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Evaluating Trauma Management Performance in Europe

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Abstract

Trauma management (TM) concerned with the medical treatment of injuries resulting from road crashes is considered as the key component in avoiding preventable death and disability, and reducing the severity and suffering caused by the injury. To better understand the concept of TM and to evaluate the level of overall performance of different countries, a hierarchical set of TM indicators is developed and subsequently combined into an overall index. To this end, the exploration of data envelopment analysis (DEA) is carried out, and a multiple layer DEA model is developed to reflect the hierarchical structure of the indicators. Using 17 TM performance indicators related to emergency medical services (EMS) and permanent medical facilities (PMF), the most optimal TM index score is computed for 21 European countries. Furthermore, the weights assigned to the indicators of each layer of the hierarchy are deduced thereby providing insight into the critical aspects of the prevalent TM system. In addition, country groups in accordance with the index score are evaluated and a particular set of benchmark countries is identified for those countries with a relatively poor performance.

1 INTRODUCTION

In 2008, about 39,000 people died in Europe as a consequence of road crashes, and many more got injured (*1*). Despite the fact that this figure keeps decreasing since 2001, the year in which the European Union (EU) set itself a target of halving the yearly number of road fatalities within 10 years (*2*), it is, however, still far away from the 25,000 objective for 2010. To this end, crash data such as the number of fatalities and casualties are widely investigated (*3*). However, they are usually treated as the "worst case scenario" in the insecure operational conditions of road traffic and are insufficient in explaining more detailed aspects of crash causation and injury prevention. Therefore, during the last years, safety performance indicators are rapidly developed and increasingly used (*4-6*). They are causally related to the number of crashes or to the injury consequences of a crash, and can be used to understand the processes that lead to crashes and monitor the effectiveness of the safety actions that are taken. In the European SafetyNet project (*4*) on road safety performance indicators, the following seven domains are designated as central road safety risk factors in Europe and selected for the development of safety performance indicators: Alcohol and drugs; Speed; Protective systems; Daytime running lights; Vehicle; Roads; and Trauma management. Amongst others, trauma management (TM) which is concerned with the medical treatment of injuries resulting from road crashes is the key component in avoiding preventable death and disability, and reducing the severity and suffering caused by the injury. A review of studies in Europe (*7*) concluded that about 50% of road traffic deaths occurred within a few minutes either at the scene of the crash or on the way to a hospital, 15% at the hospital within four hours of the crash and 35% after four hours. It means that many of these deaths could have been prevented if more immediate and better medical care would have been available (*8*). Studies worldwide (*9,10*) have shown that within the time period reaching a hospital, deaths and complications resulting in disability could be prevented in many cases. The European Commission (*11*) has stated that several thousands of lives could be saved in the EU by improving the response times of the emergency services and other elements of post-impact care in the event of road traffic crashes. A review of 1970-1996 data in several OECD countries suggested that between 5% and 25% of the reductions in road crash deaths may have been due to improvements in medical care and technology (*12*).

The above discussion shows the potential of learning lessons on how to efficiently manage TM. To better understand the concept of TM and to monitor the effectiveness of related safety actions taken in different countries, the European SafetyNet project introduced a hierarchical set of safety performance indicators characterizing the TM performance (*13*). Totally, 17 indicators related to effective and timely emergency services, professionally trained medical staff, and suitable medical equipment were selected and data collected for 21 European countries. Moreover, in order to draw an enriched TM picture and evaluate the level of overall TM performance for all these countries, the creation of a composite TM index is valuable, as it offers advantages in terms of communication, benchmarking, and prioritizing policy actions (*6*). To this end, two statistical weighting methods—principle component analysis (PCA) and factor analysis (FA)—were applied (*13*). However, there are several limitations in the use of these two methods. For example, the idea behind these methods is to account for the highest possible variation in the indicator set using the smallest possible number of factors (*14*). Therefore, if there is no correlation between the basic indicators, no composite index can be obtained unless some indicators are deleted in advance. Moreover, in these methods, all indicators are treated abreast regardless of their position in the hierarchical structure.

