Performance Measurement in Intermodal Freight transport systems: A Literature Review

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Abstract

Performance measurement plays a key role in developing appropriate strategies and evaluating the achievement of objectives in a Freight Transport System. This paper provides a critical and systematic review of the existing literature on this topic. The review is structured around different methods for performance measurement as well as different freight transport sub-domains, i.e., railway, inland waterway, port, and maritime. The study discusses the limitations of existing methods and applications, leading to several important knowledge and implementation gaps that require further research in the field.

1. Introduction

Performance measurement creates understanding about the operation of a transportation system and helps decision makers in achieving their goals by providing feedback about the success of implemented strategies. In freight transportation and logistics domain, the market share of different modalities is also believed to be closely correlated with the performance of that chain (Christopher, 2005). Therefore, a clear definition of performance measurement and an overview of existing methodology for measuring performance is needed. Performance is generally defined as “how well the resources expended are used” (Kim & Marlow, 2001). Efficient performance is also defined as using minimum inputs when the outputs are fixed, or maximizing the outputs when the inputs are fixed (Ockwell, 2001).

Despite its relevance, a comprehensive and systematic literature review on the performance measurement in freight transportation systems is still lacking based on the existing literature. In some papers, the performance of a part of a freight transport system e.g., rail transport (Oum et al., 1999), or sea-ports (Panayides et al., 2009; Ensslin et al., 2017) has been reviewed, but a comprehensive review on the freight transport system as a whole – considering the range of exiting methods for performance measurement – requires further attention. In this paper, we aim to review the literature about the performance measurement of intermodal freight transport systems, both from methodological and applications point of view.

In section 2, the main concepts and methodologies for efficiency/ performance measurement are explained. Section 3 describes the methodology of literature review. In section 4 to 7, we describe the existing literature on different performance measurement methods. For each methodology, the literature is further categorized based on the freight transport sub-domains. Finally, section 8 concludes the paper by discussing the insight from reviewed literature and an agenda for future research.

2. Performance Analysis: Concepts and Methodologies

2.1. Basic concepts

Two basic concepts in the performance measurement are productivity and efficiency (Oum et al., 1999). Productivity defines the ratio between output and input of a system. Therefore, as far as two systems are comparable, comparing productivity is a measure of performance of each of them. It can be used to evaluate the performance of one system over time as well (Oum et al., 1999). Different sources e.g., different technical efficiency levels, economies of scale, or different network characteristics could lead to different productivity levels (Oum et al., 1999).
Efficiency, however, is a measure that can be used in comparing multiple systems or decision units or compare one system with an ideal system (as the benchmark). It defines the relative productivity of each system in comparison with other systems – or with an ideal system.
In the Economic theory, three types of efficiency are mainly discussed: technical, allocative, and cost efficiency (Yu, 2016). Scoring a firm performance by comparing it relative to the best practice, shows the technical efficiency level of a firm (Yu, 2016). Allocative efficiency is selecting a certain set of inputs to produce a specified set of outputs in the minimum cost (Assaf & Josiassen, 2012). The cost efficiency is the overall combination of these two. Standard models can be used to measure technical efficiency, but productivity is typically estimated in a temporal context using panel data (Graham, 2008).

2.2. Basic methodologies for performance measurement

Stochastic Frontier Analysis (SFA)

Stochastic Frontier Analysis (SFA) is a parametric approach, which is used to measure the efficiency of an industry given its input and output data (Lin, 2005). SFA assumes a priori production/cost function of the usual regression form and a distribution type of two error items. The first item is symmetric and captures the statistical error. It usually has a normal distribution with zero mean. The second item represents the technical efficiency of firms (Lin, 2005). It mostly has a truncated normal distribution with zero mean. Two kinds of functional forms are mostly used in the SFA literature to model production/cost function: Cobb-Douglas, and Translog function (Coelli et al., 2005). The general methods to solve the SFA models are maximum likelihood estimator, Bayesian framework, or corrected ordinary least squares (Coelli et al., 2005). Using an SFA model, the statistical analysis of the results is possible, but it requires large samples to be robust (Coelli et al., 2005).

Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a typical non-parametric approach and evaluates the efficiency of a firm relative to an average or representative firms (Anderson, 2003). Therefore, a firm or sub-unit of that is the main unit of analysis and is defined as the Decision-Making Unit (DMU). In the application of DEA, the similarity of both the inputs and outputs is a fundamental assumption (Wang & Song, 2003). In fact, the DEA method compares each DMU against a convex combination of the other DMUs which are on the frontier (Charnes et al., 1994). There are different types of DEA models. To choose an appropriate DEA model, we need to consider the returns-to-scale assumption (CCR or BCC models), and the model orientation (input, or output-oriented) (Stough, 2015). CCR- and BCC-DEA models do not take into account the existence of the input and output slacks in the model. To handle this, drawbacks an extension of DEA models, called slacks-based models (SBM), is presented.

These models are useful when inputs and outputs may change non-proportionally (Tone & Tsutsui, 2009).

