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A Novel Data Envelopment Analysis Framework for Performance Evaluation of European Road Transport Systems

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ABSTRACT

The role of transportation is becoming increasingly important in the world economy, and road transport in particular plays a very important role in all types of transportation. For this reason, it is extremely important to monitor its performance regularly. Very often, this is done using Data Envelopment Analysis (DEA) performance evaluation models, and consequently, there are numerous articles in the literature on DEA evaluation of road transport systems. In this study, we first summarise these articles and classify them according to different characteristics (environmental, safety, economic, energy). Finally, we use them as a basis for developing a novel DEA framework, which is used for the evaluation of the efficiency and ranking of road transport systems that also takes into account undesirable outputs, i.e. environmental and safety outputs. As a case study, we evaluate 28 European countries from technical, safety and environmental aspects. The CCR and SBM models are used to evaluate the efficiency of these countries for the last two years of published data. The results show that Denmark ranks first and Cyprus last for both years. It was also found that safety efficiency is generally rated lower than other criteria. Finally, the results and reasons for the efficiency and inefficiency of specific decision-making units, i.e. countries, are discussed.

KEYWORDS

data envelopment analysis (DEA); performance efficiency; slacks based measure (SBM); undesirable output (UO); super efficiency; road transport system.

1. INTRODUCTION

Transportation is the backbone of a strong and dynamic economy and society. It is also an important production and mobility tool. Among the various modes of transport that connect businesses by moving goods and people from origin to destination, road transport is very important because of its easy accessibility. The road transport industry is the mode of transport committed to the objective of sustainable development. It is therefore a vital industry that ensures the prosperity of the European economy by maintaining and creating jobs not only in road transport but in all sectors. The transport of goods and passengers by road accounts for 20% of the EU's gross domestic product and up to 10% of total tax revenue. It also contributes more than 370 billion euros annually to the European economy [1]. Today, road transport is the only mode of transport that connects all businesses due to its unique door-to-door services. 85% of road transport is carried over a distance of less than 150 kilometres, while only 0.9% is carried over 1,000 kilometres. For every EU citizen, about 100 kilograms of goods are transported by truck every day. There are around 700,000 bus companies and 1.5 million cabs in Europe. Busses and cabs account for more than 15% of all passenger transport in the EU [1]. *Figure 1* shows that road transport has the highest turnover in Europe. Therefore, improving efficiency in this sector is crucial, as it can boost a country's competitiveness and economy. Since road transport systems serve as engines of growth, both locally and internationally, evaluating their efficiency is of great importance. Performance evaluation allows managers to assess their performance against other companies providing similar services. Therefore, this leads to finding solutions to improve efficiency, which in turn leads to more efficient use of resources and ultimately road transport development.

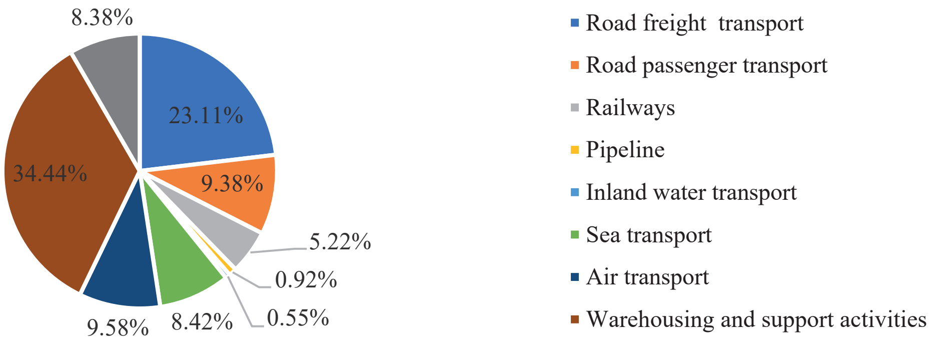

Figure 1 – Turnover by mode of transport for 2018 in million EUR (EU-28) [2]

Efficiency in a system like transportation should be studied from different aspects. This means that efficiency should be evaluated considering all indicators (general, safety, economic and environmental). This shows that it is necessary to define a model that evaluates road transport units in general and, at the same time, ranks them. Therefore, the main objective of this study is to evaluate and measure the efficiency of road transportation systems and rank them considering all undesirable outputs. In other words, the indicators of safety, environment and economic efficiency are considered simultaneously, and a model is introduced to evaluate the overall efficiency. In this way, efficient and inefficient units can be identified. To evaluate the performance, a model is developed to consider undesirable outputs and evaluate the performance accordingly. In this research, non-classical DEA methods are used. Therefore, a Slacks-based model (SBM) and the DEA model with undesirable outputs (DEA UO) are used to evaluate and rank the performance of units, as well as the Super-Efficiency UO model (SBM-UO). European road transport was selected as the subject of this study.

This paper consists of five sections. Section 2 deals with the literature review, section 3 contains an overview of the DEA models, which allow the calculation of the technical and environmental efficiency of the selected units presented in section 4. Finally, conclusions are drawn in section 5.

2. LITERATURE REVIEW

Given the scale of road transport in Europe, it is vital that the efficiency of the transport sector is assessed so that policy measures can be taken to ensure a more rational development of the sector than is currently the case. For the purposes of this study, we have defined road transport efficiency as a combination of economic, environmental, safety and energy efficiency. Recently, the DEA model has been widely used to study efficiency and has been the subject of some research studies to estimate road transport efficiency. According to this definition, the studies examined are also grouped based on their scope, i.e. the type of performance evaluated (general, energy, environmental, energy and environmental, environmental and safety, safety and sustainability). To determine the current status of published work on road transport efficiency improvement, we searched the Thomson Reuters Web of Science (WoS), Google Scholar and Scopus online scientific databases. We searched for relevant articles using the keywords "road transport performance" and "DEA". The search resulted in 86 articles. The articles on DEA road transport efficiency evaluation applications were written in English, published between 1992 and June 2022, and were available in full for free. In reviewing the literature, we found many studies evaluating road transport efficiency using different methods. *Table 1* provides an overview of these studies that used DEA to measure road transport efficiency. For each study, this table indicates the scope of the analysis, the purpose of the study, the variables used in the model, the type of model used and the time period of the analysis. *Figure 2* shows the distribution of articles based on scope.

After reviewing the articles, most of the existing methods perform the evaluation using classical models of Data Envelopment Analysis (DEA), which do not allow simultaneous evaluation and ranking. Moreover, the problem of generating undesirable outputs in transportation systems is sometimes ignored. Not all environmental and safety indicators are considered in the evaluation of environmental efficiency. In the studies conducted, in most cases, the evaluation under safety aspects or under environmental or technical aspects is examined separately. Therefore, in these cases, the evaluation is based only on some environmental indicators and only on some safety indicators. Also, the evaluation of efficiency considering all indicators (general, safety, economic and environmental) has not been carried out in the study area of this article.

Table 1 – Overview of previous studies using DEA to measure road transport efficiency

