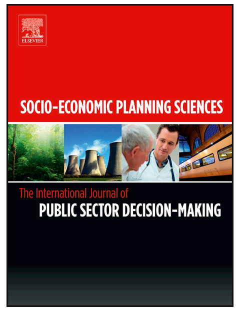
Accepted Manuscript



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PII: S0038-0121(18)30235-0

DOI: https://doi.org/10.1016/j.seps.2018.11.009

Reference: SEPS 672

To appear in: *Socio-Economic Planning Sciences*

Received Date: 25 July 2018

Revised Date: 10 November 2018

Accepted Date: 22 November 2018

Please cite this article as: Mahmoudi R, Emrouznejad A, Shetab-Boushehri S-N, Hejazi SR, The origins, development and future directions of Data Envelopment Analysis approach in transportation systems, *Socio-Economic Planning Sciences* (2019), doi: https://doi.org/10.1016/j.seps.2018.11.009.

The origins, development and future directions of Data Envelopment Analysis approach in transportation systems

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Abstract

Over the last two decades, application of Data envelopment analysis (DEA) in transportation problems have gained considerable research attention. This paper presents a literature review and classification of the applications of DEA in transportation systems (TSs). First by classifying 40 papers from 2007 to 2018, the origins of DEA in transportation problems have been reviewed. Then the development and an overall view of DEA applications in TSs have been presented. We have classified the applications of DEA into six different contexts. In each context, published papers have deeply been analyzed. Content of analysis includes "Number of published papers during the time", "target journals", "countries", "keyword frequency", "most cited papers", "map of most co-cited publications". More important, we reported the "inputs and outputs variables" used in each paper. Further "a review of the selected papers" and "gaps / future research directions" have been given within each cluster. The results show that DEA is one of the most useful approach in evaluating TSs for policy makers. On the other hand, DEA can help the decision makers in transportation especially regarding environmental factors, sustainable development and eco-design. Finally, we proposed subjects for future researches including guidance for new studies in the field of DEA applications in TSs.

Keywords: Data Envelopment Analysis; Transportation Systems; Highway/ Railway/ Air/ Maritime Transportation; Public Sector Evaluation.

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1. Introduction

Formation and development of civilizations have been affected by the transportation throughout history. Nowadays one important characteristic of developed countries is having an efficient, safe and advanced transportation system (TS). Increasing rate of the world population results lead to the need for different TSs. The transportation systems are expanding very rapidly, and so it is important to make sure the systems are efficient in order to save time and costs as well as safety.

Development of TSs have resulted in increasing energy consumption, traffic, transportation accident leading to loss of life and property and greenhouse gas emission, also change in land use because of transportation infrastructures. Transportation sector is one of the major energy consumer which produce a lot of pollutions in the world (Fuglestvedt et al., 2008). For example, in USA in 2014, transportation ranked second after the electricity power plants, among the most polluting sectors (SEPA, 2017). According to intergovernmental panel on climate change report in 2014, by producing 14% of the total pollution around the world, transportation's ranking is 4 (see Figure 1) (IPCC, 2017). Therefore, by reducing greenhouse gas emissions produced by the transport sector, it is expected to see a significant reduction in air pollution, acid rain, climate change and etc. (ECT, 2007). The statistics also show that about 1.25 million people die as a result of road accidents in each year. It is expected that the road traffic accident will be the seventh leading cause of death in 2030 (WHO, 2016). In term of supply chain management, by improving transportation methods, costs can be reduced by 15-20% (4flow, 2017). Therefore, it is important to survey the existing publication on the performance of TSs.

---------------- [Figure 1 about here] ----------------

Four decades after the introduction of Data Envelopment Analysis (DEA) by Charnes et al. (1978), this method has been applied in various subjects. including evaluating of TSs. According to Emrouznejad and Yang (2017), in the last three years transportation is ranked 4th most common application using DEA.

This paper presents a literature review and classification on the applications of DEA in TSs. More than 600 articles from 1989 to 2018 in Google scholar, Web of knowledge and Scopus have been surveyed. Only journal papers which have been published in English language are considered. Conference papers, books and non-English papers have not been included. First by classifying 40 most cited papers from 2007 to 2018, DEA models which have widely been used in evaluating the performance of TSs, are explained. Then an overall view of DEA applications in TSs has been presented. We classified transportation applications in six different categories including: (1) DEA and highway transportation (2) DEA and air transportation (3) DEA, ports and maritime transportation (4) DEA and railway transportation (5) DEA, Eco-design, sustainable development and green issues in transportation (6) DEA and other transportation research. A review of the selected papers, gaps and future directions for research have been presented for each category. Further, we have identified trend of researches' subjects. While past papers only provide overall statistical information about research in transportation and DEA field, this article presents a comprehensive analyzes of the most common used models, keywords, target journals, map of co-cited papers/authors and etc, in different TSs, separately. To the best of our knowledge, this article is the most comprehensive and the first study that has analyzed, classified and reviewed DEA applications in all major transportation fields. Further to this and for the first time a Critical Path Method (CPM) of DEA applications in TSs is also presented.

The rest of this paper is organized as follows: Method and search algorithm is presented in section 2. Section 3 presents a brief introduction of most DEA models used in transportation problems. An overall view and some important analysis for DEA applications in TSs have been presented in section 4. In section 5, compressive reviews of DEA applications in all considered categories are presented, separately. Finally, concluding remarks and directions for future research are provided in Section 6.

2. Method and search algorithm

Google scholar, Web of knowledge and Scopus have been considered as databases for articles search. First, using proposed algorithm in Table 1 list of primary articles has been prepared. Then with a closer look, related articles were identified and filtered. Only published papers in journal and English language have been considered. PRISMA (Moher et al., 2009) statement has been used in systematic search, reviews and meta-analyses (See Figure 2).

--------------- [Figure 2 about here] ---------------

--------------- [Table 1 about here] ---------------

3. Most common DEA models applied in transportation systems

In this section first by classifying 40 most cited papers from 2007 to 2018, DEA models that have been widely used in evaluating the performance of transport systems, are identified. Then 3 selected models have introduced briefly. According to Table 3, CCR (Charles, Cooper & Rhodes), BCC (Banker, Charles & Cooper) and SBM (Slacks-Based Measure) are the most popular models used in the literature. (see also Figure 3).

---------------- [Table 2 about here] ----------------

---------------- [Figure 3 about here] ----------------

3.1.The CCR model

The main idea of DEA is measuring relative efficiency of homogeneous set of decision making units (DMUs). Indeed, DEA believes that performance of a DMU should be evaluated in the presence of competitors (other DMUs). The first DEA model has proposed by Charnes et al. (1978). Suppose there are n DMUs, where each DMU_j $(j = 1,...,n)$ consumes m inputs, x_{ij} $(i = 1,...,m)$, to produce s outputs, y_{rj} $(r = 1,...,s)$. Assume u_r $(r = 1,...,s)$ and v_i $(i = 1,...,m)$ are the relative importance of each output, and input, respectively. The input-oriented CCR DEA model to evaluate the performance of DMU_O is presented as follows:

$$
\begin{aligned}
& Max \sum_{r=1}^{s} u_r y_{ro} \\
& s.t. \\
& \quad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \qquad j = 1,...,n \\
& \quad \sum_{i=1}^{m} v_i x_{io} = 1, \\
& \quad u_r > 0, \quad r = 1,...,s, \\
& \quad v_i > 0, \quad i = 1,....,m
\end{aligned}
\tag{1}
$$

This model is based on the assumption of constant returns to scale (CRS) and the dual form of model (1) is as follow:

$$
\begin{aligned}
& Min\ \theta \\
& s.t. \\
& \quad \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{io}, \qquad i = 1,\ldots,m \\
& \quad \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro}, \qquad r = 1,\ldots,s \\
& \quad \lambda_j \ge 0, \qquad j = 1,\ldots,n.
\end{aligned} \tag{2}
$$

3.2.The BCC Model

Under variable returns to scale (VRS) assumption the convexity constraint should be added to the mode, hence models (1) and (2) can be formulated as follows. In the literature these models are referred as BCC (Banker et al., 1984):

$$
\begin{aligned}
& Max\ \sum_{r=1}^{s} u_r y_{ro} - u_0 \\
& s.t. \\
& \quad \sum_{r=1}^{s} u_r y_{rj} - u_0 - \sum_{i=1}^{m} v_i x_{ij} \le 0, \qquad j = 1,\ldots,n \\
& \quad \sum_{i=1}^{m} v_i x_{io} = 1, \\
& \quad u_0 \ \textit{is free in sign} \\
& \quad u_r > 0, \quad r = 1,\ldots,s, \\
& \quad v_i > 0, \quad i = 1,\ldots.,m
\end{aligned} \tag{3}
$$

The dual form of Model (3) is as follows (Banker et al., 1984):

$$
\begin{aligned}
& Min\ \theta \\
& s.t. \\
& \quad \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{io}, \qquad i = 1,\ldots,m \\
& \quad \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro}, \qquad r = 1,\ldots,s \\
& \quad \sum_{j=1}^{n} \lambda_j = 1 \\
& \quad \lambda_j \ge 0, \qquad j = 1,\ldots,n.
\end{aligned} \tag{4}
$$

The above models are presented as input-oriented form to consider reduction in input values. Similar models can be formulated in the output-orientation to consider increase in output values.

3.3. The SBM model

The slacks-based Model (SBM) is the third most popular model used for evaluating TSs. Most researchers who study existing TSs have used SBM model in order to determine surplus in inputs/undesirable outputs and slacks of desirable outputs to improve the system by controlling surplus/slack values. SBM model under CRS assumption is as follow (Tone, 2001):

$$
\begin{aligned}
& Min\ \theta = \frac{1-(1/m)\sum_{i=1}^{m} s_i^- / x_{io}}{1+(1/s)\sum_{r=1}^{s} s_r^+ / y_{ro}} \\
& s.t. \\
& \sum_{j=1}^{n} \lambda_j x_{ij} = x_{io} - s_i^-, \qquad i=1,\ldots,m \\
& \sum_{j=1}^{n} \lambda_j y_{rj} = y_{ro} + s_r^+, \qquad r=1,\ldots,s \\
& \lambda_j \ge 0, \qquad j=1,\ldots,n \\
& s_i^-, s_r^+ \ge 0,\ \forall i,r
\end{aligned} \tag{5}
$$

where s_i^- and s_r^+ are surplus and slack values, respectively. A DMU is efficient if and only if $\theta^* = 1, s_i^-, s_r^+ = 0\ \forall i,r$.

SBM considers all inefficiencies where CCR considers technical inefficiencies. For considering VRS assumption, $\sum_{j=1}^{n} \lambda_j = 1$ must be added to model (5).

4. DEA applications in transportations: an overall view

In this study, the published papers have been classified and reviewed in six different sections including DEA applications in highway transportation, air transportation, maritime transportation, railway transportation, sustainability and environmental issues in transportation and other transportation issues. We first, in this section, give an overall view of published papers using DEA in any type of transportation issues.

Figure 4 shows the topic of a third of related papers are in air transportation system, and as seen in Figure 5, more than 80% of papers have been published in last 10 years are related to use of DEA in air transportation systems, and so this became a very interesting topic for researchers in recent years. As it is clear from Figure 6, number of papers that have focused on the DEA applications in all considered sections, is rapidly increasing over recent years. In all sections, more than 75% of identified papers, are in the last 10 years, that shows increasing importance of these subjects. Figure 7 shows the subject area of the identified papers in this section.

Table 3 and

Table 4 present the most cited papers and most active authors, respectively. By 312 citations, Tongzon (2001) is most cited papers, which is related to ports and maritime TSs. Also Yu and Barros are two most active authors. Yu focused on air, highway and railway TSs and Barros mainly focused on air and maritime TSs. Most active journals in each section and in all area of type of transportation issues are listed in Table 5. “Journal Of Air Transport Management” and “Transportation Research Part A Policy And Practice” are two journals with most published papers. Top 10 countries which have published most papers related to DEA applications in TSs are presented in Table 6. Researchers of United states and China are two active countries, with 109 published articles. Also Table 7 shows the keywords that have most frequency across the DEA and TSs literature in each section and in overall.

Recently, using social network analysis (SNA) have become very popular for studying papers citation. This method leads to understand different aspects of under study fields such as co-citation, collaboration among researchers, knowledge patterns, gaps and emerging knowledge trends within disciplines (Emrouznejad and Marra, 2014, 2017). In this study, by using mapping technique and SNA, we will try to achieve these targets (for more information about mapping and SNA technics and their advantages please see Emrouznejad and Marra (2014)). In each section, using VOSviewer and Pajek softwares, maps of most co-occurrence keywords and co-authorship network related to DEA applications in TSs have been provided. Maps of most co-occurrence keywords, co-authorship network and most co-cited papers are presented in Figure 8, Figure 9 and Figure 10, respectively. Large shapes dimension related to keyword/author which means it has more frequent between others. Also the links with more width represents a strong relation between two individuals. The most co-cited papers are listed in Table 8. Charnes et al. (1978), which introduced DEA for the first time, is the most co-cited paper. The rest of the paper will focus on each subject area in details.

-------------- [Figures 4 to 10 about here] ----------------

--------------- [Tables 3 to 8 about here] ----------------

5. DEA and its applications in transportation systems

5.1. DEA and highway transportation systems

In this section details of studies which have focused on DEA applications in highway TSs have been investigated.

Based on surveying all 63 identified papers, considered inputs and outputs for evaluating the highway TSs by DEA, have presented in Table 5.1.1. Table 5.1.2 presented highly cited papers in DEA applications in highway TSs. Also, the maps of most co-occurrence keywords and co-authorship network have been shown in Figure 5.1.1 and Figure 5.1.2, respectively. By using Critical Path Method (CPM), abstract, keywords, references and citations have been surveyed and the evolution and direction of knowledge accumulation in DEA applications in highway TSs have been shown in Figure 5.5.3. Finally, a review of selected papers has presented in Table 5.1.3.

Based on Figure 5.1.1, the most co-occurrence keywords in the published papers are DEA (data envelopment analysis), environmental efficiency, sustainability, highway maintenance and traffic safety. Data envelopment analysis and highway maintenance are two most co-occurrence keywords. By analyzing this figure, the main and hot research directions in DEA applications in highway TSs and research gaps can be identified. Co-authorship network presented in Figure 5.1.2 shows a strong relationship between Cook, Kazakov and Roll, who have focused on DEA applications in highway maintenance problems. Wade Cook has the most co-authorship with other researchers. Based on Figure 5.1.2, authors who are more eager to cooperate with other researchers can be identified and researchers can try to cooperate with them in this field. Figure 5.5.3 represents evolution and direction of knowledge accumulation and Table 5.1.3 shows the literature of DEA applications in highway TSs. Analyzing Figure 5.5.3 and Table 5.1.3 shows that most of the published papers have focused on three main topics: (a) repair and maintenance problems of highways (b) road traffic accidents management (c) the problem of environmental and energy consumption in highway transportation. The first paper has been published by Cook et al. (1990). They studied the maintenance problem in highway TS. This study was developed by Kazakov et al. (1989), Cook et al. (1991) and Roll et al. (1991). Until 2009 the main subject of the researches was repair and maintenance problem, where from 2010 the environmental and safety issues have become more interesting subjects for authors. Rogers and Weber (2011) evaluated the CO2 emissions and fatalities tradeoffs in highway transportation systems. After that Leal et al. (2012) developed their work by considering different environmental factors as inputs and outputs for prioritizing different bioethanol highway transportation modes. The environmental issues in highway TSs still is an interesting topic. Many papers related to this subject have tried to evaluate the existing systems and proposed scenarios/policies by considering CO2 emission and other sustainability factors. Recently do Castelo Gouveia and Clímaco (2018) applied DEA to evaluate fuel tax policies to overcome emission problems in highway TSs. Safety in highway TSs is another topic that recently have attracted many researches attention. The research of Vaziri (2010) was one of the first papers in this area. Their paper studied roadway accidents. This work developed by Egilmez and McAvoy (2013) and Alper et al. (2015) and also is a hot topic .

For future research, studying existing highway transportation systems in specific region, from various perspectives like environmental, economic and social sustainability or user/manager perspectives is an interesting subject and the purpose of the study can be identifying surplus and slacks values, providing solutions to improve the performance and identifying alternative systems.

A lot of papers have used a single-period data set for local TSs, while it seems using secondary datasets such as detailed socioeconomic factors, more accurate and multi-period data set of local, regional and national TSs can lead to better results and more effective policies. Highway/road TSs are the most polluted and energy consumer transportation system, therefore reducing energy consumption and improving environmental performance of these systems, can be the subject of future researches.

Based on road traffic in a lot of cities, issues like traffic enforcement camera locating, traffic light locating, traffic police management and etc. would be new challenging problems which can be surveyed by DEA.

Evaluating newly emerged traffic modes and management strategies/policies such as car sharing for low-income peoples specially in peak times, is an important issue that can be surveyed using DEA. Presentation customized DEA models to evaluate highway TSs and different investment highway transportation projects is another interesting research direction. Also, DEA can be applied to evaluate the effects of economic changes on the performance of highway TSs and other TSs in developing countries.

Many governmental interventions such as fuel tax, fuel price, subsides and public transportation tickets prices can affect the performance of highway TSs significantly. Based on the interventions, number of accidents, traffic volume, emissions and etc., can be reduced or increased. DEA is useful to evaluate these interventions.

Most transportation accidents occur on Highways/roads. How can we reduce the accidents? It can be interesting to answer this question by using DEA. Also highway management and its impacts on systems' performance, is a challenging subject to study. The issue of combined transportation and mode choice in highway transportation are other interested problems to study.

5.2. DEA and air transportation systems

Among the all considered subjects, the highest number of published papers in DEA and transportation field is related to air transportation.

221 published papers have identified and 57 papers were selected for review. The number of papers that have focused on the DEA application in air TSs, is rapidly increasing over the recent years. 97 papers of 221 papers have published in last 5 years. By surveying all identified papers, considered inputs and outputs for evaluating the air TSs by DEA, have presented in Table 5.2.1. Table 5.2.2 presented most cited papers related to DEA applications in air TSs. Also, the maps of most co-occurrence keywords and co-authorship network have been shown in Figure 5.2.1 and Figure 5.2.2, respectively. After surveying title, abstract, keywords, references and citations by using CPM, evolution and direction of knowledge accumulation in DEA applications in air TSs have been shown in Figure 5.2.3. Finally, a review of selected papers has presented in Table 5.2.3.

Based on Figure 5.2.1, the most co-occurrence keywords in the published papers are DEA (data envelopment analysis), technical/operational efficiency, benchmarking, airport and airlines. Data envelopment analysis and airport(s) are two most co-occurrence keywords. By analyzing this figure, the main and hot research directions in DEA applications in air TSs and research gaps can be identified. Investigating the co-authorship network presented in Figure 5.2.2 shows a strong relationship between (Pels, Nijkamp and Rietveld) and (Gitto and Mancuso). Pels, Nijkamp and Rietveld have focused on DEA applications in performance assessing of European airports. Gitto and Mancuso mainly have used MI and bootstrapped DEA to performance evaluation of airports. Adler, Pels, Gitto and Mancuso have more co-authorship with other researchers. Based on Figure 5.2.2, the authors who are more eager to cooperate with other researchers can be identified and authors can try to cooperate with them in this field. Analyzing the evolution and direction of knowledge accumulation presented in Figure 5.2.3 and reviewing the literature of DEA applications in air TSs (Table 5.2.3) show that most of the published papers in this field have focused on five main issues: (a) analyzing the performance of airlines (b) performance assessment of airports (c) the efficiency of air roads (d) cost efficiency and service efficiency of provided services to passengers and cargo transportation (e) analyzing performance of airports and airlines during the time. The first paper has been published by Chan and Sueyoshi (1991), who analyzed the performance of airline industries based on competition and different strategies. Evaluating the performance of airlines still is a hot topic and researchers have considered various modern issues in their analysis such as alliance, technologies and etc. (Kottas and Madas, 2018). First paper about the airport was published by Parker (1999) and still it is an interesting challenge for researchers. Until 2004 the main subjects of the studies were performance analyzing of airline industries/companies and airports. Since 2005 new subjects have been added in the literature. Investigating performance of air routes started by Chiou and Chen (2006) and continued by Lin (2008). In addition to operational efficiency, researchers tried to evaluate technical and economic performance of airlines and airports, too. Barros and Dieke (2008), Barros (2008), Barros and Dieke (2008) and Lam et al. (2009). Recently researchers used multi-period data and combined statistical models and DEA models in their analysis and tried to find a rational relation between effective factors and different efficiency scores of airlines and airports(Liu, 2017; Omrani and Soltanzadeh, 2016; Örkcü et al., 2016).

Large number of papers have studied efficiency changes of airports and airlines during a special time period or before/after a crisis or policy. To analyze the performance of air TSs, MI has been used more than any other models.

For future research, studying existing systems from various perspectives like environmental, economic and social sustainability, and users/managers perspectives is an interesting subject and the purpose of the study can be identifying surplus and slacks values, providing solutions to improve the performance and identifying alternative systems.

Other research directions can be assessing the efficiency of airports in a special region such as a country, continent, union or a company before/after a special event such as a sanctions, revolution, new rules, new aircraft. Also, adding new companies to a set of existing companies during a period can be considered for future research. Customizing DEA models for performance evaluation in air TSs is a challenging but an interesting issue. Also, negative and undesirable inputs/outputs (such as noise, pollution and etc.), have not considered by most of the researches. While undesirable inputs/outputs strongly affect efficiency score and ranks.

Surveying root risks of airports is a new and interesting issue which can be analyzed by DEA. Combining learning algorithms, system dynamic models and DEA for designing an intelligent system would be useful for such studies.

Data in air TSs is not always deterministic; therefore, developing new DEA models or customizing old DEA models for performance evaluation of air TSs in presence of non-deterministic data such as fuzzy numbers, random numbers, or even missing data is another research direction.

Identifying different effective factors on airlines performance, investment and depreciation variables using DEA is a good idea for future researches. Analyzing the effects of different price levels on inputs, outputs and efficiency is a challenge for future studies. Routing for airlines is a crucial issue, therefore optimal routing is an interesting future research for DEA applications in air TSs.

DEA can be applied to explore the effect of alliance membership on the comparative efficiency measure of national or international airlines. Operational, technical and service efficiency of air TSs can be evaluated by DEA. The authors should use DEA models to survey the role of market mechanisms in achieving sustainable targets in air TSs.

Recently, fuel consumption efficiency in air transportation has converted to a critical issue, which can be the subject of various future studies in this field. MI and panel data based DEA models are the most suitable DEA models for these studies.

5.3. DEA, ports and maritime transportation

Ports are one of the most important sectors of commerce and transportation in a country. Productivity of ports and maritime transportation are among the important and complex issues in the contemporary world economy. If international and domestic ports want to identify their advantages/disadvantages and potential opportunities for success and growth in the global competitive environment, it is necessary for them to evaluate their performance in all aspects. Hence efficiency and performance assessment of maritime TSs, especially in the ports, has attracted enormous interest.

157 published papers in DEA applications in evaluation of ports and maritime TSs have identified, then 35 papers were selected for review. As other sections, number of published papers in this section, is rapidly increasing over the recent years. 67 papers of 150 papers have published in last 5 years that shows increasing importance of this subject. Used inputs and outputs for evaluating ports and maritime TSs by DEA, have presented in Table 5.3.1.

Table 5.3.2 presented most cited papers related to DEA applications in ports and maritime TSs. Also, the maps of most co-occurrence keywords and co-authorship network have shown in Figure 5.3.1 and Figure 5.3.2, respectively. After surveying title, abstract, keywords, references and citations by using CPM, evolution and direction of knowledge accumulation in DEA applications in maritime TSs have been shown in Figure 5.3.3. Finally, a review of selected papers has presented in Table 5.3.3.

Based on Figure 5.3.1, the most co-occurrence keywords in the published papers are DEA (data envelopment analysis), container terminals, ports, sea ports, logistic and bootstrap. By analyzing this figure, the main and hot research directions in DEA applications in maritime TSs and research gaps can be identified. Investigating the co-authorship network presented in Figure 5.3.2 shows a strong relationship between Barros and Wanke, which have focused on performance assessing of Brazilian sea ports. Also Barros and Wanke have more co-authorship with other researchers. Based on Figure 5.3.2, authors who are more eager to cooperate with other researchers can be identified and the authors can try to cooperate with them in this field. The results of searches show that more than %70 papers in DEA applications in ports and maritime transportation have published in last 8 years, which introduces this field as one of the hot issues for research. Analyzing the evolution and direction of knowledge accumulation is presented in Figure 5.3.3. Reviewing the literature of DEA applications in ports and maritime TSs (Table 5.3.3) shows that most of the published papers in this field have focused on four main issues: (a) analyzing the performance of international sea ports (b) performance assessment of container terminal ports (c) cost, operational and technical efficiency of ports (d) surveying the effect of private sector participation, governance structure, new investments and infrastructure of ports on performance and efficiency. The first paper has been published by Roll and Hayuth (1993), which was the first paper that had analyzed performance of sea ports. This study developed by Martinez-Budria et al. (1999). Instead of single period data, Martinez-Budria et al. (1999) considered panel data in evaluating Spanish ports performance. Analyzing the performance of seaports from different perspectives is one of the earlier application of DEA and maritime transportation studies, and still is it is one of the hot topic for researchers. From 2002, new problems in maritime TSs considered by some articles such as Itoh (2002). These studied were related to evaluating the performance of container ports. Until 2010 the main subjects of published researches were technical and operational performance analyzing of sea ports and container ports. From 2011 new subjects have been added to the literature including environmental analysis of maritime TSs Bergantino and Musso (2011). Future research could focus on analyzing these three major and perhaps the most important is environmental and international subjects.

For future researches, studying existing systems from various perspectives like environmental, economic and social sustainability is an interesting subject and the purpose of the study can be identifying surplus and slacks values, providing solutions to improve the performance and identifying alternative systems.

In many countries, especially in developing countries, ports and maritime TSs have governmental structure. Therefore, partnership, investment and management of private sector in these countries could be the context of future studies. A large number of papers has studied efficiency changes of ports during a special time period. MI, panel data based DEA models, SFA, regression analysis and bootstrapped DEA model have been used more than any other models. For future researches, efficiency of ports in a special region such as a country, continent, union or a company before/after a special event such as a sanctions, revolution and new rules can be analyzed. Also, adding new companies to a set of existing companies during a period can be considered for future research.

According to the sustainability targets, it must be analyzed how ports can operate efficiently while pursuing diverse sustainable development objectives. Different environmental regulations must be evaluated, and the best policies should be identified. Studying, analyzing and designing combined transportation modes such as rail-maritime transportation is interesting and challenging.

Considering more factors affecting efficiency of maritime TSs as inputs and outputs, will lead to more precise analysis. Identifying more criteria and efficiency measures can be other research direction.

Recently studying the issues related to sustainability, sustainable development and emission reduction in maritime TSs have attracted many researchers. Future direction can focus on these subjects. Analyzing the effects of different management models on the efficiency of maritime TSs using DEA is another suggestion.

In real-world studies, there are a great number of uncertainties. Developing a DEA model for evaluating ports and maritime TSs using uncertain data like as fuzzy DEA model, can be an interesting research direction. Also missing data is an important issue in DEA. Developing a framework to study the performance of maritime TSs in the presence of missing data will be very useful. MI and panel data based DEA models are the most suitable DEA models for these studies.

5.4. DEA and railway transportation

According to Kyoto Protocol, all countries around the world must take actions to reduce their greenhouse gas emissions. Selecting more efficient and eco-friendly TSs is an important action. The rail transportation as one of the greenest and safest TSs has attracted the most countries attention. Due to advantages of railway transportation, studying and improving the efficiency of existing systems, increasing level of service, safety and overall productivity of the system, are the subject of a lot of researches.

74 published papers have identified and 29 papers were selected for review. Such as the previous sections, number of published papers in this section, is rapidly increasing. 34

papers of 74 papers (more than %45) have published in last 5 years that shows the increasing importance of this subject. By surveying the identified papers, used inputs and outputs for evaluating railway TSs by DEA, have presented in Table 5.4.1. Table 5.4.2 presented most cited papers related to DEA applications in railway TSs. Also, maps of most co-occurrence keywords and co-authorship network have shown in Figure 5.4.1 and Figure 5.4.2, respectively. By using CPM, title, abstract, keywords, references and citations have been surveyed and the evolution and direction of knowledge accumulation in DEA applications in railway TSs have been shown in Figure 5.4.3. Finally, a review of selected papers has presented in Table 5.4.3.

Based on Figure 5.4.1, the most co-occurrence keywords in the published papers are DEA (data envelopment analysis), railway(s), freight, passengers and technical efficiency. By analyzing this figure, the main and hot research directions in DEA applications in railway TSs and research gaps can be identified. Investigating the co-authorship network presented in Figure 5.4.2 shows a strong relationship between Yu and Lin, who have focused on environmental and technical efficiency of railways. Also Yu has the most co-authorship with other researchers. Based on Figure 5.4.2, the authors who are more eager to cooperate with other researchers can be identified and the authors can try to cooperate with them in this field. The searches show that more than %60 of papers in DEA applications in railway transportation have published in last 8 years that introduces this field as one of the hot topics for research. Analyzing the evolution and direction of knowledge accumulation presented in Figure 5.4.3 and reviewing the literature of DEA applications in railway TSs (Table 5.4.3) show that most of the published papers in this field have focused on five main issues: (a) analyzing the performance of railway transportation companies in passengers and cargo transporting (b) performance assessment of railway TSs by considering environmental factors (c) Locating of urban railway stations (d) surveying the effect of private sector participation, governance structure, new investments and infrastructure on performance and efficiency (e) studying the trend of efficiency changes during the time using panel data based DEA models and MI. Moesen (1994) published the first paper in this category, then Cowie and Riddington (1996) and Chapin and Schmidt (1999) developed Moesen (1994)'s study. The article of Cowie and Riddington (1996) was a start for evaluating railways performance, while Chapin and Schmidt (1999) encouraged other researches to study railway fright transportation. Until

2003 the main subjects of the researches were fright and railway performance analysis, while from 2004 new subjects have been added in the literature, including environmental analysis (started by Lan and Lin (2005)), safety (started by Noroozzadeh and Sadjadi (2013)), passenger transportation (started by Hilmola (2010)) and site selection (started by Mohajeri and Amin (2010)).

Private sector participation, sustainable development, energy consumption, environmental issues, identifying the surplus and slacks values, providing solutions to improve the performance in railway TSs are interesting subjects which could be some of the research directions.

In many countries, especially in developing countries, railway TSs have governmental structure. SO partnership, investment and management of private sector in these countries could be a context of future studies. Specially analyzing the effects of privatization on performance and efficiency assessment before/after privatization is a challenging research subject.

MI and panel data based DEA models have used more than any other models for studying changes of efficiency during the time. As other future researches directions, assessing the efficiency of railway TSs in a special region such as a country, continent, union or a company before/after of a special event such as sanctions, revolution and new rules in during a period, could be interesting subjects.

Surveying the railway transportation sustainability is an interesting subject. Monitoring and evaluating safety in the railway TSs is an important problem which can be analyzed by DEA. A lot of supply chains use railway TSs to distribute their products. Studying, evaluating and designing efficient railway TSs for better integration of railway TSs and supply chain management are other research directions.

To identify direct causes which leads to inefficiency/efficiency of railway TSs, maybe it will be useful to combine DEA methods with other statistical and non-statistical methods. Considering resilience engineering factors in performance analyzing has attracted attentions. Combing resilience engineering and DEA in transportation will lead to interesting results.

Investigating factors affecting the performance of different part of railway TSs, can be one of the most important applications of DEA. Also, DEA can be applied to analyze different managerial and operational strategies and their effects on railway TS.

Customizing a DEA model for performance evaluation of railway TSs is another research direction. MI and panel data based DEA models ae the most suitable DEA models for these studies. Also, an international evaluating for identifying weaknesses and deficiencies of under assessment systems could be helpful.

5.5. DEA, Eco-design, sustainable development and green issues in transportation

Emissions, energy and fuel consumption of TSs are among most challenging concern of many countries in the world. Due to increasing population growth and demand for transportation, it seems that environmental issues in transportation will be a research priority. DEA can be used as one of the best tools for identifying weaknesses and potential solutions to improve existing systems.

90 published papers in this section have identified and 18 papers have selected for review. 57 papers of 90 identified papers (more than %60) have published in last 5 years that shows papers have focused on the DEA applications in environmental issues of TSs, are rapidly increasing. Considered inputs and outputs for evaluating environmental perspectives of TSs by DEA have presented in Table 5.5.1. Table 5.5.2 presented most cited papers related to DEA applications in environmental issues of TSs. Also, the maps of most co-occurrence keywords and co-authorship network have been shown in Figure 5.5.1 and Figure 5.5.2, respectively. By using CPM, title, abstract, keywords, references and citations have been surveyed and the evolution and direction of knowledge accumulation in DEA applications in environmental issues of TSs have been shown in Figure 5.5.3. Finally, a review of selected papers has been presented in Table 5.5.3.

Based on Figure 5.5.1, the most co-occurrence keywords in the published papers are DEA (data envelopment analysis), transportation, environmental efficiency, lifecycle assessment, sustainable and undesirable outputs. By analyzing this figure, the main and hot research directions in DEA applications in environmental issues of TSs and research gaps can be identified. Investigating the co-authorship network presented in Figure 5.5.2 shows a strong relationship between (Wu, Zhu and Chu) and (Wu and Liang) who have focused on environmental efficiency of Chinese TSs. Also, Wu has more co-authorship with other researchers. Based on Figure 5.5.2, authors who are more eager to cooperate with other researchers can be identified and the authors can try to cooperate with them in this field. Publishing more than %85 of papers in DEA applications for evaluating environmental perspectives of TSs in last 8 years, introduces this field as a hot issue for research. Analyzing the evolution and direction of knowledge accumulation presented in Figure 5.5.3 and reviewing the literature (Table 5.5.3) show that most of the published papers in this field have focused on five main issues: (a) analyzing the environmental performance of different Chinese TSs (b) Repair and maintenance problems of TSs considering environmental factors (c) studying energy efficiency in TSs and identifying weaknesses and potential solution to improve the existing systems (d) surveying the efficiency of TSs by considering and non-considering undesirable outputs and comparing results (e) dynamic environmental efficiency, emission and sustainability analyzing using MI and panel data based DEA models. The first paper has been published by Chan and Sueyoshi (1991). Until 2004, this category was not a favorite category for researchers, but increasing importance of these issues in all industries and countries attracted researchers' attention. Although in the first decade, number of published papers are not significant, from 2010 the highest growth rate of published papers in each of six considered major categories belongs to environmental issues. Especially researches in this field have focused on energy consumption and emission in TSs.

A lot of researches (almost %30) have focused on Chinese TSs, as one of the largest pollution producer countries in the world. Because the results cannot be extended to other countries, similar researches can be done in other countries. Environmental and sustainability performance of TSs have a high correlation with energy consumption level. Analyzing the energy consumption problem in TSs and providing practical suggestions to improve the performance is an important research subject. Developing a DEA model for evaluating the TSs using stochastic and random variables can be an interesting research direction. Also, an international study for comparing the under evaluating systems by green and sustainable TSs in order to identify weaknesses and deficiencies could be helpful.

Analyzing the effects of TSs ownership on the sustainability of these systems is another suggestion for future researches. Governments always try to change the performance of existing TSs to better ones, by applying financial and non-financial policies. Specially they try to reduce emission and improve the sustainability of system. Before any changes, all candidate policies must be evaluated. DEA is a useful tool for this purpose.

5.6. DEA and other transportation researches

In addition to mentioned fields in previous sections, there are some other studies which have focused on the field of DEA applications in TSs. The number of these articles is not high. According to Searching algorithm presented in Section 2, only 86 articles were identified. Based on citation number, rank of journal and novelty of articles, 14 selected papers have reviewed. 53 papers of 86 identified papers have published in last 5 years. Used inputs and outputs in these studies, have presented in Table 5.6.1. Table 5.6.2 presented most cited papers related to DEA applications in environmental issues of TSs. Also, maps of most co-occurrence keywords and co-authorship network have shown in Figure 5.6.1 and Figure 5.6.2, respectively. By using CPM, title, abstract, keywords, references and citations have been surveyed and the evolution and direction of knowledge accumulation in DEA applications in other transportation problems have been shown in Figure 5.6.3. Finally, a review of selected papers has presented in Table 5.6.3.

Based on Figure 5.6.1, the most co-occurrence keywords in the published papers are DEA (data envelopment analysis), public transportation, bus transport, road transport, road safety, urban transit, fundamental analysis. By analyzing this figure, hot research directions in DEA applications in environmental issues of TSs and research gaps can be identified. Investigating co-authorship network presented in Figure 5.6.2 shows a strong relationship between Hermans, Brijs, Shen and Wets who have focused on road safety performance evaluation. Also, Hermans has the most co-authorship with other researchers. Based on Figure 5.6.2, authors who are more to cooperate with other researchers can be identified and the authors can try to cooperate with them in this field. Analyzing the evolution and direction of knowledge accumulation presented in Figure 5.6.3 and searches show that other transportation and DEA researches have focused on eight main issues: (a) Analyzing performance of transportation companies (b) Surveying investment efficiency and transportation projects selection (c) Evaluating efficiency of urban TSs specially bus transportation (d) comparing different TSs (e) Bus lines efficiency (f) Surveying efficiency of transportation networks, supply and demand management in networks (g) Safety in TSs (h) Analyzing the effects of ownership, subsides and etc. on efficiency. Based on data of

54 urban transit companies in France, Kerstens (1996) evaluated technical efficiency of transit companies. This was the first published paper in this category. This work developed by other authors in three different concepts, including urban public TSs evaluation (Costa and Markellos, 1997), investment efficiency and financial problems (Karlaftis, 2003; Rodrigues et al., 2015) and bus industries (Cowie and Asenova, 1999). Although these subjects are still interesting, recently researchers have encountered new challenges. Specially, safety is turned to the most attractive issue since 2011 (Shen et al., 2011).

The trend of recent studies shows safety problem in TSs is one of the most interesting subjects that could be a research direction. Privatization, urban bus transit, subside payment, choosing new facilities, investment and project selection are other interesting research directions.

TSs are known as large systems with a lot of information. Therefore, it will be interesting and challenging to combine big data and data mining technics by DEA. Data of GIS can be a good data set for such analysis.

Analyzing the performance of transportation vehicles, effects of transportation on housing affordability, and designing and evaluating integrated TSs are newly emerged applications of DEA in TSs.

6. Conclusions and direction for future research

TSs as one of the largest energy consumers and polluter sectors are among the most important and necessary mankind needs. Therefore, evaluating, management and planning TSs is very important. DEA has used widely in performance assessing, studying changes in efficiency, identifying advantages and disadvantages to improve existing systems and etc.

In this paper a literature review and classification of DEA applications in TSs has been presented. First DEA models which have widely used in evaluating performance of TSs, were introduced. Then applications of DEA in the TSs have been studied in six different contexts. More than 600 papers were identified and surveyed and published papers in each context, were analyzed and reviewed deeply. A review of more than 170 selected papers was presented. Comparing the reviewed papers and presented CPMs in six categories shows some interesting facts:

- Based on the CPMs, highway is the oldest category, but articles related to air TSs cover more subjects.
- Analyzing the trend of more than 600 studies shows that about 80% of articles have been published in last 10 years which demonstrate increasing importance of this field over recent years.
- The highest number of published papers is related to air transportation (221 articles), while studies related to the highway TSs have the lowest proportion of studies.
- Although wide range of problems have been studied in each category, the environmental issues are the most important common problems in all categories. In the 90s, and early 21th century, environmental issues were not hot subjects for authors. But by increasing anxiety about the global warming and GHG emission and the significate effects of TSs on these problems, many researchers have been encouraged to consider environmental issues in their studies. More than 59% of environmental related articles have been published in last 5 years and today this topic is the hottest one in DEA applications in TSs.
- It seems that most of environmental articles focus on land TSs (railway and highway TSs).
- Studying the environmental issues, analyzing the effective factors on efficiency e.g. ownership, subsides, population and local factors, efficiency changes during the time and before/after a policy or change, investment and project selection, repair and maintenance are some of the interesting research directions.

We believe that presented taxonomy, review and research gaps in this paper can highlight different research directions for future researches and are an inspiration for new studies in the field of DEA applications in TSs.

Online Supplement document

Full list of more than 600 selected published papers on DEA applications in transportation systems is provided in the supplement document.

References

4flow, 2017. Transportation cost reduction, http://www.4flow.de/en/supply-chain-consulting/transportation-and-networks/transportation-cost-reduction.html.

Adler, N., Berechman, J., 2001. Measuring airport quality from the airlines' viewpoint: an application of data envelopment analysis. Transport Policy 8, 171-181.

Adler, N., Golany, B., 2001. Evaluation of deregulated airline networks using data envelopment analysis combined with principal component analysis with an application to Western Europe. European Journal of Operational Research 132, 260-273.

Alper, D., Sinuany-Stern, Z., Shinar, D., 2015. Evaluating the efficiency of local municipalities in providing traffic safety using the Data Envelopment Analysis. Accident Analysis and Prevention 78, 39-50.

Andersen, P., Petersen, N.C., 1993. A procedure for ranking efficient units in data envelopment analysis. Management science 39, 1261-1264.

Azadeh, A., Ghaderi, S.F., Izadbakhsh, H., 2008. Integration of DEA and AHP with computer simulation for railway system improvement and optimization. Applied Mathematics and Computation 195, 775-785.

Azadeh, A., Salehi, V., Kianpour, M., 2016. Performance evaluation of rail transportation systems by considering resilience engineering factors: Tehran railway electrification system. Transportation Letters, 1-14.

Azadi, M., Shabani, A., Khodakarami, M., Saen, R.F., 2014. Planning in feasible region by two-stage target-setting DEA methods: An application in green supply chain management of public transportation service providers. Transportation Research Part E: Logistics and Transportation Review 70, 324-338.

Banker, R.D., 1984. Estimating most productive scale size using data envelopment analysis. European Journal of Operational Research 17, 35-44.

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

Banker, R.D., Morey, R.C., 1986. Efficiency analysis for exogenously fixed inputs and outputs. Operations research 34, 513-521.

Barros, C.P., 2006. A benchmark analysis of Italian seaports using data envelopment analysis. Maritime Economics & Logistics 8, 347-365.

Barros, C.P., 2008. Airports in Argentina: Technical efficiency in the context of an economic crisis. Journal of Air Transport Management 14, 315-319.

Barros, C.P., Athanassiou, M., 2004. Efficiency in European seaports with DEA: evidence from Greece and Portugal. Maritime Economics & Logistics 6, 122-140.

Barros, C.P., Dieke, P.U., 2007. Performance evaluation of Italian airports: A data envelopment analysis. Journal of Air Transport Management 13, 184-191.

Barros, C.P., Dieke, P.U., 2008. Measuring the economic efficiency of airports: a Simar–Wilson methodology analysis. Transportation Research Part E: Logistics and Transportation Review 44, 1039-1051.

Barros, C.P., Peypoch, N., 2009. An evaluation of European airlines' operational performance. International Journal of Production Economics 122, 525-533.

Bazargan, M., Vasigh, B., 2003. Size versus efficiency: a case study of US commercial airports. Journal of Air Transport Management 9, 187-193.

Bergantino, A.S., Musso, E., 2011. The role of external factors versus managerial ability in determining seaports relative efficiency: An input-by-input analysis through a multi-step approach on a panel of Southern European ports. Maritime Economics and Logistics 13, 121-141.

Chan, P.S., Sueyoshi, T., 1991. Environmental change, competition, strategy, structure and firm performance: an application of data envelopment analysis in the airline industry. International Journal of Systems Science 22, 1625-1636.

Chang, Y.-T., Park, H.K., Lee, S., Kim, E., 2018. Have Emission Control Areas (ECAs) harmed port efficiency in Europe? Transportation Research Part D: Transport and Environment 58, 39-53.

Chang, Y.-T., Zhang, N., Danao, D., Zhang, N., 2013. Environmental efficiency analysis of transportation system in China: A non-radial DEA approach. Energy policy 58, 277-283.

Chapin, A., Schmidt, S., 1999. Do mergers improve efficiency? Evidence from deregulated rail freight. Journal of Transport Economics and Policy, 147-162.

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. European journal of operational research 2, 429-444.

Chen, C., Achtari, G., Majkut, K., Sheu, J.-B., 2017. Balancing equity and cost in rural transportation management with multi-objective utility analysis and data envelopment analysis: A case of Quinte West. Transportation Research Part A: Policy and Practice 95, 148-165.

Chen, C.C., 2014. The Operation Of New Transportation Infrastructure And Regional Economic Efficiency: A Case Study Of High Speed Rail In Western Taiwan. Regional and Sectoral Economic Studies 14, 179-194.

Chen, Y., Han, B., 2012. Regional public transportation scheduling model based on welfare economics and DEA. International Journal of Modelling, Identification and Control 16, 272-276.

Chiou, Y.-C., Chen, Y.-H., 2006. Route-based performance evaluation of Taiwanese domestic airlines using data envelopment analysis. Transportation Research Part E: Logistics and Transportation Review 42, 116-127.

Chu, J.-F., Wu, J., Song, M.-L., 2016. An SBM-DEA model with parallel computing design for environmental efficiency evaluation in the big data context: a transportation system application. Annals of Operations Research, 1-20.

Coelli, T., Perelman, S., 1999. Comparison of parametric and non-parametric distance functions: With application to European railways. European Journal of Operational Research 117, 326-339.

Cook, W.D., Kazakov, A., Roll, Y., Seiford, L.M., 1991. A data envelopment approach to measuring efficiency: case analysis of highway maintenance patrols. The Journal of Socio-Economics 20, 83-103.

Cook, W.D., Roll, Y., Kazakov, A., 1990. A Dea Model For Measuring The Relative Eeficiency Of Highway Maintenance Patrols. INFOR: Information Systems and Operational Research 28, 113-124.

Costa, Á., Markellos, R.N., 1997. Evaluating public transport efficiency with neural network models. Transportation Research Part C: Emerging Technologies 5, 301-312.

Cowie, J., Asenova, D., 1999. Organisation form, scale effects and efficiency in the British bus industry. Transportation 26, 231-248.

Cowie, J., Riddington, G., 1996. Measuring the efficiency of European railways. Applied Economics 28, 1027-1035.

Cruijssen, F., Dullaert, W., Joro, T., 2010. Freight transportation efficiency through horizontal cooperation in Flanders. International Journal of Logistics: Research and Applications 13, 161-178.

Cui, Q., Li, Y., 2014. The evaluation of transportation energy efficiency: An application of three-stage virtual frontier DEA. Transportation Research Part D: Transport and Environment 29, 1-11.

Cullinane, K., Ji, P., Wang, T.-f., 2005a. The relationship between privatization and DEA estimates of efficiency in the container port industry. Journal of economics and business 57, 433-462.

Cullinane, K., Song, D.-W., Wang, T., 2005b. The application of mathematical programming approaches to estimating container port production efficiency. Journal of Productivity Analysis 24, 73-92.

Cullinane, K., Wang, T.-F., Song, D.-W., Ji, P., 2006. The technical efficiency of container ports: comparing data envelopment analysis and stochastic frontier analysis. Transportation Research Part A: Policy and Practice 40, 354-374.

