Road Safety Development in Europe: A Decade of Changes (2001-2010)

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Abstract

To evaluate the road safety development in Europe over the last decade, this study presents a new way for measuring the road safety performance change over time, which is to use the technique of data envelopment analysis (DEA) and the Malmquist productivity index. In doing so, we can not only focus on the evolution of road safety final outcomes within a given period, but also take the changes of exposure in the same period into account. In the application, the DEA-based Malmquist productivity index (DEA-MI) has proven valuable as a benchmarking tool for measuring the extent to which the EU countries have improved their road safety performance over the period 2001-2010, and it has derived more objective and insightful results than the ones based on the traditional indicator which only measures the percentage change in road fatalities. The results show considerable road safety progress in most of the Member States during these ten years, and the fatality risk on Europe's roads instead of the number of road fatalities has actually been reduced by approximately half. However, the situation differed considerably from country to country. The decomposition of the DEA-MI into efficiency change and technical change further reveals that the bulk of the improvement during the last decade was attained through the adoption of productivity-enhancing new technologies throughout the road transport sector in Europe, rather than through the relatively underperforming countries catching up with those best-performing ones.

1 INTRODUCTION

During the past decades, rapid growth of traffic volume, especially motorized road mobility, has resulted in continuously increasing safety problems. Europe, recognized as one of the safest road traffic regions in the world, also suffers from the road crash problem. Due to the high level of car ownership, road transport has emerged as the dominant segment in Europe's transport sector accounting for roughly 84% of all passenger transport and 46% of freight transport *(1)*. However, it is also responsible for the majority of negative impacts on safety, which accounts for over 100 times more deaths than all other transportation modes (rail, air, maritime, etc.) together *(2)*. The estimated annual direct and indirect cost of road traffic injuries in the European Union (EU) exceeds €130 billion, or over 1% of the EU Gross Domestic Product (GDP) *(3)*, which is becoming increasingly socially unacceptable and difficult to justify to citizens. Under these circumstances, a large number of road safety strategies and programmes have been launched and put into effect, especially over the last decade. In particular, at the early 21st century, the EU has set itself an ambitious target of halving the yearly number of road fatalities between 2001 and 2010 *(4)*. Although the initial target was not completely met by the end of 2010 (see Fig. 1), significant progress has been achieved across the EU, and the action has therefore been considered as a strong catalyst of efforts made by Member States to improve their road safety. However, the development in different Member States was unbalanced. Their contribution to this progress was therefore dissimilar. Consequently, benchmarking across countries in terms of their road safety development over the past decade is desirable, which enables policy makers to monitor the effectiveness of the implemented programme in each Member State, to update the strategy and target in the light of the gathered experience, and to further motivate all the Member States to continue their efforts in the future.

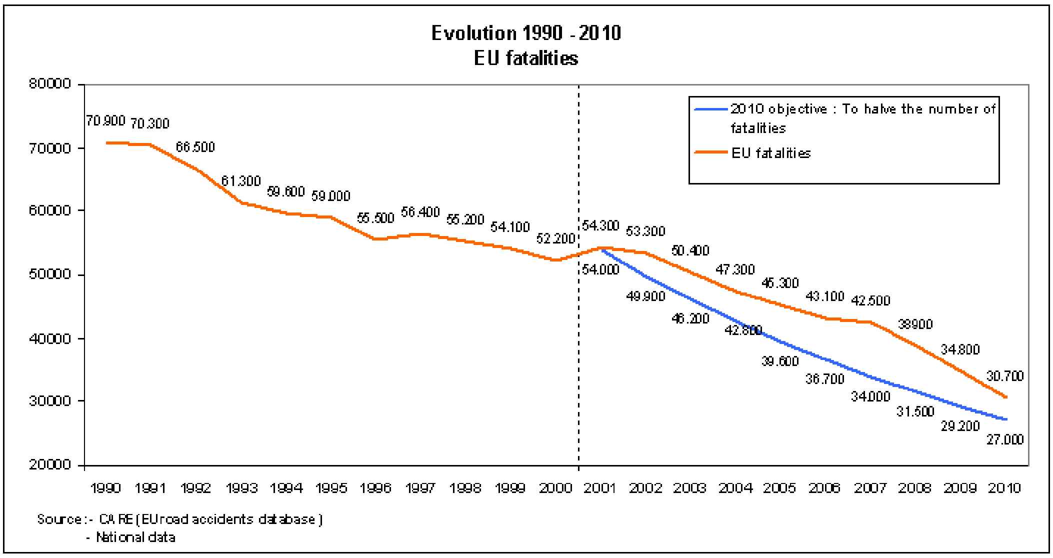

FIGURE 1 Evolution of road fatalities in the EU-27 (1990-2010).

