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A Novel Approach to Evaluate the Road Safety Index: A Case Study in the Roads of East Azerbaijan Province in Iran

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Abstract
Road safety index is an important indicator that has been recently introduced as a useful tool to measure the quality of life in many countries and cities. Road safety index is a complex index and it has at least three main components, including road user behavior, vehicle safety, and road infrastructure effects. Many researchers have selected studying road performance from road safety index perspective due to its feasibility and applicability. To calculate the road safety index, a novel approach was proposed using data envelopment analysis method. In this paper, the selected road safety indicators are classified into two groups, namely the desirable and undesirable indicators. The new approach was applied for a case study in the roads of East Azerbaijan Province in Iran. Inefficient roads were recognized applying the proposed method, and strategies were suggested to improve the efficiency of these roads.

Keywords
Road Safety Index, Data envelopment analysis, Road safety performance assessment, Undesirable indices.

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Introduction

According to the World Health Organization (WHO, 2015), more than 1.2 million people die each year on the world's roads, making road traffic damage a leading cause of death globally. WHO estimates road accidents will become the world's third leading cause of death by the year 2020. In the road accidents, financial losses are estimated one to three percent of the gross domestic product per capita (WHO, 2015). Road accidents lead to the waste of national capitals and have devastating effects on the development of countries, especially the low-income states. Presently in Iran, driving accidents are the second leading cause of death after cardiovascular diseases, and the most common reason for referral to the emergency operating rooms.

Road safety index is one of the important indicators in terms of road safety performance. The multidimensional structure and complexity of the road safety show that policy makers should apply various influential factors to the road safety (Elvik *et al.*, 2009; Shen *et al.*, 2015). Introduction of a composite road safety index could be useful to reduce the dimensions of the problem. However, determining the weight of sub-indicators or various factors affecting the road safety is challenging. Sensible judgment is needed to specify the weight of the factors affecting the road safety.

Performance evaluation is one of the main components of a successful management system, and it plays a key role in optimally allocating the road safety budget, selecting effective plans and prioritizing road safety plans. The assessment of the road safety performance is applied to improve the efficiency of the road policies that directly relate to human life. Various methods have been proposed to assess the safety of roads and highways (Cafiso et al., 2007; Harwood et al., 2010; Xie et al., 2011; Sacchi et al., 2012; Mbakwe et al., 2016; Grande et al., 2017; Schlögl, and Stütz, 2017). Data Envelopment Analysis (DEA) is one of the methods that have been recently used to evaluate road safety efficiency.

DEA is a non-parametric approach to evaluate the performance of set of decision-making units (DMUs) (Charnes et al., 1978; Banker et al., 1984). DEA measures the relative efficiency of a set of DMUs using mathematical programming and computes efficiency scores, benchmarking partners, and areas to improve.

In recent years, many researchers have studied the Road Safety Index using DEA method (Odeck, 2006; Hermans et al., 2008, 2009; Shen et al., 2011; Shen et al., 2012; Shen et al., 2013). Odeck (2006) investigated target achievements within the transport sector in regard to the road safety with the application of DEA method. Hermans et al.

(2008) studied the road safety performance that the application of a construction process that included factor analysis, analytic hierarchy process, and DEA approach. In addition, Hermans et al. (2009) have proposed benchmarking of road safety using DEA approach with regard to various risk aspects of road safety system. Shen et al. (2011) proposed a generalized multiple layer DEA model to improve the multilayer hierarchical structures of inputs and outputs. They evaluated the road safety performance in some countries according to the proposed generalized model. Shen et al. (2012) evaluated road performance in European Union countries based on the Road safety risk, and presented benchmarks for underperforming countries using nonparametric methods. Besides, they applied the DEA-based road safety model to measure road safety efficiency values, and to use the cross-efficiency method for ranking different countries. They applied their model to classify DEA models to define the best-performing and underperforming countries.

In this paper, the performance assessment of road safety system is studied with the DEA approach, and a novel method is proposed. In the proposed method, the selected road safety indicators are classified into two categories, i.e. the desirable and undesirable indicators. Moreover, the proposed method is applied to a case study of the roads of East Azerbaijan Province in Iran. East Azerbaijan Province is one of the largest provinces in Iran, and due to the existence of numerous mountains and many complex roads, studying the road performance in this province has a high degree of importance for the researchers and for the people living in this region. Furthermore, efficient and inefficient roads are clarified using the proposed method. Also, strategies are introduced to improve the road safety of the inefficient roads.

This paper is organized in five sections. In Section 2, we present the basic principles of Road Safety Index. In Section 3, a novel method is presented for evaluating the Road Safety Index according to the DEA approach. In Section 4, all roads of East Azerbaijan province in Iran are evaluated and analyzed using the proposed method. The conclusions of the study are provided in Section 5.

Road Safety Index

Road safety index is one of the most important public health indicators that have been introduced as a useful tool to compare the performance of countries, cities, and roads in terms of a safety system (Elvik et al., 2009; Shen et al., 2015). Moreover, complexity of the road safety requires researchers to consider different effective factors in their studies. For them, the consideration of indicators that facilitate an equitable assessment of the road safety is essential.

Sometimes, it is useful to reduce the number of dimensions of the problem through the introduction of the composite road safety index. Al-Haji (2007) and Hermans *et al.*, (2008, 2009) classified road safety indicators in two ways. In the first approach, they considered the effective factors in three groups: behavioral factors (driver performance), factors related to vehicle performance, and factors related to the environment and infrastructure of the road. In the second approach, they added the number of accidents, crash rates and accidents risk indicators to the foregoing factors of the first approach.

Road safety index is a general criterion of the conditions of the road safety system that indicates roads performance in three major dimensions, including the road user behavior , vehicle safety, and environmental and infrastructural effects. Since these factors are qualitative and very general, alternative variables are needed to quantify each dimension. To study different aspects of road safety WHO (2015), European Safety Net project, and European Transport Safety Council (ETSC) considered some alternative indicators, including the road user behavior (speed, alcohol and drug use, protective systems), the vehicle safety (age of the vehicle fleet), and environmental factors (road infrastructure and visibility) (Vis, M.A., 2005; WHO, 2015).