Debreu, G., 1951. The coefficient of resource utilization. Econometrica: Journal of the Econometric Society, 273-292.

do Castelo Gouveia, M., Clímaco, I., 2018. Assessment of Fuel Tax Policies to Tackle Carbon Emissions from Road Transport—An Application of the Value-Based DEA Method Including Robustness Analysis, Energy Management—Collective and Computational Intelligence with Theory and Applications. Springer, pp. 167-191.

Doyle, J., Green, R., 1994. Efficiency and cross-efficiency in DEA: Derivations, meanings and uses. Journal of the operational research society 45, 567-578.

ECT, 2007. Environment Canada "Transportation", https://web.archive.org/web/20070713192836/http://www.ec.gc.ca/cleanair-airpur/Transportation-WS800CCAF9-1_En.htm, p. Retrieved 30 July 2008.

Egilmez, G., McAvoy, D., 2013. Benchmarking road safety of US states: A DEA-based Malmquist productivity index approach. Accident Analysis & Prevention 53, 55-64.

Emrouznejad, A., Marra, M., 2014. Ordered weighted averaging operators 1988–2014: A citation-based literature survey. International Journal of Intelligent Systems 29, 994-1014.

Emrouznejad, A., Marra, M., 2017. The state of the art development of AHP (1979–2017): a literature review with a social network analysis. International Journal of Production Research, 1-23.

Emrouznejad, A., Yang, G.-l., 2017. A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. Socio-Economic Planning Sciences.

Fernandes, E., Pacheco, R., 2002. Efficient use of airport capacity. Transportation research part A: Policy and practice 36, 225-238.

Fuglestvedt, J., Berntsen, T., Myhre, G., Rypdal, K., Skeie, R.B., 2008. Climate forcing from the transport sectors. Proceedings of the National Academy of Sciences 105, 454-458.

González, M.M., Trujillo, L., 2009. Efficiency measurement in the port industry: A survey of the empirical evidence. Journal of Transport Economics and Policy (JTEP) 43, 157-192.

Hilmola, O.-P., 2007. European railway freight transportation and adaptation to demand decline: Efficiency and partial productivity analysis from period of 1980-2003. International Journal of Productivity and Performance Management 56, 205-225.

Hilmola, O.-P., 2009. Benchmarking global railway freight transportation efficiency during the period of 1980-2004. International Journal of Shipping and Transport Logistics 1, 311-328.

Hilmola, O.P., 2010. Analysing global railway passenger transport through two-staged efficiency model. International Journal of Information and Decision Sciences 2, 273-284.

IPCC, 2017. Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/ar5/wg3/.

Itoh, H., 2002. Effeciency changes at major container ports in Japan: A window application of data envelopment analysis. Review of urban & regional development studies 14, 133-152.

Jitsuzumi, T., Nakamura, A., 2010. Causes of inefficiency in Japanese railways: Application of DEA for managers and policymakers. Socio-Economic Planning Sciences 44, 161-173.

Karlaftis, M.G., 2003. Investigating transit production and performance: A programming approach. Transportation Research Part A: Policy and Practice 37, 225-240.

Karlaftis, M.G., 2004. A DEA approach for evaluating the efficiency and effectiveness of urban transit systems. European Journal of Operational Research 152, 354-364.

Kazakov, A., Cook, W.D., Roll, Y., 1989. Measurement of highway maintenance patrol efficiency: model and factors. Transportation Research Record.

Kerstens, K., 1996. Technical efficiency measurement and explanation of french urban transit companies. Transportation Research Part A: Policy and Practice 30, 431-452.

Kleinová, E., 2016. Does liberalization of the railway industry lead to higher technical effectiveness? Journal of Rail Transport Planning & Management 6, 67-76.

Kottas, A.T., Madas, M.A., 2018. Comparative efficiency analysis of major international airlines using Data Envelopment Analysis: Exploring effects of alliance membership and other operational efficiency determinants. Journal of Air Transport Management 70, 1-17.

Lam, S.W., Low, J.M.W., Tang, L.C., 2009. Operational efficiencies across Asia Pacific airports. Transportation Research Part E: Logistics and Transportation Review 45, 654-665.

Lan, L.W., Lin, E.T.J., 2005. Measuring railway performance with adjustment of environmental effects, data noise and slacks. Transportmetrica 1, 161-189.

Leal, I.C., de Almada Garcia, P.A., Márcio de Almeida, D.A., 2012. A data envelopment analysis approach to choose transport modes based on eco-efficiency. Environment, development and sustainability 14, 767-781.

Li, Z., Zhao, L., Yuan, Z., 2016. Highway Transportation Efficiency Evaluation for Beijing-Tianjin-Hebei Region Based on Advanced DEA Model. International review for spatial planning and sustainable development 4, 36-44.

Lin, E.T.J., 2008. Route-based performance evaluation of Taiwanese domestic airlines using data envelopment analysis: A comment. Transportation Research Part E: Logistics and Transportation Review 44, 894-899.

Liu, D., 2017. Evaluating the multi-period efficiency of East Asia airport companies. Journal of Air Transport Management 59, 71-82.

Liu, H., Zhang, Y., Zhu, Q., Chu, J., 2017. Environmental efficiency of land transportation in China: A parallel slack-based measure for regional and temporal analysis. Journal of Cleaner Production 142, 867-876.

Liu, Z., 1995. The comparative performance of public and private enterprises: the case of British ports. Journal of Transport Economics and Policy, 263-274.

Martín, J.C., Román, C., 2001. An application of DEA to measure the efficieny of Spanish airports prior to privatization. Journal of Air Transport Management 7, 149-157.

Martinez-Budria, E., Diaz-Armas, R., Navarro-Ibanez, M., Ravelo-Mesa, T., 1999. A study of the efficiency of Spanish port authorities using data envelopment analysis. International Journal of Transport Economics/Rivista internazionale di economia dei trasporti, 237-253.

Michaelides, P.G., Belegri-Roboli, A., Karlaftis, M., Marinos, T., 2009. International air transportation carriers: evidence from SFA and DEA technical efficiency results (1991-2000). EJTIR 4.

Min, H., Joo, S.-J., 2016. A comparative performance analysis of airline strategic alliances using data envelopment analysis. Journal of Air Transport Management 52, 99-110.

Moesen, W.A., 1994. The need for performance auditing in the public sector and the best-practice frontier. European Journal of Law and Economics 1, 263-274.

Mohajeri, N., Amin, G.R., 2010. Railway station site selection using analytical hierarchy process and data envelopment analysis. Computers & Industrial Engineering 59, 107-114.

Murillo-Melchor, C., 1999. An analysis of technical efficiency and productivity changes in Spanish airports using the Malmquist index. International Journal of Transport Economics 26, 271-292.

Noroozzadeh, A., Sadjadi, S., 2013. A new approach to evaluate railways efficiency considering safety measures. Decision Science Letters 2, 71-80.

Notteboom, T., Coeck, C., Van Den Broeck, J., 2000. Measuring and explaining the relative efficiency of container terminals by means of Bayesian stochastic frontier models. International journal of maritime economics 2, 83-106.

Novaes, A.G., Silveira, S.F., Medeiros, H.C., 2010. Efficiency and productivity analysis of the interstate bus transportation industry in Brazil. Pesquisa Operacional 30, 465-485.

Omrani, H., Soltanzadeh, E., 2016. Dynamic DEA models with network structure: An application for Iranian airlines. Journal of Air Transport Management 57, 52-61.

Örkcü, H.H., Balıkçı, C., Dogan, M.I., Genç, A., 2016. An evaluation of the operational efficiency of turkish airports using data envelopment analysis and the Malmquist productivity index: 2009–2014 case. Transport Policy 48, 92-104.

Park, R.-K., De, P., 2004. An alternative approach to efficiency measurement of seaports. Maritime Economics & Logistics 6, 53-69.

Parker, D., 1999. The performance of BAA before and after privatisation a DE a study. Journal of Transport Economics and Policy 33, 133-146.

Pels, E., Nijkamp, P., Rietveld, P., 2001. Relative efficiency of European airports. Transport Policy 8, 183-192.

Pels, E., Nijkamp, P., Rietveld, P., 2003. Inefficiencies and scale economies of European airport operations. Transportation Research Part E: Logistics and Transportation Review 39, 341-361.

Rassafi, A., Vaziri, M., 2007. Assessment of modal transportation sustainability: application of data envelopment and concordance analyses. Iranian Journal of Science and Technology 31, 179.

Rezaee, M.J., Izadbakhsh, H., Yousefi, S., 2016. An improvement approach based on DEA-game theory for comparison of operational and spatial efficiencies in urban transportation systems. KSCE Journal of Civil Engineering 20, 1526-1531.

Rodrigues, M.M., Hein, N., Wilhelm, V.E., Kroenke, A., 2015. Impact of convergence to IFRS on the economic and financial performance of construction and transportation enterprises: A study conducted through data envelopment analysis. Applied Mathematical Sciences 9, 4499-4521.

Rogers, M.M., Weber, W.L., 2011. Evaluating CO2 emissions and fatalities tradeoffs in truck transport. International Journal of Physical Distribution and Logistics Management 41, 750-767.

Roll, Y., Cook, W.D., Golany, B., 1991. Controlling factor weights in data envelopment analysis. IIE Transactions (Institute of Industrial Engineers) 23, 2-9.

Roll, Y., Hayuth, Y., 1993. Port performance comparison applying data envelopment analysis (DEA). Maritime Policy and Management 20, 153-161.

Sampaio, B.R., Neto, O.L., Sampaio, Y., 2008. Efficiency analysis of public transport systems: Lessons for institutional planning. Transportation research part A: policy and practice 42, 445-454.

Sarkis, J., 2000a. Analysis of the operational efficiency of major airports in the United States. Journal of Operations Management 18, 335-351.

Sarkis, J., 2000b. An analysis of the operational efficiency of major airports in the United States. Journal of Operations management 18, 335-351.

Sarkis, J., Talluri, S., 2004. Performance based clustering for benchmarking of US airports. Transportation Research Part A: Policy and Practice 38, 329-346.

Savolainen, V.-V., Hilmola, O.-P., 2009. The relative technical efficiency of European transportation systems concerning air transport and railways. International Journal of Business Performance Management 11, 19-42.

Schefczyk, M., 1993. Operational performance of airlines: an extension of traditional measurement paradigms. Strategic Management Journal 14, 301-317.

SEPA, 2017. States Environmental Protection Agency, https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014United

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

Simar, L., Wilson, P.W., 1998. Sensitivity analysis of efficiency scores: How to bootstrap in nonparametric frontier models. Management science 44, 49-61.

Simar, L., Wilson, P.W., 2007. Estimation and inference in two-stage, semi-parametric models of production processes. Journal of econometrics 136, 31-64.

Söderberg, M., 2009. A BROAD PERFORMANCE BENCHMARK BASED ON CITIZENS'PREFERENCES: THE CASE OF SWEDISH PUBLIC TRANSPORTATION. Annals of Public and Cooperative Economics 80, 579-603.

Song, M., Zheng, W., Wang, Z., 2016. Environmental efficiency and energy consumption of highway transportation systems in China. International Journal of Production Economics 181, 441-449.

Song, X., Hao, Y., Zhu, X., 2015. Analysis of the environmental efficiency of the Chinese transportation sector using an undesirable output slacks-based measure data envelopment analysis model. Sustainability 7, 9187-9206.

Su, J., Rogers, M.M., 2012. The role of economic variables and CO2 emissions in examining the efficiency of National Transportation Systems. International Journal of Sustainable Transportation 6, 48-66.

Sun, D., Chen, S., Zhang, C., Shen, S., 2016. A bus route evaluation model based on GIS and super-efficient data envelopment analysis. Transportation Planning and Technology 39, 407-423.

Sun, L., Rong, J., Yao, L., 2010. Measuring transfer efficiency of urban public transportation terminals by data envelopment analysis. Journal of urban planning and development 136, 314-319.

Tamaki, T., Nakamura, H., Fujii, H., Managi, S., 2016. Efficiency and emissions from urban transport: Application to world city-level public transportation. Economic Analysis and Policy.

Tone, K., 2001. A slacks-based measure of efficiency in data envelopment analysis. European journal of operational research 130, 498-509.

Tongzon, J., 2001. Efficiency measurement of selected Australian and other international ports using data envelopment analysis. Transportation Research Part A: Policy and Practice 35, 107-122.

Turner, H., Windle, R., Dresner, M., 2004. North American containerport productivity: 1984–1997. Transportation Research Part E: Logistics and Transportation Review 40, 339-356.

Vaidya, O.S., 2014. Evaluating the Performance of Public Urban Transportation Systems in India. Journal of Public Transportation 17, 11.

Vaziri, M., 2010. A comparative appraisal of roadway accident for Asia-Pacific countries. International Journal of Engineering, Transactions A: Basics 23, 111-126.

Wang, T.-F., Cullinane, K., 2006. The efficiency of European container terminals and implications for supply chain management. Maritime Economics & Logistics 8, 82-99.

Wang, Z., He, W., 2017. CO 2 emissions efficiency and marginal abatement costs of the regional transportation sectors in China. Transportation Research Part D: Transport and Environment 50, 83-97.

Wanke, P., Barros, C., Figueiredo, O., 2016. Efficiency and productive slacks in urban transportation modes: A two-stage SDEA-Beta Regression approach. Utilities Policy 41, 31-39.

WHO, 2016. World Health Organization: Road traffic injuries. http://www.who.int/mediacentre/factsheets/fs358/en/, p. Road traffic injuries.

Wu, J., Chu, J., An, Q., Sun, J., Yin, P., 2016a. Resource reallocation and target setting for improving environmental performance of DMUs: An application to regional highway transportation systems in China. Transportation Research Part D: Transport and Environment.

Wu, J., Zhu, Q., Chu, J., Liu, H., Liang, L., 2016b. Measuring energy and environmental efficiency of transportation systems in China based on a parallel DEA approach. Transportation Research Part D: Transport and Environment 48, 460-472.

Wu, Y.-C.J., Goh, M., 2010. Container port efficiency in emerging and more advanced markets. Transportation Research Part E: Logistics and Transportation Review 46, 1030-1042.

Yu, M.-M., Lin, E.T., 2008. Efficiency and effectiveness in railway performance using a multi-activity network DEA model. Omega 36, 1005-1017.

Yu, M.M., 2010. Assessment of airport performance using the SBM-NDEA model. Omega 38, 440-452.

Zhang, N., Wei, X., 2015. Dynamic total factor carbon emissions performance changes in the Chinese transportation industry. Applied Energy 146, 409-420.

Zhang, N., Zhou, P., Kung, C.-C., 2015. Total-factor carbon emission performance of the Chinese transportation industry: A bootstrapped non-radial Malmquist index analysis. Renewable and Sustainable Energy Reviews 41, 584-593.

Zhao, Y., Triantis, K., Murray-Tuite, P., Edara, P., 2011. Performance measurement of a transportation network with a downtown space reservation system: A network-DEA approach. Transportation Research Part E: Logistics and Transportation Review 47, 1140-1159.

Table 1. Searching Algorithm to select papers for review.

Algorithm:
#1. "Transportation" [Article title, Abstract, Keywords]
#2. "Highway Transportation" [Article title, Abstract, Keywords]
#3. "Airport" [Article title, Abstract, Keywords]
#4. "Airline" [Article title, Abstract, Keywords]
#5. "Air transportation" [Article title, Abstract, Keywords]
#6. "Maritime" [Article title, Abstract, Keywords]
#7. "Ports" [Article title, Abstract, Keywords]
#8. "Railway Transportation" [Article title, Abstract, Keywords]
#9. "Sustainable development" [Article title, Abstract, Keywords]
#10. "Eco-design" [Article title, Abstract, Keywords]
#11. "Emission" [Article title, Abstract, Keywords]
#12. "Data envelopment analysis" [Article title, Abstract, Keywords]
#13. "Source Type": [Journal]
#14. "Document Type": [Article] AND [Article in Press] AND [Review]
#15. "Article Language": [English]
#16. "Year": [2007-2018]
#17. Survey the article title and abstract, full text, Identify and filter related and suitable papers.
#18. For section 3: #1 AND #12 AND #13 AND #14 AND #15 AND #16 AND #17
#19. For section 5: #2 AND #12 AND #13 AND #14 AND #15 AND #17
#20. For section 6: #3 OR #4 OR #5 AND #12 AND #13 AND #14 AND #15 AND #17
#21. For section 7: #6 OR #7 AND #12 AND #13 AND #14 AND #15 AND #17
#22. For section 8: #8 AND #12 AND #13 AND #14 AND #15 AND #17
#23. For section 9: #9 OR #10 OR #11 AND #12 AND #13 AND #14 AND #15 AND #17
#24. For section 10: #1 AND #12 AND #13 AND #14 AND #15 AND #17 NOT #2 NOT #3 NOT #4 NOT #5 NOT #6 NOT #7 NOT #8 NOT #9 NOT #10 NOT #11
#25. For section 4: Put all identified papers in steps 18-24, in a set

Table 2. Common DEA models used in TSs in most cited papers published in 2007-2018.

Ref.	Model	Transport subject	Ref.	Model	Transport subject
Rassafi and Vaziri (2007)	BCC	Road, air, Rail, Sea	Cui and Li (2014)	Three-stage virtual frontier DEA	Transportation energy
Hilmola (2007)	CCR	Railway	Song et al. (2015)	SBM	Environmental efficiency of transportation
Barros and Dieke (2008)	CCR/BCC	Airport	Zhang and Wei (2015)	A combined metafrontier approach and DEA	Environmental efficiency of transportation
Sampaio et al. (2008)	BCC	Public transportation	Zhang et al. (2015)	A combined metafrontier approach and DEA, Malmquist index	Environmental efficiency of transportation
Hilmola (2009)	CCR	Railway	Kleinová (2016)	CCR	Railway
Söderberg (2009)	BCC	Public transportation	Wu et al. (2016a)	CCR	Highway
Savolainen and Hilmola (2009)	CCR	Air transport and railways	Wu et al. (2016b)	CCR/parallel DEA approach	Energy and environmental efficiency of transportation
Michaelides et al. (2009)	CCR	International air transportation	Min and Joo (2016)	CCR	Airlines
Cruijssen et al. (2010)	CCR/BCC	Road transportation	Song et al. (2016)	SBM	Railway
Sun et al. (2010)	SBM	Urban Public Transportation Terminals	Li et al. (2016)	CCR	Highway
Novaes et al. (2010)	CCR/BCC	Interstate bus transportation industry	Sun et al. (2016)	Super-efficient DEA	Bus route evaluation
Jitsuzumi and Nakamura (2010)	BCC	Railway	Wanke et al. (2016)	Two-stage Stochastic DEA	Urban transportation mode
Wu and Goh (2010)	CCR/BCC	Ports	Azadeh et al. (2016)	BCC	Railway
Zhao et al. (2011)	NDEA: radial, SBM	Down town space reservation system	Chu et al. (2016)	SBM	Environmental efficiency of transportation
Chen and Han (2012)	CCR	Regional public transport	Tamaki et al. (2016)	CCR	Urban public transportation
Su and Rogers (2012)	CCR	National Transportation Systems	Rezaee et al. (2016)	Game-DEA	Urban public transportation
Chang et al. (2013)	SBM	Regional transport sector	Liu et al. (2017)	SBM	Railway and road
Vaidya (2014)	CCR	Public urban transportation	Chen et al. (2017)	CCR	Rural transportation
Chen (2014)	CCR/BCC	Railway	Wang and He (2017)	BCC	Environmental efficiency, provincial transportation system
Azadi et al. (2014)	Goal-directed two-stage DEA	public transportation service providers	Chang et al. (2018)	SBM	Environmental efficiency of transportation

Table 3. First 30 most cited papers.

Article	Citation Value	Article	Citation Value
Tongzon (2001)	312	Pels et al. (2001)	129
Cullinane et al. (2006)	281	Sarkis and Talluri (2004)	126
Coelli and Perelman (1999)	278	Turner et al. (2004)	126
Roll et al. (1991)	219	Wang and Cullinane (2006)	126
Roll and Hayuth (1993)	192	Fernandes and Pacheco (2002)	124
Adler and Golany (2001)	191	Cullinane et al. (2005a)	119
Sarkis (2000a)	186	Cullinane et al. (2005b)	119
Adler and Berechman (2001)	162	Barros and Peypoch (2009)	114
Barros and Athanassiou (2004)	162	Bazargan and Vasigh (2003)	114
Yu and Lin (2008)	160	Barros and Dieke (2008)	110
Schefczyk (1993)	158	Park and De (2004)	105
Pels et al. (2003)	155	Kerstens (1996)	102
Martín and Román (2001)	155	Barros and Dieke (2007)	101
Martinez-Budria et al. (1999)	147	Azadeh et al. (2008)	101
Parker (1999)	146	Cowie and Asenova (1999)	94

Table 4. Top 13 most active authors.

Article	Number of published papers	Article	Number of published papers
Yu, M.M.	19	Merkert, R	8
Barros, C.P.	12	Triantis, K.	8
Wanke, P.	10	Azadeh, A.	7
Chang, Y.T.	10	Cullinane, K	7
Wu, J.	10	Odeck, J.	7
Hilmola, O.P.	9	Lozano, S.	7
Cook, W.D.	9		

Table 5. Most active journals.

Section	journal	Number of published papers
Highway TSs	Accident Analysis And Prevention	4
	European Journal Of Operational Research	4
	Benchmarking / IIE Transactions Institute Of Industrial Engineers / Journal Of Civil Engineering And Management / Journal Of Productivity Analysis / Journal Of Public Procurement / Journal Of The Operational Research Society	2
Air TSs	Journal Of Air Transport Management	56
	Transportation Research Part A Policy And Practice	18
	Transportation Research Part E Logistics And Transportation Review	11
	European Journal Of Operational Research / International Journal Of Transport Economics	7
Maritime TSs	Maritime Economics And Logistics	22
	Maritime Policy And Management	14
	International Journal Of Shipping And Transport Logistics / International Journal Of Transport Economics	10
	Transportation Research Part A Policy And Practice	7
Railway TSs	Benchmarking / Journal Of Transport Economics And Policy	3
	International Journal Of Productivity And Performance Management / Journal Of Rail Transport Planning And Management / Socio Economic Planning Sciences / Transport / Transportation Research Part A Policy And Practice / Transportation Research Part E Logistics And Transportation Review	2
Green issues	Transportation Research Part D Transport And Environment	9
	Sustainability Switzerland	8
	Journal Of Air Transport Management	6
	Journal of cleaner production	4
Other issues	Transportation Research Part A Policy And Practice	9
	Transportation Research Part E Logistics And Transportation Review	6
	Socio-Economic Planning Science	4
Overall	Journal Of Air Transport Management	57
	Transportation Research Part A Policy And Practice	38
	Maritime Economics And Logistics	24
	Transportation Research Part E Logistics And Transportation Review	23
	International Journal Of Transport Economics	18

Table 6. Top countries that have published most papers in DEA applications in TSs.

Country	Number of published paper	Country	Number of published paper
United States	109	Spain	38
China	109	United Kingdom	38
Taiwan	58	Brazil	38
South Korea	47	Canada	30
Iran	43	Australia	30

Table 7. Frequency of the keywords across the DEA and TSs literature.

Section	keywords	Frequency	keywords	Frequency
Highway TSs	Data Envelopment Analysis	50	Roads And Streets	14
	Transportation	18	Decision Making	11
	Efficiency	18	Motor Transportation	11
Air TSs	Data Envelopment Analysis	177	Efficiency	62
	Air Transportation	83	Airline Industry	54
	Airport	79	Technical Efficiency	45
Maritime TSs	Data Envelopment Analysis	119	Port Operation	34
	Efficiency	52	Ports And Harbors	23
	DEA	40	Efficiency Measurement	22
Railway TSs	Data Envelopment Analysis	51	Railway Transport	20
	Efficiency	29	Railroad transportation	17
	Railroads	25	Railways	16
Green issues	Data Envelopment Analysis	75	China	19
	Transportation	24	Sustainable development	19
	Efficiency	21	Efficiency Measurement	16
Other issues	Data Envelopment Analysis	73	Decision Making	17
	Efficiency	33	Performance Assessment	15
	DEA	19	Transportation	13
Overall	Data Envelopment Analysis	491	Technical Efficiency	80
	Efficiency	193	Air Transportation	80
	DEA	114	Airport	79

Table 8. Most co-cited papers.

Article	Co-cited value	Article	Co-cited value
Charnes et al. (1978)	159	González and Trujillo (2009)	10
Banker et al. (1984)	106	Tone (2001)	9
Martinez-Budria et al. (1999)	24	Simar and Wilson (1998)	9
Schefczyk (1993)	24	Banker (1984)	9
Roll and Hayuth (1993)	19	Itoh (2002)	9
Simar and Wilson (2007)	18	Yu (2010)	9
Banker and Morey (1986)	18	Liu (1995)	9
Barros and Athanassiou (2004)	18	Sarkis and Talluri (2004)	9
Pels et al. (2001)	18	Doyle and Green (1994)	8
Sarkis (2000b)	17	Bazargan and Vasigh (2003)	8
Martín and Román (2001)	17	Barros (2006)	8
Andersen and Petersen (1993)	13	Pels et al. (2003)	8
Tongzon (2001)	10	Murillo-Melchor (1999)	8
Karlaftis (2004)	10	Notteboom et al. (2000)	8
Debreu (1951)	10		

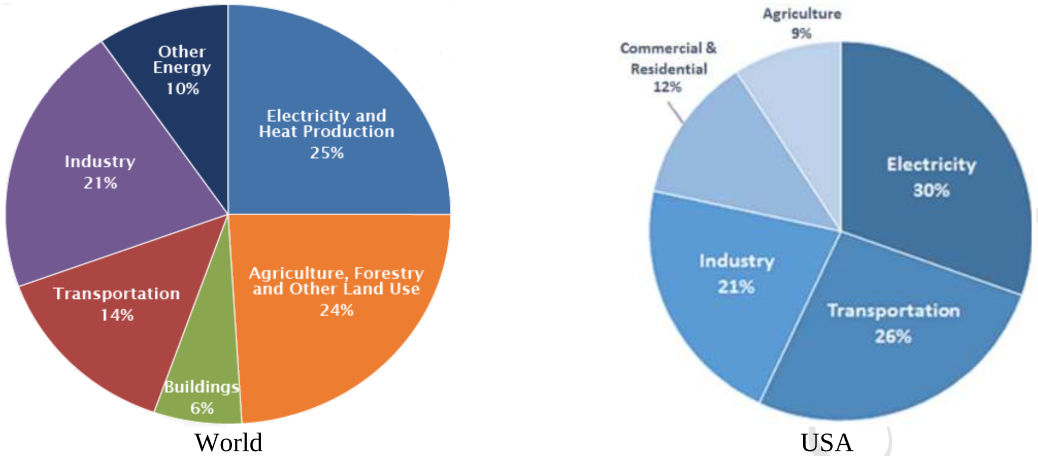


Figure 1. The contribution of different sectors impact on released pollution in the world and USA.

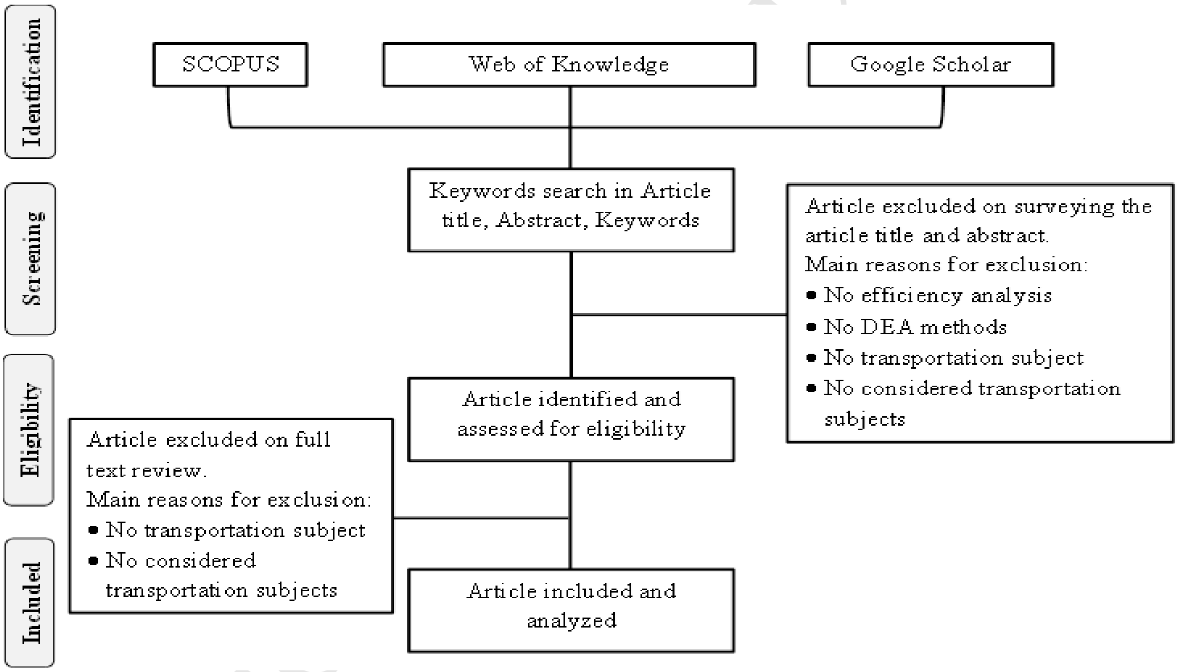


Figure 2. The PRISMA statement for systematic search, reviews and meta-analyses.

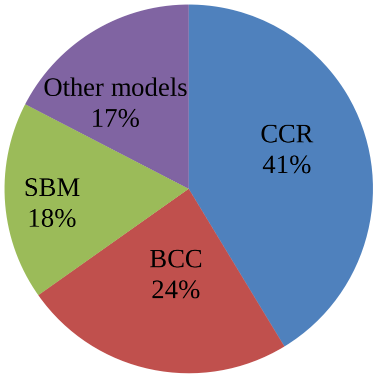


Figure 3. Frequency of DEA models used for performance evaluation of TSs.

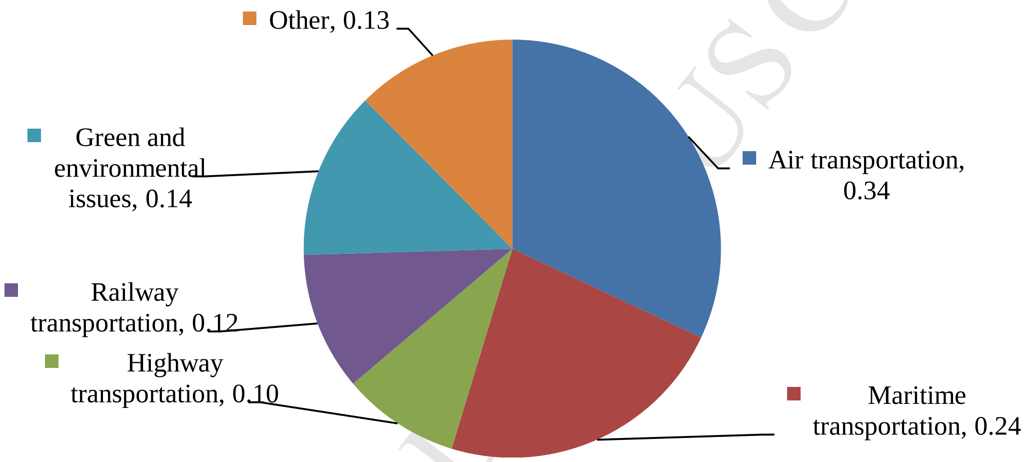


Figure 4. The contribution of different TSs in published papers.

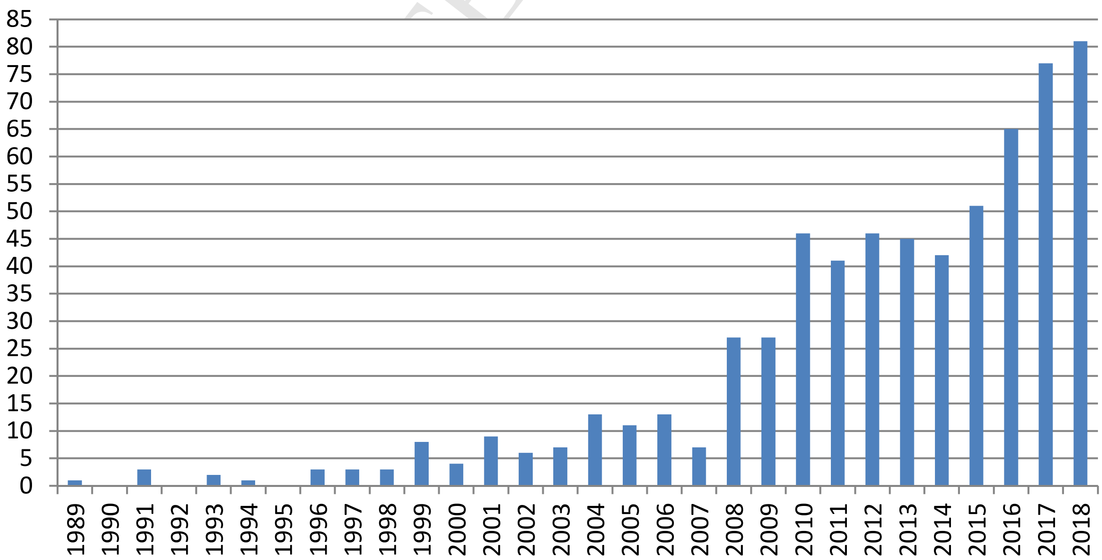


Figure 5. Annual number of published articles in DEA application in transportation problems.

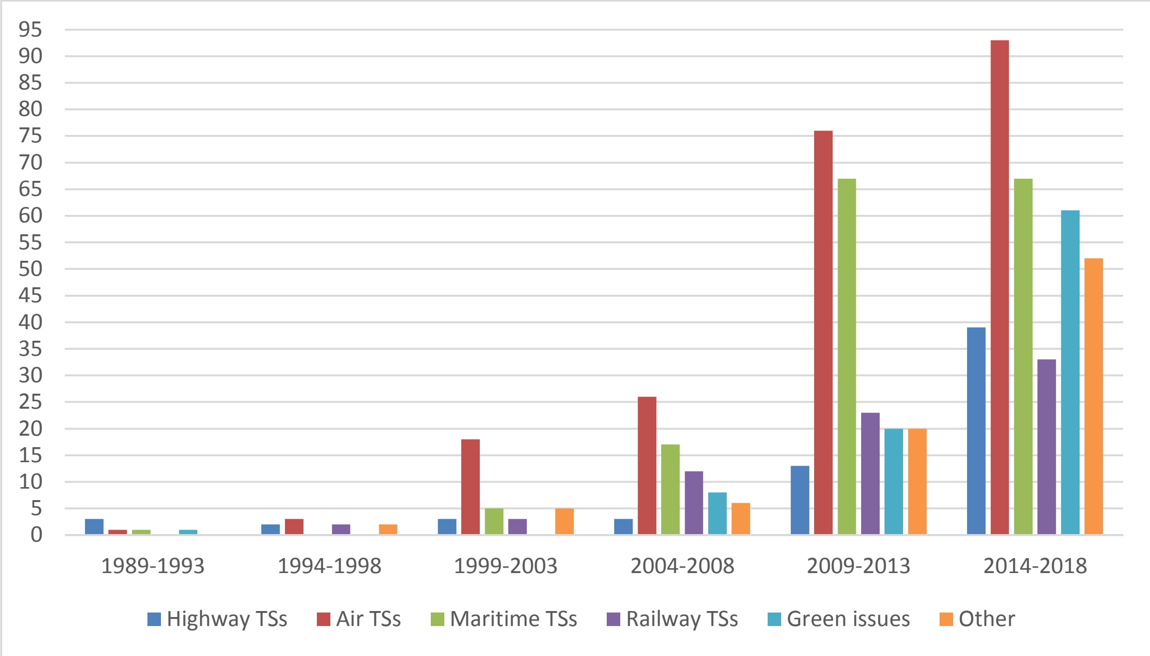


Figure 6. Annual number of published articles in each section.

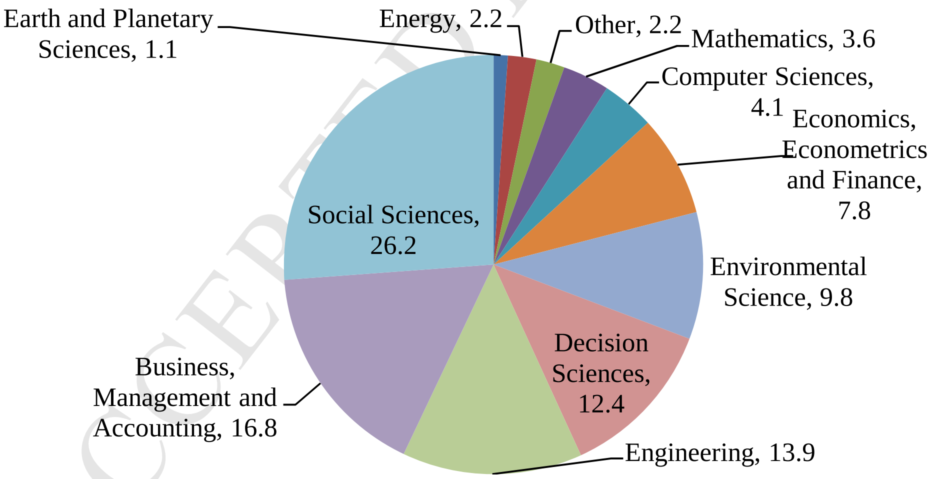


Figure 7. Subject area of identified papers in DEA applications in TSs

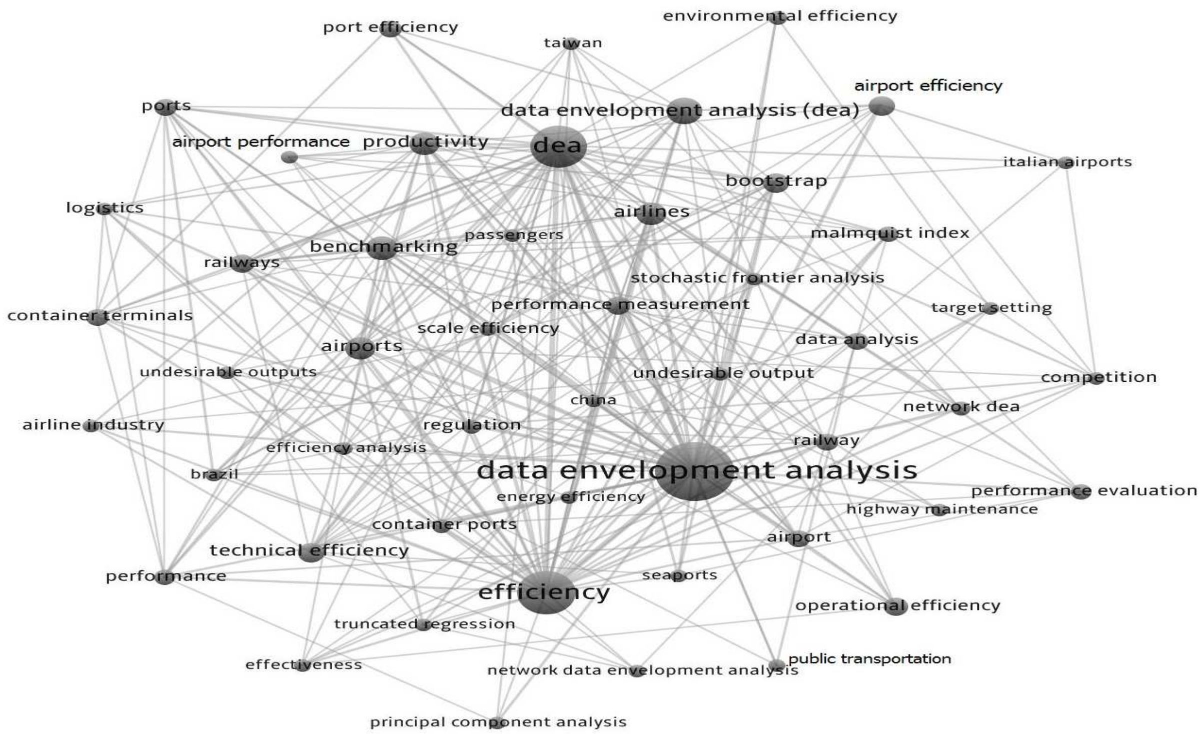


Figure 8. Map of most co-occurrence keywords related to DEA applications in transportation.

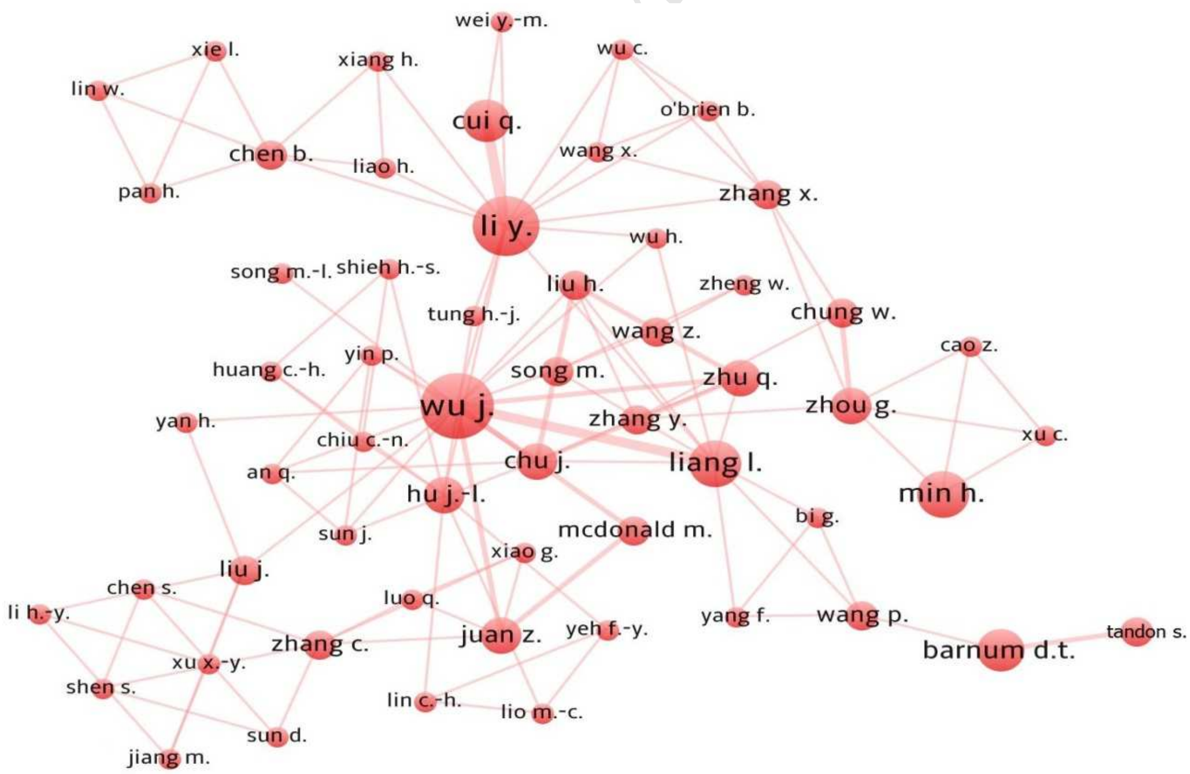


Figure 9. Map of co-authorship network related to DEA applications in transportation.

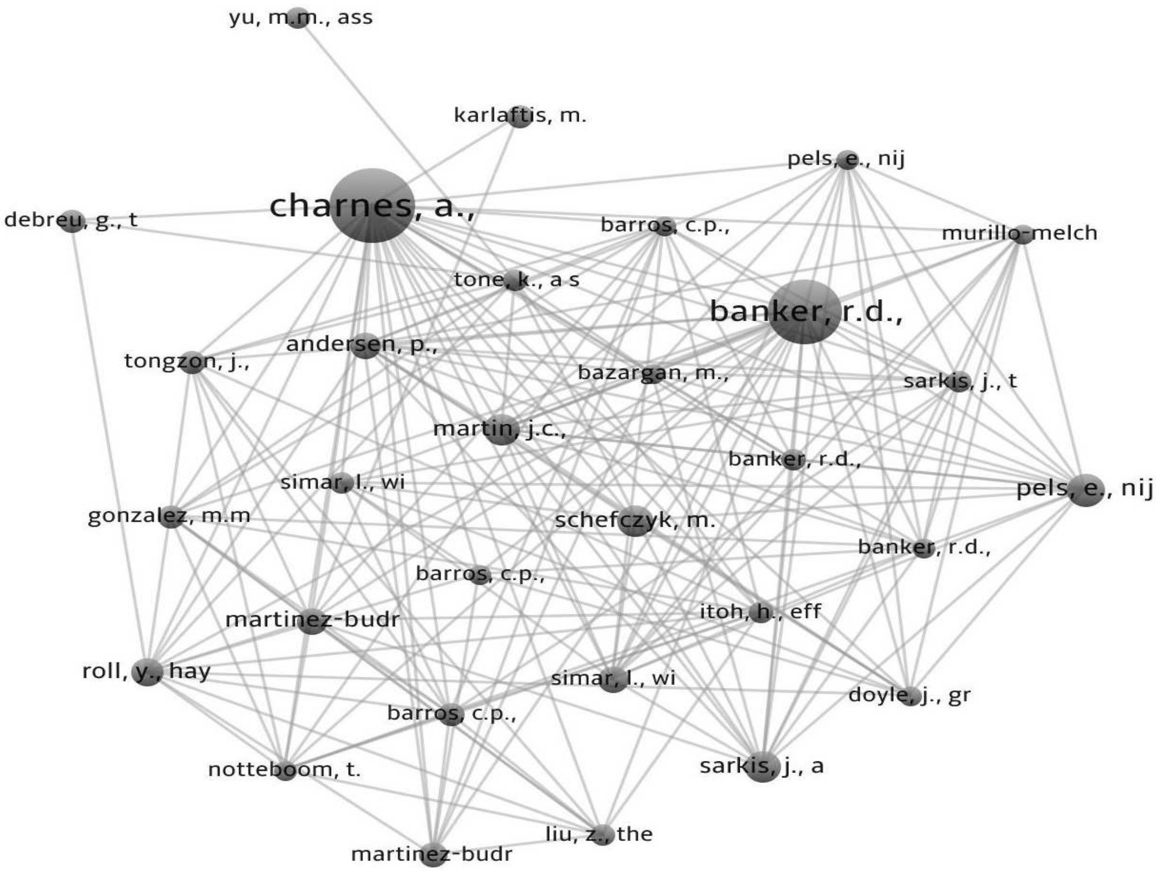


Figure 10. Map of most co-cited papers.

Online Supplement document

Mahmoudi R., A. Emrouznejad, S. N. Shetab-Boushehri, S. R. Hejazi (2018) The origins, development and future directions of Data Envelopment Analysis approach in transportation systems, *Socio-Economic Planning Sciences*, Accepted.

