Efficiency, effectiveness, and impacts assessment in the rail transport sector: a state-of-the-art critical analysis of current research

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Abstract

This paper aims at being a comprehensive reference for stakeholders, policy makers and scholars interested in analysing the problem of efficiency, effectiveness and impacts of rail transport systems in a sound empirical way, paying specific attention to passenger transport services.
The paper combines different analytical frameworks (engineering, economics, impacts), systematic review techniques and advanced mappings.
Framing economic efficiency studies into a transport planning perspective permits to move from efficiency to effectiveness issues. In addition, including *impacts*, offers a critical discussion of the existing empirical studies, relating them to the main methodological approaches used. This analysis can be useful for those interested in developing *new techniques* for the evaluation of this sector.
The critical analysis developed in this paper provides a *catalog* of inputs, outputs, external factors, possible impacts to account for, data and approaches which allows us to identify areas in which new methodological developments, new approaches, are needed to address the relevant societal challenges of the rail transport sector.

Keywords: efficiency, effectiveness, impacts, frontier analysis, DEA, rail transport, quantitative methods

1. Introduction

Railway systems are an important component of the social and economic system of many nations around the world. On a macroeconomics viewpoint, it has been estimated that the generated added value of this sector at the European level was € 66 billion in 2012, which rises to € 142 billion considering indirect effects, thus representing 1.1% of the European Union's economy (Molemaker and Pauer, 2014).

Although such figures seem not too impressive in relative terms, railways are often seen as a key component in the implementation of more effective transport policies in many countries. They can in fact represent a valid competitor of road transport, since they present attractive features such as their higher transport capacity (both for passengers and freight), higher safety standards or the possibility of easily implementing electric traction that can help in limiting environmental impacts. For instance, CO_2 emissions per traffic unit in rail transport are less than half than those of road transport for passengers (40 versus 115 grams per passenger-km) and less than one third for freight (20 versus 75 grams per tonne-km) (Molemaker and Pauer, 2014). In congested urban areas, railways can transport a number of passengers per hour larger by an order of magnitude compared to road transit lines, and even much more if one considers private cars, with comparable space consumption for the infrastructure. Rail transport is also safer than road transport, averaging 0.3 deaths per billion persons kilometres against 7 deaths per billion persons kilometres for cars (Koornstra *et al.*, 2003).

Considering those factors, railways systems are more or less heavily subsidised in many countries to promote their use versus private cars. However, related costs for public finances are generally high: for example, at the European level, subsidies in 2012 were about € 35 billion out of € 112 billion in total revenues (Steer Davies Gleave, 2015). Regulatory reforms have therefore been promoted in the last decades to increase the efficiency of railways operations, such as both vertical and horizontal separation and the opening of a former monopolistic market to competition.

The extent to which such reforms have been successful is much debated, since one inherent problem is related to the difficulty of actually evaluating the efficiency of railways operations (Makovsek *et al.*, 2015). Many railway companies are multi-product firms (passengers versus freight, intercity versus suburban services…) where the mix of outputs can dramatically change from one unit to another, thus making comparisons difficult (Oum *et al.*, 1999). In addition, much like in other forms of public transport, subsidies are given to achieve indirect benefits through the implementation of the service, such as social welfare or the limitation of environmental impacts. In such case, it would be more appropriate to consider the extent to which such transport policy goals have been achieved through an effectiveness analysis, rather than limiting oneself to check if either technical or allocative efficiency has been reached through the measurement of outputs and inputs, like for an ordinary industrial process in the private sector (Diana and Daraio, 2014).

In a related study dealing with urban public transport, Daraio *et al*. (2016) assessed the potential of filling the above research gap, namely the need to shift from an efficiency to an effectiveness analysis, by running an efficiency analysis where the measures of inputs and especially of outputs are not strictly related to the service production process, but are rather measuring the attainment of some policy goal. As hypothetical example, rather than considering production factors such as labour as input and traffic units such as vehicle*kilometres or seats*kilometres as output, one might consider some indicators related to the emissions of pollutants or to accessibility improvements to assess how effectively related policy targets are reached by investing public money on transit services. In more general terms, efficiency analyses could be turned into a more powerful decision support tool for different stakeholders in the transport sector if they considered some of the wealth of indicators that are normally employed in transport planning studies to monitor the implementation of policy measures, such as in Sustainable Urban Mobility Plans (Wefering *et al.*, 2014).
Building upon that knowledge base, the starting objective of the present paper is to perform a study similar to Daraio *et al*. (2016) in the railway sector, with additional analyses from the insights gained so far. Therefore we focused mainly on passenger railway services serving both suburban and intercity trips. While we do not consider those researches exclusively focused on freight services, for which the evaluation framework would be completely different. The goal is to assess the extent to which the existing efficiency analyses related to such services are considering input and output measures that represent broader policy goals by encompassing effectiveness and therefore be considered as monitoring tools for transport plans.

Considering the increasing importance of impacts in the evaluation of the performances of any transport system, and of railways in particular, we extend the analysis to include *impacts*. While a systematic review of transport planning studies dealing with the impacts of railways is outside the scope of this research, it is deemed important to check the extent to which existing economic analyses in this sector are enlarging their perspective beyond the mere consideration of efficiency issues that are related to the service production process.

To achieve this objective, we systematically review, in an original way, the scientific literature dealing with efficiency analyses in the railway sector being published up to 2016, therefore updating a previous review in this sector by Oum *et al.* (1999).

There are several reviews on efficiency and operational research methods applied to the public sector (see e.g. Rais and Viana 2011; Narbón-Perpiñá and De Witte, 2017a,b). Given the increasing importance of Operations Research methods such as Data Envelopment Analysis (DEA) to drive such studies (Lampe and Hilgers, 2015; Emrouznejad and Yang, 2017; Mariz, Almeida and Aloise, 2018), and the increasing use of DEA in the transport sector (see Cavaignac and Petiot, 2017 for a recent review), we believe that this activity would be relevant to readers of this journal.

The paper unfolds as follow. The next section illustrates the methodology followed to review the existing studies. Section 3 describes the main impacts which could be relevant to account for. Section 4 analyses the keywords of the reviewed papers using the software tool VosViewer. In Section 5 a description of the main inputs, outputs, external variables adopted in the different papers is reported. Section 6 reviews the main techniques applied in the surveyed papers, while Section 7 analyses their evolution over time together with the data used. Section 8 concludes the paper.

2. Methodology of the review

The objectives of this paper are framing economic efficiency studies into a transport planning perspective including impacts. By doing this, we aim at offering a critical discussion of the existing empirical studies, relating them to the main methodological approaches which have been used so far. These objectives are challenging. In order to achieve them we developed an original review approach. It combines: integration of different analytical frameworks (engineering, economics, impacts), systematic review techniques and advanced mappings. It offers a systematic and comprehensive classification (catalog) of inputs, outputs external factors used together with methodological insights for developing new methods for facing the complexity of the field (rail transport efficiency) within its extensive environment and face the societal challenges.

According to Petticrew and Roberts (2006) a systematic literature review "strives to comprehensively identify, appraise, and synthesize all the relevant studies on a given topic". The main steps of the survey implemented are the following:

1. Identification of the objectives of the survey (in our case framing economic efficiency studies into a transport planning perspective, deepened to include impacts).
2. Definition and boundaries delineation (see the discussion below).
3. Literature search.
4. Flow diagram of the protocol followed.
5. Summarizing the evidence through:
   (a) "the grid" (a structured collection of the information contained in the selected documents);
   (b) Clustering and mapping of keywords.

6. Identification of possible heterogeneity, bias and quality of the selected studies.
7. Identification of venues for further developments and future research on the topic.

We show in the following how the above steps 2 to 5 were implemented. About the possible heterogeneity, bias and quality of the selected studies, the methodology of the survey developed and applied in this paper tries to address this important point in the following way:
- we combined three surveys carried out independently by different researchers of the team, on different databases (Scopus and Google Scholar);
-the screening of the papers has been carefully carried out by interdisciplinary experts, according to the limits settled by the *definition* and *boundary* of the searches described below.
So the description that follows in the next subsection is important and should be taken into account by the users of this survey. Finally, the last point pertaining to the interpretation of the findings of the review is addressed in the concluding section.

