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Benchmarking road safety of Montenegro using data envelopment analysis

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Abstract

This paper was mainly directed at studying the relevance of benchmarking road safety at national level when only basic information is given. It aims at contributing to this issue by proposing a computational model based on data envelopment analysis (DEA). The three inputs, population size, number of registered vehicles and length of road network, and five outputs which are defined as the ratio of road safety outcomes and some measure of exposure, were used for calculating relative efficiency of 21 municipalities in Montenegro. The period of 2012–2014 was considered due to data availability. DEA looks for the optimum combination of inputs' and outputs' weights for each decision-making unit (municipality) in order to obtain the best possible road safety score based on which a ranking of states can be made. We used output-oriented DEA model with constant return to scale and to rank order the efficient municipalities the cross efficiency rank scale was used. Effective factors for whole analysis are determined by averaging the shares for all 21 DMUs. Also, coloured map is used in order to present the geographical position distribution of the final classifications of the municipalities' relative efficiency. Also, for each municipality that performs relatively poor, a particular municipality will be assigned as a useful benchmark.

Keywords: Road safety, Data envelopment analysis, Relative efficiency, Ranking, Benchmarking

1. Introduction

Road traffic crashes are an important issue because of the loss of human life and serious injuries sustained. Road traffic injuries have been recognized as the leading cause of death by injury, and are predicted to rise to become the fifth leading cause of death by 2030 without effective and sustainable prevention (World Health Organization, 2013). In 2010, 31,500 people died in the 27 Member States of the European Union (EU-27) as a consequence of road traffic crashes. Around 300,000 were seriously injured and many more slightly injured (ETSC, 2011). This is the main reason why in

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May 2011, the United Nations launched a Decade of Action for Road Safety. The goal of the Decade (2011–2020) is to stabilize and reduce the increasing trend in road traffic fatalities, saving an estimated 5 million lives over the period (WHO, 2011). In addition, more and more countries launched and put into effect a large number of road safety strategies and programs, in order to improve their road safety situation. A decrease in number of people killed in road accidents was recorded in EU by European Commission (EC, 2012). There was 53% and 17% less fatalities in regard to 2001 and 2010 retrospectively. However, the large amount of countries showed an increase in traffic fatalities; in this context, the middle and low-income countries, where motorization is an ongoing process, manifest themselves as nations with the highest risk in road safety. Alike country is Montenegro with 29.6 fatalities per 100.000 inhabitants (OECD, 2012) and approx. 266 cars per 1.000 inhabitants in 2010. Large increase in the motor vehicle fleet was during 2004-2008: the number of registered vehicles has grown by more than 70%. The negative impacts of this motorization process are reflected in the increasing and unbroken trend in the number of traffic fatalities - mortality rate was the highest in period 2007-2009. As a response at Decade of Action for Road Safety in 2010, National Coordination Board was established in Montenegro to monitor road safety parameters. In addition, government adopted Strategy for efficient traffic (2008), Strategy for improvement of road traffic safety 2010-2019, and Action plan for Strategy for improvement of road traffic safety implementation (2011). The goal is to reduce road fatalities and injuries by 50% and 30% respectively by 2019, compared to 2007. After an initial decrease in the subsequent years of the new strategies implementation, the number of traffic fatalities continues to grow again year after year: The percentage of fatalities that occurred in crashes in 2012 was reduced by 52% compared with 2010 and by 62% compared with 2007. In spite of encouraging dates in last few years, studies show that number of fatalities in first six month of 2013 is already as high as in 2012.

Apart from analyzing the road safety development of the country, investigation of the progress in each of the municipalities is also important. Consequently, it is valuable for a municipality to compare its own road safety performance with that of other municipalities for the purpose of better understanding its relative safety situation, and moreover, trying to learn from those better-performing in terms of road safety policy making and target setting. 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 Montenegro. Moreover, Montenegro is lack in detailed accident data and it is a challenge to conduct a quality analysis. In addition, observing Montenegro as main subject of this paper we used DEA method to analyze and compare road safety in local municipalities. Data envelopment analysis (DEA) is one of the methods based on weighting methods that has recently been used to analyze road safety efficiency (Hermans et al., 2008). The DEA (Charnes et al., 1978) measures relative efficiency of Decision Making Units (DMUs, in our case: local municipalities), when multiple outputs are sharing multiple inputs, and their price values or weights are not given. Basically, DEA utilizes the ratio between the weighted output and the weighted input. Moreover, the inputs and outputs used in the model can be expressed in different units of measurement. In other words, the preliminary normalization of raw data is not required. For each DMU, DEA finds the ideal weights that maximize its efficiency ratio. A DMU that achieves the maximal possible efficiency ratio 1 (100%) is considered as efficient, the others are considered as inefficient. The main goal of this paper was to create a model for benchmarking road safety situation when only basic information is given, making local municipalities comparable with municipalities of different country. In order to contribute to the field of road safety, this paper describes a first approach on applying a data envelopment analysis tool (DEA, Charnes et al., 1978) to assess the road safety situation in Montenegro. Taking into account relevant road safety information for a set of municipalities, the optimization model results in an overall road safety score for each municipality. Further on, the objective was to promote efficiency in the field of traffic safety based on selected inputs and outputs; to identify local municipalities that have to improve their performance, to rank the municipalities both, efficient and inefficient, and to assign a useful benchmark for each underperforming municipality. The motivation for this analysis is the absence of examples of such model applications for a set of DMUs composed by developing countries.