In this paper, data envelopment analysis (DEA) (*15*) as a powerful analytical research tool for modeling operational processes is applied to aggregate the indicator values of each country and determine an optimal overall index score. An attractive feature of DEA, relative to other methods (*16-18*) in developing a composite index, is that each country obtains its own best possible indicator weights, and DEA assesses the relative performance of a particular country taking the performance of all other countries into account, i.e., it is based on self appraisal. More importantly, the hierarchical structure of the indicators can be reflected in the model. As a result, a separate, best possible multiple layer DEA (MLDEA) model is constructed for each country, which results in its most optimal TM index score. Subsequently, the index score can be used to constitute groups of countries (communication), and the weights allocated in each layer of the hierarchy can be deduced for each country thereby offering insights in the key problem aspects of the TM system (policy support in terms of a prioritization of actions). Moreover, for those countries with a relatively poor performance, a particular set of countries will be assigned as useful benchmarks (benchmarking).

The paper is organized as follows. In Section 2, the TM indicators and their hierarchical structure are described and the data used in this study presented. Section 3 introduces the MLDEA model for creating a composite index, and the results from the model are provided in Section 4. Section 5 discusses the main strengths and weaknesses of this model, and the paper ends in Section 6 with conclusions and topics for future research.

2 TRAUMA MANAGEMENT INDICATORS AND DATA

TM, i.e., post-crash medical treatment, is considered to be a key aspect in avoiding preventable deaths and reducing the severity of injuries. A considerable amount of studies (*9-12*) have indicated that a more immediate post-impact care and effective emergency services are linked to a higher probability of preventing deaths as well as many complications resulting in disability. In this paper, the overall TM performance of a country is evaluated. To this end, the formulation of relevant TM indicators and the collection of indicator data are required.

2.1 Trauma Management Indicators and Their Hierarchy

In the SafetyNet D3.11b report (*13*), a hierarchical structure of safety performance indicators (illustrated in Fig. 1) is presented to characterize TM performance.

In general, the TM system covers two types of medical treatment, one is the initial medical treatment provided by emergency medical services (EMS), and the other one is the further medical treatment provided by permanent medical facilities (PMF). The first type can be further decomposed into EMS stations, EMS staff, EMS transportation units and EMS response time. Moreover, each aspect is measured by several quantifiable performance indicators. Concerning the EMS, totally 15 indicators are specified reflecting both availability and quality issues. Taking EMS stations as an example, four indicators are selected, which are the number of EMS stations per 10,000 citizens (*I1*), the number of EMS stations per 100 km rural road length (*I2*), the number of EMS stations per 1,000 km^2 area (*I3*), and the percentage of EMS stations with at least one physician (*I4*). With respect to the PMF, due to data availability limitations, only two indicators (*I16* and *I17*) are selected for representing the performance of further medical treatment.