Online Supplement: Part 1 (List of Tables in each cluster)

Table 5.1.1. Inputs and outputs across the DEA and highway transportation literature.

Labour inputs	Labor; Number of transportation workers; Number of management, staff and mechanics; Number of ticket agents; Number of management staff; Number of drivers; Number of technicians; Employees; Total manpower;
Capital inputs	Agency cost; Transport Cost; Total expenditure on reseals, rehabilitation general maintenance (contractors costs); Routine Maintenance in dollars; Gross domestic product per capita; Average of construction cost index; Maintenance funding; Fixed assets; Operational costs; Payment to board of governors; Administrative costs; Cost; Asset; Total expenditure; Average pavement condition rating; Government dollars spent via ministry operations; Private consultant dollars spent; Driver cost; Capital investment; Maintenance expenditures; Capital expenditures; safety Highway expenditures; Budget; Construction budget; Highway investment in fixed assets; Private capital; Average total receipts; Average total disbursements;
Environmental and energy Inputs	Transport Risk; Road condition; Gasoline consumption; Diesel consumption; Fuel consumed; Environmental factor; Regional effect variable; Highway network area density; Population density; Average highway network density per person;
Facilities	Freight vehicles; Highway density; Total number of passenger seats; Vehicle per capita; Total urban and rural lane miles; Vehicle-miles traveled; Number of equipment; Number of vehicles; Highway length Passenger vehicles; Framework highway mileage; Total area served; Registered vehicles;
Other production inputs	Safety belt usage; Total Volume Of Cargo Tonnage; Travel Time; Resealing in kilometers; Rehabilitation in kilometers; Quantity of maintenance; Transportation quantity; Public maintenance;
Operational Outputs	Kilometers of highway resealed; Kilometers of highway rehabilitated; General maintenance; Pavement Rating Change Factor; Annual Average Daily Traffic; Length of road; Two-lane equivalent of road; Shoulder width of road; Coefficient for road surface; Coefficient for shoulder; Coefficient for winter operations; Coefficient for other operations; Average time to work in minutes for those not working at home; Estimated number of commuters driving alone/carpool; Average time to work in minutes using mass transit; Estimated number of commuters mass transit; Average score on trucking congestion; Ton miles of truck shipment per state in millions; miles of pavement serviced by a patrol; Fatal crashes; Vehicle-kms; Passenger-kms; Number of passengers; Network length; Assignment size; Average traffic served; Size of system; Average traffic serviced; Reseal length; Rehabilitation length; Level of service; Roughness measures; Production value; Number of lanes; Annual traffic; Change In Overall Bridge Condition; Average Daily Traffic on Interstate bridges per deck area; Average age of bridges; Annual freeze-thaw cycle; Annual precipitation; Passenger capacity; Equivalent sound level; Percentage of new cars; Number of private cars; Average age of private cars; Total number of annual traffic tickets issued for moving violations; Total number of seat belt tickets issued per year; Length of highway; protection of bridges and culverts; Highway transportation output value proportion; Highway cargo transportation capacity; Urbanization rate; Lane-miles Served; Lane km of roadway managed; Volume of shoulder and median repairs and routine maintenance accomplished; Customer satisfaction; Customer coverage rate;

	Rapid Response Capability; Roughness measures combined for urban and rural highways; Smooth Travel Exposure; Surface Condition Index; Proportion of Urban to Rural Roads;
Financial outputs	Transport revenue; Revenue; Expenditures on Interstate bridge replacement and rehabilitation; Passenger turnover; Freight turnover; Routing expenditure on maintenance; Turnover volume; Expense on salvage; Revenue from helping digging and mending roads; Average GDP per Person; Unit area GDP;
Environmental and safety outputs	Accident per vehicle; Injures per vehicle; Fatalities per vehicle; Total cost for all accidents; Number of people severely injured; Number of people with minor injury; Number of pedestrians involved in accidents; Safety; Atmospheric pollution; Greenhouse gas emission; Water pollution; Soil pollution; Accident Prevention Factor; Environmental Difficulty; Number of accidents; Industry pollutant; Change in structurally deficient area; Change in functionally obsolete area; Nitrogen oxides emission; Particulate matter emission; CO_2 emission; Number of drivers involved in injury accidents, involving alcohol/drug violations, by place of residence of the driver; Number of drivers involved in injury accidents involving alcohol/drug violations, by accident location; Numbers of accident sites repaired; Total reduction in accident;

Table 5.1.2. Most cited papers related to DEA applications in highway TSs.

Article	Citation Value	Article	Citation Value
Roll et al. (1991)	219	Yu (2008b)	26
Cook and Green (2000)	53	Rouse and Chiu (2009)	24
Rouse et al. (1997)	44	Yu and Fan (2006)	23
Nozick et al. (1998)	26	Cook et al. (1991)	22

Table 5.1.3. A review of selected papers across the DEA and highway TSs literature.

Ref.	Summary of study
Kazakov et al. (1989)	Using DEA, relative efficiency of a set of active highway maintenance patrols in Ontario were obtained. This study focused on identifying inputs and outputs to evaluate highway maintenance patrols.
Cook et al. (1991)	CCR and bounded DEA models were used to evaluating 62 highway maintenance patrols in Ontario. Technical efficiency and management efficiency were obtained and analyzed.
Rouse et al. (1997)	Considering environmental factors and based on data of 1993-94, performance of 73 highway maintenance patrols in New Zealand were surveyed. Results were analyzed in three respects: Efficiency, Effectiveness and Economy.
Cook et al. (2001)	Classic CCR and bounded CCR model were used to prioritize 50 highway accident sites considering cost of repair and driver inconvenience factors.
Rouse and Putterill (2005)	In this study, efficiency and productivity of highways maintenance, before and after structural changes and merger policies was studied. This article focuses on evaluating local governments in New Zealand in 1997-1982. The results showed that merger policies have impact on efficiency scores.
Wang and Tsai (2009)	Using CCR and BCC models, productive efficiency, technical efficiency, and scale efficiency of 31 highway maintenance sectors which belongs to directorate general of Taiwan highways were obtained. Some short/long term suggestions provided to improve performance.
Rouse and Chiu	Focusing on local roads in highway systems, 74 Territorial Local Authorities in

(2009)	New Zealand were analyzed to study how efficient and economical are they. Costs, quantity, quality and environmental factors e.g. life-cycle were considered.
Ozbek et al. (2010)	Considering Virginia Department of Transportation as a case study, overall efficiency of highway bridges maintenance, due to environmental and operational factors, have been measured. Seven sections in Virginia were evaluated. Based on results, inefficiency causes for each DMU surveyed.
Lee et al. (2012)	Using two-stage DEA model and data from Directorate General of Taiwan Highways in 2002, 31 highway maintenance and construction offices were evaluated. SMB was used to identify slacks values. To evaluate highway maintenance, Multi-stage DEA models are better than single-stage models.
Leal et al. (2012)	Input and output oriented DEA models were applied for prioritizing different bioethanol transportation modes, considering environmental factors. The results help Brazilian government to improve bioethanol TSs, especially highway transportation system.
Egilmez and McAvoy (2013)	Using Malmquist index (MI), performance of 50 states of the USA during 2002-2008 was analyzed in order to reduce traffic fatalities. Average productivity of states had a slight decline in reducing fatal crashes. Policies which lead to increase use of seat belts and highway safety were effective.
Monda et al. (2014)	In this study cost and effectiveness difference between public-private and traditional partnerships in highway construction and delivery projects were studied. Technical efficiency was analyzed for both groups. The results showed that initial cost for public-private partnership projects are higher, while technical efficiencies were not significantly different.
Çipil (2014)	In this paper, DEA was used to compare TSs of Turkey to TSs in EU countries in terms of greenhouse gas emissions. Using renewable energies is a very effective policy for increasing the efficiency of TSs in Turkey
Wu et al. (2016a)	30 regional TSs in china were analyzed. DEA source reallocation is used for each DMU to maximize minimum satisfaction degree and environmental efficiency.
Tatari et al. (2016)	Sustainability of highway TSs was studied. Three perspectives of sustainability including social, economic and environmental are considered for assessing 30 highway transport systems in Oregon, USA.
Song et al. (2016)	Super-efficiency slacks-based measure model were obtained by considering desirable and undesirable outputs, environmental and energy efficiency of TSs in 30 provinces in china. Highway TSs in China are inefficient in environmental and energy consumption terms.
Li et al. (2016)	Efficiency of highway TSs in Beijing-Tianjin-Hebei regions were obtained and analyzed. Results showed that these regions have lower efficiency scores than Yangtze River Delta and Pearl River Delta urban regions. Efficiency score obtained for each region show that government must apply different appropriate strategies for every region.
Azadeh et al. (2016b)	By using statistical methods and DEA, considering severity of accidents and decision-making style of driving, effective factors on road accidents were studied based on data of 500 samples in Tehran.
Liu et al. (2017)	Using parallel SBM model, at first, performance of land TSs was analyzed then, efficiency of highway and railway TSs were obtained separately. Environmental performance of land transport system in East area is better than central and the west areas. Also the efficiency of railway transportation is more than the highway transportation.

Table 5.2.1. Inputs and outputs across the DEA and air transportation literature.

Labour inputs	Number of employees; Number of core business workers; Labor; Managerial; Engineers.
Capital inputs	Labor, capital and materials expenditures; Staff costs; Operating costs; Total economic cost; Operating expense less employee expenditure; Maintenance costs; Soft costs; Maintain Expense; Operating expenses; Capital stock; Access cost; Payroll; Employee expenditure/Staff strength; Flight capital; Other operating costs; Outsourcing costs; Total operating cost net of depreciation and amortization costs; Total non-flight assets;
Environmental and energy inputs	Annual water consumption; Final consumption of electricity; CO_2 emission per capita; Fossil Fuel Energy Consumption; Annual electricity consumption; Petroleum gas consumption; Gallons of jet fuel; Annual liquefied; Fuel;
Facilities	Number of runways; Number of gates; Terminal area; Total runway area; Route; Number of vehicle parking spaces; Baggage claim area; Distance to nearest city center; Number of baggage collection belts; Number of public parking spots; Available seat kilometers; Terminal capacity; Runway capacity; Apron capacity; Security capacity; Number of planes; Dimension of runway unit; Passenger terminal area; Airport Surface; Number Of Parking Slots; Available ton kilometer which reflects aircraft capacity; Number of operated aircraft; Runway length; Apron size; Airport ramp; Baggage handling capacity; Snow removal equipment; Fire truck & stations; Hangers; Departure lounge; Number of check-in counters; Curb frontage; Number of boarding gages;
Other production inputs	Outsourcing; Ratio of flight stage miles to trip stage miles; Maintenance; Cleaning; Security; Underutilization (in percentage);
Operational Outputs	Passengers; Air traffic movements; Tons of cargo; Number of residents who can get the airport by car in 90 minutes; Peak hour movements; Aircraft movements; Service rating; Available seat kilometres; Number of planes; Total freight; Annual passenger throughputs; Annual Number of flights; Annual cargo throughputs; Non-weather related delays; Commuter movements; Domestic passengers, boarded plus disembarked, in thousands; Tons of aviation kerosene; Charter Flights; Domestic passengers; Air transport movements;
Financial outputs	Commercial revenues; Returns from infrastructure services; Total returns; Operative returns; Final returns; Net Profit/loss; Revenue passenger kilometer; Non-passenger revenue at current prices; Operating revenue; General aviation; Non-aeronautical revenue; Earnings before interest and taxes; Duty free and retail revenues; Catering revenues; Car parking revenues; Rental revenues; Banking revenues; Entertainment revenues; Passenger services revenues; Airport cities revenues; Aircraft landing fees; Passenger charges & fees; Aircraft parking fees; Ground handling fees; Cargo fees; Centralized infrastructure fees; Aeronautical revenues; Non-aeronautical revenues; Aeronautical receipts; Handling receipts; Commercial receipts;
Environmental and safety outputs	CO_2 emission volume; Environmental & Noise surcharges; Security charges; Aircraft noise; Air pollution;

Table 5.2.2. Most cited papers related to DEA applications in air TSs.

Article	Citation Value	Article	Citation Value
Adler and Golany (2001)	191	Barros and Peypoch (2009)	114
Sarkis (2000a)	186	Bazargan and Vasigh (2003)	114
Adler and Berechman (2001)	162	Barros and Dieke (2008)	110
Schefczyk (1993)	158	Barros and Dieke (2007)	101
Pels et al. (2003)	155	Merkert and Hensher (2011)	100
Martín and Román (2001)	155	Abbott and Wu (2002)	86
Parker (1999)	146	Barbot et al. (2008)	84
Pels et al. (2001)	129	Yu (2010)	83
Sarkis and Talluri (2004)	126	Pacheco and Fernandes (2003)	78
Fernandes and Pacheco (2002)	124	Scheraga (2004)	76

Table 5.2.3. A review of selected papers across DEA and air TSs literature.

Ref.	Summary of study
Schefczyk (1993)	15 international airports were analyzed based on data of 1989-1992. Standard DEA was used. The results showed that operational efficiency, marketing performance and resource acquisition are key factors for high profitability.
Charnes et al. (1996)	Operational efficiency for domestic and international activities of airlines in Latin America in 1988 was surveyed.
Gillen and Lall (1997)	Considering data of 21 airports in USA during 1989-1993, effects of an airport manger's decision on efficiency and performance of airport were studied. DEA and Tobit regression were applied to identify managing strategies to improve efficiency scores in terminals and airsides.
Sengupta (1999)	Dynamic DEA model was used to survey trend of efficiency changes in 14 international airports from 1988 to 1994. The results showed the significant changes in efficiency scores.
Semenick Alam and Sickles (2000)	During a 20-year period from 1970 to 1990, using standard DEA model, performance of 11 US airlines was evaluated. Analysis of the results showed that competition increases efficiency.
Sarkis (2000b)	Results of evaluating 44 major American airports showed that the average of airports efficiency was increased.
Martín and Roman (2001)	To investigate privatization effects on capacity constraints at European airports, 37 Spanish airports were evaluated. Privatization and partnership with private sector can improve efficiency of airports.
Pels et al. (2001)	Relative efficiency of 34 European airports during 1995-1997 was calculated by DEA. Most airports were inefficient. There is a significant difference between performances of different airports.
Adler and Golany (2001)	Using an integrated DEA and principal component analysis (PCA), performance of deregulated airline networks in west Europe was studied.
Adler and Berechman (2001)	Using DEA and PCA relative efficiency and quality of European and non-European airports were analyzed. Airports quality is an effective factor in selection of hubs by airlines.
Fernandes and Pacheco (2002)	BCC DEA model was applied to evaluate capacity and productivity of 35 Brazilian domestic airports which are investigated in terms of number of

	serviced passengers. Slacks values were identified.
Pels et al. (2003)	Based on data from 34 European airports, efficiency were obtained and analyzed. The results showed that European airports are inefficient, on average. Airlines inefficiency is significantly affected by airports inefficiency in passenger transportation.
Pacheco and Fernandes (2003)	Standard DEA and MI were applied to evaluate performance of 16 European airlines between 1977 and 1990. The results indicated significant slacks values in East regions versus West Regions.
Bazargan and Vasigh (2003)	Performance of 45 American commercial airports in three groups including large, medium and small size, was evaluated. The results showed small airports had the highest efficiency scores.
Sarkis and Talluri (2004)	Using DEA, performance of 44 major airports in USA from 1990 to 1994 was evaluated. Some strategies were suggested to improve overall performance.
Scheraga (2004)	Standard DEA and regression analyzes were applied to evaluate performance of 38 international airlines. Passenger service costs have negative effect on efficiency when marketing costs have positive effect.
Tsikriktsis and Heineke (2004)	Efficiency of 10 American airlines in 1987-1998 was analyzed by using standard DEA and time series regression.
Capobianco and Fernandes (2004)	This study evaluated 53 international airlines during 1993-1997. Standard DEA model was used for this research. Performance of airlines highly depends on their management. Major airline companies were more efficient in using their capital for profitability.
Yoshida and Fujimoto (2004)	Based on data of 2000, 67 Japanese airports were evaluated. Effects of overinvestment on efficiency scores were analyzed.
Yu (2004)	Considering environmental factors and undesirable outputs, physical efficiency of 14 domestic Taiwan's airports was obtained during 1994-2000.
Chiou and Chen (2006)	Performance of 15 Taiwan's airlines in 2001 was evaluated using standard DEA and Tobit regression.
Lin and Hong (2006)	Operational efficiency of 20 international major airports around the world were assessed. The results showed that economic growth rate of the country which airport is located in, hub airports and airport geographical location are affective factors for operational efficiency of the airport.
Barros and Dieke (2007)	Operational and financial efficiency of Italian airports was evaluated during 2001-2003 using panel data based DEA model.
Greer (2008)	Using standard DEA model and MI, performance of 8 American airlines from 2000 to 2004 was evaluated. An increase in efficiency of energy consumption, labor and available seat-mile capacity was observed.
Barbot et al. (2008)	Based on data of 49 international airlines in 2005 total productivity was obtained by using standard DEA model. Results showed that the efficiency of airlines depends on geographical location.
Yu et al. (2008)	Considering aircraft noise and using MI, changes in efficiency of 4 major Taiwan's domestic airports from 2001 to 2005 was analyzed.
Fung et al. (2008)	DEA and MI used for evaluating trend of Chinese airport's efficiency, based on data of 25 airports in 1995-2004.
Barros and Dieke (2008)	Based on data during 2001-2003 and using a novel two-stage model, technical efficiency of Italian airports was analyzed. Due to efficient frontier, weakness

	points of airports with low efficiency identified and some suggestions were proposed to improve current situation.
Lam et al. (2009)	Operational performance of 11 Asia-Pacific airports from 2001 to 2005 was assessed.
Greer (2009)	During a 10-year period from 1999 to 2008, using standard DEA and Tobit regression, efficiency of 17 major American airlines was evaluated. Results showed that labor unions don't affect efficiency.
Bhadra (2009)	Standard DEA was used to evaluate performance of 13 American airlines during 1985-2006. By reducing block time, efficiency of airlines will increase.
Barros and Peypoch (2009)	This study surveyed performance of 27 European airlines during 2000-2005. Being a member of alliance network, effects airlines efficiency.
Chi-Lok and Zhang (2009)	Based on data of 1996-2006, 25 major Chinese airports were evaluated. Effects of policies and reforms in TSs on airports efficiency were analyzed. Results showed that localization of airports have significant effect on efficiency scores.
Curi et al. (2010)	Using DEA, effects of Italian government strategies including privatization, developing airport management services and establishment of two new hubs on productivity of 36 airports were analyzed in 2001 and 2003. Results showed that new hubs are inefficient sources.
Ouellette et al. (2010)	In a 40-year period from 1960 to 1999, performance of 7 Canadian airlines was evaluated using standard DEA model. Changes in regulation and deregulation are the main reasons of inefficiencies.
Merkert and Hensher (2011)	The impact of strategic management and fleet planning on airlines efficiency were investigated. A two-stage DEA model applied to data of 58 airline passengers from 2007 to 2009. Results showed that fleet have not a significant impact on technical efficiency but it affects allocative and cost efficiency positively.
Assaf and Gillen (2012)	Effects of governmental structure and economical regulation on airports efficiency were analyzed. Analysis of the data from several countries showed that economical regulation affects relative efficiency more than governmental structure.
Chow and Fung (2012)	To estimate indicators which affect performance of airports, performance of 30 Chinese airports from 2000 to 2006 was investigated by using MI.
Ha et al. (2013)	To survey market structure of airlines and efficiency of airports, 10 major airports in east Asia were evaluated. DEA and statistical models were applied on data of 1994-2011.
Chang et al. (2013a)	Performance of 41 Chinese airports in 2008 was evaluated by using DEA and second stage regression.
De Nicola et al. (2013)	DEA and MI were applied to assess efficiency of 20 Italian management companies during 2006-2008. Results showed that according to infrastructure, performance of airport is acceptable. However, by reducing waiting time and improving management methods, they can increase their productivity.
Fan et al. (2014)	Using DEA and data of 20 Chinese airports during 2006-2009, regarding to flight delays, performance of airports was evaluated.
Tsui et al. (2014)	Considering data of 21 airports from 2002 to 2011, operational efficiency of Asia Pacific airports were evaluated.
Ahn and Min	Performance of 23 international airports in Europe, North America and East

(2014)	Asia were evaluated during 2006-2011. Classic DEA model and MI were used for this study.
Merkert and Mangia (2014)	Using a two-stage DEA model, cost efficiency of 35 Italian and 45 Norwegian airports was analyzed during the time. Competition effects on performance were investigated. The results showed that competition level plays an important role in regional and small airports performance.
Arjomandi and Seufert (2014)	Bootstrapped DEA model was applied for performance assessing of 48 international airlines during 2007-2010.
Tavassoli et al. (2014)	Performance of 11 airlines in Middle East in 2010 was evaluated by using DEA network SBM model.
Wu and Liao (2014)	DEA was used to evaluate efficiency of 38 international airlines in 2010.
Chang et al. (2014)	Performance of 27 international airlines in 2010 was analyzed by using SBM. Energy consumption is one of the main reasons for inefficiencies.
Lee and Worthington (2014)	Using Bootstrapped DEA, 42 European and American airports were evaluated in a 5-year period, from 2001 to 2005. Results showed that major airlines which want to be able to compete with other airlines, need to reorganize and resize their operations. Results showed that capital efficiency affects energy efficiency.
Cui and Li (2015)	Considering CO_2 emission as an output, energy efficiency of 11 airlines during 2008-2012 was evaluated. Financial crisis in the USA has a significant impact on changes in energy efficiency in this period.
Merkert and Assaf (2015)	To evaluate quality of service and profitability, performance of 30 international airports were investigated by using DEA and second stage regression.
Liu (2016)	Based on panel data from 2009 to 2013 and by using network DEA, overall and operational efficiency of sub-networks in 10 airports in east Asia was studied.
Örkcü et al. (2016)	Operational performance of 21 Turkish airports during 2009-2014 was studied using by MI. Results showed that efficiency of airport was increased during the time.
Shao and Sun (2016)	Using network DEA, allocation efficiency, passenger transportation efficiency and cargo transportation efficiency of 477 Chinese airlines were evaluated. According to efficiency scores obtained from airlines, performance of 82 airports was assessed.
Omrani and Soltanzadeh (2016)	A dynamic network DEA was applied to evaluate performance of 8 Iranian airlines during 2010-2012. Results of presented model compared to existing dynamic and network DEA models results.
Liu (2017)	For evaluating efficiency and changes in efficiency of airport companies in east Asia countries, a multi-period network DEA model was used. This study planned to survey effects of internal operations of sub-networks and annual operations on airports' overall efficiency.

Table 5.3.1. Inputs and outputs across DEA, ports and maritime transportation literature.

Labour inputs	Size of labor force; Number of workers; Number of employees; Average age of employees; Average years worked of employees; Indirect labour;
Capital inputs	Personnel-related expenses, such as employees' remuneration; Harbour land, buildings, wharves, docks, waterways, warehouses and funding inputs for other equipment; Operating expenses; Net fixed asset; Depreciation expense; Salaries and wages; Current liabilities; Capital (number of berths, cranes, tugs); Equipment costs; Revenue; Profitability; Average government port charges per container; Labor expenditures; Depreciation charges; Miscellaneous expenditures; Capital (book value of the assets); Annual investment per port; Value of capital invested; Size of operating costs; Marketability;
Energy inputs	Amount of energy consumed;
Facilities	Terminal length; Terminal area; Channel width; Channel depth; Maximal quay depth; Solid bulk frequency; Outputs Solid bulk throughput; Port land area; Yard area; Warehousing area; Stocking area; Quay length; Quay cranes; Transfer cranes; Straddle carriers; Reach stackers; Berth length; Cranes; Tugs; Quayside gantry; Straddle carrier; Ship-shore container gantry; Container berth; Number of berths; Parking lot; Total length; Yard gantries; Area of container base; Number of gantry cranes; Length of container terminals; Number of deep-water piers; Container berth length; Containers; Container cranes (number); Mix of 20-foot and 40-foot containers; Size of hard areas; Number of straddle carriers; Amount of yard equipment; Straddle carrier; Cargo throughput, number of ship calls; Berthing capacity, cargo-handling capacity; Land factor; Equipment factor; Uniformity of facilities and cargo;
Other production inputs	Container frequency; Average idle time; Productivity; Length of delay; Solid in bulk; Liquid in bulk; General commodities; Frequency of ship calls; Average delays in commencing stevedoring; Difference between the berth time and gross working time; Number of containers lifted per quay crane hour; Overall efficiency;
Operational Outputs	Container throughput; Service level; User satisfaction; Ship calls; TEU berth hour; Total number of containers handled per year; Total cargo moved through the docks; Ship working rate; Total tones throughput; Number of containers; Ships; Movement of freight; Gross gauge; Break-bulk cargo; Containerized freight; Solid bulk and liquid bulk; Productivity; Cargo throughput, number of Overall efficiency; Throughput (TEU); Containers loaded and unloaded; Cargo throughput; TEUs handled; Average number of containers handled per hour per ship; Number of passengers; Number of containers with TEU; Number of containers with no TEU; Available equipment; Total equivalent units; Number of vessel arrivals at port; Quantity of goods handled; Time spent operating in port; Service standards; Total cargo handled; Service level; Total tons throughput; Total cargo moved through docks; Terminal length; Terminal area; Port traffic; Aggregate throughput; Loaded shipments; Solid bulk frequency; Container frequency; Outputs Solid bulk throughput; Solid bulk loading hours; Container loading hours;
Financial outputs	Profitability; Revenue; Marketability; Total sales; Operating income; Total revenue; Revenue from port activities, e.g. from leasing equipment, and renting commercial buildings and space; Revenue obtained from rental of port facilities; Market share;
Environmental outputs	Emissions; Port city population;

Table 5.3.2. Most cited papers related to DEA applications in maritime TSs.

Article	Citation Value	Article	Citation Value
Tongzon (2001)	312	Cullinane et al. (2005a)	119
Cullinane et al. (2006)	281	Park and De (2004)	105
Roll and Hayuth (1993)	192	Zhou et al. (2008)	95
Barros and Athanassiou (2004)	162	Panayides et al. (2009)	78
Martinez-Budria et al. (1999)	147	BARROS (2003)	76
Wang and Cullinane (2006)	126	Rios and Maçada (2006)	69
Turner et al. (2004)	126	Hung et al. (2010)	65
Cullinane et al. (2005b)	117	Itoh (2002)	57

Table 5.3.3. A review of selected papers across DEA, ports and maritime TSs literature.

Ref.	Summary of study
Roll and Hayuth (1993)	Based on data of 20 ports all around the world, port efficiencies were evaluated and analyzed.
Martinez-Budria et al. (1999)	Relative efficiency of 26 Spanish ports were obtained. This study used a 5-year period data. Based on complexity level, ports were divided in to three categories. Results showed that ports with higher level of complexity have higher efficiency scores.
Tongzon (2001)	An international comparison was done on performance of 24 Australian and other countries ports. Both of CRS and VRS assumptions were considered in this study.
Bonilla et al. (2002)	Based on data of 26 Spanish ports, goods traffic efficiency was obtained. Also by using bootstrap analysis, confidence interval was calculated.
BARROS (2003)	In this study technical efficiency and technology changes in 11 Portuguese sea ports were analyzed based on panel data. The results showed that privatization does not necessarily improve performance of all ports.
Park and De (2004)	Using DEA and data of 11 Korean ports in 1999, efficiency scores were obtained. CCR and BBC model were used for efficiency calculation and results comparison.
Barros and Athanassiou (2004)	Based on balanced panel data of 6 Portuguese and Greek ports from 1998 to 2000, performance of ports were assessed and analyzed. By analyzing the results, improving policies for European sea ports were suggested.
Turner et al. (2004)	Productivity growth of sea ports infrastructure in North America from 1984 to 1997 was studied. Using Tobit regression effective factors on infrastructure efficiency were identified. Relationship between infrastructure efficiency and industry structure were surveyed. The results indicated a strong relationship between railway industry and infrastructure efficiency of container ports.
Cullinane et al. (2005a)	By using DEA and based on data of 25 major Chinese ports, relationship of privatization and container ports efficiency were studied. This study rejected positive effect of privatization on ports efficiency.
Cullinane et al. (2005b)	By using DEA and Free Disposal Hull model, Productivity of 30 pioneer container ports and terminals were analyzed in 2001. Results showed that obtaining efficiency scores by panel data, provides better results comparing to cross-sectional data.
Rios and Maçada (2006)	Using BCC model and data of 15 Brazilian, 6 Argentinian and 2 Uruguayan container ports during 2002-2004, relative efficiency of ports was obtained and analyzed.
Wang and Cullinane (2006)	Based on data of 104 terminal ports in 29 European countries in 2003, relative efficiency scores were obtained. British ports and ports in west Europe countries have highest level of efficiency. Efficiency in Scandinavian and east

	Europe countries is weak.
Cullinane et al. (2006)	Technical efficiency of 57 major container ports in the world was evaluated using DEA and SFA. Results showed that efficiency scores were strongly dependent on privatization. For making policies, the analysts must use panel data. Because using cross-sectional data has high level of risk.
Lin and Tseng (2007)	Five different DEA models were applied to assess performance of 10 container ports in Asia-Pacific in 1998. Trend of ports efficiency scores of was analyzed. Slacks values and weaknesses were identified.
Liu (2008)	Using CCR, BCC and 3-stage DEA models efficiency changes in performance of 10 Asia-Pacific ports from 1998 to 2001 were analyzed. The results showed different models produce different results.
Pillania et al. (2008)	India's logistics competitiveness and efficiency of Indian terminal ports were studied during 2000-2005. The results showed cargo transportation industry is a competitive industry where transportation industry is not. Also major ports were not efficient.
Sharma and Yu (2009)	An integrated data mining and DEA method was used to evaluate terminals. A step by step plan was presented to achieve efficient frontier for inefficient terminals. This plan designed based on maximum capacity and input features.
Lozano (2009)	MI was applied to estimate efficiency changes in Spanish ports from 2002 to 2006. Changes in technical efficiency, technology and scale efficiency were studied in this article.
Wu and Goh (2010)	Most major ports from 25 selected countries were considered as DMUs. Using DEA and based on data of 2005, operational efficiency in advanced markets and emerging Markets were obtained and results were compared.
Cullinane and Wang (2010)	Using panel DEA model and data of 25 leading container ports, efficiency scores were obtained during 1992-1999. Results showed significant weakness in ports' performance. Also slacks values and inefficiency sources were identified.
Hung et al. (2010)	Operational efficiency, scale efficiency targets and variability of DEA efficiency estimates for 21 container ports in Asia-Pacific were analyzed by using DEA. Selected ports were among 100 leading ports in 2003.
Bichou (2011)	Operational efficiency of container ports was evaluated using a two-stage supply chain DEA model.
Lozano et al. (2011)	Considering data of 26 Spanish ports in 2006, application of centralized DEA model in capital budgeting in ports was studied.
Wanke et al. (2011)	Using DEA and SFA, performance of 25 major Brazilian terminal ports in 2009 was analyzed. The results showed that due to growing economic prosperity and lack of investment in capacity expansion, terminal has limitations in capacity.
Niavis and Tsekeris (2012)	Standard DEA and Super-efficiency DEA were applied to assess technical efficiency of major sea ports in south east Europe region. The results showed average efficiency score is less than 0.5 which indicates weakness in both management and scale.
Yuen et al. (2013)	Based on panel data, operational efficiency of terminal ports in China was evaluated from 2003 to 2007. Effects of domestic/foreign ownership and domestic/foreign competition on performance were analyzed. Domestic and foreign competition has positive effects on efficiency.
Wanke (2013)	Using two-stage network DEA model, performance of 27 Brazilian ports in 2011 was analyzed. The results showed that privatization have positive effects on physical infrastructure efficiency.
Díaz-Hernández et al. (2014)	Based on data of 27 Spanish ports during 2000-2007 and using Dynamic cost DEA model, efficiency of the ports were obtained. The results of Dynamic

	model were compared by static model. This analyze showed static model exaggerates about cost inefficiency.
De Oliveira and Cariou (2015)	Impacts of competition degree and levels of competition on efficiency of 200 container ports during 2007-2010 were studied. Regional competition has inverse impact on efficiency while the impacts of local and global competition are unclear.
Wanke and Barros (2015)	Using two-stage DEA model, efficiency scores of 27 Brazilian ports in 2011 were obtained. This study showed privatization affects physical infrastructures efficiency positively.
Nguyen et al. (2016)	Considering data of 43 Vietnamese ports, results of standard DEA, bootstrapped DEA and SFA about performance of ports, were compared. The results showed outputs of all used models are helpful although there is a significant difference between obtained values of each model.
Wanke and Barros (2016)	Different DEA models were used to analyze performance of 27 major Brazilian ports during 2007-2011. This study showed that there is a lack of capacity in Brazilian ports. Also performance of ports can be improved by participation of private sector and improving infrastructures.
Cheon et al. (2017)	Relationship between environmental and economic performance of 10 top American ports in 2004 was studied. Improvements in physical assets, organizational collaboration and performance monitoring are key factors for improving both aspect of performance.
Mousavizadeh and Khalili-Damghani (2017)	Using DEA and artificial neural and based on data of 11 Iranian main ports in 2005, 2010 and 2015, the efficiency scores were obtained. The results showed that when number of DMUs are low and number of inputs and outputs are high, presented method have more discrimination power than standard DEA model.
Chang et al. (2018)	Using non-radial SBM DEA models and panel data from 2000 to 2011, the effects of emission control areas on the efficiency of ports in the European Union and North America have been analyzed.

Table 5.4.1. Inputs and outputs across DEA and railway transportation literature.

Labour inputs	Labour; Employees; Average annual number of employees;
Capital inputs	Total expenses and construction budget; Gross national income per capita; Capital; Operating expenditure; Repair and maintenance expenditure; Total annual costs of operation;
Environmental and energy inputs	Station catchment area population; Fuel; Population density;
Facilities	Passenger cars; Freight wagons; Passenger coaches; Total routes km; Total locomotives; Number of platforms; percentage of through lines; Total number of cargo cars; Number of containers; Number of yard equipments; Number of handling terminals; Total number of traction vehicles; Materials; Fleet capacity; No. of rolling stock; Locomotives; Track; Freight cars; Engines; Equipment; Gradient; Railcars/EMUs**;** Total Length of main line; Length of platform; Way and structures;
Other production inputs	Number of passenger entries and exists; Number of passenger interchanges; Job opportunities in the catchment area; Number of train stops; Transportation density;
Operational Outputs	Track capacity; Car-miles of shipment of goods; Passenger services; Freight services; Train Km; Passenger train-kms; Freight train-kms; Passenger-kms; Ton-kms; Passenger kilometers per annum; Car kilometers per annum; Externalities on surrounding communities; Total cargo ton transported; Total

	Cargo ton per kilometers transported; Number of train stops; Railway density;
Financial outputs	Average salary growth; Passenger revenue; Freight revenue; Revenue ton-mile; Annual total revenues earned;
Environmental and safety outputs	Passenger journeys per annum; Accident; CO_2 for railway; Dust;

Table 5.4.2. Most cited papers related to DEA applications in railway TSs.

Article	Citation Value	Article	Citation Value
Coelli and Perelman (1999a)	278	Growitsch and Wetzel (2009a)	46
Yu and Lin (2008b)	160	Chapin and Schmidt (1999)	45
Azadeh et al. (2008)	101	Hilmola (2007)	45
Yu (2008a)	79	Cowie (1999a)	44
Mohajeri and Amin (2010)	47	Martín and Reggiani (2007)	43
Graham (2008)	46	George and Rangaraj (2008)	34

Table 5.4.3. A review of selected papers from DEA and railway TSs literature.

Ref.	Summary of study
Cowie and Riddington (1996)	By considering data of published papers in railways productivity analysis during1983-1989, railways were reevaluated by using DEA. The results showed that management affects railways efficiency strongly.
Chapin and Schmidt (1999)	Using panel data of class I railway companies, efficiency of railway companies after deregulation was studied. Analyzing the results showed that deregulation affects efficiency scores but merger has not significant impacts.
Coelli and Perelman (1999b)	Efficiency of European railways was surveyed and analyzed based on data of 17 companies during 1988-1993.
Cowie (1999b)	Technical efficiency for public and private ownership in railway industry was investigated by considering Swiss private railway sectors as a case study. Data of 57 small railways including 43 public sectors and 14 private sectors were considered in 1990. The results showed that private sector have a remarkably high level of managerial, organizational and technical performance than public sectors.
Mbangala Mapapa (2004)	Using standard DEA and MI, performance of railways in sub-Saharan Africa was analyzed. Due to weaknesses in using of resources in production and productivity, most of under study railways are inefficient by average efficiency score of %77.
Lan and Lin (2005)	For evaluating technical performance of railway TSs, service level, productivity and sale capability growths, four-stage DEA models were used. In this assessing, environmental factors were considered. Data was related to 44 railways around the world during 1995-2001.
Hilmola (2007)	By considering railways data of 31 European countries during 1980-2003 and using DEA, efficiency of freight railway transportation was studied. Effective factors on demand and efficiency were identified. The results showed that countries that have a high level of performance in the 80s, without exception, have compromising performance. Estonia and Lithuania has the highest efficiency level.

Yu and Lin (2008a)	To estimate technical efficiency of freight and passenger, service productivity and technical productivity of 20 selected railways in 2002, a multi-activity network DEA model was used. The results showed that obtained values in different criteria were significantly different.
Yu (2008a)	Network DEA and traditional DEA model were applied to assess technical efficiency, service and technical effectiveness of 40 global railways in 2002. Although obtained values of two used models were different but there were no significant difference in their ranking. Generally network DEA offers better insights about resource inefficiency.
Graham (2008)	Using DEA and total factor productivity, productivity and efficiency of urban railways were studied. This article considered data of 89 urban railways around the world including underground, light rail, and suburban rail during 1995-1996. The results showed that although obtained values of two used models were different but there were not any significant difference in ranking.
Jain et al. (2008)	Effects of governmental development models on performance of 15 urban railway systems around the world were investigated during1992-2002. Among all governmental models, privatization has direct and positive effects on efficiency.
Growitsch and Wetzel (2009b)	Based on a data set of 54 railways in 27 European countries from 2000 to 2004, using DEA super-efficiency bootstrapping model, effects of vertical integration on railways performance were analyzed.
Mohajeri and Amin (2010)	By combining DEA and analytical hierarchy process, train stations selection problem in Mashhad was studied. The results showed that obtained weights from AHP can be useful for identifying optimal location of stations as DEA outputs.
Jitsuzumi and Nakamura (2010)	Based on data of 53 railway companies in Tokyo, Kyushu and Kinki regions during 1998-2003, inefficiency resource were identified. Also optimal level of government's subsidies is calculated.
Hilmola (2011)	Using DEA and data of 2000-2004, the impact of geographical location of countries on efficiency of railway transportation is studied. Super efficiency model was applied for performance assessing of freight and passenger railway transportation.
Shi et al. (2011)	Economical evaluating of productivity growth and technical efficiency of 7 class I American railroads during 2002-2007 was surveyed. MI and sequential DEA models were used. Effective factors on productivity growth in recent years were identified and useful information proposed for policy making.
Kim et al. (2011)	In this article, modal shift of TSs to railway transportation, as an Eco-friendly system, was studied in Korea. By surveying freight railway transportation and local freight railway transportation features, an alternative plan is provided for green logistics.
Correa (2012)	Based on data of microeconomic and DEA, land freight TSs including trucking and railway transportation were evaluated. Overall efficiency for railway transportation was more than road transportation efficiency.
Kutlar et al. (2013)	Performance of 31 rail companies around the world was analyzed during 2000-2009, by using DEA and Tobit regression. Selected companies were doing both freight and passenger transportation. The results showed number of efficient DMUs have increased during the time.
Noroozzadeh and Sadjadi	Considering safety factors and data of 25 European railways in 2008, efficiency scores were obtained. Number of accidents was considered as undesirable

(2013)	outputs. Most inefficient DMUs converted to efficient ones by considering safety factors.
Bhanot and Singh (2014)	Indexes of business performance of container railway transportation in India, were investigated based on data of three major railway companies during 1995-2011. The results showed that efficiency of private sector is less than other sector.
Rayeni and Saljooghi (2014)	Based on a panel data related to Iranian railways from 1977 to 2010, performance of each DMU was evaluated using cross-efficiency measures.
Tavassoli et al. (2015)	A novel network DEA model was presented to evaluate performance of 13 Iranian railways in 2012. Presented model measures overall efficiency, technical efficiency of freight and passenger transportation, service effectiveness and technical effectiveness, simultaneously.
Liu et al. (2016)	Energy-environmental efficiency of road and rail TSs in 30 provenances was analyzed using non-radial DEA model in China. The results showed that railway TSs have better performance in both energy and environmental aspects compared to road transportation.
Azadeh et al. (2016a)	Using DEA and resilience engineering factors (REF), Tehran–Karaj Electrified Railway system was studied. The results showed that by considering REF, number of efficient DMUs will be increase. Group working has the highest effect on increasing railway systems efficiency.
Sameni et al. (2016)	Technical efficiency of 96 most busy passenger stations of railways in Britannia in 2008 was studied, by using a novel assessing and ranking method. According to presented method, trains stops at stations with limited capacity could be managed.
Liu et al. (2017)	Based on data of highway and railway TSs in 30 provenances of China during 2009-2012, overall environmental efficiency of land transportation, rail transportation and highway transportation were obtained. Parallel SBM DEA model was used for this study. The results showed environmental efficiency in east areas is higher than central and west areas. Also performance of railway TSs is better than highway TSs.
Zhou and Hu (2017)	Using two-stage network DEA model and considering undesirable outputs, sustainable development of Chinese railway TSs was studied during 2002-2013. This article surveyed the railway TSs in economic, social and environmental aspects. The results showed that sustainability in east area is much more than center and west area.
Djordjević et al. (2018)	Non-radial DEA model was used to survey safety at railway level crossings in European countries from 2010 to 2012 and in 2014. Desirable and undesirable outputs have been considered in this study.

Table 5.5.1. Inputs and outputs across the DEA and environmental issues of transportation literature.

Labour inputs	Number of full time employees; labor hours; Civilian transport employment;
Capital inputs	Costs of Pavement maintenance; Costs of Preventative maintenance; Costs of Major drainage; Costs of thin asphalt; Maintenance chip seals; Costs of Seal widening; Costs of area-wide pavement; Costs of Pavement smoothing; Operational costs; Land take by road infrastructure;
Environmental and energy inputs	Population; Fuel consumption; CO_2 emissions; Coal; Gasoline; Kerosene; Diesel oil; Electricity; Environmental Difficulty;

Facilities	Runway area; Apron area; Terminal area; Route; Number of aircraft; Highway Mileage; Passenger Seats; Vehicle seats;
Other production inputs	Vehicle-Kilometer (VKM) traveled by private mode; VKM traveled by transit; VKM traveled by truck; Ton-Kilometer traveled by truck; Vehicle Kilometers Travelled; Modal share by transit; Proportion of Urban to Rural Roads; Routine Maintenance; Resealing in kilometers; Rehabilitation in kilometers;
Operational Outputs	Movements; Passengers; Passenger-miles; Vehicle-miles; Smooth Travel Exposure; Surface Condition Index; Modal share by transit; Vehicle-Kilometer (VKM) traveled by private mode; VKM traveled by transit; VKM traveled by truck; Ton-Kilometer traveled by truck;
Financial outputs	Value-Added; Gross product; Passenger Turnover Volume; Freight Turnover Volume; Gross value added from transport;
Environmental and safety outputs	CO_2 emissions; Alternative energy; Emissions; Aircraft noise; Vehicles recycling; Tires recycling;

Table 5.5.2. Most cited papers related to DEA and environmental issues of TSs.

Article	Citation Value	Article	Citation Value
Chang et al. (2013b)	112	Curi et al. (2011)	52
Sheth et al. (2007)	75	Zhang and Wei (2015)	45
Yu (2004)	73	Zhou et al. (2013)	41
Zhang et al. (2015)	69	Ramanathan (2005)	37
Chang et al. (2014)	63	McMullen and Noh (2007)	30

Table 5.5.3. A review of selected papers across the DEA and environmental issues of TSs literature.

Ref.	Summary of study
Yu (2004)	Based on data of 14 domestic airports in Taiwan during 1994-2000 and considering undesirable outputs and environmental factors, efficiency was studied. Results showed that airports can improve their performance by optimal using of resources and they don't need to develop their equipment.
Ramanathan (2005)	Energy efficiency and emissions in railway and road TSs in India has been studied based on data of 1980-1994. Results showed that if %50 of land transportation is railway transportation, %35 of energy consumption will decrease.
McMullen and Noh (2007)	Based on data of 2000 and considering environmental factors, efficiency of 43 American bus transit agencies was evaluated. When environmental factor have not been considered, only 5 agencies are efficient but without considering these factors 22 agencies are efficient. Private agencies had better performance.
Rouse and Chiu (2009)	Based on data of 73 Territorial Local Authorities in New Zealand and time period 1994-2003, repair and maintenance of local roads in highways have been studied. Quantity, quality, cost and environmental criteria for efficiency, productivity and economic performance of each DMU have been considered.
Shiau and Jhang (2010)	Sustainability of transportations systems in Taiwan has evaluated by using DEA and rough set theory. This study considered data belong to 1993-2007. Cost efficiency, cost effectiveness, service effectiveness, service reduction and service impact are considered as five sustainability indicators. Results showed that cost efficiency and service reduction are the most effective factors on sustainability.
Su and Rogers	Considering economic and environmental factors, efficiency of TSs in OECD countries was analyzed. Data of 2000, 2005 and 2007 was used for this research.

(2012)	The results indicate a strong relationship between economic efficiency and environmental performance.
Zhou et al. (2013)	Based on data of 30 Chinese administrative regions during 2004-2010 and considering undesirable outputs, performance of transportation sectors was evaluated. East region had better performance, while undesirable outputs were considered. But by considering desirable and undesirable outputs simultaneously, efficiency of central region was higher than other regions.
Chang et al. (2013b)	Using non-radial DEA model with SBM and data of 30 provinces in mainland of china in 2010, environmental efficiency of transportation sector was studied. Results showed most of provinces had weak environmental efficiency scores (lees than %50)
Wu et al. (2013)	Technical efficiency of 12 Chinese and non-Chinese airports during 2006-2010 were evaluated. Salary level has positive impact on operational efficiency while international focus has negative impact.
Chang et al. (2014)	Economic and environmental efficiency of 27 airlines around the world were analyzed in 2010. Asian airports were identified as most efficient DMUs. Weakness in fuel consumption was recognized as the main cause of inefficiency.
Bi et al. (2014)	Based on data of 30 provinces in mainland of china during 2006-2010, energy consumption and environmental efficiency of transportation industry was analyzed.
Zhang et al. (2015)	Dynamic trend of CO_2 emission of TSs in 30 provinces in mainland of china from 2002 to 2010 was studied by MI. The results show that weakness in technology leads to weak environmental performance in transportation industry.
Zhang and Wei (2015)	A dynamic analyze have been done on carbon emission of TSs in 30 provinces in mainland of china from 2000 to 2012. Applying new technologies leads to better performance in environmental aspect.
Song et al. (2016)	Using super efficiency SBM and window DEA models, sustainable development, energy consumption and environmental efficiency of 30 provinces in mainland of china from 2011 to 2012, were studied. For improving the performance, surplus and slacks values were identified.
Wu et al. (2016b)	Considering data of 30 provinces in mainland of china in 2012, environmental performance and energy consumption of TSs were evaluated. Parallel DEA model was used for analyzing the sustainable development. Most of DMUs had weak efficiency scores. East areas have better performance.
Liu et al. (2016)	The non-radial DEA model and window analysis were applied to studying energy and environmental efficiency in rail and road transportation in 30 provinces in china from 1998 to 2012. Using Tobit regression, influencing factors on productivity are investigated. East areas had better performance in road transportation, while in railway transportation west areas were better.
Wang and He (2017)	This study proposed a directional distance function model for evaluating productivity, economical efficiency and CO_2 emissions efficiency. The proposed model was used for evaluating Chinese TSs during 2007-2012. The results showed that economic performance is far greater than environmental performance.
Liu et al. (2017)	Considering data of 30 provinces in china from 2009 to 2012 and using parallel SBM model, a time/region analysis of Chinese TSs was provided. Environmental factors were considered. Results showed that eastern regions have better performance compared to other areas and rail transportation have better performance compared to road transportation.