1.2 Literature review

There is currently no universally agreed upon approach for the process of road safety benchmarking, and performing the practice successfully is by no means easy (Chen et al., 2016). The DEA models have been widely studied and applied to numerous performance evaluation activities characterized by multiple inputs and multiple outputs. DEA has already been used to measure the relative performance of countries in terms of efficiency. Hermans et al. (2009) proposed a computational model for comparing countries on the performance of different risk aspects of their road safety system based on data envelopment analysis. Based on the model output, the good and bad aspects of road safety are identified for each of 21 European countries.

Shen et al. (2011) explored the incorporation of a layered hierarchy in the DEA framework. In addition, they proposed a generalized multiple layer DEA model with corresponding weights in each layer of the hierarchy and different types of weight restrictions. They applied model for road safety performance evaluation using the 13 hierarchical safety performance indicators as the model's input and the 4 layered road safety final outcomes as the output. Because road safety indicators are not comparable between countries and they are not consistent in most cases, Shen et al. (2012) tried to provide an overall perspective on a country's road safety situation by using data envelopment analysis. They considered three model extensions measurement technique is investigated to provide an overall perspective, which are the DEA based road safety model (DEA-RS), the cross efficiency method, and the categorical DEA model. In conducting DEA models, the measures of exposure to risk were used as the model's input and the number of road fatalities as output. They ranked countries in accordance with their cross efficiency scores. Further on, Shen et al. (2013) used DEA for measuring the road safety performance change over time. In this way focus can be not only on the evolution of road safety final outcomes within a given period, but also on the changes of different measures of exposure in the same period into account.

Odeck (2006) used DEA to investigate target achievements of the operational units of the Norwegian Public Roads Administration (NPRA) charged with traffic safety services. They applied DEA model with a unique constant input, or equivalently, with no inputs, which is extended to a DEA-based Malmquist index to measure productivity growth in target achievements. Egilmez and McAvoy (2013) developed DEA based Malmquist index model in order to assess the relative efficiency and productivity of U.S. states in decreasing the number of road fatalities. Their model use the single output, fatal crashes, and five inputs to aggregate road safety score.

Bastos et al. (2015) also used DEA method in order to contribute to road safety diagnosis on a national level. Their study presents a research into two indicators: mortality rate represented by fatalities per inhabitant and fatality rate represented by two sub-indicators, i.e., fatalities per vehicle and fatalities per vehicle kilometre traveled. For more realistic comparison between countries they used cluster analysis.

Azadeh et al. (2016) analyzed factors affecting road accidents by considering the severity of accident and decision-making styles of drivers. They proposed framework based on data envelopment analysis and statistical methods to assess the factors affecting road accidents. They conducted the survey among drivers in Teheran, Iran, where each driver is considered as a DMU. The input and output variables of the DEA model were selected based on experts' judgments. They identified optimum decision making styles through DEA and analyzed the obtained results through statistical methods.

Alper et al. (2015) used DEA to estimate the relative efficiency of local municipalities in traffic safety in Israel. They used 2 inputs reflecting the resources allocated to the local municipalities, 6 outputs include measures that reflect reductions in accidents (such as accidents per population), and 8 intermediate variables known as safety performance indicators: measures that are theoretically linked to crash and injury reductions (such as use of safety belts). Several DEA versions were used including a two-stage model where in the first stage the intermediate variables are the outputs, and in the second stage they are the inputs.

Rosić et al. (2017) used efficiencies obtained with DEA and TOPSIS in order to present model for selection of optimal method for composite index based on average correlation, average rank variation and average cluster variation. As the purpose of his paper is not to select different indicators forming composite index, they have not widened model with road safety performance indicators or other measures in road safety, but rather stayed in domain of traditional risk parameters and for inputs choose population and number of registered motor vehicles and number of fatalities and number of seriously injured persons for outputs.

2. Methodology

2.1 Data envelopment analysis

Data envelopment analysis (DEA), developed by Charnes et al. (1978), is a non-parametric mathematical approach based on a linear programming model and production theory, for optimizing the efficiencies of entities, called decision-making units (DMUs). Efficiency is defined as the ratio between the sum of the weighted outputs and the sum of the weighted inputs, when the weights are not known, subjected to lie between zero and unity. If this efficiency achieves value 1, then the DMU is considered an efficient unit, otherwise it is considered inefficient. DEA generates the efficient frontier that describes maximum quantity of outputs that can be obtained from a given combination of input, or in the other hand, the minimum quantity of inputs that that can be used to achieve a given quantity of output. Basically, DEA construct frontier by generating the best entities which are viewed as the most efficient under the given circumstances. The degree of inefficiency of the others entities can be measured based on the distance from the frontier. In addition, DEA may help to identify possible benchmarks toward which performance can be targeted.

Data envelopment analysis has various advantages: ability of handling multiple inputs and outputs; ability of being used with any measurement; ability to identify the benchmark members of the efficient set and identify amounts of inefficiency for each entity. However, some disadvantages are also noted: DEA compares the performance of a DMU to the performance of the other DMUs in the data set and measure efficiency relative to the best one in the sample. In addition, the efficiency of each DMU depends on the efficiency of the others and always minimum one DMU is efficient.

