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Rail versus bus local public transport services: A social cost comparison methodology

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ABSTRACT

In the last years, several Italian legislative interventions concerning the local public transport (LPT) sector aimed at inducing Local Authorities to re-programming the current services by changing the existing transport modes in favor of less expensive ones, while preserving passengers mobility. Indeed, for some local railway routes the existing level demand and its characteristics (e.g. distribution along the day) would justify a switch from rail to bus mode, when the latter are proved to be less expensive in providing comparable services. We propose a methodology to compare the social economic costs associated with the bus and the rail modes in Italy that can represent a simple and effective tool to support the Italian local policy makers in re-programming the LPT services while using more efficiently the (scarce) financial public funds. The comparison is carried out by considering a given level of exogenous demand (e.g. externally fixed), not influenced by the activated transport mode. Differences in the offered level of services are taken into account through estimation of the users cost in terms of in-vehicle trip time. The social economic costs include service production costs, infrastructure usage costs and externalities impacts (e.g. air pollution, congestion, noise). The investment costs for rail and road infrastructures construction are assumed to be sunk, while the generated infrastructure usage costs (increasing maintenance and operations) are included in the analysis. Finally, the proposed methodology is finally applied to an Italian real case.

1. Introduction

In optimizing the use of (scares) public funds in transport systems production, substantial savings would be obtained if the service were produced by the most efficient transport mode solution; namely, the solution to which is associated the lower social costs for production, for a specific area of application (path/network). Identifying the best alternative is not always easy, especially due to the lack of data and/or comparability between modes of transport. Robust methodological tools would positively support the policy makers in the selection process. The Italian context offer in this sense an interesting case study, since recent changes in the regulation recognized an increasingly important role to the local authorities in the transport system planning.

Several relevant reforms interested the Italian local public transport (LPT) sector in the last decades. A crucial variation concerned, indeed, the shift of responsibility from the national to the regional level, for planning and finance management activities. Italian local authorities are currently entitled to define formal agreements with LPT operators, indicating the conditions under which the transport services must be operated, especially concerning the quality performance (e.g. the minimum number of rides, timetable definition, travelers comfort enhancement) and fares and subsidies quantification.

Besides that, important changes revolved around the adoption of the "standard cost" as a policy instrument to promote more efficiency in the public transport sector. The "standard cost" indicates the cost of producing a unit of local public transport (e.g. passenger-km) sustained by an efficient operator, assuming as given the service quality characteristics. The efficiency level is defined by comparing the inputs/outputs ratios and cost structures of several operators active in a selected area, and/or by analyzing the technical details of the industrial process underneath the provision of the services. The concept of the standard cost was first introduced in the Italian legislation as far back as 1997.[1] For long it had no substantial practical effects, till when, between 2009 and 2012, a series of legislative measurement reaffirmed its role.[2] In 2018, the Italian Ministry of Infrastructures and Transports (henceforth MIT) defined the standard cost models for bus, rail, subway and tramway LPT services.[3] Since then, the standard cost become the main reference to define the economic

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[1] Legislative decree n. 422, art. 17, comma 1, 19 November 1997.
[2] The main important pieces of legislation on the "standard costs" notion evolution in the Italian LPT regulation are the law n. 216/2010, the law n. 228/2012 and the law n. 135/2012.
[3] Decree n. 157/2018. The standard cost models approved by MIT for bus and rail modes were based on the methodologies developed by Avenali et al. (2014, 2016, 2018, 2020).

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compensation earmarked to LPT service providers operating under formal agreements, as well as criteria of public funds allocation to local authorities.

The overall Italian regulation setting encourages the local authorities to more efficient use of public funds and aims to a fairer distribution. Thus, as already pointed out, substantial savings in public funds could be obtained by reprogramming the existing services in favor of less expensive and more efficient transport mode alternatives, according to the distinct context situations and without altering passengers' mobility. To this end, the standard cost models could naturally represent a tool for a meaningful comparison between modes of transport, mitigating the problem of limited comparability in cost structures. Following this idea, we propose a methodology combining service dimensioning (according to techniques based on demand behavior), production costs models (making use of the standard cost models adopted by the MIT) and externalities evaluation, creating an effective framework for a social-economic cost comparison tool.

In particular, we focus on the bus versus rail services comparison, which due to its potentiality in practical application. The rail services offer higher capacity, reduced time of journey and increased travel comfort; the bus services benefit of a greater degree of flexibility, usually allowing higher frequency and a more widespread network. Therefore, according to the characteristics of the demand and the existing tracks, each of the alternative modes would result in offering a different overall performance. Indeed, in several Italian local railway routes, the current level of demand could justify a switch from rail to bus service when the latter is proved to be less expensive in providing comparable services. These cases usually concern isolated or terminating railroad tracks,[4] where demand collapsed in the last decades. In general, even well-established transport systems should be reviewed, if interested by enduring structural changes such as, for example, those due to macroscopic changes in the socio-economic environment.

Before proceeding further, we clarify the conditions under which our analysis is performed.