Post- DEA Analysis

The basic DEA divides the DMUs into two sets, efficient and inefficient ones (Mehrabian & Jahanshahloo, 1999). In order to rank all the DMUs, complementary approaches are required (Mehrabian et al., 1999). These methods are considered as post-DEA analyses since they only add value to the standard DEA models and not replacing it. Adler et al (2002) have divided post-DEA analysis methods into six categories. Cross-efficiency ranking methods compute the efficiency of each DMU several times, using the multiplications (weights) reached by the different linear combination of DMUs. In Super-efficiency ranking methods, the DMU that its efficiency is evaluated, is excluded from the reference set. Thus, for extremely-efficient units, the efficiency score can be greater than one. Benchmark ranking methods rank the efficient DMUs based on their frequency in the reference set as a benchmark for the other DMUs. The other categories of post-DEA methods are ranking with multivariate statistics in the DEA context that uses statistical techniques together with DEA to achieve a complete ranking; the ranking of inefficient decision-making units that attempts to rank inefficient units using a Measure of Inefficiency Dominance (MID); and DEA and multi-criteria decision-making methods which are used to further refine the discriminatory power of the DEA models by specifying which inputs and outputs should lend greater importance to the model solution. These post-DEA analyses improve the results by improve discriminating power of DEA method.

DEA Extensions

The main drawback of the DEA model is its deterministic nature. Therefore, it is impossible to make any statistical inference or establish a hypothesis (Jorge & Suarez, 2003). To overcome this disadvantage, several stochastic version of DEA measures are developed to improve the capability of the standard DEA in the presence of noise. These models are called Bootstrapped Data envelopment (BDEA) models. Example of Bootstrapped DEA models can be found in Simar & Wilson (2000) and (1998)), Hall & Simar (2009), Simar (2007).

Because of the existence of the intermediate products/ services connecting different divisions of a chain, the traditional DEA models cannot be used directly for measuring the performance of a chain and its members. They are also incapable of capturing the impact of division-specific inefficiencies on the overall efficiency of a chain (Tone & Tsutsui, 2009). In order to measure the performance of the multidivisional chains, Network DEA models are developed in which the intermediate products/services and the relation between different divisions are explicitly considered in the performance measurement.

3. Literature Review Methodology

To conduct a structured literature review, aimed at identifying the research gaps and comparing different performance measurement methods, we used the review methodology as presented by Van Wee and Banister (2016). For paper selection, we conducted a literature search using the Scopus database. The following keywords were used to find scientific papers: “performance”, “efficiency” “productivity”, “data envelopment analysis”, and “stochastic frontier analysis”. Combining those terms with “Freight transport*”, “railway”, “inland waterway”, “port”, “maritime”, and “short sea shipping” keywords, we insured that the results are within the freight transportation domain. The search was limited to peer-reviewed journal papers published in the period of 2000 to 2017. The abstract of all papers were then scanned to exclude the irrelevant articles. Further sources were identified by searching reference lists, i.e., the “backward snowballing” strategy (Wee & Banister, 2016). Figure 1 shows the scheme of the paper selection.

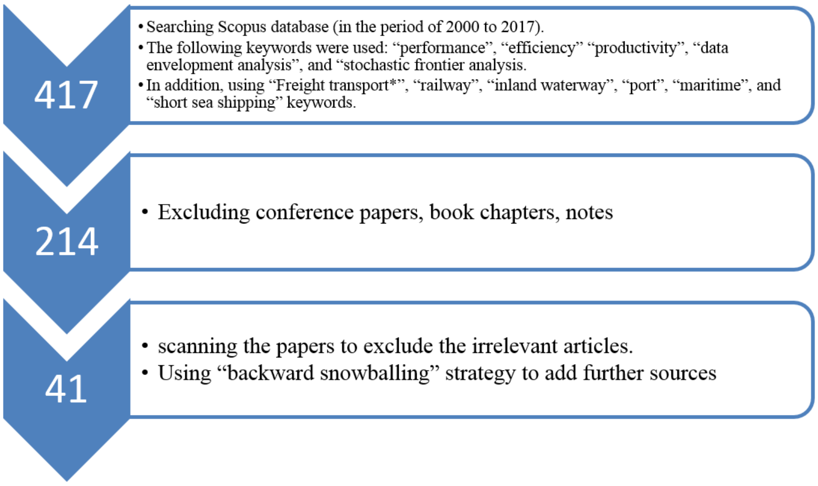

Figure 1. Paper selection scheme for literature review

4. Paper classification and literature result analysis

To classify the papers, we primarily use the adopted approach. For each approach, then, the existing literature is clustered on the basis of the application domain. Additionally, the details of studied literature (in terms of, e.g., input/output variables, the functional form), and the main findings are also discussed in this section.

4.1. Partial performance measurement (multiple indicators)

A straightforward approach to measure efficiency is defining/using multiple performance indicators (partial performance measures). Isoraite (2005) developed a step-wise approach to define meaningful transport indicators using a top-down strategic perspective. Table 1 gives an overview of papers presenting multiple performance indicators to measure the efficiency. For each paper, the transport area, the proposed indictors, and the geographical/temporal scope is shown in the table. The majority of papers are applied to ports and terminals (around 44%).