In this paper, the chosen road safety indicators are classified into two categories, i.e. desirable and undesirable indicators. Desirable indicators are Road Infrastructure Indicator (which is measured by total number of underpasses and overpasses), Speed Control Indicator (which is measured by the number of surveillance cameras and speed control cameras), Traffic Signs Indicator (which is measured by the number of traffic signs), Trauma Care Indicator (which is measured by the number of emergency and red crescent staff of road), and the Daytime Running Lights indicator (which is measured by the length of road lighting). Moreover, undesirable indicators include Unauthorized Speed Indicator (which is measured by the number of accidents took place due to unauthorized speed), Protective Systems Indicator (which is measured by the number of drivers who do not use the seat belt), Vehicle Indicator (i.e. the number of vehicles that have been used for more than 20 years), and Black Spot Point Indicator (which is measured by the number of black spot points). A large value for the desirable indicators and a small value for the undesirable indicators denote a low chance of accident, while a small value for the desirable indicators and a large value for the undesirable indicators represent a high chance of car accident.

According to the WHO (2015), safe infrastructure has an important role in reducing road traffic injuries. As a result, many developed countries have made significant strategies for making roads safer with reforming road infrastructure. Furthermore, speed cameras are an effective instrument in reducing road traffic fatalities. Speed cameras are extensively used for improving safety and decreasing traffic speeds, which will in turn reduce road traffic collisions and crash rate. Traffic signs are essential instruments that provide road users with information. Provisional warning road signs and variable electronic message signs can decrease accidents, at least in the short term. Trauma care refers to a system responsible for the medical treatment of injured people in a road accident. The number of emergency and Red Crescent staff is a proxy for trauma care. In addition, trauma care involves post-crash care along with the treatment of injuries. This involves the provision of appropriate care at a medical establishment to road crash victims with major and minor injuries. Visibility is one of the main factors in terms of road safety for all the drivers. Daytime Running lights (DRL), increases the visibility and reduces accidents, and consequently improves the road safety (Elvik *et al.*, 2009; WHO, 2015).

Furthermore, black spot point indicator is an undesirable risk factor. Black spot points are locations which are described as high-risk accident locations. According to Hauer (1997), some researchers rank locations by accident rate and accident frequency (accidents per vehicle kilometers or accidents per year). The speed indicator has been recognized as a very important risk factor influencing the severity of accidents. In this study, the speed indicator was computed by the number of accidents due to unauthorized speed. In traffic accidents, the probability of injury and death are reduced by wearing seat belt for road users. In this regard, the protective systems indicator is measured by the number of drivers not using a seat belt. The vehicle indicator is estimated by the number of the fleet over 20 years old.

To obtain an overall road safety index, two separate aggregating steps are to be performed. First, the individual sub-indicators per risk factor are aggregated into one indicator. Next, the main indicators are aggregated into one road safety index. In this paper, it was assumed that each road safety risk factor is fully represented by one carefully selected indicator, and the analysis is limited to the second aggregation step. Note that the results of these calculations can be influenced by the choice of risk factor weights. Therefore, the main focus can be on the problem of weighting various risk factors to compute one road safety index. In most studies, in order to obtain a composite index of several sub-indicators, the weights considered for each subset are selected by the same researcher. Besides, equal weights are assumed for the components of this index, which is recognized as a major methodological drawback. DEA is a nonparametric approach that can be used to select suitable weights. In this approach, the best set of weights for each road safety index was selected based on the largest value of the compound index. This is explained in the next section.

Normalization of different indicators is required to combine the road safety indicators into a single index, apply the index into different units, and rank the roads. Using the linear formula of the desirable basic index (1), we normalized all of the desirable indicators in which a larger value is more desirable. Moreover, smaller values are more appropriate for the undesirable indicators, in which the undesirable basic index (2) is used for normalization. The used normalized indices were specified, which are between zero and one. Individual indices can be computed for the basic index of the road safety index factors using the following formula:

- ✓ The desirable indicators "the higher, the better" can be normalized by the following function:

$$\text{Desirable Basic Index} = \frac{\text{actual value} - \text{min values}}{\text{max values} - \text{min values}} \qquad (1)$$

- ✓ The undesirable indicators "the lower the better" can be normalized by the following function:

$$\text{Undesirable Basic Index} = \frac{\text{max values} - \text{actual value}}{\text{max values} - \text{min values}} \qquad (2)$$

Methodology

This section presents an introduction to the basic DEA models, and has a review on the available methods for the evaluation of the Road Safety Index in DEA. Also, a novel method for obtaining the Road Safety Index was proposed.

Background

DEA is a nonparametric approach, which measures the relative technical efficiency of DMUs in a multiple inputs and multiple outputs environment (Charnes *et al.*, 1978; Banker *et al.*, 1984). Consider a set of n observed units, $DMU_j (j = 1, 2, ..., n)$, where each observation produces s output represented as $y_{rj} (r = 1, 2, ..., s)$ from m inputs represented as $x_{ij} (i = 1, 2, ..., m)$. Charnes *et al.* (1978) proposed CCR input-oriented, linear programming model. This is shown as follows:

$$
\begin{aligned}
\max \quad & \sum_{r=1}^{s} u_r y_{rk} \\
s.t. \quad & \sum_{i=1}^{m} v_i x_{ik} = 1 \\
& \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0; \qquad \forall j \qquad\qquad (3) \\
& u_r \ge 0; \qquad \forall r \\
& v_i \ge 0; \qquad \forall i
\end{aligned}
$$

Furthermore, Banker *et al.* (1984) improved the CCR model and made the BCC model, which is considered as the variable return to scale. In recent years, researchers have studied DEA for different applications such as road maintenance, transportation sector, health care, management, and public transport systems – for example, (Nakanishi and Falcocchio, 2004; Barnum *et al.*, 2008; Fallah-Fini *et al.*, 2012; Holmgren, 2013; Fu *et al.*, 2013; Georgiadis *et al.*, 2014; Roháčová, 2015; Li *et al.*, 2016; Tatari *et al.*, 2016).

