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Abstract

This paper proposes a self-contained reference for both policy makers and scholars who want to address the problem of efficiency and effectiveness of Local Public Transport (LPT) in a sound empirical way. Framing economic efficiency studies into a transport planning perspective, it offers a critical discussion of the existing empirical studies, relating them to the main methodological approaches used. The connection between such perspectives and Operations Research studies dealing with scheduling and tactical design of public transport services is also developed. The comprehensive classification of selected relevant dimensions of the empirical literature, namely inputs, outputs, kind of data analyzed, methods adopted and policy relevant questions addressed, and the systematic investigation of their interrelationships allows us to summarize the existing literature and to propose desirable developments and extensions for future studies in the field.

Keywords: Public transport, Variable and Total Cost Functions, Efficiency, Effectiveness, OLS, Translog, DEA, SFA, Transport indicators, Transit scheduling, Tactical design.

1. Introduction

The operation of public transport services has a significant impact on the budget of most territorial public bodies (central state, regions, provinces and municipalities). Moreover, in many cases only a small fraction of these costs is recovered through end user tickets and subscriptions. This expenditure of public money usually is justified both in terms of welfare efficiency and equity goals, given the pervasive socio-economic and environmental impact of transport. In terms of equity goals, a reasonable level of access to mobility services is unanimously considered an essential right in a democratic society. As far as efficiency goals are concerned, stakeholders are in fact usually interested both in the direct effects (improving the efficiency and the quality of the offer of the public transport system itself), and in the external effects such as reducing pollution and congestion and improving labour supply in urban centres. Most remarkably, these "external effects" often constitute the primary rationale for such interventions, both in the political arena, and in more technical analysis of the transport planning documents. The matter is not how much "output" one is able to produce given some input, but how the intervention impacts the transport system as a whole by modifying environmental footprints, land use patterns or territorial accessibility and more generally, how the intervention affects a vector of social goals given its use of social resources.

It should be acknowledged that any evaluation method should consider this framework, in order to provide really useful indications to transport policy decision makers. We preliminary observe that at least two radically different approaches are used, both at the research and at the practitioner level, to make such kind of assessment, according to the disciplinary background of the analysts. Civil engineers and transport planners are usually conscious of the different implications that often underlie any investment in a public transport system and are interested in studying also the technical performances of the system itself. This generally leads to the definition of a set of indicators, since this method permits to jointly consider heterogeneous kinds of data (for example, public subsidies, commercial speed and decrease of pollutants emissions) in a rather straightforward way, on an analytical point of view, often involving simple mathematical operations. On the other hand, economists tend to apply efficiency analyses at a more aggregated level, using shadow prices of the social resources and a social welfare function to design intervention policies. Their methodologies are very insightful, allowing one to evaluate how well a Decision Making Unit (DMU) is operating, if, and how much the resources could be better used, and so on. As such, these tools are very useful for a public transport operator, like for any other firm, but from the more general point of view of the stakeholder need to be integrated according to the above described framework.

We believe that a promising avenue of research is to interface the analysis based on transport indicators, whose flexibility allows us to consider a wide range of data, such as cost drivers, output, levels of use and impact measures, with the efficiency analysis literature, a powerful analytical tool that is widely used in different fields both in the public and in the private sector to estimate possible improvements in the amount and mix of used resources and the trade-offs between output attributes. To the best of our knowledge, a unified framework that jointly considers these two aspects is missing, and could provide insightful indications for researchers and policy makers. Our ambition is to provide a systematic analysis of the existing studies and elaborate a taxonomy of the main research questions, the main results and policy implications addressed in the literature by means of a careful study of the data, variables and methods applied in these growing fields of study. The most valuable output of our research will be a self-contained reference to researchers and policy makers interested in modelling and empirically investigating the urban public transport sector under their different perspectives and needs.

The first step that we accomplish here is a critical review of the research carried out so far and dealing with efficiency analysis, in order to underline its common points with the research stream on transport indicators, to analyse in what they differ and to prospect how these two approaches could be improved and then integrated at best. To this purpose we collected and deeply analysed 124 papers.

Secondly, we analyse in detail the research questions, methods applied, input and output variables definitions, main results and policy implications of existing studies in order to present a general structure of the literature. This comprehensive frame will allow us to characterize the state of the art in the assessment of public transport systems efficiency and effectiveness.

The paper ends by enlarging the perspective of the study to another disciplinary field that is of primary interest for this Journal's readership, namely Operations Research (OR) and its applications to the tactical design of urban public transport services. Such methods can be seen as the counterpart of efficiency studies that are the main focus of the present review, since they are primarily used for the design rather than the evaluation of a service. It is however apparent that both aspects should take similar objectives and viewpoints for consistency reasons: therefore, we deemed it important to make a comparative assessment of the two fields within the framework sketched above.

The paper unfolds as follows. In Section 2 we describe the methodology of the review. In Section 3 we introduce the theoretical background of the analysis, whilst Section 4 discusses in details the main inputs, outputs and other variables used in the surveyed studies. Section 5 offers a schematic view on the main methods used in the empirical works and link them to the main variables analysed. Section 6 outlines the analysed data and Section 7 presents the main policy questions addressed in the literature. Section 8 extends the perspective to the tactical planning of urban transit services. Finally, Section 9 concludes the paper outlining directions for future research.

2. Methodology of the review

Given the ambition of the present research of interfacing different disciplinary fields according to the above described framework, the bibliographic search aimed at retrieving the relevant papers both in the transport engineering and planning literature and among works dealing with efficiency analyses. However, we soon noted a connection between the latter group and an additional set of papers in the economic literature that are also of interest, since they deal with the impact of relevant issues such as deregulation processes on the efficiency of public transport services. The papers of interest for the present review have been therefore classified in the following three (broad and not completely fixed) preliminary categories, or lists:

A) *Evaluation of urban public transport systems through indicators*. Given the focus of the present research, we do not consider here papers dealing with strategic evaluation processes (such as building a new public transport infrastructure). We also privilege the stakeholder rather than the customer viewpoint, therefore not reviewing papers focused on service quality or customer satisfaction, even if indicators have been proposed also to deal with these latter aspects.
B) *Efficiency analyses of urban public transport systems*.
C) *Other economic analyses* dealing with aspects related to the efficiency of urban public transport systems: *productivity, economic performances, cost structures, cost functions, subsidies, deregulation and privatization, scale and scope*. Papers dealing with these issues are a lot, but we systematically disregarded those that do not discuss implications on efficiency, such as those merely describing deregulation and competition processes or designing and analyzing pricing structures without reporting empirical evidences.

A search of the literature was carried out and a systematic search of the bibliographic references was also done, updated at end of April 2014, on the Scopus database, by using a list of 33 relevant keywords (see Appendix A). The final number of papers retrieved for the analysis has been of 124, the oldest ones in each list (reported above as A, B and C) having been respectively published in 1974, 1977 and 1970. Each bibliographic item has been classified according to a grid that highlights the main relevant aspects of the analysed work to facilitate the systematic analysis of the different approaches, methods used and the comparison of the obtained results. More in detail, the fields in the grid summarise the information and classify each reference considering the following aspects:

- Paper Reference
- Objectives of the Study
- Method
- Kind of data and indicators - this class includes 8 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.).
- Main Results
- Policy Implications
- Comments

See Appendix B for more details.

Subsequently, we have identified 5 classes of journals where the papers analyzed have been published, see Table 1; in Appendix C we provide the full list of the journals and the distribution of publications for each journal. The majority of the publications pertain to the journals focused on Economics and Transportation Economics (45,2%) and Transport Engineering and Planning (37,9%) while only a small number of publications is found in Operations Research (OR).

Area	Papers published	%
Economics and Industrial Organization	28	22,6%
Engineering, Operations Research and Statistics	13	10,5%
Regional and Social Science	8	6,5%
Transport Economics and Policy	28	22,6%
Transport Engineering and Planning	47	37,9%

Table 1. Distribution of papers by area of research.

After having classified the relevant papers, the Software tool VosViewer (www.vosviewer.com) was used to analyse the contents of the set of selected articles that were distilled through the above grid. VoSviewer provides support for creating 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 basis of the co-occurrences in documents (titles, abstracts or full texts of scientific publications). This technique is therefore similar to Correspondence Analysis, a multivariate statistical analysis method for analysing the relationship between nominal variables, whose use is well attested both in the marketing and in the transport engineering literature (Diana, 2012). Additional technical information about VosViewer and the Vos mapping and clustering techniques can be found in Waltman and Van Eck (2013). We used maps for two key components of the summary information in our grid, namely methods used and abstracts of the papers.

3. Framing economic efficiency studies into a transport planning perspective

Before presenting the results of the above described research activity, we think it is necessary to provide a theoretical background to connect transport policy and economic analysis. The goal is to show how evaluation activities carried out in economic studies can be framed within the evaluation perspectives that are most typically encountered in transport planning and decision making processes. In doing this, we will identify the gaps that need to be addressed by future research in order to make efficiency analyses a tool that is fully usable also for transport planning activities.

In setting a framework for an evaluation exercise, the evaluated activities need first to be characterized in terms of objectives they need to pursuit. This leads to the definition of the goals of the evaluation process, and to understand which issues should be investigated. To perform this task, we have to consider the evaluation perspective of the different stakeholders, since any economic activity involves different parties, whose objectives might be conflicting.

When the analyst deals with economic activities in the private sector under ordinary market laws, setting up such framework is a relatively straightforward task. The activity must maximize profits or minimize costs, the point of view is that of the producer or provider that is making the analysis, therefore an efficiency analysis with input and output from the production process is most appropriate. However, when considering public transport, the evaluation framework can be much more complex. It is therefore important to start our review by looking at how the different evaluation perspectives have originated researches that take different viewpoints and answer different policy questions.

In the following, we consider a fairly general evaluation framework, that brings together six issues, performance measures, and goals that are typically used in public transport analyses:

- economic goals (such as cost minimization, given suitable output and quality constraints, profit maximization, or social surplus maximization);
- operational performances of the transport system;
- its role in relieving road congestion;
- its environmental impacts in terms of sustainability;
- social inclusion issues;
- territorial accessibility.

Next, we consider three groups of stakeholders and their respective points of view:

- the providers that have a private economic perspective, possibly affected by the ownership and the regulatory framework;
- the traveller that is sensible to the service quality;
- the general population and political and regulatory bodies, that measure the service effectiveness in terms of its compliance with public goals.

In the left half of Table 2, we match the two dimensions of our framework by indicating which aspects are more or less relevant for a given viewpoint through an ordinal scale (one star = little relevant; two stars = relevant to some extent; three stars = strongly relevant).