2.1 Definition and scope of the survey

In the survey we have included only published papers focusing on rail transport service systems, excluding comparisons of rail services with other non-transport services. For instance, the paper by Perelman and Pestieau (1988) has been excluded because it analyses in a comparative way, rail transport and post office services. Other papers (e.g. Savolainen and Hilmola; 2009), comparing different transport services, have been instead included in the analysis. Finally we consider:

- passenger transport or both passengers and freight transport (we have excluded the case of only freight transport);
- long-distance railways (connecting different urban areas) or regional / suburban / urban ones, or both types are considered;
- analyses of only what is strictly related to the transport service (rolling stock, traffic personnel, consumption for the year ...) not the infrastructure (railway line, fixed installations, stations).

In this survey we have excluded unpublished manuscripts, non-English published papers, proceedings and conference papers, book chapters, working papers, theoretical papers without empirical data analysis (e.g. Griliches, 1972 is excluded), papers with only descriptive statistics on data (no statistical/econometric or other analytical approaches applied) for instance the paper by Nash *et al.* (1994). We excluded also papers dealing with infrastructures and only freight, trucking industry transport services.

2.2 Literature search

Given the ambitions of the study, a general coordination of the activities on the search was agreed. Two independent searches were carried out and produced two lists of relevant selected papers according to the expert knowledge. An additional search on impacts was added later on.

The first bibliographical search was carried out between the January the 25th 2017 up to January the 30th 2017 according to a process that we called snowball-like , starting from the review of Oum *et al.* (1999) which represents the most significant antecedent of our work. Having as this paper as a base, the list of papers that are citing it according to Google Scholar were inspected and an initial list of relevant papers (Set 1) was identified based on the criteria mentioned in Section 2.1. In the following step, the list of papers that are citing any of the papers contained in Set 1 has been scrutinized, therefore identifying an additional set of relevant papers (Set 2) where duplications of papers that are already in Set 1 are

obviously removed. It is worth noting that the focus of the search is shifting on more recent papers in the second iteration. Therefore, this literature search is more intensive on more recent works, whereas on the other hand it is not capturing any work published before 1999. This first bibliographic search identified 95 papers published from 2000 onwards. Beyond these, we have five review papers relevant to ours, plus some papers that are outside the review scope (referring either to freight or to subway systems) and were not included.

The second bibliographical search was carried out from January the 23rd 2017 up to February the 2nd 2017, according to a *key words based* process. The list of papers belonging to this search has been composed with the following procedure:

1. The references of (i) Oum *et al.* (1999) - A Survey of Productivity and Efficiency Measurement in Rail Transport papers and (ii) Smith and Nash (2014) - Rail Efficiency: Cost Research and its Implications for Policy were considered as relevant to our survey and taken as starting point of the paper list.
2. No lower bounds on the publication date were considered.
3. Several searches on Google Scholar and Scopus database have been conducted by combining the following key words:

   (a) Railroad;
   (b) Transport services;
   (c) Passenger services;
   (d) Cost function;
   (e) Production function;
   (f) Efficiency analysis;
   (g) Productivity;
   (h) Data Envelopment Analysis;
   (i) Frontier Analysis.

From the obtained lists, papers have been again selected based on the criteria in Section 2.1.

The lists obtained by each bibliographic search have been integrated and duplicated were eliminated obtaining 198 papers. After a second screening process involving the other members of the research team not included in the original search other 98 papers were excluded while 100 papers survived.

The third search, specifically dedicated to the railroad systems impacts, was carried out from March 10th, 2017 up to April 10th, 2017, according to a synthesis between the *snowball* process and the *key words based* process. Several searches on Google Scholar and Scopus have been conducted from March 10th, 2017 up to April 10th, 2017 by combining the following key words:

(a) Railroad;
(b) Environmental performance;
(c) Eco-efficiency;
(d) Social efficiency;
(e) Social impact;
(f) Accidents;
(g) Externalities;
(h) Energy and environment;
(i) Cost-benefit analysis;

(j) Cost function;
(k) Data Envelopment Analysis;
(l) Frontier analysis.

From the obtained lists, papers have been discarded if they were not published on an international journal or were focused only on freight transport.
After that, some reviews on the topic were further inspected (Pérez *et al.*, 2015; Cavaignac and Petiot, 2017; Zhang and Choi, 2014), together with research reports on the quantification of impacts (DG MOVE, 2014) and relevant papers from these additional sources were added in the papers' list (same *snowball* approach followed for the previous review). This process led to 118 papers. After a screening carried out on titles and abstracts, the final number of papers maintained for the analysis was 44.

2.3 Flow Diagram

A flow chart diagram according to the Prisma model (www.prisma-statement.org) has been produced, representing the logical structure of the different steps carried out. It is reported in Appendix A.

2.4 Summary of the evidence

The summary of the evidence based on a relevant grid structure was defined after a few pilot grid tests. All the selected papers have been summarized according to the grid structure. For each paper also the keywords, the authors, the abstracts and other information reported in the paper have been collected.

We summarized the evidence also by running a mapping exercise on the relevant keywords. The mapping exercise provides information about relevant dimensions on the fields and opportunities for improving the methodological and empirical investigation on the subject (see Section 4).

The final number of papers retrieved for the analysis, as showed in Appendix A, was of 144, including 44 about impacts which followed a different grid analysis. We classified each bibliographic item (only the 100 papers selected by first two bibliographic research, and not considering the impact list) according to a grid that highlights the main relevant aspects of the work to facilitate the systematic analysis of the different inputs, outputs and other variables used, different approaches, methods used and the comparison of the obtained results. More in detail, the fields in the grid summarize the information and classify each reference considering the following aspects:

- Paper references
- Objectives of the study
- Methods
- Type of data and indicators - this class includes different sub-classes regarding the kind of data gathered (cross section, time series, panel), the size of the sample, the nationality and the geographical extension of the analysis;
- Variables used - this class divides the variables utilized in the analysed papers in three classes: input, output and variables that cannot be classified as input or output, such as those that describe the quality of the service or external factors (location, climate, pollution etc.).

A structure of the grid is reported in Appendix B.

The grid about the impacts, on the other hand, has been focused on the main typology of impacts included in the analyses, which are summarized in Section 3.

3. The consideration of impacts in economic evaluation studies for railways

From the discussion in the introduction it clearly emerged the importance of considering impacts in the evaluation of the performances of any transport system, and of railways in particular. As stated in the introduction, a systematic review of transport planning studies dealing with the impacts of railways is outside the scope of our research. Nevertheless, we consider it important to analyse the extent to which existing economic analyses in this sector are enlarging their perspective to include impacts.

To achieve this goal, the first step was to analyse transport policy documents that identify the different impacts of transport systems and recommend methodologies for consideration them in the evaluation of mobility scenarios. The term "impact" is here taken in the broadest sense, meaning any consequence of the railway service production and consumption process that falls outside producer and consumers themselves. The considered documents are listed in columns in Table 1. Beyond some key reference documents at the European level, such as Maibach *et al.* (2008) and DG MOVE (2014), a few more specific ones were also included because they present additional impacts which could be particularly important within some evaluation frameworks, for example related to the territory or to touristic activities. Moreover, it was decided to take into consideration the best-practice guide on the conduct of transport studies *Transport Analysis Guidance*, released (and constantly updated) by the British Department for Transport (WebTAG, https://www.gov.uk/guidance/transport-analysis-guidance-webtag), since its prominent position in standardization and coverage of impacts on a European level (Geurs *et al.*, 2009). The final list of identified impacts is presented in the rows of the table and they have been aggregated into the following five main categories: mobility and accessibility, environment, safety, social, and wider economic impacts. Cells in the table show which impacts are covered by the different documents. While some impacts related to congestion, environment and safety in particular are considered in most documents, others are less commonly encountered, mainly because they are more difficult to precisely define, identify and measure.

The purpose of the above exercise is twofold. On one hand, it is relevant in this context to show the potentially relevant impacts for their future inclusion in studies about the performance of rail transport through economic analysis tools. This should constitute an important item in the definition of a research agenda to advance the state of the art in the sector and to improve the assessment of the effectiveness of policies aimed at supporting rail transport. On the other, we are interested in understanding the extent to which existing studies on the economic efficiency of railways are considering any of the above listed impacts, in order to identify any research gap, which is to say impacts that are considered in transport planning activities but less so in economic analyses.