Source: European Commission (2011) (5)

To compare the development of road safety between countries, the percentage change in the number of people killed on the road is traditionally the main indicator, with a higher reduction in road fatalities indicating a better rank *(6)*. As can be seen from Fig. 2, since 2001, road fatalities have been cut by 43% in the EU as a whole. Amongst others, eight countries including Latvia, Estonia, Lithuania, Spain, Sweden, Luxembourg, France and Slovenia, reached the EU 2010 target. Ireland, Germany, United Kindom, the Netherland, Belgium and Portugal achieved reductions above the EU average, while the other countries progressed to a lesser extent. In general, there was no country in which the number of road fatalities recorded in 2010 exceeded that of 2001.

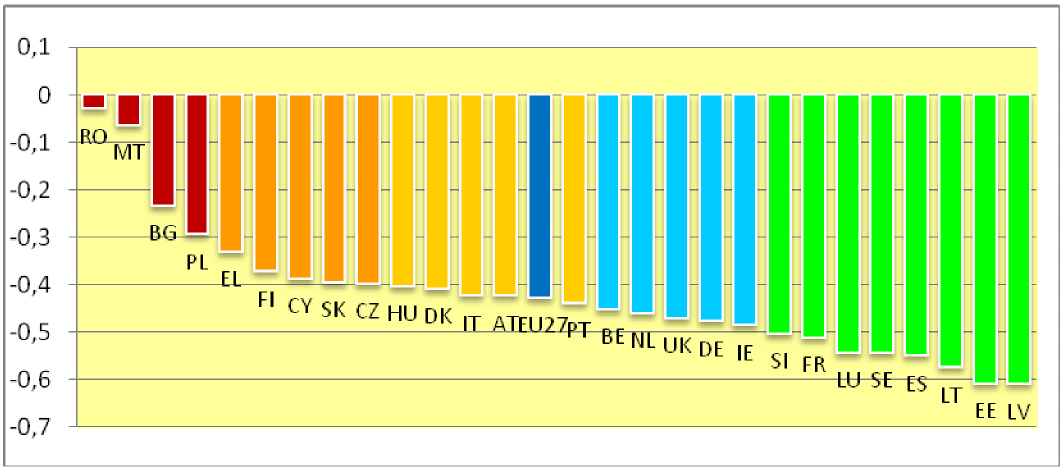

FIGURE 2 Fatality change of 27 EU countries between 2001 and 2010.

Data source: European Commission (2012) (1)

Although the idea is intuitive and the results are easy to obtain because the number of road fatalities in two years is the only information needed for the calculation, simply considering the reduction in the road fatalities may not correctly reflect the real improvement in road safety because the transport circumstances of a country underlying the road fatalities also change every year. For instance, consider a country that recorded 100 road fatalities in one year with a participation of 10 billion passenger-kilometres (pkm) in traffic, and 90 road fatalities with 9 billion pkm in the second year. Although the number of fatalities is reduced by 10% between these two years, there is actually no improvement in road safety performance because the degree of participation in traffic also decreases by 10% in this country and its fatality rate has thereby not changed during these two years. Consequently, to capture the dynamic road safety development in a country, we should not only focus on its evolution of road fatalities within a given period, but also take the changes of exposure in the same period into account. In other words, the concept of risk, which is defined as the ratio of road safety outcomes and some measure of exposure, should be applied in the context of benchmarking. In this respect, the number of fatalities per population size, the number of fatalities per registered vehicles, and the number of fatalities per distance travelled are three most widely used risk indicators *(7)*. In this study, by considering these measures of exposure to risk on the one hand, and the number of road fatalities on the other hand, we explore the extent to which the EU countries have improved their road safety performance over the period of 2001-2010. In doing so, data envelopment analysis (DEA) *(8)*, which applies a mathematical optimization technique to measure the relative efficiency of a set of decision making units (DMUs) on the basis of multiple inputs and multiple outputs, and the Malmquist productivity index *(9)*, which evaluates productivity change of DMUs over time, are employed to undertake the assessment. The results are compared with the ones from only considering the percentage change of road fatalities.

The remaining of this paper is organized as follows. In Section 2, we briefly introduce the technique of DEA and the construction of the Malmquist productivity index for road safety evaluation. In Section 3, we demonstrate the application of this DEA-based Malmquist productivity index for measuring the road safety development of EU countries over the last decade, and the results are subsequently provided and discussed. The paper ends with conclusions in Section 4.