TABLE 1 . Reviewed articles using multiple performance indicators to measure the efficiency

No	paper	Performance Indicators	Area	Period
Railway systems				
1	Wiegmans et al., (2007)	▪ Tons/employee ▪ Sales/employee ▪ Employees/locomotive ▪ Sales/ton ▪ Sales/ton-km	EU	-
2	Hilmola (2007)	▪ Ton-km/wagons ▪ Ton-km/staff ▪ Ton-km/locomotives ▪ Ton-km/tracks(km) ▪ Tons/wagons ▪ Tons/staff ▪ Tons/locomotives ▪ Tons/tracks(km)	EU	1980-2003

No	paper	Performance Indicators	Area	Period
3	Oum et al.(1999)	▪ Average Train Speed ▪ Average Number Of Cars Per Train ▪ Locomotive Unit-Miles ▪ Revenue Per Tone ▪ Man-Hours Per Train-Mile ▪ ...	-	-
		Inland Waterways		
4	Caris et al. (2011)	▪ Average turnaround time ▪ Average waiting time ▪ Average capacity utilization	Belgium & Netherlands	-
		Ports & Terminals		
5	Cullinane & Wang (2005)	▪ Tonnage worked ▪ Berth occupancy revenue ▪ Cargo handling revenue ▪ Labour ▪ Capital equipment ▪ Total contribution ▪ Arrival late ▪ Waiting time ▪ Service time ▪ Turn-around time ▪ Tonnage per ship Fraction of time ▪ berthed ships worked ▪ Number of gangs employed ▪ Tons per ship-hour in port ▪ Tons per ship hour at berth ▪ Fraction of time gangs idle	worldwide	-
6	Tongzon (2006)	▪ Throughput ▪ Commercial ship visits ▪ Vessel size and cargo exchange ▪ Nature and role of the port ▪ Port functions ▪ Infrastructure	worldwide	1991
7	Fourgeaud (2000)	▪ Average cargo dwelling time ▪ Average waiting time of a trailer ▪ Ratio loaded vs. unloaded containers ▪ Unproductive moves ▪ Level of automation of the gantry-cranes ▪ Average weight of containers ▪ Commercial constraints	-	-
8	Bichou (2013)	▪ Operating ratio ▪ Operating surplus ▪ Return on investment (ROI) ▪ Return on assets (ROA) ▪ Return on equity (ROE) ▪ Capital and labor expenditures per handled ship or cargo unit ▪ Berth occupancy per cargo-ton ▪ Handling revenues per cargo-ton	-	-
		Maritime transport		
9	Valdez Banda et al. (2016)	▪ Number of reviews to the safety and environmental policy in a year ▪ Assigned personnel per shift, available to perform safety operations ▪ Assigned ships to a person working with ISM matters ▪ Percentage of the safety programmers performed pear year ▪ Number of fires reported pear year	-	-

Railway systems

In order to measure the performance of the rail operators Wiegmans and Donders (2007) has defined partial efficiency indicators and compared them with the best practice benchmarks. The details of performance measures are presented in Table 1. Hilmola (2007) also studied the efficiency of European railways using 8 different partial efficiency indices. He also compared the results of partial efficiency analysis with the results of the DEA model. Oum et al. (1999) present a list of indicators for rail efficiency measurement in different categories, i.e., general operations, locomotives, cars, track, capital, and labour.

Inland waterways

The studies on performance measurement of inland waterways systems are quite limited. Caris et al. (2011) analysed alternative bundling strategies for container barge transport in the port of Antwerp by defining different performance indicators for barge transport.

Ports & Terminals

Several studies have presented a set of measures to evaluate the performance of the ports and terminals. Cullinane & Wang (2005) use a list of performance indicators suggested by UNCTAD in 1976 to measure the performance of the ports in two categories, i.e. Financial indicators, and Operational indicators. Considering large number of indicators is one of the challenges here (Lu & Wang, 2017). Tongzon (2006) introduced a quantitative approach to decrease the number of performance indicators, and presented six measures to classify and compare the ports. There are other works which have presented or measured the port performance by using partial multiple performance indicators, i.e., Fourgeaud (2000), Ensslin et al.(2017), and Bichou (2013). Fourgeaud (2000), proposes an approach to develop a relevant set of indicators to monitor port performance. Ensslin et al.(2017) by reviewing the literature, found that the most commonly used performance indicators focus on operational aspects of seaports. Bichou (2013) presents the indicators in three main categories: input measures (e.g. time, cost, resource), output measures (e.g. production, throughput, profit) and ratio measures.

Maritime transport

Valdez Banda et al. (2016) identified 53 key performance indicators for monitoring and reviewing 23 identified safety management components that are commonly integrated into the functioning of maritime safety management systems. These indicators can systematically measure the most relevant components of the maritime safety management systems.

Reflection on the partial performance literature

The main disadvantage of partial performance (multiple indicators) analysis is difficulty to evaluate the performance improvement, in the cases when some indicators show improvement, and the rest not (Lu & Wang, 2017).

To overcome this problem, Total Performance analysis was developed, which is defined as a measure of total output per unit of the input (Windle & Dresner, 1992). For example, Talley(1994) presents an overall performance indicator to measure the performance of the ports. This indicator which is a weighted summation of multiple performance indicators is useful when changes in these indicators have opposite effects on port performance. Indeed, more structured methods for preforming total performance analysis are Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA) which are described and reviewed in the following sub-sections.

4.2. Stochastic Frontier Analysis (SFA)

The SFA model has also been applied in the transport domain to measure the efficiency of different transportation systems. Yet, we did not find any article applying SFA in the Inland waterways sub-domain; therefore, that domain is not mentioned as a sub-section in the following. The details of papers, including the domain of application, functional form, and temporal/geographical area of application are presented in Table 2.