Evaluation aspect	Relevance for different viewpoints			Relevance for the five identified groups of papers				
	Producer (Efficiency)	*User (Quality)*	*Community (Effectiveness)*	*I Efficiency Productivity*	*II Determinants of technical efficiency*	*III Effect of alternative regulatory regimes*	*IV Public versus private ownership*	*V Economies of density, scope and scale*
Profit/cost analysis	***	*	**	***	***	***	***	***
Service performance	**	***	**	***	***	**	***	**
Road congestion	**	**	***	*	**	*	*	*
Sustainability	*	*	***	**	**	*	*	**
Social inclusion	*	**	***	*	*	*	**	*
Accessibility	*	***	***	*	*	*	**	*

Table 2. Matching evaluation aspects with viewpoints and with the literature on efficiency

Legend: * = little relevant; ** = relevant to some extent; *** = strongly relevant.

We do not discuss in detail our grades that are rather intuitive in most cases. On the other hand, we acknowledge that our assessment is to some extent sketchy. However, what matters here is to propose a general structure useful to classify the existing literature. Based on such evaluation framework, this review therefore identified five main areas of research in which the literature tried to measure the effect of alternative public policies. This constitutes a more targeted classification of papers compared to the preliminary distinction between lists "B" and "C" that was proposed in the preceding section. We label these five groups of papers with roman numerals and we briefly describe them in the following, before trying to understand to what extent these papers can cover the six aspects listed in the rows of Table 2.

First, there are studies aiming simply at identifying the technical efficiency of transit systems, in a more descriptive than interpretative setting. This avenue of research applies tools from the efficiency/productivity literature to the public transport industry and, in this sense, its originality relies more on applying new methods to an old problem than proposing an answer to a policy question. It is then of strict interest of the public transport provider, since it is focusing on the first of the above evaluation aspects (cost minimisation and/or profit maximisation). On the other hand, it is widely acknowledged that there is a close relationship between operational efficiency and service performance, so that these studies are also indirectly useful to study the latter aspect.

Second, part of the literature goes a step further, by asking which factors affect technical efficiency. In particular, in Tables 6 and 7, and mostly in Table 8, we classify as P (external or environmental parameters) the variables added to the estimated input-output frontiers, i.e. both in NFA (Nonparametric Frontier Analysis) and in PFA (Parametric Frontier Analysis). The usual approach, here, is to identify a number of possible explanatory variables that could affect technical efficiency and then incorporate them in the analysis via one of the methods proposed in the literature on efficiency estimation (see Section 5 for more details). Estimating a more precise model of the efficient frontier is of interest both for service providers and for regulators. From the service provider's point of view, there is an obvious interest in understanding how she can improve technical efficiency using the instruments under her control. However it should be noted that the above mentioned factors are also related to broader issues that are not totally under the control of the service provider, and are on the other hand also relevant for different evaluation perspectives. One good example is the role of congestion that affects commercial speed and thus both productivity and efficiency of public transport (Kerstens, 1999).

Third, some authors go to the problem of looking at the effect of alternative regulatory regimes on the efficiency of the operation. In particular, consider two polar regulatory regimes: cost-plus and fixed price schemes. In the first regime the government subsidies public transport by paying the unbalances (deficits) of local transit systems. These systems require a detailed analysis of the service provider's accounts and the regulators can reject, in principle, the reimbursement of incurred costs if they do not consider them relevant and prudently incurred for an efficient service provision. However, these analyses are costly, and the regulator has less information on technology and costs than the provider has. Consequently, the local transit systems have an incentive to operate in deficit or, at least, do not exert enough effort to reduce costs. Moreover, such a system can produce a bias in the allocation of inputs, leading a local transit system to overcapitalize (Averch-Johnson effect) or hire more workers than needed. On the contrary, in a fixed price, or price-cap scheme, the government commits to pay to the local transit system an amount fixed or exogenously indexed. This creates an incentive to reduce costs, because the local transit system retains the surplus resources that derive from cost reduction. Even in this case, the regulator needs information on relevant revenues and costs, but the analysis becomes forward-looking: the regulator forecasts future cash flows of the regulated firms using technology and demand models, in order to set the end-of period constraint on regulated prices. The papers in this group analyze the relative merits of these mechanisms, focusing on aspects such as the scope of deregulation processes, the possible evolution of vertical and horizontal market structure, the allocation of subsidies.

A fourth group of papers enlarges the discussion of regulation and analyses the relative merits of public versus private ownership and/or operation. The recent privatization wave has been mainly justified on the basis that private, profit-oriented organizations have stronger incentives towards efficiency with respect to public organizations. Franchise bidding implements competition for the market among private firm as a mean of determining the cost of production in an asymmetric information setting, and as an exit strategy from public monopolies. However, the dynamics of franchise bidding and tendering does not solve all regulatory problems. In particular, in a transit system, the ownership of the infrastructure and of other durable goods could put the incumbent firm in favourable position when the franchise contract is renewed. Moreover, the franchisee incentives to lower costs could undermine the quality with which the service is provided.

Finally, the fifth group of papers analyses the economies of density, scope and scale which are fundamental in transport economics in that they pertain to the space and time dimension of service provision and to the characterization of transportation technology (infrastructures, indivisible capacity of transportation means, connections, incidence of fixed costs, and so on). Geographical characteristics of the service area and the spatial and temporal distribution of the travel demand have a major impact over dimensional economies and affect the transit system performance in terms of average levels and distribution of costs and attainable quality. The coordination and dimensional economies also affect the tendering process: an effort should be made to define traffic catchment areas of appropriate size; the synergies associated to the joint use of different public transport modes (bus lines, shuttle and feeder services, tramways, metro) should be preserved even if different technologies are managed by different providers.

We want now to understand to which extent these five groups of papers, focusing on different policy issues, are relevant for an assessment analysis according to any of the above mentioned six evaluation perspectives. We present our proposal on the right half of Table 2, using the previously defined scale (from one to three stars). It is clear from the table that the state of the art of the research dealing with economic efficiency analyses in urban public transport, while spanning over an appreciable range of issues, is nevertheless far from dealing with all the relevant evaluation perspectives that we believe are worth of consideration. In particular, it appears that those aspects that are more relevant to study effectiveness deserve more attention. Therefore, one of the sought methodological developments in this area should focus on issues that are more relevant for those individuals and entities that are not directly involved in public transport production or consumption (e.g. public bodies or communities living in areas where the service is taking place). This review has identified only a handful of papers that take such perspective, i.e. that run efficiency analyses considering both productive efficiency and environmental issues (Chang et al., 2013; Fraquelli et al., 2004; Karlaftis, 2003; Miller, 1970; Starr McMullen and Dong-Won, 2007; Oh et al., 2011; Yu and Fan, 2006; Yu, 2008) or service quality aspects (Hensher, 2014; Mouwen and Rietveld, 2013).

We finally note that in order to close the gap between different perspectives, the internalisation of external and social costs and benefits is often proposed as an evaluation method (shadow prices) or policy measure (environmental or congestion taxes and subsidies). Were such an ideal condition achieved, all the five classes of research would become much more relevant for the social issues that we put in the last four row of Table 2. However, the focus of this review is not to suggest ways to more closely match different evaluation perspectives, but rather to analyse how the current state of the art in efficiency analyses could evolve in order to better fit a more general framework. As discussed in the introduction, a promising research avenue seems to focus on the transport engineering literature on indicators that makes use of a wide range of data (Diana and Daraio, 2014). We therefore focus now our analysis on the variables used in the transport engineering studies we have reviewed.

4. Input, output and external variables

The preliminary review of the literature in the preceding section has shown the interest in enriching the set of variables used in economic analyses to make them relevant for a higher number of evaluation perspectives.

The definitions of the set of inputs and outputs used in a production model is of paramount importance in evaluating efficiency, yet the literature on efficiency analysis in urban public transport is relatively homogeneous with regards to the definition of inputs and outputs. This is consistent with the fairly narrow evaluation perspective of the majority of these papers, as it emerged in the previous section. We report in Table 3 the list of input and output variables that are used in the studies we have reviewed.

Turning first our attention to input variables, these normally fall in two main categories: “physical” production factors with their own measurement units (number of employees, hours of work etc.) on one side, and costs in monetary units on the other, that are further split into capital expenses (CAPEX) and operating expenses (OPEX)[1] in Table 3. Concerning the first category, the number of employees (or hours of work), fuel consumption, number of vehicles in the fleet 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 administrative staff and number of drivers. The other two above mentioned “physical” inputs are a measure of the stock of capital (number of vehicles) and of the variable input associated to the use of the capital stock (fuel).

It is worth to remark that differences between operators may exist in terms of quality and composition of inputs, typically highly heterogeneous, that we are not considering in this review. As an example, consider the differentiation between driving and non-driving staff. The rolling stock, predominant part of capital, typically differs in terms of average age of the fleet, intensity of usage and patterns of depreciation. Moreover, some variability exists in terms of fuels used. Conceptually, however, if the data incorporate the required information, it is quite feasible to correct for input quality differences.

On the output side, the range of considered measures, reported in Table 3 (right panel), is wider. We believe that it is nevertheless possible to categorize the output variables in three groups. In the first group, we put

[1] To avoid excessive proliferation of classes we have inserted in the CAPEX class also the price of capital and in the OPEX class the price of fuel and labour.

indicators that measure the production efficiency of the service under investigation: vehicles by travelled kilometres, seats offered by travelled kilometres and vehicles by total number of seats are the most frequently used (see the upper part of the right side of Table3). All these measures are from the supply side. In the second group, we put indicators related to the effectiveness of the production process, such as number of passengers and passengers by travelled kilometres. The third group represents the financial counterpart of the second one, since it considers the service revenues. Unlike the preceding one, these two latter groups consider output measures on the demand (service consumption) side. The first groups of efficiency indicators is therefore reflecting the producer perspective, while the other two groups of effectiveness indicators describe the community point of view, according to the framework of the preceding section.

Input		**Output**	
Class	Variable	Class	Variable
Physical measure	Drivers	Service Supply	Revenue-vehicle km
	Employees * hours of work		Seats offered * hours of operations
	Fuel consumption		Seats offered * travelled kms
	Hours of work during service		Vehicles * hours of operations
	Non-driving employees		Vehicles * revenue hours of service
	Number of depots		Vehicles * travelled kms
	Number of employees	Service Consumption	Load Factor
	Number of vehicles		Number of bus traffic trips on routes
	Seat Capacity (total seats of the fleet)		Number of passengers
CAPEX	Capital expenses (CAPEX)/Fixed Assets//Investment		Number of trips
	ICT (soft capital) cost		Passengers * travelled kms
	Possession costs (generalized cost of capital including leasing etc.)	Revenue	Fare revenues per unlinked trips
	Price of capital		Operating revenues
OPEX	Expenses excluding labour and Fuel costs (Other Operating expenses)		Total Revenue
	Fuel Costs		
	Maintenance		
	Materials costs (tires lubricants etc.)		
	Non-labour Maintenance and repair costs		
	Operating costs of vehicles		
	Operating expenses (OPEX)		
	Operating labour expenses		
	Overhead - General/Administrative expenses		
	Price of fuel		
	Price of labour		
	Total expenses (OPEX+CAPEX) - Total Cost		

Table3. Input and output variables.