2 METHODOLOGY

Data envelopment analysis, originally developed by Charnes, Cooper and Rhodes in 1978, is a powerful benchmarking tool for measuring the relative efficiency of a homogeneous set of decision making units (DMUs) by constructing an efficient production frontier based on the best performers within the observations. Due to its built-in capability of allowing direct peer comparisons on the basis of multiple inputs and multiple outputs related to DMUs, DEA is superior to the simple ratio analysis which provides only partial measures of the multiple input-output relations and thus often leads up to misclassifications and incorrect judgments *(10)*. Furthermore, to measure the performance change of DMUs over time, Färe et al. (1992) *(11)* combined the ideas on the measurement of efficiency and the measurement of productivity to construct a Malmquist productivity index (originally introduced by Malmquist (1953) *(9)* as a quantity for analyzing the consumption of inputs) directly from input and output data using DEA. Specifically, by using longitudinal data, the DEA-based Malmquist productivity index, hereafter referred to as DEA-MI, relies on firstly constructing an efficient production frontier over the whole sample realized by DEA, and then computing the distance of individual observations to this frontier, denoted as $D(\cdot)$. To describe this methodology, we consider a set of n DMUs, each consuming m different inputs to produce s different outputs. x_{ij}^{t}, y_{rj}^{t} denote the ith input and rth output respectively of the jth DMU at any given point in time t. The calculation of DEA-MI requires two single-period and two mixed-period measures. The two single-period measures are obtained by solving the basic DEA model. However, as opposed to the original application field of economics, in which the definition of the best practices relies on the assumption that inputs have to be minimized and outputs have to be maximized, here, to use DEA for road safety evaluation, we want the output, i.e., the number of road fatalities, to be as low as possible with respect to the level of exposure. Consequently, an adjusted output-oriented DEA model has to be applied *(12,13)*:

$$
\begin{aligned}
& D_o^t(x_o^t, y_o^t) = \min \theta_o \\
& s.t. \quad \sum_{j=1}^{n} x_{ij}^t \lambda_j \geq x_{io}^t, \quad i = 1, \cdots, m \\
& \qquad \sum_{j=1}^{n} y_{rj}^t \lambda_j \leq \theta_o y_{ro}^t, \quad r = 1, \cdots, s \\
& \qquad \lambda_j \geq 0, \quad j = 1, \cdots, n
\end{aligned}
\tag{1}
$$

This linear program is computed separately for each DMU, and the subscript, o, refers to the DMU whose efficiency is to be evaluated. λ_j is an n×1 nonnegative vector of the weight given to the jth DMU's inputs and outputs in constructing for DMU$_o$ a hypothetical composite unit (HCU) that outperforms it. In other words, for those DMUs that contribute to the construction of the HCU, they will obtain a non-zero value of λ, and make up the reference set for DMU$_o$ to learn from *(14)*. Moreover, θ ($0<\theta\le 1$) is the uniform proportional reduction in the DMU$_o$'s outputs. Its minimum amount is known as the DEA efficiency score for DMU$_o$, which also equals to its distance function in time *t*, i.e., $D_o^t(x_o^t, y_o^t)$. Generally, solving this linear programming problem enables us to find the lowest possible value of θ, for which there exists a HCU that owns at least as much of each input as DMU$_o$, meanwhile leading to no more than θ times each of the outputs of that DMU. Hence, if the value of θ equals to one, it means no reduction is needed for this DMU, so it is efficient and its input-output combination lies on the efficient production frontier. In the case that θ<1, the DMU is inefficient, and it lies inside the frontier. In a similar way, using *t*+1 instead of *t* for the above model, we obtain the efficiency score of DMU$_o$ in the time period *t*+1, denoted as $D_o^{t+1}(x_o^{t+1}, y_o^{t+1})$.

For the mixed-period measures, the first one is defined as $D_o^t(x_o^{t+1}, y_o^{t+1})$ for DMU$_o$, which is computed as the optimal value resulting from the following linear programming problem:

$$
\begin{aligned}
& D_o^t(x_o^{t+1}, y_o^{t+1}) = \min \theta \\
& s.t. \quad \sum_{j=1}^{n} x_{ij}^t \lambda_j \ge x_{io}^{t+1}, \quad i = 1, \cdots, m \\
& \qquad\;\; \sum_{j=1}^{n} y_{rj}^t \lambda_j \le \theta y_{ro}^{t+1}, \quad r = 1, \cdots, s \\
& \qquad\;\; \lambda_j \ge 0, \quad j = 1, \cdots, n
\end{aligned} \tag{2}
$$

This model compares (x_o^{t+1}, y_o^{t+1}) to the frontier at time *t*. Similarly, we can obtain the other mixed-period measure $D_o^{t+1}(x_o^t, y_o^t)$.

The (output-oriented) DEA-MI, which measures the productivity change of a particular DMU$_o$ at time *t*+1 and *t*, can now be expressed as *(11)*:

$$
MI_o = \left[\frac{D_o^t(x_o^{t+1}, y_o^{t+1})}{D_o^t(x_o^t, y_o^t)} \frac{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{D_o^{t+1}(x_o^t, y_o^t)} \right]^{1/2} \tag{3}
$$

MI_o>1 indicates progress in the total factor productivity of the DMU$_o$ from the period *t* to *t*+1, while MI_o=1 and MI_o<1 means respectively the status quo and decay in productivity.