TABLE 2 . Reviewed articles using Stochastic Frontier Analysis (SFA) to measure the efficiency

No	paper	Variables	Functional form	Area	Period
Railway systems					
1	Coelli and Perelman (1996)	Inputs: ▪ Staff number ▪ Energy consumption ▪ Lines length (km) Outputs: ▪ Passenger-km ▪ Tonnes-km	Translog distance function	EU	1979- 1983
2	Gathon and Perelman (1999)	Inputs: ▪ Passenger train-km ▪ Freight train-km ▪ Length of lines ▪ Passenger and freight mean distance ▪ Passenger and freight load factor ▪ Electrification percentage Output: ▪ Labor	Factor requirement function	EU	1961-1988
3	Sanchez & Villarroya (2000)	Inputs: ▪ Labor cost ▪ Energy cost ▪ Material cost ▪ Purchases ▪ External services Outputs: ▪ Passenger train-km ▪ Freight train-km	Translog distance function	EU	1970-1990
4	Christopoulos et al. (2001)	Input: ▪ Interest depreciation costs ▪ Capital prices ▪ Number of employees ▪ Labor costs ▪ Energy cost Output: ▪ Total traffic units	McFadden flexible cost function	EU	1969-1992
5	Jorge & Suarez (2003)	Inputs: ▪ Labor cost ▪ Electrification percentage ▪ Percentage of lengths of double lines Outputs: ▪ Passengers ▪ Line lengths (km)	Factor requirement and quadratic production functions	EU	1965-1998
6	Lan & Lin (2006)	Inputs: ▪ Number of passenger cars ▪ Number of freight cars ▪ Number of employees Outputs ▪ Passenger train-kilometers ▪ Freight train-kilometers	Stochastic input distance function	worldwide	1995–2002
Ports &Terminals					

7	Coto-Millan et al. (2000)	Inputs: ▪ Unit employee cost ▪ Unit depreciation of quays ▪ Consumption per port activity (tons) Output: ▪ Total cost	Translog cost function	Spain	1985-1989
8	Estache et al.(2002)	Inputs: ▪ Number of workers ▪ Length of docks Output: ▪ Handling volume (tons)	Cobb-Douglas and Translog production function	Mexico	1996–1999
9	Cullinane, et al. (2002)	Inputs: ▪ Terminal quay length ▪ Terminal area in hectares ▪ Number of cargo handling equipment Output: ▪ Annual throughput (TEU)	Log-linear Cobb–Douglas production function	Asia	1989- 1998
10	Cullinane & Song (2006)	Inputs: ▪ Quay length (m) ▪ Terminal area ▪ Number of pieces of cargo handling equipment Outputs: ▪ Container throughput (TEU)	Log-linear Cobb-Douglas production function	EU	2002
Maritime transport					
11	Panayides et al. (2011)	Inputs: ▪ Inputs profits ▪ Book value of equity ▪ Total assets ▪ Number of employees ▪ Capital expenditure Output: ▪ Market value of equity ▪ Sales	Log-Log Cobb–Douglas production function	Worldwide	2008

Railway systems

Cheristopoulos & Tsionas (2001), used McFadden flexible functional form to represent the cost structure of railway systems in ten EU countries for the period 1969-1992. De Jorge & Suarez (2003) and Sànchez and Villarroya (2000) measured the efficiency of European railways, estimating the stochastic cost frontier function. Lan & Lin (2006) examine the performance of 39 worldwide railway systems over eight years (1995–2002), using a stochastic input distance function. Other works e.g., Gathon and Perelman (1999), and Coelli and Perelman (1996) have also used Translog distance function and Factor requirement function and present SFA model to measure the efficiency of European Railways.

Ports &Terminals

The number of articles on the application of SFA for ports and terminals is large and on the increase. The majority of studies have found a positive correlation between size of the port or terminal and its efficiency, i.e., Cullinane & Song (2006), Estache et al. (2002), and Cullinane, et al. (2002). Coto-Millan et al. (2000) applied SFA to study the economic efficiency of Spanish ports using panel data of 27 Spanish ports from 1985 to 1989. Contrary to previous findings, this paper has found that larger ports were less efficient.

Maritime transport

The application of SFA to the maritime transport domain is quite limited. Panayides et al. (2011) examine the relative market efficiency and operating performance efficiency of 26 international maritime firms in bulk and container shipping sectors using SFA. Their findings show that tanker companies are more market-efficient, while container-shipping firms have high operating performance efficiency and market inefficiency. Dry bulk firms were found to have the lowest market efficiency.

Reflection on the SFA literature

Table 2 shows the list of papers applying SFA models to measure the efficiency of the transport systems.

Application of SFA models to measure performance of transport systems has some disadvantages/challenges. A big challenge is selection of the functional form. Moreover, the efficiency scores are mostly sensitive to distributional assumptions on the error terms, and the model requires large samples to be robust (Martín, Román, & Voltes-Dorta, 2009). The application of the SFA models to the freight transport domain after 2010 is very limited, which could be cause by aforementioned disadvantages/challenges. DEA is an approach that has been developed to overcome mentioned disadvantages of SFA model.

4.3. Data Envelopment Analysis (DEA)

Table 3 provides an overview of studies using DEA method for the performance measurement of transportation systems. Similar to the previous section, in our search, we did not find any application of DEA in inland waterways domain.