Basic DEA model is so-called CCR model, since it was presented by Charnes, Cooper and Rhodes. Model uses the ratio of weighted output to weighted input as a scale to measure efficiency. Considering that each unit contains m input to produce s output, than mathematical formulation of model is:

$$maxEf_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \qquad (1)$$

Subject to:

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1; j = 1, \dots, n$$

$$u_r \geq 0; r = 1, \dots, s$$

$$v_i \geq 0; i = 1, \dots, m$$

wherey_{rj} is the r^{th}outpu and x_{ij} is the r^{th} input of the j^{th} DMU, ur is the weight given to output r, v_i is the weight given to input i. This model determines optimal input and output weights for each DMU separately, with the purpose to maximize efficiency (model must be run n times).

Presented model is non-linear. In addition to simplify it Charnes et al. (1978), transformed it into linear model, known as multiplier form of this problem. In this model the denominator has been set equal to 1 and the numerator is being maximized, presented as follows:

$$maxEf = \sum_{r=1}^{s} u_r y_{rj} \qquad (2)$$

Subject to:

$$\sum_{i=1}^{m} v_i x_{ij} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0$$

$$u_r \geq \varepsilon; r = 1, \dots, s$$

$$v_i \geq \varepsilon; i = 1, \dots, m$$

As non-linear, linear model runs n times to identify the relative optimal efficiency scores of all DMUs by selecting the best possible input and output weights. Presented CCR model is built on the assumption of constant returns to scale.

As original application of DEA model implies output to be as high as possible, in road safety they should be as low as possible. In addition, output-oriented model is used. An inefficient unit is made efficient through the proportional increase of its outputs, while the inputs proportions remain unchanged. So, in presented DEA model reciprocals values for outputs are used.

2.2 Safety performance indicators – selection of inputs and outputs

According to the literature, the most prominent relative indicators for describing the level of road safety on the particular territories are road accidents, consequences of road accidents, population, registered motor vehicles, road network length, distance travelled and AADT value. For compering road safety level among countries the number of inhabitant, the number of registered vehicles, and the distance travelled are the three most frequently used measures of exposure to risk (IRTAD, 2014). Population data are most commonly used since they are readily available in most countries. In Kukić et al. (2013) the number of fatalities per population is defined as public risk and exposure to risk in terms of traffic volume as dynamic traffic risk.

Dynamic traffic risk takes into account the mobility of the population and gives better results of road safety levels and risk assessments. Only a limited number of countries collect data on this exposure measure. Benchmarking road safety in Montenegro in which the motor vehicle kilometres are not available, we will use the traffic risk defined as the number of fatalities per motor vehicle. It is always a question about which one is the most reliable, because they describe risk in different terms and from different points of view. When ranking, countries may have different evaluation results or ranking positions using different exposure information (Shen et al., 2012). Therefore, it would be desirable if all these risk indicators could be considered together in order to make comparisons of performance between countries (Kukić et al., 2016).

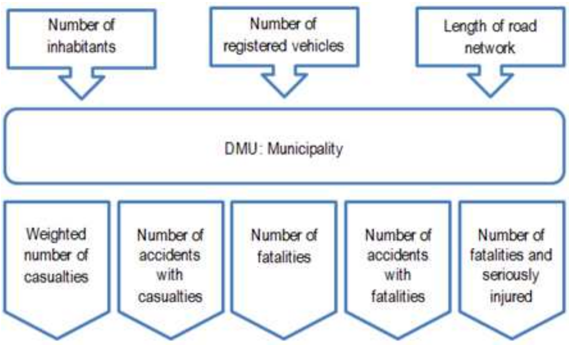

Figure 1: Proposed DEA model

Kukić et al. (2013) proposed a model for selection of a relevant indicator. Model represents the calculation of five types of output indicators of road safety for both, public and traffic risk. For public risk outputs were divided with number of inhabitant and for traffic risk outputs were divided with number of registered vehicles. Also, Rosić et al. (2017) in order to create composite index, used DEA methodology with population and number of registered motor vehicles as inputs and number of fatalities and number of seriously injured persons as outputs. Relying on those researches, for ranking municipalities in Montenegro in this paper, and compering results with mentioned risks, we use DEA model with following inputs:

- X1 Population size.
- X2 Number of registered vehicles.
- X3 Length of road network.

Egilmez (2013) found that road length was determined as the most sensitive input, even more sensitive than road condition or safety belt usage. Namely, the magnitude of such input variables affects the fatal crashes more than safety belt usage and road condition as expected. According to this statement we used road length as a third input in our DEA model. Road length for each municipality in Montenegro implies length of highway and regional network, but not local and uncategorized roads. It must be noted that choosing a great amount of indices as input data can make the analysis procedure complicated and disorder the required balance between the inputs and outputs of the DEA analysis (Behnood et al., 2014). Further on, relying to Kukić el al. (2013), five outputs for DEA are being singled out creating proposed DEA model presented in Figure 1:

- Y1 Weighted number of casualties. WNC
- Y2 Number of accidents with casualties. NAC
- Y3 Number of fatalities. NF
- Y4 Number of accidents with fatalities. NAF
- Y5 Number of fatalities and seriously injured. NFS

The first output, weighted number of casualties is shown in the Eq. (3). It is calculated depending on the type of consequences of road accidents weighted by coefficients corresponding to the level of injuries.

$$WNC = Li \cdot P1 + Si \cdot P2 + F \cdot P3 \qquad (3)$$

In following equation Li, Si and F represent the number of slight injuries, number of serious injuries and number of fatalities, respectively. Coefficients P1, P2 and P3 stand for certain levels of injury and valued P1=1, P2=10 and P3=85. Kukić et al. (2013) took those coefficients from the Report of the Road World Association – PIARC published in the document Road Safety Manual, Recommendations from the Road World Association and successfully implemented them in their model for selection of a relevant risk. There is no calculation of the accident costs in Montenegro and for that reason in this paper we will use same values.