Moreover, in contrast to conventional production functions or other index approaches, the DEA-MI owns an advantage of being able to be further decomposed into two components, one measuring the change in efficiency (*EFFCH*) and the other measuring the change in the frontier technology (*TECHCH*). Mathematically, these two components can be measured by the following modification of *MI* in (3) *(11)*:

$$
MI_o = \frac{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{D_o^t(x_o^t, y_o^t)} \left[\frac{D_o^t(x_o^{t+1}, y_o^{t+1})}{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})} \frac{D_o^t(x_o^t, y_o^t)}{D_o^{t+1}(x_o^t, y_o^t)} \right]^{1/2} \tag{4}
$$

The first term, i.e., $EFFCH = D_o^{t+1}(x_o^{t+1}, y_o^{t+1}) \big/ D_o^t(x_o^t, y_o^t)$, indicates the magnitude of the efficiency change from the period t to t+1, which also reflects the capability of an inefficient DMU in catching up with those efficient ones. The second one, i.e., $TECHCH = \left[\frac{D_o^t(x_o^{t+1}, y_o^{t+1})}{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})} \frac{D_o^t(x_o^t, y_o^t)}{D_o^{t+1}(x_o^t, y_o^t)} \right]^{1/2}$, measures the shift in the efficient production frontier between two time periods. It therefore captures the genuine progress or regress of those efficient DMUs. For these two components, values greater than one indicate an improvement in that aspect, while values equal to and less than one imply status quo and deterioration, respectively. For more information on *EFFCH* and *TECHCH*, we refer to *(15)*.

From the output-oriented view of road safety development assessed in this study, an improvement in efficiency occurs when there are decreases in the quantities of output (i.e., road fatalities) based on a given set of inputs (i.e., measures of exposure). In other words, the number of road fatalities should be reduced without the change of exposure. Operationally, maintaining the same population size, more and better road user education and driver training is a useful way to reduce road crash risk and consequent injury and fatality. Moreover, without changing the number of registered vehicles and/or the distance travelled, encouraging citizens to use public transport instead of private cars is also widely recognized as an effective solution of reducing road crash risk in a country. In contrast to a change in efficiency, technical change occurs through the adoption of new road safety technologies that reduce the *minimum* quantities of output given a certain level of inputs. In this case, the number of road fatalities could be reduced even if the exposure is enlarging. In this respect, the introduction of safer vehicles, betterment of road infrastructure, and improvement in medical treatment of people involved in crashes are all related to productivity-enhancing technical changes.

Towards a safer use of the road, both efficiency enhancements and technical improvements are required. In the following section, the DEA-MI is applied to measure the combined effect of *EFFCH* and *TECHCH* in terms of road safety development in Europe over time, and meanwhile to capture the separate impact of each effect for cross-country comparison.

3 APPLICATION

To assess the dynamic road safety progress in Europe during the last decade, this study considers simultaneously the evolution in the number of road fatalities and the changes in three common measures of exposure to risk, i.e., the number of inhabitants, passenger-kilometres travelled and passenger cars, as output and input, respectively. Data from 2001 to 2010 are collected for the 26 EU countries (the EU-27 except Malta[1]), which are Belgium (BE), Bulgaria (BG), Czech Republic (CZ), Denmark (DK), Germany (DE), Estonia (EE), Ireland (IE), Greece (EL), Spain (ES), France (FR), Italy (IT), Cyprus (CY), Latvia (LV), Lithuania (LT), Luxembourg (LU), Hungary (HU), the Netherlands (NL), Austria (AT), Poland (PL), Portugal (PT), Romania (RO), Slovenia (SI), Slovakia (SK), Finland (FI), Sweden (SE), and United Kingdom (UK) *(1)*. The data for 2001 and 2010 are shown in Table 1.

[1] The initial examination revealed the very distinct nature of the data for Malta (see also *(13)*) and consequently, it was decided to eliminate this outlier and to consider only 26 EU countries.

TABLE 1 Input and output data of the 26 EU countries for 2001 and 2010

Country	Input						Output	
	Population (million)		Passenger-kilometres (10 billion)		Passenger cars (million)		Fatalities	
	2001	2010	2001	2010	2001	2010	2001	2010
BE	10.29	10.90	10.69	10.91	4.71	5.23	1486	812
BG	8.02	7.53	2.79	4.69	2.04	2.55	1011	776
CZ	10.24	10.52	6.35	6.36	3.48	4.47	1333	802
DK	5.36	5.55	4.96	5.10	1.86	2.14	431	255
DE	82.35	81.78	85.26	88.70	39.22	42.02	6977	3648
EE	1.36	1.34	0.68	1.01	0.44	0.55	199	78
IE	3.87	4.47	3.98	4.60	1.37	1.92	412	212
EL	10.95	11.31	6.80	9.96	3.31	5.17	1880	1258
ES	40.72	46.07	30.80	34.16	17.80	22.07	5517	2479
FR	59.48	62.96	71.57	72.73	30.07	31.55	8162	3992
IT	56.98	60.48	72.05	70.02	32.91	36.56	7096	4090
CY	0.70	0.80	0.40	0.59	0.27	0.46	98	60
LV	2.36	2.24	1.20	1.65	0.57	0.77	558	218
LT	3.48	3.29	2.60	2.99	1.15	1.69	706	300
LU	0.44	0.51	0.58	0.65	0.28	0.33	70	32
HU	10.19	10.00	4.62	5.26	2.42	3.00	1239	740
NL	16.05	16.62	14.16	14.12	6.62	7.58	993	537
AT	8.04	8.39	6.71	7.30	4.14	4.40	958	552
PL	38.25	38.18	15.77	29.79	10.25	16.87	5534	3908
PT	10.29	10.64	7.32	8.37	3.52	4.47	1670	937
RO	22.13	21.44	5.25	7.55	2.83	4.28	2450	2377
SI	1.99	2.05	2.08	2.56	0.87	1.06	278	138
SK	5.38	5.43	2.41	2.69	1.28	1.63	614	371
FI	5.19	5.36	5.70	6.47	2.15	2.83	433	272
SE	8.90	9.38	9.28	9.92	4.01	4.32	583	266
UK	59.11	62.23	65.38	65.38	25.44	29.24	3598	1905

