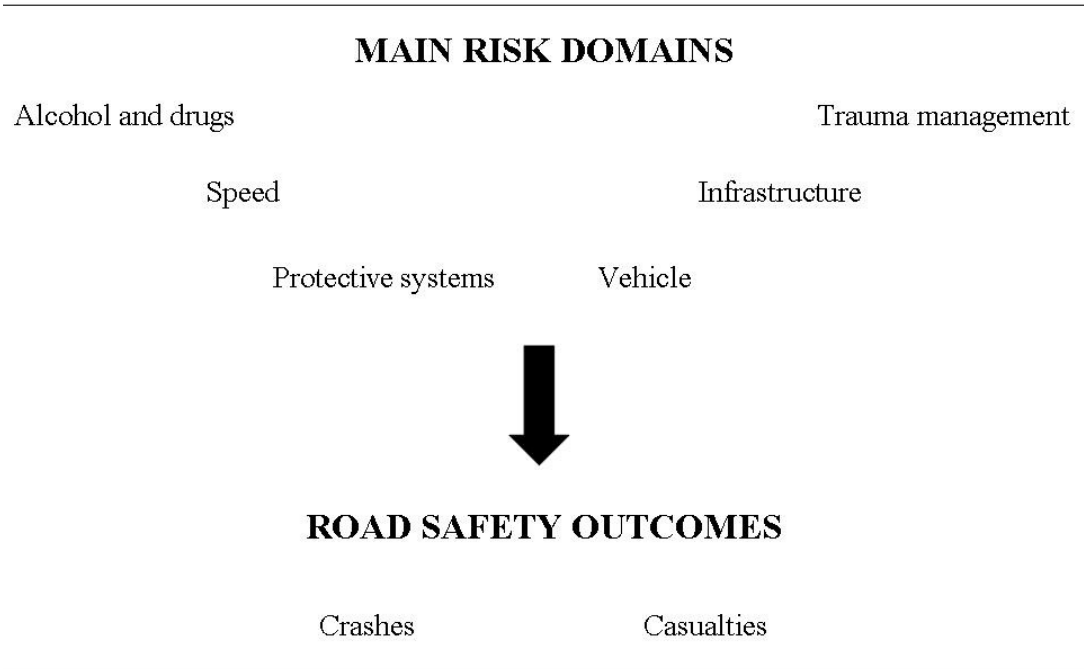

FIGURE 2 Data