Author(s), Year	Study purpose	DEA model and Variables
Scope: EFFICIENCY EVALUATION		
Chu, Fielding and Lamar, 1992 [4]	In this paper, DEA is used to develop a single measure of efficiency and a single measure of effectiveness for a U.S. transit agency in 1986 relative to other agencies within the same peer group.	Models: CCR Inputs: annual vehicle operating expenses, annual maintenance expenses, annual general/administrative expenses, other annual expenses Outputs: annual revenue vehicle hours
Kerstens, 1996 [5]	The performance of a sample of 114 French urban transit operators outside the Paris region in 1990 is evaluated using a wide range of nonparametric reference technologies for two specifications of the production process.	Models: VRS, FDH Inputs: vehicles, employees, fuel Outputs: vehicles km, seat km
Philip Viton, 1997 [6]	This paper examines the efficiency of U.S. multimode motor-bus transit systems (217 DMUs in 1990) by asking whether they could expand their service (outputs) without requiring additional resources (inputs), or whether they could reduce the use of inputs without having to reduce service.	Models: CRS, VRS Inputs: average speed, average fleet age, fleet, gallons of fuel, labour hours Outputs: vehicle miles, passenger trips
Cowie and Asenova, 1999 [7]	This analysis examines the issue of efficiency of publicly and privately owned bus operators in Great Britain in 1989, 1993 and 1997, to determine whether the efficiencies associated with private ownership are evident based on property rights theories (Parker 1994).	Models: CRS, VRS Inputs: labour, capital Outputs: passenger kilometres
Odeck and Alkadi, 2001 [8]	This paper focuses on the performance of 40 Norwegian bus operators in 1994 that are subsidised by the government.	Models: CCR, BCC, hybrid model Inputs: efficiency driving hours, total no. of staff, fuel consumption in litres, equipment Outputs: seat km, passenger km, total no. of seats
Pina and Torres, 2001 [9]	The objective of this paper is to compare the efficiency of the public and private sectors in the provision of urban transport services in Spain.	Models: classic models Inputs: fuel, cost, subsidy Outputs: employee, year/bus, year/inhabitant, population, accident rate, frequency
Boame, 2004 [10]	In this paper, a bootstrap method DEA is used to estimate the technical efficiency of Canadian urban transportation systems between 1990 and 1998.	Models: bootstrap DEA Inputs: fleet size, fuel, labour Outputs: revenue speed
Karlaftis, 2004 [11]	The research presented in this paper uses DEA and globally efficient frontier production functions to examine two important aspects of 256 U.S. transportation systems between 1990 and1994.	Models: DEA Inputs: number of systems, number of vehicles, fuel, employee Outputs: annual vehicle-miles travelled, passenger
Jiang, 2009 [12]	This paper proposes a DEA approach to evaluate the efficiency of transportation systems for 31 major regions (including 23 provinces, 4 municipalities and 4 autonomous regions) in China in 2007.	Models: CRS and VRS Inputs: total retail sales of consumer goods, volume of transaction at large commodity markets, number of chain enterprises, number of staff and employed workers in transport, possession of civil motor vehicles, possession of watercraft Outputs: passenger traffic, turnover volume of passenger traffic, freight traffic, turnover volume of freight traffic
Sanchez, 2009 [13]	This paper presents a comparative efficiency analysis of public bus transport in Spain using DEA.	Models: CCR, BCC Inputs: staff, fuel, number of operating buses Outputs: vehicles, seating capacity, number of hours of service, number of passengers
Rouse and Chiu, 2009 [14]	This work focuses on the local road aspects of the highway system and aims to assess how efficiently, effectively and economically the 73 Territorial Local Authorities (TLAs) in New Zealand maintained their respective local road networks from a life cycle perspective between 1994 and 2003.	Models: DEA Inputs: total expenditure in dollars, routine maintenance in dollars Outputs: vehicle kilometres travelled, environmental difficulty
Welde and Odeck, 2011 [15]	This paper analyses the efficiency level of 20 toll companies in Norway between 2003 and 2008.	Models: DEA, SFA Inputs: operational cost, administrative costs Outputs: traffic lanes (the annual traffic handled through tolls divided by the number of lanes served.)
Zhenlin, Peng and Shulin, 2012 [16]	A corresponding super-efficiency DEA model is developed and the degree of coordination between the Intelligent Traffic Management System (ITMS) level and urban development is investigated for the evaluation of urban traffic in Beijing, China) between 2000 and 2010.	Models: Super DEA Inputs: transportation, energy and environment, economy Outputs: ITMS efficiency, external influence of traffic management
Caulfield, Bailey and Mullarkey, 2013 [17]	The main objective of this study is to identify the most efficient traffic solution for the route between Dublin city centre and the airport.	Models: CCR, BCC Inputs: cost – construction costs and operation and maintenance costs Outputs: number of car trips removed, patronage, ravel time saving
Fancello, Uccheddu and Fadda, 2013 [18]	The objective of the proposed paper is to compare the performances of different urban networks by using a non-parametric linear programming technique such as DEA for eight Italian urban roads.	Models: CRS, VRS Inputs: number of vehicles registered in the metropolitan area, number of major attractors within 300 m from the town hall, number of public buses, spent by the administration Outputs: level of service, rate of average time needed to reach the town hall, number of fatal accidents, number of passengers transported in a year from bus system
Li et al. 2013 [19]	This paper presents a method to evaluate the performance of three bus routes in Beijing (2012) within a public transport system, using the revised DEA method and a sensitivity analysis of the indices.	Models: sensitivity analysis Inputs: virtual input index Outputs: passenger load rate index, service reliability, average dwell time index, average running speed
Fu, Zhan and Wu, 2013 [20]	This paper examines the highway systems in terms of freight and passenger traffic of 30 provinces in China using DEA-CCR and DEA.	Models: CCR, BCC Inputs: road operational population, highway mileage Outputs: volume of passenger/freight transport, passenger /freight turnover, traffic accident rate
Georgiadis, Politis and Papaioanno, 2014 [21]	In this paper, DEA is used to evaluate the performance of individual bus lines that make up the public transport network in Thessaloniki, Greece, between 2009 and 2011.	Models: CRS Inputs: length (m), span of service, vehicles Outputs: revenue vehicles km, revenue seat km, passengers
Fancello, Uccheddu and Fadda, 2014 [22]	In this paper, performance of the urban road networks of eight Italian cities is compared using a non-parametric linear programming technique such as DEA.	Models: CRS, VRS Inputs: number of vehicles registered in the metropolitan area, number of major attractors within 300 m from the town hall, number of public buses, spent by the administration Outputs: level of service, rate of average time needed to reach the town hall, number of fatal accidents, number of passengers transported in a year from bus system
Álvarez and Blázquez, 2014 [23]	In this paper, the economic impacts of the road network investment on Spain's private regional activity over the period between 1980 and 2007 was evaluated.	Models: DEA Inputs: labour, private capital, public capital, road network public capital Outputs: passengers
Maroto and Zofío, 2016 [24]	The contribution of this study is to improve this non-parametric frontier approach to measure the static (annual) productivity of the road network in terms of accessibility of each region, which is reviewed in the regional accessibility in Spain between 1995 and 2005.	Models: Malmquist DEA Inputs: fuel costs, fuel, toll costs, toll, accommodation and allowance costs, vehicle maintenance and repairing operating costs Outputs: kilometres
Li, Cao and Yang, 2016 [25]	This paper attempts to evaluate the integrated transportation efficiency of 30 provinces in China between 1988 and 2009 based on the DEA model.	Models: DEA Inputs: network length, total staff Outputs: passenger, freight, emissions
Regalado López and Campos Cacheda, 2018 [26]	This study takes an academic approach to determine the relative efficiency of 29 Spanish toll roads in 2016 managed by the Administration General del Estado using a DEA approach.	Models: CCR, BCC Inputs: toll road identifier, daily average intensity of the vehicles, cost of construction, operator expenses Outputs: toll road identifier, daily average intensity of the vehicles that paid toll during the year 2016
Yang et al., 2019 [27]	This paper presents an integrated RTLU efficiency analysis that examines the degree of coordination from 2012 and 2016 in 14 cities in central China's Hunan Province to provide evidence for future adjustments needed for sustainable urban development.	Models: super efficiency, window DEA Inputs: investment in road, road length of road network, number of transportation employees, investment in urban land use, expanded built-up area of each city, total number of employees for land Outputs: second GDP, third GDP
Saeedi et al. 2019 [28]	This paper presents a modified Network DEA model to measure the performance of intermodal freight transport (IFT) chains in the European IFT network and identify the causes of inefficiencies.	Models: SBM, network DEA
Georgiadis, Papaioanno and Politis, 2020 [29]	This paper analysed the performance of 34 multimodal public transport networks worldwide.	Models: DEA Inputs: bus vehicles, total bus kilometres, metro vehicles, total metro vehicle kilometres Outputs: metro journeys, bus journeys
Norouzian-Maleki et al. 2020 [30]	This paper addressed the need for managers to determine the most effective measures to respond to changing transport demand. The paper proposed a new framework to achieve this goal by using a combination of a System Dynamics approach and a DEA technique that is being reviewed in 23 Iranian urban transportation systems.	Models: Simulation, DEA Inputs: capacity of personal transport, length of personal transport, capacity of public transport, length of public transport Outputs: travel demand for personal, public modes of transport
Gadepalli and Rayaprolu, 2020 [31]	This paper presents an objective framework for measuring the efficiency of Indian urban bus transport in 2009/10 and 2015/16 and conducts a disaggregated analysis of the key internal and external variables affecting efficiency.	Models: DEA Inputs: buses held, total staff, staff per bus, fuel, total cost Outputs: effective kilometres, passenger carried, passenger kilometres travelled, load factor, total revenue, total earing for per bus, traffic revenue
Neves, Marques and Moutinho, 2020 [32]	By using the two-stage DEA methodology, this paper aims to provide useful insights to increase the market share of Battery Electric Vehicles (BEVs) in 20 European countries between 2010 and 2018.	Models: CRS Inputs: gross capital formation, labour, industrial production index, crude oil price, electricity intensity on economy, number of different BEV models Outputs: BEV market share in total new registration, accumulated number of public policies supporting electric mobility
Kumar, Singh, and Vaidya, 2020 [33]	This paper evaluates the performance of major public road transport companies in India between 2014 and 2016.	Models: CCR
Stefaniec et al. 2021 [34]	The DEA-based framework is applied to regional road transport in the EU between 2004 and 2017.	Models: DEA Inputs: GDP, GDP per capita, passenger cars per 1000 inhabitants, passenger cars per length of road network, population density, length of road network, employment, expenditure of households on transport Outputs: passenger transport, road accidents, GHG emissions
Aloulou and Ghannouchi, 2021[35]	The objective of this paper was to assess the impact of ownership and contracting practices on technical efficiency in the public bus transport sector of eight Tunisian companies and 30 companies from France, Spain and Belgium during the period 2009–2016.	Models: TFE, CRS Inputs: capital (buses), labour (employees), SKO (seats-offered/km), occupancy rate, number of lines, average network length (ANL) Outputs: number of passengers per kilometre transported (PKT)
Izadikhah et al. 2021 [36]	The sustainable resilient supply chains of 21 large public transport companies in three megacities are examined.	Models: Fuzzy 2 stage DEA Inputs: number of seats, cost for training staff on safety and health issues, operating network, staff cost Carryovers: preventive cost, average number of breakdowns, environmental cost Outputs: profit, delay time average, number of received warnings, CO2 emission
Chen and et al. 2021 [37]	This study examines the sustainability factors of China's road transport system over the period 1985–2017 in terms of its freight and environmental productivity.	Models: Fuzzy Double-Frontier NDEA Inputs: employees, length of highways, number of vehicles, fuel Intermediates: power Outputs: CO2, NOx, passengers, freight
Khanh Van et al. 2022 [38]	In this study, the spatial efficiency of transportation system of Sapporo city in Japan was measured using DEA.	Models: CCR, BCC Inputs: bus, car, road, car parking, rail Outputs: commercial floor area ratio, housing floor area ratio, full rate
Fitzova and Matulov, 2022 [39]	The aim of this work is to identify the conditions that are important for efficient public transport in the Czech Republic and Slovakia in the period 2004–2017.	Models: CRS, VRS Inputs: employees, rolling stock, energy Outputs: passengers, revenue
Scope: ENERGY AND ENVIRONMENTAL EFFICIENCY EVALUATION		
Wu and et al. 2015 [40]	In this paper, DEA is used to measure the energy and environmental performance of transportation systems in 30 provincial-level regions in mainland China in 2012 with the goal of sustainable development.	Models: DEA Inputs: passenger seats, energy, capital, highway mileage Outputs: passenger turnover volume, CO2
Liu, Qin and Zhang, 2016 [41]	In this study, the non-radial DEA model is combined with window analysis to measure the energy-environment efficiency of the road and railroad sectors of 30 provinces in China from 1998 to 2012.	Models: Window DEA Inputs: labour, coal, diesel, gasoline, electricity Outputs: passenger turnover, freight turnover, CO2
Scope: ENERGY EFFICIENCY EVALUATION		
Ramanatha, 2000 [42]	In this paper, DEA is used to study the energy efficiency of transport modes in India between 1980 and 1994.	Models: DEA Inputs: energy, passenger kilometres Outputs: tonne kilometres
Ruzzenenti and Basosi, 2009 [43]	This paper evaluates energy efficiency in the European freight transport sector over three decades using various indicators, methodologies and databases.	Models: DEA Inputs: vehicle size, number of trucks evaluated Outputs: fuel economy, adjusted fuel economy
Cui and Li, 2014 [44]	In this paper, energy efficiency in transport is redefined and its inputs and outputs are identified through a literature review conducted in the thirty provincial administrative regions (PARs) of China between 2003 and 2012.	Models: 3 stage DEA Inputs: labour, capital, energy Outputs: turnover