Source: European Commission (2012) (1)

3.1 The overall results

The DEA-MI is now adopted to measure the extent to which the 26 EU countries have improved their level of road safety during the period under study. The overall results are shown in Fig. 3.

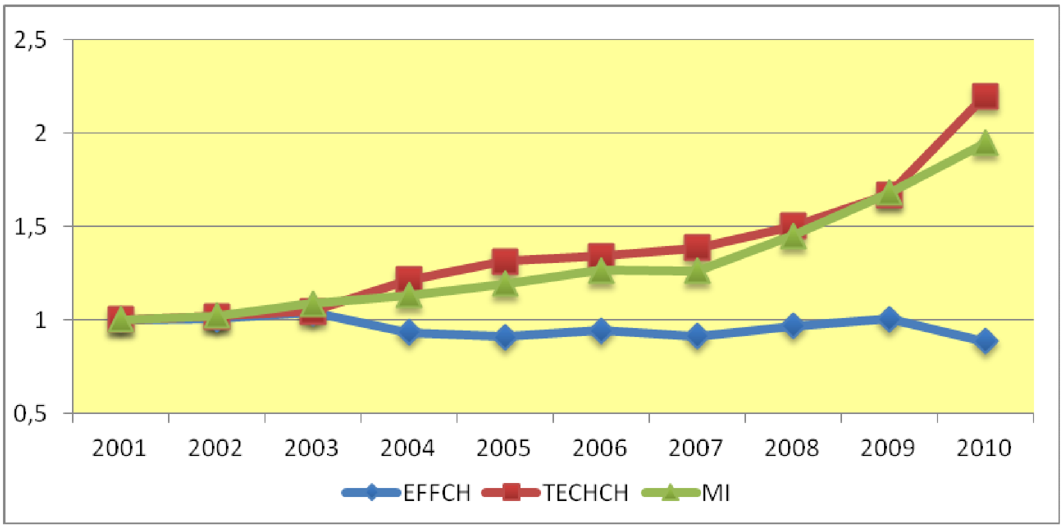

FIGURE 3 The evolution in MI of the 26 EU countries and its decomposition into efficiency and technical changes in 2001-2010.

This figure indicates the cumulative *MI* of the 26 EU countries and its decomposition (i.e., *EFFCH* and *TECHCH*) from 2001 to 2010 by sequential multiplication of the improvements in each year with 2001 as the index year (equal to one). From the trend of *MI*, we can see that the EU as a whole achieved considerable improvement in road safety performance during the last decade (i.e., 95%). Although a slight decrease existed in 2007, the total 'productivity' went steadily up during this period, and the trend was much steeper in the last three years. Comparing the *MI* result with the evolution of road fatalities during the same time period shown in Fig. 1, we can see that they are mirror images of each other, but are not identical. First, the number of road fatalities was slightly decreased between 2006 and 2007. However, from the fatality risk point of view, the situation was actually deteriorating in this period. Moreover, considering the total reduction of the number of road fatalities, around 43% has been cut during the last decade. If we use the concept that 50% reduction of road fatalities means the improvement in road safety by 100%, we can calculate that during the last decade, the EU has achieved a road safety improvement of 75%. However, if we also take the changes of exposure into account, the improvement over these ten years was actually 20% more. In addition, by decomposing the *MI* score into *EFFCH* and *TECHCH*, we can see that the road safety improvement in Europe during the last decade was mostly dominated by the technical component, which means that the main source of this growth came about through the adoption of productivity-enhancing new technologies throughout the road transport sector in Europe, which was partially offset through a slight decrease in efficiency.

3.2 Cross-country comparisons

Although remarkable improvement in terms of road safety performance has been achieved in Europe during the last decade, the situation could differ considerably from one country to another. Therefore, apart from analyzing the road safety development of the EU countries by considering them as a whole, investigation of the progress in each of these countries is also worthwhile. Based on the country-specific *MI* results, the cross-country comparisons are provided in the following sections.

3.2.1 Efficiency change

To compare the road safety progress in these 26 EU countries during the past decade, we first look at the changes in their relative efficiency. Tables 2 and 3 present the DEA efficiency scores and the corresponding efficiency changes of these countries over the period 2001-2010.