In the production process of some applications, there may also exist undesirable factors such as electricity generators contributing to air pollution or waste, which are called undesirable outputs. In order to deal with the undesirable factors via DEA, several methods have been proposed according to the data transformation and directional distance functions and direct approaches (Scheel, 2001). Seiford and Zhu (2002) proposed a method to incorporate the undesirable outputs based on the data transformation. They applied additional DEA models in which the undesirable outputs are treated as outputs and whose efficiency evaluation is reduced. Moreover, Fare and Grosskopf (2004) presented an alternative approach to handle the undesirable factors using a directional distance function. They applied weak and strong disposability assumptions to deal with the undesirable factors. One of the proposed direct approaches to take into account the undesirable factors is presented by Korhonen and Luptacik (2004) which considers all outputs as the composite weighted sum. In fact, the undesirable outputs are directly incorporated into the assigned model. Moreover, some studies have been carried out to assess DMUs in the presence of undesirable outputs (Liu *et al.* (2010); Puri and Yadav, 2016; Kao and Hwang, 2017; Izadikhah and Saen, 2018).

Some researchers have chosen DEA to study road safety efficiency including Odeck, 2006; Hermans *et al.* (2008, 2009), Shen *et al.* (2011), Shen *et al.* (2012), and Shen *et al.* (2013). Odeck (2006) used DEA approach to study his opinions in the transport sector in regard to the road safety. Hermans *et al.* (2008) studied the road safety performance in the construction process using factor analysis, analytic hierarchy process, and DEA approach. Hermans *et al.* (2009) presented benchmarking of road safety using DEA and considering the different risk aspects of road safety system. Shen *et al.* (2011) proposed a generalized multiple layers DEA model to improve multilayer hierarchical structures of inputs and outputs. Shen *et al.* (2012) evaluated road safety risk applying a DEA-based road safety model and using the cross-efficiency method as well as the categorical DEA model. In fact, although they used the proposed method to evaluate the road safety risk in the European Union countries and their study had many strong aspects, some concerns about the study have been pointed out.

In this study, a novel approach is proposed to evaluate road safety index, which includes several features as follows.

i. Road safety index is evaluated through the consideration of all risk factors on the roads, using road safety indicators.
ii. Desirable indicators and undesirable indicators are introduced for every road under study.
iii. According to the DEA approach, a new method is proposed to compute road safety index.
iv. Obtained optimal index is applied to identify the efficient and inefficient roads.
v. Strategies are suggested for each of the inefficient roads to improve their safety.

Proposed approach

Road safety index is a multifaceted index which is calculated using three major components, including road user behavior, vehicle safety, and road infrastructure effects. In this regard, the chosen road safety indicators are considered in two groups, i.e. the desirable and undesirable indicators. In this paper, a new method is proposed to evaluate the road safety performance using DEA approach. The proposed method applies to compute the weight of road safety index for its components. Indeed, the components weights are evaluated, the sum of the weighted desirable indicators is maximized, and at the same time the sum of the weighted undesirable indicators is minimized.

According to the proposed DEA model, the most appropriate weights are selected for each road, so that it has the highest value of the compound index. The road safety index is benchmarked for every road against the best performance from other roads.

Suppose that the performance of n units (DMUs) is evaluated to obtain an optimal composite index. Let y_{rj} be the value of the desirable indicator $\mathbf{r}\,(r = 1,2,...,m)$ for unit $\mathbf{j}\,(j = 1,2,...,n)$, and y_{tj}^{b} be the value of the undesirable indicator $\mathbf{t}\,(t = 1,2,...,s)$ for unit $\mathbf{j}$. Furthermore, suppose that w_r is the vector of desirable indicator r, and w_t^b is the vector of the undesirable indicator $\mathbf{t}$.

In this study, an index-maximizing model is proposed to calculate an ideal value of the composite index of DMU_k, which can be measured by the optimal objective function value of the following LP model.

$$
\begin{aligned}
CI_k = \max \ & \sum_{r=1}^{m} w_r y_{rk} - \sum_{t=1}^{s} w_t^b y_{tk}^b \\
s.t. \ & \sum_{r=1}^{m} w_r y_{rj} - \sum_{t=1}^{s} w_t^b y_{tj}^b \le 1; \quad \forall j \qquad (4) \\
& w_r \ge \varepsilon; \qquad \forall r \\
& w_t^b \ge \varepsilon; \qquad \forall t
\end{aligned}
$$

The sum of the weighted component indices is constrained to be less or equal to 1 for all the units. The infinitesimal ε is introduced to assure that none of the weights will take a zero value. The linear model (4) is an additional model that calculated the optimal weights w_r, and w_t^b of the desirable indicators and the undesirable indicator, respectively. In addition, this model computes the maximum value of the sum of the weighted composite index, in which the undesirable factors are considered as negative weights. Moreover, model (4) is equivalent to an input-oriented DEA model that includes m desirable outputs, s undesirable outputs and one dummy input of 1 for all the DMUs.

All said, the proposed model can now be applied to evaluate the road safety index. The proposed model is a mathematical programming problem in light of nonparametric DEA methodology that constructs suitable weights for aggregation. Thus, an equitable assessment is obtained for road safety performance.

In this respect, the desirable and undesirable indicators are considered as follows:

Desirable indicators:

- Road infrastructure Indicator: Total number of underpasses and overpasses (RI),
- Trauma Care Indicator: Number of emergency and Red Crescent staff on the road. (TCI),
- Visibility (Daytime Running Lights Indicator): The length of road lighting (DRLI),
- Speed Control Indicator: Number of surveillance and speed control cameras (SCI),
- Traffic Signs Indicator: Number of traffic signs (TSI).