Scope: ENVIRONMENTAL EFFICIENCY EVALUATION		
Song, Hao and Zhu, 2015 [45]	An undesirable output-oriented DEA model with SBM was used to evaluate the changes in environmental efficiency of the transportation sector in 30 Chinese provinces (municipalities and autonomous regions) between 2003 and 2012.	Models: SBM Inputs: labour, capital, energy Outputs: added value, CO2
Buzzo Margari et al. 2007 [46]	The aim of this paper is to investigate the impact of statistical noise and exogenous regulatory and environmental factors on the efficiency of 42 Italian public transport operators between 1993 and 1999 in a DEA-based framework.	Models: DEA-SFA Inputs: number of yearly seat-kilometres supplied, number of drivers and indirect employees, litres of gasoline consumed Outputs: real value of yearly expenses for materials and services
Chang and et al. 2013 [47]	This study aims to contribute to the literature by proposing a non-radial DEA model with the SBM to analyse the environmental efficiency of the Chinese transportation sector.	Models: SBM Inputs: labour, capital, energy Outputs: value-added, CO2
Pal and Mitra, 2016 [48]	This study measures the technical efficiency of 37 Indian state road transport enterprises (SRTUs) between 2012 and 2013, using DDF as a tool to analyse a joint production function with desirable and undesirable outputs	Models: CCR, DDF Inputs: fleet size, staff strength, fuel consumption, operating expenses, fleet age Outputs: bus kilometres, passenger kilometres, passengers transported, revenue, accidents
Li, Yang, Zhang and Cao, 2016 [49]	This paper attempts to evaluate the overall regional transport efficiency in China based on the Super-SBM DEA model considering the undesirable output and to investigate the influencing factors of transport efficiency in China between1995 and 2012.	Models: Super-SBM DEA Inputs: labour, capital, energy, GDP Outputs: turnover, CO2
Kang et al. 2019 [50]	In this study, a two-stage network performance evaluation model is presented to determine the efficiency and effectiveness of bus transportation systems.	Models: Two stage Network DEA Inputs: number of employees, number of vehicles, fuel consumption Outputs: CO2, vehicle, passengers
Stefaniec, Hosseini, Xie and Li, 2020 [51]	The proposed measure network DEA organises the three components of the system into a parallel structure, distributes the common input to the subsystems and integrates the undesirable output reviewed in regional inland transportation systems in China from 2006 to 2015.	Models: NDEA Inputs: vehicles, capital, employment, energy consumption Outputs: energy consumption, traffic casualties, value-added, turnover, green energy usage, CO2
Liu et al. 2020 [52]	In this study, a parallel DEA model with subsystem preference is proposed to measure the integrated environmental efficiency of the road transportation industry in China between 2013and 2017, considering various undesirable outputs.	Models: DEA Inputs: passenger seats, gasoline, diesel, highway mileage, employees Outputs: passenger turnover volume, CO2, direct property damage, noise
Yang, Choi and Lee, 2021 [53]	In this paper, a life-cycle of DEA framework was developed to study the environmental efficiency of the atmosphere in China's transportation sector between 2013 and 2017.	Models: DEA Inputs: labour, capital Outputs: fossil depletion potential gross regional domestic product, global warming potential, particulate matter forming potential
Wang et a l. 2022 [54]	This study focuses on evaluating the environmental efficiency of land transport in 25 OECD countries between 2015 and 2019 using the DEA method with undesirable output to address unwanted data.	Models: DEA Inputs: infrastructure investment and maintenance, length of transport routes, labour force, energy consumption Outputs: freight transport, passenger transport, CO2
Zhou, Chung and Zhang, 2014 [55]	This study presents an application of the DEA approach while accounting undesirable outputs and does not only examine the energy efficiency of China's transportation sector from 2003 to 2009.	Models: CRS, VRS Inputs: labour, coal, gasoline, kerosene, diesel oil, electricity, other energy Outputs: passenger kilometres, tonne kilometres, CO2
Scope: ENVIRONMENTAL AND SAFETY EFFICIENCY EVALUATION		
Wang, 2019 [56]	This paper formulated a unified performance measure using DEA, a nonparametric method for benchmarking units with multiple inputs and multiple outputs for OECD countries between 2000 and 2014.	Models: SBM Inputs: road, investment, Outputs: passenger, freight, CO2, other emissions
Hermans et al. 2009 [57]	This paper aims to contribute to road safety by proposing a calculation model based on DEA in 21 European countries.	Models: DEA Inputs: alcohol, speed, protective system Outputs: casualties, crashes
Shen et al. 2011 [58]	To demonstrate the proposed MLDEA model, a case study was conducted to evaluate road safety in 19 European countries.	Models: multiple layer DEA model Inputs: alcohol, speed, protective system Outputs: casualties, crashes
Shen et al. 2012[59]	In this study, DEA is examined as a performance measurement method to provide an overall view of the road safety situation in 27 European countries in 2008.	Models: DEA RS, Cross efficiency Inputs: population, passenger kilometres, passenger cars Outputs: fatalities
Shen et al. 2013 [60]	In this study, a new method for measuring the development of road safety over time for 26 European countries from 2001 to 2010 is presented, using the DEA method and the Malmquist productivity index.	Models: DEA-MI Inputs: population, passenger kilometres, passenger cars Outputs: fatalities
Egilmez and Mc Avoy, 2013 [61]	In this study, a Malmquist index model based on DEA was developed to evaluate the relative efficiency and productivity of 50 U.S. states (2002–2008) in reducing traffic fatalities.	Models: DEA Malmquist Inputs: HS expenditures, registered vehicles, licenced drivers, total road length (miles), road condition, safety belt usage Outputs: vehicle miles travelled (VMT), fatal crashes.
Shen et al. 2014 [62]	The main objective of this article was to explore the feasibility of including serious injury rates in addition to traffic fatality rates in road safety benchmarking and to highlight the impact on country rankings in 10 European countries roads between 2006 and 2008.	Models: DEA RS Inputs: population, passenger kilometres, passenger cars Outputs: fatalities, adjusted serious injuries
Sadeghi and Moghaddam, 2016 [63]	This paper presents a multidimensional methodology for prioritising safety system retrofit projects on Iranian roads between 2006 and 2010, taking into account the uncertainty in estimating benefits (reduction of accidents) and costs.	Models: DEA Inputs: cost of counter measure Outputs: fatality, injury, PDO crash reductions
Behnood, 2017 [64]	The main objective of this study is to introduce a ranking criterion that explains success in each pillar of road safety using the concept of results-based management and also to identify best practices within a range of developing countries, focusing on archived results for Iranian roads in 2015.	Models: DEA Inputs: population, passenger kilometres, passenger cars Outputs: fatalities
Rosic et al. 2017 [65]	In this paper, the efficiencies (composite indices) obtained with different models based on DEA and TOPSIS were used to present a PROMETHEE-RS model to select the optimal method for the composite index for 27 DMUs in Serbia.	Models: DEA, Topsis Inputs: passenger kilometres, number of registered passenger cars Outputs: number of fatalities
Nikolaou and Dimitriou, 2018 [66]	The aim of this paper is to analyse the road safety performance of EU-23 countries over a ten-year period (2005–2014), taking into account the socio-economic and demographic background.	Models: Cross efficiency Inputs: GDP, industry value, mobile cellular, unemployment, internet users, land area, energy consumption of transport Outputs: mortality rate, fatality risk
Ganji, Rassafi and Ling Xu, 2018 [67]	The main objective of this work was to measure the RSP of 31 Iranian provinces in 2016 by proposing and implementing a novel integrated CEM (DF-CEM-ERA) that considers both pessimistic and optimistic perspectives.	Models: cross efficiency Inputs: police station, road maintenance depot, equipment and vehicles, camera, emergency medical service, road with lighting system Outputs: fatality risk
Ganji and Rassafi, 2019 [68]	In this paper, a Double-Frontier SBM-based Malmquist Productivity Index (DF-SBM- MPI) is provided to analyse the efficiency and technological changes of safety performance for roads of Iranian provinces between 2014 and 2016.	Models: SBM Malmquist Inputs: police station, road maintenance depot, equipment and vehicles, camera, emergency medical service, road with lighting system Outputs: fatality risk
Omrani, Amini and Alizadeh, 2019 [69]	The proposed model is applied to estimate the provincial efficiency road safety efficiency of 31 provinces roads in Iran.	Models: DEA RS Inputs: passenger kilometre, tonne kilometre, free/highway length, number of registered automobiles, number of speed camera, population Outputs: number of fatalities, number of injuries, number of crashes
Ganji and Rassafi, 2019 [70]	This study aims to present a Double-Frontier CEM aggregated by ERA (DF-CEM-ERA) to evaluate RSP considering the preference structure of DM in European countries.	Models: cross efficiency Inputs: number of inhabitants, number of registered Outputs: motor vehicles fatalities, seriously injured
Ganji, Rassafi and Babdari, 2020 [71]	In this regard, this study aims to provide a double-frontier CEM to evaluate RSP by considering the best and worst frontiers simultaneously for European countries.	Models: double frontier cross efficiency Inputs: number of inhabitants, number of registered Outputs: motor vehicles fatalities, seriously injured
Fancello, Carta and Serra, 2020 [72]	In this paper, a decision support methodology based on DEA is proposed to assist Italian urban road safety management practitioners in identifying the roads where the need for safety improvements is the greatest.	Models: CCR, BCC Inputs: average annual daily traffic, number of conflict points Outputs: social cost of accidents
Antić et al. 2020 [73]	The aim of this study was to evaluate the performance, i.e. the relative efficiency of different regions (21 municipalities in Montenegro) using DEA.	Models: DEA Inputs: total number of traffic accidents Outputs: number of fatalities
Fancello and Serra, 2020 [74]	This paper proposes a decision support methodology based on DEA to assist urban road safety management practitioners in identifying the roads where the need for safety improvements is greatest, which is verified on nine Italian roads.	Models: CCR, BCC Inputs: traffic flow divided by the length, average number of conflict points Outputs: social cost of accidents
Shen et al. 2020 [75]	In this study, a comprehensive set of hierarchically structured safety performance indicators was developed based on the identification of the main road safety risk factors for 28 European countries in 2006.	Models: DEA CI Inputs: alcohol, speed Outputs: protective systems
Zhu et al. 2021 [76]	In this study, a road safety evaluation model based on CEM, regret theory and WASPAS was developed and examined for roads in Chinese provinces.	Models: cross efficiency Inputs: percentage of registered drivers in total population, percentage of heavy goods vehicles in motor vehicles, percentage of freeway in classified highway, life expectancy, gross domestic production (GDP) per capita, health technicians per inhabitants person, percentage of health expenditure Outputs: fatalities per road accidents, number of injured per road accidents
Pajkovic et al. 2021 [77]	In this study, fuzzy numbers were used to describe self-reported behaviour on Montenegrin roads, using DEA.	Models: cross efficiency, GRA Inputs: driving above the speed limit, driving under the influence of alcohol, not wearing a seat belt, using phone Outputs: number of accidents, number of fatalities
Kang and Wu, 2021 [78]	This method was developed based on DEA and Malmquist Productivity Index (MPI) and therefore named DEA-MPI. It was studied in the period 2007–2016 on Chinese provincial road.	Models: DEA MPI Inputs: population, passenger cars, passenger kilometres Outputs: number of accidents, fatalities, injuries, direct property damage
Nikolaou et al. 2021 [79]	This paper aims to support road safety decision makers by examining the road safety performance of 18 EU countries between 2007 and 2016 and measuring the impact of these factors on the countries' road safety performance.	Models: DEA Tobit Inputs: registered passenger cars (thousand), total registered vehicles (thousand), total length of road network Outputs: passenger cars traffic (billion pkm), buses and coaches' traffic (billion pkm)
Raheel Shah et al. 2021 [80]	This study proposes a road safety analysis method using a combination of DEA and the decision tree technique (DT) for the two Belgian freeways E-313 and E-314 (sections in the province of Limburg).	Models: cross efficiency Inputs: speed, flow, road feature data Outputs: number of accidents, number of persons injured or killed
Kang and Wu, 2022 [81]	This paper develops a nonparametric method based on DEA to evaluate the performance of traffic safety in Chinese provinces based on the output-input ratio.	Models: output-input ratio, DEA Inputs: population (million), passenger cars (million), passenger kilometres (billion) Outputs: the number of accidents, fatalities, injuries, direct property damage
Scope: SUSTAINABILITY EVALUATION		
Tian et al. 2020 [82]	In this study, an improved super-efficiency SBM-DEA model with weighted preference was proposed to evaluate the sustainability of regional traffic studied in Shaanxi Province, China, between 2000 and 2015.	Models: SBM, super-efficiency Inputs: length of highways, number of employees, energy consumption, total investment in fixed asset, ordinary trucks for highways, ordinary passenger cars for highways, land take by transportation Outputs: passenger capacity, freight capacity, passenger kilometres, tonne kilometres, carbon emissions for transportation, cost of air pollution emissions, cost of traffic noise pollution
Hahn, Kho, Choi and Kim, 2017 [83]	In this study, a model of the network DEA is constructed to evaluate the sustainability of public transportation services base on to rapid routes for buses in the Seoul metropolitan area.	Models: NDEA Inputs: total transportation costs, ratio of stops of median bus lanes to all bus stops, ratio of compressed natural gas Outputs: total riders, equity estimates, air pollution cost.
Hussain et al. 2022 [84]	This paper aims to analyse whether and how environmental pollution and fatality, economic-oriented transport and socioeconomic factors affect transport efficiency.	Models: SBM, Window DEA Inputs: road inf investment, rail inf investment, road density, rail density Outputs: road passenger, rail passenger, road freight, rail freight, trans value added, trans employment, road CO2, rail CO2