TABLE 2 Efficiency scores of the 26 EU countries over the period 2001-2010

Country	Efficiency score									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
BE	0.448	0.499	0.516	0.485	0.479	0.484	0.480	0.491	0.439	0.397
BG	0.483	0.495	0.481	0.407	0.372	0.330	0.330	0.296	0.318	0.275
CZ	0.467	0.431	0.417	0.365	0.366	0.431	0.366	0.399	0.440	0.372
DK	0.757	0.701	0.737	0.725	0.756	0.801	0.597	0.563	0.689	0.617
DE	0.795	0.792	0.786	0.794	0.803	0.825	0.822	0.838	0.803	0.710
EE	0.417	0.368	0.487	0.392	0.364	0.294	0.296	0.418	0.517	0.487
IE	0.571	0.631	0.700	0.564	0.501	0.569	0.633	0.683	0.705	0.599
EL	0.355	0.406	0.406	0.327	0.308	0.300	0.301	0.297	0.293	0.255
ES	0.456	0.472	0.459	0.466	0.477	0.511	0.541	0.642	0.653	0.548
FR	0.521	0.545	0.660	0.652	0.612	0.700	0.708	0.668	0.587	0.489
IT	0.656	0.657	0.675	0.645	0.628	0.629	0.671	0.688	0.687	0.551
CY	0.436	0.456	0.440	0.315	0.360	0.432	0.427	0.472	0.511	0.474
LV	0.257	0.253	0.258	0.221	0.239	0.251	0.235	0.295	0.336	0.291
LT	0.300	0.300	0.288	0.226	0.211	0.238	0.236	0.298	0.365	0.348
LU	0.559	0.627	0.714	0.686	0.687	0.740	0.678	0.844	0.553	0.644
HU	0.501	0.429	0.451	0.385	0.363	0.345	0.353	0.415	0.461	0.383
NL	0.984	0.988	0.932	1	1	1	1	1	0.970	0.878
AT	0.611	0.585	0.563	0.538	0.573	0.584	0.593	0.570	0.548	0.491
PL	0.421	0.396	0.400	0.330	0.322	0.325	0.296	0.289	0.315	0.277
PT	0.375	0.378	0.400	0.401	0.389	0.488	0.471	0.494	0.479	0.322
RO	0.550	0.546	0.576	0.438	0.378	0.373	0.333	0.289	0.290	0.256
SI	0.445	0.452	0.487	0.398	0.394	0.403	0.371	0.453	0.518	0.498
SK	0.533	0.532	0.493	0.441	0.409	0.392	0.350	0.358	0.539	0.415
FI	0.729	0.756	0.854	0.804	0.739	0.853	0.750	0.719	0.792	0.640
SE	0.972	0.985	1	1	1	1	0.951	0.993	0.982	1
UK	1	1	1	0.999	0.915	0.948	1	1	1	0.946

It can be seen from Table 2 that the SUN countries, i.e., Sweden, United Kingdom, and the Netherlands, were the three best-performing countries in terms of road safety because they obtained the efficiency score of one alternatively during these ten years. In other words, they determined the efficiency levels of other countries since they were the ones that shifted the frontier in this period. The remaining countries, however, had an efficiency score less than one in each time period, and both improvement and decline occurred during these ten years. Within these countries, there were still more than half whose overall efficiency change (2010 compared to 2001) was less than one (see the last column of Table 3), which implies their weak capability in catching up with those best-performing countries. On the contrary, comparison of development up to 2010 shows that Spain, Estonia, Lithuania and Luxembourg achieved the best improvement in terms of efficiency (all over 15%). In other words, the road safety progress in these countries during the last decade was at least 15% faster than that of the SUN countries.