TABLE 3 . Reviewed articles using Data Envelopment Analysis (DEA) to measure the efficiency

No	paper	Method	Variables	Functional form	Area	Period
Railway systems						
1	Cantos et al (1999)	DEA	Inputs: ▪ Number of workers, ▪ Consumption of energy, ▪ Number of locomotives ▪ Number of passenger carriages ▪ Number of freight cars ▪ Number of kilometers of track Outputs: ▪ Passenger-km ▪ Tones-km	CCR Input-oriented	EU	1970–1995
2	Hilmola (2007)	DEA	Inputs: ▪ Number of freight wagons ▪ Total track route (kilometers) ▪ Total number of locomotives ▪ Staff Outputs: ▪ Freight-tonne-kilometers ▪ Freight-tons	CCR output-oriented	EU	1980-2003

3	Merkert et al. (2010)	Two-stage Bootstrapped DEA	Inputs: ▪ Operating cost ▪ Staff number ▪ Transaction dedicated staff outputs: ▪ Train-km Explanatory variables in the Tobit regression model: ▪ Vertical separation and type of operation ▪ Competition ▪ Monetary values of transaction costs	BCC input-oriented model	Sweden, Germany, UK	2006-2007
Ports &Terminals						
4	Roll and Hayuth (1993)	DEA	Inputs: ▪ Manpower ▪ Capital ▪ Cargo uniformity Outputs: ▪ Throughput ▪ Level of service: ratio of handling time to the total time ▪ Users' satisfaction ▪ Ship Calls	-	EU	-
5	Martinez-Budria et al. (1999)	DEA	Inputs: ▪ Labour cost ▪ Depreciation charge ▪ Other costs Outputs: ▪ Total cargo movement (ton) ▪ Revenue	BCC input-oriented	Spain	1993-1997
6	Tongzon(2001)	DEA	Inputs: ▪ Number of berths ▪ Number of cranes ▪ Number of tugs ▪ Stevedoring labor ▪ Terminal area outputs: ▪ Throughput (TEU) ▪ Ship working rate (TEU/ h)	CCR & additive input-oriented	worldwide	1996-2000
7	Barros (2003)	DEA	Inputs: ▪ Number of workers ▪ Book value of the assets outputs: ▪ Ships ▪ Movement of freight ▪ Gross gauge ▪ Break-bulk cargo ▪ Containerized freight, ▪ Solid bulk ▪ Liquid bulk	BCC input-oriented	Portugal	1990-2000
8	Barros (2006)	DEA	Inputs : ▪ Number of employees ▪ Book value of assets outputs: ▪ Liquid bulk ▪ Dry bulk ▪ Number of ships ▪ Passengers ▪ Number of Containers ▪ Sales	CCR & BCC output-oriented model	Italy	2002-2003

9	Barros & Managi (2008)	Two-stage Bootstrapped DEA	Inputs : ▪ Number of personnel ▪ Number of cranes outputs: ▪ Throughput (TEU) ▪ Number of ships ▪ Tons of bulk	CCR & BCC output-oriented model	Japan	2003-2005
10	Wu & Goh (2010)	Super-efficient DEA	Inputs: ▪ Terminal area (ha) ▪ Total quay length (m) ▪ No. of pieces of equipment (number of quayside gantries, yard gantries, and straddle carriers) outputs: ▪ No. of containers (TEU)	CCR and BCC output-oriented models	Emerging markets	2005
11	Barros et al. (2010b)	Two-stage Bootstrapped DEA	Inputs : ▪ Depths of berths ▪ Total area ▪ Number of quay cranes ▪ Number of employees outputs: ▪ Number of ships call ▪ Total tons embarked ▪ Total number of containers embarked and disembarked	BCC output-oriented model	Africa	2004-2006
12	Jiang et al. (2011)	Modified DEA	Inputs: ▪ The total area ▪ Container quay length ▪ Storage capacity outputs: ▪ Number of direct calls ▪ Container throughput	CCR & BCC non-oriented model	Asia	2008
13	Almawsheki & Shah (2015)	DEA	Inputs: ▪ Terminal area (ha) ▪ Quay length (m) ▪ Quay crane (no.) ▪ Yard equipment (no.) ▪ Maximum draft (m) outputs: ▪ Throughput (TEU)	CCR input-oriented	Middle-east	2012
14	Nguyen et al. (2016)	Two-stage Bootstrapped DEA	Inputs: ▪ Berth length ▪ Terminal areas ▪ Warehouse capacity ▪ Cargo handling equipment outputs: ▪ Throughput (TEU)	Bootstrapped CCR DEA model	Vietnam	-
Maritime transport						
15	Panayides et al. (2011)	DEA	Inputs: ▪ Inputs profits ▪ Book value of equity ▪ Total assets ▪ Number of employees ▪ Capital expenditure ▪ Output: ▪ Market value of equity ▪ Sales	CCR & BCC input-oriented	World wide	2008

16	Hilmola (2013)	DEA	Inputs: ▪ Lead time ▪ Total costs ▪ Diesel consumption ▪ CO2 emission Outputs: ▪ Transported freight (tons)	CCR	Finland	-
17	Mantalis et al. (2016)	DEA	Inputs: ▪ Total Shareholders' Equity ▪ Total Assets ▪ Capital Expenditure Outputs: ▪ sales	BCC input-oriented	Greece	2007-2011
Multimodal transport						
18	Dotoli et al. (2016)	Cross-efficient DEA	Inputs: ▪ Total cost ▪ Overall travel time ▪ Level of emissions ▪ Value of Time (VOT) ▪ Quantity of emitted noise outputs: ▪ Mortality rate per accident for each transport mode ▪ Added value of a transport mode for each hour of transport	BCC output-oriented model	EU	-

Railway systems

Different articles including Hilmola (2007), Cantos et al (1999), and Merkert et al.(2010) have studied the efficiency of European railways using DEA analysis and provide insights about the source of inefficiency. Hilmola (2007) found that to improve the performance of the railways, the locomotives and railway tracks should be primarily improved. Cantos et al (1999) show that separation of ownership and management between the infrastructure and the services - which was initiated in 1988 - has had a positive effect in improving the efficiency of the rail operators in Sweden. Merkert et al.(2010) evaluate the role of transaction cost measures in determining the relative efficiency performance of different rail systems by running a bootstrapped DEA model. The results of the model show that transactional factors (like monetary values of transaction costs) are more important than institutional factors (e.g., the vertical separation and type of operation) in determining technical efficiency.