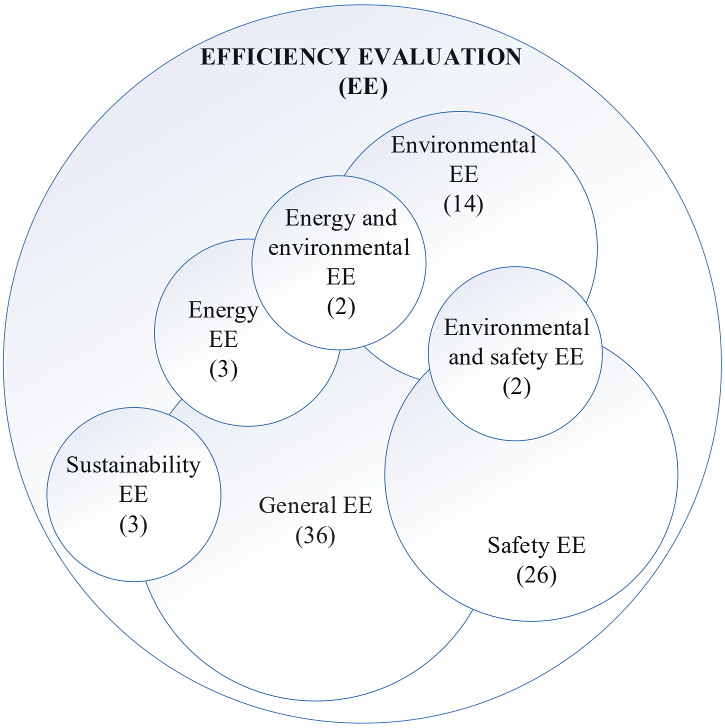

Figure 2 – Distribution of articles based on scope

3. DEA METHODOLOGY

As a performance evaluation method, DEA applies linear programming techniques to estimate the relationships between multiple inputs and multiple outputs with respect to a set of DMUs. The models of DEA can be divided into several types depending on the nature of the problem and the characteristics of the given data. The classical models are radial models. In non-radial models the efficiency value of the decision-making units is determined in addition to the efficiency measurement [3]. Some DMUs in the production process may produce undesirable outputs such as pollution, etc. in addition to desirable outputs. The presence of these undesirable outputs plays an important role in estimating efficiency. Therefore, in this paper, we present a model that considers the presence of undesirable outputs and then calculates the efficiency.

The test of the classical DEA models in the case of undesirable outputs has shown that these models cannot fully classify most units and classify them as efficient. Therefore, according to the data and conditions of the models, the DEA model with undesirable outputs (DEA-UO) and Non-radial DEA model with undesirable outputs (SBM UO) were selected for evaluation and ranking in this study because these models are more accurate in evaluating units than other models DEA. This is because the SBM model takes into account not only the technical inefficiency but also the inefficiency of the decision-making units using auxiliary variables.