Table 5.6.1. Inputs and outputs across DEA applications in other transportation problems.

Inputs	Vehicles; Employees; Fuel; Fleet; Workhorse; Passenger kilometers; Numbers of buses operated; effective driving hours; Equipment; Cost; Transfer area; Operating expense; Number of staff in terminal; Capacity of Bus; Infrastructure cost; Travel

	Demand;
Outputs	Vehicle kms; Seat kms; Passenger km; Total no. of seats; Revenue vehicle; Level-of-service score; Timeliness-of-response score; Transfer safety; Average transfer time; Average Speed; Average Delay; Accidents;

Table 5.6.2. Most cited papers related to DEA applications in other transportation problems.

Article	Citation Value	Article	Citation Value
Kerstens (1996)	102	Jafari Songhori et al. (2011)	46
Cowie and Asenova (1999)	85	Lin et al. (2008)	46
Costa and Markellos (1997)	83	Odeck (2008)	43
Boame (2004)	77	Karlaftis (2003)	41
Odeck and Alkadi (2001)	65	Zhao et al. (2011)	38

Table 5.6.3. A review of selected papers across DEA applications in other transportation problems.

Ref.	Summary of study
Kerstens (1996)	Based on data of 54 urban transit companies in France technical efficiency was obtained and analyzed in 1990. The results showed that subsides have negative effects on efficiency.
Costa and Markellos (1997)	Using data of London subway from 1970 to 1994, efficiency of public TSs was evaluated.
Cowie and Asenova (1999)	Effect of privatization on British bus industry was evaluated using DEA. Data of 1995-96 was used. Private companies have higher efficiency. Small companies have an increasing efficiency trend.
Odeck and Alkadi (2001)	Data of 47 bus transit companies, which receive subsidy from the government was used for evaluating Norwegian bus transit systems in 1994. Effects of ownership form and operation region on efficiency scores were studied. Ownership form has not any direct effects on efficiency.
Boame (2004)	Using bootstrap DEA model and based on data of 30 selected systems during 1990-1998, technical efficiency of urban transit systems in Canada was obtained. An increasing efficiency trend was observed. Efficiency mean was %78.
Odeck (2006)	Effective factors on operational efficiency of Norwegian bus transit industries were studied. Data of 33 companies in 1994 was used. High operational costs are one of the main inefficiency reasons. Ownership form has not any effect.
Odeck (2008)	Considering data of 17 companies in pre-merger period (1995-1998) and 10 companies in post-merger period (1999-2002), the effect of mergers on Norwegian bus transit industries, was studied. Merging has positive effect.
Sun et al. (2010)	Transportation efficiency of urban public transit terminals based on data of 10 urban terminals in Beijing in 2008 was studied. Potential opportunities for improving performance were identified.
Zhao et al. (2011)	Network DEA model used for demand management in transportation networks. This study has surveyed transportation networks from service providers, users and society perspectives. Results showed that improving efficiency of nodes can lead to high efficiency in network.
Chen et al. (2012)	Using integer DEA model, considering safety records and data during 1994-2009, operational efficiency of Kaohsiung city bus systems was evaluated.
Behnood et al. (2014)	Road safety performance in 30 Iranian provinces based on data of the years 2008-2009 was studied. Indicators that cause inefficiency in the performance of each province have been identified, then some suggestions provided for improvement.
Guo et al. (2015)	Investment efficiency in transportation projects was analyzed. 13 selected

	projects were analyzed from technological efficiency, pure technological efficiency and scale efficiency perspectives.
Sun et al. (2016)	Using AHP and super-efficiency model and based on GIS data, 18 bus transit lines in Shenzhen were evaluated. This study analyzed efficiency scores in view of transit planning, operation and quality of service
Wei et al. (2017)	By combining DEA, Geographic Information System, and multi-objective spatial optimization, a new approach has been developed for evaluating public transit services for operational efficiency and access equity. The proposed approach has been applied to public transit services of Wasatch Front, Utah.

References

Abbott, M., Wu, S., 2002. Total factor productivity and efficiency of Australian airports. Australian Economic Review 35, 244-260.

Adler, N., Berechman, J., 2001. Measuring airport quality from the airlines' viewpoint: an application of data envelopment analysis. Transport Policy 8, 171-181.

Adler, N., Golany, B., 2001. Evaluation of deregulated airline networks using data envelopment analysis combined with principal component analysis with an application to Western Europe. European Journal of Operational Research 132, 260-273.

Ahn, Y.-H., Min, H., 2014. Evaluating the multi-period operating efficiency of international airports using data envelopment analysis and the Malmquist productivity index. Journal of Air Transport Management 39, 12-22.

Arjomandi, A., Seufert, J.H., 2014. An evaluation of the world's major airlines' technical and environmental performance. Economic Modelling 41, 133-144.

Assaf, A.G., Gillen, D., 2012. Measuring the joint impact of governance form and economic regulation on airport efficiency. European Journal of Operational Research 220, 187-198.

Azadeh, A., Ghaderi, S.F., Izadbakhsh, H., 2008. Integration of DEA and AHP with computer simulation for railway system improvement and optimization. Applied Mathematics and Computation 195, 775-785.

Azadeh, A., Salehi, V., Kianpour, M., 2016a. Performance evaluation of rail transportation systems by considering resilience engineering factors: Tehran railway electrification system. Transportation Letters, 1-14.

Azadeh, A., Zarrin, M., Hamid, M., 2016b. A novel framework for improvement of road accidents considering decision-making styles of drivers in a large metropolitan area. Accident Analysis & Prevention 87, 17-33.

Barbot, C., Costa, Á., Sochirca, E., 2008. Airlines performance in the new market context: A comparative productivity and efficiency analysis. Journal of Air Transport Management 14, 270-274.

BARROS, C.P., 2003. The measurement of efficiency of Portuguese sea port authorities with DEA. International Journal of Transport Economics/Rivista internazionale di economia dei trasporti, 335-354.

Barros, C.P., Athanassiou, M., 2004. Efficiency in European seaports with DEA: evidence from Greece and Portugal. Maritime Economics & Logistics 6, 122-140.

Barros, C.P., Dieke, P.U., 2007. Performance evaluation of Italian airports: A data envelopment analysis. Journal of Air Transport Management 13, 184-191.

Barros, C.P., Dieke, P.U., 2008. Measuring the economic efficiency of airports: a Simar–Wilson methodology analysis. Transportation Research Part E: Logistics and Transportation Review 44, 1039-1051.

Barros, C.P., Peypoch, N., 2009. An evaluation of European airlines' operational performance. International Journal of Production Economics 122, 525-533.

Bazargan, M., Vasigh, B., 2003. Size versus efficiency: a case study of US commercial airports. Journal of Air Transport Management 9, 187-193.

Behnood, H.R., Ayati, E., Hermans, E., Neghab, M.P., 2014. Road safety performance evaluation and policy making by data envelopment analysis: A case study of provincial data in Iran. Scientia Iranica. Transaction A, Civil Engineering 21, 1515.

Bhadra, D., 2009. Race to the bottom or swimming upstream: performance analysis of US airlines. Journal of Air Transport Management 15, 227-235.

Bhanot, N., Singh, H., 2014. Benchmarking the performance indicators of Indian Railway container business using data envelopment analysis. Benchmarking: An International Journal 21, 101-120.

Bi, G., Wang, P., Yang, F., Liang, L., 2014. Energy and environmental efficiency of China's transportation sector: a multidirectional analysis approach. Mathematical Problems in Engineering 2014.

Bichou, K., 2011. A two-stage supply chain DEA model for measuring container-terminal efficiency. International Journal of Shipping and Transport Logistics 3, 6-26.

Boame, A.K., 2004. The technical efficiency of Canadian urban transit systems. Transportation Research Part E: Logistics and Transportation Review 40, 401-416.

Bonilla, M., Medal, A., Casaus, T., Sala, R., SALA, T., 2002. The traffic in Spanish ports: An efficiency analysis. International Journal of Transport Economics/Rivista internazionale di economia dei trasporti, 215-230.

Capobianco, H.M.P., Fernandes, E., 2004. Capital structure in the world airline industry. Transportation Research Part A: Policy and Practice 38, 421-434.

Chang, Y.-C., Yu, M.-M., Chen, P.-C., 2013a. Evaluating the performance of Chinese airports. Journal of Air Transport Management 31, 19-21.

Chang, Y.-T., Park, H.-s., Jeong, J.-b., Lee, J.-w., 2014. Evaluating economic and environmental efficiency of global airlines: A SBM-DEA approach. Transportation Research Part D: Transport and Environment 27, 46-50.

Chang, Y.-T., Park, H.K., Lee, S., Kim, E., 2018. Have Emission Control Areas (ECAs) harmed port efficiency in Europe? Transportation Research Part D: Transport and Environment 58, 39-53.

Chang, Y.-T., Zhang, N., Danao, D., Zhang, N., 2013b. Environmental efficiency analysis of transportation system in China: A non-radial DEA approach. Energy policy 58, 277-283.

Chapin, A., Schmidt, S., 1999. Do mergers improve efficiency? Evidence from deregulated rail freight. Journal of Transport Economics and Policy, 147-162.

Charnes, A., Gallegos, A., Li, H., 1996. Robustly efficient parametric frontiers via multiplicative DEA for domestic and international operations of the Latin American airline industry. European Journal of Operational Research 88, 525-536.

Chen, C.-M., Du, J., Huo, J., Zhu, J., 2012. Undesirable factors in integer-valued DEA: Evaluating the operational efficiencies of city bus systems considering safety records. Decision Support Systems 54, 330-335.

Cheon, S., Maltz, A., Dooley, K., 2017. The link between economic and environmental performance of the top 10 US ports. Maritime Policy & Management 44, 227-247.

Chi-Lok, A.Y., Zhang, A., 2009. Effects of competition and policy changes on Chinese airport productivity: An empirical investigation. Journal of Air Transport Management 15, 166-174.

Chiou, Y.-C., Chen, Y.-H., 2006. Route-based performance evaluation of Taiwanese domestic airlines using data envelopment analysis. Transportation Research Part E: Logistics and Transportation Review 42, 116-127.

Chow, C.K.W., Fung, M.K.Y., 2012. Estimating indices of airport productivity in Greater China. Journal of Air Transport Management 24, 12-17.

Çipil, F., 2014. Performance Analysis of Turkey's Transport Sector Greenhouse Gas Emissions. Energy & Environment 25, 357-367.

Coelli, T., Perelman, S., 1999a. Comparison of parametric and non-parametric distance functions: With application to European railways. European Journal of Operational Research 117, 326-339.

Coelli, T., Perelman, S., 1999b. A comparison of parametric and non-parametric distance functions: With application to European railways. European journal of operational research 117, 326-339.

Cook, W.D., Green, R.H., 2000. Project prioritization: A resource-constrained data envelopment analysis approach. Socio-Economic Planning Sciences 34, 85-99.

Cook, W.D., Kazakov, A., Persaud, B.N., 2001. Prioritising highway accident sites: a data envelopment analysis model. Journal of the Operational Research Society 52, 303-309.

Cook, W.D., Kazakov, A., Roll, Y., Seiford, L.M., 1991. A data envelopment approach to measuring efficiency: case analysis of highway maintenance patrols. The Journal of Socio-Economics 20, 83-103.

Correa, C.A.V., 2012. Economic evaluation of current conditions of competition and efficiency of automotive and rail systems in Colombia. Energy policy 46, 78-87.

Costa, Á., Markellos, R.N., 1997. Evaluating public transport efficiency with neural network models. Transportation Research Part C: Emerging Technologies 5, 301-312.

Cowie, J., 1999a. The technical efficiency of public and private ownership in the rail industry: The case of Swiss private railways. Journal of Transport Economics and Policy 33, 241-252.

Cowie, J., 1999b. The technical efficiency of public and private ownership in the rail industry: the case of Swiss private railways. Journal of transport economics and policy, 241-251.

Cowie, J., Asenova, D., 1999. Organisation form, scale effects and efficiency in the British bus industry. Transportation 26, 231-248.

Cowie, J., Riddington, G., 1996. Measuring the efficiency of European railways. Applied Economics 28, 1027-1035.

Cui, Q., Li, Y., 2015. Evaluating energy efficiency for airlines: An application of VFB-DEA. Journal of Air Transport Management 44, 34-41.

Cullinane, K., Ji, P., Wang, T.-f., 2005a. The relationship between privatization and DEA estimates of efficiency in the container port industry. Journal of economics and business 57, 433-462.

Cullinane, K., Song, D.-W., Wang, T., 2005b. The application of mathematical programming approaches to estimating container port production efficiency. Journal of Productivity Analysis 24, 73-92.

Cullinane, K., Wang, T.-F., Song, D.-W., Ji, P., 2006. The technical efficiency of container ports: comparing data envelopment analysis and stochastic frontier analysis. Transportation Research Part A: Policy and Practice 40, 354-374.

Cullinane, K., Wang, T., 2010. The efficiency analysis of container port production using DEA panel data approaches. OR spectrum 32, 717-738.

Curi, C., Gitto, S., Mancuso, P., 2010. The Italian airport industry in transition: a performance analysis. Journal of Air Transport Management 16, 218-221.

Curi, C., Gitto, S., Mancuso, P., 2011. New evidence on the efficiency of Italian airports: A bootstrapped DEA analysis. Socio-Economic Planning Sciences 45, 84-93.

De Nicola, A., Gitto, S., Mancuso, P., 2013. Airport quality and productivity changes: A Malmquist index decomposition assessment. Transportation Research Part E: Logistics and Transportation Review 58, 67-75.

De Oliveira, G.F., Cariou, P., 2015. The impact of competition on container port (in) efficiency. Transportation Research Part A: Policy and Practice 78, 124-133.

Díaz-Hernández, J.J., Martínez-Budría, E., Salazar-González, J.J., 2014. Measuring cost efficiency in the presence of quasi-fixed inputs using dynamic Data Envelopment Analysis: The case of port infrastructure. Maritime Economics & Logistics 16, 111-126.

Djordjević, B., Krmac, E., Mlinarić, T.J., 2018. Non-radial DEA model: A new approach to evaluation of safety at railway level crossings. Safety Science 103, 234-246.

Egilmez, G., McAvoy, D., 2013. Benchmarking road safety of US states: A DEA-based Malmquist productivity index approach. Accident Analysis & Prevention 53, 55-64.

Fan, L., Wu, F., Zhou, P., 2014. Efficiency measurement of Chinese airports with flight delays by directional distance function. Journal of Air Transport Management 34, 140-145.

Fernandes, E., Pacheco, R., 2002. Efficient use of airport capacity. Transportation research part A: Policy and practice 36, 225-238.

Fung, M.K.Y., Wan, K.K.H., Van Hui, Y., Law, J.S., 2008. Productivity changes in Chinese airports 1995–2004. Transportation Research Part E: Logistics and Transportation Review 44, 521-542.

George, S.A., Rangaraj, N., 2008. A performance benchmarking study of Indian Railway zones. Benchmarking 15, 599-617.

Gillen, D., Lall, A., 1997. Developing measures of airport productivity and performance: an application of data envelopment analysis. Transportation Research Part E: Logistics and Transportation Review 33, 261-273.

Graham, D.J., 2008. Productivity and efficiency in urban railways: Parametric and non-parametric estimates. Transportation Research Part E: Logistics and Transportation Review 44, 84-99.

Greer, M., 2009. Is it the labor unions' fault? Dissecting the causes of the impaired technical efficiencies of the legacy carriers in the United States. Transportation Research Part A: Policy and Practice 43, 779-789.

Greer, M.R., 2008. Nothing focuses the mind on productivity quite like the fear of liquidation: changes in airline productivity in the United States, 2000–2004. Transportation Research Part A: Policy and Practice 42, 414-426.

Growitsch, C., Wetzel, H., 2009a. Testing for economies of scope in European railways. Journal of Transport Economics and Policy 43, 1-24.

Growitsch, C., Wetzel, H., 2009b. Testing for economies of scope in European railways: an efficiency analysis. Journal of Transport Economics and Policy (JTEP) 43, 1-24.

Guo, W., Gong, D., Hu, J., 2015. Applying Data Envelopment Analysis (DEA) approach to analyse investment efficiency of transportation projects. Advances in Transportation Studies.

Ha, H.-K., Wan, Y., Yoshida, Y., Zhang, A., 2013. Airline market structure and airport efficiency: Evidence from major Northeast Asian airports. Journal of Air Transport Management 33, 32-42.

Hilmola, O.-P., 2007. European railway freight transportation and adaptation to demand decline: Efficiency and partial productivity analysis from period of 1980-2003. International Journal of Productivity and Performance Management 56, 205-225.

Hilmola, O.-P., 2011. Role of location in railway sector efficiency. International Journal of Logistics Systems and Management 10, 478-494.

Hung, S.-W., Lu, W.-M., Wang, T.-P., 2010. Benchmarking the operating efficiency of Asia container ports. European journal of operational research 203, 706-713.

Itoh, H., 2002. Effeciency changes at major container ports in Japan: A window application of data envelopment analysis. Review of urban & regional development studies 14, 133-152.

Jafari Songhori, M., Tavana, M., Azadeh, A., Khakbaz, M.H., 2011. A supplier selection and order allocation model with multiple transportation alternatives. International Journal of Advanced Manufacturing Technology 52, 365-376.

Jain, P., Cullinane, S., Cullinane, K., 2008. The impact of governance development models on urban rail efficiency. Transportation Research Part A: Policy and Practice 42, 1238-1250.

Jitsuzumi, T., Nakamura, A., 2010. Causes of inefficiency in Japanese railways: Application of DEA for managers and policymakers. Socio-Economic Planning Sciences 44, 161-173.

Karlaftis, M.G., 2003. Investigating transit production and performance: A programming approach. Transportation Research Part A: Policy and Practice 37, 225-240.

Kazakov, A., Cook, W.D., Roll, Y., 1989. Measurement of highway maintenance patrol efficiency: model and factors. Transportation Research Record.

Kerstens, K., 1996. Technical efficiency measurement and explanation of French urban transit companies. Transportation Research Part A: Policy and Practice 30, 431-452.

Kim, H.-G., Choi, C.-Y., Woo, J.-W., Choi, Y., Kim, K., Wu, D.D., 2011. Efficiency of the modal shift and environmental policy on the Korean railroad. Stochastic environmental research and risk assessment 25, 305-322.

Kutlar, A., Kabasakal, A., Sarikaya, M., 2013. Determination of the efficiency of the world railway companies by method of DEA and comparison of their efficiency by Tobit analysis. Quality & Quantity 47, 3575-3602.

Lam, S.W., Low, J.M., Tang, L.C., 2009. Operational efficiencies across Asia Pacific airports. Transportation Research Part E: Logistics and Transportation Review 45, 654-665.

Lan, L.W., Lin, E.T., 2005. Measuring railway performance with adjustment of environmental effects, data noise and slacks. Transportmetrica 1, 161-189.

Leal, I.C., de Almada Garcia, P.A., Márcio de Almeida, D.A., 2012. A data envelopment analysis approach to choose transport modes based on eco-efficiency. Environment, development and sustainability 14, 767-781.

Lee, B.L., Worthington, A.C., 2014. Technical efficiency of mainstream airlines and low-cost carriers: New evidence using bootstrap data envelopment analysis truncated regression. Journal of Air Transport Management 38, 15-20.

Lee, G., Yu, M.-M., Wang, L.-C., 2012. DEA-based integrated relationship of returns to scale–an application to road maintenance in Taiwan. Journal of Civil Engineering and Management 18, 709-723.

Li, Z., Zhao, L., Yuan, Z., 2016. Highway Transportation Efficiency Evaluation for Beijing-Tianjin-Hebei Region Based on Advanced DEA Model. International review for spatial planning and sustainable development 4, 36-44.

Lin, J., Wang, P., Barnum, D.T., 2008. A quality control framework for bus schedule reliability. Transportation Research Part E: Logistics and Transportation Review 44, 1086-1098.

Lin, L., Hong, C., 2006. Operational performance evaluation of international major airports: An application of data envelopment analysis. Journal of Air Transport Management 12, 342-351.

Lin, L., Tseng, C., 2007. Operational performance evaluation of major container ports in the Asia-Pacific region. Maritime Policy & Management 34, 535-551.

Liu, C.-C., 2008. Evaluating the operational efficiency of major ports in the Asia-Pacific region using data envelopment analysis. Applied economics 40, 1737-1743.

Liu, D., 2016. Measuring aeronautical service efficiency and commercial service efficiency of East Asia airport companies: An application of Network Data Envelopment Analysis. Journal of Air Transport Management 52, 11-22.

Liu, D., 2017. Evaluating the multi-period efficiency of East Asia airport companies. Journal of Air Transport Management 59, 71-82.

Liu, H., Zhang, Y., Zhu, Q., Chu, J., 2017. Environmental efficiency of land transportation in China: A parallel slack-based measure for regional and temporal analysis. Journal of Cleaner Production 142, 867-876.

Liu, Z., Qin, C.-X., Zhang, Y.-J., 2016. The energy-environment efficiency of road and railway sectors in China: Evidence from the provincial level. Ecological Indicators 69, 559-570.

Lozano, S., 2009. Estimating productivity growth of Spanish ports using a non-radial, non-oriented Malmquist index. International Journal of Shipping and Transport Logistics 1, 227-248.

Lozano, S., Villa, G., Canca, D., 2011. Application of centralised DEA approach to capital budgeting in Spanish ports. Computers & Industrial Engineering 60, 455-465.

Martín, J.C., Reggiani, A., 2007. Recent methodological developments to measure spatial interaction: Synthetic accessibility indices applied to high-speed train investments. Transport Reviews 27, 551-571.

Martín, J.C., Román, C., 2001. An application of DEA to measure the efficieny of Spanish airports prior to privatization. Journal of Air Transport Management 7, 149-157.

Martín, J.C., Roman, C., 2001. An application of DEA to measure the efficiency of Spanish airports prior to privatization. Journal of Air Transport Management 7, 149-157.

Martinez-Budria, E., Diaz-Armas, R., Navarro-Ibanez, M., Ravelo-Mesa, T., 1999. A study of the efficiency of Spanish port authorities using data envelopment analysis. International Journal of Transport Economics/Rivista internazionale di economia dei trasporti, 237-253.

Mbangala Mapapa, A., 2004. Management of railways in Sub-Saharan Africa. Rail International 35.

McMullen, B.S., Noh, D.-W., 2007. Accounting for emissions in the measurement of transit agency efficiency: A directional distance function approach. Transportation Research Part D: Transport and Environment 12, 1-9.

Merkert, R., Assaf, A.G., 2015. Using DEA models to jointly estimate service quality perception and profitability–Evidence from international airports. Transportation Research Part A: Policy and Practice 75, 42-50.

Merkert, R., Hensher, D.A., 2011. The impact of strategic management and fleet planning on airline efficiency–A random effects Tobit model based on DEA efficiency scores. Transportation Research Part A: Policy and Practice 45, 686-695.

Merkert, R., Mangia, L., 2014. Efficiency of Italian and Norwegian airports: A matter of management or of the level of competition in remote regions? Transportation Research Part A: Policy and Practice 62, 30-38.

Mohajeri, N., Amin, G.R., 2010. Railway station site selection using analytical hierarchy process and data envelopment analysis. Computers & Industrial Engineering 59, 107-114.

Monda, B., Giorgino, M., Daito, N., Gifford, J.L., 2014. US highway public private partnerships: Are they more expensive or efficient than the traditional model? Managerial Finance 40, 1131-1151.

Mousavizadeh, R., Khalili-Damghani, K., 2017. Cooperative mechanism based on data envelopment analysis and artificial neural network to measure efficiency: case study of Iranian ports. International Journal of Applied Decision Sciences 10, 52-68.

Nguyen, H.-O., Nguyen, H.-V., Chang, Y.-T., Chin, A.T., Tongzon, J., 2016. Measuring port efficiency using bootstrapped DEA: the case of Vietnamese ports. Maritime Policy & Management 43, 644-659.

Niavis, S., Tsekeris, T., 2012. Ranking and causes of inefficiency of container seaports in South-Eastern Europe. European Transport Research Review 4, 235-244.

Noroozzadeh, A., Sadjadi, S., 2013. A new approach to evaluate railways efficiency considering safety measures. Decision Science Letters 2, 71-80.

Nozick, L.K., Borderas, H., Meyburg, A.H., 1998. Evaluation of travel demand measures and programs: A data envelopment analysis approach. Transportation Research Part A: Policy and Practice 32, 331-343.

Odeck, J., 2006. Congestion, ownership, region of operation, and scale: Their impact on bus operator performance in Norway. Socio-Economic Planning Sciences 40, 52-69.

Odeck, J., 2008. The effect of mergers on efficiency and productivity of public transport services. Transportation Research Part A: Policy and Practice 42, 696-708.

Odeck, J., Alkadi, A., 2001. Evaluating efficiency in the Norwegian bus industry using data envelopment analysis. Transportation 28, 211-232.

Omrani, H., Soltanzadeh, E., 2016. Dynamic DEA models with network structure: An application for Iranian airlines. Journal of Air Transport Management 57, 52-61.

Örkcü, H.H., Balıkçı, C., Dogan, M.I., Genç, A., 2016. An evaluation of the operational efficiency of turkish airports using data envelopment analysis and the Malmquist productivity index: 2009–2014 case. Transport Policy 48, 92-104.

Ouellette, P., Petit, P., Tessier-Parent, L.-P., Vigeant, S., 2010. Introducing regulation in the measurement of efficiency, with an application to the Canadian air carriers industry. European Journal of Operational Research 200, 216-226.

Ozbek, M.E., de la Garza, J.M., Triantis, K., 2010. Efficiency measurement of bridge maintenance using data envelopment analysis. Journal of Infrastructure Systems 16, 31-39.

Pacheco, R., Fernandes, E., 2003. Managerial efficiency of Brazilian airports. Transportation Research Part A: Policy and Practice 37, 667-680.

Panayides, P.M., Maxoulis, C.N., Wang, T.F., Ng, K.Y.A., 2009. A critical analysis of DEA applications to seaport economic efficiency measurement. Transport Reviews 29, 183-206.

Park, R.-K., De, P., 2004. An alternative approach to efficiency measurement of seaports. Maritime Economics & Logistics 6, 53-69.

Parker, D., 1999. The performance of BAA before and after privatisation a DE a study. Journal of Transport Economics and Policy 33, 133-146.

Pels, E., Nijkamp, P., Rietveld, P., 2001. Relative efficiency of European airports. Transport Policy 8, 183-192.

Pels, E., Nijkamp, P., Rietveld, P., 2003. Inefficiencies and scale economies of European airport operations. Transportation Research Part E: Logistics and Transportation Review 39, 341-361.

Pillania, R.K., Jim Wu, Y.-C., Lin, C.-W., 2008. National port competitiveness: implications for India. Management Decision 46, 1482-1507.

Ramanathan, R., 2005. Estimating energy consumption of transport modes in India using DEA and application to energy and environmental policy. Journal of the Operational Research Society 56, 732-737.

Rayeni, M.M., Saljooghi, F.H., 2014. Ranking and measuring efficiency using secondary goals of cross-efficiency evaluation–a study of railway efficiency in Iran. International Journal of Services and Operations Management 17, 1-16.

Rios, L.R., Maçada, A.C.G., 2006. Analysing the relative efficiency of container terminals of Mercosur using DEA. Maritime Economics & Logistics 8, 331-346.

Roll, Y., Cook, W.D., Golany, B., 1991. Controlling factor weights in data envelopment analysis. IIE Transactions (Institute of Industrial Engineers) 23, 2-9.

Roll, Y., Hayuth, Y., 1993. Port performance comparison applying data envelopment analysis (DEA). Maritime Policy and Management 20, 153-161.

Rouse, P., Chiu, T., 2009. Towards optimal life cycle management in a road maintenance setting using DEA. European Journal of Operational Research 196, 672-681.

Rouse, P., Putterill, M., 2005. Local government amalgamation policy: A highway maintenance evaluation. Management Accounting Research 16, 438-463.

Rouse, P., Putterill, M., Ryan, D., 1997. Towards a general managerial framework for performance measurement: A comprehensive highway maintenance application. Journal of Productivity Analysis 8, 127-149.

Sameni, M.K., Preston, J., Sameni, M.K., 2016. Evaluating efficiency of passenger railway stations: A DEA approach. Research in Transportation Business & Management 20, 33-38.

Sarkis, J., 2000a. Analysis of the operational efficiency of major airports in the United States. Journal of Operations Management 18, 335-351.

Sarkis, J., 2000b. An analysis of the operational efficiency of major airports in the United States. Journal of Operations management 18, 335-351.

Sarkis, J., Talluri, S., 2004. Performance based clustering for benchmarking of US airports. Transportation Research Part A: Policy and Practice 38, 329-346.

Schefczyk, M., 1993. Operational performance of airlines: an extension of traditional measurement paradigms. Strategic Management Journal 14, 301-317.

Scheraga, C.A., 2004. Operational efficiency versus financial mobility in the global airline industry: a data envelopment and Tobit analysis. Transportation Research Part A: Policy and Practice 38, 383-404.

Semenick Alam, I.M., Sickles, R.C., 2000. Time series analysis of deregulatory dynamics and technical efficiency: the case of the US airline industry. International Economic Review 41, 203-218.

Sengupta, J.K., 1999. A dynamic efficiency model using data envelopment analysis. International Journal of Production Economics 62, 209-218.

Shao, Y., Sun, C., 2016. Performance evaluation of China's air routes based on network data envelopment analysis approach. Journal of Air Transport Management 55, 67-75.

Sharma, M.J., Yu, S.J., 2009. Performance based stratification and clustering for benchmarking of container terminals. Expert Systems with Applications 36, 5016-5022.

Sheth, C., Triantis, K., Teodorović, D., 2007. Performance evaluation of bus routes: A provider and passenger perspective. Transportation Research Part E: Logistics and Transportation Review 43, 453-478.

Shi, F.X., Hoon Lim, S., Chi, J., 2011. Railroad productivity analysis: case of the American Class I railroads. International Journal of Productivity and Performance Management 60, 372-386.

Shiau, T.-A., Jhang, J.-S., 2010. An integration model of DEA and RST for measuring transport sustainability. International Journal of Sustainable Development & World Ecology 17, 76-83.

Song, M., Zheng, W., Wang, Z., 2016. Environmental efficiency and energy consumption of highway transportation systems in China. International Journal of Production Economics 181, 441-449.

Su, J., Rogers, M.M., 2012. The role of economic variables and CO2 emissions in examining the efficiency of National Transportation Systems. International Journal of Sustainable Transportation 6, 48-66.

Sun, D., Chen, S., Zhang, C., Shen, S., 2016. A bus route evaluation model based on GIS and super-efficient data envelopment analysis. Transportation Planning and Technology 39, 407-423.

Sun, L., Rong, J., Yao, L., 2010. Measuring transfer efficiency of urban public transportation terminals by data envelopment analysis. Journal of urban planning and development 136, 314-319.

Tatari, O., Egilmez, G., Kurmapu, D., 2016. Socio-eco-efficiency analysis of highways: a data envelopment analysis. Journal of Civil Engineering and Management 22, 747-757.

Tavassoli, M., Faramarzi, G.R., Saen, R.F., 2014. Efficiency and effectiveness in airline performance using a SBM-NDEA model in the presence of shared input. Journal of Air Transport Management 34, 146-153.

Tavassoli, M., Faramarzi, G.R., Saen, R.F., 2015. A joint measurement of efficiency and effectiveness using network data envelopment analysis approach in the presence of shared input. Opsearch 52, 490-504.

Tongzon, J., 2001. Efficiency measurement of selected Australian and other international ports using data envelopment analysis. Transportation Research Part A: Policy and Practice 35, 107-122.

Tsikriktsis, N., Heineke, J., 2004. The impact of process variation on customer dissatisfaction: Evidence from the US domestic airline industry. Decision Sciences 35, 129-141.

Tsui, W.H.K., Balli, H.O., Gilbey, A., Gow, H., 2014. Operational efficiency of Asia–Pacific airports. Journal of Air Transport Management 40, 16-24.

Turner, H., Windle, R., Dresner, M., 2004. North American containerport productivity: 1984–1997. Transportation Research Part E: Logistics and Transportation Review 40, 339-356.

Wang, L.-C., Tsai, H.-Y., 2009. Evaluation of Highway Maintenance Performance Using Data Envelopment Analysis (DEA) in Taiwan. Journal of Marine Science and Technology 17, 145-155.

Wang, T.-F., Cullinane, K., 2006. The efficiency of European container terminals and implications for supply chain management. Maritime Economics & Logistics 8, 82-99.

Wang, Z., He, W., 2017. CO 2 emissions efficiency and marginal abatement costs of the regional transportation sectors in China. Transportation Research Part D: Transport and Environment 50, 83-97.

Wanke, P., Barros, C.P., 2016. New evidence on the determinants of efficiency at Brazilian ports: a bootstrapped DEA analysis. International Journal of Shipping and Transport Logistics 8, 250-272.

Wanke, P.F., 2013. Physical infrastructure and shipment consolidation efficiency drivers in Brazilian ports: A two-stage network-DEA approach. Transport Policy 29, 145-153.

Wanke, P.F., Barbastefano, R.G., Hijjar, M.F., 2011. Determinants of efficiency at major Brazilian port terminals. Transport Reviews 31, 653-677.

Wanke, P.F., Barros, C.P., 2015. Public-private partnerships and scale efficiency in Brazilian ports: Evidence from two-stage DEA analysis. Socio-Economic Planning Sciences 51, 13-22.

Wei, R., Liu, X., Mu, Y., Wang, L., Golub, A., Farber, S., 2017. Evaluating public transit services for operational efficiency and access equity. Journal of Transport Geography 65, 70-79.

Wu, J., Chu, J., An, Q., Sun, J., Yin, P., 2016a. Resource reallocation and target setting for improving environmental performance of DMUs: An application to regional highway transportation systems in China. Transportation Research Part D: Transport and Environment.

Wu, J., Zhu, Q., Chu, J., Liu, H., Liang, L., 2016b. Measuring energy and environmental efficiency of transportation systems in China based on a parallel DEA approach. Transportation Research Part D: Transport and Environment 48, 460-472.

Wu, W.-Y., Liao, Y.-K., 2014. A balanced scorecard envelopment approach to assess airlines' performance. Industrial Management & Data Systems 114, 123-143.

Wu, Y.-C.J., Goh, M., 2010. Container port efficiency in emerging and more advanced markets. Transportation Research Part E: Logistics and Transportation Review 46, 1030-1042.

Wu, Y., He, C., Cao, X., 2013. The impact of environmental variables on the efficiency of Chinese and other non-Chinese airlines. Journal of Air Transport Management 29, 35-38.

Yoshida, Y., Fujimoto, H., 2004. Japanese-airport benchmarking with the DEA and endogenous-weight TFP methods: testing the criticism of overinvestment in Japanese regional airports. Transportation Research Part E: Logistics and Transportation Review 40, 533-546.

Yu, M.-M., 2004. Measuring physical efficiency of domestic airports in Taiwan with undesirable outputs and environmental factors. Journal of Air Transport Management 10, 295-303.

Yu, M.-M., 2008a. Assessing the technical efficiency, service effectiveness, and technical effectiveness of the world’s railways through NDEA analysis. Transportation Research Part A: Policy and Practice 42, 1283-1294.

Yu, M.-M., Hsu, S.-H., Chang, C.-C., Lee, D.-H., 2008. Productivity growth of Taiwan’s major domestic airports in the presence of aircraft noise. Transportation Research Part E: Logistics and Transportation Review 44, 543-554.

Yu, M.-M., Lin, E.T., 2008a. Efficiency and effectiveness in railway performance using a multi-activity network DEA model. Omega 36, 1005-1017.

Yu, M.M., 2008b. Measuring the efficiency and return to scale status of multi-mode bus transit - Evidence from Taiwan's bus system. Applied Economics Letters 15, 647-653.

Yu, M.M., 2010. Assessment of airport performance using the SBM-NDEA model. Omega 38, 440-452.

Yu, M.M., Fan, C.K., 2006. Measuring the cost effectiveness of multimode bus transit in the presence of accident risks. Transportation Planning and Technology 29, 383-407.

Yu, M.M., Lin, E.T.J., 2008b. Efficiency and effectiveness in railway performance using a multi-activity network DEA model. Omega 36, 1005-1017.

Yuen, A.C.-l., Zhang, A., Cheung, W., 2013. Foreign participation and competition: A way to improve the container port efficiency in China? Transportation Research Part A: Policy and Practice 49, 220-231.

Zhang, N., Wei, X., 2015. Dynamic total factor carbon emissions performance changes in the Chinese transportation industry. Applied Energy 146, 409-420.

Zhang, N., Zhou, P., Kung, C.-C., 2015. Total-factor carbon emission performance of the Chinese transportation industry: A bootstrapped non-radial Malmquist index analysis. Renewable and Sustainable Energy Reviews 41, 584-593.

Zhao, Y., Triantis, K., Murray-Tuite, P., Edara, P., 2011. Performance measurement of a transportation network with a downtown space reservation system: A network-DEA approach. Transportation Research Part E: Logistics and Transportation Review 47, 1140-1159.

Zhou, G., Chung, W., Zhang, X., 2013. A study of carbon dioxide emissions performance of China's transport sector. Energy 50, 302-314.

Zhou, G., Min, H., Xu, C., Cao, Z., 2008. Evaluating the comparative efficiency of Chinese third-party logistics providers using data envelopment analysis. International Journal of physical distribution & logistics management 38, 262-279.

Zhou, H., Hu, H., 2017. Sustainability Evaluation of Railways in China Using a Two-Stage Network DEA Model with Undesirable Outputs and Shared Resources. Sustainability 9, 150.

Online Supplement: Part 2 (List of Figures in each cluster)

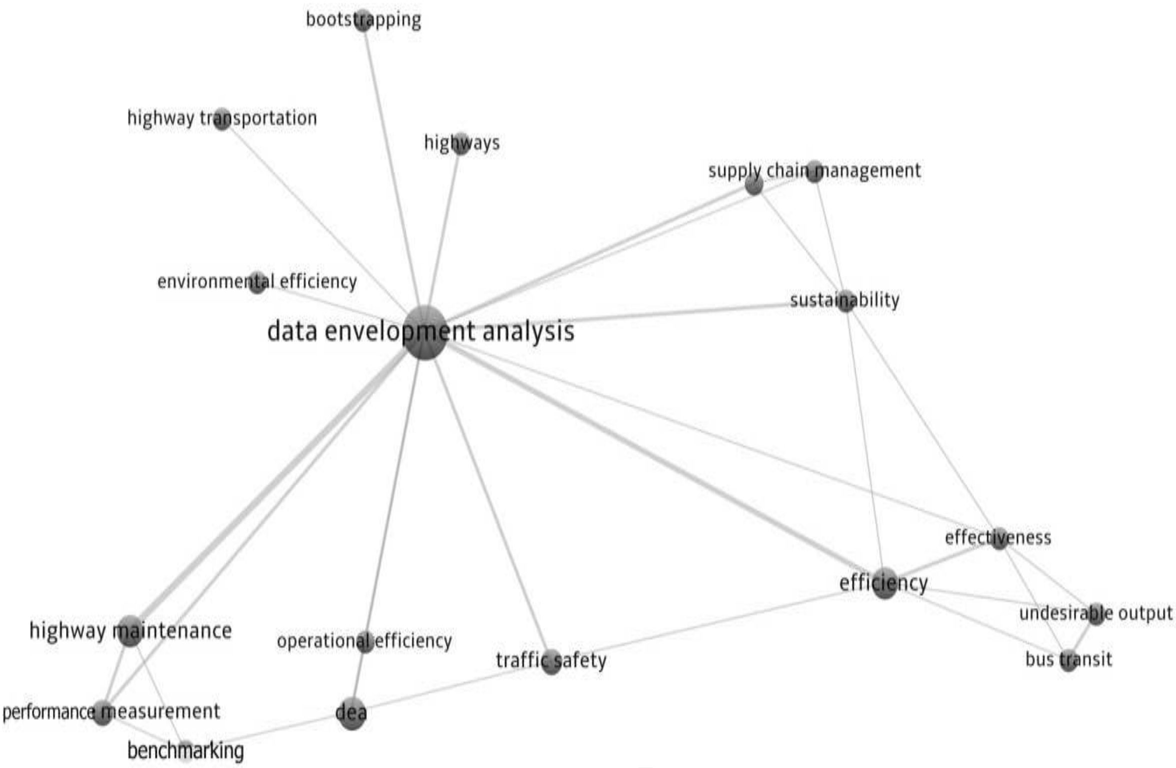


Figure 5.1.1. Map of most co-occurrence keywords related to DEA applications in highway transportation

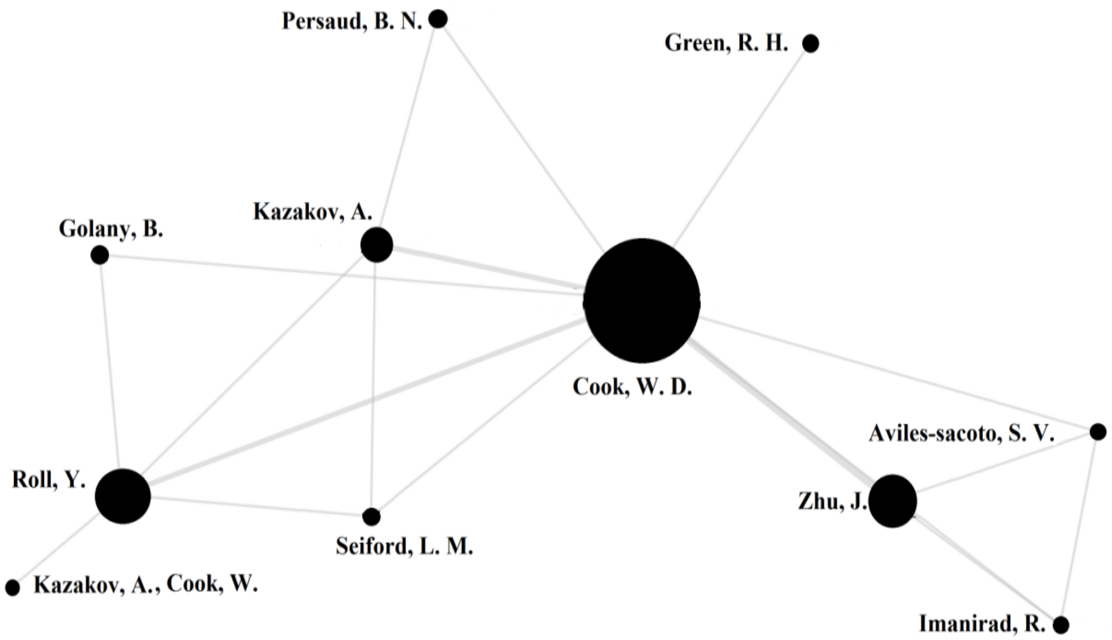


Figure 5.1.2. Map of co-authorship network related to DEA applications in highway TSs

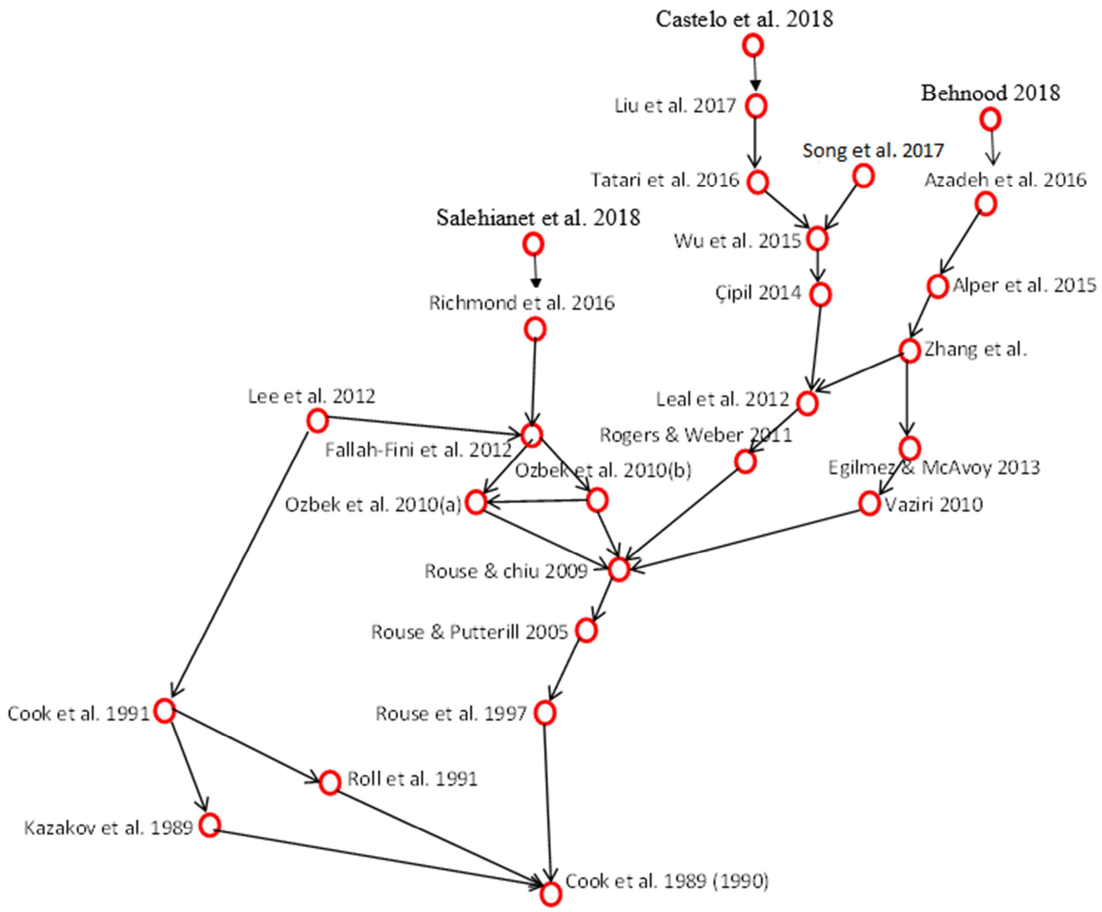


Figure 5.5.3. CPM of development of DEA applications in highway TSs.