Concerning this latter point, it is here interesting to recall the debate in the efficiency analysis literature on the most appropriate kind of output measures (De Borger et al., 2002). For example Berechman, (1993) considers supply-side indicators more appropriate. We concur with that argument if the evaluation itself is only involving the public transport service supply and the service provider is constrained in its operational choices: in this case, factors not under the control of the firm (such as the level of demand or required quality of service) should not be considered. However, transport policy decision makers need broader evaluation exercises, as shown in Table 2: effectiveness analyses cannot just focus on the supply side. Moreover, in an appropriate regulatory setting, the providers could enjoy of the operational flexibility that make them responsible also of the effectiveness of the service.

Moreover, if we consider how the characteristics of demand, the spatial and quality attributes of supply strongly influence an appropriate specification of technology for the purpose of performance evaluation, the debate between demand oriented or supply oriented output measures loses much of its significance. In fact, the surrounding social, political and regulatory environment intimately shape objective functions and constraints of transit firms. For instance, when the regulator or the public owner implicitly stimulates over-hiring labour, then cost minimization at observed input prices is an inappropriate benchmarking model yielding highly misleading results. It is now also generally recognized that transport outputs are heterogeneous in terms of temporal, spatial and quality characteristics. Transport planners have in fact debated over the past decades about the spatial and temporal transferability of their models (Ortúzar, 2011). A suitable spatial and temporal disaggregation of the evaluation model would help in understanding the meaning and origin of differences between offered capacity measures and satisfied demand measures.

Some of the reviewed studies are considering such issues by taking into account an additional set of variables, that are listed in Table 4. These latter are not rigidly considered as inputs or outputs of production models, and in some cases they appear as model parameters, or simply terms of reference that are taken to draw meaningful comparisons across services in different areas and different time periods. In the following, we name such group as "external" variables.

Interestingly enough, the biggest cluster in this list refers to quality and service characteristics aspects, 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 of them. We see here a reflection of the burgeoning literature dealing with quality aspects in public transport. Variables in this first group are well representing both service performances (e.g. commercial speed, on time performance) and accessibility (e.g. length of network, number of stops), that are the two relevant aspects for end users as shown in the third column of Table 2.

The three groups listed in the right half of the table all refer to situational variables that 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 patronage, while the other two pertain to management and economic characteristics of the service. Finally yet importantly, in a handful of papers some variables represent externalities, an issue of central interest for an effectiveness analysis: the most popular aspect here considered is the number of accidents.

External			
Class	Variable	Class	Variable
Quality and characteristics of service	% Compressed Natural Gas vehicles	Socio/Demographic-Geographic	% of poor households
	% vehicle-kms in urban areas		% people with disabilities, % of elderly people
	Average Commercial Speed		Average duration of a private motorized trip
	Average distance between stops		Car ownership
	Average Fleet Age		Climate
	Average length of a route		Dummy for Location
	Average number of stops per route		GDP Gross domestic product per inhabitant
	Departure times in relation to departure need		Gini index for income inequality
	Dummy - alternative public transport		Number of parking spaces
	Dummy for Intercity/urban/mixed company		Perceived difference between men and women
	Intensity - Vehicle miles per route mile		Population in the service area
	Length of Network		Population that has access to service
	Number of Night routes		Population Density
	Number of routes		Ratio of inhabitants living in urban areas
	Number of stops		Ratio of inhabitants who are unemployed
	On-time performance (time reliability)		Size of the area where the service is accessible
	Operating cost/km		Size of the area where the service is implemented
	Overlapped route lengths	Managerial/Organizational	Dummy for competitive tendering
	Passengers' perceived quality		Dummy for Contract Type
	Peak to Base Ratio		Dummy for Public Company
	Proximity to train station/bus stop		Dummy -Size of the company
	Ratio of bus-kms to total vehicle-kms		Number of owners
	Service frequency/Headway		Size of largest owner (%)
	Service satisfaction score		Unionization rate
	Spares ratio	Subsidies	Dummies for type of subsidy
	Transport route in relation to route need		Local subsidy / total subsidies
	Travel time		Ratio of Subsidy in total revenue
Externalities	Emissions		Subsidies from public funds
	Number of accidents		Subsidies to operating expenses

Table 4.Variables that are considered as neither input nor output in efficiency models.

We propose a match of the variables in the above tables against the evaluation framework in Table 2 to summarise the findings of this analysis. It is immediate to see that the variables considered in the literature fully cover the first evaluation aspect and are mainly considering the point of view of the service operator (first column of Table 2). Quality issues are increasingly being included, even if their measures and indicators are not univocally embedded in models as either input or output variables. Finally, effectiveness issues are represented through output variables as far as patronage levels are considered. Output is in turn related to road congestion, sustainability, social inclusion or accessibility (last four lines of Table 2). However, other, more direct, measures of these latter dimensions are seldom considered, as the last two rows of the left panel of Table 4 show.

The findings from the classification of the papers presented in the previous section seem therefore largely confirmed here. Considering our detailed review of the variables, we think that one promising research avenue could focus on the integration of a broader set of variables in the analysis itself, thus making it relevant for different evaluation perspectives as reported in Table 2. In other words, input and output variables of models, currently mainly restricted to the sets shown in Table 3, could consider a larger number of variables among the "external" ones listed in Table 4, in addition to others that better represent important issues such as congestion relief, environmental impacts, or social inclusion aspects.

This integration requires wider applications and methodological extensions of economic efficiency analysis. Nevertheless, some papers already take such broader perspective when considering input and output variables. Nolan et al. (2002) measure both the technical and the social efficiency of transit agencies through DEA (Data Envelopment Analysis; Charnes et al., 1978). McMullen and Noh (2007) include the amount of emissions of pollutants into an efficiency analysis of transit agencies. Shet et al. (2007) explicitly address both the provider and the passenger perspective when evaluating public transport systems, although their paper does not provide an analysis with real data but only a simulation.

Considering some of the input and output variables that are routinely used in transport engineering to monitor urban public transport operations, could allow researchers to more systematically extend the above results. These variables were analysed in a previous study (Diana and Daraio, 2014) that focused on the "List A" that was mentioned in Section 2. The interested reader is referred to that paper for more details; here it is sufficient to note that, according to such findings, the indicators already available in the transport engineering literature, are related to the following eight aspects:

1. "Operational efficiency"[2], to relate the quantities of produced service with the resources being used (example: expenses / (vehicles*km)).
2. Intensity of use of the service, to relate the quantities of produced service with the patronage (example: (passenger*km) / (vehicles*km)).
3. Service use related to input, to relate the patronage with resources being used (example: expenses / (passenger*km)).
4. Relative service dimension, to relate the used resources with the dimension of the potential market (example: fleet dimension / population of the service area).
5. Service coverage, to relate the produced service with the dimension of the potential market (example: lines length / population of the service area).
6. Market penetration, to relate the patronage with the dimension of the potential market (example: passengers / population of the service area).
7. Revenues generation, to relate the revenues with consumed resources, produced service or patronage (example: revenues / vehicle).
8. Externalities, to relate some key effects of the system operations with consumed resources, produced service or patronage (example: number of accidents / (vehicle * km)).

It can be easily recognized that the above eight groups of indicators can cover most of the evaluation perspectives of Table 2, while only some of them can be found in Tables 3 and 4. Integrating more of such indicators into an efficiency analysis could make the latter a powerful tool for transport policy makers.

5. Main methods and econometric approaches

After the detailed investigation of the input, output and other variables used in the reviewed papers, we concentrate our attention on the methods applied by researchers for their empirical investigations on LPT.

[2] In a broad sense, according to a transport planning view; this concept is different from technical efficiency which refers to output-input relations, for more details see Section 5.

The classification of the main econometric approaches used in the LPT literature required a dedicated effort and the combination of an exploratory analysis and a subsequent systematic investigation.

5.1. Initial assessment through density maps

We started by exploring the main methodological terms with the help of the VosViewer software, to have a first approximated picture. Figure 1 shows the density map of the most relevant terms in the methodological section of the analysed studies. Colours indicate the density of terms, ranging from blue (lowest density) to red (highest density).

As it clearly appears from Figure 1 there are two well-identified groups of methods that have been applied in the literature on LPT analysed in this study. A predominant parametric approach[3] on the West (W) side of the figure, going from the South-West (SW) of the figure, based on Cobb Douglas cost functions, to the North-Center (NC) part of the figure, characterized by the predominance of Translog cost functions. These studies use on the one hand parametric frontier models (the so called Stochastic Frontier Analysis, SFA, see e.g. Kumbhakar and Lovell, 2000). On the other hand, they use multistage analyses ("stage" in Figure 1) of cost functions, when the model includes parameters to represent the determinants of cost-based performance. Most studies that estimate total cost are located in the SW corner of Figure 1. A smaller group of studies, located at the CE of the figure, adopt a nonparametric approach based on DEA; this group includes also total factor productivity analysis based on Malmquist indices. Interestingly it seems that the nonparametric approach application originated by the evolution of a part of the literature on the cost function on "average cost function" based analysis (SW corner of the figure). Close to the group of studies that use the Translog cost function we find works that applied a demand analysis, namely estimated the parameters of total demand for travelling by LPT as a function of deregulation measures, fares, and other factors. Of course, within each cluster that identify a predominant approach less typical methods or variations co-exist.