3.1 DEA models with undesirable outputs (DEA-UO)

Let us first define the model variables. Assume that there is a set of n DMUs. Each DMU uses m number of inputs to produce the number of desirable outputs s_1 and the number of undesirable outputs s_2. Unit j is denoted by $\text{DMU}_j\,(j=1,...,n)$ The i^{th} input and r^{th} outputs (desirable and undesirable) of DMU_j are denoted by $X_{ik}\,(i=1,...,m)$, $y^g_{rk}\,(r=1,...,s_1)$ and $y^b_{pk}\,(p=1,...,s_2)$, respectively. Furthermore, we denote the inputs, desirable outputs and undesirable outputs as $X \in R^{n\times m}$, $Y^g \in R^{n\times s_1}$ and $Y^b \in R^{n\times s_2}$ matrices, respectively. The production possibility set is defined as follows:

$$T=\left\{(X,Y)\,|\sum_{j=1}^{n}\lambda_j X_j \le X,\ \sum_{j=1}^{n}\lambda_j Y_j^g \ge Y^g,\ \sum_{j=1}^{n}\lambda_j Y_j^b \le Y^b,\ \lambda_j \ge 0,\ j=1,...,n\right\}$$

On the above assumptions, Korhonen and Luptacik [85] proposed the following DEA model, in which negative weights are considered as undesirable outputs:

$$Max\ E_k = \frac{\sum_{r=1}^{s_1} u_{rk}^g y_{rk}^g - \sum_{p=1}^{s_2} u_{pk}^b y_{pk}^b}{\sum_{i=1}^{m} v_{ik} x_{ik}}$$

$$\text{s.t.} \quad E_j = \frac{\sum_{r=1}^{s_1} u_{rk}^g y_{rk}^g - \sum_{p=1}^{s_2} u_{pk}^b y_{pk}^b}{\sum_{i=1}^{m} v_{ik} x_{ij}} \le 1,\ j=1,...,n,\ u_{rk}^g \ge \varepsilon\ \forall r,\ u_{pk}^b \ge \varepsilon\ \forall p,\ v_{ik} \ge \varepsilon\ \forall i,\ \varepsilon > 0 \tag{1}$$

where u_{rk}^g, u_{pk}^b and v_{ik} are the weights for the r^{th} desirable output, p^{th} undesirable output and i^{th} input, respectively, and ε is a very small non-Archimedean number. To obtain a non-negative efficiency score for each DMU, we propose the following model, which includes additional constraints $(E_j = 1,...,n)$ on the model (*Equation 1*), then the model is obtained as follows (*Equation 2*).

$$Max\ E_k = \frac{\sum_{r=1}^{s_1} u_{rk}^g y_{rk}^g - \sum_{p=1}^{s_2} u_{pk}^b y_{pk}^b}{\sum_{i=1}^{m} v_{ik} x_{ik}}$$

$$\text{s.t.} \quad 0 \le E_j = \frac{\sum_{r=1}^{s_1} u_{rk}^g y_{rk}^g - \sum_{p=1}^{s_2} u_{pk}^b y_{pk}^b}{\sum_{i=1}^{m} v_{ik} x_{ij}} \le 1,\ j=1,...,n,\ u_{rk}^g \ge \varepsilon\ \forall r,\ u_{pk}^b \ge \varepsilon\ \forall p,\ v_{ik} \ge \varepsilon\ \forall i,\ \varepsilon > 0 \tag{2}$$

Using the Charnes and Cooper conversion [86], the above model can be converted to the linear programming problem (*Equation 3*):

$$Max\ E_k = \sum_{r=1}^{s_1} u_{rk}^g y_{rk}^g - \sum_{p=1}^{s_2} u_{pk}^b y_{pk}^b$$

$$\text{s.t.} \quad \sum_{i=1}^{m} v_{ik} x_{ik} = 1,\ \sum_{r=1}^{s_1} u_{rk}^g y_{rk}^g - \sum_{p=1}^{s_2} u_{pk}^b y_{pk}^b - \sum_{i=1}^{m} v_{ik} x_{ij} \le 0,\ j=1,...,n, \tag{3}$$

$$u_{rk}^g \ge \varepsilon\ \forall r,\ u_{pk}^b \ge \varepsilon\ \forall p,\ v_{ik} \ge \varepsilon\ \forall i, \varepsilon > 0$$

3.2 Non radial DEA model with undesirable outputs

The SBM model is a non-radial performance evaluation model. The difference between the SBM model and other DEA models is that the SBM model is based on slacks variables. SBM-UO models are explained in this section. According to Tone [87, 88] the undesirable outputs SBM-UO model can be expressed as shown in *Equation 4*. The i^{th} input and r^{th} outputs (desirable and undesirable) of DMU$_j$ are denoted by $x_{io}(i=1,...,m)$, $y_{ro}^g(r=1,...,s_1)$ and $y_{ro}^b(r=1,...,s_2)$, respectively. s_i^-, s_r^g and s_r^b are slacks variables of input, desirable output and undesirable output, respectively. Furthermore, we denote the inputs, desirable outputs and undesirable outputs as $X \in R^{n \times m}$, $Y^g \in R^{n \times s_1}$ and $Y^b \in R^{n \times s_2}$ matrices, respectively.

$$\rho^* = Min \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{io}}}{1 + \frac{1}{s_1 + s_2}\sum_{r=1}^{s_1} \frac{s_r^g}{y_{ro}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{ro}^b}}$$

$$\text{s.t.} \quad \sum_{j=1}^{n} \lambda_j x_{rj} + s_i^- = x_{io},\ i=1,\ldots,m,\ \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^g = y_{ro}^g,\ r=1,\ldots s_1, \tag{4}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} + s_r^b = y_{ro}^b,\ r=1,\ldots s_2,\ \lambda_j \ge 0, s_i^- \ge 0, s_r^b \ge 0, s_r^g \ge 0, i=1,...m, r=1,...,s, j=1,...,n$$

DMUo is efficient despite the undesirable outputs if and only if $\rho^*=1$, that is $s^{g*}=0$, $s^{b*}=0$, and $s^{-*}=0$.

The modified linear SBM-UO model is as follows:

$$\begin{aligned}
&\tau^* = Min \;\; t - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}} \\
&\text{s.t.} \quad t + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g}+\sum_{r=1}^{s_2}\frac{s_r^b}{y_{ro}^b}\right)=1,\; \sum_{j=1}^{n}\Lambda_j x_{ij}+s_i^- = tx_{io},\; i=1,\ldots,m, \\
&\quad \sum_{j=1}^{n}\Lambda_j y_{rj}-s_r^g = ty_{ro}^g,\; r=1,\ldots,s_1,\; \sum_{j=1}^{n}\Lambda_j y_{rj}+s_r^b = ty_{ro}^b,\; r=1,\ldots,s_2, \\
&\quad \Lambda_j \ge 0,\; s_i^- \ge 0,\; s_r^g \ge 0,\; s_r^b \ge 0,\; i=1,\ldots,m,\; r=1,\ldots,s,\; j=1,\ldots,n,\; t>0.
\end{aligned} \tag{5}$$

An important property of the efficiency SBM model is that τ is independent of the measurement unit used for inputs and outputs and decreases monotonically with each input and output slack.

3.3 Super-efficiency model with undesirable outputs (S-SBM-UO)

The basis of the super-efficiency model is to remove the evaluated efficient unit and implement the model for other units so that the super-efficiency frontier (and reference set) for efficient units is different from the main efficiency frontier and each unit has its own super-efficiency frontier. Assuming that the DMUo is an efficient unit, the super-efficiency of the DMUo with undesirable outputs is defined as the following model:

$$\begin{aligned}
&\tau^* = Min \;\; t - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}} \\
&\text{s.t.} \quad t + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g}+\sum_{r=1}^{s_2}\frac{s_r^b}{y_{ro}^b}\right)=1,\; \sum_{j=1,j\ne o}^{n}\Lambda_j x_{ij}+s_i^- = tx_{io},\; i=1,\ldots,m, \\
&\quad \sum_{j=1,j\ne o}^{n}\Lambda_j y_{rj}-s_r^g = ty_{ro}^g,\; r=1,\ldots,s_1,\; \sum_{j=1,j\ne o}^{n}\Lambda_j y_{rj}+s_r^b = ty_{ro}^b,\; r=1,\ldots,s_2, \\
&\quad \Lambda_i \ge 0,\; s_i^- \ge 0,\; s_r^g \ge 0,\; s_r^b \ge 0,\; i=1,\ldots,m,\; r=1,\ldots,s,\; j=1,\ldots,n,\; j\ne o,\; t>0.
\end{aligned} \tag{6}$$

4. EMPIRICAL ANALYSIS AND EVALUATION

The efficiency of road transport was studied considering technical, environmental and safety indicators, i.e. energy consumption, CO_2 emissions, traffic accidents and traffic noise on the roads of 27 European countries and the United Kingdom. The data are taken from the Eurostat [1] and from the last available European Statistical Pocket Books and the European Road Safety Observatory [89–91] and are marked as DS1 (for the year 2018) and DS2 (for the year 2017). Due to the use of improved models, there is no concern about the number of DMUs with any number of variables. This case was also evaluated with a larger number of units ignored due to the purpose of the article, which concerns only European countries. In this article, countries are evaluated in two areas – passenger and freight transport.

In this analysis, *Equations 3 and 5* are used to evaluate countries based on indicators, and *Equation 6* is used to rank them.

4.1 Inputs and outputs selection

The aim of this article is to evaluate the efficiency of road transport on the roads of European countries, taking into account all indicators, including energy consumption, emissions, traffic accidents and traffic noise. The inputs and outputs were determined based on the results of the literature review and the opinions of road transport experts. The inputs used for road transport efficiency analysis should include both capital and labour elements. The capital elements in this study are total road length, fuel consumption in litres and equipment.

The input indicators used (see *Table 2*) are the following:

– The input variable *Employment* represents *the number of employees in road freight* ($x1$) and *road passenger transport enterprises* ($x2$). Here, the number of all employees in freight and passenger transport systems is taken into account.

– The indicator *Length of roads* (*x*3) represents the length of all types of roads in the Europe under study. The length of standard roads, including the length of motorways, the length of major or national roads, the length of minor or regional roads and the length of other roads, is selected according to the statistics of the Statistical Book [2].
– The input *Equipment* (*x*4) represents all types of vehicles. The total available equipment registered in all countries is calculated, including passenger cars, buses, trucks and motorised two-wheelers.
– Since the road transport accounts for the largest share of energy consumption in the transport sector, the indicator *Fuel* (*x*5), which represents the final energy consumption in road transport (freight and passenger transport) of each European country, was used as the fourth input indicator.