Undesirable indicators:

- Unauthorized Speed Indicator: Number of accidents due to the unauthorized speed (USI),
- Protective Systems Indicator: Non-fastened seat belt rate (PSI),
- Vehicle Indicator: The fleet is over 20 years old (VI), and
- Black Spot Points Indicator: Number of black spot points (BSPI).

According to the proposed model (4), by the use of the foregoing indicators, a new linear model is presented to calculate the optimal road safety index as follows:

$$RSI_k = \max \begin{bmatrix} (w_{RI} RI_k + w_{TCI} TCI_k + w_{DRLI} DRLI_k + w_{SCI} SCI_k + w_{TSI} TSI_k) \\ -(w_{USI} USI_k - w_{PSI} PSI_k - w_{VI} VI_k - w_{BSPI} BSPI_k) \end{bmatrix}$$

$$s.t. \begin{bmatrix} (w_{RI} RI_j + w_{TCI} TCI_j + w_{DRLI} DRLI_j + w_{SCI} SCI_j + w_{TSI} TSI_j) \\ -(w_{USI} USI_j - w_{PSI} PSI_j - w_{VI} VI_j - w_{BSPI} BSPI_j) \le 1; \quad \forall j \end{bmatrix} \tag{5}$$

$$w_{TCI},\ w_{DRLI},\ w_{SCI},\ w_{TSI},\ w_{USI},\ w_{PSI},\ w_{VI},\ w_{BSPI} \ge 0$$

Theorem 1:
The feasible region of linear programming model (5) is nonempty, and the optimal objective function value is less than or equal to one.

Proof:
In order to prove that the feasible region for linear programming model (5) is nonempty, a feasible solution is introduced. Consider a particular solution for the linear model (5) where $w_{TCI}=0, w_{DRLI}=0, w_{SCI}=0, w_{TSI}=0, w_{USI}=0, w_{PSI}=0, w_{VI}=0, w_{BSPI}=0$. Thus, this particular solution is also feasible for the model (5). Therefore, the feasible region of model (5) is nonempty. Now, suppose $w^*_{TCI}, w^*_{DRLI}, w^*_{SCI}, w^*_{TSI}, w^*_{USI}, w^*_{PSI}, w^*_{VI}, w^*_{BSPI}$ is an optimal solution in (5). According to the constraint of the model (5) and the presented particular solution, the optimal objective function value $0 \le RSI_k \le 1$. This completes the proof.

The optimal objective function value of the proposed linear model (5) is used for measuring the road safety index and is used to recognize the efficient and inefficient roads. Moreover, a definition of the efficient roads is required to specify an efficient road. This is provided as follows:

Definition 1: A road is defined as an efficient road in terms of the road safety performance, when it is obtained the most value of road safety index. That is, the optimal value obtained from RSI_k for the efficient road is equal to 1 based on the proposed model (5).

Furthermore, this method can be used to construct an improvement strategy for the inefficient roads. The dual problem (envelopment form) of the proposed index-maximizing model (5) is provided to suggest the improvement strategy as follows:

$$CI_k = \min \sum_{j=1}^{n} \lambda_j \tag{6}$$

$$\begin{aligned} s.t.\quad & \sum_{j=1}^{n} \lambda_j RI_j \ge RI_k, \quad \sum_{j=1}^{n} \lambda_j TCI_j \ge TCI_k, \quad \sum_{j=1}^{n} \lambda_j DRLI_j \ge DRLI_k, \\ & \sum_{j=1}^{n} \lambda_j SCI_j \ge SCI_k, \quad \sum_{j=1}^{n} \lambda_j TSI_j \ge TSI_k, \quad \sum_{j=1}^{n} \lambda_j PSI_j \le PSI_k, \\ & \sum_{j=1}^{n} \lambda_j USI_j \le USI_k, \quad \sum_{j=1}^{n} \lambda_j VI_j \le VI_k, \quad \sum_{j=1}^{n} \lambda_j BSPI_j \le BSPI_k, \\ & \lambda_j \ge 0; \quad \forall j \end{aligned}$$

Case Study

East Azerbaijan is a border province that has always been considered as an important province due to its location and the importance of transportation. This province is located in the neighborhood of the South Caucasus region, on the ground and railway transportation route from Iran to Europe. The connection of its major and central cities to the peripheral and border regions is established through provincial roads. Thus, an exact study of the road performance of this province is important in order to analyze the road safety and improve its performance. In this regard, 41 roads of East Azerbaijan Province are evaluated. The required data for the considered indicators was obtained from available sources including WHO, the Department of Roads and Urban Development of East Azerbaijan province, and Iran Road Maintenance and Transportation Organization. The selected roads for this study are listed in Table 1.

Table 1. Roads of East Azerbaijan Province in Iran

Road	DMU	Road	DMU
Tabriz - Sufian	1	Jolfa - Poldasht	22
Ilkhchi - Azarshahr	2	Tabriz - Zanjan Highway (Mianeh - Zanjan	23
Tabriz – Islami island (junction of Khaseban- Lake Urmia Bridge)	3	Sarcham – Khalkhal T-junction	24
Tabriz-Zanjan Highway (Tabriz-Hashtrood)	4	Mianeh - Zanjan (old road)	25
Tabriz – Zanjan Highway (Hashtrood - Mianeh)	5	Bonab - Ajabshir	26
Bostanabad - Tabriz (Old Road)	6	Bonab - Malekan	27
Tabriz - Ilkhchi	7	Malekan - Miandoab	28
First Part of Tabriz - Zanjan Highway (Kasai highway - Shiboli tunnel)	8	Heris - Heris T-junction	29
Western Ring road of Tabriz - Sufian	9	Heris- Ahar T-junction	30
Azarshahr - Ajabshir	10	Sarab - Bostanabad	31
Tabriz - Ahar	11	Bostanabad - Mianeh	32
Ahar - Kaleybar	12	Tabriz - Bostanabad	33