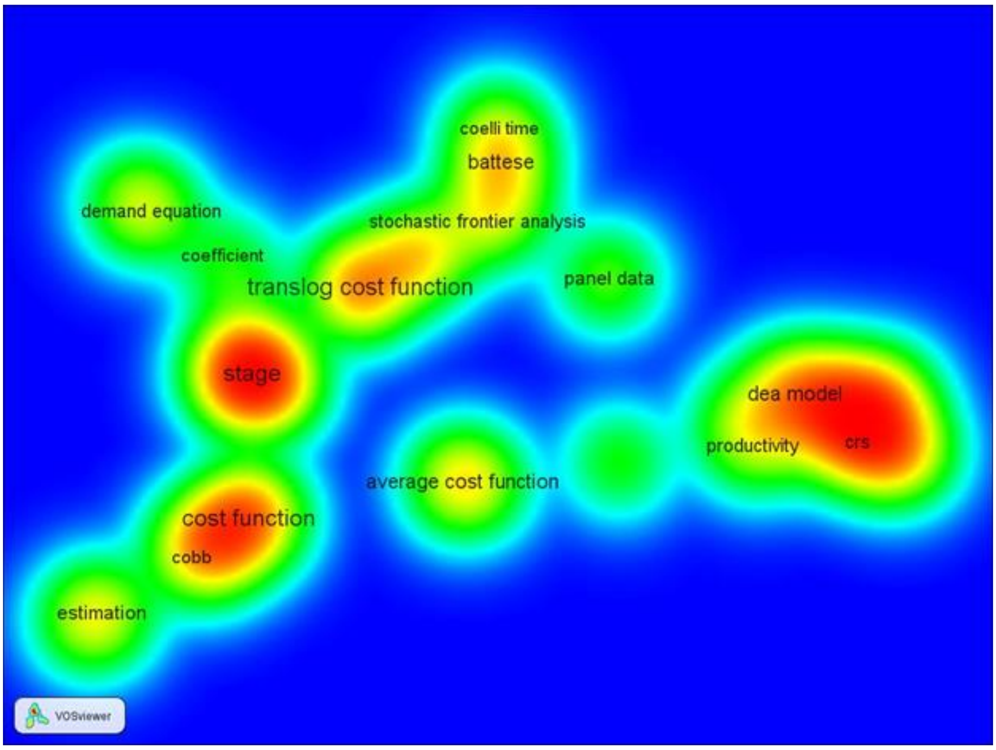

Figure 1 Density map of the most relevant terms in the methodological section of the analysed studies.

[3] In the parametric approach a pre-defined functional form for the relation among variables is specified and the relative parameters are estimated afterwards.

Widening the perspective, we can see in Figure 2 a density map of the objectives of the surveyed studies in which also the main used methods are included. Figure 2, in fact, illustrates the density map of the most relevant terms in the abstracts of the analysed studies.

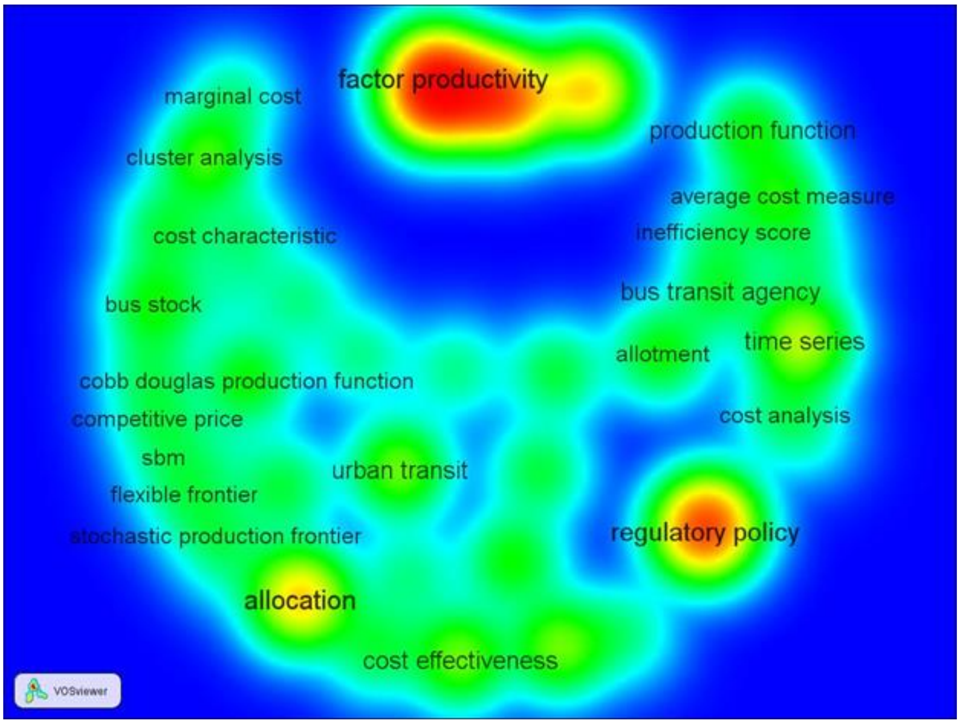

Figure 2 Density map of the most relevant terms in the abstracts of the analysed studies.

By inspecting Figure 2 we observe that nonparametric methods based on DEA and total factor productivity ("factor productivity" in the NC of the map) are entering into the empirical analysis of LPT showing peculiarities with respect to the traditional "economic" analysis based on total cost and average cost function estimates, which are based on standard regression methods. On the contrary, SFA seems closer and more integrated with the traditional approach: it looks like a kind of evolution of the standard regression approach keeping as link the functional specification of the relationship between inputs and output of the analysis (very often a Cobb Douglas, even if also Translog functions are applied).

Regulatory policies (SE corner in Figure 2) seem closer to traditional cost analysis based on ordinary least squares estimates methods (in CE of Figure 2). Regulatory policies are linked with "allocations" and "cost effectiveness" (SC of Figure 2) which are related to parametric production frontiers, which represent a kind of evolution of the traditional cost analysis ("stochastic production frontiers" and "Cobb Douglas" in Centre-SW part of Figure 2). Far away are located the nonparametric methods, including DEA ("factor productivity" in NC of Figure 2), which are more flexible and are characterized by a wider range of used variables, as we shall see in the following of this section. It seems that the nonparametric approach entered later and is growing within this literature.

5.2. Classification of the methods

We will investigate later in the section what are the relationships between inputs/outputs and other variables adopted in the different studies and how the usage of these variables changes according to the methods applied.

Before, to deepen our understanding of the main methods applied in the literature, we carried out a systematic examination of the selected studies that were classified according to an overall methodological framework, summarized in Table 5, whose main dimensions are:

- *Benchmarking.* This dimension relates to the benchmark against which the researchers compare the analysed sample. We find here two main approaches: *average analysis* vs *frontier analysis*. The main difference relies on the kind of benchmark selected for the analysis. In the *average analysis*, using regression methods, the expected value of the dependent variable, given the independent ones, is estimated, pointing to estimate a kind of "average" performance of a representative unit of the analysed sample. Instead, in the *frontier analysis*, the benchmark is set at the most efficient estimated level for the analysed units in the sample, that is at the boundary of the production possibility set. Deviations from the best performing behaviour are estimated as the distance of units from the efficient boundary.
- *Assumptions on the Data Generating Process (DGP). Parametric vs nonparametric approach.* This distinction derives from the functional specification of the relationships among variables. We observe two main approaches: a parametric functional specification vs a nonparametric specification of this relationship.
- *Kind of analysis.* This distinction opposes studies that analyse only "physical" (input-output) relationships vs studies that investigate the cost dimension of the analysed units. In a frontier setup, this distinction amounts to the analysis in terms of distance from the efficient boundary of the input-output production possibility set (technical efficiency) against the specification of additional behavioural goal expressed minimizing costs, considering also information on prices. In this latter case, we talk about allocative or price efficiency.

		Assumption on the DGP	**Kind of Analysis**	
		Parametric (P) vs Nonparametric (N)	*Input-Output (IO)*	*Cost (C)*
Benchmark	*Regression (R)*	*PR*		
		NR		
	Frontier Analysis (FA)	*PFA*		
		NFA		

Table 5.Taxonomy of the econometric approaches used in the literature.

It is interesting to note that no surveyed paper, applied a nonparametric regression (NR) framework, and therefore the corresponding cells in Table 5 are shadowed. On the contrary, all empirical studies that investigated the average behaviour of public transport units have used a parametric regression approach: in most cases Ordinary Least Squares (OLS), see e.g. Merewitz (1977) and Alexanderson et al. (1998); in other cases, Seemingly Unrelated Regressions (SUR, Zellner, 1962), such as Cambini et al. (2007). While earlier studies (such as Koshal, 1970; Miller, 1970; Pucher et al 1983) consider mainly input-output relations, in more recent studies prevail the estimation of variable and total costs (e.g. Obeng and Sakano, 2002; Fraquelli et al. 2004; Cambini et al. 2007; Ottoz and Di Giacomo, 2012, among others).

On the other hand, the efficiency literature provides a number of alternative ways of measuring the technical efficiency of production. In our sample of papers the main methods used are SFA, DEA and parametric cost functions.

The empirically most used SFA model is the Battese and Coelli (1995) Cobb Douglas production function specification in a panel setting which allows for the introduction in the estimation of external factors or parameters that affect the inefficiency term (see e.g. Piacenza, 2006). Most SFA literature estimated Cobb-Douglas or Translog frontiers.

DEA in its various forms (i.e. input oriented, output oriented, pooled DEA in which all the observations for all the years are considering together, or Malmquist DEA or simple DEA with different RTS (Returns to Scale) assumptions, such as VRS (Variable Returns to Scale), CRS (Constant Returns to Scale)) provides estimates of technical efficiency for each single observation. Most papers focus exclusively on the identification of those efficiency scores, without neither investigating the statistical precision of the estimates nor analysing the influence of external variables on the obtained estimates. Some notable exceptions which applied the bootstrap are the papers of Boame (2004), de Borger et al. (2008) and von Hirschhausen and Cullmannn (2010). Some papers nevertheless tried to identify the effect of a number of external environmental variables onto the efficiency of production. There are several ways for introducing external factors in a nonparametric efficiency analysis (see e.g. Badin et al. 2014 for an overview). In the so called "one stage approach" the external factors are included directly in the estimation of the efficient frontier and hence of the efficiency scores. If the external factor has a positive role in the production process it is introduced in the analysis as an additional input freely available; if it has a negative impact it is introduced in the analysis as an extra undesired output to be produced. However, even if simple to implement, this approach shows several weaknesses. Firstly, the analyst should know in advance what the sign of the impact of the external factor is. Secondly, non-linear impacts (such as u-shaped or inverse u-shaped impacts) cannot be included. Thirdly, the free disposability (that broadly speaking means the possibility of destroying goods without costs) of these factors is assumed as well as the free disposability of the extended production set (including the external factors). This approach is not used any more frequently, given the strict assumptions it requires.