Table 2 – Input indicators

Employment		**Length of roads**	**Equipment**	**Fuel**
*x*1	*x*2	*x*3	*x*4	*x*5
Road freight transport *	Road passenger transport *	Length of motorways, length of major or national roads, length of minor or regional roads, length of other roads	Passenger cars*, buses, trucks, motorised two wheelers	Final energy consumption in road transport by type of fuel

**per 1000*

Table 3 – Output indicators

Turnover (desirable)		**Volume of transport (desirable)**	**Emissions (undesirable)**	**Noise (undesirable)**	**Damage (undesirable)**	
*Y*1	*Y*2	*Y*3	*Y*4 (Environmental criteria)	*Y*5 (Environmental criteria)	*Y*6 (Safety criteria)	*Y*7 (Safety criteria)
Road freight transport (million EUR)	Road passenger transport (million EUR)	Volume of national and international transport (billion tkm)	Greenhouse gas emissions by source sector	Number of people exposed to high noise pollution*	Number of road accidents involving personal injury by country	Number of fatalities by country

** These data refer to the year 2017, as these statistics are only provided by countries every 5 years [92].*

The following were used as output indicators (see *Table 3*):
– *Road transport turnover* is considered separately for freight (*Y*1) and passenger (*Y*2) transport. Data refer to transportation and storage activities (including postal and courier services, removal services).
– The *Volume of transport* (*Y*3) is an output variable that includes the volume of domestic and international road passenger and freight traffic based on registered vehicle types.
– *Emissions* (*Y*4) are one of the most important undesirable outputs of the transport system. Passenger cars and motorcycles account for the largest share of emissions (62%), heavy trucks and buses for 26% and light trucks for another 13%, while road transport as a whole was responsible for 26% of all carbon dioxide emissions in the EU in 2018, compared to 16% in 1990 [1].
– Road traffic *Noise* (*Y*5) is a major environmental problem in Europe. This undesirable output shows the number of people exposed to high noise pollution from road traffic in EU countries.
– Direct property *Damage* is another undesirable output, which is the number of accidents with injuries (*Y*6) and fatalities (*Y*7). These outputs calculate the number of personal injury accidents and fatalities by country.

4.2 Efficiency analysis results

The UO radial model (3) and the SBM-UO non-radial model (8) are used to evaluate the European road transport systems. The results of the analysis are presented in *Table 6*. In the UO analysis, 19 transport systems are evaluated as efficient, representing 68% of the total systems. In the SBM model analysis, 19 transport systems were also rated as efficient. As can be seen (see *Table 5*), the efficiency scores of the SBM-UO model are lower than those of the UO model because this model is based on slacks variables and shows more accurate results.

Table 4 – Data for input and output variables (DS1)

Countries	Input variables					Output variables						
	*X*1	*X*2	*X*3	*X*4	*X*5	*Y*1	*Y*2	*Y*3	*Y*4	*Y*5	*Y*6	*Y*7
Belgium	62.300	19.100	155,210	7,425.300	8,558.537	11,945	1,248	32.700	25.026	14.000	38.455	604
Bulgaria	73.900	30.600	19,693	3,421.800	3,181.429	4,288	521	27.000	9.258	16.700	6.684	610
Czech Republic	131.300	41.200	130,663	7,613.100	6,375.730	9,606	1,703	41.100	18.350	28.800	21.890	656
Denmark	32.100	28.500	74,763	3,238.400	4,028.200	6,269	3,304	15.000	12.297	18.500	2.964	171
Germany	452.800	495.200	229,826	54,956.100	11,990.828	4,4248	3,8613	316.800	155.928	6.900	308.721	3,275
Estonia	16.300	3.800	59525	927.500	807.271	1,417	160	5.800	2.353	22.700	1.474	67
Ireland	24.100	29.000	98,898	2,534.100	3,942.573	2,449	2,991	11.600	11.553	14.400	6.093	141
Greece	36.500	61.400	117,861	8,278.300	5,002.363	2,531	1,512	29.300	14.592	7.900	10.737	700
Spain	342.200	192.800	666,679	34,739.100	28,735.907	34,479	10,584	239.000	82.663	24.800	102.299	1,806
France	372.700	267.300	1,103,774	48,453.200	42,029.960	49,430	25,210	171.900	123.167	23.500	55.762	3,246
Croatia	23.000	15.400	26,691	2,010.700	2,048.839	1,745	480	12.600	6.113	7.700	10.450	317
Italy	347.200	166.400	256,567	52,786.700	32,805.798	50,081	12,576	124.900	95.776	13.700	172.553	3,334
Cyprus	2.100	3.500	12,996	704.900	682.220	180	153	0.900	2.077	49.200	0.499	49
Latvia	27.100	13.500	68,821	857.700	1,041.169	1,546	208	15.000	3.107	27.000	3.975	150
Lithuania	82.400	17.200	72,227	1,609.500	1,982.878	5,862	343	43.600	5.756	26.300	2.926	173
Luxembourg	7.800	1.900	2,914	492.600	2,084.647	1,443	311	6.800	5.951	24.500	0.947	36
Hungry	81.200	52.800	213,300	4,407.700	4,571.067	6,295	1,837	37.900	13.378	16.400	16.951	633
Malta	1.300	4.000	2,640	378.200	217.976	121	137	0.300	0.559	22.400	1.346	18
Netherland	128.800	59.300	139,690	11,494.400	10,472.870	23,470	4,133	68.900	29.992	19.300	19.270	598
Austria	61.900	55.900	127,498	6,331.700	8,213.522	9,547	4,887	25.800	23.361	24.200	36.846	409
Poland	458.400	141.300	424,564	30,162.400	21,505.609	36,361	4,348	315.900	62.920	11.600	31.674	2,900
Portugal	73.500	36.900	47,713	7,286.600	5,514.410	6,027	1,437	33.000	16.277	5.200	35.816	700
Romania	160.800	80.400	86,234	7,677.500	6,026.312	10,483	1,515	58.800	17.605	13.300	30.202	1,867
Slovenia	27.600	5.800	51,962	1,387.200	1,945.671	3,088	291	22.200	5.742	9.800	6.013	91
Slovakia	50.900	16.000	56,940	2,796.200	2,527.275	4,350	377	35.600	7.255	6.700	5.335	260
Finland	45.200	25.400	7,7943	4,754.600	3,946.543	6,925	1,795	28.300	10.852	8.800	4.312	239
Sweden	82.200	75.200	215,690	6,217.500	6,568.116	11,253	8,453	43.500	15.135	13.200	14.317	324
United Kingdom	290.000	247.200	422755	38521.200	38959.783	29095	22875	159.300	111.418	14.500	128.384	1839

Table 5 – Data for input and output variables (DS2)

Countries	Inputs					Outputs						
	X1	*X2*	*X3*	*X4*	*X5*	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6*	*Y7*
Belgium	59.700	19.500	155,210	7,333.200	8,515.745	12,067	1,402	34.200	24.892	14.000	38.020	609
Bulgaria	72.200	31.600	19,861	3,396.100	3,091.867	3,906	458	35.200	8.955	16.700	6.888	682
Czech Republic	129.600	38.700	130,659	7,355.300	6,316.771	8,993	1,508	44.300	18.154	28.800	21.263	577
Denmark	31.100	26.200	7,4674	3,179.400	3,933.573	6,182	3,119	15.500	12.006	18.500	2.789	175
Germany	460.000	465.400	229,890	54,169.500	54,584.037	44,824	34,411	313.100	156.720	6.900	302.656	3,180
Estonia	16.300	3.700	5,8974	897.400	777.710	1,288	147	6.200	2.346	22.700	1.405	48
Ireland	22.400	29.300	98,898	2,486.300	3,908.628	1,867	1,983	11.800	11.395	14.400	6.023	156
Greece	33.100	60.200	117,606	8,237.000	4,992.087	2,363	1,476	28.400	14.534	7.900	10.848	731
Spain	330.100	186.100	666,661	33,991.000	28,052.814	32,812	9,501	231.100	81.791	24.800	102.233	1,830
France	366.900	396.500	1,103,545	42,101.700	43,007.829	47,648	24,379	167.700	125.964	23.500	58.609	3,444
Croatia	22.900	20.100	26,822	2,425.400	2,099.925	1,651	682	11.800	6.343	7.700	10.939	331
Italy	337.900	165.300	256,567	52,093.800	31,654.020	47,648	12,219	119.700	92.746	13.700	174.933	3,378
Cyprus	2.000	3.300	9,870	676.700	678.556	166	150	0.800	2.106	49.200	0.608	53
Latvia	26.600	13.800	68,507	834.600	1,015.048	1,448	202	15.000	3.089	27.000	3.875	136
Lithuania	70.200	16.400	71,724	1,521.800	1,862.857	4,638	315	39.100	5.407	26.300	3.059	191
Luxembourg	7.500	2.700	2,889	478.500	1,950.893	1,341	376	8.100	5.576	24.500	0.955	25
Hungry	78.500	49.300	210,802	4,200.600	4,288.451	5,800	1,742	39.700	12.594	16.400	16.489	625
Malta	1.300	3.500	2,855	365.800	193.407	200	90	0.300	0.554	22.400	1.497	19
Netherland	123.800	65.800	139,690	11,279.100	1,0134.321	22,215	3,925	67.500	29.724	19.300	18.706	535
Austria	62.900	58.600	130,388	6,217.500	8,083.019	10,554	4,882	26.000	23.188	24.200	37.402	414
Poland	384.400	137.800	405,958	29,014.100	20,657.084	27,669	4,000	335.200	61.219	11.600	32.760	2,831
Portugal	69.900	34.600	14,313	7,003.500	5,470.300	5,670	1,287	34.200	16.207	5.200	34.416	602
Portugal	73.500	36.900	47,713	7,286.600	5,514.410	6,027	1,437	33.000	16.277	5.200	35.816	700
Romania	155.100	78.900	86,083	7,150.800	5,853.350	9,325	1,297	54.700	17.066	13.300	31.106	1,951
Slovenia	25.700	5.600	38,934	1,349.200	1,904.523	2,760	263	20.800	5.758	9.800	6.185	104
Slovakia	48.000	15.500	56,918	2,682.200	2,539.735	3,931	366	35.400	7.094	6.700	5.317	276
Finland	45.400	28.800	77,981	4,649.400	3,912.741	6,396	2,347	28.000	10.688	8.800	4.432	238
Sweden	83.300	72.700	215,379	6,164.100	6,748.385	11,124	8,542	41.900	15.463	13.200	14.951	253
United Kingdom	266.800	228.400	422,513	38,104.700	39,121.935	29,131	24,238	153.900	112.975	14.500	136.063	1,856