		Highway (Shibolitunnel)	
Ahar - Meshginshahr	13	Mianeh - QarahAghaj	34
Ahar - Hurand	14	Sufian - Shabestar	35
Sarab - Nir	15	Sufian - Marand	36
Hashtrood - Maragheh	16	Shabestar - Tasuj	37
Maragheh - Bonab	17	Tasuj - Salmas	38
Jolfa - Marand	18	Kaleybar - Jananlu	39
Marand - Koshksaray	19	Khajeh - Varzaqan	40
Spacecraft - Ovagli T-junction	20	Khajeh T-junction - Heris T-junction	41
Jolfa - Nurduz	21		

The considered indicators are Road Infrastructure Indicator (RI), Trauma Care Indicator (TCI), Daytime Running Lights Indicator (DRLI), Speed Control Indicator (SCI), Traffic Signs Indicator (TSI), (PSI), Vehicle Indicator (VI), Black Spot Points Indicator, Unauthorized Speed Indicator (USI), and Protective Systems Indicator (BSPI). Since, the indicators are expressed in different measurement units, the standardized indicator values are used to evaluate these indicators. The normalized indicator values are listed in Table 2.

Table 2. Values for the selected indicators of Road Safety Index

	Desirable Indicators					**Undesirable Indicators**			
DMU	**RI**	**TCI**	**DRLI**	**SCI**	**TSI**	**USI**	**PSI**	**BSPI**	**VI**
1	0.3333	0.125	0.75	0.2857	0.2326	0.4902	0.5637	0	0.2938
2	0.2667	0.375	0.25	0.1429	0.2093	0.3529	0.2762	0	0.0565
3	0.0667	0.375	0	0	0.2791	0.0784	0.0446	0	0.0011
4	1	0.375	0.05	1	1	0.0588	0.1760	0.7143	0.0124
5	0.4	0.25	0.05	0.4286	0.4651	0.0196	0.2767	0.7143	0.1898
6	0.3333	0.25	1	0.1429	0.4884	0.2353	0.3876	0.2857	0.9096
7	0.2	0.75	0.35	0.2857	0.1860	0.4902	1	0	0.5706
8	0.2	0.125	0	0.1429	0.1628	0.1765	0.2942	0.1429	0.1718
9	0.2667	0	0	0	0.0930	0	0.1547	0	0.1763
10	0.1333	0.25	0	0.1429	0.3953	0.2353	0.1212	0.4286	0.3040
11	0.1333	0.125	0.25	0.4286	0.1395	0.3137	0.6897	0.4286	1

12	0	0.375	0.1	0.1429	0.6047	0.4902	0.0507	0.1429	0.0441
13	0	0.25	0	0	0.0465	0.1961	0.1182	0.1429	0.0542
14	0	0.125	0	0	0.3023	0.1961	0	0.1429	0.0339
15	0	0.25	0.1	0.1429	0.0233	0.2745	0.2582	0.1429	0.1661
16	0.2	0.5	0.4	0.1429	0.5116	1	0.6273	0.8571	0.0102
17	0.1333	0.25	0.15	0	0	0.0196	0.1866	0.1429	0.1345
18	0.1333	0.25	0	0.1429	0.4884	0.2549	0.5348	0	0.9944
19	0	0.25	0	0	0.1163	0.3529	0.7915	0	0.7085
20	0	0.125	0	0.1429	0.1628	0.1765	0.3502	0	0.0350
21	0	0.5	0	0	0.2558	0.2745	0.0921	0	0.0226
22	0	0.125	0	0	0.0233	0.0392	0.0368	0	0.0305
23	0.4	0.25	0	0.2857	0.5349	0.0196	0.2642	0.2857	0.2023
24	0	0.25	0	0	0.1628	0.1373	0.1191	0.1429	0.1797
25	0.2	0.375	0	0.1429	0.2326	0.4706	0.1326	0	0.1345
26	0.1333	0.125	0	0	0.2093	0.2941	0.1757	0.1429	0.0701
27	0.1333	0.125	0	0	0.1628	0.4314	0.1866	0.5714	0.2859
28	0.0667	0.125	0	0.1429	0.1163	0.0588	0.2193	0.1429	0.1469
29	0.0667	0.25	0	0	0.0698	0.1373	0	0	0.0621
30	0	0.25	0	0.1429	0.1395	0.1176	0.1436	0.1429	0.0599
31	0	0.625	0	0	0.3488	0.6078	0.3104	0.5714	0.2215
32	0.0667	0.625	0.2	0.1429	0.6279	0.1765	0.2199	1	0.3198
33	0	0	0.2	0	0.0233	0	0.3125	0.1429	0.1695
34	0.0667	0.375	0	0	0.6047	0.2353	0.0317	0	0.2271
35	0.1333	0.375	0	0	0.2791	0.1176	0.1849	0.1429	0.0260
36	0.3333	0.25	0.35	0.1429	0.2326	0.7059	0.2759	0	0.0339
37	0	0.375	0	0.1429	0.1163	0.0980	0.0790	0.5714	0.1729
38	0.0667	0.125	0	0	0	0	0.0032	0	0.0215
39	0	1	0	0	0.1395	0.2157	0	0	0.1220
40	0	0.5	0	0	0.1628	0.3529	0.0169	0	0.0362
41	0	0.25	0	0.1429	0.1628	0.0784	0.1774	0.7143	0

The proposed model was applied to the indicators listed in Table 2. In this study, the proposed model was solved using GAMS software and CPLEX solver. The maximum value of the Road Safety Index was measured by the optimal objective function value of model (5). Obtained results are presented in Table 3.