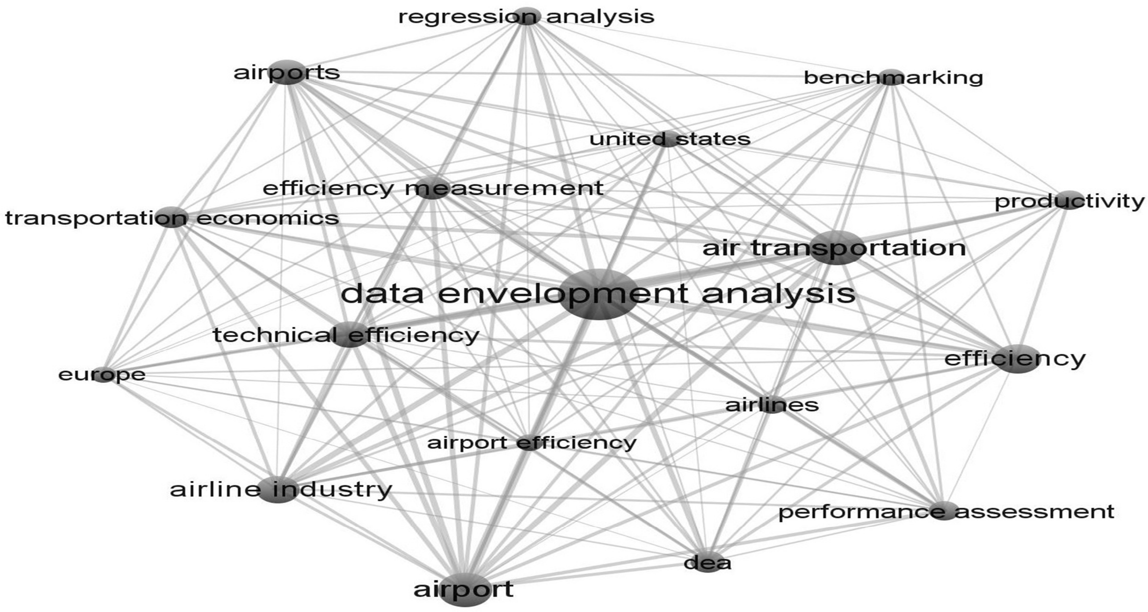
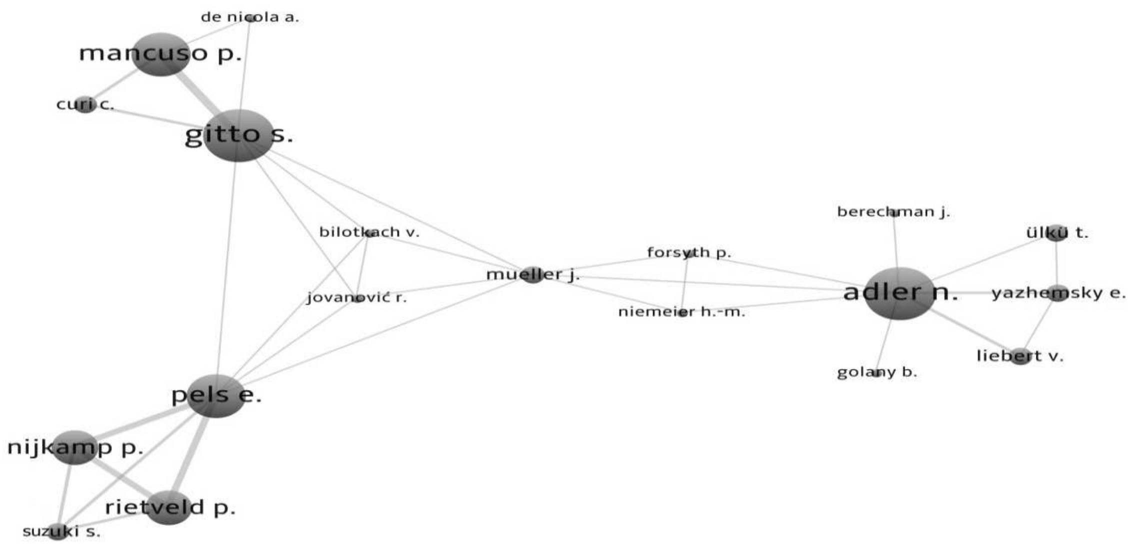


Figure 5.2.1. Map of most co-occurrence keywords related to DEA applications in air TSs



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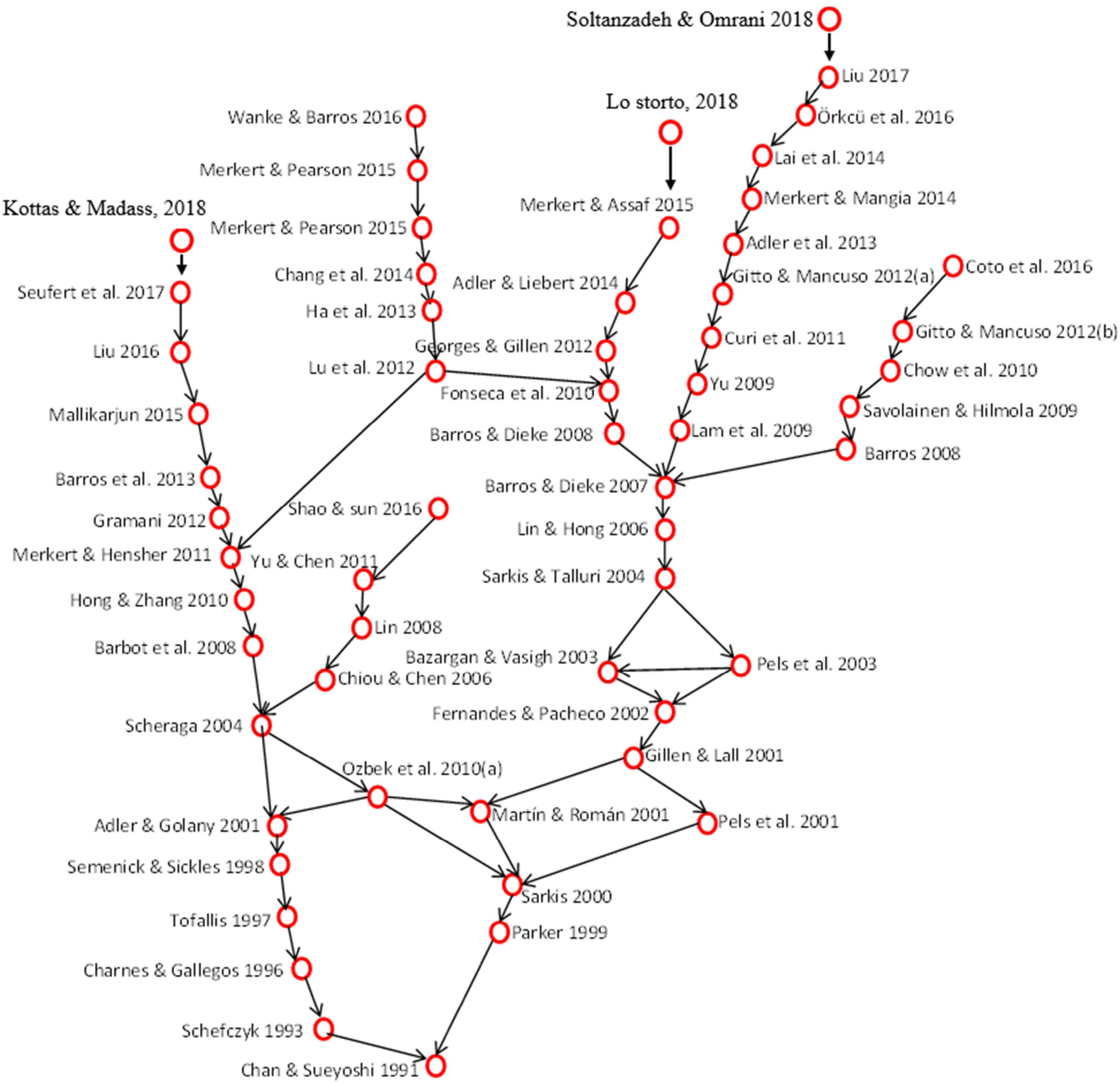

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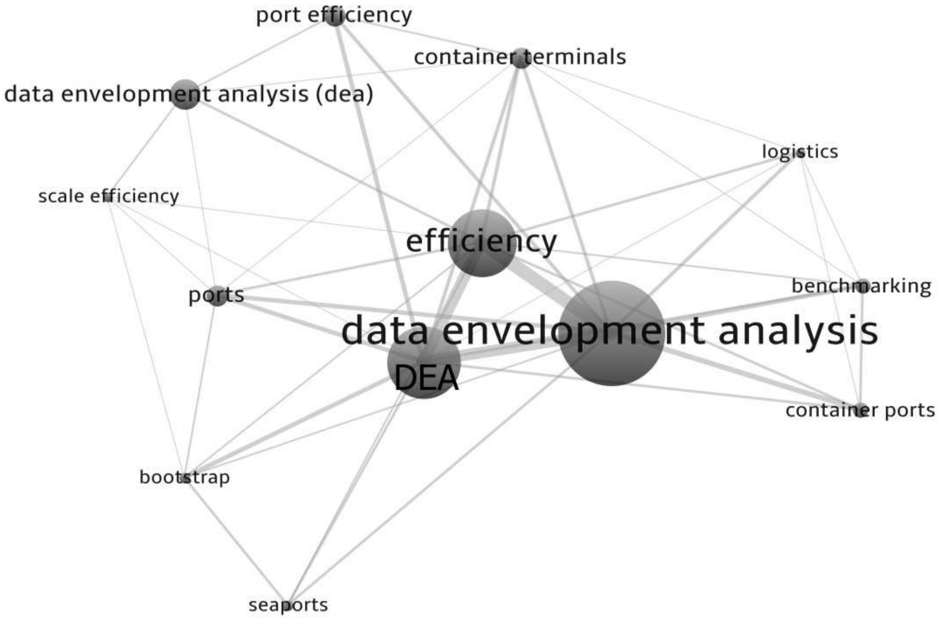
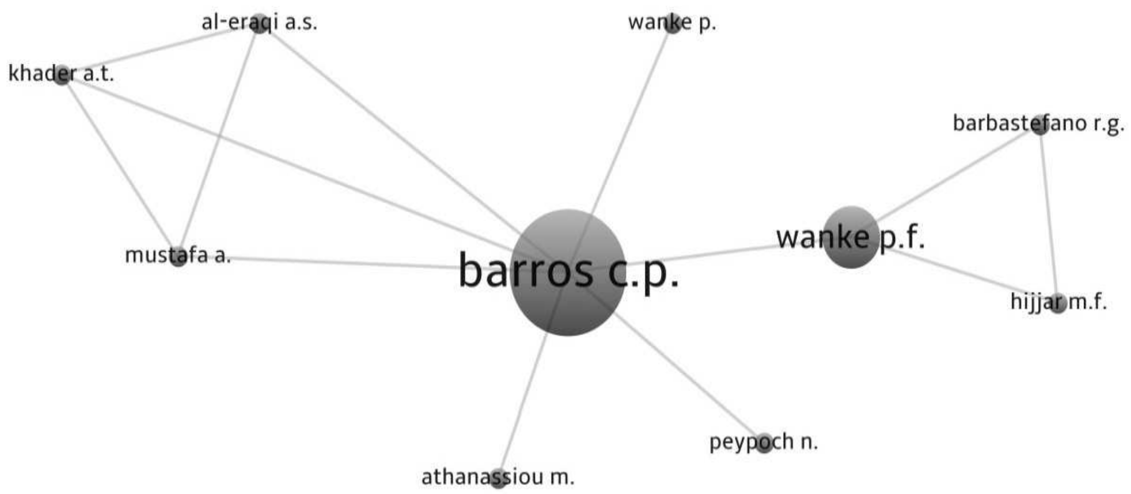


Figure 5.3.1. Map of most co-occurrence keywords related to DEA applications in maritime TSs



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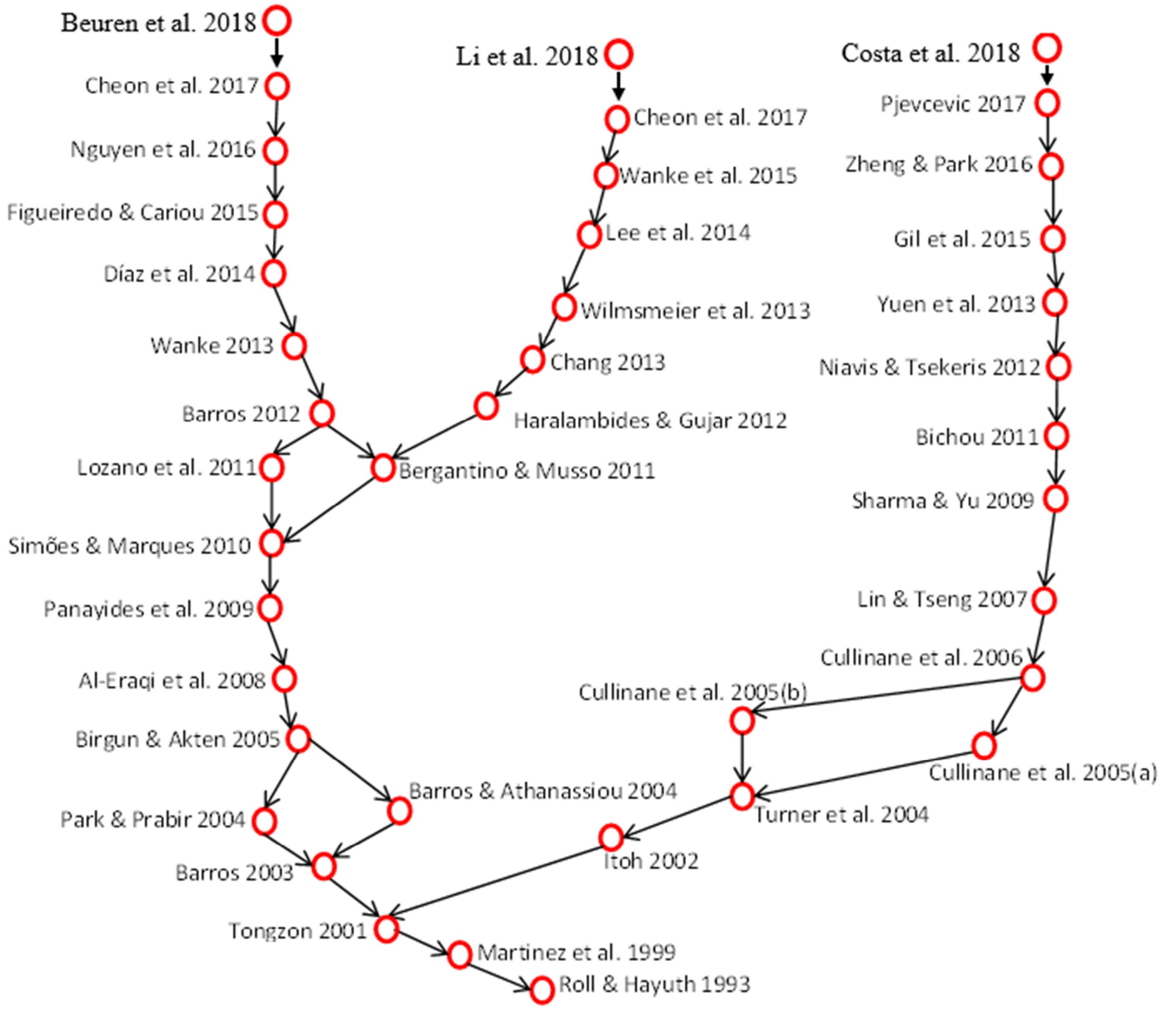

Figure 5.3.3. CPM of development of DEA applications in maritime TSs.

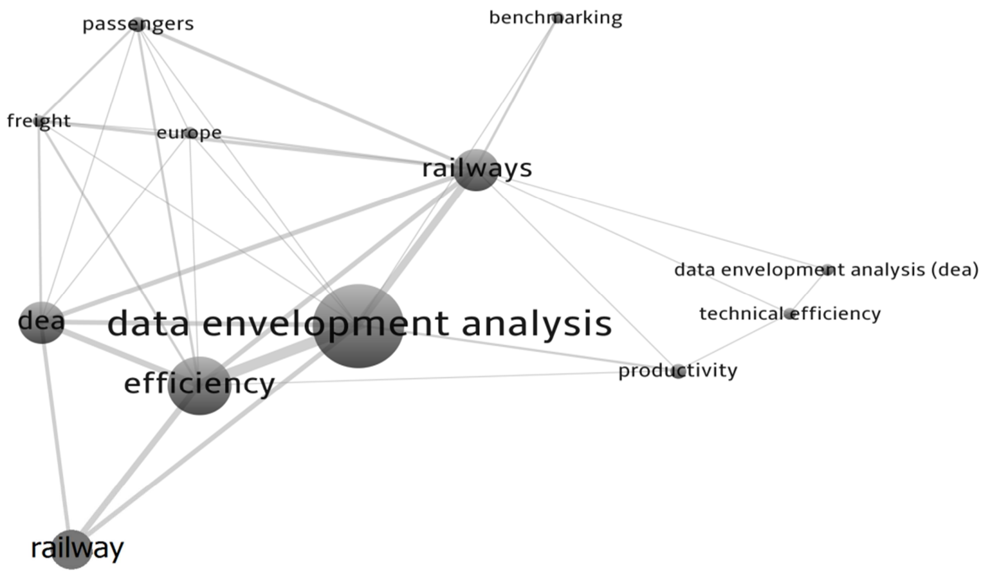

Figure 5.4.1. Map of most co-occurrence keywords related to DEA applications in railway TSs

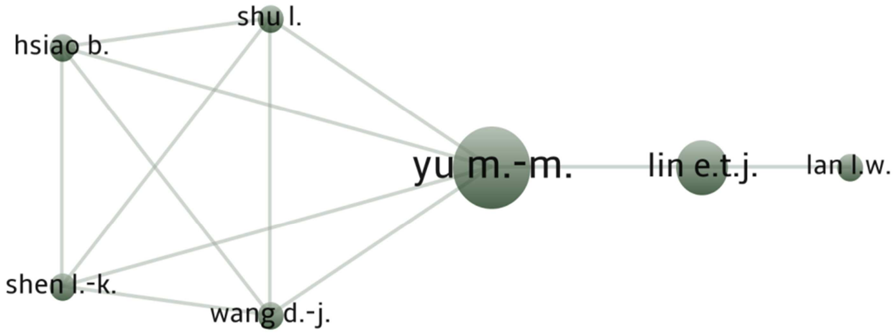

Figure 5.4.2. Map of co-authorship network related to DEA applications in railway TSs

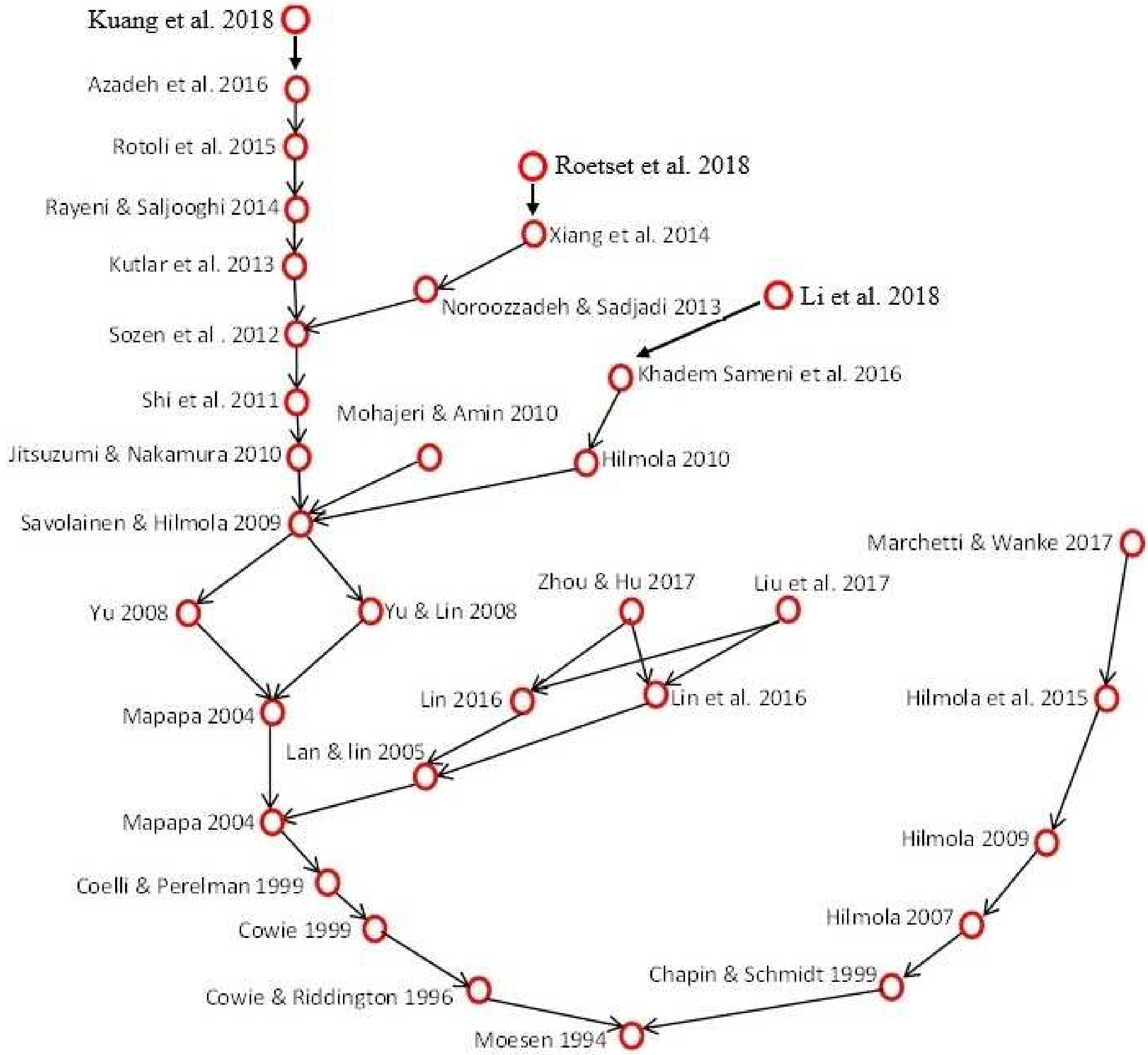

Figure 5.4.3. CPM of development of DEA applications in railway TSs.

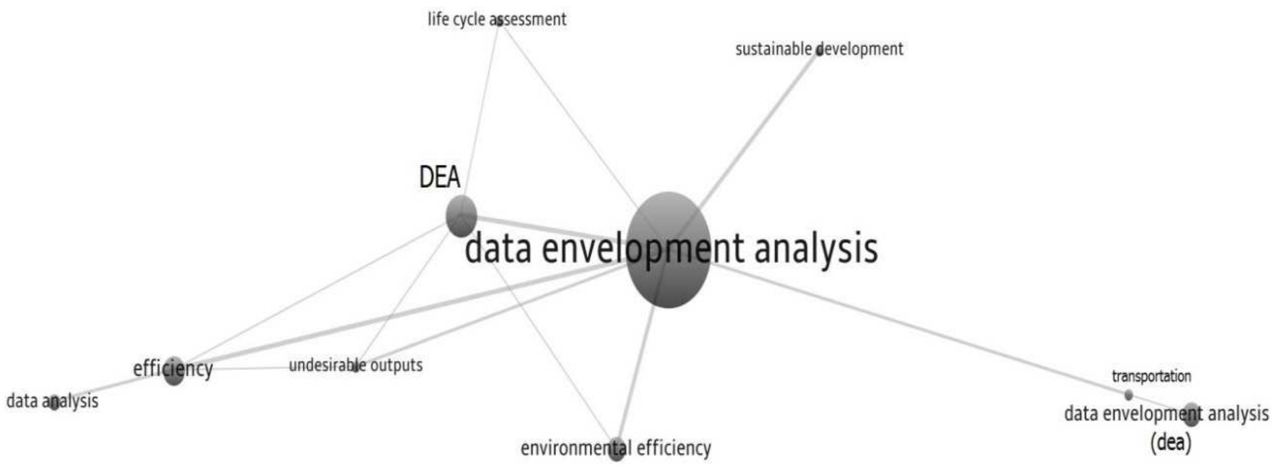

Figure 5.5.1. Map of most co-occurrence keywords related to DEA and environmental issues of TSs

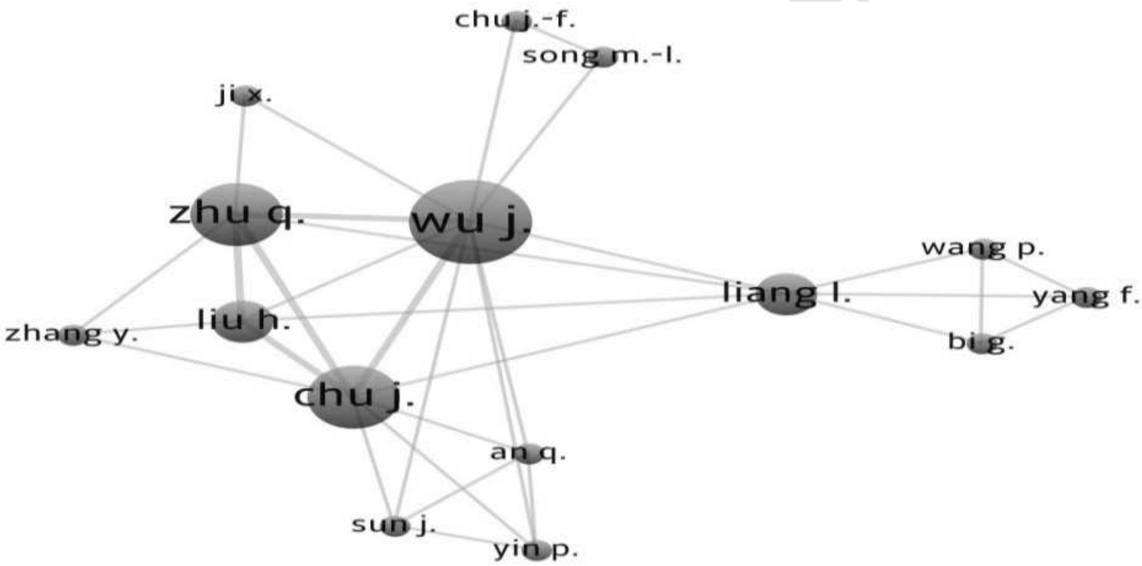

Figure 5.5.2. Map of co-authorship network related to DEA and environmental issues of TSs

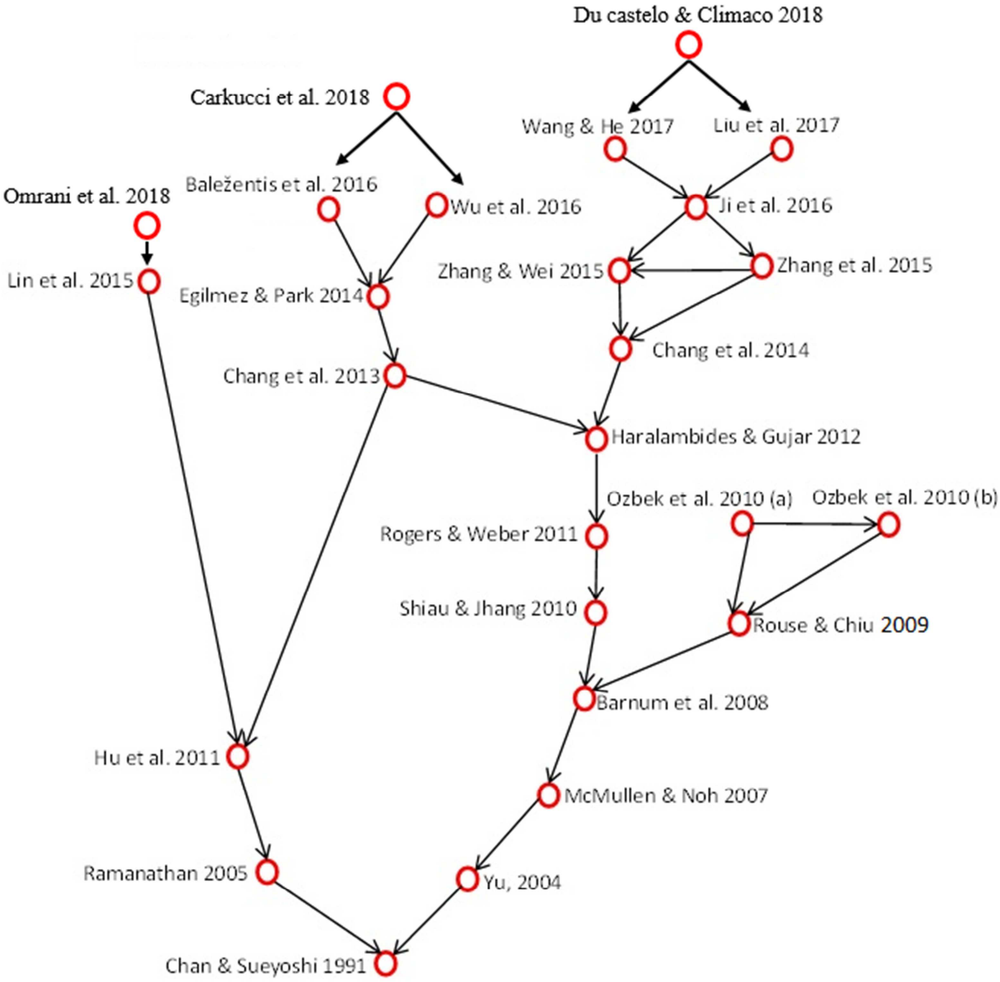

Figure 5.5.3. CPM of development of DEA applications in environmental issues in TSs.

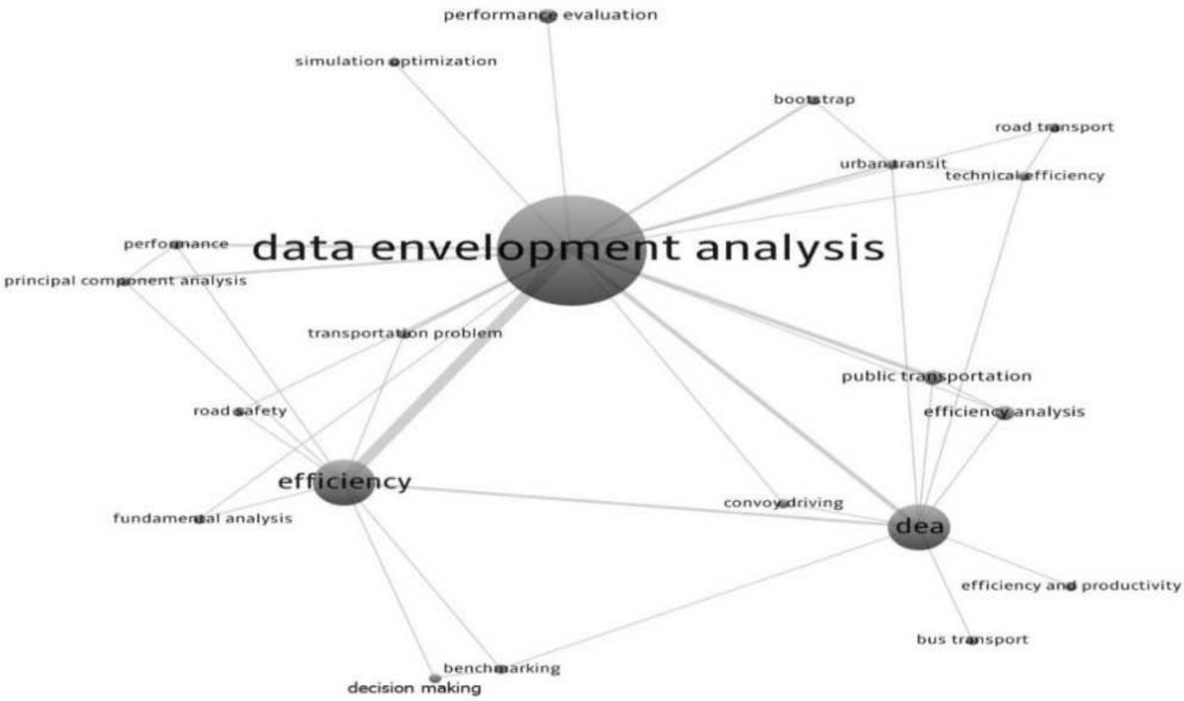

Figure 5.6.1. Map of most co-occurrence keywords related to DEA applications in other transportation problems.

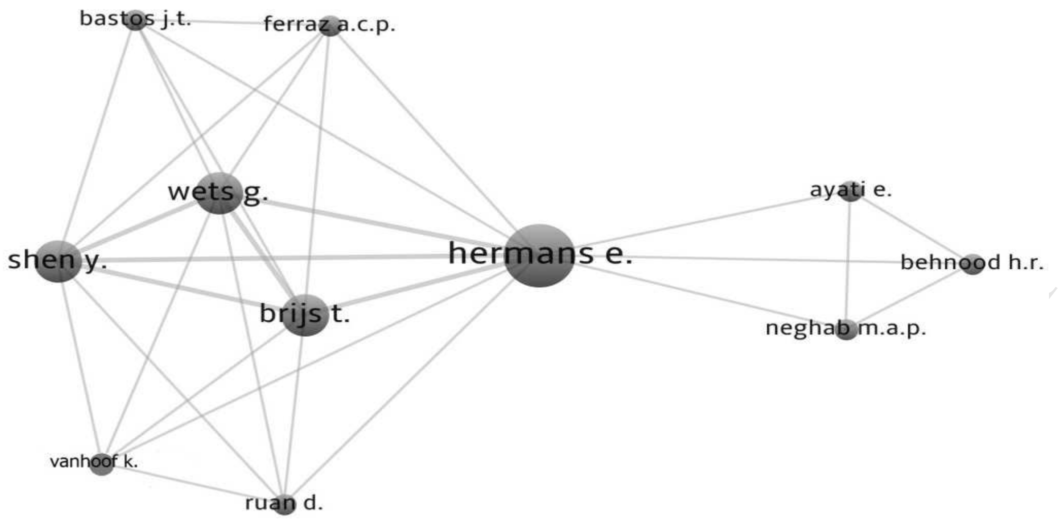

Figure 5.6.2. Map of co-authorship network related to DEA applications in other transportation problems.

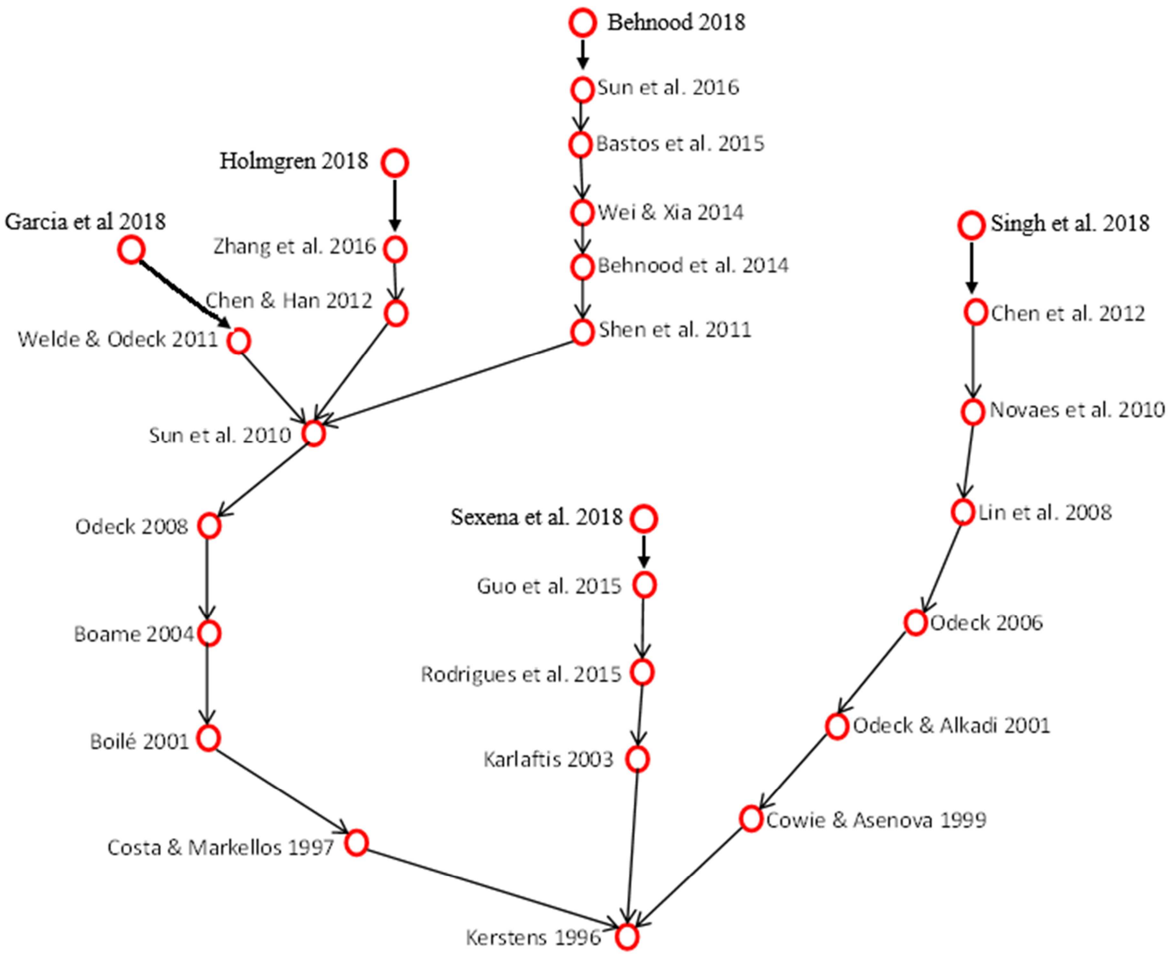

Figure 5.6.3. CPM of development of DEA applications in other transportation problems.

Online Supplement: Part 3 (DEA publications in each cluster)

DEA publications: highway transportation system

1. Alper, D., Sinuany-Stern, Z. & Shinar, D. 2015, "Evaluating the efficiency of local municipalities in providing traffic safety using the Data Envelopment Analysis", Accident Analysis and Prevention, vol. 78, pp. 39-50.
2. Ancarani, A., Guccio, C. & Rizzo, I. 2016, "The role of firms' qualification in public contracts execution: An empirical assessment", Journal of Public Procurement, vol. 16, no. 4, pp. 554-582.
3. Azadeh, A., Zarrin, M. & Hamid, M. 2016, "A novel framework for improvement of road accidents considering decision-making styles of drivers in a large metropolitan area", Accident Analysis and Prevention, vol. 87, pp. 17-33.
4. Bastos, J.T., Shen, Y., Hermans, E., Brijs, T., Wets, G. & Ferraz, A.C.P. 2015, "Traffic fatality indicators in Brazil: State diagnosis based on data envelopment analysis research", Accident Analysis and Prevention, vol. 81, pp. 61-73.
5. Behnood, H.R. 2018, "Best practice analysis of action for road safety in Iran amongst the leading developing countries using an optimized success indicator", Transport Policy, vol. 66, pp. 76-84.
6. Behnood, H.R., Ayati, E., Brijs, T., Neghab, M.P. & Shen, Y. 2017, "A fuzzy decision-support system in road safety planning", Proceedings of the Institution of Civil Engineers: Transport, vol. 170, no. 5, pp. 305-317.
7. Chen, X., Gao, Y., An, Q., Wang, Z. & Neralić, L. 2018, "Energy efficiency measurement of Chinese Yangtze River Delta's cities transportation: a DEA window analysis approach", Energy Efficiency, pp. 1-13.
8. Cheng, X. 2014, "Research on the performance evaluation of road transportation supply chain based on interval DEA method", BioTechnology: An Indian Journal, vol. 10, no. 3, pp. 699-703.
9. Choi, N.H. & Jung, K. 2017, "Measuring efficiency and effectiveness of highway management in sustainability", Sustainability (Switzerland), vol. 9, no. 8.
10. Çipil, F. 2014, "Performance analysis of Turkey's transport sector greenhouse gas emissions", Energy and Environment, vol. 25, no. 2, pp. 357-368.
11. Cook, W.D. & Green, R.H. 2000, "Project prioritization: A resource-constrained data envelopment analysis approach", Socio-economic planning sciences, vol. 34, no. 2, pp. 85-99.
12. Cook, W.D., Kazakov, A. & Persaud, B.N. 2001, "Prioritising highway accident sites: A data envelopment analysis model", Journal of the Operational Research Society, vol. 52, no. 3, pp. 303-309.
13. Cook, W.D., Kazakov, A., Roll, Y. & Seiford, L.M. 1991, "A data envelopment approach to measuring efficiency: Case analysis of highway maintenance patrols", Journal of Socio-economics, vol. 20, no. 1, pp. 83-103.
14. Cook, W.D. & Zhu, J. 2009, "Piecewise linear output measures in DEA (third revision)", European Journal of Operational Research, vol. 197, no. 1, pp. 312-319.
15. Cook, W.D. & Zhu, J. 2003, "Output deterioration with input reduction in data envelopment analysis", IIE Transactions (Institute of Industrial Engineers), vol. 35, no. 3, pp. 309-320.
16. Cui, X., Fang, C. & Zhang, Q. 2018, "Spatial relationship between high-speed transport superiority degree and land-use efficiency in Shandong Peninsula urban agglomeration", Dili Xuebao/Acta Geographica Sinica, vol. 73, no. 6, pp. 1149-1161.
17. Daito, N. & Gifford, J.L. 2014, "U.S. highway public private partnerships: Are they more expensive or efficient than the traditional model?", Managerial Finance, vol. 40, no. 11, pp. 1131-1151.
18. do Castelo Gouveia, M. & Clímaco, I. 2018, Assessment of fuel tax policies to tackle carbon emissions from road transport—an application of the value-based DEA method including robustness analysis.
19. Egilmez, G. & McAvoy, D. 2013, "Benchmarking road safety of U.S. states: A DEA-based Malmquist productivity index approach", Accident Analysis and Prevention, vol. 53, pp. 55-64.

20. Fallah-Fini, S., Triantis, K., De La Garza, J.M. & Seaver, W.L. 2012, "Measuring the efficiency of highway maintenance contracting strategies: A bootstrapped non-parametric meta-frontier approach", European Journal of Operational Research, vol. 219, no. 1, pp. 134-145.
21. Fathian, M. & Jafarian-Moghaddam, A.R. 2015, "New clustering algorithms for vehicular ad-hoc network in a highway communication environment", Wireless Networks, vol. 21, no. 8, pp. 2765-2780.
22. Guccio, C., Pignataro, G. & Rizzo, I. 2012, "Measuring the efficient management of public works contracts: A non-parametric approach", Journal of Public Procurement, vol. 12, no. 4, pp. 528-546.
23. Imanirad, R., Cook, W.D., Aviles-Sacoto, S.V. & Zhu, J. 2015, "Partial input to output impacts in DEA: The case of DMU-specific impacts", European Journal of Operational Research, vol. 244, no. 3, pp. 837-844.
24. Jiang, C., Li, S. & Li, L. 2017, "Research on productive efficiencies measurement based on three-stage super DEA model: A case of Chinese road and bridge enterprises", International Journal of Computing Science and Mathematics, vol. 8, no. 5, pp. 475-493.
25. Juan, W., Huapu, L., Xu, S., Xianfeng, L. & Huijun, Y. 2014, "The best path analysis in military highway transport based on DEA and multiobjective fuzzy decision-making", Mathematical Problems in Engineering, vol. 2014.
26. Kazakov, A., Cook, W.D. & Roll, Y. 1989, "Measurement of highway maintenance patrol efficiency. Model and factors", Transportation Research Record, , no. 1216, pp. 39-45.
27. Kelle, P., Schneider, H., Raschke, C. & Shirazi, H. 2013, "Highway improvement project selection by the joint consideration of cost-benefit and risk criteria", Journal of the Operational Research Society, vol. 64, no. 3, pp. 313-325.
28. Kim, H.J., Kim, S.W. & Shin, J.S. 2014, "Efficiency analysis of privatization using DEA and MPI", Public Performance and Management Review, vol. 38, no. 1, pp. 48-75.
29. Leal Jr., I.C., de Almada Garcia, P.A. & de Almeida D'Agosto, M. 2012, "A data envelopment analysis approach to choose transport modes based on eco-efficiency", Environment, Development and Sustainability, vol. 14, no. 5, pp. 767-781.
30. Lee, G., Yu, M.-. & Wang, L.-. 2012, "DEA-based integrated relationship of returns to scale - An application to road maintenance in Taiwan", Journal of Civil Engineering and Management, vol. 18, no. 5, pp. 709-723.
31. Li, Z., Zhao, L. & Yuan, Z. 2016, "Highway transportation efficiency evaluation for Beijing-Tianjin-Hebei region based on advanced DEA model", International Review for Spatial Planning and Sustainable Development, vol. 4, no. 3, pp. 36-44.
32. Liu, H., Zhang, Y., Zhu, Q. & Chu, J. 2017, "Environmental efficiency of land transportation in China: A parallel slack-based measure for regional and temporal analysis", Journal of Cleaner Production, vol. 142, pp. 867-876.
33. Liu, L.-., Zhao, W.-., Liu, X.-. & Shao, H.-. 2017, "Evaluation on underground road transportation engineering design project based on data envelopment analysis", Chang'an Daxue Xuebao (Ziran Kexue Ban)/Journal of Chang'an University (Natural Science Edition), vol. 37, no. 3, pp. 106-112.
34. Løvold Rødseth, K. 2017, "Productivity growth in urban freight transport: An index number approach", Transport Policy, vol. 56, pp. 86-95.
35. Min, H. & Lambert, T. 2015, "An exploratory evaluation of state road provision to commuters and shippers", Benchmarking, vol. 22, no. 5, pp. 900-919.
36. Nikolaou, P. & Dimitriou, L. 2018, "Evaluation of road safety policies performance across Europe: Results from benchmark analysis for a decade", Transportation Research Part A: Policy and Practice, vol. 116, pp. 232-246.
37. Nozick, L.K., Borderas, H. & Meyburg, A.H. 1998, "Evaluation of travel demand measures and programs: A data envelopment analysis approach", Transportation Research Part A: Policy and Practice, vol. 32, no. 5, pp. 331-343.

38. O'Donnell, C.J., Fallah-Fini, S. & Triantis, K. 2017, "Measuring and analysing productivity change in a metafrontier framework", Journal of Productivity Analysis, vol. 47, no. 2, pp. 117-128.

39. Ozbek, M.E., de la Garza, J.M. & Triantis, K. 2010, "Efficiency measurement of bridge maintenance using data envelopment analysis", Journal of Infrastructure Systems, vol. 16, no. 1, pp. 31-39.

