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Traffic fatality indicators in Brazil: State diagnosis based on data envelopment analysis research

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ABSTRACT

The intense economic growth experienced by Brazil in recent decades and its consequent explosive motorization process have evidenced an undesirable impact: the increasing and unbroken trend in traffic fatality numbers. In order to contribute to road safety diagnosis on a national level, this study presents a research into two main indicators available in Brazil: mortality rate (represented by fatalities *per capita*) and fatality rate (represented by two sub-indicators, i.e., fatalities per vehicle and fatalities per vehicle kilometer traveled). These indicators were aggregated into a composite indicator or index through a multiple layer data envelopment analysis (DEA) composite indicator model, which looks for the optimum combination of indicators' weights for each decision-making unit, in this case 27 Brazilian states. The index score represents the road safety performance, based on which a ranking of states can be made. Since such a model has never been applied for road safety evaluation in Brazil, its parameters were calibrated based on the experience of more consolidated European Union research in ranking its member countries using DEA techniques. Secondly, cluster analysis was conducted aiming to provide more realistic performance comparisons and, finally, the sensitivity of the results was measured through a bootstrapping method application. It can be concluded that by combining fatality indicators, defining clusters and applying bootstrapping procedures a trustworthy ranking can be created, which is valuable for nationwide road safety planning.

1. Introduction

According to the most recent Global Status Report in Road Safety produced by the World Health Organization (2013), traffic fatalities showed an overall reduction from 2007 to 2010, a period in which 88 countries managed to decrease the total number of fatalities on their road system. However, approximately the same amount of countries showed an increase in traffic fatalities; in this context, the middle-income countries, where motorization is a fast-ongoing process, manifest themselves as nations with the highest risk in road safety. Brazil, the largest economy in Latin America, is a typical example of this group. In recent years, Brazil has experienced a period of intense economic growth. In 2011, the country ranked sixth among the largest economies in the world, reaching a GDP (Gross Domestic Product) of 2.5 trillion dollars (International Monetary Fund, 2013). The changes resulting from this process directly affect the transportation system and, consequently, it generates a road safety issue, mainly due to the large increase in the motor vehicle fleet. From 2002 to 2012, the vehicle fleet more than doubled, with an average annual growth rate equal to 8.29% (Departamento Nacional de Trânsito, 2013).

The negative impacts of this motorization process are reflected in the increasing and unbroken trend in the number of traffic fatalities, which in 2011 (the most recent year with available statistics) amounted to more than 43,000 (Ministério da Saúde, 2013a). By simple comparison, this number is about 40% higher than the number of fatalities in the set of 27 European Union member countries (European Commission, 2013a), whose population is about two times larger and has a geographical area which is about two times smaller. In terms of fatality rates, estimations

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point to 52.30 fatalities per billion vehicle kilometer traveled in 2011 – a number which is about 10 times higher in comparison to most developed European countries. Although the numbers are alarming, there is still a clear policy in Brazil which encourages people to purchase their first vehicle, overriding the concern about road safety with unacceptable levels of casualties.

During the last decades, some important actions toward road safety have been gradually implemented (which are part of the improvements of the reformulated Brazilian National Traffic Code applicable since 1998), with a main focus into protective systems and drink-driving legislation. Nevertheless, after an initial decrease in the subsequent years of the new code implementation, the number of traffic fatalities continues to grow again year after year (Vasconcellos and Sivak, 2009). The absence of a systematic and scientific monitoring process of road safety related information is still a barrier for practical research in the issue in the country. In this sense, strategic analysis tools are a potential field to be developed in road safety research. Moreover, due to the vast dimensions of the country and the contrasting figures between its 27 states, more individualized evaluations and recommendations are required, since nationwide actions would probably generate diverse effects, depending on each region's background.

Information about traffic fatalities in Brazil has been published by the Ministry of Health. The basic information comes from the notary office death certificates, which is entered into the SIM – Mortality Information System, linked to this ministry. In this document, the cause of death has been recorded since 1996, according to the 10th revision of the International Classification of Diseases (ICD-10) of WHO – World Health Organization (Ministério da Saúde, 2013a), respectively. From the fatalities data, three key indicators to measure the road safety situation were considered for the country: mortality rate, represented by fatalities per 100 thousand inhabitants (MR); and two fatality rates, represented by both fatalities per 10 thousand vehicles (FR1) and fatalities per billion vehicle kilometer traveled (FR2). To compose these indicators, fatality data were obtained from the Ministério da Saúde (2013a); vehicle fleet data from the Departamento Nacional de Trânsito (2013), population data from the Ministério da Saúde (2013b) and traveled distance data from a model based on automotive fuel sales data and vehicle fleet characterization developed in academic researches of Bastos (2011),Bastos et al. (2012) and Ferraz et al. (2012), since there is no governmental source regarding this parameter.