For the latter purpose, we selected a set of 44 papers dealing with railways from the economics literature and considering any of the above impacts, and we checked which ones are covered.

Table 2 shows the results of this analysis, i.e. which papers amongst the reviewed ones deal with each specific impact. Consistently with findings from Table 1, emissions (of pollutants and greenhouse gases) are within the most frequently studied issues. Most remarkably, beyond transport safety we notice that social and welfare impacts are also relatively frequent, which is often not the case in transport planning studies due to the broadness of implications and the difficulty in quantifying them. Amongst the remainder, accessibility analysis and travel time savings are on the other hand less frequently encountered compared to standard transport planning practice, where they often constitute the primary justification for a field intervention such as an infrastructural development. The perspective of service consumers seems rather to be represented by considering transport quality issues, which is more typical of marketing research studies.

Table 1
Main impacts of transport systems

	DG MOVE (2014)	Maibach *et al.* (2008)	VTPI (2017)	Lane and Sherman (2013)	Cascetta (2009)	Geurs *et al.* (2009)	WebTAG (DfT)	Nash and Matthews (2005)	Loukaitou-Sideris *et al.* (2013)
Mobility and Accessibility									
Congestion (included scares infrastructure)	•	•	•	•				•	
Travel Time		•	•	•				•	
Journey quality						•	•	•	
Mobility (included severnance)				•		•	•		
Accessibility				•	•	•	•		
Improve access to job and amenities				•			•		
Environment									
Air pollution	•	•	•	•	•	•	•	•	
Climate change	•	•		•	•		•	•	
Material use			•						
Energy consumption			•						
Noise and vibration	•	•	•	•	•	•	•	•	
Water waste, pollution		•	•	•	•	•	•	•	
Soil pollution		•			•	•		•	
Nature and landscape		•				•	•		
Biodiversity and wildlife					•		•		
Land use			•	•		•	•		
Up- and Downstream processes (LCA)	•	•	•				•	•	
Safety									
Accidents	•	•	•		•	•	•	•	
Human health				•					
Security of energy production and supply		•		•				•	
Personal safety						•	•		
Social impact									
Equity			•	•			•		
Neighborhood and city image (also historic environment)				•	•	•	•		
Quality of life		•							
Wider economic impact									
Employment							•		•
Activities agglomeration and production					•		•		
Property values					•				
Regional investment									•
Real Estate Market									•
Tourism impact									•

Table 2
Main impacts included in the listed papers

Energy consumption	Climate change	Air pollution	Other env. impacts	Noise	Safety	Transport quality	Other consumer surplus	Social & welfare (for the community)	Accessibility	Land use
20%	48%	36%	16%	20%	27%	50%	14%	27%	7%	20%

4. Mapping the main keywords and their evolution over time

We used the Software tool VosViewer (www.vosviewer.com) to analyse the contents of the selected articles. VOSviewer creates term maps based on a corpus of documents. A term map is a two-dimensional map in which terms are located in such a way that the distance between two terms can be interpreted as an indication of the *relatedness* of the terms. In general, the smaller the distance between two terms, the stronger the terms are related to each other. The relatedness of terms is determined on the base of the *co-occurrences* in documents (titles, abstracts or full texts of scientific publications). We used maps for the keywords of the articles considered in our main grid. We extracted the relevant information from Scopus where we found 78 out of 100 papers of our main list of papers (the impacts were classified according to a different search as detailed in Section 2). VOSViewer extracts the keywords from the Scopus files. The list obtained can be further elaborated in order to:

- Unify plural / singular;
- Unify key words with the same meaning, but expressed differently;
- Group key words with a similar meaning;
- Delete key words that are not relevant or representative.

The elaboration is done by providing a thesaurus .txt file to the software.
A first mapping is performed to verify that the thesaurus file performs the intended manipulations and to identify further groupings also based on the strength of the relationships shown in a graphical way.
The mapping can be repeated until the structure of the thesaurus is considered stable. Multiple thesauri can be used, with groupings that allow to see different aspects of the topic of interest. And if this may create some ambiguity to the analysis, it allows also some flexibility. As a matter of fact, the created maps that we will illustrate in the following should be considered only as exploratory tools, to detect broad features of the analysis. In fact, in the following sections, we will analyse the content of the surveyed paper on the base of the main elements contained in the papers as gathered in the grid.
To summarize, the creation of a term map based on a corpus of documents, by means of VOSviewer, the following main steps are required:

1. *Identification* of noun phrases and transformation of plural noun phrases into singular ones.
2. *Selection* of the most relevant noun phrases, i.e. the terms. VOSviewer implemented a technique for selecting the most relevant noun phrases based on the investigation of the distribution of co-occurrences of each noun phrase over all noun phrases. This distribution is compared with the overall distribution of co-occurrences over noun phrases. The larger the difference between the two distributions (measured using the Kullback-Leibler distance), the higher the relevance of a noun phrase. Intuitively, the idea is that noun phrases with a general meaning, such as paper, result and method, have a more or less equal distribution of their co-occurrences. On the other hand, noun phrases with a specific meaning have a distribution of their co-occurrences that is significantly biased towards certain other noun phrases. Hence, it is assumed that in a co-occurrence network noun phrases with a high relevance are grouped together into clusters. Each cluster may be seen as a topic.

3. *Mapping* and *clustering* of the terms.
4. *Visualization* of the mapping and clustering results. VOSviewer offers various types of visualizations. For our purposes, in addition to an illustrative *heat-map*, we realize *clusters maps*, in which the colours indicate the time frame in which the keywords were introduced. Additional technical information about VOsViewer and the VOS mapping and clustering techniques can be found in Van Eck and Waltman (2014).

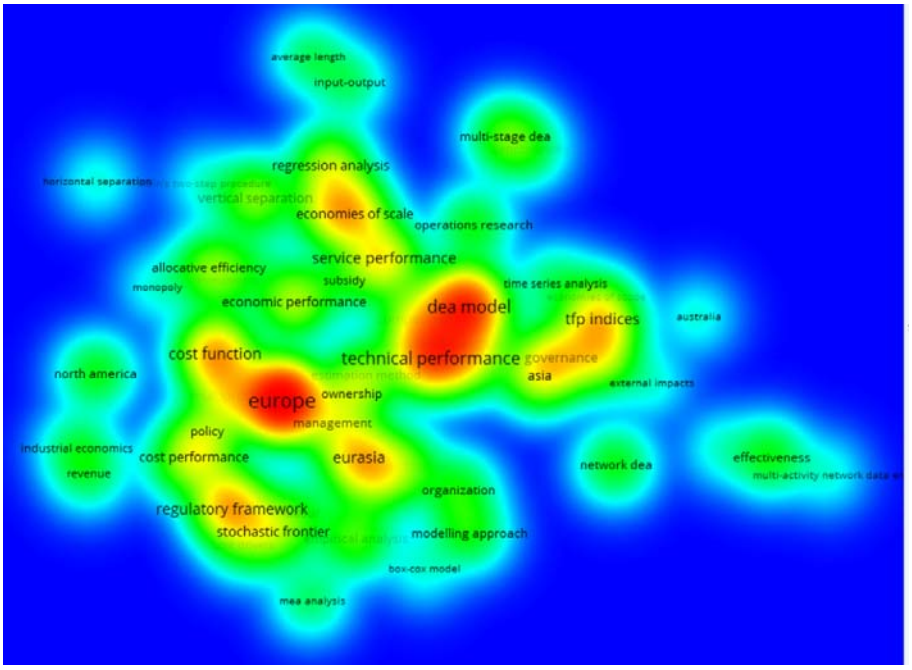

Fig. 1 - Keywords co-occurrence Heat Map. Options: Full counting, Occurrences weight, Linlog/Modularity, attraction set to 2 and repulsion set to 1. Advanced parameters (for the analysis; default values if not specified): random starts set to 50, max. iterations set to 1000, random seed set to 100. From the thesaurus, the following keywords have been eliminated: railway, performance, effectiveness, efficiency, costs, and productivity.