40. Qi, Y.-. 2015, "DEA-based operational efficiency empirical study for China's listed construction firms with the Belt and Road Initiative", Metallurgical and Mining Industry, vol. 7, no. 9, pp. 1058-1061.

41. Rahimi, H., Soori, H., Nazari, S.S.H., Motevalian, S.A., Azar, A., Momeni, E. & Javartani, M. 2017, "The relative efficiency of Iranian's rural traffic police: A three-stage DEA model", BMC Public Health, vol. 17, no. 1.

42. Richmond, C.M., Kielhauser, C. & Adey, B.T. 2016, "Performance measures for road managers facing diverse environments", Benchmarking, vol. 23, no. 7, pp. 1876-1891.

43. Rogers, M.M. & Weber, W.L. 2011, "Evaluating CO2 emissions and fatalities tradeoffs in truck transport", International Journal of Physical Distribution and Logistics Management, vol. 41, no. 8, pp. 750-767.

44. Roll, Y., Cook, W.D. & Golany, B. 1991, "Controlling factor weights in data envelopment analysis", IIE Transactions (Institute of Industrial Engineers), vol. 23, no. 1, pp. 2-9.

45. Rouse, P. & Chiu, T. 2009, "Towards optimal life cycle management in a road maintenance setting using DEA", European Journal of Operational Research, vol. 196, no. 2, pp. 672-681.

46. Rouse, P. & Putterill, M. 2005, "Local government amalgamation policy: A highway maintenance evaluation", Management Accounting Research, vol. 16, no. 4, pp. 438-463.

47. Rouse, P., Putterill, M. & Ryan, D. 1997, "Towards a General Managerial Framework for Performance Measurement: A Comprehensive Highway Maintenance Application", Journal of Productivity Analysis, vol. 8, no. 2, pp. 127-149.

48. Salehian, F., Razmi, J. & Jolai, F. 2018, "A hybrid ranking approach based on fuzzy analytical hierarchy process and data envelopment analysis: Road maintenance and transport organization of Iran", Journal of Intelligent and Fuzzy Systems, vol. 34, no. 4, pp. 2373-2383.

49. Sarmento, J., Renneboog, L. & Matos, P.V. 2017, "Measuring highway efficiency by a DEA approach and the Malmquist index", European Journal of Transport and Infrastructure Research, vol. 17, no. 4, pp. 530-551.

50. Song, M., Zheng, W. & Wang, Z. 2016, "Environmental efficiency and energy consumption of highway transportation systems in China", International Journal of Production Economics, vol. 181, pp. 441-449.

51. Sozen, A. & Cipil, F. 2018, "Efficiency analysis of Turkey's transportation system using decision support model: Data envelopment method" in Intelligent Transportation and Planning: Breakthroughs in Research and Practice, pp. 480-509.

52. Tatari, O., Egilmez, G. & Kurmapu, D. 2016, "Socio-eco-efficiency analysis of highways: a data envelopment analysis", Journal of Civil Engineering and Management, vol. 22, no. 6, pp. 747-757.

53. Tsai, Y.-., Swartz, S.M. & Megahed, F.M. 2018, "Estimating the relative efficiency of highway safety investments on commercial transportation", Transportation Journal, vol. 57, no. 2, pp. 193-218.

54. Ueasin, N. 2017, "An analysis of the operational efficiency of massage and SPA businesses on Asian highway number 15", Journal of Environmental Management and Tourism, vol. 8, no. 2, pp. 329-333.

55. Vaziri, M. 2010, "A comparative appraisal of roadway accident for Asia-Pacific countries", International Journal of Engineering, Transactions A: Basics, vol. 23, no. 2, pp. 111-126.

56. Wang, L.-. & Tsai, H.-. 2009, "Evaluation of highway maintenance performance using Data Envelopment Analysis (DEA) in Taiwan", Journal of Marine Science and Technology, vol. 17, no. 2, pp. 145-155.

57. Wang, Y., Zhang, J. & Xu, W. 2017, "The research on the efficiency of Beijing-Tianjin-Hebei traffic integration", 4th International Conference on Industrial Economics System and Industrial Security Engineering, IEIS 2017.

58. Wu, J., Chu, J., An, Q., Sun, J. & Yin, P. 2016, "Resource reallocation and target setting for improving environmental performance of DMUs: An application to regional highway transportation systems in China", Transportation Research Part D: Transport and Environment, vol. 61, pp. 204-216.

59. Yao, L. & Chen, K. 2018, Efficiency evaluation model of car sharing for low-income people.

60. Yu, M.-. 2008, "Measuring the efficiency and return to scale status of multi-mode bus transit - Evidence from Taiwan's bus system", Applied Economics Letters, vol. 15, no. 8, pp. 647-653.

61. Yu, M.-., Chen, L.-. & Hsiao, B. 2016, "Dynamic performance assessment of bus transit with the multi-activity network structure", Omega (United Kingdom), vol. 60, pp. 15-25.

62. Yu, M.-. & Fan, C.-. 2006, "Measuring the cost effectiveness of multimode bus transit in the presence of accident risks", Transportation Planning and Technology, vol. 29, no. 5, pp. 383-407.

63. Zhang, M., Liu, L.B., Li, Y.H. & Shu, H.B. 2013, "Explore the influence of natural environment to highway traffic safety of mountainous area based on DEA theory", International Journal of Applied Environmental Sciences, vol. 8, no. 23-24, pp. 2883-2891.

DEA publications: air transportation system

64. Abbott, M. 2015, "Reform and efficiency of New Zealand's airports", Utilities Policy, vol. 36, pp. 1-9.

65. Abbott, M. & Wu, S. 2002, "Total factor productivity and efficiency of Australian airports", Australian Economic Review, vol. 35, no. 3, pp. 244-260.

66. Ablanedo-Rosas, J.H. & Gemoets, L.A. 2010, "Measuring the efficiency of Mexican airports", Journal of Air Transport Management, vol. 16, no. 6, pp. 343-345.

67. Adler, N. & Berechman, J. 2001, "Measuring airport quality from the airlines' viewpoint: An application of data envelopment analysis", Transport Policy, vol. 8, no. 3, pp. 171-181.

68. Adler, N., Forsyth, P., Mueller, J. & Niemeier, H.-. 2015, "An economic assessment of airport incentive regulation", Transport Policy, vol. 41, pp. 5-15.

69. Adler, N. & Golany, B. 2001, "Evaluation of deregulated airline networks using data envelopment analysis combined with principal component analysis with an application to Western Europe", European Journal of Operational Research, vol. 132, no. 2, pp. 260-273.

70. Adler, N. & Liebert, V. 2014, "Joint impact of competition, ownership form and economic regulation on airport performance and pricing", Transportation Research Part A: Policy and Practice, vol. 64, pp. 92-109.

71. Adler, N., Liebert, V. & Yazhemsky, E. 2013, "Benchmarking airports from a managerial perspective", Omega (United Kingdom), vol. 41, no. 2, pp. 442-458.

72. Adler, N., Ülkü, T. & Yazhemsky, E. 2013, "Small regional airport sustainability: Lessons from benchmarking", Journal of Air Transport Management, vol. 33, pp. 22-31.

73. Ahn, Y.-. & Min, H. 2014, "Evaluating the multi-period operating efficiency of international airports using data envelopment analysis and the Malmquist productivity index", Journal of Air Transport Management, vol. 39, pp. 12-22.

74. Amalnick, M.S. & Zadeh, S.A. 2017, "Concurrent Evaluation of Customer Relationship Management and Organizational Excellence: An Empirical Study", Performance Improvement Quarterly, vol. 30, no. 1, pp. 55-88.

75. Amoroso, S., Castelluccio, F. & Maritano, L. 2015, "A DEA-based transport heliports' efficiencies evaluation", Aircraft Engineering and Aerospace Technology, vol. 87, no. 2, pp. 131-138.

76. Arjomandi, A., Dakpo, K.H. & Seufert, J.H. 2018, "Have Asian airlines caught up with European Airlines? A by-production efficiency analysis", Transportation Research Part A: Policy and Practice, vol. 116, pp. 389-403.

77. Arjomandi, A. & Seufert, J.H. 2014, "An evaluation of the world's major airlines' technical and environmental performance", Economic Modelling, vol. 41, pp. 1-12.

78. Assaf, A. 2011, "A fresh look at the productivity and efficiency changes of UK airlines", Applied Economics, vol. 43, no. 17, pp. 2165-2175.

79. Assaf, A.G. & Josiassen, A. 2011, "The operational performance of UK airlines: 2002-2007", Journal of Economic Studies, vol. 38, no. 1, pp. 5-16.

80. Augustyniak, W. 2014, "Efficiency change in regional airports during market liberalization", Economics and Sociology, vol. 7, no. 1, pp. 85-93.

81. Baležentis, A. & Baležentis, T. 2011, "Assessing the efficiency of Lithuanian transport sector by applying the methods of multimoora and data envelopment analysis", Transport, vol. 26, no. 3, pp. 263-270.

82. Barak, S. & Dahooei, J.H. 2018, "A novel hybrid fuzzy DEA-Fuzzy MADM method for airlines safety evaluation", Journal of Air Transport Management, vol. 73, pp. 134-149.

83. Barbot, C., Costa, A. & Sochirca, E. 2008, "Airlines performance in the new market context: A comparative productivity and efficiency analysis", Journal of Air Transport Management, vol. 14, no. 5, pp. 270-274.

84. Barros, C.P. 2008, "Airports in Argentina: Technical efficiency in the context of an economic crisis", Journal of Air Transport Management, vol. 14, no. 6, pp. 315-319.

85. Barros, C.P., Bin Liang, Q. & Peypoch, N. 2013, "The efficiency of French regional airports: An inverse B-convex analysis", International Journal of Production Economics, vol. 141, no. 2, pp. 668-674.

86. Barros, C.P. & Dieke, P.U.C. 2008, "Measuring the economic efficiency of airports: A Simar-Wilson methodology analysis", Transportation Research Part E: Logistics and Transportation Review, vol. 44, no. 6, pp. 1039-1051.

87. Barros, C.P., Goncalves, O. & Peypoch, N. 2012, "French regional public airports technical efficiency", International Journal of Transport Economics, vol. 39, no. 2, pp. 255-274.

88. Barros, C.P., Liang, Q.B. & Peypoch, N. 2013, "The technical efficiency of US Airlines", Transportation Research Part A: Policy and Practice, vol. 50, pp. 139-148.

89. Barros, C.P. & Peypoch, N. 2009, "An evaluation of European airlines' operational performance", International Journal of Production Economics, vol. 122, no. 2, pp. 525-533.

90. Barros, C.P. & Sampaio, A. 2004, "Technical and allocative efficiency in airports", International Journal of Transport Economics, vol. 31, no. 3, pp. 355-377.

91. Bazargan, M. & Vasigh, B. 2003, "Size versus efficiency: A case study of US commercial airports", Journal of Air Transport Management, vol. 9, no. 3, pp. 187-193.

92. Bhadra, D. 2009, "Race to the bottom or swimming upstream: Performance analysis of US airlines", Journal of Air Transport Management, vol. 15, no. 5, pp. 227-235.

93. Bilotkach, V., Gitto, S., Jovanović, R., Mueller, J. & Pels, E. 2015, "Cost-efficiency benchmarking of European air navigation service providers", Transportation Research Part A: Policy and Practice, vol. 77, pp. 50-60.

94. Bowlin, W.F. 2004, "Financial analysis of civil reserve air fleet participants using data envelopment analysis", European Journal of Operational Research, vol. 154, no. 3, pp. 691-709.

95. Brandaõ, L.C. & Soares De Mello, J.C.C.B. 2017, "Improvements to smooth data envelopment analysis", RAIRO - Operations Research, vol. 51, no. 1, pp. 157-171.

96. Button, K. & Neiva, R. 2014, "Economic efficiency of european air traffic control systems", Journal of Transport Economics and Policy, vol. 48, no. PART 1, pp. 65-80.

97. Button, K. & Neiva, R. 2013, "Single European Sky and the functional airspace blocks: Will they improve economic efficiency?", Journal of Air Transport Management, vol. 33, pp. 73-80.

98. Button, K. & Neiva, R. 2013, "Spatial autocorrelation in the European air navigation system", Applied Economics Letters, vol. 20, no. 15, pp. 1431-1434.

99. Cao, Q., Lv, J. & Zhang, J. 2015, "Productivity efficiency analysis of the airlines in China after deregulation", Journal of Air Transport Management, vol. 42, pp. 135-140.

100. Capobianco, H.M.P. & Fernandes, E. 2004, "Capital structure in the world airline industry", Transportation Research Part A: Policy and Practice, vol. 38, no. 6, pp. 421-434.

101. Carlucci, F., Cirà, A. & Coccorese, P. 2018, "Measuring and explaining airport efficiency and sustainability: Evidence from Italy", Sustainability (Switzerland), vol. 10, no. 2.

102. Caulfield, B., Bailey, D. & Mullarkey, S. 2013, "Using data envelopment analysis as a public transport project appraisal tool", Transport Policy, vol. 29, pp. 74-85.

103. Chae, M. & Kim, T.S. 2015, "Factors affecting the development of hub airport clusters: focusing on the roles of low-cost carriers in the Asia-Pacific region", International Journal of Urban Sciences, vol. 19, no. 3, pp. 305-319.

104. Chan, P.S. & Sueyoshi, T. 1991, "Environmental change, competition, strategy, structure and firm performance: An application of data envelopment analysis in the airline industry", International Journal of Systems Science, vol. 22, no. 9, pp. 1625-1636.

105. Chang, Y.-. & Yu, M.-. 2014, "Measuring production and consumption efficiencies using the slack-based measure network data envelopment analysis approach: The case of low-cost carriers", Journal of Advanced Transportation, vol. 48, no. 1, pp. 15-31.

106. Chang, Y.-., Yu, M.-. & Chen, P.-. 2013, "Evaluating the performance of Chinese airports", Journal of Air Transport Management, vol. 31, pp. 19-21.

107. Chang, Y.-., Kevin Park, H., Zou, B. & Kafle, N. 2016, "Passenger facility charge vs. airport improvement program funds: A dynamic network DEA analysis for U.S. airport financing", Transportation Research Part E: Logistics and Transportation Review, vol. 88, pp. 76-93.

108. Chang, Y.-., Park, H.-., Jeong, J.-. & Lee, J.-. 2014, "Evaluating economic and environmental efficiency of global airlines: A SBM-DEA approach", Transportation Research Part D: Transport and Environment, vol. 27, pp. 46-50.

109. Charnes, A., Gallegos, A. & Li, H. 1996, "Robustly efficient parametric frontiers via Multiplicative DEA for domestic and international operations of the Latin American airline industry", European Journal of Operational Research, vol. 88, no. 3, pp. 525-536.

110. Chen, Y.-., Lai, P.-. & Piboonrungroj, P. 2017, "The relationship between airport performance and privatisation policy: A nonparametric metafrontier approach", Journal of Transport Geography, vol. 62, pp. 229-235.

111. Chen, Z., Wanke, P., Antunes, J.J.M. & Zhang, N. 2017, "Chinese airline efficiency under CO2emissions and flight delays: A stochastic network DEA model", Energy Economics, vol. 68, pp. 89-108.

112. Cheng, K. 2010, "Evaluation of US legacy airline distribution strategies", Journal of Air Transport Management, vol. 16, no. 6, pp. 337-339.

113. Cheng, K., Lee, Z.-. & Shomali, H. 2012, "Airline firm boundary and ticket distribution in electronic markets", International Journal of Production Economics, vol. 137, no. 1, pp. 137-144.

114. Chi-Lok, A.Y. & Zhang, A. 2009, "Effects of competition and policy changes on Chinese airport productivity: An empirical investigation", Journal of Air Transport Management, vol. 15, no. 4, pp. 166-174.

115. Chiou, Y.-. & Chen, Y.-. 2006, "Route-based performance evaluation of Taiwanese domestic airlines using data envelopment analysis", Transportation Research Part E: Logistics and Transportation Review, vol. 42, no. 2, pp. 116-127.

116. Choi, K., Lee, D.H. & Olson, D.L. 2013, "Service quality and productivity in the U.S. airline industry: a service quality-adjusted DEA model", Service Business, vol. 9, no. 1, pp. 137-160.

117. Chou, H.-., Lee, C.-., Chen, H.-. & Tsai, M.-. 2016, "Evaluating airlines with slack-based measures and meta-frontiers", Journal of Advanced Transportation, vol. 50, no. 6, pp. 1061-1089.

118. Chow, C.K.W., Fung, M.K.Y. & Law, J.S. 2010, "Estimating technical efficiencies of airports in the Greater China: Stochastic output distance function method vs. Data envelopment analysis method", International Journal of Shipping and Transport Logistics, vol. 2, no. 3, pp. 284-299.

119. Coli, M., Nissi, E. & Rapposelli, A. 2011, "Efficiency evaluation in an airline company: Some empirical results", Journal of Applied Sciences, vol. 11, no. 4, pp. 737-742.

120. Coto-Millán, P., Casares-Hontañón, P., Inglada, V., Agüeros, M., Pesquera, M.T. & Badiola, A. 2014, "Small is beautiful? The impact of economic crisis, low cost carriers, and size on efficiency in Spanish airports (2009-2011)", Journal of Air Transport Management, vol. 40, pp. 34-41.

121. Coto-Millán, P., Inglada, V., Fernández, X.L., Inglada-Pérez, L. & Pesquera, M.T. 2016, "The "effect procargo" on technical and scale efficiency at airports: The case of Spanish airports (2009-2011)", Utilities Policy, vol. 39, pp. 29-35.

122. Cui, Q. & Li, Y. 2015, "Evaluating energy efficiency for airlines: An application of VFB-DEA", Journal of Air Transport Management, vol. 44-45, pp. 34-41.

123. Cui, Q. & Li, Y. 2015, "The change trend and influencing factors of civil aviation safety efficiency: The case of Chinese airline companies", Safety Science, vol. 75, pp. 56-63.

124. Cui, Q., Li, Y. & Lin, J.-. 2018, "Pollution abatement costs change decomposition for airlines: An analysis from a dynamic perspective", Transportation Research Part A: Policy and Practice, vol. 111, pp. 96-107.

125. Cui, Q., Wei, Y.-. & Li, Y. 2016, "Exploring the impacts of the EU ETS emission limits on airline performance via the Dynamic Environmental DEA approach", Applied Energy, vol. 183, pp. 984-994.

126. Curi, C., Gitto, S. & Mancuso, P. 2011, "New evidence on the efficiency of Italian airports: A bootstrapped DEA analysis", Socio-economic planning sciences, vol. 45, no. 2, pp. 84-93.

127. Curi, C., Gitto, S. & Mancuso, P. 2010, "The Italian airport industry in transition: A performance analysis", Journal of Air Transport Management, vol. 16, no. 4, pp. 218-221.

128. Da Silveira, J.Q., De Mello, J.C.C.B.S. & Meza, L.A. 2012, "Brazilian airlines efficiency evaluation using a data envelopment analysis (DEA) and multiobjective linear programming hybrid model", Ingeniare, vol. 20, no. 3, pp. 331-342.

129. D'Alfonso, T., Daraio, C. & Nastasi, A. 2015, "Competition and efficiency in the Italian airport system: New insights from a conditional nonparametric frontier analysis", Transportation Research Part E: Logistics and Transportation Review, vol. 80, pp. 20-38.

130. De Nicola, A., Gitto, S. & Mancuso, P. 2013, "Airport quality and productivity changes: A Malmquist index decomposition assessment", Transportation Research Part E: Logistics and Transportation Review, vol. 58, pp. 67-65.

131. Diana, T. 2010, "Can we explain airport performance? A case study of selected New York airports using a stochastic frontier model", Journal of Air Transport Management, vol. 16, no. 6, pp. 310-314.

132. Domney, M.D., Wilson, H.I.M. & Chen, E. 2005, "Natural monopoly privatisation under different regulatory regimes: A comparison of New Zealand and Australian airports", International Journal of Public Sector Management, vol. 18, no. 3, pp. 274-292.

133. Duygun, M., Prior, D., Shaban, M. & Tortosa-Ausina, E. 2016, "Disentangling the European airlines efficiency puzzle: A network data envelopment analysis approach", Omega (United Kingdom), vol. 60, pp. 2-14.

134. Ennen, D. & Batool, I. 2018, "Airport efficiency in Pakistan - A Data Envelopment Analysis with weight restrictions", Journal of Air Transport Management, vol. 69, pp. 205-212.

135. Fan, L.W., Wu, F. & Zhou, P. 2014, "Efficiency measurement of Chinese airports with flight delays by directional distance function", Journal of Air Transport Management, vol. 34, pp. 140-145.

136. Fernandes, E. & Pacheco, R.R. 2018, "Managerial performance of airports in Brazil before and after concessions", Transportation Research Part A: Policy and Practice, vol. 118, pp. 245-257.

137. Fernandes, E. & Pacheco, R.R. 2002, "Efficient use of airport capacity", Transportation Research Part A: Policy and Practice, vol. 36, no. 3, pp. 225-238.

138. Ferreira, D.C., Marques, R.C. & Pedro, M.I. 2016, "Comparing efficiency of holding business model and individual management model of airports", Journal of Air Transport Management, vol. 57, pp. 168-183.

139. Fethi, M.D., Jackson, P.M. & Weyman-Jones, T.G. 2008, "Productivity growth and structural changes in a partially liberalised market: A distance function approach", International Journal of Business Performance Management, vol. 10, no. 4, pp. 391-411.

140. Fonseca, A.B.M., de Mello, J.C.C.B.S., Gomes, E.G. & Meza, L.A. 2010, "Uniformization of frontiers in non-radial ZSG-DEA models: An application to airport revenues", Pesquisa Operacional, vol. 30, no. 1, pp. 175-193.

141. Foroughi, A., Tahari Mehrjardi, M.H., Meybodi, H.B. & Esfahani, M.J. 2012, "Pragmatics of hybrid approach DEA/VIKOR to assess international airports of Iran", Indian Journal of Science and Technology, vol. 5, no. 8, pp. 3115-3121.

142. Fragoudaki, A. & Giokas, D. 2016, "Airport performance in a tourism receiving country: Evidence from Greece", Journal of Air Transport Management, vol. 52, pp. 80-89.

143. Fragoudaki, A., Giokas, D. & Glyptou, K. 2016, "Efficiency and productivity changes in Greek airports during the crisis years 2010–2014", Journal of Air Transport Management, vol. 57, pp. 306-315.

144. Fung, M.K.Y., Chow, C.K.W. & Van Hui, Y. 2008, "Measuring the efficiency of airports in China with the DEA and endogenous-weight TFP methods", International Journal of Transport Economics, vol. 35, no. 1, pp. 45-73.

145. Georges Assaf, A. & Gillen, D. 2012, "Measuring the joint impact of governance form and economic regulation on airport efficiency", European Journal of Operational Research, vol. 220, no. 1, pp. 187-198.

146. Gillen, D. & Lall, A. 2001, "Non-parametric measures of efficiency of U.S. airports", International Journal of Transport Economics, vol. 28, no. 3, pp. 283-306.

147. Gitto, S. & Mancuso, P. 2012, "Bootstrapping the Malmquist indexes for Italian airports", International Journal of Production Economics, vol. 135, no. 1, pp. 403-411.

148. Gitto, S. & Mancuso, P. 2012, "Two faces of airport business: A non-parametric analysis of the Italian airport industry", Journal of Air Transport Management, vol. 20, pp. 39-42.

149. Gok, U. & Ugural, S. 2014, "Assessment of Turkish airports' efficiency using data envelopment analysis", Actual Problems of Economics, vol. 152, no. 2, pp. 470-478.

150. Gomes Júnior, S.F., Rubem, A.P.S., Soares de Mello, J.C.C.B. & Angulo Meza, L. 2016, "Evaluation of Brazilian airlines nonradial efficiencies and targets using an alternative DEA approach", International Transactions in Operational Research, vol. 23, no. 4, pp. 669-689.

151. Gramani, M.C.N. 2012, "Efficiency decomposition approach: A cross-country airline analysis", Expert Systems with Applications, vol. 39, no. 5, pp. 5815-5819.

152. Greer, M.R. 2008, "Nothing focuses the mind on productivity quite like the fear of liquidation: Changes in airline productivity in the United States, 2000-2004", Transportation Research Part A: Policy and Practice, vol. 42, no. 2, pp. 414-426.

153. Greer, M.R. 2006, "Are the discount airlines actually more efficient than the legacy carriers?: A data envelopment analysis", International Journal of Transport Economics, vol. 33, no. 1, pp. 37-55.

154. Grubesic, T.H. & Wei, F. 2012, "Evaluating the efficiency of the Essential Air Service program in the United States", Transportation Research Part A: Policy and Practice, vol. 46, no. 10, pp. 1562-1573.

155. Gutiérrez, E. & Lozano, S. 2016, "Efficiency assessment and output maximization possibilities of European small and medium sized airports", Research in Transportation Economics, vol. 56, pp. 3-14.

156. Ha, H.-., Wan, Y., Yoshida, Y. & Zhang, A. 2013, "Airline market structure and airport efficiency: Evidence from major Northeast Asian airports", Journal of Air Transport Management, vol. 33, pp. 32-42.

157. Ha, H.-., Yoshida, Y. & Zhang, A. 2010, "Comparative analysis of efficiency for major Northeast Asia airports", Transportation Journal, vol. 49, no. 4, pp. 9-23.

158. Hantziagelis, S. & McCabe, B. 2006, "Benchmarking airport reconstruction projects", Canadian Journal of Civil Engineering, vol. 33, no. 12, pp. 1571-1584.

159. Hong, S. & Zhang, A. 2010, "An efficiency study of airlines and air cargo/passenger divisions: A DEA approach", World Review of Intermodal Transportation Research, vol. 3, no. 1-2, pp. 137-149.

160. Hu, J.-., Li, Y. & Tung, H.-. 2017, "Operational efficiency of ASEAN airlines: based on DEA and bootstrapping approaches", Management Decision, vol. 55, no. 5, pp. 957-986.

161. Hu, J.-., Shieh, H.-., Huang, C.-. & Chiu, C.-. 2009, "Cost efficiency of International tourist hotels in Taiwan: A data envelopment analysis application", Asia Pacific Journal of Tourism Research, vol. 14, no. 4, pp. 371-384.

162. Jahangoshai Rezaee, M. & Yousefi, S. 2018, "An intelligent decision making approach for identifying and analyzing airport risks", Journal of Air Transport Management, vol. 68, pp. 14-27.

163. Jain, R.K. & Natarajan, R. 2015, "A DEA study of airlines in India", Asia Pacific Management Review, vol. 20, no. 4, pp. 285-292.

164. Jang, S., Choi, K. & Lee, K. 2011, "External shocks and efficiency changes in the US airline industry", Service Industries Journal, vol. 31, no. 14, pp. 2411-2435.

165. Jaržemskiene, I. 2012, "Applying the method of measuring airport productivity in the Baltic region", Transport, vol. 27, no. 2, pp. 178-186.

166. Jaržemskis, A. & Jaržemskienė, I. 2018, "Upgraded data envelopment analysis model application for total productivity comparison in major airports of the European Union", Economic Research-Ekonomska Istrazivanja, vol. 31, no. 1, pp. 1273-1288.

167. Joo, S.-. & Fowler, K.L. 2014, "Exploring comparative efficiency and determinants of efficiency for major world airlines", Benchmarking, vol. 21, no. 4, pp. 675-687.

168. Kadziński, M., Labijak, A. & Napieraj, M. 2017, "Integrated framework for robustness analysis using ratio-based efficiency model with application to evaluation of Polish airports", Omega (United Kingdom), vol. 67, pp. 1-18.

169. Kan Tsui, W.H., Balli, H.O., Gilbey, A. & Gow, H. 2014, "Operational efficiency of Asia-Pacific airports", Journal of Air Transport Management, vol. 40, pp. 16-24.

170. Khezrimotlagh, D., Salleh, S. & Mohsenpour, Z. 2013, "A new robust mixed integer-valued model in DEA", Applied Mathematical Modelling, vol. 37, no. 24, pp. 9885-9897.

171. Kim, H.-., Choi, C.-., Woo, J.-., Choi, Y., Kim, K. & Wu, D.D. 2011, "Efficiency of the modal shift and environmental policy on the Korean railroad", Stochastic Environmental Research and Risk Assessment, vol. 25, no. 3, pp. 305-322.

172. Kim, J.-. & Prater, E. 2011, "Service marketing productivity and firm profit: Evidence from U.S. domestic airline companies", Services Marketing Quarterly, vol. 32, no. 3, pp. 181-198.

173. Kottas, A.T. & Madas, M.A. 2018, "Comparative efficiency analysis of major international airlines using Data Envelopment Analysis: Exploring effects of alliance membership and other operational efficiency determinants", Journal of Air Transport Management, vol. 70, pp. 1-17.

174. Lai, P., Potter, A., Beynon, M. & Beresford, A. 2015, "Evaluating the efficiency performance of airports using an integrated AHP/DEA-AR technique", Transport Policy, vol. 42, pp. 75-85.

175. Lai, P.-., Potter, A. & Beynon, M. 2012, "The development of benchmarking techniques in airport performance evaluation research", Transportation Journal, vol. 51, no. 3, pp. 305-337.

176. Lam, S.W., Low, J.M.W. & Tang, L.C. 2009, "Operational efficiencies across Asia Pacific airports", Transportation Research Part E: Logistics and Transportation Review, vol. 45, no. 4, pp. 654-665.

177. Lee, B.L. & Worthington, A.C. 2014, "Technical efficiency of mainstream airlines and low-cost carriers: New evidence using bootstrap data envelopment analysis truncated regression", Journal of Air Transport Management, vol. 38, pp. 15-20.

178. Lee, C.-. & Johnson, A.L. 2012, "Two-dimensional efficiency decomposition to measure the demand effect in productivity analysis", European Journal of Operational Research, vol. 216, no. 3, pp. 584-593.

179. Li, S.-. 2014, "The cost allocation approach of airport service activities", Journal of Air Transport Management, vol. 38, pp. 48-53.

180. Li, Y. & Cui, Q. 2018, "Investigating the role of cooperation in the GHG abatement costs of airlines under CNG2020 strategy via a DEA cross PAC model", Energy, vol. 161, pp. 725-736.

181. Li, Y. & Cui, Q. 2017, "Carbon neutral growth from 2020 strategy and airline environmental inefficiency: A Network Range Adjusted Environmental Data Envelopment Analysis", Applied Energy, vol. 199, pp. 13-24.

182. Lin, E.T.J. 2008, "Route-based performance evaluation of Taiwanese domestic airlines using data envelopment analysis: A comment", Transportation Research Part E: Logistics and Transportation Review, vol. 44, no. 5, pp. 894-899.

183. Lin, L.C. & Hong, C.H. 2006, "Operational performance evaluation of international major airports: An application of data envelopment analysis", Journal of Air Transport Management, vol. 12, no. 6, pp. 342-351.

184. Lin, W.-. 2012, "Financial performance and customer service: An examination using activity-based costing of 38 international airlines", Journal of Air Transport Management, vol. 19, no. 1, pp. 13-15.

185. Liu, D. 2017, "Evaluating the multi-period efficiency of East Asia airport companies", Journal of Air Transport Management, vol. 59, pp. 71-82.

186. Liu, D. 2016, "Measuring aeronautical service efficiency and commercial service efficiency of East Asia airport companies: An application of Network Data Envelopment Analysis", Journal of Air Transport Management, vol. 52, pp. 11-22.

187. lo Storto, C. 2018, "Ownership structure and the technical, cost, and revenue efficiency of Italian airports", Utilities Policy, vol. 50, pp. 175-193.

188. lo Storto, C. 2018, "The analysis of the cost-revenue production cycle efficiency of the Italian airports: A NSBM DEA approach", Journal of Air Transport Management, vol. 72, pp. 77-85.

189. lo Storto, C. 2017, "Product benchmarking in the air cargo industry: Non-parametric measurement of an aircraft value for money", Benchmarking, vol. 24, no. 4, pp. 857-881.

190. Loos, M.J., Taboada Rodriguez, C.M., Petri, S.M. & Matos, L.S. 2016, "Mapping the state of the art of airport performance measurement", Espacios, vol. 37, no. 26.

191. Lozano, S. & Gutiérrez, E. 2014, "A slacks-based network DEA efficiency analysis of European airlines", Transportation Planning and Technology, vol. 37, no. 7, pp. 623-637.

192. Lozano, S. & Gutiérrez, E. 2011, "Efficiency Analysis and Target Setting of Spanish Airports", Networks and Spatial Economics, vol. 11, no. 1, pp. 139-157.

193. Lu, W.-., Wang, W.-., Hung, S.-. & Lu, E.-. 2012, "The effects of corporate governance on airline performance: Production and marketing efficiency perspectives", Transportation Research Part E: Logistics and Transportation Review, vol. 48, no. 2, pp. 529-544.

194. Mallikarjun, S. 2015, "Efficiency of US airlines: A strategic operating model", Journal of Air Transport Management, vol. 43, pp. 46-56.

195. Marti, L., Puertas, R. & Calafat, C. 2015, "Efficiency of airlines: Hub and spoke versus point-to-point", Journal of Economic Studies, vol. 42, no. 1, pp. 157-166.

196. Martín, J.C. & Román, C. 2010, "Evaluating the service quality of major air carriers: A DEA approach", International Journal of Applied Management Science, vol. 2, no. 4, pp. 351-371.

197. Martín, J.C. & Román, C. 2006, "A benchmarking analysis of Spanish commercial airports. A comparison between SMOP and DEA ranking methods", Networks and Spatial Economics, vol. 6, no. 2, pp. 111-134.

198. Martín, J.C. & Román, C. 2001, "An application of DEA to measure the efficieny of Spanish airports prior to privatization", Journal of Air Transport Management, vol. 7, no. 3, pp. 149-157.

199. Merkert, R. & Assaf, A.G. 2015, "Using DEA models to jointly estimate service quality perception and profitability - Evidence from international airports", Transportation Research Part A: Policy and Practice, vol. 75, pp. 42-50.

200. Merkert, R. & Hensher, D.A. 2011, "The impact of strategic management and fleet planning on airline efficiency - a random effects tobit model based on dea efficiency scores", Transportation Research Part A: Policy and Practice, vol. 45, no. 7, pp. 686-695.

201. Merkert, R. & Mangia, L. 2014, "Efficiency of Italian and Norwegian airports: A matter of management or of the level of competition in remote regions?", Transportation Research Part A: Policy and Practice, vol. 62, pp. 30-38.

202. Merkert, R. & Morrell, P.S. 2012, "Mergers and acquisitions in aviation - Management and economic perspectives on the size of airlines", Transportation Research Part E: Logistics and Transportation Review, vol. 48, no. 4, pp. 853-862.

203. Merkert, R. & Pearson, J. 2015, "A non-parametric efficiency measure incorporating perceived airline service levels and profitability", Journal of Transport Economics and Policy, vol. 49, pp. 261-275.

204. Merkert, R. & Williams, G. 2013, "Determinants of European PSO airline efficiency - Evidence from a semi-parametric approach", Journal of Air Transport Management, vol. 29, pp. 11-16.

205. Mhlanga, O. 2018, "Factors impacting airline efficiency in southern Africa: a data envelopment analysis", GeoJournal, , pp. 1-12.

206. Mhlanga, O., Steyn, J. & Spencer, J. 2018, "The airline industry in South Africa: drivers of operational efficiency and impacts", Tourism Review, vol. 73, no. 3, pp. 389-400.

207. Michaelides, P.G., Belegri-Roboli, A., Karlaftis, M. & Marinos, T. 2009, "International air transportation carriers: Evidence from SFA and DEA technical efficiency results (1991-2000)", European Journal of Transport and Infrastructure Research, vol. 9, no. 4, pp. 347-362.

208. Min, H. & Joo, S.-. 2016, "A comparative performance analysis of airline strategic alliances using data envelopment analysis", Journal of Air Transport Management, vol. 52, pp. 99-110.

209. Mohammad Zarandini, H. 2013, "Designing the productivity system with the aid of the dynamic complex models of the data envelopment analysis for the administrative discipline of the Mehrabad International Airport through focusing on the airport operation department", Life Science Journal, vol. 10, no. 1, pp. 731-738.

210. Murillo-Melchor, C. 1999, "An analysis of technical efficiency and productivity changes in Spanish airports using the Malmquist index", International Journal of Transport Economics, vol. 26, no. 2, pp. 271-292.

211. Olfat, L. & Pishdar, M. 2017, "Interval type-2 fuzzy dynamic network data envelopment analysis with undesirable outputs considering double frontiers: An application to Iran Airports sustainability evaluation", International Journal of Industrial Engineering : Theory Applications and Practice, vol. 24, no. 6, pp. 635-662.

212. Omrani, H. & Soltanzadeh, E. 2016, "Dynamic DEA models with network structure: An application for Iranian airlines", Journal of Air Transport Management, vol. 57, pp. 52-61.

213. Örkcü, H.H., Balikçi, C., Dogan, M.I. & Genç, A. 2016, "An evaluation of the operational efficiency of turkish airports using data envelopment analysis and the Malmquist productivity index: 2009-2014 case", Transport Policy, vol. 48, pp. 92-104.

214. Ouellette, P., Petit, P., Tessier-Parent, L.-. & Vigeant, S. 2010, "Introducing regulation in the measurement of efficiency, with an application to the Canadian air carriers industry", European Journal of Operational Research, vol. 200, no. 1, pp. 216-226.

215. Öztürk, E. & Bal, H. 2017, "Ranking the airports with data envelopment analysis and canonical correlation analysis", Gazi University Journal of Science, vol. 30, no. 2, pp. 237-245.

216. Pacheco, R.R. & Fernandes, E. 2003, "Managerial efficiency of Brazilian airports", Transportation Research Part A: Policy and Practice, vol. 37, no. 8, pp. 667-680.

217. Pacheco, R.R., Fernandes, E. & de Sequeira Santos, M.P. 2006, "Management style and airport performance in Brazil", Journal of Air Transport Management, vol. 12, no. 6, pp. 324-330.

218. Pandey, M.M. 2016, "Evaluating operational efficiency of airports in Thailand with special reference to low cost traffic", Journal of Applied Economic Sciences, vol. 11, no. 2, pp. 321-323.

219. Parker, D. 1999, "The performance of BAA before and after privatisation a DE a study", Journal of Transport Economics and Policy, vol. 33, no. 2, pp. 133-146.

220. Peck Jr., M.W., Scheraga, C.A. & Boisjoly, R.P. 1998, "Assessing the relative efficiency of aircraft maintenance technologies: An application of data envelopment analysis", Transportation Research Part A: Policy and Practice, vol. 32, no. 4, pp. 261-269.

221. Pegels, C.C. & Yang, B. 2000, "The impact of managerial characteristics on strategic assets management capabilities", Team Performance Management: An International Journal, vol. 6, pp. 97-107.

222. Pegels, C.C. & Yang, B. 2000, "Top management team impact on strategic assets accumulation capabilities", Management Decision, vol. 38, no. 10, pp. 694-710.

223. Pels, E., Nijkamp, P. & Rietveld, P. 2003, "Inefficiencies and scale economies of European airport operations", Transportation Research Part E: Logistics and Transportation Review, vol. 39, no. 5, pp. 341-361.

224. Pels, E., Nijkamp, P. & Rietveld, P. 2001, "Relative efficiency of European airports", Transport Policy, vol. 8, no. 3, pp. 183-192.

225. Perelman, S. & Serebrisky, T. 2012, "Measuring the technical efficiency of airports in Latin America", Utilities Policy, vol. 22, pp. 1-7.

226. Périco, A.E., Santana, N.B. & Do Nascimento Rebelatto, D.A. 2017, "Efficiency of Brazilian international airports: Applying the bootstrap data envelopment analysis", Gestao e Producao, vol. 24, no. 2, pp. 370-381.

227. Pestana Barros, C. & Dieke, P.U.C. 2007, "Performance evaluation of Italian airports: A data envelopment analysis", Journal of Air Transport Management, vol. 13, no. 4, pp. 184-191.

228. Rai, A. 2013, "Measurement of efficiency in the airline industry using data envelopment analysis", Investment Management and Financial Innovations, vol. 10, no. 1, pp. 38-45.

229. Ray, S.C. 2008, "The directional distance function and measurement of super-efficiency: An application to airlines data", Journal of the Operational Research Society, vol. 59, no. 6, pp. 788-797.

230. Roghanian, E. & Foroughi, A. 2010, "An empirical study of iranian regional airports using robust data envelopment analysis", International Journal of Industrial Engineering Computations, vol. 1, no. 1, pp. 65-72.

231. Rouse, P., Putterill, M. & Ryan, D. 2002, "Integrated performance measurement design: Insights from an application in aircraft maintenance", Management Accounting Research, vol. 13, no. 2, pp. 229-248.

232. Rubem, A.P.S., Soares de Mello, J.C.C.B., Angulo Meza, L. & Gomes, S.F. 2017, "An analysis of airlines efficiency using a DEA model and dynamic clusters", Espacios, vol. 38, no. 37.

233. Sakthidharan, V. & Sivaraman, S. 2018, "Impact of operating cost components on airline efficiency in India: A DEA approach", Asia Pacific Management Review.

234. Salazar De La Cruz, F. 1999, "A DEA approach to the airport production function", International Journal of Transport Economics, vol. 26, no. 2, pp. 255-270.

235. Saranga, H. & Nagpal, R. 2016, "Drivers of operational efficiency and its impact on market performance in the Indian Airline industry", Journal of Air Transport Management, vol. 53, pp. 165-176.

236. Sarkis, J. 2000, "Analysis of the operational efficiency of major airports in the United States", Journal of Operations Management, vol. 18, no. 3, pp. 335-351.

237. Sarkis, J. & Talluri, S. 2004, "Performance based clustering for benchmarking of US airports", Transportation Research Part A: Policy and Practice, vol. 38, no. 5, pp. 329-346.

238. Savolainen, V.-. & Hilmola, O.-. 2009, "The relative technical efficiency of European transportation systems concerning air transport and railways", International Journal of Business Performance Management, vol. 11, no. 1-2, pp. 19-42.

239. Savolainen, V.-. & Hilmola, O.-. 2008, "Does privatisation matter in the efficiency of airline freight transports? Evidence from the European market", World Review of Intermodal Transportation Research, vol. 2, no. 1, pp. 9-29.

240. Schefczyk, M. 1993, "Operational performance of airlines: An extension of traditional measurement paradigms", Strategic Management Journal, vol. 14, no. 4, pp. 301-317.

241. Scheraga, C.A. 2004, "Operational efficiency versus financial mobility in the global airline industry: A data envelopment and Tobit analysis", Transportation Research Part A: Policy and Practice, vol. 38, no. 5, pp. 383-404.

242. Scheraga, C.A. 2004, "The relationship between operational efficiency and customer service: A global study of thirty-eight large international airlines", Transportation Journal, vol. 43, no. 3, pp. 48-58.

243. Semenick Alam, I.M. & Sickles, R.C. 1998, "The Relationship between Stock Market Returns and Technical Efficiency Innovations: Evidence from the US Airline Industry", Journal of Productivity Analysis, vol. 9, no. 1, pp. 35-51.

244. Seufert, J.H., Arjomandi, A. & Dakpo, K.H. 2017, "Evaluating airline operational performance: A Luenberger-Hicks-Moorsteen productivity indicator", Transportation Research Part E: Logistics and Transportation Review, vol. 104, pp. 52-68.

245. Shao, Y. & Sun, C. 2016, "Performance evaluation of China's air routes based on network data envelopment analysis approach", Journal of Air Transport Management, vol. 55, pp. 67-75.

246. Sickles, R.C., Good, D.H. & Getachew, L. 2002, "Specification of distance functions using semi- and nonparametric methods with an application to the dynamic performance of Eastern and Western European air carriers", Journal of Productivity Analysis, vol. 17, no. 1-2, pp. 133-155.

247. Soltanzadeh, E. & Omrani, H. 2018, "Dynamic network data envelopment analysis model with fuzzy inputs and outputs: An application for Iranian Airlines", Applied Soft Computing Journal, vol. 63, pp. 268-288.

248. Suzuki, S., Nijkamp, P., Pels, E. & Rietveld, P. 2014, "Comparative performance analysis of European airports by means of extended data envelopment analysis", Journal of Advanced Transportation, vol. 48, no. 3, pp. 185-202.

249. Suzuki, S., Nijkamp, P., Rietveld, P. & Pels, E. 2010, "A distance friction minimization approach in data envelopment analysis: A comparative study on airport efficiency", European Journal of Operational Research, vol. 207, no. 2, pp. 1104-1115.

250. Tapiador, F.J., Mateos, A. & Martí-Henneberg, J. 2008, "The geographical efficiency of Spain's regional airports: A quantitative analysis", Journal of Air Transport Management, vol. 14, no. 4, pp. 205-212.

251. Tavassoli, M., Faramarzi, G.R. & Farzipoor Saen, R. 2014, "Efficiency and effectiveness in airline performance using a SBM-NDEA model in the presence of shared input", Journal of Air Transport Management, vol. 34, pp. 146-153.

252. Tofallis, C. 1997, "Input efficiency profiling: An application to airlines", Computers and Operations Research, vol. 24, no. 3, pp. 253-258.

253. Tsekeris, T. 2011, "Greek airports: Efficiency measurement and analysis of determinants", Journal of Air Transport Management, vol. 17, no. 2, pp. 139-141.

254. Tseng, K.-., Ho, J.-. & Liu, Y.-. 2008, "A study on the performance evaluation of major international airports in the world", Journal of Modelling in Management, vol. 3, no. 1, pp. 71-81.

255. Ülkü, T. 2015, "A comparative efficiency analysis of Spanish and Turkish airports", Journal of Air Transport Management, vol. 46, pp. 56-68.

256. Wang, Q., Liu, Z. & Zhang, Y. 2017, "A Novel Weighting Method for Finding Common Weights in DEA", Asia-Pacific Journal of Operational Research, vol. 34, no. 5.

257. Wang, W.-., Lin, F., Ting, I.W.K., Kweh, Q.L., Lu, W.-. & Chiu, T.-. 2017, "Does asset-light strategy contribute to the dynamic efficiency of global airlines?", Journal of Air Transport Management, vol. 62, pp. 99-108.

258. Wang, W.-., Lu, W.-. & Tsai, C.-. 2011, "The relationship between airline performance and corporate governance amongst US Listed companies", Journal of Air Transport Management, vol. 17, no. 2, pp. 147-151.

259. Wang, Y. & Chou, C.-. 2018, "Analysis on criteria influencing air cargo efficiency", Journal of Quality, vol. 25, no. 4, pp. 258-270.

260. Wanke, P. & Barros, C.P. 2017, "Efficiency thresholds and cost structure in Senegal airports", Journal of Air Transport Management, vol. 58, pp. 100-112.

261. Wanke, P. & Barros, C.P. 2016, "Efficiency in Latin American airlines: A two-stage approach combining Virtual Frontier Dynamic DEA and Simplex Regression", Journal of Air Transport Management, vol. 54, pp. 93-103.

262. Wanke, P.F. 2013, "Physical infrastructure and flight consolidation efficiency drivers in Brazilian airports: A two-stage network-DEA approach", Journal of Air Transport Management, vol. 31, pp. 1-5.