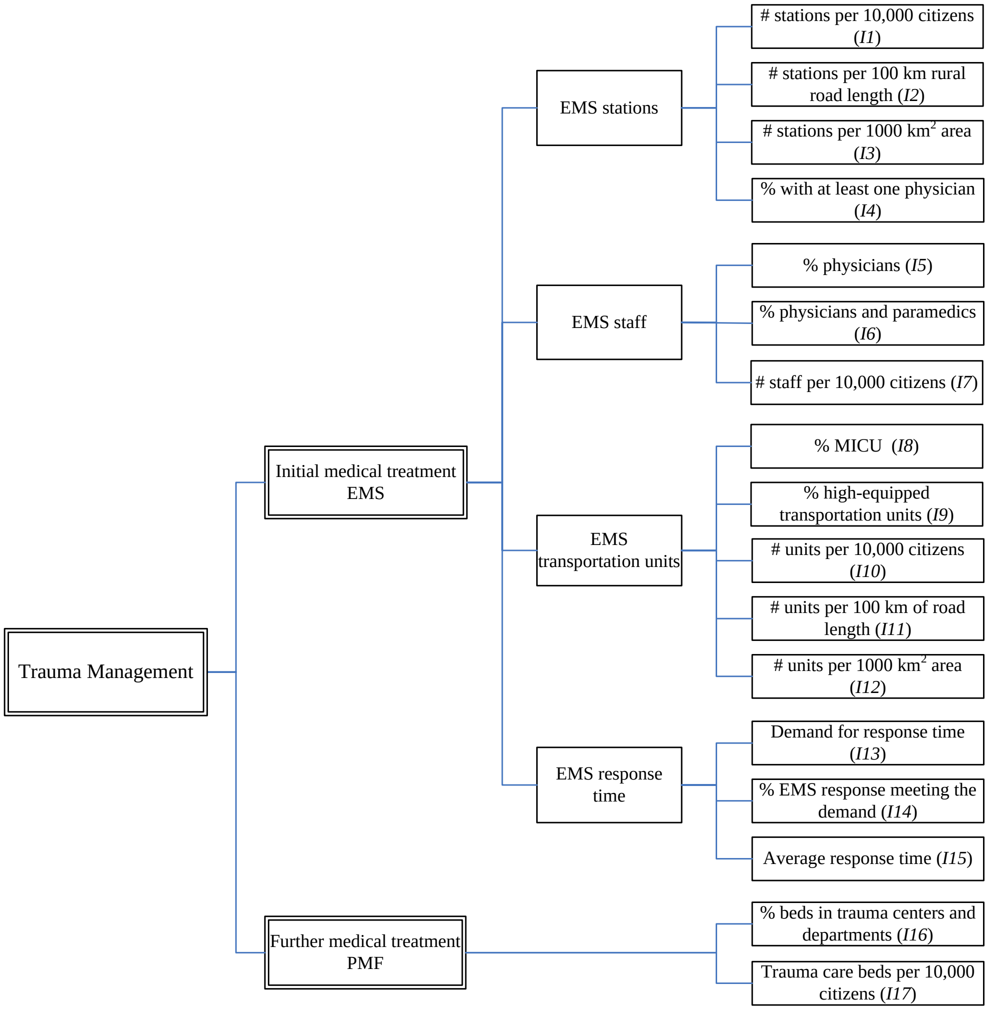

FIGURE 1 Hierarchical framework of TM performance indicators.

2.2 Data

In addition to the formulation of indicators representing the characteristics of the TM system, collected indicator data were given in the report (*13*). Values related to 2006 were obtained for 21 European countries being Austria (AT), Belgium (BE), Bulgaria (BG), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), Germany (DE), Greece (EL), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), the Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Slovakia (SK), Sweden (SE), and United Kingdom (UK).

To ensure that all the indicators that will be combined in an index are expressed in the same direction, i.e., a higher value representing a better performance, we use the reciprocals of *I13* (the demand for response time) and *I15* (the average response time). Furthermore, to eliminate the effects of the measurement unit and the scale of the indicators, the raw indicator values are divided by the maximum value of each indicator in the data set. As a result, value one indicates the best performing country with regard to a particular TM indicator. The resulting normalized data (21×17) are presented in Table 1. In this study, the 17 indicator values characterizing each country will be combined into a trauma management index score in order to evaluate the relative level of overall TM performance of these 21 countries.