Information for outputs of DEA model has been published by the Ministry of the interior, population and vehicle fleet data by the Statistical office of Montenegro and road network data by Ministry of transport and maritime affairs. Information about accidents, casualties and registered vehicle is average value for period 2012-2014. Number of inhabitant is for year 2011 and number of road length is for year 2014. Values of all variables are shown in Appendix A.

2.3 Ranking

Using data envelopment analysis the overall road safety score for 21 municipality in Montenegro is obtained. Also, to perform full rank-scaling cross efficiency score has been used (Markovits-Somogyi, 2011). The underperforming municipalities can be ranked directly by their score, while the best performing, with score of one, an ordering can be deduced by computing cross efficiency score, an average value over all model results (Markovits-Somogyi, 2011). The cross efficiency method was developed as a DEA extension to rank DMUs with the main idea being to use DEA to do peer evaluation rather than to have it operate in a pure self-evaluation mode (Wu et al., 2010). Therefore, cross efficiency score is more representative of efficiency than the traditional DEA-score and it eliminates unrealistic weight schemes (Adler et al., 2002). It can also be treated as a kind of sensitivity analysis since different sets of weights are applied to each unit. Since the model leads up to municipality-specific outcomes, the index scores resulting from all 21 models are shown in Appendix B. This table represents matrix which each column indicates the index score of municipalities in Montenegro with the optimal weights of the country under study. Moreover, the elements along the major diagonal represent the optimal road safety index score of each municipality. Doyle and Green (1994) propose the use of the maverick index to identify DMUs that select unrealistic weighting schemes. We will calculate maverick index for each of the municipalities where relatively high value suggests that DMU is probably using unrealistic weighting schemes for its self-appraisal.

Further on, comparison between DEA scores, CE scores and the most commonly used indicators for compering countries will be made. Moreover, assessment of DEA scores will be calculating using coefficient of linear correlation.

3. Results

This study covers the road safety performance data available in all of 21 municipalities of Montenegro for three years (2012, 2013 and 2014). Using the road safety data of three inputs and five outputs the most optimal road safety efficiency score is computed by selecting the best possible input and output weights in DEA model presented in Section 2.1. Free software MaxDEA Basic 6.11, was used for calculating DEA scores and also for defining benchmark municipalities. To conduct the calculations for cross efficiency scores, the solver add-in program in Microsoft Excel software was used as the tool. Ultimately, DEA yields the results of a ranking based on the optimal road safety score, ranking based on the optimal cross efficiency score, identification of relevant benchmarks for each inefficient municipality and detailed outcomes per municipality.

Table 1:Municipalities' results

Municipality	*DEA*	*Cross-efficiency*	*Maverick index*	*St.dev*
Danilovgrad	1.000	0.876	0.142	0.280
Andrijevica	1.000	0.874	0.145	0.215
Žabljak	1.000	0.872	0.147	0.156
Šavnik	1.000	0.790	0.266	0.194
Tivat	1.000	0.676	0.480	0.430
Plav	0.756	0.517	0.461	0.122
Plužine	0.672	0.425	0.582	0.089
Mojkovac	0.576	0.410	0.405	0.093
Berane	0.396	0.278	0.423	0.111
Ulcinj	0.350	0.265	0.320	0.088
Herceg Novi	0.452	0.229	0.976	0.114
Rožaje	0.211	0.162	0.299	0.035
Cetinje	0.194	0.137	0.409	0.047
Bijelo Polje	0.179	0.125	0.427	0.050
Pljevlja	0.141	0.115	0.219	0.027
Budva	0.150	0.107	0.407	0.037
Kotor	0.141	0.098	0.440	0.040
Bar	0.125	0.086	0.454	0.042
Kolašin	0.141	0.068	1.086	0.032
Nikšić	0.041	0.029	0.407	0.011
Podgorica	0.018	0.010	0.879	0.005

Using output oriented DEA model (maximizing the output rather than minimizing the inputs) with constant returns to scale, the efficiency score of the Montenegrin municipalities is obtained. Results are shown in Table 1 with underlined score of one.

Also, Table 1 presents cross-efficiency (CE) score, Maverick value and standard deviation of each municipality's 21 efficiency scores. It can be seen that among the municipalities analyzed in three years 5 municipalities are identified as best-performing ones. Andrijevica, Danilovgrad, Šavnik, Tivat and Žabljak were the most efficient since they obtained the efficiency score of one, while the remaining 16 municipalities obtaining a value less than one and they are considered to be underperforming. Furthermore, Danilovgrad is municipality which was efficient and it was rank-scaled the highest with CE value of 0.876. This score (CE) is more representative of efficiency than the traditional DEA score, as all the elements of the cross efficiency matrix are included in it (Markovits-Somogyi, 2011). The Maverick value of Danilovgrad is 0.142 indicating that the DEA efficiency value score deviates from its cross efficiency value by 14.2%, which is low compared to other municipalities. As shown in Table 1, the Maverick index was lower for municipalities positioned high on rank scale, indicating that the higher ranked municipalities are more solid in their high ranking. Podgorica, Nikšić and Kolašin are the worst performing municipalities which facing a great challenges to improve their road safety performance.