Ports &Terminals

One of the first applications of DEA approach to the ports context is presented by Roll and Hayuth (1993), who applied DEA model to twenty different hypothetical cases . Martinez-Budria et al (1999) classified 26 Spanish ports into three groups, namely high, medium and low complexity. After examining the efficiency of these ports, the authors conclude that the ports with high complexity are more efficient. Tongzon (2001) uses DEA to analyse the efficiency of 16 international container ports and based on constant and variable returns to scale assumptions, he found that the ports of Melbourne, Rotterdam, Yokohama, and Osaka as the most inefficient ports in the sample - mainly because of enormous slacks in their container berths, terminal area, and labour inputs. Almawsheki & Shah (2015) measured the technical efficiency of 19 container terminals in the Middle-East region using DEA model. Their findings show that the Jebel Ali, Beirut and Salalah terminals are the most efficient terminals in the region. Barros (2003) evaluates the productivity of the Portuguese seaports. His findings

show that during a period of 1990-2000, almost all ports achieved improvements in technical efficiency. Barros (2006) evaluates the performance of Italian seaports from 2002 to 2003. He concludes that the Italians seaports display relatively high efficiency.
Some of the papers, i.e. Nguyen et al. (2016), Barros & Managi (2008), and Barros et al.(2010a) have used bootstrap technique and done the second step regression model to find the source of the inefficiency. Nguyen et al. (2016) applied a BDEA model to a sample of 43 Vietnamese ports. Their findings show that the average mean of efficiency scores for Vietnamese ports is very low. Barros & Managi (2008) found that Japanese seaports which have adopted hub strategy are on average more efficient than others. Barros et al.(2010a) show that Nigerian seaports are the most efficient ones between African seaports.

Maritime transport

The DEA analysis have been applied to maritime transport in different sectors i.e., bulk, tanker and container. Panayides et al. (2011) examine the relative market efficiency and operating performance efficiency of 26 major international maritime firms in bulk and container shipping sectors. Their findings show that Tanker companies are more market efficient, while container-shipping firms have high operating performance efficiency but were market inefficient. Dry bulk firms were found to have the lowest market efficiency. Hilmola (2013) evaluated the performance of the container shipping in a transportation routes of Finland. The findings show that containers could be carried efficiently either in container ships or even at currently favoured RoRo or RoPax ships. In another case, Mantalis et al. (2016) analysed the efficiency of different Greek shippers using different class of vessels in a period of 2007-2011. Their findings show that firms with dry bulk carriers operate more efficiently.

Reflection on the DEA literature

Table 3 shows the list of the papers applied DEA model to the different freight transport domains. As you can see more than half of them (52%) have used input-oriented DEA models. 40% of the papers applied only BCC models, while 20% applied only CCR models. The rest applied both CCR and BCC DEA models. Around one third of papers have done post-DEA analysis. Moreover, around 80% of the papers have used one or two parameter as output in the model. Reviewing the trend of publications, we see that more than 55% of the papers have published after 2010, which shows DEA is the favourite method in efficiency measurement of the freight transport domain.
Because of the existence of the intermediate products/ services connecting different activities or divisions of a system, the traditional DEA models cannot be used directly for measuring the performance of a multi-activity/-division system and its members. Network DEA models are extension of DEA models to overcome this issue.

4.4. Network Data Envelopment Analysis (NDEA)

There can be many situations in a transport system that the performance of one firm is partly influenced by the performance of other collaborative firms in a transport chain. This is especially because, as an independent decision maker, each chain member maximizes its own efficiency, without considering other members or the overall chain (Yang, Wu, Liang, Bi, & Wu, 2009). A good example of this is an intermodal freight transport service that involves the transportation of freight using multiple modes of transportation (and in some cases, door-to-door solutions). NDEA models can be a solution to capture the chain characteristics of transport systems. They can also be used to evaluate the performance of sub-systems in one transportation systems (e.g., the sequence of activities in a port or inland terminal).