Table 3. RSI scores of 41 roads in the East Azerbaijan Province of Iran

Case	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
DMU	USI, PSI, BSPI, VI	USI, PSI, BSPI	USI, PSI, VI	USI, BSPI, VI	PSI, BSPI, VI	USI, PSI,	USI, BSPI	USI, VI	PSI, BSPI	PSI, VI	BSPI, VI	USI	PSI	BSPI	VI
1	1	1	1	1	1	0.921	1	1	1	1	1	0.921	0.921	1	1
2	1	1	1	1	1	0.661	1	1	1	0.825	1	0.648	0.661	0.927	0.751
3	1	1	1	1	1	0.525	1	1	0.706	1	1	0.525	0.525	0.664	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	0.543	1	1	1	0.543	0.543	0.543	1	0.543	0.543	0.543
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
9	1	1	1	1	1	1	1	1	1	0.267	0.800	1	0.267	0.800	0.267
10	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488	0.488
11	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626
12	1	1	1	1	1	1	0.949	0.772	1	1	1	0.749	1	0.949	0.772
13	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258	0.258
14	1	1	1	0.377	1	1	0.369	0.313	1	1	0.377	0.313	1	0.369	0.313
15	0.365	0.365	0.365	0.359	0.365	0.365	0.359	0.359	0.365	0.365	0.359	0.359	0.365	0.359	0.359
16	1	0.939	1	1	1	0.939	0.939	1	0.939	1	1	0.939	0.939	0.939	1
17	1	1	1	1	0.421	1	1	1	0.404	0.421	0.421	1	0.404	0.394	0.421
18	1	1	0.549	1	1	0.549	1	0.549	1	0.549	1	0.549	0.549	1	0.549
19	0.342	0.342	0.304	0.342	0.342	0.304	0.342	0.304	0.342	0.304	0.342	0.304	0.304	0.342	0.304
20	1	1	0.221	1	0.995	0.221	1	0.221	0.566	0.221	0.995	0.221	0.221	0.566	0.221
21	1	0.711	1	1	1	0.623	0.711	0.998	0.711	1	1	0.623	0.623	0.711	0.878
22	0.132	0.132	0.129	0.132	0.132	0.129	0.132	0.129	0.132	0.129	0.132	0.129	0.129	0.132	0.129
23	1	1	1	1	0.637	1	1	1	0.637	0.580	0.637	1	0.580	0.637	0.580
24	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334	0.334
25	1	1	0.5	0.937	1	0.5	0.833	0.5	1	0.5	0.937	0.5	0.5	0.833	0.500
26	0.253	0.253	0.252	0.253	0.253	0.252	0.253	0.252	0.253	0.252	0.253	0.252	0.252	0.253	0.252
27	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221	0.221
28	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214	0.214
29	1	1	1	0.392	1	1	0.380	0.292	1	1	0.387	0.292	1	0.342	0.292
30	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339	0.339
31	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798
32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

33	1	1	1	1	0.208	1	1	1	0.2	0.208	0.208	1	0.2	0.2	0.208
34	1	1	1	1	1	1	1	0.739	1	1	1	0.739	1	1	0.739
35	0.666	0.542	0.666	0.666	0.657	0.525	0.542	0.666	0.542	0.611	0.657	0.525	0.525	0.542	0.594
36	1	1	1	1	1	0.634	1	1	1	1	1	0.634	0.634	1	0.947
37	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464
38	1	1	1	1	1	1	1	1	0.938	1	0.273	1	0.746	0.250	0.167
39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
40	1	0.605	1	0.823	1	0.563	0.605	0.789	0.605	1	0.823	0.561	0.563	0.605	0.744
41	1	0.339	1	1	1	0.339	0.339	1	0.339	1	1	0.339	0.339	0.339	1

This method was applied to 15 cases, in some of the cases a number of undesirable indicators are ignored. The analysis and evaluation of Road Safety Index is based on four major contributions. First, all four undesirable indicators were considered in case 1, and the obtained results were shown in column 2 of Table 3. Second, in some cases, three undesirable indicators were considered, i.e. only one undesirable factor was ignored. Vehicle Indicator, Black Spot Points Indicator, Protective Systems Indicator, and Unauthorized Speed Indicator were ignored in case 2, case 3, case 4, and case 5, respectively. The obtained results were presented in columns 3 to 6 of Table 3. Third, from case 6 to case 11, two undesirable indicators were considered and the obtained results were provided in the columns 7 to 12 of Table 3. Fourth, the last category involved some cases where only one undesirable indicator was considered. Unauthorized Speed Indicator, Protective Systems Indicator, Black Spot Points Indicator, and Vehicle Indicator are used only in case 12, case 13, case 14, and case 15, respectively.

Below are some of the important analyses that were carried out according to the results presented in Table 3.

(1) In all 15 cases, DMU_4, DMU_6, DMU_7, DMU_{32}, and DMU_{39} have the maximum value of the Road Safety Index (RSI). In fact, the RSI values for these DMUs are equal to 1.

(2) It is important to note, however, that the optimal value of Road Safety Index is always smaller than 1 for 15 roads in each 15 cases. As a result, these roads are always inefficient roads.

(3) As shown in the second column, 26 roads gained the highest possible DEA score of 1 (efficient index). Thus, when all undesirable indicators are considered in the evaluation, almost 60 percent of roads are identified as efficient ones.

(4) Moreover, the thirteenth to sixteenth columns show that when just one undesirable indicator is considered, the number of the efficient roads is reduced. In case 12, eleven roads, and in cases 13, 14 and 15, nine roads were underlined as efficient road in terms of Road Safety Index.

As an example for the inefficient roads, case 5 was evaluated and strategies for its improvement were suggested. In case 5, just one undesirable indicator USI was ignored and the three undesirable indicators PSI, BSPI, and VI were taken into account. The improved indicators were calculated based on model (6) for 41 roads. These are shown in Table 4.