Figure 1 illustrates the Heat Map of the co-occurrences of the keywords in the thesaurus extracted from the Scopus documents[1]. Some first observations are in order here; we identify two hot spots in the map, the first one in the central area highlights the relevance of non-parametric approaches in the reviewed studies. In particular DEA models appear as the most utilized when dealing with technical performance analysis. Technical performance is a keyword strictly connected to the DEA models showing a strong connection and centrality of these two issues in the reviewed studies. Satellite to this central cluster we find another important issue such as scale economies that can be addressed with different methodological approaches that seemingly are migrating from more traditional regression based models, relegated to a peripheral position, to non –parametric models. We also note the central role of DEA which is in the deepest area but still isolated and at the boundaries of the mainstream methodological approaches. The second hot spot in the map shows that Europe as an international entity or as single nations is the area where most of the studies are focused. Interestingly, we find, connected to this point, a satellite spot referring to regulatory issues. This is not surprising since European countries are in general more keen on regulating economic sectors characterized by enduring bottlenecks such as in network industries and in the past the issues of ownership (public or private) vertical/horizontal separation and service subsidization in railways has been widely debated by policy makers and academics. More interestingly, close to this point appears the keyword related to stochastic frontier analysis, this suggests that those who focus their

[1] The thesaurus of the keywords and the technical specifications used to obtain this heat-map are available from the authors upon request.

studies on regulatory and policy issues prefer this methodological approach. Finally, we observe that effectiveness studies are quite far from technical and cost efficiency analyses.

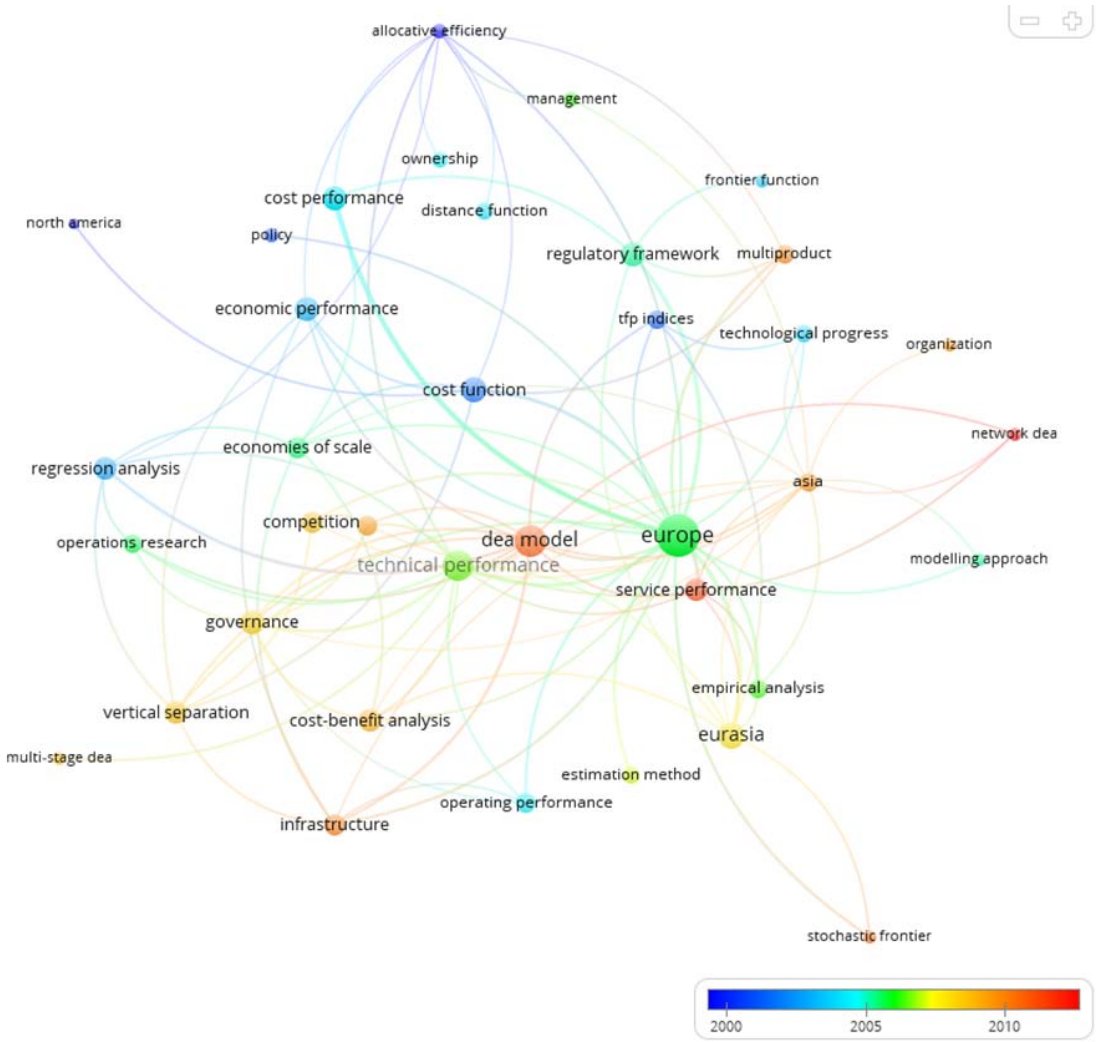

Fig. 2 - Time evolution of keywords with the main 100 links shown. The size of the balls are proportional to the frequency of the keywords. The colours of the balls (keywords) show the year in which the keywords were introduced. Options: Full counting, Occurrences weight (minimum number of occurrence for each keyword: 2), Linlog/Modularity, attraction set to 2 and repulsion set to 1. Advanced parameters (for the analysis; default values if not specified): random starts set to 50, max. iterations set to 1000, random seed set to 100. From the thesaurus the following keywords have been eliminated: railway, performance, effectiveness, efficiency, costs, productivity.

Figure 2 shows the time evolution of keywords clustered with different colors referring to time and the links that each keyword has with the others. We have focused on papers published after 2000 to simplify the map and give the reader a clearer view on the most recent trends.

From the appearance of the map we can derive some insights about the evolution of the studies addressing efficiency and effectiveness of the rail transport. Around the year 2000, the studies focused prevalently on North America dealing with economic performance, cost performance and policy issues. These themes were addressed still with more traditional tools based on the modelling of cost functions, regression

analysis and total factor productivity (tfp) indices. Starting from 2005-2007, technical and cost performance as well as regulatory issues in Europe became prevalent, linked to this cluster we find operational research methods that in this time lapse start coming up beside the more traditional regression based analysis. From 2007-2008, Eurasia appears and the study of the performance of railway transport focuses on regulatory issues such as the vertical separation, governance, competition and cost-benefit analysis. Finally, from 2010 on, the assessment of service performance seems dominated by DEA, Asia appears as a main empirical investigation and Network DEA is introduced to investigate railway transport efficiency.

5. Inputs, outputs and additional variables

Railways employ a variety of inputs. The definitions of the set of inputs and outputs in a production/cost model is crucial in evaluating efficiency, the literature analysed in this study shows a certain heterogeneity in the set of input variables. Considering the basic classification of inputs in a production model related to transport industries (labour, materials and capital) we found a considerable variance in the definition of these classes. This is mainly attributable to the availability of sufficiently disaggregated data and to the specific aims of each study.

Input variables are classified in two main categories: "physical" production factors with their own measurement units (number of employees, hours of work etc.) on one side, and monetary units on the other, that are further split into unit price of inputs or total cost of inputs, sometimes used as proxy of physical consumption of an input. Table 3 shows the different variables related to physical measures of inputs, Tables 4 and 5 show the variables related to the monetary evaluation of inputs, inputs variables are ordered by type: labour (L), capital (K) and materials (M) and then by frequency of occurrence.

Concerning the first category, the number of employees (or hours of work), materials (mainly energy/fuel) and capital (rolling stock and infrastructure) are the most considered variables since they represent the main inputs in the production process. Some authors use to divide the total number of employees in operative (driving and on board personnel) and non-operative (administrative staff etc.). Amongst the two other inputs the stock of capital deserves a particular mention.