TABLE 3 Efficiency changes of the 26 EU countries from 2001 to 2010

Country	*EFFCH*									
	02/01	03/02	04/03	05/04	06/05	07/06	08/07	09/08	10/09	10/01
BE	1.114	1.033	0.94	0.988	1.012	0.990	1.023	0.895	0.904	0.886
BG	1.026	0.972	0.847	0.912	0.887	1.000	0.898	1.076	0.865	0.571
CZ	0.921	0.967	0.876	1.002	1.179	0.849	1.089	1.103	0.845	0.794
DK	0.926	1.051	0.984	1.042	1.060	0.746	0.942	1.224	0.895	0.814
DE	0.996	0.993	1.011	1.011	1.027	0.997	1.019	0.959	0.883	0.893
EE	0.881	1.325	0.804	0.928	0.808	1.007	1.411	1.237	0.942	1.165
IE	1.105	1.109	0.806	0.888	1.137	1.112	1.079	1.033	0.849	1.049
EL	1.145	0.999	0.806	0.941	0.976	1.000	0.990	0.985	0.870	0.718
ES	1.035	0.973	1.014	1.024	1.072	1.059	1.186	1.017	0.840	1.203
FR	1.046	1.212	0.988	0.938	1.143	1.012	0.943	0.880	0.832	0.938
IT	1.001	1.029	0.955	0.973	1.002	1.066	1.025	0.999	0.802	0.840
CY	1.047	0.965	0.717	1.143	1.197	0.990	1.106	1.082	0.927	1.089
LV	0.983	1.022	0.858	1.081	1.050	0.936	1.256	1.137	0.868	1.135
LT	1.001	0.958	0.784	0.935	1.130	0.991	1.262	1.225	0.952	1.159
LU	1.121	1.138	0.961	1.002	1.077	0.916	1.245	0.655	1.165	1.151
HU	0.857	1.051	0.854	0.942	0.952	1.023	1.174	1.111	0.831	0.765
NL	1.004	0.944	1.073	1.000	1.000	1.000	1.000	0.970	0.904	0.892
AT	0.957	0.962	0.955	1.065	1.019	1.016	0.96	0.963	0.896	0.803
PL	0.941	1.010	0.825	0.976	1.008	0.910	0.977	1.093	0.878	0.658
PT	1.008	1.057	1.002	0.970	1.255	0.966	1.048	0.969	0.673	0.858
RO	0.993	1.055	0.761	0.862	0.985	0.894	0.869	1.004	0.881	0.465
SI	1.017	1.077	0.818	0.991	1.021	0.922	1.221	1.142	0.962	1.121
SK	0.998	0.925	0.895	0.927	0.960	0.893	1.022	1.507	0.770	0.779
FI	1.037	1.129	0.942	0.918	1.155	0.879	0.959	1.102	0.808	0.878
SE	1.013	1.015	1.000	1.000	1.000	0.951	1.044	0.989	1.018	1.028
UK	1.000	1.000	0.999	0.916	1.037	1.055	1.000	1.000	0.946	0.947

3.2.2 Technical change

Having analyzed the efficiency changes for all these countries, we now take into account their changes in the frontier technology so as to fully evaluate the total factor productivity change of each country. The results are shown in Table 4.

TABLE 4 Technical changes of the 26 EU countries from 2001 to 2010

Country	TECHCH									
	02/01	03/02	04/03	05/04	06/05	07/06	08/07	09/08	10/09	10/01
BE	1.033	1.051	1.122	1.091	1.017	1.025	1.115	1.133	1.304	2.282
BG	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
CZ	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
DK	1.008	1.022	1.194	1.069	1.023	1.030	1.066	1.099	1.333	2.164
DE	1.033	1.051	1.127	1.087	1.035	1.037	1.089	1.132	1.304	2.295
EE	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
IE	1.008	1.022	1.131	1.088	0.994	1.016	1.146	1.135	1.317	2.193
EL	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
ES	1.029	1.034	1.143	1.087	1.044	1.051	1.070	1.129	1.304	2.285
FR	1.033	1.049	1.109	1.097	0.990	1.017	1.144	1.136	1.298	2.239
IT	1.033	1.051	1.127	1.087	1.044	1.051	1.070	1.129	1.304	2.299
CY	1.008	1.022	1.190	1.086	1.044	1.051	1.070	1.129	1.304	2.301
LV	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
LT	1.008	1.022	1.196	1.079	0.993	1.027	1.148	1.135	1.304	2.304
LU	1.033	1.051	1.127	1.087	1.041	1.040	1.077	1.131	1.304	2.287
HU	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
NL	1.008	1.022	1.196	1.077	1.035	1.041	1.059	1.094	1.333	2.208
AT	1.033	1.051	1.127	1.087	1.044	1.051	1.070	1.129	1.304	2.299
PL	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
PT	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
RO	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
SI	1.030	1.040	1.110	1.095	0.985	1.025	1.145	1.135	1.281	2.188
SK	1.008	1.022	1.196	1.075	1.029	1.032	1.051	1.089	1.333	2.146
FI	1.015	0.982	1.097	1.095	0.985	1.027	1.145	1.135	1.292	2.034
SE	1.033	1.049	1.110	1.097	0.992	1.015	1.137	1.131	1.326	2.265
UK	1.024	0.988	1.099	1.095	0.985	1.027	1.150	1.137	1.294	2.084

We can see that although fluctuations occurred in every country within these ten years, the overall technology performance of these 26 EU countries were all doubled (see the last column of Table 4). Among others, Lithuania, Cyprus, Italy, Austria and Germany were the technological innovators, which recorded an improvement of around 130% compared to 2001.

3.2.3 Total factor productivity change

Considering both efficiency change and technical change together, the overall road safety progress in each of these 26 EU countries during the last decade can now be deduced, which is illustrated in Fig. 4.