TABLE 1 Normalized data on the 17 TM performance indicators

	EMS															PMF	
	EMS stations				EMS staff			EMS transportation units					EMS response time				
	I1	*I2*	*I3*	*I4*	*I5*	*I6*	*I7*	*I8*	*I9*	*I10*	*I11*	*I12*	*I13*	*I14*	*I15*	*I16*	*I17*
Austria	0.81	0.30	0.72	0.29	0.11	0.40	1.00	0.05	1.00	0.93	1.00	0.62	0.50	0.95	0.65	0.05	1.00
Belgium	0.23	0.07	0.66	0.27	0.28	0.20	0.17	0.22	1.00	0.14	0.13	0.30	0.50	1.00	1.00	0.74	0.01
Bulgaria	0.45	0.35	0.32	1.00	0.41	0.30	0.19	0.55	0.87	0.23	0.24	0.19	0.49	0.77	0.40	0.74	0.01
Cyprus	0.36	0.14	0.28	1.00	0.35	0.26	0.08	0.50	1.00	0.33	0.29	0.19	0.52	1.00	0.59	0.00	0.02
Czech Republic	0.29	0.32	0.35	0.79	0.28	0.21	0.07	0.59	1.00	0.19	0.49	0.17	0.50	0.89	0.77	0.74	0.13
Denmark	0.41	0.15	0.46	0.56	0.09	0.08	0.07	0.03	1.00	0.27	0.28	0.23	1.00	1.00	0.75	0.35	0.36
Estonia	0.62	0.06	0.17	0.55	0.27	0.25	0.19	0.07	1.00	0.21	0.07	0.04	0.50	0.64	0.26	0.71	0.03
Finland	0.75	0.21	0.11	0.02	0.02	0.38	0.02	0.25	1.00	0.24	0.04	0.03	0.65	0.96	0.63	0.32	0.52
Germany	0.35	0.51	0.73	0.39	0.59	1.00	0.13	0.49	0.85	0.29	0.53	0.45	0.50	0.92	0.74	0.16	0.79
Greece	0.02	0.02	0.01	0.74	0.13	0.18	0.04	0.03	0.99	0.21	0.18	0.12	0.43	0.92	0.40	0.00	0.59
Hungary	0.34	0.18	0.33	0.38	0.24	0.18	0.02	0.13	1.00	0.30	0.31	0.22	0.50	0.72	0.38	0.46	0.04
Latvia	0.29	0.05	0.09	1.00	0.32	0.23	0.14	1.00	1.00	0.33	0.18	0.08	0.30	0.88	0.35	0.16	0.00
Lithuania	0.29	0.21	0.13	1.00	0.34	0.26	0.09	0.00	1.00	0.39	0.87	0.14	0.38	0.74	0.31	0.15	0.00
Malta	0.04	0.14	0.45	1.00	1.00	0.74	0.03	0.00	1.00	0.12	0.29	1.00	0.45	0.81	0.27	0.74	0.01
Netherlands	0.05	0.05	0.18	0.49	0.00	0.00	0.03	0.00	1.00	0.13	0.24	0.33	0.50	0.80	0.52	0.19	0.42
Norway	0.69	0.14	0.09	0.46	0.29	0.39	0.10	0.00	0.93	0.46	0.32	0.04	0.57	0.90	0.60	0.30	0.36
Poland	0.09	0.07	0.09	1.00	0.33	0.17	0.04	0.35	1.00	0.12	0.16	0.09	0.50	0.90	0.50	0.74	0.01
Portugal	0.72	0.20	0.74	0.23	0.13	0.24	0.07	0.22	0.93	0.25	0.42	0.24	0.41	0.74	0.55	1.00	0.37
Slovakia	1.00	1.00	1.00	1.00	0.39	0.29	0.14	0.01	0.53	0.22	0.92	0.16	0.50	0.78	0.35	0.74	0.02
Sweden	0.48	0.18	0.09	0.21	0.00	0.00	0.09	0.89	1.00	0.17	0.11	0.02	0.48	0.84	0.48	0.17	0.21
United Kingdom	0.27	0.25	0.61	0.39	0.00	0.87	0.09	0.00	0.21	1.00	0.76	0.45	0.86	1.00	0.68	0.36	0.77

3 METHODOLOGY

Data envelopment analysis developed by Charnes et al. (*15*) is a mathematical programming methodology to measure the relative efficiency of a homogeneous set of decision making units (DMUs), such as countries. Since its first introduction in 1978, DEA has been quickly recognized as a powerful analytical research tool for modeling operational processes in terms of performance evaluations (*19*), benchmarking (*20*), decision making (*21*), etc. An attractive feature of DEA, relative to other common methods applied for developing a composite index, is that each country obtains its own indicator weights, and DEA assesses the relative performance of a particular country by comparing it against all other countries, i.e., country-specific models will be set up, in which from all possible sets of weights, the set that results in the highest index score is selected. In the following sections, the basic DEA model is briefly presented and a multiple layer DEA model proposed. The latter one will be used to combine all TM indicators into a composite index meanwhile reflecting the hierarchical structure of these indicators.