Rail transport is a capital intensive industry, the measure of capital stock is crucial in rail efficiency analysis since investments in infrastructure and rolling stock and the cost related to their usage account for a prominent part of firms expenses. In railways, capital stock is roughly divided in way and structures (W&S) capital, equipment capital (primarily rolling stock), and land.

It is worth noting that differences between operators may exist in terms of quality and composition of this highly heterogeneous input. To give an example of such heterogeneity, the rolling stock may differ in terms of composition, average age of the fleet, intensity of usage and patterns of depreciation.

Table 3
Physical Input

Variable description	%	Type
Numbers of pass cars	19	K
Numbers of freight cars	16	K
Fixed assets (Capital stock or ways and fixed installations)	14	K

Numbers of locomotive	13	K
Network lenght	12	K
Number of vehicles	12	K
Way and Infrastructure	11	K
Track length	9	K
Length of lines/routes	6	K
Number of stations	2	K
Number of available seats	2	K
Number of available tons	2	K
Equipment	1	K
Fleet capacity (standing and seating)	1	K
lenght of electrified rail lines	1	K
lenght of not electrified rail lines	1	K
Number of employees	40	L
Total hours of labour	5	L
Number of operative (drivers or non managerial+administrative)	3	L
Number of non operative employees (non-driver or management+administrative)	1	L
Transaction staff managerial	1	L
Transaction staff non managerial	1	L
Number of transaction staff operative	1	L
Energy/Fuel consumptions	17	M
Materials consumptions	1	M
Materials and external services	1	M
Materials and equipment	4	M/K

Thus, capital is one of the most difficult inputs to measure correctly. In principle, measuring capital inputs in physical units poses several issues since authors use a vast range of variables and it is quite hard to define a unique unit of measure. Beside the measurement of capital stock in units, the assessment of the economic value of capital is even harder.

The perpetual inventory method (see OECD, 2009) is the most widely used approach towards measuring stocks and flows of fixed assets, and in our opinion the most correct. It requires developing a constant monetary measure of rail capital stocks. Starting from the earliest records, the capital stock is accumulated by adding new investments, deducting an assumed economic rate of depreciation, and converting these to constant dollars by use of rail asset price indices. Possible extraordinary maintenance of the assets is usually capitalized and thus should be considered as an additional asset. Another ambiguity relates to the book value versus the market value of assets. In principle the actual market value of assets is the correct measure, however such data may not be available. In such cases book values of assets are used. However operators may not apply the international accounting standards, being unable to determine the fair values of their assets. In such cases, since, depreciation reflects just a nominal amount of the assets value yearly consumed in the production process, it is appropriate to apply the current cost accounting method where current market value of the assets is obtained by multiplying the gross book value of assets by a suitable deflation index, depending on the age of the asset.

Table 4
Input prices

Variable description	%	Type

Price of Capital	17	K
Price of rolling stocks	5	K
Price of rolling stock maintenance	1	K
Price of intermediate inputs	1	K
Price of way and structure	1	K
Price of labour	44	L
Price of non-payroll	1	L
Price of Energy/Fuel	33	M
Price of materials	9	M
Price of energy, materials and external services	4	M
Price of materials and external services	3	M
Price of maintenance	2	M
Price of materials and equipment	3	M/K
Price of materials and capital expenditures	1	M/K

Table 5
Input consumption described by cost

Variable description	%	Type
Capital expenses (CAPEX)	5	K
Rolling stock expenses	2	K
Infrastructure access charge	2	K
Renewals (expenses, km renewed, dummy yes/no)	1	K
Rolling stock leasing costs	1	K
Total Labour expenses	9	L
Operating labour expenses	1	L
Pension/compensation expenses	1	L
Operating expenses (OPEX)	5	L/M/K
Total expenses	3	L/M/K
Energy/Fuel Expenses	6	M
Materials costs	5	M
Operating expenses without staff	3	M/K
Materials and mainentenance expenses	1	M/K

Finally a third issue relates to the opportunity cost of capital. The opportunity cost of the capital is the expected rate of return of the best alternative investment of equivalent risk, namely the risk and consequently the expected rate of return from investing into freight services rather than high speed services is, in principle, different. Thus the risk to incorporate into the measure of the cost of capital should reflect the risk related to investing capital into activities similar to those analysed in the models. We noted that some of the reviewed papers limit their measure of the cost of capital to the rate of return of riskless activities (or proxies such as treasury bonds), this underestimates the real cost of capital. There exist a vast literature on how the opportunity cost of capital can be measured when dealing with risky activities; a widely adopted measure of the cost of capital is based on an estimation of the pre-tax Weighted Average Cost of Capital (WACC), namely, the minimum return on the net invested capital that has to be generated to fully reward all providers of financial resources, that is, debt and equity.

Considering output, railways provide a great many services. Historically, the most important distinction in rail outputs was between passenger and freight services. Passenger services distinguish between intercity and commuter services. It is possible to categorize the output variables in three groups.

In the first group, we put indicators related to the efficiency of the service that measure output from the supply side and consists of those measures provided by a railway such as passenger train-km and freight train-km, which can be defined as a train (passenger or freight) multiplied by the distance it has travelled. In the second group, we consider indicators related to the effectiveness of the production process that measure output from the consumption side of the service such as passenger-km and freight ton-km. The passenger-km is defined as the summation of each passenger multiplied by the distance he/she has travelled. The ton-km is defined as the summation of the tonnage of freight multiplied by the distance transported. A third group represents the financial counterpart of the second one, since it considers the service revenues (see Table 6).

Table 6
Output variables

Variable description	%
Passengers*travelled kilometres	63
Freight-ton kilometers	59
Train(pass) * travelled kilometres	17
Train(freight) * travelled kilometres	15
Train* travelled kilometres	9
Number of passengers	6
Average passenger travel length	5
Average freight length of haul	5
Seats*km	5
Total Revenue	5
Passenger revenue	4
Number of freight tons	4
Number of stations	3
Tons offered*travelled kilometres	3
Pass tons*km	3
Passenger journeys	3
Train*hours of operations	2
Car*travelled km	2
Vehicles(pass) * travelled kilometres	2
Track length	1
Number of passengers - urban	1
Number of passengers - non urban	1
Freight revenue	1

From the supply side point of view, railway transport has a large variance in terms of seats available on trains used. In order to determine a statistically significant and robust cost model we deemed appropriate to estimate the economic cost of the service by means of seat-km of service. Seat-kilometres is preferred as output over vehicle-kilometres, because the size of vehicles, a substantial cost driver, is then included. Both measures, however, represent a pure supply-side consideration of output. From the consumption perspective, passenger-kilometres, passengers, or revenues also take demand into account.

Which output specification to use has been discussed intensively in the literature. However, when measuring efficiency caution should be observed when considering consumption data (as passenger-km and freight ton-km) as the only output variables since they are service-consumed data purchased by customers (passengers or shippers), rather than the real measure of the output produced (eventually not consumed) by a railway firm. Since, the process of production is different from that of consumption i.e. due to public service obligations or other external constraints that do not allow a perfect matching between demand and supply. To find out the source of poor performance, both supply and consumption variables should be used in the models.

Most of the reviewed studies take into account an additional set of variables, that are listed in Tables 7, 8, 9, 10 and 11. These last ones cannot be considered as inputs or outputs of a production model. However, their introduction in the models is of paramount importance since they are able to capture aspects of the quality of the service (i.e. the different technologies adopted or other characteristics that influence the service performance) which can make the difference when measuring or comparing efficiency and/or effectiveness of rail services. The reviewed literature reveals a broad set of such variables that are often tailored to the purpose of each study. We have clustered them into a few main classes describing the service characteristics, the network and technological aspects of the services, managerial and policy related variables. We observed some clusters related to the socio economic context and the externalities produced when offering rail transport services. Finally we ended up with Tables 7 to 11.