Table 4. The improved indicators for case 5

		Desirable Indicators					**Undesirable Indicators**		
DMU	RSI value	RI	TCI	DRLI	SCI	TSI	PSI	BSPI	VI
1	1	0.333	0.125	0.750	0.286	0.233	0.564	0	0.294
2	1	0.267	0.375	0.250	0.143	0.209	0.276	0	0.057
3	1	0.067	0.375	0	0	0.279	0.045	0	0.001
4	1	1	0.375	0.050	1	1.000	0.176	0.714	0.012
5	0.543	0.419	0.250	0.050	0.429	0.465	0.129	0.368	0.055
6	1	0.333	0.250	1	0.143	0.488	0.388	0.286	0.910
7	1	0.200	0.750	0.350	0.286	0.186	1	0	0.571
8	0.250	0.200	0.125	0.010	0.200	0.207	0.035	0.143	0.009
9	1	0.267	0	0	0	0.093	0.155	0	0.176
10	0.488	0.380	0.250	0.019	0.380	0.395	0.067	0.272	0.018
11	0.626	0.472	0.206	0.250	0.429	0.508	0.159	0.348	0.214
12	1	0	0.375	0.100	0.143	0.605	0.051	0.143	0.044
13	0.258	0.012	0.250	0.001	0.012	0.047	0.002	0.009	0.030
14	1	0	0.125	0	0	0.302	0	0.143	0.034
15	0.365	0.125	0.250	0.100	0.143	0.129	0.258	0.055	0.154
16	1	0.200	0.500	0.400	0.143	0.512	0.627	0.857	0.010
17	0.421	0.133	0.250	0.150	0.107	0.192	0.096	0.139	0.135
18	1	0.133	0.250	0	0.143	0.488	0.535	0	0.994
19	0.342	0.010	0.250	0	0	0.116	0.005	0	0.057
20	0.995	0.332	0.248	0.350	0.143	0.231	0.276	0	0.035

21	1	0	0.500	0	0	0.256	0.092	0	0.023
22	0.132	0.001	0.125	0	0	0.023	0.000	0	0.017
23	0.637	0.415	0.250	0.020	0.400	0.535	0.077	0.286	0.057
24	0.334	0.135	0.250	0.007	0.135	0.163	0.024	0.096	0.026
25	1	0.200	0.375	0	0.143	0.233	0.133	0	0.135
26	0.253	0.200	0.125	0.010	0.200	0.209	0.035	0.143	0.009
27	0.221	0.153	0.125	0.008	0.153	0.163	0.027	0.110	0.010
28	0.214	0.143	0.125	0.007	0.143	0.153	0.025	0.102	0.010
29	1	0.067	0.250	0	0	0.070		0	0.062
30	0.339	0.143	0.250	0.007	0.143	0.170	0.025	0.102	0.026
31	0.798	0.276	0.625	0.014	0.276	0.349	0.049	0.197	0.067
32	1	0.067	0.625	0.200	0.143	0.628	0.220	1	0.320
33	0.208	0.069	0.048	0.200	0.034	0.093	0.086	0.050	0.170
34	1	0.067	0.375	0	0	0.605	0.032	0	0.227
35	0.657	0.165	0.375	0.022	0.163	0.279	0.080	0.143	0.026
36	1	0.333	0.250	0.350	0.143	0.233	0.276	0	0.034
37	0.464	0.143	0.375	0.007	0.143	0.188	0.025	0.102	0.041
38	1	0.067	0.125	0	0	0	0.003	0	0.022
39	1	0	1	0	0	0.140	0	0	0.122
40	1	0	0.500	0	0	0.163	0.017	0	0.036
41	1	0	0.250	0	0.143	0.163	0.177	0.714	0

As shown in Table 4, 21 roads are efficient roads in terms of Road Safety Index. It can be seen from Table 3-4 that for the efficient roads in improvement strategy, the improved indicator values are not changing. Moreover, it can be observed from Table 4 that for 20 roads such as DMU_5, DMU_8, DMU_{10}, DMU_{11}, DMU_{13}, DMU_{15}, DMU_{17}, DMU_{19}, DMU_{20}, DMU_{22}, DMU_{23}, DMU_{24}, DMU_{17}, DMU_{26}, DMU_{27}, DMU_{28}, DMU_{30}, DMU_{31}, DMU_{33}, DMU_{35}, and DMU_{37}, the obtained optimal value for RSI_k is less than one, hence these roads are deemed as inefficient.

In the improvement strategy for the inefficient roads, desirable indicators were increased, while undesirable indicators were reduced. For instance, applying the improvement strategy for DMU_{11}, the values of three desirable indicators, including RI, TCI, and TSI, were increased (i.e. RI=0.1333, TCI=0.125, and TSI=0.1395 were improved to RI=0.4724, TCI=0.2059, and TSI=0.5081, respectively). Furthermore, the values of three undesirable indicators, including PSI, BSPI, and VI were decreased (i.e. PSI = 0.6897, BSPI =0.3484, and VI =1 were improved to PSI = 0.1589, BSPI =0.4286 and VI = 0.2143, respectively).

In the same way, the improvement strategies can be obtained for other cases.

Conclusion

Road safety is an important parameter that has been used to evaluate the quality of life in different countries. Road Safety Index has recently been presented as a useful tool for quantifying the performance of the roads. In this paper, a novel approach was proposed for the evaluation of the road safety performance according to the DEA approach. In this method, the road safety indicators were considered in two categories, i.e. desirable and undesirable indicators. To apply the new method and case study, all roads of East Azerbaijan were analyzed. Inefficient roads in this province were identified, and strategies were suggested to advance the performance of these roads.

References

Al-Haji, G. (2007). *Road safety development index: Theory, philosophy and practice*. Doctoral dissertation, Linköping University Electronic Press.

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management science*, *30*(9), 1078-1092.

Barnum, D. T., Tandon, S., & McNeil, S. (2008). Comparing the performance of bus routes after adjusting for the environment using data envelopment analysis. *Journal of Transportation Engineering*, *134*(2), 77-85.

Cafiso, S., Cava, G., & Montella, A. (2007). Safety index for evaluation of two-lane rural highways. *Journal of the Transportation Research Board*, 2019(1), 136-145.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European journal of operational Research*, *2*(6), 429-444.