263. Wanke, P.F. 2012, "Capacity shortfall and efficiency determinants in Brazilian airports: Evidence from bootstrapped DEA estimates", Socio-economic planning sciences, vol. 46, no. 3, pp. 216-229.

264. Widener, S., Erkoc, M. & Sharit, J. 2011, "Assessment of airport air side performability from the perspective of the consumer", International Journal of Performability Engineering, vol. 7, no. 2, pp. 121-136.

265. Wu, C., Wang, X., Zhang, X., Li, Y. & O'Brien, B. 2013, "Chinese airline competitiveness evaluation based on extended binary relative evaluation(BRE) model", Journal of Business Economics and Management, vol. 14, no. SUPPL1, pp. S227-S256.

266. Wu, W.-. & Liao, Y.-. 2014, "A balanced scorecard envelopment approach to assess airlines' performance", Industrial Management and Data Systems, vol. 114, no. 1, pp. 123-143.

267. Wu, Y., He, C. & Cao, X. 2013, "The impact of environmental variables on the efficiency of Chinese and other non-Chinese airlines", Journal of Air Transport Management, vol. 29, pp. 35-38.

268. Yang, H.-. 2010, "Efficiency and productivity evidence from international airports in the Asia-Pacific region", Journal of the Chinese Institute of Industrial Engineers, vol. 27, no. 2, pp. 157-168.

269. Yang, H.-. 2010, "Measuring the efficiencies of Asia-Pacific international airports - Parametric and non-parametric evidence", Computers and Industrial Engineering, vol. 59, no. 4, pp. 697-702.

270. Yoshimoto, D., Alves, C.J.P. & Caetano, M. 2018, "Airport economic efficient frontier", Journal of Operations and Supply Chain Management, vol. 11, no. 1, pp. 26-36.

271. Yu, M.-. 2012, "Performance assessment of transport services with the ERM-NDEA model: Evidence from a domestic airline in Taiwan", Transportation Planning and Technology, vol. 35, no. 7, pp. 697-714.

272. Yu, M.-. 2010, "Assessment of airport performance using the SBM-NDEA model", Omega, vol. 38, no. 6, pp. 440-452.

273. Yu, M.-. 2010, "Capacity efficiency measurement using a three-stage DEA approach: Evidence from domestic airports in Taiwan", Transportation Planning and Technology, vol. 33, no. 2, pp. 221-235.

274. Yu, M.-. 2004, "Measuring physical efficiency of domestic airports in Taiwan with undesirable outputs and environmental factors", Journal of Air Transport Management, vol. 10, no. 5, pp. 295-303.

275. Yu, M.-., Chang, Y.-. & Chen, L.-. 2016, "Measurement of airlines' capacity utilization and cost gap: Evidence from low-cost carriers", Journal of Air Transport Management, vol. 53, pp. 186-198.

276. Yu, M.-., Chen, L.-. & Chiang, H. 2017, "The effects of alliances and size on airlines’ dynamic operational performance", Transportation Research Part A: Policy and Practice, vol. 106, pp. 197-214.

277. Yu, M.-. & Chen, P.-. 2011, "Measuring air routes performance using a fractional network data envelopment analysis model", Central European Journal of Operations Research, vol. 19, no. 1, pp. 81-98.

278. Yu, M.-., Chern, C.-. & Hsiao, B. 2013, "Human resource rightsizing using centralized data envelopment analysis: Evidence from Taiwan's Airports", Omega (United Kingdom), vol. 41, no. 1, pp. 119-130.

279. Zandieh, M., Azadeh, A., Hadadi, B. & Saberi, M. 2009, "Application of artificial neural networks for airline number of passenger estimation in time series state", Journal of Applied Sciences, vol. 9, no. 6, pp. 1001-1013.

280. Zhang, B., Wang, J., Meng, L., Zhu, C. & Nie, R. 2014, "Estimating returns to scale of Chinese airport airside activities using the CCR-0-objective RTS method", Journal of the Operational Research Society, vol. 65, no. 5, pp. 755-762.

281. Zhu, D.-., Lin, C.-., Yang, C.-. & Chang, K.-. 2012, "Managing airline productivity using data envelopment analysis", International Journal of Business Performance Management, vol. 13, no. 3-4, pp. 294-311.

282. Zou, B., Kafle, N., Chang, Y.-. & Park, K. 2015, "US airport financial reform and its implications for airport efficiency: An exploratory investigation", Journal of Air Transport Management, vol. 47, pp. 66-78.

DEA publications: maritime transportation system

283. Abid, C. & Tadj, L. 2012, "Using data envelopment analysis to measure ports efficiency", International Journal of Business Performance Management, vol. 13, no. 3-4, pp. 257-273.

284. Ablanedo-Rosas, J.H., Gao, H., Zheng, X., Alidaee, B. & Wang, H. 2010, "A study of the relative efficiency of Chinese ports: A financial ratio-based data envelopment analysis approach", Expert Systems, vol. 27, no. 5, pp. 349-362.

285. Affuso, A., Ferrarese, C. & Nannariello, G. 2013, "Spending review: A port authorities efficiency analysis", Scienze Regionali, vol. 12, no. 3, pp. 111-143.

286. Al-Eraqi, A.S., Mustafa, A., Khader, A.T. & Barros, C.P. 2008, "Efficiency of middle eastern and East African seaports: Application of DEA using window analysis", European Journal of Scientific Research, vol. 23, no. 4, pp. 597-612.

287. Asić, A. 2011, "Analysis of passenger port efficiency in the Republic of Croatia", Pomorstvo, vol. 25, no. 1, pp. 71-86.

288. Badau, F. 2015, "Ranking trade resistance variables using data envelopment analysis", European Journal of Operational Research, vol. 247, no. 3, pp. 978-986.

289. Barros, C.P. 2003, "The measurement of efficiency of Portuguese sea port authorities with DEA", International Journal of Transport Economics, vol. 30, no. 3, pp. 335-354.

290. Barros, C.P. & Athanassiou, M. 2004, "Efficiency in European seaports with DEA: Evidence from Greece and Portugal", Maritime Economics and Logistics, vol. 6, no. 2, pp. 122-140.

291. Barros, C.P. & Peypoch, N. 2012, "Productivity assessment of African seaports with biased technological change", Transportation Planning and Technology, vol. 35, no. 6, pp. 663-675.

292. Bergantino, A.S. & Musso, E. 2011, "The role of external factors versus managerial ability in determining seaports relative efficiency: An input-by-input analysis through a multi-step approach on a panel of Southern European ports", Maritime Economics and Logistics, vol. 13, no. 2, pp. 121-141.

293. Bergantino, A.S., Musso, E. & Porcelli, F. 2013, "Port management performance and contextual variables: Which relationship? Methodological and empirical issues", Research in Transportation Business and Management, vol. 8, pp. 39-49.

294. Beuren, M.M., Andriotti, R., Vieira, G.B.B., Ribeiro, J.L.D. & Neto, F.J.K. 2018, "On measuring the efficiency of Brazilian ports and their management models oa", Maritime Economics and Logistics, vol. 20, no. 1, pp. 149-168.

295. Bichou, K. 2013, "An empirical study of the impacts of operating and market conditions on container-port efficiency and benchmarking", Research in Transportation Economics, vol. 42, no. 1, pp. 28-37.

296. Bichou, K. 2011, "A two-stage supply chain DEA model for measuring container-terminal efficiency", International Journal of Shipping and Transport Logistics, vol. 3, no. 1, pp. 6-26.

297. Bichou, K. 2011, "Assessing the impact of procedural security on container port efficiency", Maritime Economics and Logistics, vol. 13, no. 1, pp. 1-28.

298. Birgun, S. & Akten, N. 2005, "Relative efficiencies of seaport container terminals: a DEA perspective", International Journal of Integrated Supply Management, vol. 1, no. 4, pp. 442-456.

299. Bonilla, M., Casasús, T., Medal, A. & Sala, R. 2004, "An efficiency analysis with tolerance of the Spanish port system", International Journal of Transport Economics, vol. 31, no. 3, pp. 379-400.

300. Bonilla, M., Medal, A., Casaus, T. & Sala, R. 2002, "The traffic in Spanish ports: An efficiency analysis", International Journal of Transport Economics, vol. 29, no. 2, pp. 215-230.

301. Caillaux, M.A., Sant'Anna, A.P., Meza, L.A. & Soares De Mello, J.C.C.B. 2011, "Container logistics in Mercosur: Choice of a transhipment port using the ordinal Copeland method, data envelopment analysis and probabilistic composition", Maritime Economics and Logistics, vol. 13, no. 4, pp. 355-370.

302. Carvalho, P., Marques, R.C., Fonseca, Á. & Simões, P. 2010, "Governance and comparative performance of Iberian Peninsula seaports. An application of non-parametric techniques", International Journal of Transport Economics, vol. 37, no. 1, pp. 31-51.

303. Cavaignac, L. & Petiot, R. 2017, "A quarter century of Data Envelopment Analysis applied to the transport sector: A bibliometric analysis", Socio-economic planning sciences, vol. 57, pp. 84-96.

304. Chang, S.-., Wang, J.-., Yu, M.-., Shang, K.-., Lin, S.-. & Hsiao, B. 2015, "An application of centralized data envelopment analysis in resource allocation in container terminal operations", Maritime Policy and Management, vol. 42, no. 8, pp. 776-788.

305. Chang, V. & Tovar, B. 2017, "Metafrontier analysis on productivity for West Coast of South Pacific terminals", Transportation Research Part A: Policy and Practice, vol. 103, pp. 118-134.

306. Chang, Y.-. 2013, "Environmental efficiency of ports: A Data Envelopment Analysis approach", Maritime Policy and Management, vol. 40, no. 5, pp. 467-478.

307. Chang, Y.-., Park, H.K., Lee, S. & Kim, E. 2018, "Have Emission Control Areas (ECAs) harmed port efficiency in Europe?", Transportation Research Part D: Transport and Environment, vol. 58, pp. 39-53.

308. Chang, Z., Yang, D., Wan, Y. & Han, T. 2018, "Analysis on the features of Chinese dry ports: Ownership, customs service, rail service and regional competition", Transport Policy, .

309. Chao, S. 2017, "Integrating multi-stage data envelopment analysis and a fuzzy analytical hierarchical process to evaluate the efficiency of major global liner shipping companies", Maritime Policy and Management, vol. 44, no. 4, pp. 496-511.

310. Chen, C. & Lam, J.S.L. 2018, "Sustainability and interactivity between cities and ports: a two-stage data envelopment analysis (DEA) approach", Maritime Policy and Management, vol. 45, no. 7, pp. 944-961.

311. Chen, J., Wan, Z., Zhang, F., Park, N.-., He, X. & Yin, W. 2016, "Operational Efficiency Evaluation of Iron Ore Logistics at the Ports of Bohai Bay in China: Based on the PCA-DEA Model", Mathematical Problems in Engineering, vol. 2016.

312. Cheon, S., Maltz, A. & Dooley, K. 2017, "The link between economic and environmental performance of the top 10 U.S. ports", Maritime Policy and Management, vol. 44, no. 2, pp. 227-247.

313. Costa, E.F., Meza, L.A. & Roboredo, M.C. 2018, "A DEA model to evaluate Brazilian container terminals", RAIRO - Operations Research, vol. 52, no. 3, pp. 743-754.

314. Cullinane, K., Ji, P. & Wang, T.-. 2005, "The relationship between privatization and DEA estimates of efficiency in the container port industry", Journal of economics and business, vol. 57, no. 5, pp. 433-462.

315. Cullinane, K., Song, D.-. & Wang, T. 2005, "The application of mathematical programming approaches to estimating container port production efficiency", Journal of Productivity Analysis, vol. 24, no. 1, pp. 73-92.

316. Cullinane, K. & Wang, T. 2010, "The efficiency analysis of container port production using DEA panel data approaches", OR Spectrum, vol. 32, no. 3, pp. 717-738.

317. Cullinane, K., Wang, T.-., Song, D.-. & Ji, P. 2006, "The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis", Transportation Research Part A: Policy and Practice, vol. 40, no. 4, pp. 354-374.

318. Cunha Marques, R. & Luz Carvalho, M. 2009, "Governance and performance evaluation of the Portuguese seaports in the European context", International Journal of Services, Economics and Management, vol. 1, no. 4, pp. 340-357.

319. da Cruz, M.R.P. & de Matos Ferreira, J.J. 2016, "Evaluating Iberian seaport competitiveness using an alternative DEA approach", European Transport Research Review, vol. 8, no. 1, pp. 1-9.

320. de Koster, M.B.M., Balk, B.M. & van Nus, W.T.I. 2009, "On using DEA for benchmarking container terminals", International Journal of Operations and Production Management, vol. 29, no. 11, pp. 1140-1155.

321. de Oliveira, G.F. & Cariou, P. 2011, "A DEA study of the efficiency of 122 iron ore and coal ports and of 15/17 countries in 2005", Maritime Policy and Management, vol. 38, no. 7, pp. 727-743.

322. Díaz-Hernández, J.J., Martínez-Budría, E. & Salazar-González, J.J. 2014, "Measuring cost efficiency in the presence of quasi-fixed inputs using dynamic data envelopment analysis: The case of port infrastructure", Maritime Economics and Logistics, vol. 16, no. 2, pp. 111-126.

323. Díaz-Hernández, J.J., Nez-Budría, E.M. & Jara-Díaz, S. 2012, "The economic efficiency in stevedoring determinants industry", International Journal of Transport Economics, vol. 39, no. 3, pp. 369-396.

324. Ensslin, L., Dezem, V., Dutra, A., Ensslin, S.R. & Somensi, K. 2017, "Seaport-performance tools: an analysis of the international literature", Maritime Economics and Logistics, , pp. 1-16.

325. Espino, D.C., Del Hoyo, J.J.G. & Sharp, B.M.H. 2005, "Capacity and capacity utilization of the "voracera" fleet in the strait of gibraltar", Marine Resource Economics, vol. 20, no. 4, pp. 367-384.

326. Faed, A., Chang, E., Saberi, M., Hussain, O.K. & Azadeh, A. 2016, "Intelligent customer complaint handling utilising principal component and data envelopment analysis (PDA)", Applied Soft Computing Journal, vol. 47, pp. 614-630.

327. Ferrari, C. & Basta, M. 2009, "Port concession fees based on the price-cap regulation: A DEA approach", Maritime Economics and Logistics, vol. 11, no. 1, pp. 121-135.

328. Figueiredo De Oliveira, G. & Cariou, P. 2015, "The impact of competition on container port (in)efficiency", Transportation Research Part A: Policy and Practice, vol. 78, pp. 124-133.

329. Fu, B.-., Song, X.-. & Guo, Z.-. 2009, "DEA-based malmquist productivity index measure of operating efficiencies: New insights with an application to container ports", Journal of Shanghai Jiaotong University (Science), vol. 14 E, no. 4, pp. 490-496.

330. Gan, G.-., Lee, H.-., Chung, C.-. & Chen, S.-. 2017, "Performance evaluation of the security management of Changjiang maritime safety administrations: Application with undesirable outputs in data envelopment analysis", Journal of Marine Science and Technology (Taiwan), vol. 25, no. 2, pp. 213-219.

331. Gil-Ropero, A., Cerban, M. & Turias, I.J. 2015, "Analysis of the global and technical efficiencies of major Spanish container ports", International Journal of Transport Economics, vol. 42, no. 3, pp. 377-407.

332. Gil-Ropero, A., Turias, I.J. & Cerban, M. 2018, "Efficiency evolution of largest Iberian peninsula container ports: An application of malmquist productivity index", International Journal of Transport Economics, vol. 45, no. 1, pp. 53-81.

333. Güner, S. 2017, "Incorporating value judgments into port efficiency measurement models: insights from Turkish ports", Maritime Economics and Logistics, , pp. 1-18.

334. Güner, S. 2015, "Investigating infrastructure, superstructure, operating and financial efficiency in the management of Turkish seaports using data envelopment analysis", Transport Policy, vol. 40, pp. 36-48.

335. Gurpinar, N. & Balcioglu, H.B. 2018, "Impact of famagusta port efficiency on North Cyprus economic development", Revista de Cercetare si Interventie Sociala, vol. 60, no. March, pp. 143-156.

336. Gutiérrez, E., Lozano, S., Adenso-Díaz, B. & González-Torre, P. 2015, "Efficiency assessment of container operations of shipping agents in Spanish ports", Maritime Policy and Management, vol. 42, no. 6, pp. 591-607.

337. Haralambides, H. & Gujar, G. 2012, "On balancing supply chain efficiency and environmental impacts: An eco-DEA model applied to the dry port sector of India", Maritime Economics and Logistics, vol. 14, no. 1, pp. 122-137.

338. He, D., Gao, P., Sun, Z. & Lau, Y.-. 2017, "Measuring water transport efficiency in the Yangtze River Economic Zone, China", Sustainability (Switzerland), vol. 9, no. 12.

339. Humberto Ablanedo-Rosas, J. & Ruiz-Torres, A.J. 2009, "Benchmarking of Mexican ports with data envelopment analysis", International Journal of Shipping and Transport Logistics, vol. 1, no. 3, pp. 276-294.

340. Hung, S.-., Lu, W.-. & Wang, T.-. 2010, "Benchmarking the operating efficiency of Asia container ports", European Journal of Operational Research, vol. 203, no. 3, pp. 706-713.

341. Itoh, H. 2002, "Efficiency changes at major container ports in Japan: A window application of data envelopment analysis", Review of Urban and Regional Development Studies, vol. 14, no. 2, pp. 133-152.

342. Jang, H.M., Park, H. & Kim, S.Y. 2016, "Efficiency analysis of major container ports in Asia: Using DEA and Shannon's entropy", International Journal of Supply Chain Management, vol. 5, no. 2, pp. 1-6.

343. Jiang, B. & Li, J. 2009, "DEA-based performance measurement of seaports in northeast Asia: Radial and non-radial approach", Asian Journal of Shipping and Logistics, vol. 25, no. 2, pp. 219-236.

344. Jiang, J.L., Chew, E.P., Lee, L.H. & Sun, Z. 2012, "DEA based on strongly efficient and inefficient frontiers and its application on port efficiency measurement", OR Spectrum, vol. 34, no. 4, pp. 943-969.

345. Jiang, Z., Zhu, H. & Cao, Y. 2017, "Efficiency pattern and spatial strategy of ports in Yangtze River Delta Region", Chinese Geographical Science, vol. 27, no. 2, pp. 298-310.

346. Ju, S.-. & Liu, N. 2015, "Efficiency and its influencing factors in port enterprises: empirical evidence from Chinese port-listed companies", Maritime Policy and Management, vol. 42, no. 6, pp. 571-590.

347. Kamble, S.S., Raoot, A.D. & Khanapuri, V.B. 2010, "Improving port efficiency: A comparative study of selected ports in India", International Journal of Shipping and Transport Logistics, vol. 2, no. 4, pp. 444-470.

348. Kang, H.-. & Kim, Y.-. 2017, "Measuring the efficiency of maritime transport companies", Journal of Distribution Science, vol. 15, no. 11, pp. 59-72.

349. Kengpol, A., Tuammee, S. & Tuominen, M. 2014, "The development of a framework for route selection in multimodal transportation", International Journal of Logistics Management, vol. 25, no. 3, pp. 581-610.

350. Kutin, N., Nguyen, T.T. & Vallée, T. 2017, "Relative Efficiencies of ASEAN Container Ports based on Data Envelopment Analysis", Asian Journal of Shipping and Logistics, vol. 33, no. 2, pp. 67-77.

351. Lee, T., Yeo, G.-. & Thai, V.V. 2014, "Environmental efficiency analysis of port cities: Slacks-based measure data envelopment analysis approach", Transport Policy, vol. 33, pp. 82-88.

352. Leem, B.-. & Chun, H. 2015, "Measuring the influence of efficient ports using social Network Metrics", International Journal of Engineering Business Management, vol. 7, no. 1, pp. 1-8.

353. Li, D., Luan, W. & Pian, F. 2013, "The efficiency measurement of coastal container terminals in China", Journal of Transportation Systems Engineering and Information Technology, vol. 13, no. 5, pp. 10-15.

354. Li, X., Li, F., Zhao, N. & Zhu, Q. 2018, "Measuring environmental sustainability performance of freight transportation seaports in China: A data envelopment analysis approach based on the closest targets", Expert Systems, .

355. Li, X. & Zheng, L. 2010, "Investment efficiency evaluation of china ports based on DEA", ICIC Express Letters, vol. 4, no. 4, pp. 1195-1201.

356. Lin, L.C. & Tseng, C.C. 2007, "Operational performance evaluation of major container ports in the Asia-Pacific region", Maritime Policy and Management, vol. 34, no. 6, pp. 535-551.

357. Liu, C.-. 2008, "Evaluating the operational efficiency of major ports in the Asia-Pacific region using data envelopment analysis", Applied Economics, vol. 40, no. 13, pp. 1737-1743.

358. Liu, Q. & Hoon Lim, S. 2017, "Toxic air pollution and container port efficiency in the USA oa", Maritime Economics and Logistics, vol. 19, no. 1, pp. 94-105.

359. Low, J.M.W. 2010, "Capacity investment and efficiency cost estimations in major East Asian ports", Maritime Economics and Logistics, vol. 12, no. 4, pp. 370-391.

360. Lozano, S. 2009, "Estimating productivity growth of Spanish ports using a non-radial, non-oriented Malmquist index", International Journal of Shipping and Transport Logistics, vol. 1, no. 3, pp. 227-248.

361. Lozano, S. & Villa, G. 2009, "Multiobjective target setting in data envelopment analysis using AHP", Computers and Operations Research, vol. 36, no. 2, pp. 549-564.

362. Lozano, S., Villa, G. & Canca, D. 2011, "Application of centralised DEA approach to capital budgeting in Spanish ports", Computers and Industrial Engineering, vol. 60, no. 3, pp. 455-465.

363. Lu, B. & Park, N.K. 2013, "Sensitivity analysis for identifying the critical productivity factors of container terminals", Strojniski Vestnik/Journal of Mechanical Engineering, vol. 59, no. 9, pp. 536-546.

364. Lu, B., Park, N.K. & Huo, Y. 2015, "The evaluation of operational efficiency of the world's leading container seaports", Journal of Coastal Research, , pp. 248-254.

365. Lu, B. & Wang, X.L. 2012, "Comparative studies on efficiency evaluation of chinese and Korean major container terminals", Advances in Information Sciences and Service Sciences, vol. 4, no. 23, pp. 434-442.

366. Luna, J.H., Mar-Ortiz, J., Gracia, M.D. & Morales-Ramírez, D. 2018, "An efficiency analysis of cargo-handling operations at container terminals", Maritime Economics and Logistics, vol. 20, no. 2, pp. 190-210.

367. Markovits-Somogyi, R. 2011, "Measuring efficiency in transport: The state of the art of applying Data Envelopment Analysis", Transport, vol. 26, no. 1, pp. 11-19.

368. Martinez-Budria, E., Diaz-Armas, R., Navarro-Ibanez, M. & Ravelo-Mesa, T. 1999, "A study of the efficiency of Spanish Port Authorities using Data Envelopment Analysis", International Journal of Transport Economics, vol. 26, no. 2, pp. 237-253.

369. Medal, A. & Sala, R. 2011, "An efficiency ranking of Spanish seaports using FDH methodology", International Journal of Transport Economics, vol. 38, no. 2, pp. 201-226.

370. Medal-Bartual, A., Molinos-Senante, M. & Sala-Garrido, R. 2016, "Assessment of the total factor productivity change in the Spanish ports: Hicks-Moorsteen productivity index approach", Journal of Waterway, Port, Coastal and Ocean Engineering, vol. 142, no. 1.

371. Medal-Bartual, A., Molinos-Senante, M. & Sala-Garrido, R. 2012, "Benchmarking in Spanish seaports: A tool for Specialization", International Journal of Transport Economics, vol. 39, no. 3, pp. 329-348.

372. Merkel, A. & Holmgren, J. 2017, "Dredging the depths of knowledge: Efficiency analysis in the maritime port sector", Transport Policy, vol. 60, pp. 63-74.

373. Min, H. & Park, B.-. 2005, "Evaluating the inter-temporal efficiency trends of international container terminals using data envelopment analysis", International Journal of Integrated Supply Management, vol. 1, no. 3, pp. 258-277.

374. Monteiro, J.G.R. 2010, "Measuring productivity and efficiency of major ports of India", Economic and Political Weekly, vol. 45, no. 26-27, pp. 325-331.

375. Mousavizadeh, R. & Khalili-Damghani, K. 2017, "Cooperative mechanism based on data envelopment analysis and artificial neural network to measure efficiency: Case study of Iranian ports", International Journal of Applied Decision Sciences, vol. 10, no. 1, pp. 52-68.

376. Ng, A.S.-., Lim, A.L.C., Leong, C.H. & Cheng, C.H. 2010, "A competitiveness measurement framework for regional container hub ports: A case study in East Asia", International Journal of Logistics Systems and Management, vol. 7, no. 3, pp. 368-392.

377. Nguyen, H.-., Nghiem, H.-. & Chang, Y.-. 2018, "A regional perspective of port performance using metafrontier analysis: The case study of Vietnamese ports", Maritime Economics and Logistics, vol. 20, no. 1, pp. 112-130.

378. Nguyen, H.-., Nguyen, H.-., Chang, Y.-., Chin, A.T.H. & Tongzon, J. 2016, "Measuring port efficiency using bootstrapped DEA: the case of Vietnamese ports", Maritime Policy and Management, vol. 43, no. 5, pp. 644-659.

379. Nguyen, N.-. & Tran, T.-. 2018, "Raising opportunities in strategic alliance by evaluating efficiency of logistics companies in Vietnam: a case of Cat Lai Port", Neural Computing and Applications, .

380. Niavis, S. & Tsekeris, T. 2012, "Ranking and causes of inefficiency of container seaports in South-Eastern Europe", European Transport Research Review, vol. 4, no. 4, pp. 235-244.

381. Odeck, J. & Bråthen, S. 2012, "A meta-analysis of DEA and SFA studies of the technical efficiency of seaports: A comparison of fixed and random-effects regression models", Transportation Research Part A: Policy and Practice, vol. 46, no. 10, pp. 1574-1585.

382. Panayides, P.M., Maxoulis, C.N., Wang, T.-. & Ng, K.Y.A. 2009, "A critical analysis of DEA applications to seaport economic efficiency measurement", Transport Reviews, vol. 29, no. 2, pp. 183-206.

383. Pantouvakis, A. & Dimas, A. 2010, "Does ISO 9000 series certification matter for the financial performance of ports? Some preliminary findings from Europe", Maritime Policy and Management, vol. 37, no. 5, pp. 505-522.

384. Park, J., Lim, S. & Bae, H. 2012, "DEA-based port efficiency improvement and stepwise benchmarking target selection", Information (Japan), vol. 15, no. 12 C, pp. 6155-6171.

385. Park, J. & Sung, S.-. 2016, "Integrated approach to construction of benchmarking network in DEA-based stepwise benchmark target selection", Sustainability (Switzerland), vol. 8, no. 7, pp. 1-15.

386. Park, R.-. & De Prabir, P. 2004, "An alternative approach to efficiency measurement of seaports", Maritime Economics and Logistics, vol. 6, no. 1, pp. 53-69.

387. Paul, J.A. & MacDonald, L. 2017, "An empirical analysis of US vessel-related port accidents (2002-2012): Impact of union membership and port efficiency on accident incidence and economic damage oa", Maritime Economics and Logistics, vol. 19, no. 4, pp. 723-748.

388. Pestana Barros, C. 2012, "Productivity Assessment of African Seaports", African Development Review, vol. 24, no. 1, pp. 67-78.

389. Pjevcevic, D., Nikolic, M., Vidic, N. & Vukadinovic, K. 2017, "Data envelopment analysis of AGV fleet sizing at a port container terminal", International Journal of Production Research, vol. 55, no. 14, pp. 4021-4034.

390. Pjevčević, D., Radonjić, A., Hrle, Z. & Čolić, V. 2012, "Dea window analysis for measuring port efficiencies in Serbia", Promet - Traffic - Traffico, vol. 24, no. 1, pp. 63-72.

391. Quaresma Dias, J.C., Garrido Azevedo, S., Ferreira, J. & Palma, S.F. 2009, "A comparative benchmarking analysis of main Iberian container terminals: a DEA approach", International Journal of Shipping and Transport Logistics, vol. 1, no. 3, pp. 260-275.

392. Radonjić, A., Pjevčević, D., Hrle, Z. & Čolić, V. 2011, "Application of DEA method to intermodal container transport", Transport, vol. 26, no. 3, pp. 233-239.

393. Rios, L.R. & Maçada, A.C.G. 2006, "Analysing the relative efficiency of container terminals of mercosur using DEA", Maritime Economics and Logistics, vol. 8, no. 4, pp. 331-346.

394. Roll, Y. & Hayuth, Y. 1993, "Port performance comparison applying data envelopment analysis (DEA)", Maritime Policy and Management, vol. 20, no. 2, pp. 153-161.

395. Russo, F. & Rindone, C. 2011, "Container maritime transport on an international scale: Data envelopment analysis for transhipment port", WIT Transactions on Ecology and the Environment, vol. 150, pp. 831-846.

396. Sabri, H.T., Ha, M.-. & Kim, G.-. 2013, "Measuring “energy use efficiency”of container terminals", Journal of Korea Trade, vol. 17, no. 4, pp. 53-70.

397. Schøyen, H., Bjorbæk, C.T., Steger-Jensen, K., Bouhmala, N., Burki, U., Jensen, T.E. & Berg, Ø. 2018, "Measuring the contribution of logistics service delivery performance outcomes and deep-sea container liner connectivity on port efficiency", Research in Transportation Business and Management, .

398. Schøyen, H. & Odeck, J. 2017, "Comparing the productivity of Norwegian and some Nordic and UK container ports - An application of Malmquist productivity index", International Journal of Shipping and Transport Logistics, vol. 9, no. 2, pp. 234-256.

399. Schøyen, H. & Odeck, J. 2013, "The technical efficiency of Norwegian container ports: A comparison to some Nordic and UK container ports using Data Envelopment Analysis (DEA)", Maritime Economics and Logistics, vol. 15, no. 2, pp. 197-221.

400. Sharma, M.J. & Yu, S.J. 2010, "Benchmark optimization and attribute identification for improvement of container terminals", European Journal of Operational Research, vol. 201, no. 2, pp. 568-580.

401. Sharma, M.J. & Yu, S.J. 2009, "Performance based stratification and clustering for benchmarking of container terminals", Expert Systems with Applications, vol. 36, no. 3 PART 1, pp. 5016-5022.

402. Simões, P. & Marques, R.C. 2010, "Influence of congestion efficiency on the european seaports performance: Does it matter?", Transport Reviews, vol. 30, no. 4, pp. 517-539.

403. Simões, P. & Marques, R.C. 2010, "Seaport performance analysis using robust non-parametric efficiency estimators", Transportation Planning and Technology, vol. 33, no. 5, pp. 435-451.

404. Sislioglu, M., Celik, M. & Ozkaynak, S. 2018, "A simulation model proposal to improve the productivity of container terminal operations through investment alternatives", Maritime Policy and Management, , pp. 1-22.

405. Suárez-Alemán, A., Trujillo, L. & Cullinane, K.P.B. 2014, "Time at ports in short sea shipping: When timing is crucial", Maritime Economics and Logistics, vol. 16, no. 4, pp. 399-417.

406. Sun, J., Yuan, Y., Yang, R., Ji, X. & Wu, J. 2017, "Performance evaluation of Chinese port enterprises under significant environmental concerns: An extended DEA-based analysis", Transport Policy, vol. 60, pp. 75-86.

407. Taliani, E.C., Escobar, S.G. & Silva Da Rosa, F. 2017, "Environmental disclosure and economic efficiency: A correlational evaluation of Spanish ports authorities", Intangible Capital, vol. 13, no. 4, pp. 745-780.

408. Tetteh, E.A., Yang, H. & Gomina Mama, F. 2016, "Container ports throughput analysis: A comparative evaluation of China and five west african countries seaports efficiencies", International Journal of Engineering Research in Africa, vol. 22, pp. 162-173.

409. Tongzon, J. 2001, "Efficiency measurement of selected Australian and other international ports using data envelopment analysis", Transportation Research Part A: Policy and Practice, vol. 35, no. 2, pp. 107-122.

410. Tovar, B. & Wall, A. 2017, "Specialisation, diversification, size and technical efficiency in ports: An empirical analysis using frontier techniques", European Journal of Transport and Infrastructure Research, vol. 17, no. 2, pp. 279-303.

411. Turner, H., Windle, R. & Dresner, M. 2004, "North American containerport productivity: 1984-1997", Transportation Research Part E: Logistics and Transportation Review, vol. 40, no. 4, pp. 339-356.

412. Vázquez-Rowe, I. & Tyedmers, P. 2013, "Identifying the importance of the "skipper effect" within sources of measured inefficiency in fisheries through data envelopment analysis (DEA)", Marine Policy, vol. 38, pp. 387-396.

413. Venkatasubbaiah, K., Rao, K.N., Rao, M.M. & Challa, S. 2018, "Performance Evaluation and Modelling of Container Terminals", Journal of The Institution of Engineers (India): Series C, vol. 99, no. 1, pp. 87-96.

414. Wang, T.F. & Cullinane, K. 2006, "The efficiency of European container terminals and implications for supply chain management", Maritime Economics and Logistics, vol. 8, no. 1, pp. 82-99.

415. Wang, Y.-. & Han, T.-. 2018, "Efficiency measurement for international container ports of Taiwan and surrounding areas by fuzzy data envelopment analysis", Journal of Marine Science and Technology (Taiwan), vol. 26, no. 2, pp. 185-193.

416. Wanke, P. & Barros, C.P. 2016, "New evidence on the determinants of efficiency at Brazilian ports: A bootstrapped DEA analysis", International Journal of Shipping and Transport Logistics, vol. 8, no. 3, pp. 250-272.

417. Wanke, P., Chen, Z., Moreira Antunes, J.J. & Barros, C. 2018, "Malmquist productivity indexes in Chinese ports: A fuzzy GMSS DEA approach", International Journal of Shipping and Transport Logistics, vol. 10, no. 2, pp. 202-236.

418. Wanke, P., Nwaogbe, O.R. & Chen, Z. 2018, "Efficiency in Nigerian ports: handling imprecise data with a two-stage fuzzy approach", Maritime Policy and Management, vol. 45, no. 5, pp. 699-715.

419. Wanke, P.F. 2013, "Physical infrastructure and shipment consolidation efficiency drivers in Brazilian ports: A two-stage network-DEA approach", Transport Policy, vol. 29, pp. 145-153.

420. Wanke, P.F., Barbastefano, R.G. & Hijjar, M.F. 2011, "Determinants of efficiency at major Brazilian port terminals", Transport Reviews, vol. 31, no. 5, pp. 653-677.

421. Wanke, P.F. & Barros, C.P. 2015, "Public-private partnerships and scale efficiency in Brazilian ports: Evidence from two-stage DEA analysis", Socio-economic planning sciences, vol. 51, pp. 13-22.

422. Wiegmans, B. & Dekker, S. 2016, "Benchmarking deep-sea port performance in the Hamburg-Le Havre range", Benchmarking, vol. 23, no. 1, pp. 96-112.

423. Wiegmans, B. & Witte, P. 2017, "Efficiency of inland waterway container terminals: Stochastic frontier and data envelopment analysis to analyze the capacity design- and throughput efficiency", Transportation Research Part A: Policy and Practice, vol. 106, pp. 12-21.

424. Wilmsmeier, G., Tovar, B. & Sanchez, R.J. 2013, "The evolution of container terminal productivity and efficiency under changing economic environments", Research in Transportation Business and Management, vol. 8, pp. 50-66.

425. Wu, H., Wu, J., Liang, L. & Li, Y. 2012, "Efficiency assessment of Chinese logistics firms using DEA", International Journal of Shipping and Transport Logistics, vol. 4, no. 3, pp. 212-234.

426. Wu, J. & Liang, L. 2009, "Performances and benchmarks of container ports using data envelopment analysis", International Journal of Shipping and Transport Logistics, vol. 1, no. 3, pp. 295-310.

427. Wu, J., Liang, L. & Song, M. 2010, "Performance based clustering for benchmarking of container ports: An application of dea and cluster analysis technique", International Journal of Computational Intelligence Systems, vol. 3, no. 6, pp. 709-722.

428. Wu, J., Yan, H. & Liu, J. 2010, "DEA models for identifying sensitive performance measures in container port evaluation", Maritime Economics and Logistics, vol. 12, no. 3, pp. 215-236.

429. Wu, Y.C.J. & Goh, M. 2010, "Container port efficiency in emerging and more advanced markets", Transportation Research Part E: Logistics and Transportation Review, vol. 46, no. 6, pp. 1030-1042.

430. Wu, Y.-J. & Lin, C.-. 2008, "National port competitiveness: Implications for India", Management Decision, vol. 46, no. 10, pp. 1482-1507.

431. Yang, C.-. 2013, "A dea-based approach for evaluating the opportunity cost of environmental regulations", Asia-Pacific Journal of Operational Research, vol. 30, no. 2.

432. Yang, C.-. 2012, "Productivity changes in Taiwan's port industry incorporating environmental regulations on harbor water quality", Transportation Planning and Technology, vol. 35, no. 8, pp. 769-789.

433. Yu, Y.-. 2017, "Evaluation of development efficiency of Ningbo port logistics and its synergy with urban economy", Journal of Discrete Mathematical Sciences and Cryptography, vol. 20, no. 6-7, pp. 1369-1373.

434. Yuen, A.C.-., Zhang, A. & Cheung, W. 2013, "Foreign participation and competition: A way to improve the container port efficiency in China?", Transportation Research Part A: Policy and Practice, vol. 49, pp. 220-231.

435. Zahran, S.Z., Alam, J.B., Al-Zahrani, A.H., Smirlis, Y., Papadimitriou, S. & Tsioumas, V. 2017, "Analysis of port authority efficiency using data envelopment analysis oa", Maritime Economics and Logistics, vol. 19, no. 3, pp. 518-537.

436. Zahran, S.Z., Alam, J.B., Al-Zahrani, A.H., Smirlis, Y., Papadimitriou, S. & Tsioumas, V. 2017, "Analysis of port efficiency using imprecise and incomplete data", Operational Research, , pp. 1-28.

437. Zheng, X.B. & Park, N.K. 2016, "A Study on the Efficiency of Container Terminals in Korea and China", Asian Journal of Shipping and Logistics, vol. 32, no. 4, pp. 213-220.

438. Zhou, G., Chung, W. & Zhang, Y. 2014, "Measuring energy efficiency performance of China's transport sector: A data envelopment analysis approach", Expert Systems with Applications, vol. 41, no. 2, pp. 709-722.

439. Zhou, G., Min, H., xu, C. & Cao, Z. 2008, "Evaluating the comparative efficiency of Chinese third-party logistics providers using data envelopment analysis", International Journal of Physical Distribution & Logistics Management, vol. 38, no. 4, pp. 262-279.

DEA publications: railway transportation system

440. Abate, M., Lijesen, M., Pels, E. & Roelevelt, A. 2013, "The impact of reliability on the productivity of railroad companies", Transportation Research Part E: Logistics and Transportation Review, vol. 51, no. 1, pp. 41-49.

441. Azadeh, A., Ghaderi, S.F. & Izadbakhsh, H. 2008, "Integration of DEA and AHP with computer simulation for railway system improvement and optimization", Applied Mathematics and Computation, vol. 195, no. 2, pp. 775-785.

442. Azadeh, A., Salehi, V. & Kianpour, M. 2018, "Performance evaluation of rail transportation systems by considering resilience engineering factors: Tehran railway electrification system", Transportation Letters, vol. 10, no. 1, pp. 12-25.

443. Baležentis, A. & Baležentis, T. 2011, "Assessing the efficiency of Lithuanian transport sector by applying the methods of multimoora and data envelopment analysis", Transport, vol. 26, no. 3, pp. 263-270.

444. Bhanot, N. & Singh, H. 2014, "Benchmarking the performance indicators of Indian Railway container business using data envelopment analysis", Benchmarking, vol. 21, no. 1, pp. 101-120.

445. Bian, Y., Hu, M. & Xu, H. 2015, "Measuring efficiencies of parallel systems with shared inputs/outputs using data envelopment analysis", Kybernetes, vol. 44, no. 3, pp. 336-352.

446. Cavone, G., Dotoli, M., Epicoco, N. & Seatzu, C. 2017, "A decision making procedure for robust train rescheduling based on mixed integer linear programming and Data Envelopment Analysis", Applied Mathematical Modelling, vol. 52, pp. 255-273.

447. Chapin, A. & Schmidt, S. 1999, "Do mergers improve efficiency? Evidence from deregulated rail freight", Journal of Transport Economics and Policy, vol. 33, no. 2, pp. 147-162.

448. Chen, C.C. 2014, "The operation of new transportation infrastructure and regional economic efficiency: A case study of taiwan high speed rail on regions in western Taiwan", Regional and Sectoral Economic Studies, vol. 14, no. 1, pp. 179-194.

449. Coelli, T. & Perelman, S. 1999, "Comparison of parametric and non-parametric distance functions: With application to European railways", European Journal of Operational Research, vol. 117, no. 2, pp. 326-339.

450. Cowie, J. 1999, "The technical efficiency of public and private ownership in the rail industry: The case of Swiss private railways", Journal of Transport Economics and Policy, vol. 33, no. 3, pp. 241-252.

451. Cowie, J. & Riddington, G. 1996, "Measuring the efficiency of European railways", Applied Economics, vol. 28, no. 8, pp. 1027-1035.

452. Cullinane, K., Bergqvist, R., Cullinane, S., Zhu, S. & Wang, L. 2017, "Improving the quality of Sweden’s rail freight rolling stock: The use of date envelopment analysis in benchmarking and pricing", Benchmarking, vol. 24, no. 6, pp. 1552-1570.

453. Djordjević, B., Krmac, E. & Mlinarić, T.J. 2018, "Non-radial DEA model: A new approach to evaluation of safety at railway level crossings", Safety Science, vol. 103, pp. 234-246.

454. Eguchi, S. 2017, "Understanding productivity declines of resource accumulation in the prefectures of Japan", Environmental Economics and Policy Studies, vol. 19, no. 2, pp. 337-357.

455. George, S.A. & Rangaraj, N. 2008, "A performance benchmarking study of Indian Railway zones", Benchmarking, vol. 15, no. 5, pp. 599-617.

456. Graham, D.J. 2008, "Productivity and efficiency in urban railways: Parametric and non-parametric estimates", Transportation Research Part E: Logistics and Transportation Review, vol. 44, no. 1, pp. 84-99.

457. Growitsch, C. & Wetzel, H. 2009, "Testing for economies of scope in European railways", Journal of Transport Economics and Policy, vol. 43, no. 1, pp. 1-24.

458. Guo, J., Nakamura, F., Li, Q. & Zhou, Y. 2018, "Efficiency Assessment of Transit-Oriented Development by Data Envelopment Analysis: Case Study on the Den-en Toshi Line in Japan", Journal of Advanced Transportation, vol. 2018.

459. Hilmola, O. 2007, "European railway freight transportation and adaptation to demand decline: Efficiency and partial productivity analysis from period of 1980-2003", International Journal of Productivity and Performance Management, vol. 56, no. 3, pp. 205-225.

460. Hilmola, O.-. 2011, "Role of location in railway sector efficiency", International Journal of Logistics Systems and Management, vol. 10, no. 4, pp. 478-494.

461. Hilmola, O.-. 2010, "Analysing global railway passenger transport through two-staged efficiency model", International Journal of Information and Decision Sciences, vol. 2, no. 3, pp. 273-284.

462. Hilmola, O.-. 2010, "Revenue vs. technical efficiency in railways", International Journal of Value Chain Management, vol. 4, no. 4, pp. 305-318.

463. Hilmola, O.-. 2009, "Benchmarking global railway freight transportation efficiency during the period of 1980-2004", International Journal of Shipping and Transport Logistics, vol. 1, no. 4, pp. 311-328.

464. Hilmola, O.-. 2008, "Railway efficiency analysis from larger Europe during the period 1994-2003", International Journal of Operational Research, vol. 3, no. 3, pp. 255-280.

465. Hilmola, O.-., Lorentz, H. & Rhoades, D.L. 2015, "New environmental demands and the future of the Helsinki-Tallinn freight route", Maritime Economics and Logistics, vol. 17, no. 2, pp. 198-220.

466. Hsiao, B., Shu, L.C., Yu, M.-., Shen, L.-. & Wang, D.-. 2017, "Performance evaluation of the Taiwan railway administration", Annals of Operations Research, vol. 259, no. 1-2, pp. 119-156.

467. Jafarian-Moghaddam, A.R. & Ghoseiri, K. 2012, "Multi-objective data envelopment analysis model in fuzzy dynamic environment with missing values", International Journal of Advanced Manufacturing Technology, vol. 61, no. 5-8, pp. 771-785.

468. Jafarian-Moghaddam, A.R. & Ghoseiri, K. 2011, "Fuzzy dynamic multi-objective Data Envelopment Analysis model", Expert Systems with Applications, vol. 38, no. 1, pp. 850-855.

469. Jain, P., Cullinane, S. & Cullinane, K. 2008, "The impact of governance development models on urban rail efficiency", Transportation Research Part A: Policy and Practice, vol. 42, no. 9, pp. 1238-1250.

470. Jitsuzumi, T. & Nakamura, A. 2010, "Causes of inefficiency in Japanese railways: Application of DEA for managers and policymakers", Socio-economic planning sciences, vol. 44, no. 3, pp. 161-173.

471. Kabasakal, A., Kutlar, A. & Sarikaya, M. 2013, "Efficiency determinations of the worldwide railway companies via DEA and contributions of the outputs to the efficiency and TFP by panel regression", Central European Journal of Operations Research, vol. 23, no. 1, pp. 69-88.

472. Khadem Sameni, M., Preston, J. & Khadem Sameni, M. 2016, "Evaluating efficiency of passenger railway stations: A DEA approach", Research in Transportation Business and Management, vol. 20, pp. 33-38.

473. Kim, H.-., Choi, C.-., Woo, J.-., Choi, Y., Kim, K. & Wu, D.D. 2011, "Efficiency of the modal shift and environmental policy on the Korean railroad", Stochastic Environmental Research and Risk Assessment, vol. 25, no. 3, pp. 305-322.

474. Kleinová, E. 2016, "Does liberalization of the railway industry lead to higher technical effectiveness?", Journal of Rail Transport Planning and Management, vol. 6, no. 1, pp. 67-76.

475. Krmac, E. & Djordjević, B. 2018, "Evaluation of the levels of safety at railway level crossings using data envelopment analysis (DEA) method: A case study on slovenian railways", European Transport - Trasporti Europei, , no. 67.

476. Kuang, X. 2018, "Evaluation of railway transportation efficiency based on super-cross efficiency", IOP Conference Series: Earth and Environmental Science.

477. Kutlar, A., Kabasakal, A. & Sarikaya, M. 2013, "Determination of the efficiency of the world railway companies by method of DEA and comparison of their efficiency by Tobit analysis", Quality and Quantity, vol. 47, no. 6, pp. 3575-3602.