This proves that efficiency evaluation with the SBM-UO model can avoid the angular and radial weaknesses of the traditional DEA model and improve the accuracy and reliability of efficiency evaluation. Radial models deal only with proportional changes in inputs/outputs and neglect input/output slacks. Non-radial models, on the other hand, deal with input/output slacks directly. However, the efficient units do not differ in the two models, only the efficiency scores are more accurate in the SBM-UO model. In addition, the safety efficiency and environmental efficiency scores of the units were calculated separately using the SBM-UO model and considering their specific inputs and outputs (see *Table 6*). In the safety analysis (without considering other environment-related outputs), nine transport systems are classified as efficient, while in the environmental analysis (without considering safety-related outputs), 15 are classified as efficient, indicating that the efficiency of the systems is lower in terms of safety. In the safety analysis, the Czech Republic, Romania, Estonia, Portugal, Belgium and Croatia score the lowest. The environmental efficiency of the transport sector was also poor in Cyprus and Croatia compared to other European countries during this period. The results show that most countries have good environmental quality standards in the transport sector, that emissions are reasonably well controlled and that environmental policies in this area are forcing continuous improvements.

Table 6 – Efficiency analysis results for DS1

Countries	**Efficiency score (UO model)**	**Efficiency score (SBM-UO model)**	**Environmental efficiency (SBM-UO model)**	**Safety efficiency (SBM-UO model)**
Belgium	1.00000	1.00000	1.00000	0.25715
Bulgaria	1.00000	1.00000	1.00000	0.27760
Czech Republic	0.66102	0.50165	0.55260	0.21117
Denmark	1.00000	1.00000	1.00000	1.00000
Germany	1.00000	1.00000	1.00000	1.00000
Estonia	0.88677	0.49200	0.55808	0.23522
Ireland	1.00000	1.00000	1.00000	1.00000
Greece	1.00000	1.00000	1.00000	0.28323
Spain	1.00000	1.00000	0.69117	0.35941
France	1.00000	1.00000	0.6346807	0.5209602
Croatia	0.71499	0.44148	0.47258	0.25991
Italy	1.00000	1.00000	1.00000	0.33728
Cyprus	0.7216702	0.24725	0.28412	0.29841
Latvia	0.89527	0.50083	0.51697	0.38201
Lithuania	1.00000	1.00000	1.00000	1.00000
Luxembourg	1.00000	1.00000	1.00000	1.00000
Hungry	0.70799	0.48024	0.52078	0.27725
Malta	1.00000	1.00000	1.00000	1.00000
Netherland	1.00000	1.00000	1.00000	0.42233
Austria	0.84210	0.64018	0.72425	0.57738
Poland	1.00000	1.00000	1.00000	1.00000
Portugal	0.87067	0.52444	0.55537	0.2449316
Romania	0.94438	0.57492	0.57041	0.23209
Slovenia	1.00000	1.00000	1.00000	1.00000
Slovakia	1.00000	1.00000	1.00000	0.3410715
Finland	1.00000	1.00000	0.88426	0.48690
Sweden	1.00000	1.00000	1.00000	1.00000
United Kingdom	1.00000	1.00000	0.67026	0.70003

Table 7 – Efficiency analysis results for DS2

Countries	Efficiency score (UO model)	Efficiency score (SBM-UO model)	Environmental efficiency (SBM-UO model)	Safety efficiency (SBM-UO model)
Belgium	1.00000	1.00000	1.00000	1.00000
Bulgaria	1.00000	1.00000	1.00000	0.27791
Czech Republic	0.71258	0.52953	0.57135	0.24644
Denmark	1.00000	1.00000	1.00000	1.00000
Germany	1.00000	1.00000	1.00000	1.00000
Estonia	0.91529	0.54538	0.51565	0.28148
Ireland	0.87345	0.45180	0.45857	0.47638
Greece	1.00000	0.97579	1.00000	0.22085
Spain	1.00000	1.00000	0.71614	0.29889
France	1.00000	1.00000	1.00000	0.43092
Croatia	0.67241	0.43898	0.48759	0.23422
Italy	1.00000	1.00000	1.00000	0.32576
Cyprus	0.74645	0.24903	0.26539	0.27053
Latvia	0.87726	0.52022	0.52753	0.30110
Lithuania	1.00000	1.00000	1.00000	1.00000
Luxembourg	1.00000	1.00000	1.00000	1.00000
Hungry	0.69911	0.52536	0.57258	0.25371
Malta	0.78128	0.35441	0.38123	0.26165
Netherland	1.00000	1.00000	1.00000	0.50665
Austria	0.91956	0.69089	1.00000	0.55992
Poland	1.00000	1.00000	1.00000	1.00000
Portugal	1.00000	1.00000	1.00000	0.34670
Romania	0.89087	0.54726	0.61304	0.20549
Slovenia	1.00000	1.00000	1.00000	1.00000
Slovakia	1.00000	1.00000	1.00000	0.31195
Finland	1.00000	1.00000	0.94279	0.53948
Sweden	1.00000	1.00000	1.00000	1.00000
United Kingdom	1.00000	1.00000	1.00000	1.00000

The average efficiency score of the 28 countries studied is 0.83582. For environmental efficiency, the average efficiency score is 0.80841, but for safety efficiency, the average efficiency score is 0.560869, indicating that these countries need to improve their safety efficiency. In terms of safety, Denmark, Germany, Lithuania, Luxembourg, Hungary, Malta, Poland, Slovenia and Sweden achieve the best results.

The above analysis shows that the road transport sector is efficient in most European countries, as it does not need a massive increase in resource input to increase its outputs. It can be concluded that the road transport sector as a whole is efficient in general and environmental terms.

Table 7 shows the evaluation results for DS2. In this analysis, 18 systems are rated as radially efficient, representing 64% of the total systems. The results of the SBM-UO model analysis show that 17 transportation systems are efficient, which corresponds to 61% of the total systems. The comparison of results shows that Ireland, Greece and Malta, which were not efficient in the first year, became efficient the following year.

In contrast, Portugal, which was efficient in that the first year, became inefficient in the following year and needs to improve its performance. A comparison of environmental performance assessment results shows that Ireland, Malta, France, Austria and the United Kingdom, which were efficient in the first year, performed worse in the following year. Croatia dropped four places, and Cyprus' efficiency score improved slightly, but it is still the country with the lowest efficiency score among European countries. For safety efficiency, Malta and Ireland improved their poor scores and received the best performance rating. Belgium and England performed worse than last year. Overall, however, seven countries maintained their efficiency scores and 13 countries improved their safety efficiency scores very significantly.

4.3 Results of Ranking and Discussion

We use *Equation 6* to rank the countries. There are 19 efficient units for which super-efficiency scores were calculated using *Equation 6*, which are shown in *Table 5*. The results of applying this model show that the highest super-efficiency scores are for Denmark, Bulgaria, Germany, Italy, Belgium and the Netherlands, which are ranked 1 to 6 in terms of road transport sector performance. Denmark ranks first in technical (technology), safety and environment (general) areas. This shows that this country has made good progress in the areas of technology and road transport equipment. Bulgaria follows in the next place, which shows that the country is successful in the areas of technology and environment. The country is also successful in the field of safety. In third place is Germany, which is one of the best performers due to its superior position in the areas of economy and tourism, as well as in environmental factors.

Table 8 shows the ranking results for first data set, DS1. The ranking results also show that countries that have more undesirable than desirable outputs score lower in the rankings than other countries. Cyprus performs the worst, which is due to its high noise pollution compared to other countries. In second place is Croatia, whose poor performance is due to its high number of accidents and fatalities. In the case of Hungary, it can be said that the high values of inputs and the high values of undesirable outputs, especially the number of accidents and fatalities, are the reasons for the low efficiency of this country. Estonia, which is ranked 25th, seems to have low efficiency due to high noise pollution. The next country in the ranking is Latvia, where noise pollution is very high compared to the other outputs, while the country has a very low input. This logic also applies to the Czech Republic, where the level of pollution, accidents and fatalities is high. In the case of Portugal, the level of accidents and fatalities is very high, which is one reason for the relatively low rank of this country in the

Table 8 – Super-efficiency scores and ranking using DS1

Countries	Super-efficiency	Rank (general)	Countries	Super-efficiency	Rank (general)
Belgium	1.51982	5	Lithuania	1.00564	19
Bulgaria	1.71713	2	Luxembourg	1.02556	16
Czech Republic	-	23	Hungary	-	26
Denmark	1,75043	1	Malta	1.03598	13
Germany	1.69653	3	Netherland	1.33126	6
Estonia	-	25	Austria	-	20
Ireland	1.20605	7	Poland	1.01654	18
Greece	1.11340	9	Portugal	-	22
Spain	1.15781	8	Romania	-	21
France	1.02986	15	Slovenia	1.02177	17
Croatia	-	27	Slovakia	1.03255	14
Italy	1.55467	4	Finland	1.06167	11
Cyprus	-	28	Sweden	1.05322	12
Latvia	-	24	United Kingdom	1.06591	10

performance evaluation. Romania ranks 21st in the performance evaluation, and this country also has a very high number of fatalities, so the number of accident fatalities is 5th in Europe, which is a high value considering the volume of traffic in this country. In the case of Austria, noise pollution and the number of accidents is high, which is the reason for inefficiency.