Table 2: Rank of municipalities

Municipality	*DEA*	*Cross-efficiency*	*PRWNC*[a]	*TRWNC*[b]	*PRNAF*[c]	*TRNAF*[d]	*PRNF*[e]	*TRNF*[f]
Danilovgrad	1	1	5	10	1	1	7	12
Andrijevica	2	2	15	16	20	19	16	17
Žabljak	3	3	16	17	17	17	15	16
Šavnik	4	4	20	20	21	21	20	20
Tivat	5	5	11	5	13	10	12	10
Plav	6	6	4	14	12	15	11	14
Plužine	7	7	19	19	19	20	19	19
Mojkovac	8	8	17	18	16	16	18	18
Berane	10	9	1	1	4	9	1	1
Ulcinj	11	10	12	8	5	3	8	6
Herceg Novi	9	11	8	3	8	4	9	8
Rožaje	12	12	9	15	10	14	13	15
Cetinje	13	13	14	13	11	11	10	11
Bijelo Polje	14	14	3	11	3	7	2	9
Pljevlja	18	15	2	4	7	8	3	7
Budva	15	16	18	12	15	13	17	13
Kotor	16	17	13	7	14	12	12	5
Bar	19	18	10	6	9	5	5	2
Kolašin	17	19	21	21	18	18	21	21
Nikšić	20	20	6	9	6	6	4	4
Podgorica	21	21	7	2	2	2	6	3

[a] Public risk: weighted number of casualties per 10.000 inhabitants
[b] Traffic risk: weighted number of casualties per 10.000 vehicles
[c] Public risk: Number of accidents with fatalities. per 10.000 inhabitants
[d] Traffic risk: Number of accidents with fatalities per 10.000 vehicles
[e] Public risk: Number of fatalities per 10.000 inhabitants
[f] Traffic risk: Number of fatalities per 10.000 vehicles

In addition, by computing the standard deviation shown in the last column of Table 1, we find that Tivat obtains the highest value of 0.430 which means that the set of efficiency scores calculated for Tivat varies the most from its cross-efficiency score. It indicates that Tivat has the highest level of uncertainty on its efficiency score, and is probably allocated with unreasonable weights in the DEA model.

4. Discussion

Approach applied in this study can be easily used considering that for inputs and outputs we used data available in almost every country. This is important because our goal was to define DEA model in order to make countries and municipalities suitable for compering. Doing so, it is possible to monitor road safety of each of them. Using presented DEA model we can rank municipalities: the underperforming municipalities were ranked directly by their score, and for ranking an efficient municipalities cross efficiency index was used. In addition, weights allocated for each indicator can be deduced for every municipality, providing information on relative importance of the corresponding one.

DEA enable a ranking of municipalities in accordance with their safety performance. The resulting ranks are given in Table 2 along with the ones obtained from the most used risk exposure. The rankings of countries based on the DEA score are not necessarily identical to the traditional ranking by using fatality rate or another measure of exposure (per head of population or per motorization). Detailed information about all the calculated risks for the municipalities in Montenegro are given in the Appendix C. Closer look at municipalities' rankings in Table 2 indicates that Berane and Danilovgrad are municipalities with the highest average rank. These two municipalities were positioned at first place in four of all presented rank scales and have no bottom rank number, even more they are in upper half of the all rank scales. However, Berane have a low DEA rank. Kolašin, Šavnik and Plužine have the worst average rank. Furthermore, ranks show the most accordance for Cetinje, Rožaje and Budva.

Table 3: Correlation between scores

	CE	PRWNC	TRWNC	PRNAF	TRNAF	PRNF	TRNF
DEA	0.9822	0.0614	0.1956	0.5128	0.5283	0.1145	0.2032
CE		0.0395	0.1687	0.5119	0.5192	0.0878	0.1736
PRWNC			0.9532	0.6889	0.6370	0.9886	0.9469
TRWNC				0.7807	0.7833	0.9732	0.9964
PRNAF					0.9771	0.7029	0.7706
TRNAF						0.6697	0.7760
PRNF							0.9759

Correlations marked correlations are significant at p < .05000 N = 21
All negative correlations changed to positive (absolute values).

Table 4: Correlation between scores

Variable	*%.share of weights*
Inputs	
X1	0.00031
X2	0.00343
X3	0.40604
Outputs	
Y1	52.7497
Y2	6.11919
Y3	9.89913
Y4	3.61416
Y5	27.2079

In order to grasp insight into the relationship among the rankings related to the different methods, a quantitative assessment, Pearson's correlation analysis, is performed. A correlation analysis on each risk scores and the DEA road safety scores is performed and presented in Table 3 in order to identify relations between DEA scores and scores obtained from calculating both, public and traffic risks using different measure of exposure. In this case, the efficiency scores of the municipalities based on the data envelopment analysis has the best fit with the score obtained using the number of fatalities per 10.000 vehicles (0.5283).

As it can be seen, there is a great variation in ranks based on DEA and other ranks. It can be explained with the fact that data envelopment analysis relays on choosing different sets of weights for each municipality with the only purpose of maximizing the relative performance. Moreover, analyzing allocated weights insight can be gained into the relative importance of the inputs and outputs. Percentages of assigned weights for each input and output are presented in Table 4. Because of the fact we used output oriented DEA model, inputs allocated negligible weights. Further on, the assigned weights imply that output Y1 (weighted number of casualties) should be given priority over the other since the highest share of weight (52.7%) is allocated to this indicator. Although a large amount of weight share, ranking municipalities in regard to the weighted number of accident don't correlate much with ranking using DEA (r=0.0614 for PRWNC and r=0.1956 for TRWNC).