The most used approach to include external factors in the analysis is the so-called "two stage approach" in which the efficiency scores are estimated using a nonparametric approach in a first stage and are regressed in a second stage versus external environmental variables. Some papers in our sample have been published in years in which the nonparametric statistical approach in efficiency analysis was less known. We observe in fact that most of those that applied a two stage approach (e.g. Kerstens, 1996; Nolan, 1996; Nolan et al. 2001; Pina and Torres, 2001; Cowie, 2002; Boame, 2004; Tsamboulas, 2006; Soderberg, 2009) did not specified a general and correct statistical framework. As a consequence, their estimates could be unreliable and biased. As demonstrated in Simar and Wilson (2007), the efficiency scores estimated in the first stage are biased estimates and if they have to be regressed in a second stage, standard inference does not work and hence a bootstrap procedure is necessary. Also, the Tobit regression that has been applied in other studies is not appropriate: instead, a truncated regression has to be implemented in a two stage semi-parametric approach[4]. However, even if correctly implemented, the two-stage approach relies on a very strong assumption, namely the *separability condition*, on the base of which, it is assumed that the external factors do not influence the "efficient frontier" but only the distribution of the distances of the observations from the efficient frontier. This is a strong assumption because external factors may affect both the efficient boundary and the distribution of inefficiency (Badin et al., 2012).

Only very few studies (including Starr, McMullen and Dong-Won, 2007; Oh et al., 2011; Pestana Barros and Peypoch, 2010) applied a directional distance framework which allows for a more flexible specification of the direction of movement of an observed unit towards the frontier. None of the analysed studies implemented robust nonparametric methods in efficiency analysis[5].

5.3. Relationships between kind of I/O variables and method of analysis

Having completed the short description of the main methods applied in the surveyed papers, we can investigate in details the relationships between input, output and external variables, as they were presented in Section 4, and how they vary according to the method empirically applied in the analysed studies.

The following Tables 6, 7 and 8 are the relative contingency tables (percent of occurrences) respectively of the input, output and external variables (rows of the tables) considered in the 124 reviewed papers, matched against the different methods (columns of the tables). The columns consider the combinations of the following three methodological variants: assumptions, according to the left side of Table 5, (columns PR (Parametric Regression), NFA (Nonparametric Frontier Analysis) and PFA (Parametric Frontier Analysis) respectively), approaches, according to the right side of Table 5 (columns IO (Input-output or technical

[4] See the Appendix of Simar and Wilson (2007) for an extensive description of why the Tobit regression cannot be applied in this context and for a clarification of the misunderstanding in the use of terms truncation and censoring.

[5] These are methods which estimate the efficient boundary of the units analysed being less influenced by outlying and anomalous observations. For an introduction and an overview, see Daraio and Simar (2007).

approach) and C (Cost approach)) and ways of considering the variable, according to the discussion in Section 4 (columns I (Inputs), O (Outputs) and P (Parameters)). In such cases, the % shown in each column for each variable has been calculated with respect to the number of papers classified by method and approach. For example, in Table 6, the variable “Number of vehicles” has been used by the 60,5% of all (124) reviewed papers. The same variable has been used as input variable by the 50% of the papers (10) classified as Parametric Regressions based papers (PR) with an input-output approach and as parameter variable (P) by the 3,8% of the papers (53) classified as Nonparametric Frontier Analysis (NFA) with an input-output approach.

Tables 6, 7 and 8 offer a lot of interesting information that could be useful for applied researchers or policy makers which aim to analyse efficiency and effectiveness of LPT units. Interested readers can focus on the most frequently used variables and see also how the variables used change according to the methods applied. Considering only those cells in the table that are related to a sufficiently high number of papers, the most dramatic changes in relative frequencies of a given variable (row) according to the method could be observed for fuel consumption, price of labour and of fuel for input variables (Table 6); number of passengers and passengers*travelled km for output variables (Table 7) and commercial speed or population density for “external” ones (Table 8). At the other extreme relative frequencies of many other variables are not significantly affected by the used method. Such discrepancies could be an indication that some of the reviewed variables can more or less easily be considered through some methods, whereas for others this is not a real issue.

Input

Class	Variable	All (124)	PR (41) IO (10) I	PR (41) IO (10) P	PR (41) C (31) I	PR (41) C (31) P	NFA (54) IO (53) I	NFA (54) IO (53) P	NFA (54) C (1) I	PFA (29) IO (10) I	PFA (29) IO (10) P	PFA (29) C (19) I	PFA (29) C (19) P
Physical measure	Number of vehicles	60,5%	50%		51,6%		64,2%	3,8%		70%		57,9%	
	Number of employees	40,3%	10%	10%	22,6%		66,0%			50%		5,3%	
	Fuel consumption	36,3%		10%	19%		58,5%			40%		15,8%	
	Employees * hours of work	10,5%			6,5%		15,1%			20%		5,3%	
	Seat Capacity (total seats of the fleet)	1,6%			6,5%	6,5%	9,4%						10,5%
	Hours of work during service	8,9%			6,5%		1,9%			10%			
	Drivers	3,2%					3,8%						
	Non-driving employees	1,6%					3,8%						
	Number of depots	0,8%					1,9%						
CAPEX	Price of Capital	21,0%	10%		45,2%		1,9%			20%		42,1%	
	Capital expenses (CAPEX)/Fixed Assets//Investment	4,0%	10%		3,2%	3,2%		1,9%			10%		
	ICT (soft capital) cost	1,6%			3,2%							5,3%	
	Possession costs (generalized price of capital or cost of capital including leasing etc.)	0,8%					1,9%						
OPEX	Price of labour	38,7%	40%		77,4%		1,9%			30%		84,2%	
	Price of Fuel	29,0%	20%		58,1%		1,9%			20%		68,4%	
	Operating expenses (OPEX)	12,1%	30%		3,2%		17,0%			20%			
	Materials costs (tires lubricants etc.)	11,3%	10%		19%		7,5%					15,8%	
	Fuel Costs	8,9%			10%		9,4%		100%	20%			
	Operating costs of vehicles	6,5%	10%		6,5%		5,7%			10%		5,3%	
	Maintenance	5,6%			10%		3,8%	1,9%		10%			
	Operating labour expenses	4,0%	10%		3,2%		1,9%		100%	10%			
	Overhead - General/Administrative expenses	4,0%	20%		3,2%		3,8%						
	Expenses excluding labour and Fuel costs (Other Operating expenses)	2,4%					3,8%		100%				
	Non-labour Maintenance and repair costs	1,6%	10%		3,2%								
	Total expenses (OPEX+CAPEX) Total Cost	2,4%								20%		5,3%	

Table 6.Distribution (%) of input variables per paper and method.

Output

Class	Variable	All (124)	PR (41) IO (10) O	PR (41) IO (10) P	PR (41) C (31) O	PR (41) C (31) P	NFA (54) IO (53) O	NFA (54) IO (53) P	NFA (54) C (1) O	PFA (29) IO (10) O	PFA (29) C (19) O	PFA (29) C (19) P
Service Supply	Vehicles * travelled kms	53,2%	36,4%	9,1%	56,7%		52,8%	1,9%		50%	52,6%	
	Seats offered * travelled kms	25,8%	18,2%		26,7%		28,3%		100%	20%	21,1%	
	Vehicles * hours of operations	4,0%	18,2%				3,8%				5,3%	
	Revenue-vehicle km	4,8%	9,1%				7,5%					5,3%
	Vehicles * revenue hours of service	3,2%					5,7%					5,3%
	Seats offered * hours of operations	0,8%					1,9%					
Service Consumption	Passengers * travelled kms	24,2%	9,1%		16,7%	3,3%	32,1%			10%	21,1%	5,3%
	Number of passengers	16,9%	9,1%		10%		26,4%	1,9%		10%	5,3%	
	Number of trips	5,6%	9,1%		3,3%			3,8%		20%	5,3%	
	Number of bus traffic trips on routes	1,6%					3,8%					
	Load Factor	1,6%					1,9%					5,3%
Revenue	Operating revenues	11,3%	9,1%	9,1%	13,3%		9,4%			10%	10,5%	
	Fare revenues per unlinked trips	0,8%								10%		
	Total Revenue	0,8%			3,3%							

Table 7.Distribution (%) of output variables per paper and method.

External														
			PR (41)			NFA (54)				PFA (29)				
		All (124)	IO (10)	C (30)		IO (53)			C (1)	IO (10)			C (19)	
	Variable		P	I	P	I	O	P	P	I	O	P	I	P
Quality and characteristics of service	Length of Network	24%	10%		22,6%	18,9%		3,8%				30%		36,8%
	Average Commercial Speed	21%	50%		19,4%	1,9%	3,8%	15,1%						21,1%
	Average Fleet Age	14,5%	30%		12,9%	3,8%	1,9%	9,4%						15,8%
	Service frequency/Headway	6,5%	10%				7,5%	3,8%						5,3%
	Peak to Base Ratio	1,6%	30%					5,7%						5,3%
	Number of stops	5,6%			9,7%	1,9%								
	Average length of a route	3,2%			3,2%			1,9%						5,3%
	Average number of stops per route	2,4%						5,7%						
	Intensity - Vehicle miles per route mile	0,8%	10%			1,9%								5,3%
	Spares ratio	2,4%	10%			1,9%								
	On-time performance (time reliability)	2,4%	10%				1,9%							
	Dummy for Intercity/urban/mixed company	1,6%			3,2%			1,9%						
	Service satisfaction score	1,6%			3,2%			1,9%						
	% vehicle-kms in urban areas	1,6%					1,9%					10%		
	Passengers' perceived quality	1,6%	10%											
	Number of Night routes	0,8%												5,3%
	Number of routes	0,8%						1,9%						
	Average distance between stops	0,8%						1,9%						
	% Compressed Natural Gas vehicles	0,8%						1,9%						
	Overlapped route lengths	0,8%						1,9%						
	Dummy - alternative public transport	0,8%						1,9%						
	Proximity to train station/bus stop	0,8%					1,9%							
	Ratio of bus-kms to total vehicle-kms	0,8%					1,9%							
	Transport route in relation to route need	0,8%					1,9%							
	Departure times in relation to departure need	0,8%					1,9%							
	Operating cost/km	0,8%				1,9%								
	Travel time	0,8%					1,9%							
Socio/Demographic- Geographic	Population Density	16,1%	20%		12,9%	5,7%		9,4%				30%		15,8%
	Dummy for Location	12,9%	20%		6,5%	3,8%		5,7%	100%					31,6%
	Car ownership	7,3%	10%					13,2%				10%		
	Population in the service area	6,5%	10%			7,5%		1,9%		10%			5,3%	
	Size of the area where the service is accessible	4,8%			3,2%			1,9%				30%		5,3%
	Climate	2,4%						3,8%					5,3%	
	GDP Gross domestic product per inhabitant	1,6%	10%					1,9%						
	Size of the area where the service is implemented	1,6%			3,2%									5,3%
	Population that has access to service	1,6%						1,9%				10%		
	Ratio of inhabitants who are unemployed	1,6%						3,8%						
	Average duration of a private motorized trip	0,8%	10%											
	Number of parking spaces	0,8%	10%											
	Gini index for income inequality	0,8%	10%											
	% people with disabilities, % of elderly people	0,8%										10%		
	Perceived difference between men and women	0,8%					1,9%							
	Ratio of inhabitants living in urban areas	0,8%						1,9%						
	% of poor households	0,8%										10%		
Managerial/Organizational	Dummy for Public Company	15,3%	20%		25,8%			3,8%	100%			20%		21,1%
	Dummy for Contract Type	10,5%			6,5%			5,7%	100%			10%		31,6%
	Dummy -Size of the company	2,4%			3,2%			1,9%						5,3%
	Dummy for competitive tendering	0,8%			3,2%									
	Unionization rate	0,8%											5,3%	
	Number of owners	0,8%						1,9%						
	Size of largest owner (%)	0,8%						1,9%						
Subsidies	Subsidies from public funds	9,7%	10%		12,9%	1,9%		1,9%				20%		15,8%
	Subsidies to operating expenses	8,1%	10%	3,2%				7,5%				10%		15,8%
	Local subsidy / total subsidies	2,4%	10%		3,2%									5,3%
	Ratio of Subsidy in total revenue	1,6%			3,2%								5,3%	
	Dummies for type of subsidy	1,6%			3,2%									5,3%
Externalities	Number of accidents	7,3%	10%		3,2%		3,8%	7,5%			10%			
	Emissions	4,0%					7,5%					10%		

Table 8.Distribution (%) of external variables per paper and method.