In the evaluation and ranking in this study, Denmark performed the best, which is due to the low values of inputs and the low number of accidents and fatalities. In second place is Bulgaria, which has low energy consumption and where pollution and the number of accidents is also low. Germany is 3rd in this study because the values for desirable outputs are very high and noise pollution is very low in this country. The same logic applies to the next places of Italy and Belgium: Italy has a very low noise pollution and very high values for the desirable outputs, while Belgium also has a low noise pollution and a low number of fatalities.

Table 9 shows the ranking results for the second data set, DS1. Comparing the ranking results of these two years, we can see that Denmark maintained its first place. Germany was in second place in the first year, but in the following year it reached third place. This process is also true for Belgium and the Netherlands, which were each relegated once. Bulgaria and Spain moved up one spot in the following year. Italy moved up two spots on the ranking. The United Kingdom dropped three places from 7th to 10th, and Sweden and Slovakia are also ranked lower than in previous year. The ranking results of the second data set (DS2) also show that Cyprus performed the worst. It is followed by Malta and Croatia, which dropped one place. After these countries, Ireland, Latvia and Hungary had the lowest results. Comparing the results of the two tables, it can be seen that Hungary performed three ranks worse in the following year. Latvia's rank did not change from the previous year. The Czech Republic, ranked 22nd, seems to have low efficiency due to high undesirable results. The next country in this ranking is Estonia, followed by Romania. A comparison of the results shows that Estonia has lost four places compared to the previous year, and the Czech Republic and Romania have lost one place each.

Among the most important and biggest changes in the ranking of countries in comparison of these two years are Ireland, Greece and Malta. Ireland rose from 25th place to 7th place, Greece from 18th to 9th, and Malta from 27th to 13th place. France also fell from 10th to 15th place, losing five places. Portugal has almost the same situation, rising from 17th to 22nd place. Another notable change is Sweden, which dropped from 8th to 12th place. According to the European transport system statistics (2020), the reasons for the results can be explained and justified. The statistics show that the countries Cyprus, Croatia and Hungary, which received the lowest rank, had the highest increase in the accident and fatality rate, or that Denmark, Bulgaria and Germany,

Table 9 – Super-efficiency scores and ranking using DS2

Countries	Super-efficiency	Rank (general)	Countries	Super-efficiency	Rank (general)
Belgium	1.50995	4	Lithuania	1.01666	15
Bulgaria	1.68346	3	Luxembourg	1.02562	13
Czech Republic	-	22	Hungary	-	23
Denmark	1.73346	1	Malta	-	27
Germany	1.70455	2	Netherland	1.39543	5
Estonia	-	21	Austria	-	19
Ireland	-	25	Poland	1.02066	14
Greece	-	18	Portugal	1.00895	17
Spain	1.08658	9	Romania	-	20
France	1.05456	10	Slovenia	1.01088	16
Croatia	-	26	Slovakia	1.04425	11
Italy	1.36568	6	Finland	1.03783	12
Cyprus	-	28	Sweden	1.15734	8
Latvia	-	24	United Kingdom	1.24677	7

which received the best rank, had a very small increase in the mentioned area, or even in some cases, in 2018 compared to 2017, a remarkable decrease. Of course, this situation applies to other countries as well. This problem also applies to all undesirable outputs, so it can be concluded that the selected models of this study and the results are consistent with the published statistical facts of the European Union.

5. CONCLUSION

In this study, we considered technical, safety and environmental criteria to evaluate the relative performance of European road transport systems. We used models (UO, SBM-UO and SSBM-UO) to calculate the efficiency scores of DMUs and rank them. We concluded that in the second year, 19 of these systems were efficient and nine were inefficient while in the first year, 17 systems were efficient and 11 were inefficient, although some systems did not have very low efficiency scores. Some countries have weaknesses in safety, but most of them perform well in terms of environment, while in some countries high noise pollution is the reason for poor performance.

The empirical results and the comparison of the results can provide helpful implications for improving the efficiency of the road transport industry in Europe, taking into account various undesirable outputs. Important implications can be derived from these research results. A large expansion of road transport without the application of advanced technologies related to green productivity is likely to lead to wasted resources and environmental and safety problems. In order to increase productivity while reducing emissions, traffic noise and accidents, the highest priority should be given to the introduction of advanced transportation technologies and equipment and the continuous expansion of their scope.

The road transport industry in Europe has reached a nearly high level of efficiency. However, the main reason for this efficiency is the increasing economies of scale in the transport industry. The results show that the best actions are to maintain economies of scale and promote the use of advanced technologies to reduce noise, emissions, accidents and fatalities. Fortunately, environmental efficiency was good in most countries, although some countries had low environmental efficiency. Although in our analysis the DEA does not provide a precise mechanism for achieving efficiency, it does help to quantify the magnitude of change needed to make inefficient countries more efficient. In addition, and probably most importantly, sharing these results with managers of transportation systems could identify factors and conditions (variables) that help explain the observed differences. Managers of inefficient systems could then learn from the frontier systems and, more importantly, attempt to explain the causes of their own inefficiencies.

The results obtained in this study should be of interest to policy makers. The DEA results obtained here can help in identifying factors that can explain efficiency differences. The task is to compare the inefficient countries with the corresponding efficient countries. The information needed by an inefficient company consists of the identifying the efficient position on the frontier, the companies that define the efficient point, and the relative weights of the companies that define the efficient frontier. DEA methods such as those used in this study may be of interest to decision makers in the road transportation industry. They tend to believe that it is better to use fewer than more inputs such as labour and capital, to produce the same or a greater amount of output. This argues for DEA as a tool for evaluating the performance of DMUs or production units, such as road transportation systems, over other methods.

Current research will be expanded in the future to other countries or areas or to other modes of transportation. The goal of future studies may also be to introduce new models for evaluating performance in the presence of uncertain or stochastic data and to develop methods for increasing efficiency and avoiding inefficiency. Evaluation based on technical, environmental and safety criteria may also be used in other areas, including industry and management.

AVAILABILITY OF DATA

The data come from Eurostat (https://ec.europa.eu/eurostat/databrowser/explore/all/transp?lang=en&subtheme=road&display=list&sort=category&extractionId=ROAD_GO_CA_D_C) and from the European Statistical Pocket Books (https://op.europa.eu/en/publication-detail/-/publication/f0f3e1b7-ee2b-11e9-a32c-01aa75ed71a1 and https://transport.ec.europa.eu/media-corner/publications/statistical-pocketbook-2021_en). Materials are available from the authors on request.

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یک روش تحلیل پوششی داده های جدید برای ارزیابی عملکرد سیستم های حمل و نقل جاده ای اروپا

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چکیده:

نقش حمل و نقل در اقتصاد جهانی اهمیت فزاینده ای پیدا می کند و به ویژه حمل و نقل جاده ای نقش بسیار مهمی در انواع حمل و نقل ایفا می کند. به همین دلیل، نظارت منظم بر عملکرد آن بسیار مهم است. اغلب، این کار با استفاده از مدل‌های ارزیابی عملکرد تحلیل پوششی داده (DEA)انجام می‌شود. مقالات متعددی در ادبیات ارزیابی DEA سیستم‌های حمل‌ونقل جاده‌ای وجود دارد. در این تحقیق ابتدا به جمع بندی این مقالات و طبقه بندی آن ها بر اساس ویژگی های مختلف (زیست محیطی، ایمنی، اقتصادی، انرژی) می پردازیم. سپس، از آنها به عنوان مبنایی برای توسعه یک چارچوب جدید DEA استفاده می‌کنیم، که برای ارزیابی کارایی و رتبه‌بندی سیستم‌های حمل‌ونقل جاده‌ای استفاده می‌شود. این مدلها خروجی‌های نامطلوب، یعنی خروجی‌های زیست‌محیطی و ایمنی را نیز در نظر می‌گیرند. به عنوان یک مطالعه موردی، ۲۸ کشور اروپایی را از جنبه های فنی، ایمنی و زیست محیطی ارزیابی می کنیم. از مدل‌های CCR و SBM برای ارزیابی کارایی این کشورها در دو سال گذشته استفاده می‌شود. نتایج نشان می دهد که دانمارک در هر دو سال رتبه اول و قبرس آخرین رتبه را دارد. همچنین می توان دریافت که رتبه کارایی ایمنی به طور کلی کمتر از سایر معیارها می باشد. در انتها، نتایج و دلایل کارایی و ناکارآمدی واحدهای تصمیم‌گیری، یعنی کشورها، مورد بحث قرار می‌گیرد.

کلمات کلیدی:

تحلیل پوششی داده ها (DEA)، کارایی، روش مبتنی بر متغیر کمکی (SBM)، خروجی نامطلوب (UO)، ابرکارایی، سیستم حمل و نقل جاده ای.