Elvik, R., Vaa, T., Hoye, A., & Sorensen, M. (Eds.). (2009). *The handbook of road safety measures*. European Journal of Transport Infrastructure Research, Emerald Group Publishing Limited, ISBN: 9781848552500.

Fallah-Fini, S., Triantis, K., Jesus, M., & Seaver, W. L. (2012). Measuring the efficiency of highway maintenance contracting strategies: A bootstrapped non-parametric meta-frontier approach. *European journal of operational research*, *219*(1), 134-145.

Färe, R., & Grosskopf, S. (2004). Modeling undesirable factors in efficiency evaluation: Comment. *European Journal of Operational Research*, *157*(1), 242-245.

Fu, P., Zhan, Z., & Wu, C. (2013). Efficiency analysis of Chinese Road Systems with DEA and order relation analysis method: Externality concerned. *Procedia-Social and Behavioral Sciences*, *96*, 1227-1238.

Georgiadis, G., Politis, I., & Papaioannou, P. (2014). Measuring and improving the efficiency and effectiveness of bus public transport systems. *Research in*

Transportation Economics, *48*, 84-91.
Grande, Z., Castillo, E., Mora, E., & Lo, H. K. (2017). Highway and road probabilistic safety assessment based on bayesian network models. *Computer‐ Aided Civil and Infrastructure Engineering*, *32*(5), 379-396.
Harwood, D., Bauer, K., Gilmore, D., Souleyrette, R., & Hans, Z. (2010). Validation of U.S. road assessment program star rating protocol: Application to safety management of U.S. roads. *Journal of the Transportation Research Board*, 2147(1), 33-41.
Hauer, E. (1997). *Observational before/after studies in road safety: Estimating the effect of highway and traffic engineering measures on road safety*, Elsevier Science Ltd., Oxford.
Hermans, E., Van den Bossche, F., & Wets, G. (2008). Combining road safety information in a performance index. *Accident Analysis & Prevention, 40*(4), 1337-1344.
Hermans, E., Van den Bossche, F., & Wets, G. (2009). Uncertainty assessment of the road safety index. *Reliability Engineering & System Safety*, *94*(7), 1220-1228.
Holmgren, J. (2013). The efficiency of public transport operations–An evaluation using stochastic frontier analysis. *Research in Transportation Economics*, *39*(1), 50-57.
Korhonen, P. J., & Luptacik, M. (2004). Eco-efficiency analysis of power plants: An extension of data envelopment analysis. *European journal of operational research*, *154*(2), 437-446.
Li, T., Yang, W., Zhang, H., & Cao, X. (2016). Evaluating the impact of transport investment on the efficiency of regional integrated transport systems in China. *Transport Policy*, *45*, 66-76.
Liu, W. B., Meng, W., Li, X. X., & Zhang, D. Q. (2010). DEA models with undesirable inputs and outputs. *Annals of Operations Research*, *173*(1), 177-194.
Mbakwe, A. C., Saka, A. A., Choi, K., & Lee, Y. J. (2016). Alternative method of highway traffic safety analysis for developing countries using Delphi technique and Bayesian network. *Accident Analysis & Prevention*, *93*, 135-146.
Nakanishi, Y. J., & Falcocchio, J. C. (2004). Performance assessment of intelligent transportation systems using data envelopment analysis. *Research in Transportation Economics*, *8*, 181-197.
Odeck, J. (2006). Identifying traffic safety best practice: An application of DEA and Malmquist indices. *Omega*, *34*(1), 28-40.
Roháčová, V. (2015). A DEA based approach for optimization of urban public transport system. *Central European journal of operations Research*, *23*(1), 215-233.
Sacchi, E., Persaud, B., & Bassani, M. (2012). Assessing international transferability of highway safety manual crash prediction algorithm and its components. *Journal of the Transportation Research Board*, 2279(1), 90-98.
Scheel, H. (2001). Undesirable outputs in efficiency valuations. *European journal of operational research*, *132*(2), 400-410.
Schlögl, M., & Stütz, R. (2017). *Methodological considerations with data uncertainty in road safety analysis*. Accident Analysis & Prevention, In Press, https://doi.org/10.1016/j.aap.2017.02.001.
Seiford, L. M., & Zhu, J. (2002). Modeling undesirable factors in efficiency evaluation. *European journal of operational research*, *142*(1), 16-20.
Shen, Y., Hermans, E., Bao, Q., Brijs, T., & Wets, G. (2013). Road safety development in Europe: A decade of changes (2001–2010). *Accident Analysis & Prevention*, *60*, 85-94.
Shen, Y., Hermans, E., Bao, Q., Brijs, T., Wets, G., & Wang, W. (2015). Inter-national

benchmarking of road safety: State of the art. *Transportation research part C: Emerging technologies*, *50*, 37-50.

Shen, Y., Hermans, E., Brijs, T., Wets, G., & Vanhoof, K. (2012). Road safety risk evaluation and target setting using data envelopment analysis and its extensions. *Accident Analysis & Prevention*, *48*, 430-441.

Shen, Y., Hermans, E., Ruan, D., Wets, G., Brijs, T., & Vanhoof, K. (2011). A generalized multiple layer data envelopment analysis model for hierarchical structure assessment: A case study in road safety performance evaluation. *Expert systems with applications*, *38*(12), 15262-15272.

Tatari, O., Egilmez, G., & Kurmapu, D. (2016). Socio-eco-efficiency analysis of highways: A data envelopment analysis. *Journal of Civil Engineering and Management, 22*(6), 747-757.

Vis, M.A. (2005). *State of the art report on road safety performance indicators.* Deliverable D3.1 of the EU Integrated Project Safety Net.

World Health Organization. (2015). *Global status report on road safety* 2015. World Health Organization, Electronic Press. ISBN: 97 8 92 4 156506 6.

Xie, F., Gladhill, K., Dixon, K., & Monsere, C. (2011). Calibration of highway safety manual predictive models for Oregon state highways. *Journal of the Transportation Research Board*, 2241(1), 19-28.