478. Lan, L.W. & Lin, E.T.J. 2005, "Measuring railway performance with adjustment of environmental effects, data noise and slacks", Transportmetrica, vol. 1, no. 2, pp. 161-189.

479. Li, Y., Li, X. & Khalid, M.A. 2018, "Measuring technical efficiency of Chinese railway administrations by DEA method", Journal of Interdisciplinary Mathematics, vol. 21, no. 4, pp. 825-836.

480. Lin, E. 2016, "Measuring firms' input congestion with consideration of environmental factors: The case of European railway transport", Acta Oeconomica, vol. 66, no. 1, pp. 153-171.

481. Liu, H., Zhang, Y., Zhu, Q. & Chu, J. 2017, "Environmental efficiency of land transportation in China: A parallel slack-based measure for regional and temporal analysis", Journal of Cleaner Production, vol. 142, pp. 867-876.

482. Liu, Z., Qin, C.-. & Zhang, Y.-. 2016, "The energy-environment efficiency of road and railway sectors in China: Evidence from the provincial level", Ecological Indicators, vol. 69, pp. 559-570.

483. Mapapa, A.M. 2004, "Management of railways in Sub-Saharan Africa", Rail International, vol. 35, no. OCT./DEC., pp. P13-P21.

484. Marchetti, D. & Wanke, P. 2017, "Brazil's rail freight transport: Efficiency analysis using two-stage DEA and cluster-driven public policies", Socio-economic planning sciences, vol. 59, pp. 26-42.

485. Markovits-Somogyi, R. 2011, "Measuring efficiency in transport: The state of the art of applying Data Envelopment Analysis", Transport, vol. 26, no. 1, pp. 11-19.

486. Martín, J.C. & Reggiani, A. 2007, "Recent methodological developments to measure spatial interaction: Synthetic accessibility indices applied to high-speed train investments", Transport Reviews, vol. 27, no. 5, pp. 551-571.

487. Merkert, R., Smith, A.S.J. & Nash, C.A. 2010, "Benchmarking of train operating firms - A transaction cost efficiency analysis", Transportation Planning and Technology, vol. 33, no. 1, pp. 35-53.

488. Moesen, W.A. 1994, "The need for performance auditing in the public sector and the best-practice frontier", European Journal of Law and Economics, vol. 1, no. 4, pp. 263-274.

489. Mohajeri, N. & Amin, G.R. 2010, "Railway station site selection using analytical hierarchy process and data envelopment analysis", Computers and Industrial Engineering, vol. 59, no. 1, pp. 107-114.

490. Noroozzadeh, A. & Sadjadi, S.J. 2013, "A new approach to evaluate railways efficiency considering safety measures", Decision Science Letters, vol. 2, no. 2, pp. 71-80.

491. Rayeni, M.M. & Saljooghi, F.H. 2014, "Ranking and measuring efficiency using secondary goals of cross-efficiency evaluation - A study of railway efficiency in Iran", International Journal of Services and Operations Management, vol. 17, no. 1, pp. 1-16.

492. Roets, B. & Christiaens, J. 2015, "Evaluation of railway traffic control efficiency and its determinants", European Journal of Transport and Infrastructure Research, vol. 15, no. 4, pp. 396-418.

493. Roets, B., Verschelde, M. & Christiaens, J. 2018, "Multi-output efficiency and operational safety: An analysis of railway traffic control centre performance", European Journal of Operational Research, vol. 271, no. 1, pp. 224-237.

494. Rotoli, F., Navajas Cawood, E. & Christidis, P. 2015, "A Data Envelopment Analysis approach for accessibility measures: Simulating operational enhancement scenarios for railway across Europe", European Transport Research Review, vol. 7, no. 2.

495. Rotoli, F., Valeri, E., Ricci, S., Rizzetto, L. & Malavasi, G. 2018, "An analysis of the railway access charges regime in the Italian context", Transport Policy, vol. 64, pp. 20-28.

496. Salerian, J. & Chan, C. 2005, "Restricting multiple-output multiple-input DEA models by disaggregating the output-input vector", Journal of Productivity Analysis, vol. 24, no. 1, pp. 5-29.

497. Samà, M., Meloni, C., D'Ariano, A. & Corman, F. 2015, "A multi-criteria decision support methodology for real-time train scheduling", Journal of Rail Transport Planning and Management, vol. 5, no. 3, pp. 146-162.

498. Sameni, M.K. & Preston, J.M. 2012, Value for railway capacity.

499. Savolainen, V.-. & Hilmola, O.-. 2009, "The relative technical efficiency of European transportation systems concerning air transport and railways", International Journal of Business Performance Management, vol. 11, no. 1-2, pp. 19-42.

500. Sharma, M.G., Debnath, R.M., Oloruntoba, R. & Sharma, S.M. 2016, "Benchmarking of rail transport service performance through DEA for Indian railways", International Journal of Logistics Management, vol. 27, no. 3, pp. 629-649.

501. Shi, F.X., Lim, S.H. & Chi, J. 2011, "Railroad productivity analysis: Case of the American Class I railroads", International Journal of Productivity and Performance Management, vol. 60, no. 4, pp. 372-386.

502. Sozen, A., Alp, I. & Kurt, B. 2012, "Total factor efficiency of Turkish state railways", Energy Education Science and Technology Part A: Energy Science and Research, vol. 29, no. 1, pp. 663-678.

503. Sozen, A. & Cipil, F. 2018, "Efficiency analysis of Turkey's transportation system using decision support model: Data envelopment method" in Intelligent Transportation and Planning: Breakthroughs in Research and Practice, pp. 480-509.

504. Tahir, N. 2013, "Efficiency analysis of Pakistan Railway in comparison with China and India", International Journal of Transport Economics, vol. 40, no. 1, pp. 71-98.

505. Tavassoli, M., Faramarzi, G.R. & Saen, R.F. 2015, "A joint measurement of efficiency and effectiveness using network data envelopment analysis approach in the presence of shared input", OPSEARCH, vol. 52, no. 3, pp. 490-504.

506. Vasco Correa, C.A. 2012, "Economic evaluation of current conditions of competition and efficiency of automotive and rail systems in Colombia", Energy Policy, vol. 46, pp. 78-87.

507. Wanke, P., Chen, Z., Liu, W., Antunes, J.J.M. & Azad, M.A.K. 2018, "Investigating the drivers of railway performance: Evidence from selected Asian countries", Habitat International, vol. 80, pp. 49-69.

508. Wanke, P. & Kalam Azad, M.A. 2018, "Efficiency in Asian railways: a comparison between data envelopment analysis approaches", Transportation Planning and Technology, vol. 41, no. 6, pp. 573-599.

509. Xiang, H., Li, Y., Chen, B. & Liao, H. 2014, "Protection effect of railway wind barrier on running safety of train under cross winds", Advances in Structural Engineering, vol. 17, no. 8, pp. 1177-1187.

510. Yu, M.-. 2008, "Assessing the technical efficiency, service effectiveness, and technical effectiveness of the world's railways through NDEA analysis", Transportation Research Part A: Policy and Practice, vol. 42, no. 10, pp. 1283-1294.

511. Yu, M.-. & Lin, E.T.J. 2008, "Efficiency and effectiveness in railway performance using a multi-activity network DEA model", Omega, vol. 36, no. 6, pp. 1005-1017.

512. Zhou, H. & Hu, H. 2017, "Sustainability evaluation of railways in China using a two-stage network DEA model with undesirable outputs and shared resources", Sustainability (Switzerland), vol. 9, no. 1.

DEA publications: sustainability development and green issues in transportation

513. Azadi, M., Mirhedayatian, S.M., Saen, R.F., Hatamzad, M. & Momeni, E. 2017, "Green supplier selection: A novel fuzzy double frontier data envelopment analysis model to deal with undesirable outputs and dual-role factors", International Journal of Industrial and Systems Engineering, vol. 25, no. 2, pp. 160-181.

514. Azadi, M., Shabani, A., Khodakarami, M. & Farzipoor Saen, R. 2014, "Planning in feasible region by two-stage target-setting DEA methods: An application in green supply chain management of public transportation service providers", Transportation Research Part E: Logistics and Transportation Review, vol. 70, no. 1, pp. 324-338.

515. Baležentis, T., Li, T., Streimikiene, D. & Baležentis, A. 2016, "Is the Lithuanian economy approaching the goals of sustainable energy and climate change mitigation? Evidence from DEA-based environmental performance index", Journal of Cleaner Production, vol. 116, pp. 23-31.

516. Barnum, D.T., Gleason, J.M. & Hemily, B. 2008, "Using panel data analysis to estimate DEA confidence intervals adjusted for the environment", Journal of Transportation Engineering, vol. 134, no. 5, pp. 215-223.

517. Barnum, D.T., Tandon, S. & McNeil, S. 2008, "Comparing the performance of bus routes after adjusting for the environment using data envelopment analysis", Journal of Transportation Engineering, vol. 134, no. 2, pp. 77-85.

518. Beltrán-Esteve, M. & Picazo-Tadeo, A.J. 2015, "Assessing environmental performance trends in the transport industry: Eco-innovation or catching-up?", Energy Economics, vol. 51, pp. 570-580.

519. Bi, G., Wang, P., Yang, F. & Liang, L. 2014, "Energy and environmental efficiency of china's transportation sector: A multidirectional analysis approach", Mathematical Problems in Engineering, vol. 2014.

520. Carlucci, F., Cirà, A. & Coccorese, P. 2018, "Measuring and explaining airport efficiency and sustainability: Evidence from Italy", Sustainability (Switzerland), vol. 10, no. 2.

521. Chan, P.S. & Sueyoshi, T. 1991, "Environmental change, competition, strategy, structure and firm performance: An application of data envelopment analysis in the airline industry", International Journal of Systems Science, vol. 22, no. 9, pp. 1625-1636.

522. Chang, Y.-., Yu, M.-. & Chen, P.-. 2013, "Evaluating the performance of Chinese airports", Journal of Air Transport Management, vol. 31, pp. 19-21.

523. Chang, Y.-., Park, H.K., Lee, S. & Kim, E. 2018, "Have Emission Control Areas (ECAs) harmed port efficiency in Europe?", Transportation Research Part D: Transport and Environment, vol. 58, pp. 39-53.

524. Chang, Y.-., Park, H.-., Jeong, J.-. & Lee, J.-. 2014, "Evaluating economic and environmental efficiency of global airlines: A SBM-DEA approach", Transportation Research Part D: Transport and Environment, vol. 27, pp. 46-50.

525. Chang, Y.-. & Zhang, N. 2017, "Environmental efficiency of transportation sectors in China and Korea oa", Maritime Economics and Logistics, vol. 19, no. 1, pp. 68-93.

526. Chang, Y.-., Zhang, N., Danao, D. & Zhang, N. 2013, "Environmental efficiency analysis of transportation system in China: A non-radial DEA approach", Energy Policy, vol. 58, pp. 277-283.

527. Chen, C., Achtari, G., Majkut, K. & Sheu, J.-. 2017, "Balancing equity and cost in rural transportation management with multi-objective utility analysis and data envelopment analysis: A case of Quinte West", Transportation Research Part A: Policy and Practice, vol. 95, pp. 148-165.

528. Chen, C. & Lam, J.S.L. 2018, "Sustainability and interactivity between cities and ports: a two-stage data envelopment analysis (DEA) approach", Maritime Policy and Management, vol. 45, no. 7, pp. 944-961.

529. Chen, L., He, F. & Wang, J. 2018, "Allocative efficiency of carbon emission allowances among sectors in China", Polish Journal of Environmental Studies, vol. 27, no. 2, pp. 557-564.

530. Chen, X., Gao, Y., An, Q., Wang, Z. & Neralić, L. 2018, "Energy efficiency measurement of Chinese Yangtze River Delta’s cities transportation: a DEA window analysis approach", Energy Efficiency, pp. 1-13.

531. Chen, Z., Wanke, P., Antunes, J.J.M. & Zhang, N. 2017, "Chinese airline efficiency under CO2emissions and flight delays: A stochastic network DEA model", Energy Economics, vol. 68, pp. 89-108.

532. Cheong, J.P., Kim, C. & Chang, J.-. 2011, "Evaluation of Green House Gases (GHGs) reduction plan in combination with air pollutants reduction in Busan Metropolitan City in Korea", Asian Journal of Atmospheric Environment, vol. 5, no. 4, pp. 228-236.

533. Chu, J.-., Wu, J. & Song, M.-. 2018, "An SBM-DEA model with parallel computing design for environmental efficiency evaluation in the big data context: a transportation system application", Annals of Operations Research, vol. 270, no. 1-2, pp. 105-124.

534. Çipil, F. 2014, "Performance analysis of Turkey's transport sector greenhouse gas emissions", Energy and Environment, vol. 25, no. 2, pp. 357-368.

535. Cui, Q., Li, Y. & Lin, J.-. 2018, "Pollution abatement costs change decomposition for airlines: An analysis from a dynamic perspective", Transportation Research Part A: Policy and Practice, vol. 111, pp. 96-107.

536. Curi, C., Gitto, S. & Mancuso, P. 2011, "New evidence on the efficiency of Italian airports: A bootstrapped DEA analysis", Socio-economic planning sciences, vol. 45, no. 2, pp. 84-93.

537. do Castelo Gouveia, M. & Clímaco, I. 2018, Assessment of fuel tax policies to tackle carbon emissions from road transport—an application of the value-based DEA method including robustness analysis.

538. Egilmez, G., Kucukvar, M. & Park, Y.S. 2016, "Mode-specific eco-efficiency analysis of the freight transportation in the USA: An integrated life cycle assessment and linear programming approach", World Review of Intermodal Transportation Research, vol. 6, no. 1, pp. 16-42.

539. Egilmez, G. & Park, Y.S. 2014, "Transportation related carbon, energy and water footprint analysis of U.S. manufacturing: An eco-efficiency assessment", Transportation Research Part D: Transport and Environment, vol. 32, pp. 143-159.

540. Fathi, A. & Saen, R.F. 2018, "A novel bidirectional network data envelopment analysis model for evaluating sustainability of distributive supply chains of transport companies", Journal of Cleaner Production, vol. 184, pp. 696-708.

541. Gu, W. & Bordoloi, S. 2012, "Performance evaluation of metro stations in Shanghai: A service contact perspective", International Journal of Services and Operations Management, vol. 11, no. 2, pp. 151-169.

542. Guo, J., Nakamura, F., Li, Q. & Zhou, Y. 2018, "Efficiency Assessment of Transit-Oriented Development by Data Envelopment Analysis: Case Study on the Den-en Toshi Line in Japan", Journal of Advanced Transportation, vol. 2018.

543. Gupta, P., Mehlawat, M.K., Aggarwal, U. & Charles, V. 2018, "An integrated AHP-DEA multi-objective optimization model for sustainable transportation in mining industry", Resources Policy.

544. Ha, H.K., Kaneko, S., Yamamoto, M., Yoshida, Y. & Zhang, A. 2017, "On the discrepancy in the social efficiency measures between parametric and non-parametric production technology identification", Journal of Air Transport Management, vol. 58, pp. 9-14.

545. Hahn, J.-., Kim, D.-., Kim, H.-. & Lee, C. 2013, "Efficiency analysis on bus companies in Seoul city using a network DEA model", KSCE Journal of Civil Engineering, vol. 17, no. 6, pp. 1480-1488.

546. Hahn, J.-., Kim, H.-. & Kho, S.-. 2011, "Analysis of the efficiency of Seoul Arterial Bus routes and its determinant factors", KSCE Journal of Civil Engineering, vol. 15, no. 6, pp. 1115-1123.

547. Haralambides, H. & Gujar, G. 2012, "On balancing supply chain efficiency and environmental impacts: An eco-DEA model applied to the dry port sector of India", Maritime Economics and Logistics, vol. 14, no. 1, pp. 122-137.

548. He, Q., Han, J., Guan, D., Mi, Z., Zhao, H. & Zhang, Q. 2018, "The comprehensive environmental efficiency of socioeconomic sectors in China: An analysis based on a non-separable bad output SBM", Journal of Cleaner Production, vol. 176, pp. 1091-1110.

549. Hilmola, O.-., Lorentz, H. & Rhoades, D.L. 2015, "New environmental demands and the future of the Helsinki-Tallinn freight route", Maritime Economics and Logistics, vol. 17, no. 2, pp. 198-220.

550. Holden, R., Xu, B., Greening, P., Piecyk, M. & Dadhich, P. 2016, "Towards a common measure of greenhouse gas related logistics activity using data envelopment analysis", Transportation Research Part A: Policy and Practice, vol. 91, pp. 105-119.

551. Hu, J.-., Lio, M.-., Yeh, F.-. & Lin, C.-. 2011, "Environment-adjusted regional energy efficiency in Taiwan", Applied Energy, vol. 88, no. 8, pp. 2893-2899.

552. Ji, X., Wu, J. & Zhu, Q. 2016, "Eco-design of transportation in sustainable supply chain management: A DEA-like method", Transportation Research Part D: Transport and Environment, vol. 48, pp. 451-459.

553. Jiang, J. 2017, "Transport energy consumption achievement based on indicator analysis", IOP Conference Series: Earth and Environmental Science.

554. Kengpol, A., Tuammee, S. & Tuominen, M. 2014, "The development of a framework for route selection in multimodal transportation", International Journal of Logistics Management, vol. 25, no. 3, pp. 581-610.

555. Kim, H.-., Choi, C.-., Woo, J.-., Choi, Y., Kim, K. & Wu, D.D. 2011, "Efficiency of the modal shift and environmental policy on the Korean railroad", Stochastic Environmental Research and Risk Assessment, vol. 25, no. 3, pp. 305-322.

556. Klumpp, M. 2017, "Do forwarders improve sustainability efficiency? Evidence from a European DEA Malmquist index calculation", Sustainability (Switzerland), vol. 9, no. 5.

557. Li, X., Li, F., Zhao, N. & Zhu, Q. 2018, "Measuring environmental sustainability performance of freight transportation seaports in China: A data envelopment analysis approach based on the closest targets", Expert Systems.

558. Li, Y. & Cui, Q. 2018, "Investigating the role of cooperation in the GHG abatement costs of airlines under CNG2020 strategy via a DEA cross PAC model", Energy, vol. 161, pp. 725-736.

559. Li, Y. & Cui, Q. 2017, "Carbon neutral growth from 2020 strategy and airline environmental inefficiency: A Network Range Adjusted Environmental Data Envelopment Analysis", Applied Energy, vol. 199, pp. 13-24.

560. Lin, W., Chen, B., Xie, L. & Pan, H. 2015, "Estimating energy consumption of transport modes in China using DEA", Sustainability (Switzerland), vol. 7, no. 4, pp. 4225-4239.

561. Liu, H., Wu, J. & Chu, J. 2018, "Environmental efficiency and technological progress of transportation industry-based on large scale data", Technological Forecasting and Social Change.

562. Liu, H., Zhang, Y., Zhu, Q. & Chu, J. 2017, "Environmental efficiency of land transportation in China: A parallel slack-based measure for regional and temporal analysis", Journal of Cleaner Production, vol. 142, pp. 867-876.

563. Liu, X. & Wu, J. 2017, "Energy and environmental efficiency analysis of China's regional transportation sectors: a slack-based DEA approach", Energy Systems, vol. 8, no. 4, pp. 747-759.

564. Liu, Z., Qin, C.-. & Zhang, Y.-. 2016, "The energy-environment efficiency of road and railway sectors in China: Evidence from the provincial level", Ecological Indicators, vol. 69, pp. 559-570.

565. lo Storto, C. 2018, "The analysis of the cost-revenue production cycle efficiency of the Italian airports: A NSBM DEA approach", Journal of Air Transport Management, vol. 72, pp. 77-85.

566. Ma, F., Li, X., Sun, Q., Liu, F., Wang, W. & Bai, L. 2018, "Regional differences and spatial aggregation of sustainable transport efficiency: A case study of China", Sustainability (Switzerland), vol. 10, no. 7.

567. Moutinho, V., Madaleno, M. & Robaina, M. 2017, "The economic and environmental efficiency assessment in EU cross-country: Evidence from DEA and quantile regression approach", Ecological Indicators, vol. 78, pp. 85-97.

568. Omrani, H., Shafaat, K. & Alizadeh, A. 2018, "Integrated data envelopment analysis and cooperative game for evaluating energy efficiency of transportation sector: a case of Iran", Annals of Operations Research, pp. 1-29.

569. Onat, N.C., Noori, M., Kucukvar, M., Zhao, Y., Tatari, O. & Chester, M. 2017, "Exploring the suitability of electric vehicles in the United States", Energy, vol. 121, pp. 631-642.

570. Ozbek, M.E., de la Garza, J.M. & Triantis, K. 2010, "Data and modeling issues faced during the efficiency measurement of road maintenance using data envelopment analysis", Journal of Infrastructure Systems, vol. 16, no. 1, pp. 21-30.

571. Ozbek, M.E., de la Garza, J.M. & Triantis, K. 2010, "Efficiency measurement of bridge maintenance using data envelopment analysis", Journal of Infrastructure Systems, vol. 16, no. 1, pp. 31-39.

572. Park, Y.S., Lim, S.H., Egilmez, G. & Szmerekovsky, J. 2016, "Environmental efficiency assessment of U.S. transport sector: A slack-based data envelopment analysis approach", Transportation Research Part D: Transport and Environment, vol. 61, pp. 152-164.

573. Ramanathan, R. 2005, "Estimating energy consumption of transport modes in India using DEA and application to energy and environmental policy", Journal of the Operational Research Society, vol. 56, no. 6, pp. 732-737.

574. Rassafi, A.A. & Vaziri, M. 2007, "Assessment of modal transportation sustainability: Application of data envelopment and concordance analyses", Iranian Journal of Science and Technology, Transaction B: Engineering, vol. 31, no. 2, pp. 179-193.

575. Rassafi, A.A. & Vaziri, M. 2005, "Application of data envelopment analysis in identifying milestones for passenger and freight transportation sustainability", Scientia Iranica, vol. 12, no. 4, pp. 426-436.

576. Raut, R., Kharat, M., Kamble, S. & Kumar, C.S. 2018, "Sustainable evaluation and selection of potential third-party logistics (3PL) providers: An integrated MCDM approach", Benchmarking, vol. 25, no. 1, pp. 76-97.

577. Rogers, M.M. & Weber, W.L. 2011, "Evaluating CO2 emissions and fatalities tradeoffs in truck transport", International Journal of Physical Distribution and Logistics Management, vol. 41, no. 8, pp. 750-767.

578. Rouse, P. & Chiu, T. 2009, "Towards optimal life cycle management in a road maintenance setting using DEA", European Journal of Operational Research, vol. 196, no. 2, pp. 672-681.

579. Sheth, C., Triantis, K. & Teodorović, D. 2007, "Performance evaluation of bus routes: A provider and passenger perspective", Transportation Research Part E: Logistics and Transportation Review, vol. 43, no. 4, pp. 453-478.

580. Shiau, T.-. & Jhang, J.-. 2010, "An integration model of DEA and RST for measuring transport sustainability", International Journal of Sustainable Development and World Ecology, vol. 17, no. 1, pp. 76-83.

581. Song, M., Zheng, W. & Wang, Z. 2016, "Environmental efficiency and energy consumption of highway transportation systems in China", International Journal of Production Economics, vol. 181, pp. 441-449.

582. Song, X., Hao, Y. & Zhu, X. 2015, "Analysis of the environmental efficiency of the Chinese transportation sector using an undesirable output slacks-based measure data envelopment analysis model", Sustainability (Switzerland), vol. 7, no. 7, pp. 9187-9206.

583. Starr McMullen, B. & Noh, D.-. 2007, "Accounting for emissions in the measurement of transit agency efficiency: A directional distance function approach", Transportation Research Part D: Transport and Environment, vol. 12, no. 1, pp. 1-9.

584. Su, J. & Rogers, M.M. 2012, "The role of economic variables and CO2emissions in examining the efficiency of national transportation systems", International Journal of Sustainable Transportation, vol. 6, no. 1, pp. 48-66.

585. Sun, Z., Luo, R. & Zhou, D. 2016, "Optimal path for controlling sectoral CO2emissions among China's regions: A centralized dea approach", Sustainability (Switzerland), vol. 8, no. 1, pp. 1-20.

586. Tamaki, T., Nakamura, H., Fujii, H. & Managi, S. 2016, "Efficiency and emissions from urban transport: Application to world city-level public transportation", Economic Analysis and Policy.

587. Tatari, O., Egilmez, G. & Kurmapu, D. 2016, "Socio-eco-efficiency analysis of highways: a data envelopment analysis", Journal of Civil Engineering and Management, vol. 22, no. 6, pp. 747-757.

588. Wang, C.-., Ho, H.T., Luo, S.-. & Lin, T.-. 2017, "An integrated approach to evaluating and selecting green logistics providers for sustainable development", Sustainability (Switzerland), vol. 9, no. 2.

589. Wang, Z. & He, W. 2017, "CO2emissions efficiency and marginal abatement costs of the regional transportation sectors in China", Transportation Research Part D: Transport and Environment, vol. 50, pp. 83-97.

590. Wu, J., Chu, J., An, Q., Sun, J. & Yin, P. 2016, "Resource reallocation and target setting for improving environmental performance of DMUs: An application to regional highway transportation systems in China", Transportation Research Part D: Transport and Environment, vol. 61, pp. 204-216.

591. Wu, J., Zhu, Q., Chu, J., Liu, H. & Liang, L. 2016, "Measuring energy and environmental efficiency of transportation systems in China based on a parallel DEA approach", Transportation Research Part D: Transport and Environment, vol. 48, pp. 460-472.

592. Wu, Y., He, C. & Cao, X. 2013, "The impact of environmental variables on the efficiency of Chinese and other non-Chinese airlines", Journal of Air Transport Management, vol. 29, pp. 35-38.

593. Yang, C.-. 2012, "Productivity changes in Taiwan's port industry incorporating environmental regulations on harbor water quality", Transportation Planning and Technology, vol. 35, no. 8, pp. 769-789.

594. Yu, M.-. 2004, "Measuring physical efficiency of domestic airports in Taiwan with undesirable outputs and environmental factors", Journal of Air Transport Management, vol. 10, no. 5, pp. 295-303.

595. Zhang, J.Y., Sun, H., Li, P.F. & Li, C.C. 2017, "The Comprehensive Benefit Evaluation of Take Shared Bicycles as Connecting to Public Transit", IOP Conference Series: Earth and Environmental Science.

596. Zhang, M., Liu, L.B., Li, Y.H. & Shu, H.B. 2013, "Explore the influence of natural environment to highway traffic safety of mountainous area based on DEA theory", International Journal of Applied Environmental Sciences, vol. 8, no. 23-24, pp. 2883-2891.

597. Zhang, N. & Wei, X. 2015, "Dynamic total factor carbon emissions performance changes in the Chinese transportation industry", Applied Energy, vol. 146, pp. 409-420.

598. Zhang, N., Zhou, P. & Kung, C.-. 2015, "Total-factor carbon emission performance of the Chinese transportation industry: A bootstrapped non-radial Malmquist index analysis", Renewable and Sustainable Energy Reviews, vol. 41, pp. 584-593.

599. Zhang, Q., Wang, H. & Zhou, Z. 2017, "A location decision for Chinese remanufacturing logistics network based on improved super-efficiency dea: Carbon emission constraints perspective", ACM International Conference Proceeding Series, pp. 87.

600. Zhou, G., Chung, W. & Zhang, X. 2013, "A study of carbon dioxide emissions performance of China's transport sector", Energy, vol. 50, no. 1, pp. 302-314.

601. Zhou, H. & Hu, H. 2017, "Sustainability evaluation of railways in China using a two-stage network DEA model with undesirable outputs and shared resources", Sustainability (Switzerland), vol. 9, no. 1.

602. Zhu, W., Yang, X. & Preston, J. 2016, "Efficiency measurement of bus routes and exogenous operating environment effects on efficiency", Transportation Planning and Technology, vol. 39, no. 5, pp. 464-483.

DEA and other transportation researches

603. Álvarez, I.C. & Blázquez, R. 2014, "The influence of the road network on private productivity measures using Data Envelopment Analysis: A case study from Spain", Transportation Research Part A: Policy and Practice, vol. 65, pp. 33-43.

604. Amelian, S., Shojaie, A.A. & Davoodi, S.M.R. 2017, "Road safety evaluation using data envelopment analysis case study: Roads in provinces in Iran", International Journal of Vehicle Safety, vol. 9, no. 3, pp. 253-261.

605. Amirteimoori, A. 2011, "An extended transportation problem: A DEA-based approach", Central European Journal of Operations Research, vol. 19, no. 4, pp. 513-521.

606. Andrejić, M., Bojović, N. & Kilibarda, M. 2016, "A framework for measuring transport efficiency in distribution centers", Transport Policy, vol. 45, pp. 99-106.

607. Azadeh, A., Pourebrahim Ahvazi, M., Motevali Haghighii, S. & Keramati, A. 2016, "Simulation optimization of an emergency department by modeling human errors", Simulation Modelling Practice and Theory, vol. 67, pp. 117-136.

608. Barnum, D.T., Karlaftis, M.G. & Tandon, S. 2011, "Improving the efficiency of metropolitan area transit by joint analysis of its multiple providers", Transportation Research Part E: Logistics and Transportation Review, vol. 47, no. 6, pp. 1160-1176.

609. Bastos, J.T., Shen, Y., Hermans, E., Brijs, T., Wets, G. & Ferraz, A.C.P. 2015, "Bootstrapping DEA scores for road safety strategic analysis in Brazil", International Journal of Computational Intelligence Systems, vol. 8, pp. 29-38.

610. Behnood, H.R. 2018, "Best practice analysis of action for road safety in Iran amongst the leading developing countries using an optimized success indicator", Transport Policy, vol. 66, pp. 76-84.

611. Behnood, H.R., Ayati, E., Hermans, E. & Neghab, M.A.P. 2014, "Road safety performance evaluation and policy making by data envelopment analysis: A case study of provincial data in Iran", Scientia Iranica, vol. 21, no. 5, pp. 1515-1528.

612. Boame, A.K. 2004, "The technical efficiency of Canadian urban transit systems", Transportation Research Part E: Logistics and Transportation Review, vol. 40, no. 5, pp. 401-416.

613. Boilé, M.P. 2001, "Estimating technical and scale inefficiencies of public transit systems", Journal of Transportation Engineering, vol. 127, no. 3, pp. 187-194.

614. Cesaroni, G. 2018, "Industry cost efficiency in data envelopment analysis", Socio-economic planning sciences, vol. 61, pp. 37-43.

615. Chen, C., Achtari, G., Majkut, K. & Sheu, J.-. 2017, "Balancing equity and cost in rural transportation management with multi-objective utility analysis and data envelopment analysis: A case of Quinte West", Transportation Research Part A: Policy and Practice, vol. 95, pp. 148-165.

616. Chen, C.-., Du, J., Huo, J. & Zhu, J. 2012, "Undesirable factors in integer-valued DEA: Evaluating the operational efficiencies of city bus systems considering safety records", Decision Support Systems, vol. 54, no. 1, pp. 330-335.

617. Chen, S.-., Mao, B.-., Liu, S., Sun, Q.-., Wei, W. & Zhan, L.-. 2013, "Computer-aided analysis and evaluation on ramp spacing along urban expressways", Transportation Research Part C: Emerging Technologies, vol. 36, pp. 381-393.

618. Chen, Y. & Han, B. 2012, "Regional public transportation scheduling model based on welfare economics and DEA", International Journal of Modelling, Identification and Control, vol. 16, no. 3, pp. 272-276.

619. Chen, Y.-., Lai, P.-. & Piboonrungroj, P. 2017, "The relationship between airport performance and privatisation policy: A nonparametric metafrontier approach", Journal of Transport Geography, vol. 62, pp. 229-235.

620. Costa, Á. & Markellos, R.N. 1997, "Evaluating public transport efficiency with neural network models", Transportation Research Part C: Emerging Technologies, vol. 5, no. 5, pp. 301-312.

621. Cowie, J. & Asenova, D. 1999, "Organisation form, scale effects and efficiency in the British bus industry", Transportation, vol. 26, no. 3, pp. 231-248.

622. Cruijssen, F., Dullaert, W. & Joro, T. 2010, "Freight transportation efficiency through horizontal cooperation in flanders", International Journal of Logistics Research and Applications, vol. 13, no. 3, pp. 161-178.

623. Dewita, Y., Yen, B.T.H. & Burke, M. 2018, "The effect of transport cost on housing affordability: Experiences from the Bandung Metropolitan Area, Indonesia", Land Use Policy, vol. 79, pp. 507-519.

624. Djordjević, B., Krmac, E. & Mlinarić, T.J. 2018, "Non-radial DEA model: A new approach to evaluation of safety at railway level crossings", Safety Science, vol. 103, pp. 234-246.

625. Fanou, E.H. & Wang, X. 2018, "Assessment of transit transport corridor efficiency of landlocked African countries using data envelopment analysis", South African Journal of Science, vol. 114, no. 1-2.

626. Fayyaz S, S.K., Cathy Liu, X. & Wei, R. 2018, Transit Vehicle Performance Analysis for Service Continuity/Termination: A Data Envelopment Analysis Approach.

627. Fitzová, H., Matulová, M. & Tomeš, Z. 2018, "Determinants of urban public transport efficiency: case study of the Czech Republic", European Transport Research Review, vol. 10, no. 2.

628. García-Palomares, J.C., Gutiérrez, J., Martín, J.C. & Moya-Gómez, B. 2018, "An analysis of the Spanish high capacity road network criticality", Transportation, vol. 45, no. 4, pp. 1139-1159.

629. Gibson, E., van Blommestein, K., Kim, J., Daim, T. & Garces, E. 2017, "Forecasting the electric transformation in transportation: the role of battery technology performance", Technology Analysis and Strategic Management, vol. 29, no. 10, pp. 1103-1120.

630. Güner, S. & Coşkun, E. 2016, "Determining the best performing benchmarks for transit routes with a multi-objective model: the implementation and a critique of the two-model approach", Public Transport, vol. 8, no. 2, pp. 205-224.

631. Guo, W., Gong, D.Q. & Hu, J.Z. 2015, "Applying Data Envelopment Analysis (DEA) approach to analyse investment efficiency of transportation projects", Advances in Transportation Studies, vol. 2, pp. 139-150.

632. Hanauerová, E. 2018, "Assessing the technical efficiency of public procurements in the bus transportation sector in the Czech Republic", Socio-economic planning sciences, .

633. Hanumappa, D., Ramachandran, P., Sitharam, T.G. & Lakshmana, S. 2015, "Performance evaluation of Bangalore metropolitan transport corporation: An application of data envelopment analysis", Journal of Public Transportation, vol. 18, no. 2, pp. 1-19.

634. Holmgren, J. 2018, "The effects of using different output measures in efficiency analysis of public transport operations", Research in Transportation Business and Management, .

635. Jafari Songhori, M., Tavana, M., Azadeh, A. & Khakbaz, M.H. 2011, "A supplier selection and order allocation model with multiple transportation alternatives", International Journal of Advanced Manufacturing Technology, vol. 52, no. 1-4, pp. 365-376.

636. Jiang, C. 2010, "Research on logistics network infrastructure based on HCA and DEA-PCA approach", Journal of Computers, vol. 5, no. 4, pp. 533-540.

637. Juan, Z., Wu, J. & McDonald, M. 2006, "Socio-economic impact assessment of intelligent transport systems", Tsinghua Science and Technology, vol. 11, no. 3, pp. 339-350.

638. Juan, Z., Wu, J. & McDonald, M. 2003, "The socio-economic impacts assessment of advanced convoy driving on motorway", Transportation Research Part A: Policy and Practice, vol. 37, no. 9, pp. 731-747.

639. Karlaftis, M.G. 2003, "Investigating transit production and performance: A programming approach", Transportation Research Part A: Policy and Practice, vol. 37, no. 3, pp. 225-240.

640. Kawamoto, K. & Kim, K. 2016, "Social capital and efficiency of earthquake waste management in Japan", International Journal of Disaster Risk Reduction, vol. 18, pp. 256-266.

641. Kerstens, K. 1996, "Technical efficiency measurement and explanation of french urban transit companies", Transportation Research Part A: Policy and Practice, vol. 30, no. 6 PART A, pp. 431-452.

642. Lan, L.W., Chiou, Y.-. & Yen, B.T.H. 2014, "Integrated fuzzy data envelopment analysis to assess transport performance", Transportmetrica A: Transport Science, vol. 10, no. 5, pp. 401-419.

643. Lau, K.H. 2013, "Measuring distribution efficiency of a retail network through data envelopment analysis", International Journal of Production Economics, vol. 146, no. 2, pp. 598-611.

644. Lin, J., Wang, P. & Barnum, D.T. 2008, "A quality control framework for bus schedule reliability", Transportation Research Part E: Logistics and Transportation Review, vol. 44, no. 6, pp. 1086-1098.

645. Liu, H.-. 2014, "Evaluating knowledge outsourcing performance of public sectors with data envelopment analysis", Revista Internacional de Sociologia, vol. 72, no. Extra 2, pp. 23-32.

646. Matulová, M. & Fitzová, H. 2018, "Transformation of urban public transport financing and its effect on operators' efficiency: evidence from the Czech Republic", Central European Journal of Operations Research, pp. 1-17.

647. Merkert, R., Mulley, C. & Hakim, M.M. 2017, "Determinants of bus rapid transit (BRT) system revenue and effectiveness – A global benchmarking exercise", Transportation Research Part A: Policy and Practice, vol. 106, pp. 75-88.

648. Min, H., Ahn, Y.-. & Lambert, T. 2017, "Benchmarking and improving mass transit systems in the United States based on best-in class practices: Policy implications", International Journal of Logistics Management, vol. 28, no. 1, pp. 172-193.

649. Mohd. Zaid, Z.B., Shah, M.Z. & Rahim, A.B.A. 2016, "Modelling the road transport for efficiency analysis", Trends in Bioinformatics, vol. 9, no. 2, pp. 65-69.

650. Neumann, A., Nieswand, M. & Schubert, T. 2016, "Estimating alternative technology sets in nonparametric efficiency analysis: restriction tests for panel and clustered data", Journal of Productivity Analysis, vol. 45, no. 1, pp. 35-51.

651. Novaes, A.G.N., Silveira, S.F. & Medeiros, H.C. 2010, "Efficiency and productivity analysis of the interstate bus transportation industry in Brazil", Pesquisa Operacional, vol. 30, no. 2, pp. 465-485.

652. Noveiri, M.J.S., Kordrostami, S. & Amirteimoori, A. 2018, "Detecting the multi-period performance and efficiency changes of systems with undesirable outputs", Discrete Mathematics, Algorithms and Applications, vol. 10, no. 3.

653. Odeck, J. 2008, "The effect of mergers on efficiency and productivity of public transport services", Transportation Research Part A: Policy and Practice, vol. 42, no. 4, pp. 696-708.

654. Odeck, J. 2006, "Congestion, ownership, region of operation, and scale: Their impact on bus operator performance in Norway", Socio-economic planning sciences, vol. 40, no. 1, pp. 52-69.

655. Odeck, J. & Alkadi, A. 2001, "Evaluating efficiency in the Norwegian bus industry using data envelopment analysis", Transportation, vol. 28, no. 3, pp. 211-232.

656. Onat, N.C., Noori, M., Kucukvar, M., Zhao, Y., Tatari, O. & Chester, M. 2017, "Exploring the suitability of electric vehicles in the United States", Energy, vol. 121, pp. 631-642.

657. Ozbek, M.E., de la Garza, J.M. & Triantis, K. 2012, "Efficiency measurement of the maintenance of paved lanes using data envelopment analysis", Construction Management and Economics, vol. 30, no. 11, pp. 995-1009.

658. Ozbek, M.E., de la Garza, J.M. & Triantis, K. 2009, "Data envelopment analysis as a decision-making tool for transportation professionals", Journal of Transportation Engineering, vol. 135, no. 11, pp. 822-831.

659. Pal, D. & Mitra, S.K. 2016, "An application of the directional distance function with the number of accidents as an undesirable output to measure the technical efficiency of state road transport in India", Transportation Research Part A: Policy and Practice, vol. 93, pp. 1-12.

660. Panayides, P.M. & Lambertides, N. 2011, "The relative efficiency of maritime firms: Evidence from container lines", Singapore Economic Review, vol. 56, no. 4, pp. 503-522.

661. Panayides, P.M., Lambertides, N. & Savva, C.S. 2011, "The relative efficiency of shipping companies", Transportation Research Part E: Logistics and Transportation Review, vol. 47, no. 5, pp. 681-694.

662. Park, H.G. & Lee, Y.J. 2015, "The Efficiency and Productivity Analysis of Large Logistics Providers Services in Korea", Asian Journal of Shipping and Logistics, vol. 31, no. 4, pp. 469-476.

663. Pendar, P., Mokhatab-Rafiei, F. & Nilipour-Tabatabaei, S.A. 2018, "Performance evaluation of the public transportation system in Esfahan Steel Company from the production line employees' perspective with data envelopment analysis approach", International Journal of Productivity and Quality Management, vol. 23, no. 2, pp. 137-162.

664. Rodrigues, M.M., Hein, N., Wilhelm, V.E. & Kroenke, A. 2015, "Impact of convergence to IFRS on the economic and financial performance of construction and transportation enterprises: A study conducted through data envelopment analysis", Applied Mathematical Sciences, vol. 9, no. 89-92, pp. 4499-4521.

665. Salehian, F., Razmi, J. & Jolai, F. 2018, "A hybrid ranking approach based on fuzzy analytical hierarchy process and data envelopment analysis: Road maintenance and transport organization of Iran", Journal of Intelligent and Fuzzy Systems, vol. 34, no. 4, pp. 2373-2383.

666. Saxena, M., Chotia, V. & Rao, N.V.M. 2018, "Estimating the Efficiency of Public Infrastructure Investment: A State-wise Analysis", Global Business Review, vol. 19, no. 4, pp. 1037-1049.

667. Saxena, P., Dewan, K.K. & Mustafa, M. 2006, "Data Envelopment Analysis: An application in the transport sector", Journal of Interdisciplinary Mathematics, vol. 9, no. 2, pp. 385-395.

668. Saxena, P. & Saxena, R.R. 2010, "Measuring efficiencies in Indian public road transit: A data envelopment analysis approach", OPSEARCH, vol. 47, no. 3, pp. 195-204.

669. Shabani, A., Torabipour, S.M.R. & Saen, R.F. 2015, "A new super-efficiency dual-role FDH procedure: An application in dairy cold chain for vehicle selection", International Journal of Shipping and Transport Logistics, vol. 7, no. 4, pp. 426-456.

670. Shah, S.A.R., Ahmad, N., Shen, Y., Pirdavani, A., Basheer, M.A. & Brijs, T. 2018, "Road safety risk assessment: An analysis of transport policy and management for low-, middle-, and high-income Asian countries", Sustainability (Switzerland), vol. 10, no. 2.

671. Shen, Y., Hermans, E., Ruan, D., Wets, G., Brijs, T. & Vanhoof, K. 2011, "A generalized multiple layer data envelopment analysis model for hierarchical structure assessment: A case study in road safety performance evaluation", Expert Systems with Applications, vol. 38, no. 12, pp. 15262-15272.

672. Singh, P., Singh, A.K., Singh, P., Kumari, S. & Sangaiah, A.K. 2018, "Multimodal data modeling for efficiency assessment of social priority based urban bus route transportation system using GIS and data envelopment analysis", Multimedia Tools and Applications, , pp. 1-19.

673. Sun, D., Chen, S., Zhang, C. & Shen, S. 2016, "A bus route evaluation model based on GIS and super-efficient data envelopment analysis", Transportation Planning and Technology, vol. 39, no. 4, pp. 407-423.

674. Sun, L., Rong, J. & Yao, L. 2010, "Measuring transfer efficiency of urban public transportation terminals by data envelopment analysis", Journal of Urban Planning and Development, vol. 136, no. 4, pp. 314-319.

675. Tešić, M., Hermans, E., Lipovac, K. & Pešić, D. 2018, "Identifying the most significant indicators of the total road safety performance index", Accident Analysis and Prevention, vol. 113, pp. 263-278.

676. Venkatesh, A. & Kushwaha, S. 2018, "Short and long-run cost efficiency in Indian public bus companies using Data Envelopment Analysis", Socio-economic planning sciences, vol. 61, pp. 29-36.

677. Wei, J. & Xia, W. 2014, "Evaluation of Industrial-Accidents Management Performance in China", Human and Ecological Risk Assessment, vol. 20, no. 2, pp. 537-558.

678. Wei, R., Liu, X., Mu, Y., Wang, L., Golub, A. & Farber, S. 2017, "Evaluating public transit services for operational efficiency and access equity", Journal of Transport Geography, vol. 65, pp. 70-79.

679. Welde, M. & Odeck, J. 2011, "The efficiency of Norwegian road toll companies", Utilities Policy, vol. 19, no. 3, pp. 162-171.

680. Wey, W.-. & Chang, Y.-. 2009, "A comparative location study for the joint development station of mass rapid transit system: A case in Taichung City in Taiwan", Environment and Planning B: Planning and Design, vol. 36, no. 4, pp. 573-587.

681. Wu, G., Miao, Z., Shao, S., Jiang, K., Geng, Y., Li, D. & Liu, H. 2018, "Evaluating the construction efficiencies of urban wastewater transportation and treatment capacity: Evidence from 70 megacities in China", Resources, Conservation and Recycling, vol. 128, pp. 373-381.

682. Xu, N. & Lu, W. 2015, "Super efficiency DEA evaluation model with entropy weight restriction for expressway transport effectiveness", ICIC Express Letters, Part B: Applications, vol. 6, no. 8, pp. 2101-2105.

683. Xu, X.-., Liu, J., Li, H.-. & Jiang, M. 2016, "Capacity-oriented passenger flow control under uncertain demand: Algorithm development and real-world case study", Transportation Research Part E: Logistics and Transportation Review, vol. 87, pp. 130-148.

684. Yu, M.-., Chen, L.-. & Chiang, H. 2017, "The effects of alliances and size on airlines' dynamic operational performance", Transportation Research Part A: Policy and Practice, vol. 106, pp. 197-214.

685. Yu, M.-. & Hsiao, B. 2016, "Measuring the technology gap and logistics performance of individual countries by using a meta-DEA–AR model", Maritime Policy and Management, vol. 43, no. 1, pp. 98-120.

686. Zhang, C., Juan, Z., Luo, Q. & Xiao, G. 2016, "Performance evaluation of public transit systems using a combined evaluation method", Transport Policy, vol. 45, pp. 156-167.

687. Zhang, K., Xu ME, Y. & Sun, D. 2018, "A mixed frontier model for urban bus performance evaluation", Proceedings of the Institution of Civil Engineers: Transport, vol. 171, no. 2, pp. 65-74.

688. Zhao, Y., Triantis, K., Murray-Tuite, P. & Edara, P. 2011, "Performance measurement of a transportation network with a downtown space reservation system: A network-DEA approach", Transportation Research Part E: Logistics and Transportation Review, vol. 47, no. 6, pp. 1140-1159.

- Present full review of Data Envelopment Analysis approach in transportation systems
- Cluster and provide full analysis of DEA papers in transportation systems
- Propose subjects for future researches in the area of DEA applications in transportation systems

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