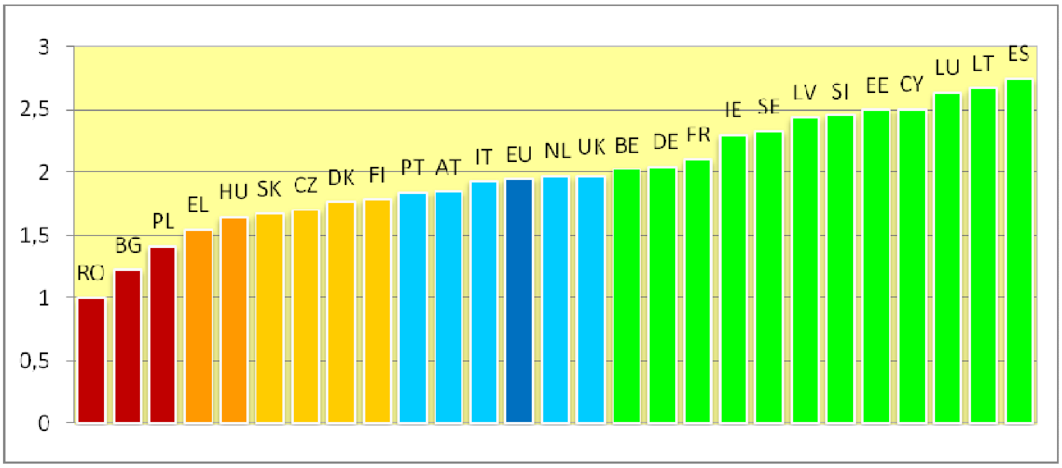

FIGURE 4 Overall road safety progress in the 26 EU countries from 2001 to 2010.

Except for Romania, which had an overall *MI* score less than one (0.998) indicating slight deterioration in its road safety development, all other countries have improved their road safety performance during this period. Further comparing the result with the one in Fig. 2, which is based only on the fatality change between 2001 and 2010, a relatively high correlation coefficient (0.856) can be derived, and the country ranking, especially of those worst-performing ones, are quite consistent. However, some differences can also be found. First, apart from the eight countries who have reached the EU 2010 target of halving the road fatalities over the last decade, four more countries have also doubled their performance if the fatality risk is taken into account. They are Cyprus, Ireland, Germany and Belgium, in which Cyprus has only reduced its road fatalities by less than 40%. However, due to its rapid growth in the degree of participation in traffic during the past decade (14.6% increase in population size (ranking third among the 26 EU countries), 47.5% more passenger-kilometres travelled compared to 2001 (ranking fourth), and 68.6% more registered passenger cars (ranking first), see also Table 1), the fatality risk in Cyprus has actually been reduced by more than half. Moreover, although Latvia achieved the highest reduction in road fatalities (i.e., 61%), its overall road safety performance change was inferior to countries like Spain based on the DEA-MI, which could be mainly attributable to the fact that its population size was declined during the last decade (see Table 1). In other words, the great progress in the number of road fatalities in Latvia was partially offset by the reduction of its exposure during the same time period. On the contrary, due to the prominent reduction in road fatalities and rapid growth in the degree of participation in traffic as well, Spain actually achieved the greatest road safety progress among all these 26 EU countries. All these verify the fact that simply considering the reduction of road fatalities may not correctly reflect the real improvement in road safety performance because the transport circumstances of a country which can impact on the fatalities also changes every year. The approach used in this study thus makes the comparisons between countries more justly.

4 CONCLUSIONS

In this study, we investigated the road safety development in Europe over the last decade (2001-2010). Different from only considering the percentage change in road fatalities, this paper presented a new way for assessing the road safety performance change of countries over time, which was to use the technique of data envelopment analysis and the Malmquist productivity index. In doing so, we could not only focus on the evolution of road safety final outcomes within a given period, but also take the changes of exposure in the same period into account. More specifically, using the information on the three common measures of exposure, i.e., the number of inhabitants, passenger-kilometres travelled and passenger cars on the one hand, and the number of road fatalities on the other hand, the DEA-based Malmquist productivity index was applied as a valuable benchmarking tool for measuring the extent to which the EU countries have improved their road safety performance over the period 2001-2010, and it provided more objective and insightful results than the ones based on the traditional indicator which only measures the percentage change in road fatalities. The analysis found that although the ambitious target set in 2001 to halve the number of road fatalities by 2010 was not completely met, there was significant road safety progress over these ten years, and the fatality risk on Europe's roads was actually reduced by approximately half (with an overall improvement of 95%). However, the development in different countries was unbalanced. Some of them were still getting stuck in the rut or even deteriorating in terms of their road safety performance. Moreover, the decomposition of the DEA-MI into efficiency change and technical change further revealed that the bulk of this progress was attained through an overall improvement in the technological environment of the road transport sector in Europe, rather than through the relatively underperforming countries catching up with those best-performing ones.

In 2010, the European Commission proposed in its 'Policy Orientations on Road Safety 2011-2020' *(3)* to continue with the target of halving the total number of road fatalities in the EU by 2020, which is apparently more challenging than the previous one yet gives a clear signal of Europe's commitment towards road safety. However, achieving such an ambitious target requires great efforts from all the Member States to better understand their own relative road safety situation, and moreover, to learn from those best-performing ones as a basis for developing their own road safety policy. Consequently, by collecting the crash and exposure data at regular intervals, systematic country comparisons over time should be conducted throughout the whole target period so as to evaluate the results of policy interventions and to monitor the progress in road safety performance of each country. The approach applied in this study is therefore valuable for this purpose. In the future, more research attention should be paid to the sensitivity and stability analysis of DEA. In addition, explorations on the reasons behind the progress or decline in each country and the prediction for its future development are also worthwhile.

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