TABLE 4 . Reviewed articles using Network Data Envelopment Analysis (NDEA) to measure the efficiency

No	paper	Method	Variables	Functional form	Area	Period
Railway systems						
1	Yu & Lin (2008)	Network DEA	Inputs: ▪ Number of employees ▪ Length of lines ▪ Number of freight (passenger) cars Intermediate: ▪ Freight (passenger) train-km outputs: ▪ Ton-km ▪ Passenger-km	CCR Input-oriented NDEA model	Worldwide	2002
2	Yu (2008)	Network DEA	Inputs: ▪ Length of line ▪ Number of passenger cars ▪ Number of freight cars ▪ Number of employees Intermediate: ▪ Passenger–train–kilometers ▪ Freight–train–kilometers associated Outputs: ▪ Ton-km ▪ Passenger-km	CCR Input-output oriented NDEA model	Worldwide	2002
Maritime transport						
3	Omrani and Keshavarz (2016)	Network DEA	Inputs: ▪ Ship purchase cost ▪ Crew cost ▪ Costs of spare parts, provisions, insurance, etc. ▪ Costs of repairs ▪ Commercial container operation cost ▪ Commercial passenger operation cost Intermediates: ▪ Lease + purchasing ▪ Ship manning cost ▪ Supply of spares & provisions ▪ Total available days per year ▪ Time charter to service provider (container) ▪ Time charter to service provider (passenger) ▪ No. of containers carried per year ▪ No. of passenger + cars carried per year outputs: ▪ Net income	CCR output oriented NDEA	Iran	2008-2011

Railway systems

Applying NDEA to the rail systems, Yu & Lin (2008) and Yu (2008) divide the service into the production and consumption sub-services. They define the concepts of Efficiency, Service effectiveness, and Technical Effectiveness to give a better insight on the performance. In their definitions, efficiency represents the ratio of physical inputs to physical services; service effectiveness is the ratio of produced service to consumed services; and technical effectiveness is the ratio of inputs and consumed services. Yu & Lin (2008) show that freight service is resource intensive compared to the passenger service. Yu (2008) found that Western Europe railways have the highest technical efficiency.

Ports &Terminals

While there is a rich literature on the application of simple DEA to the ports and terminals, Bichou (2011) is the only article using NDEA to evaluate the performance of ports and terminals. He used a Two-stage NDEA model to capture the transformational process within the container-terminal system, and across its sub-systems. The findings show the existence of disproportionate performances and efficiency levels between container-terminal operating sites and sub-processes.

Maritime transport

Omrani & Keshavarz (2016) is the only study we found in our search on the application of NDEA models for performance of measurement of shipping lines. They define 3 sub-processes: supplying process, service production, and distribution of the service to measure the efficiency of an international shipping company during 2008-2011. Their results show that the shipping company was always inefficient during this period.

Reflection on the NDEA literature

Table 4 shows the list of the papers applied NDEA model to the different freight transport domains. All the papers in table 4 applied CCR NDEA models. Moreover, they have used more than 3 parameters as inputs. Clearly, there has been limited research on using NDEA in the transport domain. Also in the existing studies, the focus is on the multi-activity (-function) cases and not the multi-division NDEA. Intermodal or synchromodal freight transport are domains for which multi-division NDEA can be applied in order to measure the efficiency of different chains and their respective divisions simultaneously.

5. Discussion and concluding remarks

In this paper, different methods for performance measurement in the freight transport systems are reviewed. The papers are categorized based on the freight transport sub-domains, i.e., railway, inland waterway, port, and maritime. Each performance measurement method has pros and cons as summarized in Table 6. The main disadvantage of partial performance (multiple indicators) analysis is the difficulty to evaluate the performance improvement, in the cases when some indicators show improvement, and the rest do not (Lu & Wang, 2017). The trend of application of this method during the last years also confirm the less interest to apply this method – since only 33% of papers using this method are published after 2010.
Stochastic Frontier Analysis (SFA) is a parametric approach, which is used to measure the efficiency of industry given its input and output data. Although with an SFA model we can perform a statistical analysis of the results, assuming a priori production or cost functional form is the main challenge. Moreover, the efficiency scores are sensitive to distributional assumptions on the error terms, and the model requires large samples to be robust (Martín et al., 2009). Therefore, applying SFA models, especially in cases that we have limited data for a freight transport system, can be a challenge. Reviewing the literature shows most of the papers

have used production function to apply SFA model (around 42%). Moreover, most of the cases (around 58%) are about the European cases and the application to the railway systems, ports and terminals are dominant in the literature. Again, a limited number of papers using SFA after 2010 can indicate a decreasing interest in using this method in the freight transport domain.
On the other hand, reviewing the trend of publications shows an increase in the application of Data Envelopment Analysis (DEA) in efficiency measurement of the freight transport domain. DEA is a typical non-parametric approach which evaluates the efficiency of a firm or a decision unit relative to an average or representative firms. The main drawback of DEA is that it is a deterministic model, and the estimated coefficients don't have statistical properties (Jorge & Suarez, 2003). Moreover, the basic DEA model does not fully rank the DMUs which calls for post-DEA analysis or using the extensions of DEA method. Yet, these extensions may cause a significant increase in the computation time and cost.
The other disadvantage of DEA is that the standard DEA models treat a freight transport chain as a black-box, and – as a result- it misses all the intermediate effects and the trade-offs between the performance of different operators in a chain. To overcome this, the Network DEA models were developed. Network DEA models take into account the efficiencies of different divisions as well as the efficiency of the overall chain in a unified framework.

TABLE 5 . Pros and Cons of Application of Different Performance Measures in Freight Transport Domain

performance measurement method	Advantage	Disadvantage
partial performance measures	▪ Simple calculation	▪ Difficulty to evaluate the performance, in the case of indicators with different signs
Stochastic Frontier Analysis (SFA)	▪ Total performance measure ▪ a parametric approach ▪ The statistical analysis of the results is possible	▪ Assuming a priori production or cost functional form ▪ Efficiency scores are sensitive to distributional assumptions on the error terms ▪ It requires large samples to be robust
Data Envelopment Analysis (DEA)	▪ Total performance measure ▪ Non-parametric approach ▪ It does not need any priori assumption about functional form ▪ It can be run by small number of samples	▪ It is a deterministic model that is impossible to make any statistical inference or establish hypothesis contrasts from it ▪ It does not fully rank the DMUs ▪ It cannot consider the intermediate products/ services in evaluating the performance of the multidivisional DMUs.