5.4. Temporal evolution of the analytical approaches

To conclude our analysis on the methods, we show in Figure 3 the evolution over time of the number of papers published for each type of method.

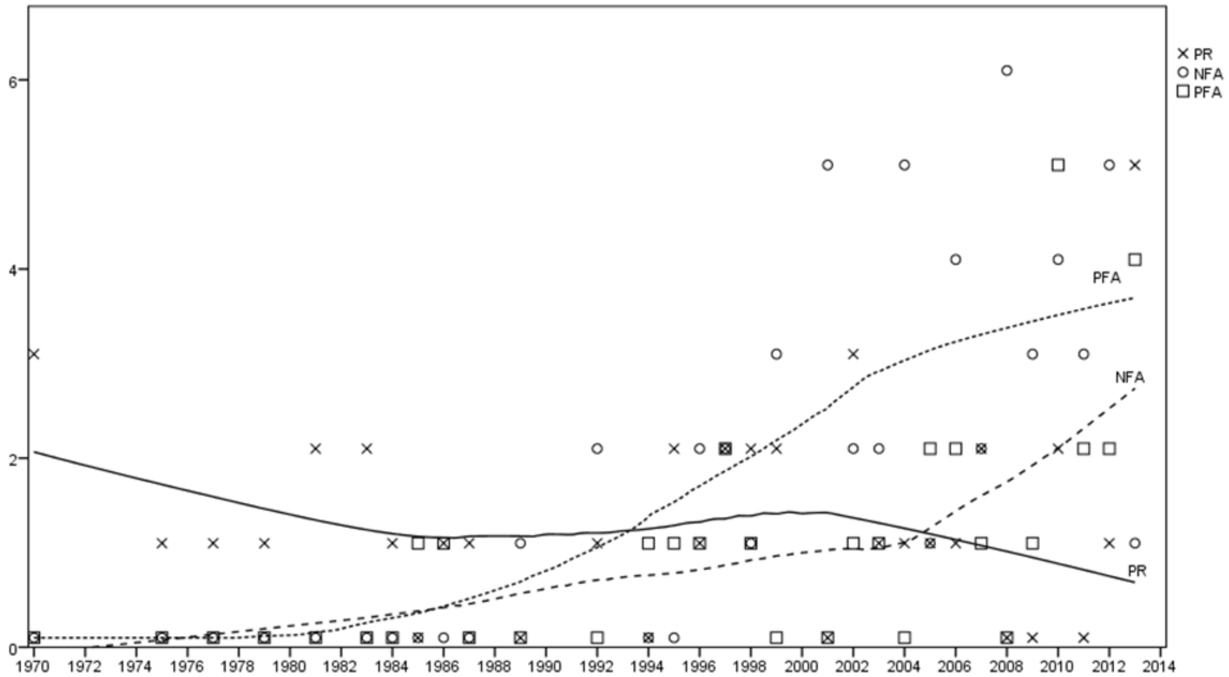

Figure 3. Evolution of the number of papers per publication, year and method (PR is Parametric Regression, NFA is Nonparametric Frontier Analysis and PFA stands for Parametric Frontier Analysis). Lines are nonparametric smoothed trends (loess with 65% of interpolated points).

From Figure 3 it appears that the Parametric Frontier Approach (PFA) has taken the heritage of the traditional Parametric Regression approach (PR) which is less and less used in the applied works. On the contrary, we observe a deep increase in the use of the Nonparametric Frontier Approach (NFA) and foresee a great potential for future application of recently proposed advancements within this field. In our view, the main advances rely on the overcoming of the traditional limitations of the nonparametric approach based on DEA techniques, namely:

-deterministic nature and impact of extreme or outlying points on the estimates;

-separability condition to be assumed for the estimation of the impact of external factors and hence for taking into account the heterogeneity of the analysed units;

-more flexible specification of the benchmark moving from equi-proportional radial-based efficiency scores based on DEA to more flexible directional distance measures.

As showed by Badin et al. (2012), robust nonparametric conditional efficiency analysis is a more general approach to evaluate the impact of external factors in nonparametric frontier models and to allow for the heterogeneity of units in the performance measurement without relying on the separability condition we recalled above. Moreover, a framework in which the efficient boundary does not envelop all points is more robust to extremes and outliers. The main idea of conditional efficiency analysis is to estimate the probability of being dominated of each unit, according to its inputs and outputs in a multidimensional framework frontier, keeping into account the external factors which might influence its performance, and allowing for a finer comparison of units with other units sharing the same external environmental conditions.

Within this framework, Daraio and Simar (2014) extended Badin et al. (2012) approach to the directional distance framework and propose a bootstrap based test for the estimation of the statistical significance of the impact of external factors on the performance. We see a great potential in the application of robust (to outliers and extreme values) and nonparametric conditional directional distances for running a more general and robust assessment of the LPT performance.

6. 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 9 by providing information on the type of data and the sample size shows that panel and cross-sectional studies prevail in the literature. The sample size varies widely both on the number of entities observed (from 1 up to 444, 68 on average) and time span that, excluding cross-sectional studies, ranges from 2 to 33 years (6,43 years on average). Of the 124 papers reviewed, the great majority takes transit operators (95 papers) or municipalities (22 papers) as sample unit. Of the remaining 7 papers 4 utilize wide geographical areas (i.e. counties), 2 papers collect data at route level and 1 at passenger level; see Table 10 which summarizes.

			N_firms (entities)			Time_span		
	N	%	Mean	Max	Min.	Mean	Max	Min.
Time Series	8	6,5%	31,2	168	1	7,13	16	1
Pooled Cross Section	9	7,3%	132,3	440	3	8,56	20	2
Panel	62	50,0%	59,9	444	5	9,85	33	2
Cross Section	45	36,3%	76,3	261	8	1	1	1
Total	**124**	**100%**	**69,6**	**444**	**1**	**6,37**	**33**	**1**

Table 9. Distribution of papers by type of data used, sample size and time span.

Sample unit	N.	%
Large-scale (national, regional, counties etc.)	4	3,2%
City-wide system, transit agency	22	17,7%
Operator	95	76,6%
Transit line	2	1,6%
Passengers	1	0,8%

Table 10. Distribution of papers by unit of analysis.

Table 11 shows that the majority of the studies deals with EU or USA national data, at country level(73%), 13 papers deal with international data, of which only 6 deals with EU countries. Table 11 also shows that only a very small number of studies have analyzed transport systems at regional (6%) or city level (10%). Table 11 provides also information on the data source: the data source panel compares the number and % of papers that make use of official and sometimes publicly available databases ("official data" in the table) with the papers that utilize *ad hoc* surveys such as questionnaires or interviews with the transit operators. The availability of transport and economic data in this branch of literature is fundamental and the availability of public databases is strictly correlated with the production of quality papers. The majority of the selected papers (78%) takes data from official sources such as transport authorities or statistical offices. In particular, 36 of the 124 published papers (29%) use data provided by the National Transit Database, a US public databank in which detailed data on transit systems are freely available.

			Coverage								Data source			
			International		National		Regional		City		Official data		Ad hoc survey	
Country	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Australia	3	2,4%			1	33%	1	33%	1	33%			3	100%
Belgium	1	0,8%			1	100%							1	100%
Canada	1	0,8%			1	100%					1	100%		
France	6	4,8%			5	83%			1	17%	6	100%		
Germany	2	1,6%			2	100%					2	100%		
India	4	3,2%			3	75%	1	25%			1	25%	3	75%
Israel	2	1,6%			2	100%					2	100%		
Italy	7	5,6%			5	71%	2	29%					7	100%
Japan	2	1,6%			2	100%					2	100%		
Korea	3	2,4%			1	33%			2	67%	3	100%		
Netherlands	1	0,8%			1	100%							1	100%
Norway	11	8,9%			10	91%	1	9%			11	100%		
Portugal	2	1,6%			2	100%							2	100%
Spain	5	4,0%			4	80%	1	20%			1	20%	4	80%
Sweden	4	3,2%			4	100%					4	100%		
Switzerland	5	4,0%			5	100%					5	100%		
Taiwan	11	8,9%			8	73%			3	27%	11	100%		
UK	4	3,2%			4	100%					4	100%		
United Arab Emirates (UAE)	1	0,8%			1	100%							1	100%
USA	36	29,0%			30	83%	2	6%	4	11%	35	97%	1	3%
EU	7	5,6%	7	100%							3	43%	4	57%
International	6	4,8%	6	100%							6	100%		
Total	**124**	**100%**	**13**	**10%**	**92**	**74%**	**8**	**6%**	**11**	**9%**	**97**	**78%**	**27**	**22%**

Table 11.Distribution of papers by country and coverage of the study.

7. Empirical analyses and policy questions addressed

In section 3 we identified, in Table 2, five main areas of research of which groups III, IV and V were characterized by specific policy questions. In detail, the main policy questions referred to the effect of alternative regulatory regimes (group III), the effect of the ownership structure (group IV) and the presence of scale and/or density economies (group V). In this section we briefly illustrate the main policy implications of the selected papers for each of the three groups.

As regards the effect of alternative regulatory regimes on the efficiency of transit systems (group III), we have identified in section 3 two alternative regimes: cost-plus and fixed-price contracts.

