Accident Analysis and Prevention 41 (2009) 174–182

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Benchmarking road safety: Lessons to learn from a data envelopment analysis

Elke Hermans, Tom Brijs, Geert Wets*, Koen Vanhoof

Hasselt University, Transportation Research Institute (IMOB), Wetenschapspark 5 bus 6, 3590 Diepenbeek, Belgium

ARTICLE INFO

Article history:
Received 20 May 2008
Received in revised form 2 September 2008
Accepted 15 October 2008

Keywords:
Road safety
Performance indicator
Data envelopment analysis
Benchmark
Target setting
Priorities

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 and drugs, speed, protective systems, vehicle, infrastructure and trauma management. For each country that performs relatively poor, a particular country will be assigned as a useful benchmark.

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 have decreased to 39,500 in 2006 (European Commission, 2006). 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, 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]

* Corresponding author. Tel.: +32 11 26 91 58; fax: +32 11 26 91 99.
E-mail addresses: elke.hermans@uhasselt.be (E. Hermans), tom.brijs@uhasselt.be (T. Brijs), geert.wets@uhasselt.be (G. Wets), koen.vanhoof@uhasselt.be (K. Vanhoof).

0001-4575/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.aap.2008.10.010

[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 the 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). 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.

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 summarized and the total road safety picture can be presented. As already done in other domains like economy, environment and technology (Saisana and 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 aggregated into one indicator per domain. Next, the domain indicators are aggregated in one road safety index. In the 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 and 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 et al. (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 (here we focus on fatalities) are the outputs while the performance on the underlying risk domains are the inputs (see Fig. 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 fatalities.

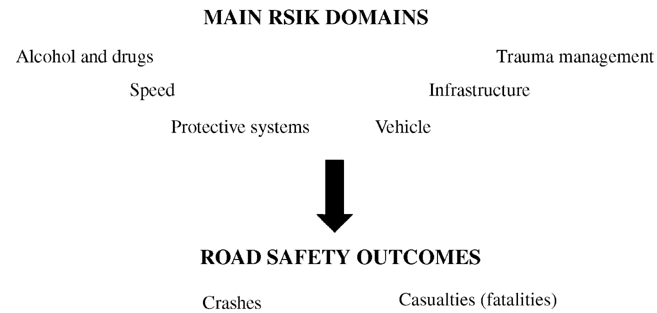

Fig. 1. Overview of road safety variables.

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.

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

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 more 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