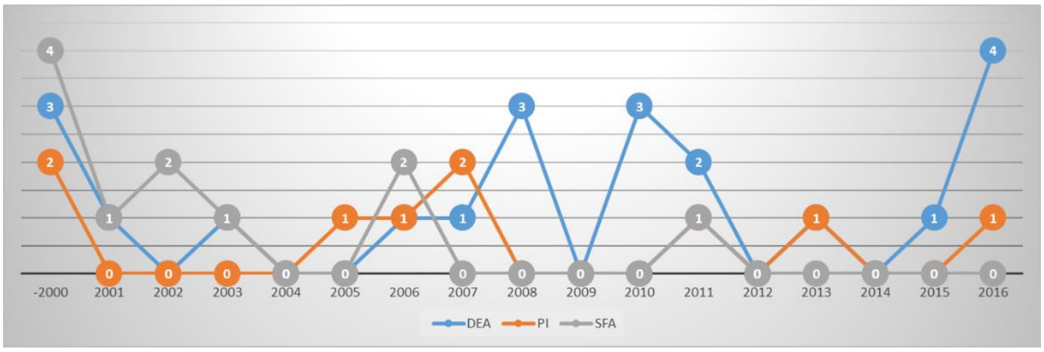

Figure 2. Distribution of Different Papers Based on the Publication Year and the Applied Method

Comparing the trend of applying different performance measurement methods during years (Figure 2), we are able to conclude that DEA (and its extensions) are the most-commonly used (and possibly the most suitable) methods to the freight transport domain, and the related sub-domains. Network DEA has also been applied to the freight transport domain, but so far, papers have applied multi-activity (-function) NDEA with focus on the un-storable feature of transportation service, by dividing the transport service to production and consumption activities. As a result, papers have not studied the multi-division NDEA where a transport service is considered a vertical chain of different operators. Our review also shows that Inland waterway and multimodal freight transport as a whole system are under-researched areas (Figure 3).

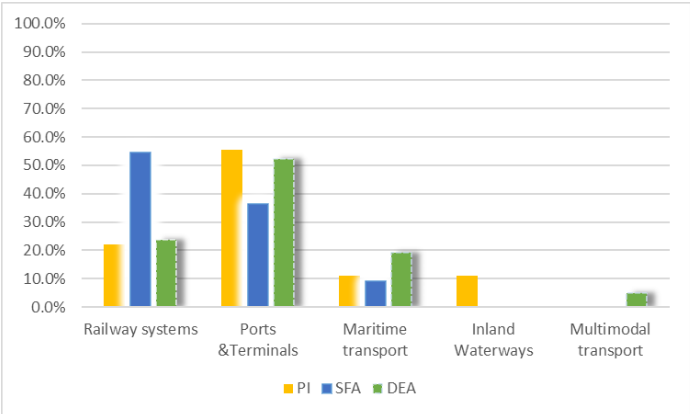

Figure 3. Application of Different Methods to Different Sub-domains of Freight Transport

In terms of issues that need researching, this review has identified the following as key areas for further research.

- *Research on defining performance measures for transport systems:*

Applying total performance indicators by combining different partial indicator deserves more attention in future research. Most of the papers have applied partial performance indicators to ports and terminals and the application to other freight transport domains call for further work. Additionally, "should defining performance measures focus on processes, the outputs of a transport system, or both?" and "how defining performance measure should balance the short-term results and long-term (e.g., sustainability) consequences in a fright transport system" are examples of research questions in defining appropriate performance measurement frameworks. This can also be considered in choosing the appropriate methodology since some methods like NDEA are useful in evaluating separate processes as well as a whole transport system.

- *Research on extending methodologies for performance measuring:*

The trend of application of the partial performance and SFA models highlight less interest to apply these methods to the freight transport domain. Extending the theoretical models based on these methods to overcome their difficulties and limitations (e.g., adjusting the SFA model to be robust with a smaller number of observations or combining different methods to release the assumptions or reduce the computational needs), could be a direction for the future research. Additionally, these methods can be further customized according to the specific requirements of the transportation domain. A recent example is a study by Saeedi et al. (2019) which presents a modified network DEA method for measuring the performance of intermodal freight transport (IFT) chains inside a freight network.

- *Research on defining multi-stakeholder performance measurement systems:*

The majority of existing papers discuss the performance measurement from the perspective of one single actor (e.g., the port operator, or a terminal operator). Yet, in reality, multiple stakeholders (with different interests and possibly conflicting objectives) are involved in every transportation system. Additionally, every transportation system needs to work in broader legal, social, economical, and environmental context. Developing methods that cover the perspective of multiple actors and multiple viewpoints in defining performance measures – like Multi-Actor Multi-Criteria Analysis (Baudry et al. , 2018) – is a potential direction for future research. Related to this multi-actor nature of transport chain, questions like "how can performance measures be designed so that they stimulate inter-functional co-operation" or "how can conflicts between performance measures in a multi-stakeholder transport system be eliminated" deserves more scholarly scrutiny and empirical investigation.

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