To capture further graphical insight into the geographical position distribution of the final classifications of the municipalities' relative efficiency related to road safety level and based on the DEA scores, is illustrated using colour map in Figure 2. We used colour palette based on five colour bands signifying low to high performance (EuroRAP, 2013). Borders of efficiency class were defined with step of 0.2 (20%) and presented in table 5. Municipalities with low efficiency are dark coloured at the presented map and those are municipalities with main national roads with high level of traffic flow. It can be explained with the fact that Montenegro is transit country and also tourist destination and large amount of foreign vehicles have been driven on its roads.

Table 5:Classes of efficiency

Efficiency	Class colors
(0-0.2]	
(0.2-0.4]	
(0.4-0.6]	
(0.6-0.8]	
(0.8-1.0]	

Figure 2: Regional distribution of 21 Montenegro municipalities related to road safety efficiency.

4.1 Benchmarking road safety in Montenegro by using the DEA model

All municipalities should try to improve their road safety situation. For that matter, it is useful to have one or more municipalities as example to follow, so-called benchmark municipality. Having found the inefficiency rates, less prosperous municipalities in a given time period can systematically be compared with leading ones. The optimal weights for the municipality under study cause the weighted output of another municipality in the data set to become equal to its weighted input. This municipality is a benchmark municipality.

The comparison can lead us into setting benchmarks as a means to prioritize DMU-specific safety requirements. Thereby, the concept of benchmarking is used as an applicatory approach in the literature of performance evaluation analysis. (Behnood et al., 2014). By DEA analysis, five municipalities are identified as benchmarks representing those having the best performance. Given calculated inefficiency scores for each municipality, benchmarks for every unsuccessful municipality are defined. Table 6 indicates for each of the 16 underperforming municipalities which municipality out of the efficient one – Andrijevica, Danilovgrad, Šavnik, Tivat, Žabljak – is suitable for comparing their road safety performance to. Benchmark municipality is one that is similar to the one under study but it scores better. For example Kolšin should take Danilovgrad and Šavnik as an example while Tivat is a benchmark for Herceg Novi.

Table 6: Benchmark countries for the inefficient countries

	Andrijevica	*Danilovgrad*	*Šavnik*	*Tivat*	*Žabljak*
Bar		X		X	X
Berane		X		X	X
Bijelo Polje		X		X	X
Budva	X	X		X	
Cetinje		X	X		X
Herceg Novi		X		X	
Kolašin		X	X		
Kotor		X		X	X
Mojkovac	X	X	X		
Nikšić		X		X	X
Plav	X	X		X	
Pljevlja	X	X		X	
Plužine			X		X
Podgorica		X		X	
Rožaje	X	X	X		
Ulcinj		X		X	X

5. Discussion

According to the advantageous application of DEA, several road safety studies have utilized the approach as a performance evaluation method. In this study, we investigated road safety situation in Montenegro benchmarking the most performing municipalities. Different from only considering the percentage change in road fatalities or road accidents, or conducting the simple ratio analysis using a single risk indicator, this paper presented a new way for assessing the road safety performance of a country and its municipalities which was to use the technique of data envelopment. This is the first use of DEA for analyzing road safety situation in Montenegro. In doing so, we took into account different combination of final outcomes that are usually used for describing measures of exposure in road safety. Main advantage of DEA model presented in this paper is availability of data used as inputs and outputs.

Montenegro as developing country does not have national database with detailed information about accidents and yet it is more than necessary if want to road safety situation perform better. In order to monitor road safety and determine safety situation in each municipality, DEA model with basic accident data is proposed. The model results in the best possible score which represent its relative efficiency and is based on relevant road safety variables for each municipality. Considering number of inhabitants, number of registered vehicles and road length on the one hand, and the weighted number of casualties, number of accidents with casualties, number of fatalities, number of accidents with fatalities, number of fatalities and seriously injured on the other hand, the DEA score was used as a valuable benchmarking tool to target the best municipality. DEA generated more than one efficient municipality; therefore cross efficiency method was introduced to rank efficient units. Doing this, it makes comparison between municipalities more justly. In this paper we used the original model of DEA which is quite general, allowing the free allocation of weights without restrictions in order to reach an optimum solution. Also, instead of defining a minimization problem in which the indicator values should be as high as possible while the outcomes should be minimized we used reciprocal values for outputs and transformed it to maximization model so all the needed improvements are in the outputs and not in the inputs. The purpose is to improve the safety parameters, not to reduce number of registered vehicles or road length. This study is an extended application of the method developed by Kukić et al. (2013) and it has been carried out for all municipalities in a single country. The strategies made by such a process can be adopted either by the government authorities or individually on a local basis.

Five municipalities, Andrijevica, Danilovgrad, Tivat, Šavnik and Žabljak are identified as best-performing ones in terms of road safety because they obtained the efficiency score of one. The remaining municipalities had an efficiency score less than one and to rank order it, the cross efficiency score based on the DEA was used. Taking mentioned five efficient municipalities as benchmark for improving road safety situation, relevant measures can be taken. Also, underperforming municipalities can learn from policy actions in the benchmark municipalities and its performance so a municipality has some ideas about possibly efficient measures to improve their own road safety aspects.