In cost-plus contracts, local authorities reimburse the production cost of the operators increased by some pre-specified amount. This contract is risk free for the operators as profits are independent of the realized revenues and cost and therefore there are no incentives to reduce costs. Moreover such a system can produce a bias in the allocation of inputs.

In a fixed price contract, local authorities pay a fixed amount to the transport company, which has strong incentives to reduce cost. Some papers distinguish between two variants of fixed price contract (see, for example, Roy, Yvrande-Billon, 2007): gross cost contract, where an agreed price will remunerate the production of a fixed amount of services, and net cost contract, where the difference between anticipated total operating costs and revenues determines the price the local authority pays to the transport company. A realised difference between costs and revenues that does not correspond to the anticipated difference is the responsibility of the transport company. These contracts mainly differ in their degree of risk sharing. In the net cost contract, both production risk (that is, the risk associated with the production costs of a fixed production quantity, independent of the amount of passengers) and revenue risk (that is, the risk associated with the sale of transport services) are borne by the transport company. In the gross cost contract, the transport company takes the production risk, while the revenue risk is borne by the local authority.

Many papers highlight that operators regulated by fixed-price contracts exhibit a higher level of technical efficiency, than operators under cost-plus contracts do. Interestingly, efficiency was higher in the case of net cost contracts (where the operator bears both production and revenue risk), than in the case gross cost contract systems (where the operator bears only production risk). The reverse holds, however, in the case of effectiveness: public systems perform much better that contracted systems and net cost systems are significantly less effective than gross cost systems (see, Karlaftis, Tsamboulas, 2012).

It is interesting to observe that, according to the network size and the presence of network density economies, the regulator can devise subsidy contracts, including incentive mechanisms, such as fixed-price schemes, that differentiate among companies characterized by different user density.

Other papers point out that subsidies to operators seem to push up the cost inefficiency, thereby suggesting that cost efficiency decreases as the subsidy ratio increases. These results drive us to conclude that, even though local governments need to subsidize municipal bus systems to run them and maintain unprofitable routes, they should avoid disorderly subsidies, in order to reduce losses (see, for example, Sakai, Takahashi, 2013).

However, the policy maker must take into account that a regulatory regime performing well in the dimension of efficiency, generally do not perform well in the dimension of effectiveness, so that it is necessary to compare the advantage of a high powered incentive contract to reduce costs with the risk of reduction of quality. For example, increased emphasis on making the public transport system more accessible to disabled and elderly people implies restraints on the location of bus stops, since most municipalities could require short walking distances for all their inhabitants. The use of low floor busses and giving assistance to people boarding increase costs and travel times. Costs might also be increased due to higher environmental and safety standards (Holmgren, 2013).

Therefore, even if many empirical analyses suggest that fixed-price contracts enhance production efficiency, a careful design of contractual schemes is crucial in providing the proper incentives to efficiency and effectiveness, with or without competitive tendering, with private or public ownership of the firms.

As regards the relation between ownership structure and efficiency (group IV of Table 2), many papers find that ownership matters: public firms are generally less efficient than private firms. The higher productivity of private firms may have a simple explanation: private shareholders simply have stronger incentives to make sure that the firm is efficient.

Nevertheless, some papers underline that private and public firms differ both in the operation scales and in the diversification strategies. Privately owned firms are often small and mainly diversify in nonsubsidized transport-related competitive market, while publicly owned firms operate at a larger scale and provide services in non-transport-related regulated markets (see, for example Ottoz, Di Giacomo, 2012). The latter always display lower scope economies (and in some cases also diseconomies), while firms diversifying in transport-related activities have high cost savings. In addition, also LPT companies diversifying in noncore businesses enjoy scope economies, even if smaller. Diversification in industries related to the core business should be encouraged, as it encompasses larger scope economies as compared to non-transport-related diversification. Another explanation of the higher productivity of private firms may be that during the privatization process more productive and profitable firms have been acquired by private shareholders, so that only less productive firms have now remained in public hands. In addition, it was observed that mixed firms are still less efficient than private ones (Boitani, Nicolini, Scarpa, 2013). In conclusion, the empirical analyses of the relation between ownership structure and efficiency do not allow to conclude that privatization implies higher efficiency.

Finally, as regards the scale and density economies issue (group V), many papers present evidence of both scale and density economies. This suggests that public transport operators can benefit by increasing output level and network size (scale economies) and, within a given network, the number of seat-km supplied (density economies). Regarding this point, the restriction of the use of private vehicles and the introduction of road pricing schemes in urban areas, together with incentives for the use of LPT services could significantly increase demand and supply of seat kilometers, so fostering a higher network density. Dimensional and coordination economies suggest encouraging mergers of operating companies both in the case of small urban networks, and in the case of urban and feeder networks. In the latter case, by offering a mixed service, firms could exploit potential cost synergies existing between these two segments of the public transport industry (see, for example, Cambini, Piacenza, Vannoni, 2007).

Other papers observe that scale economies are exhausted beyond a certain amount of vehicle-kilometers per year inducing a U-shape form of the average cost (see, for example, Croissant, Roy, Canton, 2013). So, a governance strategy to reduce public transport costs consists of dividing a large network into several lots (allotment). This permits to multiply the number of calls for tender and increase competition for the market, and the risk of negative consequences on production costs, in terms of lower returns to scale, can be neutralized by the large size of a urban network. In addition, it was noted that inefficiencies of public firms increase with firm size, so that while mergers could allow for the exploitation of economies of density and scale for private firms, a desirable size has already been exceeded by large publicly owned transport firms. Interestingly, we observe that in the density map of Figure 2 the term “allotment” is in the east side together with regulatory policy, average cost measure inefficiency score and cost analysis.

8. The tactical planning of urban transit services through OR techniques and its connections with our evaluation perspectives

This article has reviewed the state of the art of applications of economic efficiency analyses to the operations of urban public transport. Moreover, it has given evidence on how such analyses could broaden their scope by taking into consideration the transport engineering and planning viewpoint. Before coming to our conclusions, we however feel that the review would not be complete without making a connection with another related research sector, namely the design and operation of urban public transport systems through operations research techniques.

A full review of the wealth of scientific production in this latter field is beyond the scope of this paper: here we rather focus on showing the points in common between efficiency analysis and operations research, when both are applied to the study of public transport systems. From our perspective, it is interesting in particular to look at the decision variables, objective functions and constraints that are normally considered in transit-related optimization tools, that are somewhat the counterpart of the input and output variables of efficiency models. The goal is then to understand to which extent it could be possible to make also such tools more relevant under different perspectives by considering different sets of variables, according to the framework developed in Sections 3 and 4. Economic efficiency analyses are often employed to run ex-post evaluations, while operations research methods are normally used as ex-ante design tools. Therefore, it is of interest here to understand to which extent such design process could better take into consideration the different viewpoints shown in the left part of Table 2.

Consistently with the definitions of the three initial bibliographic lists in section 2, we focus here on the tactical planning level, where the schedule of the urban public transport service (excluding railways and intercity services) has to be determined and decision variables are typically headways, frequencies or timetables. Therefore, we let aside the strategic level involving the design of the network and the definition of the routes. Such distinction between the two levels is quite relevant in practice, since the network (re)-design occurs in real systems not too frequently, whereas service schedules are typically adjusted on a seasonal basis. However, it is sometimes blurred in the scientific literature, since models are often implemented to jointly perform both tasks. In this case, we only considered articles that primarily address tactical design problems (e.g. headways adjustments, routes synchronisation, optimisation of transfers). On the other hand, also the operational level, that is concerned with the scheduling of vehicles and crews, is not relevant here, since it is exclusively related to the production of the service and therefore to the point of view of the service operator. We are also disregarding more specific scheduling problems, such as short-turning, corridor express services, feeder services, or deadheading, along with issues related to dynamic and real-time service management or equilibrium problems involving travel demand assignment to the network.

An overview and definition of the tactical design of a public transport service can be found in Ceder (2002 and 2007), whereas Liebchen (2007) provides a mathematical treatment of the timetabling problem. A number of good reviews of the state of the art in this very active research area has appeared, starting from the works of Odoni et al. (1994) and Desaulniers and Hickman (2007). Kepaptsoglou and Karlaftis (2009) focus on the state of the art of strategic transit network design, while Guihaire and Hao (2008) cover both strategic and tactical planning levels. The most recent reviews include the works of Farahani et al. (2013), that show the common points between transit and road network design, and Yan et al. (2013), that focus on researchers jointly addressing the design of the routes and of the service frequencies. Even if our perspective is different, since we are particularly interested in making a connection with economic efficiency studies, in the following we are mainly focusing on more recent works, or works that have not been included in the above reviews, letting the interested reader to extend the analysis to the wealth of previous works that were already considered there. Those reviews are fact already presenting in most cases some summary tables with an indication of the objective functions, the constraints or the model parameters of the considered papers.

Keeping into consideration such framework, we analyse a representative set of 30 papers that have been published in the last 10 years. Table 12 lists such works, indicating the kind of tactical problem being studied in the second column. It can be seen that the two most studied problems are the setting of headways (or their reciprocal, i.e. service frequencies) and the synchronisation of timetables at transfer points. Actually the two problems are related, and some works are explicitly addressing both in their modelling efforts. In other works, such tactical problems are embedded in the network design or in a bi-level optimisation approach, involving either the interaction between transport offer and demand (definition of passenger paths to find the flows in all lines through an assignment model) or operational problems such as vehicle scheduling.