Table 7
Capacity and service performance

Variable description	%
Load Factor	17
Average passengers' travel length	12
Average load per train (freight)	9
Average freight length of haul	8
PPM (percentage of train in time)	5
Railway pass density (train pass*km / track length)	4
Network density (rail km/area of country)	4
Quality of service (composite index)	3
Railway freight density (train freight*km / track length)	3
Number of stations	2
Train freigth density (train*km / route length)	2
Average commercial speed	1
Broken rails	1
Frequency of service	1
Peak to base ratio	1
Customer satisfaction (satisfied per number of complain)	1
Tonnage density (gross tonne-km / route-km)	1
Train density (train*km / route length)	1
Train pass density (train*km / route length)	1

Table 8
Network and service characteristics

Variable description	%
Electrificated lines (dummy or percentage)	19
Railway density (train*km / network length)	7
Train (pass)*km / Train (tot) * km	5

High speed (yes/no, number of km)	5
Dispersion index (eg. Average distance between stations)	4
Dummy area of service (urban, regional, long haul)	3
Dummy titling train vehicles	3
Average train length (cars per train)	3
Rolling stock age	3
Number of high-speed vehicles	3
Dummy light vs heavy service	2
Dummy type of urban transport (metro, light rail, suburban)	2
Rolling stock type (EMU, DMU, electric, diesel) - dummy or number	2
Share of bulk freight	2
Revenue freight/tons*km	2
Potential max speed	2
Percentage double-track	2
Gauge characteristics (dummy)	2
Average length of a route	1
Diversification of service (% from the firm total revenue, per each service type)	1
Non-underground km per route length	1
Ratio Japan Rail-pass users	1
Dummy "streetcars"	1
Mean number of track by line	1
Number of routes	1
Number of stops	1
Change in vehicles characteristics	1
Railcar utilisation rate	1
Ratio of train service in urban areas to total train service	1
Size of the area where the service is implemented	1
Travel time	1
New electrification (new metropolitan lines)	1
Percentage of lines/vehicles equipped with ERTMS	1
Automatic ticket machine (level of automatation)	1
Introduction of centralized train control signaling	1
Introduction of automated points and turnover	1
Introduction of fiber optics	1
Percentage of grade track (no elevated, no tunnels)	1
Mean number of track per line	1
Line density (Pass*km or tons*km / line*km)	1
Railway density (train*km / track length)	1
Automated system (high/low)	1
Automated system (high/low)	1

The first cluster in this list refers to quality and service characteristics aspects (Table 7), two issues that are often not easily distinguishable through the variables that are shown in the table, since such variables are often relevant for both. We see here a reflection of the burgeoning literature dealing with quality aspects in transport. Amongst the most commonly used variables we notice those reflecting how the service responds to the demand (i.e. load factor and reliability of the service). Quality was also one of the key impacts according to the analysis presented in Table 2. The range of related variables used in the reviewed models, as shown in Table 7, seems rather narrow compared to standard practice in transport planning studies. We see here a good example of cross-fertilisation between different research ambits that should help in enhancing effectiveness studies that are making use of econometric models.

Almost each paper analysed in this review makes use of variables related to network and service characteristics in order to encompass the specific aspects of the services that are studied. This produces a fairly vast cluster of variables describing aspects of the technology underlying the transport service such as high speed, level of automation, presence of tilting trains or other type of trains, level of electrification of the lines just to reckon the most used. Moreover, the characteristic of the service are well described by a broad set of variables, ranging from the diversification freight/passengers, to the description of the network and rolling stock. This group of variables is strictly related to the quality of the service and therefore to cost efficiency and effectiveness by means of passengers served and service performance (see Table 8).

Situational variables are typically considered to improve the comparability of results in the analysis of different systems. In particular, one cluster contains variables describing the socioeconomic characteristics of the service (see Table 9), while the other two pertain to management and economic characteristics of the service (see Table 10). Amongst the most popular variables we notice those related to the structure of the market (i.e. vertical or horizontal separation) and the way services are subsidised (i.e. amount of subsidies or measures of the financial independence of the firm).

Table 9
Socio-economic contextual variables

Variable description	%
Population density	13
GDP gross domestic product per inhabitant	12
General index of technical change/progress	8
Population in the service area	3
Number of metropolitan cities potentially served by the firm network	3
National Income	1
Inverse density index (population in the area / track length)	1
Vkm per head of population	1
Level of competition (HHI, sum of dummy) - pass	1
Level of competition (HHI, sum of dummy) - freight	1
Number of rail enterprises in the country	1
Non-rail transport share in metropolitan area (%)	1
Gasoline price (proxy for price of substitute transport modes)	1
Number of passenger cars per capita	1
Contry population	1
Percentage urban population	1
Road density	1
Annual growth rate of capita taxable income	1

Table 10
Policy/regulation and managerial variables

Variable description	P
Vertical separation (dummy separated/holding/integrated)	13
Fin. independence (Revenue/Cost ratio; Subsidy/Cost ratio; Subsidy/Revenue)	7
Dummy for deregulation/competition	6
Indipendent management from government (level of autonomy)	5
Horizontal separation (dummy type of organization -pass/freight)	5
Competitive tendering (dummy or share of train*km)	4
Contract Type (dummy fixed-price vs cost-plus / share of net contract)	2
Dummy for Public Company	2
IBM-Kirchner's Competition Index	2
IBM-Kirchner's Liberalization index	2
Sequential or package reforms introduction (dummy)	2
Dummy yardstick regulation	2
Labour/equipment ratio	1
Investement rate (CAPEX/Revenue)	1
Book leverage	1
Number of employees per train*km	1
Equity-share from public funds	1
Managerial/organizational changes (time dummy)	1
Government influence on tariffs	1
Contract duration (average, specific planned in contract)	1
Dummy last year of franchise contract	1
Type of public bodies (regional, national, …)	1
Subsidies on deficit	1
Subsidies on investment	1
Subsidies for obligation services	1
EU directive or national regolation on manager behaviour	1
Competitive access to the infrastructure, based on the principle of vertical disintegration	1

Last but not least, a few of papers deal with some variables representing externalities, environmental and socio economic aspects related to the rail services, an issue of central interest for an effectiveness analysis: the most popular aspect here considered is the number of accidents (see Table 11).

Table 11
Externalities and environmental aspects

Variable description	%
Safety (number of accidents/victims, mean km per accident)	4
Weather conditions	3
Terrain conditions	3
CO2 emissions	2

The set of efficiency studies dealing with such aspects is too small to draw well-grounded conclusions, nevertheless we can notice that safety and climate change (CO2 emissions) issues were also addressed in the impact studies (Table 2). Along with the above discussed importance of service quality, these two

externalities seem therefore good candidates to further develop effectiveness studies through economic efficiency analysis methods.

6. Main techniques applied in the reviewed papers

In this section we present an overview of the main methods applied in the selected papers which were summarized according to the grid reported in Appendix (see Appendix B).

The methods have been classified in: Regression-based methods (Reg); Parametric frontier methods (Pfro), Nonparametric Frontier Methods (Npfro).

By and large, regression-based methods aim at estimating an *expected value* or average behaviour over the units of analysis. On the contrary, frontier-based approaches aim at estimating the *best practice* in terms of *maximum* outputs that can be realized or *minimum* costs achieved or associated to the analysed process. For a general overview on frontier-based approaches see e.g. Fried, Lovell and Schmidt (2008). Frontier-based methods can be further characterized by the level of specification of the functional form of the input-output relationship. Parametric frontier methods, also called Stochastic Frontier Approaches (SFA), are based on the specification of a functional form for the input-output relationship and the parameters of this relationship are estimated over the observed data. On the contrary, Nonparametric frontier methods do not rely on the specification of the functional relationship of the input-output: this relationship is empirically derived from the observed data. This is a main advantage of nonparametric methods that are more general and empirically driven, compared with the parametric approaches. For an introduction to the main limitations of the nonparametric approach and to the recently introduced statistical and robust methods to overcome them, see Daraio and Simar (2007). Charnes, Cooper and Rhodes (1978) introduced the Data Envelopment Analysis (DEA), the main nonparametric approach in efficiency analysis. DEA is based on linear programming techniques to estimate the piece-wise-envelop of the *efficient* frontier or frontier of the best practice, empirically, without assuming any functional relationship for the frontier.

Table 12
Summary of the methods applied in the reviewed studies

Method	*Acronym*	*N. of obs.*
Regression-based	Reg	31
Parametric Frontier	Pfro	32
Nonparametric Frontier	Npfro	38
-Two-stage DEA	2stDEA	15
-Network DEA	N-DEA	9

Notes: i) the sum of Regression-based methods, parametric and nonparametric methods, is not 100 (the total number of papers analysed) because in some papers more methods were applied; ii) the Npfro studies include 2stDEA, N-DEA and simple DEA based studies.