Considering the information on some common measures of exposure the correlations between DEA scores and usually used risk indicators were calculated. It is important to note that the different models had significant correlations between them and the DEA. This research and the correlation study include all the data on the number of road accidents and their consequences, from 21 municipalities in Montenegro, in the period 2012 to 2014. In order to make simple comparison among municipalities, presenting results in simple way for wider auditorium and to best detect a real state, coloured maps are used.

The data envelopment analysis model presented here introduces new insights in road safety relative efficiency considering usage of simple data. However, discussion on results shows that some limitations still exist in the application of this approach. Firstly, the model only measures the performance of one municipality with respect to the other municipalities within the sample. The conclusions are affected by the inputs and outputs used in the model and changing the data set may lead to other outcomes. Moreover, the results obtained from this model are sensitive to the number of municipalities and to indicator specification. Therefore, future research will focus on the construction of a data envelopment analysis model with different combination of inputs and outputs in order to describe road safety. The progress of the municipalities could be quantified because model is suitable for comparisons over time as well. Also, restrictions for the weight distribution can be added. Sensitivity analysis should be conducted to reveal the impact of a change in indicator set and incorporate the concept of layered hierarchy.

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Appendix A. Variable values for municipalities in Montenegro

	Data for input values					*Data for output values*			
Municipality	*Number of Inhabitants*	*Number of registered mot. vehicles*			*Road length*[a]	*Number of accidents*[b]	*Fatalities*[c]	*Serious injured*[d]	*Slight injured*[e]
		2012	*2013*	*2014*					
Andrijevica	5081	975	1021	923	43	17	3	8	30
Bar	42128	16941	17566	17388	86.2	334	8	98	504
Berane	34035	6489	6713	6268	91	43	3	20	58
BijeloPolje	46138	9201	9232	9168	84.1	198	7	55	284
Budva	19255	10850	11283	11775	55.5	240	13	66	325
Cetinje	16689	6177	6283	6089	134	141	5	53	213
Danilovgrad	18507	4574	4881	4546	31.6	102	4	24	143
Herceg Novi	30923	12510	12746	12328	26	181	9	47	226
Kolašin	8396	1797	1815	1666	121.6	74	27	48	139
Kotor	22644	10023	10647	10164	109	152	7	78	176
Mojkovac	8638	1682	1686	1503	51	62	7	11	96
Nikšić	72581	19477	19589	18144	224	468	12	122	650
Plav	13133	2154	2378	2171	58	18	4	10	33
Pljevlja	30844	7179	7186	7038	171	87	5	28	128
Plužine	3252	527	512	470	89	16	4	12	29
Podgorica	186290	67699	69318	66761	147.2	1293	37	248	1830
Rožaje	23008	4998	5092	4878	88.6	83	9	20	126
Šavnik	2074	338	332	339	61	13	4	5	24
Tivat	14058	6051	6592	6453	10	94	5	23	99
Ulcinj	19959	7246	7399	6938	66	179	5	43	232
Žabljak	3576	761	772	794	60.4	19	2	9	24

[a] Data for year 2014
[b] Sum of the number of accidents with casualties for period 2012-2014
[c] Sum of the number of fatalities for period 2012-2014
[d] Sum of the number of serious injured for period 2012-2014
[e] Sum of the number of slight injured for period 2012-2014