The corresponding values for 2011, together with the annual growth/reduction rates for the last five years are as follows: 43,256 fatalities (+3.53%); 22.48 fatalities per 100 thousand inhabitants (+2.93%); 6.27 fatalities per 10 thousand vehicles (−5.22%); and 52.30 fatalities per billion vehicle kilometer traveled (−3.87%). Although the number of fatalities shows a growing tendency, fatality rates are decreasing over the last years (the reduction being more evident on FR2). This can most probably be attributed to a proportionally higher increase in the vehicle fleet (and consequently the mobility level) in comparison to the increase in the number of fatalities.

In order to contribute to the field of road safety, this paper describes a first approach on applying a data envelopment analysis tool to assess the road safety situation in Brazilian states. The subject is carried out following a full step approach, including: (I) the combination of traffic fatality indicators into a composite indicator and posterior ranking of Brazilian states; (II) preliminary results interpretation based on the European experience; (III) model calibration; (IV) clustering techniques application; and (V) sensitivity analysis. Because of the originality of such an approach on road safety evaluation in Brazil, the model parameters were calibrated making reference to the analyzed European model results.

The paper has the following structure. Firstly, in Section 2, traffic fatality related indicators are discussed and the question of choosing the adequate indicator is addressed. In Section 3, the data envelopment analysis method is presented as an approach capable of offering a scientifically sound composite indicator. In the same section, the bootstrapping technique is introduced as a method to test the sensitivity of DEA scores. The available Brazilian road safety data are presented in Section 4.1, and the European data are shown in Section 4.2. Afterwards, in Section 5, the model calibration procedure is described and the results are examined. Still in this section, the 27 Brazilian states are classified into clusters and bootstrapped scores for each cluster are computed and discussed. Finally, Section 6 contains the conclusive comments and recommendations for future research.

2. Traffic fatality indicators

The most commonly used indicators to express the road safety situation of geographical areas (i.e., countries, states or cities) are formed by the ratio between a certain type of outcome and an exposure measure. Here, the outcome is considered as the undesirable consequence of the phenomena under investigation. Since traffic fatality statistics present higher reliability levels compared to e.g. traffic injury data (Connor et al., 2007), it was selected as the outcome measure on which the analysis is based in this paper. As the ratio denominator, four exposure measures are most frequently considered (Elvik and Vaa, 2004; Elvik et al., 2009; Jørgensen, 2006):

- Number of inhabitants (I) – it assumes the whole population is exposed to the risk of being killed in a traffic accident;
- Number of motor vehicles (II) – it assumes the risk of a traffic fatality is related to the registered number of motor vehicles;
- Number of traveled kilometers (III) – the same assumption of the previous indicator, however now considering the distance traveled by each vehicle, this is, the amount of traffic (given in vehicle × km);
- Number of passenger kilometers (IV) – the same assumption of the previous indicator, however now considering the vehicle occupancy ratio (given in passenger × km).

In summary, each indicator consists of a complementation to the previous, providing some extra information and leading to a more precise exposure measure (Evans, 2004). The choice of which indicator to use depends on the type of approach taken for the road safety evaluation. Indicator I is used to measure the negative impact of traffic accidents on society, enabling the comparison of traffic accidents with other causes of death, such as diseases and homicides (Organisation for Economic Co-operation and Development, 2011). Some authors even named this indicator as "health risk" (Elvik and Vaa, 2004; Elvik et al., 2009; Jørgensen, 2006), probably due to its relevance in public health policy planning; although here it is going to be referred to as "mortality rate" (MR), as e.g. is the case in the Institute for Road Safety Research (2013). In quite general terms, indicators II, III and IV provide the same information in three different levels of refinement regarding the risk exposure parameter definition; the last one being the most precise on quantifying the amount of exposure, but also the most rarely available. For a more detailed investigation, they can all be disaggregated to produce risk information on different transportation modes. This second group of indicators is referred to in literature as "traffic risk" (Elvik and Vaa, 2004; Elvik et al., 2009; Jørgensen, 2006), or "fatality rate" (FR), a denomination adopted in this study and also in e.g., Hermans et al. (2009).

Whichever traffic fatality indicator is adopted, it is important to interpret it under the delimitated perspective provided by the