Over the 100 papers analysed, 31 applied a regression-based approach and specified a Translog or -in a few cases- a Cobb-Douglas functional form. Translog is also the main functional specification used by the papers which apply the Parametric Frontier approach (32 papers over 100). A few studies applied a generalized McFadden functional form (Christopoulos *et al.*, 2000, 2001) or a Berndt and Khaled's Box-Cox function (De Borger, 1992). Most studies adopted a Seemingly Unrelated method of estimation

(SURE). None of the reviewed papers described why the production process of rail-transport investigated can be modelled according to these functional forms.

Most of the reviewed papers (38 out of 100) applied a nonparametric frontier approach for assessing the efficiency of railway transport. Within these papers, 15 of them carried out a two-stage DEA analysis which consists in estimating in a first stage the efficiency scores and in regressing them in a second stage over a set of explanatory variables, looking for factors which may affect the performance of the analysed units. Unfortunately, none of the reviewed studies applied a correct approach for inference: 3 out of 15 studies run only simple descriptive correlation analyses while 12 out of 15 employed a Tobit regression for the second stage. As explained in the Appendix of the paper by Simar and Wilson (2007), the Tobit approach is not a correct approach: a truncated regression should be carried out and a bootstrap based inference is required in this context. Moreover, implicit in the two-stage approach described so far is the so called *separability condition,* according to which the external-environmental factors (explanatory variables in the analysis) do not influence the efficient frontier but only the distribution of inefficiency (how far a unit is from the efficient frontier): this is a strong assumption that should at least be tested (Daraio, Simar and Wilson, 2017) or alternative more robust estimation approaches, like conditional efficiency analysis, which do not rely on the separability condition, may be employed (see Simar and Wilson, 2015 for a recent survey).

There is then room for improvement with respect to the methods applied for analysing the efficiency, effectiveness and impact of the railway transport sector.

A final observation is related to Network Data Envelopment Analysis (Kao, 2017) which aims at investigating within the black box of the decision making units, analysing sub-technologies and more complex relationships related to the production process. 9 of the reviewed studies applied a Network DEA approach.
In the next section we will analyse the temporal evolution of methods and will relate them to the variables used by the reviewed papers.

7. Temporal evolution of methods, data used and analysed countries

7.1 Temporal evolution of the analytical approaches

Figure 3 displays the evolution over time of the number of papers published for three main categories of method, namely regression (Reg), non-parametric frontier (Npfro) and Parametric frontier (Pfro).

Figure 3 shows a slightly decreasing trend of the traditional Parametric Regression approach (Reg) which appears less used over time. This decreasing trend seems to be compensated by the increasing trend of the Parametric Frontier Approach (Pfro). This suggests that the Pfro Approach has substituted the traditional Reg approach over time. More interestingly, the use of the Nonparametric Frontier Approach (Npfro) has increased quite dramatically from the late nineties. This result confirms the exploratory findings described in Section 4 about the mapping of keywords and their evolution over time. As already observed in Section 4, there is room for improving the nonparametric approach applied for the assessment of efficiency and effectiveness of the rail transport sector. We foresee a great potential for future application of recently proposed advancements within this field. In particular, robust nonparametric conditional analysis (Badin *et al.* 2012) and its extensions to directional distances (Daraio and Simar, 2014 and 2016) seem promising. Their feature of not relying of the very restrictive *separability* condition (according to which the external factors do not influence the efficient frontier but may affect only the distance of the units from the estimated efficient frontier) makes this kind of efficiency approach an interesting candidate for assessing rail transport efficiency and effectiveness.

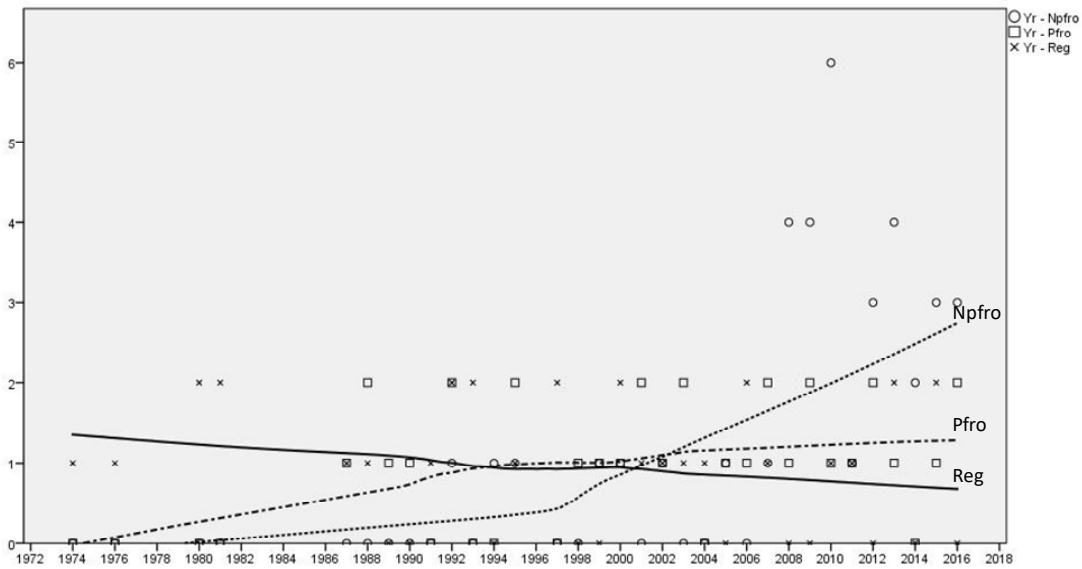

Fig. 3 - Evolution of the number of papers per publication, year and method (regression (Reg), non-parametric frontier (Npfro) and Parametric frontier (Pfro). Lines are nonparametric smoothed trends (loess with 95% of interpolated points).

7.2 Data analysed

This paragraph provides information about the type of dataset used (i.e. cross-section, time-series, pooled cross-section or panel data), sample size (number of operators and years analyzed) and the countries in which the transit systems analyzed in the selected studies operate.
In particular, Table 13 provides information on the type of data and the sample size and shows that panel studies prevail in the literature. The sample size (excluding time series) is on average quite homogeneous across datasets but varies a lot within each dataset class. As regards time span we observe that, excluding cross-sectional studies, ranges from 2 to 30 years.

Table 13
Distribution of papers by type of data used, sample size and time span

		Sample size			Time_span		
Dataset	%	Mean	Max	Min.	Mean	Max	Min
Time Series	14%	1	1	1	26,5	30	19
Panel	55%	24,9	60	5	13,9	27	2
Unbalanced Panel	12%	26,6	81	4	16,8	29	8
Cross Section	14%	39,2	89	13	1	1	1
Pooled Cross Section	5%	32,8	56	22	5,8	7	5

The great majority of the reviewed papers takes transit operators (70 papers), 24 papers make their analysis on a large scale, namely comparing data at country or regional level while a few papers considers city wide transit systems and a single paper considers local units of bigger firms; see Table 14 which summarizes.

Table 14
Distribution of papers by unit of analysis

Sample unit	%
Large-scale (national, regional, counties etc.)	24
City-wide system, transit agency	5
Operator (whole firm)	70
Local unit of the firm	1

Table 15
Distribution of papers by country and data sources

Country	N	Data source			
		Official Statistic	Ad hoc surveys	Secondary use data	Combination different sources of data
Australia	3	0	0	2	1
Belgium	2	0	0	1	1
China	2	1	0	0	1
Germany	1	0	0	0	1
Greece	1	1	0	0	0
India	1	1	0	0	0
Iran	2	1	0	1	0
Ireland	1	0	0	1	0
Italy	1	0	0	1	0
Japan	6	3	0	3	0
Netherlands	1	0	0	1	0
Spain	1	0	0	0	1
Sweden	1	0	0	0	1
Switzerland	4	4	0	0	0
Taiwan	1	1	0	0	0
UK	7	0	0	1	6
USA	15	9	0	5	1
Europe	38	21	1	2	14
International	12	3	1	1	7
Total	100	45	2	19	34

Table 15 shows that 40 of the reviewed studies deal with international data, and that within these papers 38 relates to European countries while the remaining 12 (denoted with International) consider different combination of countries worldwide. When focused on a single country, the majority of the studies deals with EU or USA national data. As regards data sources, the majority of the selected papers takes data from official sources such as transport authorities or statistical offices but often such data are integrated with information retrieved from secondary sources, such as firm financial reports, plus ad hoc surveys.