3.1 Basic DEA Model

Consider a set of *n* countries, each having *m* different indicators. The basic DEA model for computing the composite index score for a particular country *c* is shown in (**1**) (*15*):

$$
\begin{aligned}
CI_c &= \max \sum_{i=1}^{m} v_i x_{ic} \\
s.t.\quad & \sum_{i=1}^{m} v_i x_{ij} \le 1, \quad j = 1, \cdots, n \\
& v_i \ge \varepsilon, \quad i = 1, \cdots, m
\end{aligned}
\qquad \mathbf{(1)}
$$

In this constrained optimization problem, x_{ij} is the ith indicator of the jth country, v_i is the weight given to indicator i, and ε is a small non-Archimedean number (*22*) for restricting the model to assign a weight of 0 to unfavorable factors, thereby guaranteeing the use of all indicators in the index to some extent. This linear program is solved separately for each country to determine its optimal index score using a particular set of weights. In other words, the weights in the objective function are chosen to maximize country *c*'s index score and meanwhile respect the less than unity constraint for the computed index score of all the countries including *c* itself. Consequently, a country is considered to be best-performing if it obtains a score of one whereas a score less than one implies that it is an underperforming country.

3.2 Multiple Layer DEA Model

The application of the basic DEA model to the composite index field provides an interesting way of combining a set of indicators into an optimal overall score for each country. However, in order to take the hierarchical structure of indicators into account, a multiple layer DEA model (*23*) should be utilized. Suppose that a set of *n* countries is to be evaluated in terms of *m* indicators with an *L* layered hierarchical structure. The MLDEA model can then be formulated as in (**2**) and solved with a software package such as Lingo (*24*).

$$
\begin{aligned}
CI_0 &= \max \sum_{i=1}^{m} v_i x_{i0} \\
s.t.\quad & \sum_{i=1}^{m} v_i x_{ij} \le 1, \quad j = 1, \cdots, n \\
& \underset{g_l \in B_{g_{l+1}}^{(l+1)}}{q_{g_l}^{(l)}} = \frac{\sum_{i \in B_{g_l}^{(l)}} v_i}{\sum_{i \in B_{g_{l+1}}^{(l+1)}} v_i} \in \Psi, \quad g_l = 1, \cdots, m^{(l)}, \quad l = 1, \cdots, L-1 \\
& \sum_{i \in B_{g_L}^{(L)}} v_i = \hat{v}_{g_L}, \quad i = 1, \cdots, m, \quad g_L = 1, \cdots, m^{(l)} \\
& v_i \ge 0, \quad i = 1, \cdots, m \\
& \hat{v}_{g_L} \ge \varepsilon, \quad g_L = 1, \cdots, m^{(l)}
\end{aligned}
\qquad \mathbf{(2)}
$$

where $m^{(l)}$ denotes the number of categories in the *l*th layer, $B_{g_l}^{(l)}$ denotes the set of indicators of the *g*th category in the *l*th layer, $g_l = 1, \cdots, m^{(l)}$, $l = 1, \cdots, L$, and $q_{g_l}^{(l)}$ are the corresponding weights. For more information on the development of the MLDEA model we refer to (*23*).

The idea of incorporating the layered hierarchy into the DEA model is achieved by first aggregating the values of the indicators within a particular category of a particular layer by the weighted sum approach, and next with respect to the final layer determining weights using the basic DEA approach shown in (**1**). Mathematically, the weights of all indicators in each category of each layer can be deduced from the second restriction of model (**2**) (for the detailed deduction process, please refer to (*23*)). Each weight can be interpreted as the relative importance of the corresponding indicator. Therefore, the value judgment from decision makers or experts can be easily incorporated into this model. By restricting the weight flexibility in a category, which is denoted as Ψ, consistency with prior knowledge and the obtainment of realistic and acceptable weights are guaranteed (*25-27*). In this case, the indicators belonging to the same category of a layer are considered to be of similar importance and their weights can only vary within a range from 0.8 to 1.2 of the average weights. Taking EMS stations as an example, the weights of the four indicators *I1* to *I4* (with an average weight of 0.25) are required to lie between 0.2 and 0.3. With respect to the last layer, i.e., EMS and PMF, an ordinal relationship is incorporated in the model to reflect the relative importance of EMS, which can be expressed as: $Share_{EMS} > Share_{PMF}$, where the share is the sum of the products of the indicator values and the corresponding weights divided by the final index score.