Appendix B. Overall results from the DEA model

	AN	BR	BA	BP	BD	CT	DG	HN	KL	KO	MK	NK	PL	PV	PŽ	PG	RO	ŠV	TV	UL	ŽB
AN	1.000	1.000	1.000	1.000	1.000	0.541	0.350	1.000	0.392	0.850	1.000	0.901	1.000	1.000	0.560	1.000	1.000	1.000	0.901	0.850	1.000
BR	0.032	0.125	0.125	0.125	0.124	0.060	0.048	0.105	0.031	0.124	0.050	0.125	0.054	0.125	0.013	0.105	0.050	0.032	0.125	0.124	0.106
BA	0.159	0.396	0.396	0.396	0.345	0.144	0.104	0.318	0.130	0.325	0.227	0.391	0.226	0.396	0.088	0.318	0.227	0.159	0.391	0.325	0.379
BP	0.053	0.179	0.179	0.179	0.152	0.078	0.067	0.148	0.082	0.145	0.107	0.178	0.090	0.179	0.027	0.148	0.107	0.053	0.178	0.145	0.155
BD	0.078	0.131	0.131	0.131	0.150	0.095	0.083	0.144	0.039	0.141	0.083	0.122	0.088	0.131	0.012	0.144	0.083	0.078	0.122	0.141	0.115
CT	0.060	0.169	0.169	0.169	0.173	0.194	0.173	0.115	0.125	0.184	0.097	0.176	0.075	0.169	0.055	0.115	0.097	0.060	0.176	0.184	0.150
DG	0.302	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.093	1.000	1.000	0.302	1.000	1.000	0.698
HN	0.118	0.294	0.294	0.294	0.300	0.118	0.104	0.452	0.067	0.260	0.162	0.265	0.264	0.294	0.016	0.452	0.162	0.118	0.265	0.260	0.245
KL	0.056	0.051	0.051	0.051	0.058	0.128	0.141	0.055	0.141	0.053	0.079	0.046	0.097	0.051	0.033	0.055	0.079	0.056	0.046	0.053	0.042
KO	0.044	0.133	0.133	0.133	0.136	0.099	0.080	0.096	0.048	0.141	0.061	0.136	0.066	0.133	0.024	0.096	0.061	0.044	0.136	0.141	0.121
MK	0.475	0.416	0.416	0.416	0.435	0.385	0.361	0.494	0.426	0.354	0.576	0.356	0.316	0.416	0.147	0.494	0.576	0.475	0.356	0.354	0.362
NK	0.012	0.040	0.040	0.040	0.037	0.025	0.022	0.029	0.021	0.038	0.022	0.041	0.017	0.040	0.008	0.029	0.022	0.012	0.041	0.038	0.034
PL	0.494	0.573	0.573	0.573	0.559	0.366	0.314	0.602	0.411	0.476	0.627	0.517	0.756	0.573	0.188	0.602	0.627	0.494	0.517	0.476	0.542
PV	0.076	0.141	0.141	0.141	0.138	0.118	0.103	0.114	0.105	0.136	0.107	0.139	0.076	0.141	0.047	0.114	0.107	0.076	0.139	0.136	0.130
PŽ	0.384	0.383	0.383	0.383	0.404	0.566	0.532	0.355	0.545	0.371	0.411	0.357	0.537	0.383	0.672	0.355	0.411	0.384	0.357	0.371	0.376
PG	0.004	0.013	0.013	0.013	0.012	0.005	0.005	0.018	0.003	0.011	0.007	0.012	0.010	0.013	0.001	0.018	0.007	0.004	0.012	0.011	0.010
RO	0.149	0.175	0.175	0.175	0.178	0.154	0.147	0.195	0.162	0.154	0.211	0.157	0.150	0.175	0.038	0.195	0.211	0.149	0.157	0.154	0.150
ŠV	1.000	0.644	0.644	0.644	0.716	1.000	1.000	0.776	1.000	0.564	1.000	0.533	0.966	0.644	1.000	0.776	1.000	1.000	0.533	0.564	0.586
TV	0.000	1.000	1.000	1.000	1.000	0.340	0.275	1.000	0.158	1.000	0.180	1.000	1.000	1.000	0.055	1.000	0.180	0.000	1.000	1.000	1.000
UL	0.115	0.331	0.331	0.331	0.342	0.309	0.289	0.272	0.209	0.350	0.221	0.334	0.185	0.331	0.048	0.272	0.221	0.115	0.334	0.350	0.273
ŽB	0.619	1.000	1.000	1.000	1.000	1.000	0.773	0.741	0.750	1.000	0.680	1.000	0.701	1.000	1.000	0.741	0.680	0.619	1.000	1.000	1.000

Appendix C. Overall road safety efficiency scores and corresponding rank of the 21 Montenegro' municipalities

Municipality	DEA		Cross Efficiency		Ranking based on different indicators											
					PRWNC		TRWNC		PRNAF		TRNAF		PRNF		TRNF	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Andrijevica	1.000	2	0.874	2	239.471	15	1250.428	16	5.249	20	27.407	19	1.968	16	10.277	17
Bar	0.125	19	0.086	18	171.225	10	416.996	6	0.712	9	1.734	5	0.633	5	1.542	2
Berane	0.396	10	0.278	9	50.243	1	263.482	1	0.490	4	2.568	9	0.294	1	1.541	1
BijeloPolje	0.179	14	0.125	14	103.240	3	517.735	11	0.433	3	2.174	7	0.506	2	2.536	9
Budva	0.150	15	0.107	16	361.820	18	616.374	12	1.904	15	3.244	13	2.251	17	3.834	13
Cetinje	0.194	13	0.137	13	233.292	14	629.684	13	0.999	11	2.696	11	0.999	10	2.696	11
Danilovgrad	1.000	1	0.876	1	130.220	5	516.392	10	0.180	1	0.714	1	0.720	7	2.857	12
Herceg Novi	0.452	9	0.229	11	157.490	8	388.729	3	0.647	8	1.596	4	0.970	9	2.395	8
Kolašin	0.141	17	0.068	19	1156.911	21	5521.031	21	3.970	18	18.947	18	10.719	21	51.156	21
Kotor	0.141	16	0.098	17	228.317	13	503.016	7	1.325	14	2.919	12	1.030	12	2.270	5
Mojkovac	0.576	8	0.410	8	309.086	17	1644.426	18	1.929	16	10.265	16	2.701	18	14.371	18
Nikšić	0.041	20	0.029	20	132.726	6	505.156	9	0.505	6	1.923	6	0.551	4	2.098	4
Plav	0.756	6	0.517	6	120.055	4	705.654	14	1.015	12	5.967	15	1.015	11	5.967	14
Pljevlja	0.141	18	0.115	15	90.021	2	389.198	4	0.540	7	2.336	8	0.540	3	2.336	7
Plužine	0.672	7	0.425	7	501.204	19	3240.557	19	5.125	19	33.135	20	4.100	19	26.508	19
Podgorica	0.018	21	0.010	21	133.394	7	365.839	2	0.394	2	1.080	2	0.662	6	1.816	3
Rožaje	0.211	12	0.162	12	158.064	9	728.888	15	0.724	10	3.340	14	1.304	13	6.013	15
Šavnik	1.000	4	0.790	4	665.402	20	4103.072	20	6.429	21	39.643	21	6.429	20	39.643	20
Tivat	1.000	5	0.676	5	178.787	11	394.847	5	1.186	13	2.618	10	1.186	12	2.618	10
Ulcinj	0.350	11	0.265	10	181.540	12	503.637	8	0.501	5	1.390	3	0.835	8	2.317	6
Žabljak	1.000	3	0.872	3	292.710	16	1349.377	17	3.729	17	17.190	17	1.864	15	8.595	16