8. Conclusions

Railway systems belong to the great societal challenges nowadays. The key point of the present survey is that *efficiency* analyses could be turned into a much more powerful decision support tool for different stakeholders in the transport sector, by including the *effectiveness* dimension, if they considered some of the wealth of indicators that are normally employed in transport planning studies to monitor the implementation of policy measures. On this premise, the paper surveyed the existing studies about the railway sector, focusing mainly on passenger railway services serving both suburban and intercity trips. A special attention has been devoted, on top of this, to the issue of impacts, which is becoming more important for the field.

The critical investigation on the existing state of the art literature has been based on a mix of different methods, namely the integration of different analytical frameworks (engineering, economics, impacts); the application of systematic review techniques and the exploitation of advanced mappings. The result is aimed at offering a comprehensive classification, a kind of catalog, for developing new methods, novel empirical investigations and facing the complexity of the field.

The comprehensive classification of selected relevant dimensions of the empirical literature, carried out in this paper allowed us to summarise the existing literature in such a way that facilitate the proposal of desirable developments and extensions for future studies and analyses in the field, a sort of research agenda that can be proposed to the research community.

This study offers insights to define the catalog and the related research agenda. At the outset, our semantic analysis of the contents of the surveyed papers has shown that effectiveness issues are still quite unrelated to technical and cost efficiency studies (see Figure 1). There is the need for a better integration with respect to the methods applied for analysing the efficiency, effectiveness and impact of the railway transport sector.

The first step that is needed to facilitate the evolution of existing efficiency studies in the railway sector into more policy relevant effectiveness studies is to more systematically adopt the most advanced economic analysis techniques. Data Envelopment Analysis has been more and more consistently used in the last decade compared to less performing methods, however railway studies could benefit from more advanced methods such as robust nonparametric conditional analysis (Badin et al. 2012) and its extensions to directional distances (Daraio and Simar, 2014 and 2016).

The second step is to gradually move from the mere consideration of outputs in a production process to a broader set of indicators that can better capture those impacts and externalities that justify the public intervention in this sector. By looking first at studies dealing with the impact of railways, our review has shown that quality, air pollution, climate change and safety are within the most frequently studied issues (see Section 3). On the other hand, a handful of efficiency studies is also considering quality-related indicators, carbon dioxide emissions and number of accidents as contextual variables (see Section 5). It seems therefore reasonable to initially focus on those three ambits to build an effectiveness assessment tool based on economic efficiency analysis methods. The way in which these three externalities are captured in current models can be improved by considering the transport policy documents that are summarised in Table 1.

Following those two initial steps, the main inputs, outputs, contextual variables, kind of data analysed and methods adopted, and the systematic investigation of their interrelationships offer to the readers a useful kit to think further and introduce new methods for addressing the main issues analysed in this field.

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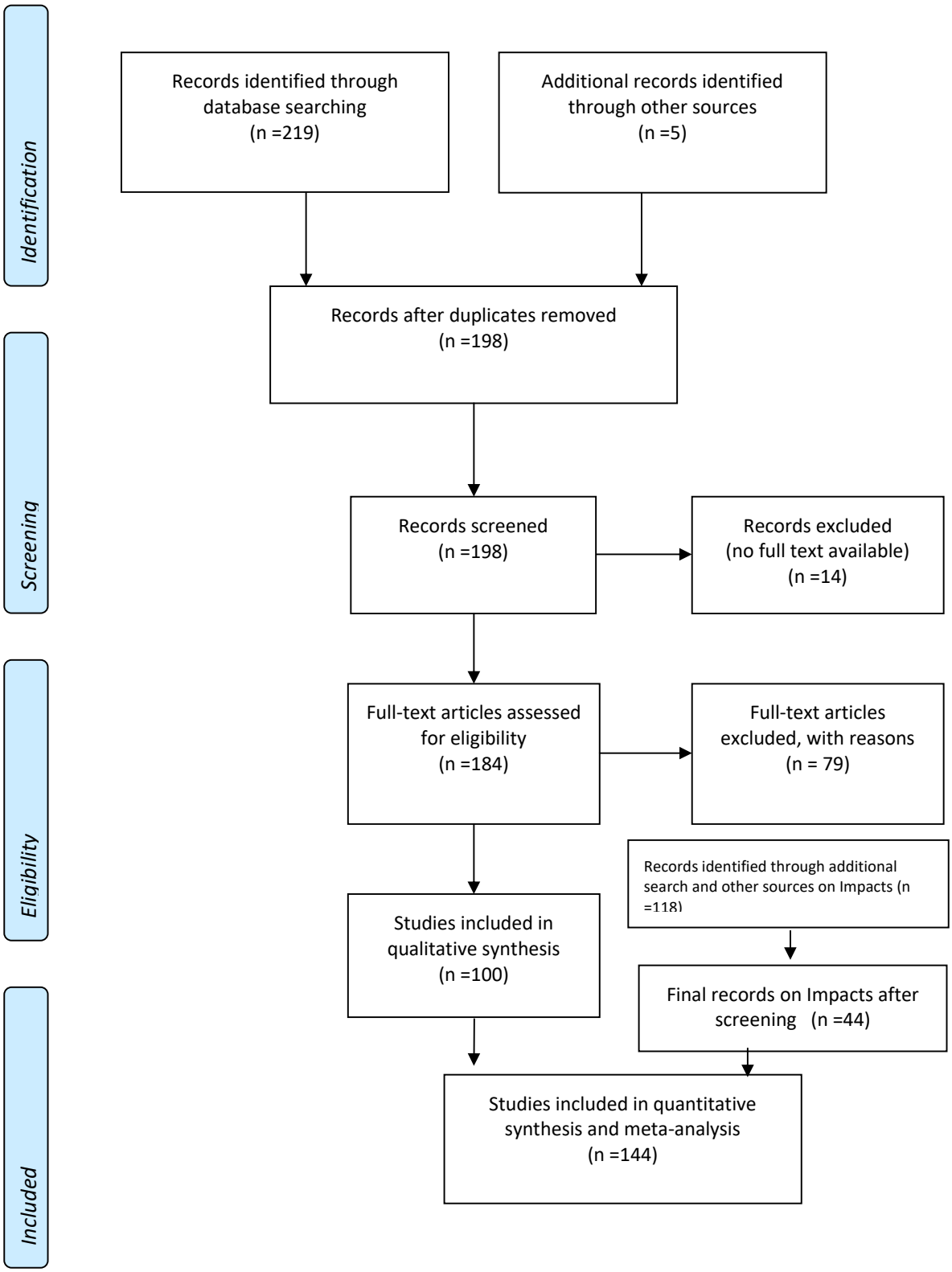
Appendix A – Methodology of the survey: Flow diagram of the review

Flow Diagram of the review Adapted from: Moher *et al.* (2009).



Appendix B - Outline of the grid used for the analysis of the selected papers.

Paper Reference		
Method	Extensive Description	
	Typology	Reg = Regression-based Fro = Frontier-based (with Pfro=parametric frontiers and Npfro=nonparametric frontiers) Oth = Others (specify, e.g. CBA, Multicriteria, TFP)
Type of data and indicators	Data_source	O = Official statistics A = Ad-hoc survey S = Secondary use
	Data_type	C = Cross section T = Time series P = Panel PC = Pooled cross section
	Reference Years	
	T (number of years analysed)	
	N of observations (sample size)	
	Coverage	I = International comparison N = National level R = Regional level C = Metropolitan level
	Sample unit	L = Large-scale (national, regional or Provinces) C = City-wide system, transit agency O = Operator (whole firm) U = local unit of the firm T = transit line V = vehicle
	Country	
	Dummy regarding freight inclusion	
	Comments on data	
Variables		I = input O = output P = parameter D = dependent variable
Dummy regarding inclusion of impacts		
Comments		