4 RESULTS

Using the developed MLDEA model, we now combine the 17 TM indicator values into a composite index score for each country by selecting the most optimal weights under the imposed restrictions. The overall TM performance of the 21 European countries is presented in Table 2.

TABLE 2 TM performance of the 21 European countries based on MLDEA

Country	Optimal TM index score	Groups	Level of TM performance	Groups from SafetyNet (*13*)
Austria	1	1	High	1
Germany	1	1	High	1
United Kingdom	1	1	High	1
Slovakia	1	1	High	2
Portugal	1	1	High	3
Malta	0.9879	1	High	3
Czech Republic	0.9439	2	Relatively high	3
Bulgaria	0.8946	2	Relatively high	3
Belgium	0.8762	2	Relatively high	3
Cyprus	0.8618	2	Relatively high	3
Denmark	0.8420	2	Relatively high	3
Poland	0.8089	3	Medium	5
Finland	0.7691	3	Medium	3
Latvia	0.7684	3	Medium	3
Norway	0.7609	3	Medium	3
Lithuania	0.7406	4	Relatively low	3
Estonia	0.7381	4	Relatively low	3
Hungary	0.6497	5	Low	3
Sweden	0.6421	5	Low	4
Netherlands	0.5890	5	Low	5
Greece	0.5888	5	Low	5

The second column shows that Austria, Germany, United Kingdom, Slovakia and Portugal are the 5 best-performing countries in terms of TM since they obtain the optimal index score of one. The remaining 16 countries (obtaining values less than one) are considered to be underperforming. One thing that should be mentioned here is that TM is only one of several road safety risk factors (besides alcohol and drugs, speed, vehicle, etc). Therefore, high performance on this factor does not guarantee good final outcomes, i.e., few fatalities (e.g., Slovakia), and vice versa (e.g., the Netherlands), unless the performance on all road safety risk factors is taken into account simultaneously.

Moreover, based on the final index score, countries can be classified into groups. In this respect, we distinguish five groups related to a particular degree of TM performance as defined in the SafetyNet report (*13*): Values higher than the mean plus standard deviation represent the 'high level'; values between the percentiles 40% and 60% are 'medium level'; values lower than the mean minus standard deviation are labeled as 'low level'; and the values between these three levels belong to the 'relative high' and 'relative low' levels, respectively. The results of this classification are shown in the third and fourth column of Table 2, while the last column presents the country groups from that report (*13*) in which the indicator values of each country are combined using PCA/FA. It can be seen that the ordering of countries in decreasing level of performance is more or less consistent between the two studies except for Poland. This is mainly due to the preliminary elimination of some indicators (such as *I4* and *I16*) when using PCA/FA, which leads up to a low index score of Poland since the values of these indicators are relatively high for this country (see Table 1). Moreover, it can be noted that in the last column more than half of the countries are located at the medium level whereas the country groups based on the MLDEA model are more evenly sized.

In addition to the final TM index score, the weights allocated in each layer of the hierarchy can be deduced for each country. One of the principles of DEA is that an indicator is assigned a high weight if the country performs relatively well on that aspect. On the contrary, low weights provide policymakers with valuable information about the aspects requiring most action to improve the road safety performance of a country (*28*). Taking Belgium as an example, the assigned weights (the values in brackets are shares) in each layer are presented in Table 3.

TABLE 3 The assigned weights (or shares) of each layer of the hierarchy for Belgium

3rd layer	EMS															PMF	
Weight	1.21 (0.67)															0.64 (0.33)	
2nd layer	EMS stations				EMS staff			EMS transportation units				EMS response time					
Weight	0.28				0.22			0.20				0.30					
1st layer	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17
Weight	0.20	0.20	0.30	0.30	0.40	0.33	0.27	0.24	0.24	0.16	0.16	0.20	0.27	0.33	0.40	0.60	0.40

The accordance of the final weights with the imposed constraints can be seen from Table 3. More specifically, the EMS part obtains a higher share (0.67) than the PMF part (0.33) and the indicators belonging to a particular aspect (in the 1st and 2nd layer) are of similar importance. However, the assigned weights indicate that for the case of Belgium, EMS transportation units, (especially *I10* and *I11*) should be paid more attention to and given priority over the other three aspects in terms of policy actions since the lowest weight (0.20) is allocated to this category.