Reference	**Addressed problem**	**Objective function***	**Decision variables** **	**Relevant constraints*****
Castelli et al. (2004)	transfer synchronisation	operator cost + wait time		
Ting and Schonfeld (2005)	headway setting and transfer synchronisation	operator cost + wait time + number of transfers	headway	
Cevallos and Zhao (2006)	transfer synchronisation	wait time for transfers		
Fleurent et al. (2007)	transfer synchronisation	difference between actual and ideal wait time, headway evenness, fleet size, deadheads		
Guihaire and Hao (2008)	headway / frequency setting	difference between actual and ideal wait time, headway evenness, fleet size	timetable s	
Sun et al. (2008)	headway / frequency setting	operator cost + total travel time (transfer, in-vehicle and wait)		headway
Zhao and Zheng (2008)	bi-level: network design and headway setting	total travel time (transfer, in-vehicle and wait)		headway, capacity
Bruno et al. (2009)	transfer synchronisation	operator cost + wait time		
Michaelis and Schöbel (2009)	bi-level: network design and headway setting	difference between bus and car travel time		fleet size
Mauttone and Urquhart (2009)	network design, headway setting	transfers, travel time, wait time and min fleet size (multi-objective)		load factor, frequency
Guihaire and Hao (2010)	timetabling optimisation, vehicle scheduling	difference between actual and ideal wait time, headway evenness, fleet size, dead-ending trips	timetable s	
Shafahi and Khani (2010)	transfer synchronisation	wait time		headway
Yu et al. (2010)	bi-level: headway setting and assignment	total travel time (in-vehicle and wait)	headway	fleet size
Szeto and Wu (2011)	network design and headway setting	total travel time (transfer, in-vehicle and wait)		fleet size, frequency
Gallo et al. (2011)	headway setting	operator cost + travel cost + environmental cost	frequenc y	frequency, fleet size, fleet run, capacity
Yu et al. (2011)	headway / frequency setting	operator cost + total travel time (in-vehicle and wait)	headway	fleet size
Chowdhury and JyChieng (2011)	headway setting and transfer synchronisation	operator cost + total travel time (transfer, in-vehicle and wait)	headway, bus size	
Hadas and Shnaiderman (2012)	headway / frequency setting	cost of capacity shortage + cost of capacity overage	headway, bus size	

dell'Olio et al. (2012)	bi-level: headway setting and assignment	operator cost + total travel time (transfer, in-vehicle and wait)	headway, bus size	fleet size, capacity
Ruisanchez et al. (2012)	bi-level: headway setting and assignment	operator cost + total travel time (transfer, in-vehicle and wait)	headway, bus size	fleet size, capacity
Ferguson et al. (2012)	headway / frequency setting	accessibility evenness		capital and operating budget
Ibarra-Rojas and Rios-Solis (2012)	transfer synchronisation	number of synchronised transfers		headway
Verbas and Mahmassani(2013)	headway / frequency setting	ridership + wait time		subsidy or profit, fleet size, headway, capacity
Li et al. (2013)	headway / frequency setting	profits (revenues - costs), wait time (multi-objective)		headway, capacity
Petersen et al. (2013)	timetabling optimisation, vehicle scheduling	operator cost + transfer cost (wait time)		fleet size
Szeto and Jiang (2014)	bi-level: network design and assignment	transfers		fleet size, frequency, line capacity
Saharidis et al. (2014)	transfer synchronisation	wait time		headway
Hu and Liu (2014)	headway / frequency setting	operator cost + wait time		headway, fleet size
Ibeas et al. (2014)	bi-level: headway setting and assignment	operator cost + total travel time (transfer, in-vehicle and wait)	headway, bus size	fleet size
Martínez et al. (2014)	headway / frequency setting	travel time + wait time		frequency

*Legend: * in case of bi-level studies, only objective functions and constraints related to the tactical problem are indicated*
*** if not indicated, then objective functions are usually defined in terms of the quantities indicated in the third column of the table*
**** not including the "obvious" ones from mathematical programming (e.g. subtour elimination, flow continuity…).*

Table 12. Classification of recent papers dealing with the tactical design of urban public transport.

The definition of the objective function, that is of central interest in our analysis, is reported in the third column of the table. Almost all the considered works include the minimisation of wait times at bus stops, or the minimisation of its difference from an ideal wait time in case of transfers, when transfer times from one line to another are taken into account. Other measures related to service quality include the minimisation of in-vehicle travel times and transfer times. Two thirds of the works are also considering efficiency aspects, minimising operator costs (sometimes defined also considering capital costs), fleet sizes, or the difference between subsidies and costs. These two clearly conflicting objectives are jointly considered in most objective functions through a weighted sum (we put a "+" sign in the table whenever this is the case), even if other approaches, including Pareto frontiers and multi-objective programming techniques, are sometimes employed. Headways are explicitly considered in virtually all works, either directly entering the objective function or as decision variables that are used to express the quantities in the objective function itself (for example, expressing wait times or operator costs as a function of headways). In many works headway values are bounded to some upper and lower limits, while additional operational constraints, such as fleet sizes, are sometimes considered.

By considering in particular the objective function definitions, we are in the position of mapping such works against the six evaluation dimensions represented by the rows of Table 2. The following considerations are stemming out:

- Profit and cost aspects related to the operation of the service are considered in all the reviewed works. In most cases, operator cost minimisation is directly considered, while in others the available resources are a modelling constraint. The operator viewpoint is therefore well taken into account in the state of the art.

- Service performances are considered mainly in terms of travel and wait times, and as such they enter in all models as well. This portion of O.R. literature is therefore equally addressing the operator and the customer viewpoint, a first difference from economic efficiency studies reviewed so far. From a transport planning viewpoint, it is particularly interesting that some works are addressing relative performances rather than absolute ones within a multimodal network setting (Michaelis and Schöbel, 2009; Verbas and Mahmassani, 2013).

- The other four evaluation perspectives, i.e. the last four rows of Table 2, are much less consistently studied, as in the economic efficiency literature, but some notable exceptions could be spotted. In particular, congestion issues are at least indirectly considered whenever competing travel means are analysed (Michaelis and Schöbel, 2009; Verbas and Mahmassani, 2013). Gallo et al. (2011) show how sustainability issues, in particular related to environmental external costs, can be embedded into an objective function formulation within the tactical design process of a public transport service, whereas Ferguson et al. (2012) exclusively focus on equity, social inclusion and accessibility issues, considering service production costs issues ancillary.

In summary, the reviewed literature shows that both the service operator and the customer viewpoints are fully embedded in the tactical design of transit services. The community viewpoint is more sporadically considered, even if a handful of works has already shown how this could be achieved. We hope that the short overview we offered in this section can contribute in accelerating the evolution of the state of the art towards a more systematic consideration of transit service effectiveness issues also in the service design phase.

9. Conclusions and directions for further research

In their quest for relevance, economics, both as a positive and as a normative discipline, and engineering, the science of design, have increasingly recurred to mathematical and statistical modelling to advance their understanding of technologies and behaviours and to improve the effectiveness of the design of goods, policies, and institutions. Production research is the subject in which, at least conceptually, the scope and reward from cooperation would be highest. Transportation is probably the application ambit in which the two disciplinary fields have more concretely verified the importance of analytical approaches that are at the same time theoretically and empirically sound.

This review has systematically analysed objectives, methods, kind of data used, main results and policy implications of the existing literature related to the evaluation of urban public transport services. Thus, by combining the effectiveness indicators from the transport engineering and planning literature with the variables and the methods from the literature on efficiency, and by matching them with the most relevant typology of research questions and results of the previous studies, we offered a comprehensive reference framework to provide insightful indications to both researchers and policy makers in this area. We hope to have shown both the benefits of a closer match between such different evaluation perspectives, and the actual gap that needs to be bridged between the two research fields. The systematic investigation carried out in this paper therefore highlights some areas of potential improvements for future studies that we briefly outline below.

a) *Widening the policy questions addressed.* The analytical needs of transportation research, in each of its declinations, are propelled by the more and more challenging objectives that modern societies are pursuing. This still exerts a pressure to increase the accuracy in the representation of technical details that affect cost, quality, impacts, and their distribution in space and time, and among users. A representative case in the economics literature is the treatment of dimensional economies and capacity constraints. The landmark introduction of the concept of *density economies* in Caves et al. (1984) is only a first step towards a full representation of the multiproduct and network nature of the transportation services. This is even more important in an urban setting, where time and space patterns of use of transport infrastructures have a direct impact on property values, urban attractivity, congestion costs, and so on. We think this is an interesting area to be developed in future studies.

b) *Using more general and flexible quantitative methods.* As the analysis of the evolution of the econometric methods used in the surveyed studies showed (from ordinary least squares to parametric frontiers towards nonparametric frontiers to estimate inputs-outputs relations, average or total cost functions), the operations research and technological proxy models that are available today to decision makers and analysts are incomparable for sophistication and details with those models that inspired, more than sixty years ago, the concept of engineering production function (Chenery, 1949) or activity analysis (Koopmans, 1951). In fact, recent developments in mathematical programming techniques used in design and management context, are part of a toolbox that different stakeholders can use flexibly, for different goals. We see a great potential of applications of recently introduced techniques for future studies in this area.

c) *Deepening the coverage and comparability of available data for the empirical analysis*, by promoting and developing international comparable data at the national and regional level. This is another important area in which to invest in the future to provide sound empirical evidence at the European level, that, as the analysis of existing literature showed, is still scant.

In this context, public agencies could take into account the complexities of external effects of urban transport without resorting only to aggregated, monetary measures of the welfare effect of policy measures, but using also the disaggregated physical indicators, that better represent the impact of policies on the community. Transport planning methods routinely deal with such indicators, and their use also for evaluation purposes is a potentially promising avenue of research.

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Note: In the reference list that follows with (*) we identify the 124 papers reviewed in the first part of the present research, while with (**) we identify the papers reviewed in Section 8.

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Appendix A List of keywords used in the automatic literature search

Urban bus service	Urban transit	Performance Measures
Urban public transportation	Public Transit Performance	Assessing Measurement
Measuring accessibility	Transit Systems	Performance Assessment
Network connectivity	Transit Evaluation	Performance Evaluation
Index of transit service	Index of Transit	Efficiency
Productivity frequency index	Transit Performance	Measurement
Transit network	Transit Productivity	DEA
Public services	Public Transit	Frontier estimation
Transit performance	Public Transportation	Production frontiers
Transit systems	Performance	Cost efficiency
Transportation	Evaluation	Cobb-Douglas
Public transport	Productivity	Cost function approach
Public transit	Indicators	Returns to scale
Transit service	Methodology	Cost

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

Paper Reference
Objectives of the Study

Method		
Kind of data and indicators	Data_source	O = Official statistics
		A = Ad-hoc survey
	Data_kind	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)
		T = transit line
		V = vehicle
	Country	
	Comments on data	
Variables		I = input
		O = output
		P = parameter
Main Results		
Policy Implications		
Comments		

Appendix C. Distribution of papers by journal and area of research

Area	Journal	Papers published	%
Economics and Industrial Organization	Annals of Public and Cooperative Economics	4	3,2%
	Applied Economics	8	6,5%
	Applied Economics Letters	1	0,8%
	Contemporary Economic Policy	1	0,8%
	Empirical Economics	1	0,8%
	Journal of Economic Behavior and Organization	1	0,8%
	Journal of Industrial Economics	4	3,2%
	Journal of Productivity Analysis	3	2,4%
	Journal of Regulatory Economics	2	1,6%
	Journal of the Economics of Business	1	0,8%
	Review of Industrial Organization	1	0,8%
	The RAND Journal of Economics	1	0,8%
Engineering, Operations Research and Statistics	Advances in Operations Research	1	0,8%
	Annales d'Economie et de Statistique	1	0,8%
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