Furthermore, for the 16 underperforming countries listed in Table 2, we could further explore the reasons why they are unable to obtain a value of one. Theoretically, the mechanism of the MLDEA approach is to choose the best possible weights to maximize the index value of a certain country under all imposed restrictions. If the optimal weights of a country *A* under study do not result in a value of one for this country but cause the weighted index score of another country *B* in the data set to become one, then the model stops. This implies that country *B* performs better than country *A* on at least one of the TM aspects since the index score of *B* is relatively higher with the same set of weights. Therefore, country *A* could take country *B* as an example for improving its TM performance. In other words, country *B* can be seen as a valuable benchmark for country *A*. Using this principle, Table 4 points out the corresponding benchmark countries—Austria, Germany, Portugal, Slovakia—for each of the 16 underperforming countries. Taking Belgium as an example, Austria, Germany and Portugal are the three benchmark countries since they obtain an index score of one using the optimal weights of Belgium. Therefore, these three countries are suitable for comparing the Belgian TM performance to. In other words, they can be considered as best practice cases to help enhance the trauma management performance of Belgium.

TABLE 4 Benchmark countries for the underperforming countries

	Austria	Germany	Portugal	Slovakia
Belgium	×	×	×	
Bulgaria	×	×	×	×
Cyprus	×	×		×
Czech Republic	×	×	×	×
Denmark	×	×		×
Estonia	×		×	×
Finland	×		×	×
Greece	×	×		
Hungary	×		×	×
Latvia	×			
Lithuania	×			
Malta	×	×	×	
Netherlands	×		×	
Norway	×			
Poland	×	×	×	×
Sweden	×			

5 DISCUSSIONS

Having developed the MLDEA model and having applied it for creating a composite TM index, we now further discuss the main strengths and weaknesses of this model. First of all, the reflection of the layered hierarchy of the indicators and the incorporation of weight restrictions at different layers are realized in this model, which is commonly ignored in traditional methods. Subsequently, using country-specific models, the most optimal TM index score is calculated for the 21 European countries, based on which the best-performing and underperforming countries are discriminated, and groups of countries constituted. Moreover, by analyzing the assigned weights in each layer of the hierarchy for each country, valuable information in terms of priorities for policy actions is obtained. Furthermore, for the underperforming countries, a particular set of benchmark countries is provided, which can be considered as best practice cases.

At the same time, there are some limitations in using this approach that should be kept in mind. Firstly, the model only measures the performance of a country with respect to the other countries within the sample and a change in the data set may lead to other outcomes, e.g., best-performing and benchmark countries. Moreover, the results obtained from this model are sensitive to indicator specification, data quality and chosen weight restrictions. In general, as much countries as possible should be considered, appropriate indicators selected, reliable data collected and accepted views from experts adopted to ensure the robustness of the results to an utmost extent.

6 CONCLUSIONS

Trauma management concerned with the medical treatment of injuries resulting from road crashes is an important topic at study in order to avoid preventable deaths and to reduce the severity of injuries. Moreover, it has been designated as one of the seven key road safety risk domains for the development of safety performance indicators in Europe. In this paper, a method for combining a hierarchy of indicators into a composite index is presented. In particular, the overall TM performance of a particular country is assessed taking all information in the data set into account. The developed multiple layer data envelopment analysis model provides useful results. Based on the most optimal TM index scores, country groups are determined. Moreover, weights on the various layers of the hierarchy are assessed in order to identify the areas most urgently requiring improvements. Finally, a particular set of benchmark countries is obtained for those countries with a relatively poor performance.

In the future, more aspects could be investigated. Firstly, uncertainty and sensitivity analysis should be conducted to reveal the impact of a change in indicator set, hierarchical structure or weight restriction. In addition, extending this MLDEA to consider both TM indicators and the number of fatalities (in the form of an input-output model) is valuable in exploring the relations between safety performance indicators and final safety outcomes.

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