The *investment costs* for rail and road infrastructures are assumed to be sunk. This assumption avoids a high penalization over the rail service alternative (which requires an expensive dedicated infrastructure) and makes our tool especially suitable for transport system re-planning.

Also, we consider *exogenous demand*, namely, the demand level is given independently of the transport mode. The bus and rail services can vary largely on quality (e.g. different frequencies, load factor, comfort) and be perceived by the users as imperfect substitutes. The effects potentially produced by the difference in the level of service are modal split between the two activated modes and/or level of diversion of users from/to private modes (changes of daily demand level for public transport). These effects are usually taken into account in the transport planning analysis by including the user costs, that allow for the adoption of an endogenous demand. The tool proposed by the present paper focuses on a type of demand that could be considered captive on the path. The element of modal split inside public transport offer is not considered, since the transport modes are compared only as alternative solutions. Furthermore, the tool is dedicated to the optimization of existing services to respond to structural changes on the demand level. Based on these points of discussion, the use of an endogenous demand is considered not suitable and beyond the scope of the paper. Nevertheless, since the most important difference perceived by users is usually the difference in travel time, it was decided to include in the social-economic cost computation the *monetary value of time* faced by passengers (as a proxy for the *users' cost*). Finally, the possible presence of diversion from/to private mode is, instead, assumed to have a not significant effect on our results, mainly due to the “captive” nature of the demand. This assumption is a limitation. The diversion to private modes has normally impacts on public transports profitability (e.g. reducing the average load factor) and on the externalities (travels by car are usually more polluting, induce congestion problems in road infrastructure and are associated with a higher risk for accidents). Further research could cover these aspects, extending the range of application for our tool.

The present paper is contributing to the literature in transport modes efficiency comparison, that to the best of our knowledge is still scarce to this day. Especially in the Italian context, a tool to support decision/policy makers in choosing which of two alternative modes is the most efficient could be useful in transport system optimization. As already underlined, the paper considers for the comparison a broad perimeter of costs, including in the analysis the externalities produced in transport modes production (in particular, air quality, climate change, well-to-tank, congestion, accidents, noise, habitat damage), that are usually overlooked (Catalano et al., 2019). Furthermore, an important element of novelty in our paper is specifically the inclusion of the standard cost models in the methodology. The standard cost models have been until now used exclusively as tools for the quantification of subsidies to transport operator; to the best of our knowledge, this will be the first attempt to utilize the standard cost models as part of a tool for transport system planning. In fact, the coordinated use of bus standard cost model and rail standard cost model, allows a more robust transport mode comparison, since both the cost estimation methodologies follow the same structure.

The rest of the paper is organized as follows. Section 2 displays the literature review on the topic. Section 3 presents the methodology to perform the transport modes comparison. Section 4 describes the application of the methodology to a real case study (regarding an Italian region), to show its practical potential; while Section 5 contains the concluding remarks of our analysis.

2. Literature review

A vast literature explores the cost structure of LPT companies, for critical reviews Daraio et al. (2016) and Catalano et al. (2019) can be consulted for, respectively, bus LPT services and rail LPT services.

In the following we provide a short review of the literature related to our paper considering the previous works that analyze only one mode (bus or rail services); finally, we consider the existing literature that compares the two modes under the efficiency viewpoint.

2.1. Bus services

The literature that analyzes the cost efficiency of bus services has focused mainly on three aspects, the first (also from a chronological perspective) refers to costs measures and input-output relations; the second widely debated topic refers to which output is the most appropriate when considering cost efficiency; the third issue refers to the existence of scale economies[5] and scope economies.[6]

2.1.1. Costs measures and input-output relations

At first, papers studying LPT costs (e.g., among others Koshal, 1970; Miller, 1970; Pucher et al., 1983) focused on input-output relations; then, the literature has mainly focused on estimating variable and total costs (e.g., among others, Obeng and Sakano, 2002; Fraquelli et al., 2004; Ottoz and Di Giacomo, 2012).

2.1.2. Output measures

When analyzing the efficiency of LPT services, an appropriate measure of output is crucial. Usually, researchers adopt one of the two following approaches: reference to *supply-side indicators*, such as vehicle-kilometers or seat-kilometers, or reference to *demand-oriented indicators*, such as passenger-trips or passenger-kilometers.

The academic debate on which approach is more relevant has not yet brought to an agreement (see Berechman and Giuliano, 1985; De Borger

[4] An isolated railroad branch is a direct connection origin-destination which is completely disconnected by other railroad branches, while a terminating railroad truck is characterized by one head station close to or interconnected with a station of another railroad branch.

[5] Namely an observed reduction in the average cost function due to an increase in output.

[6] Namely an increase in cost efficiency due to the variety of offered services rather than an increase in output of one service.

and Kerstens, 2000; De Borger et al., 2002). However, when the analysis focuses on costs as in this paper, supply-side output measures are assumed to be the best fitting.

2.1.3. Scale and scope economies

A third widely discussed subject that is central in our paper, relates to the presence of scale economies in transport services production. The literature concerning this topic also appears to have not reached yet a univocal position.

On one side, Cambini et al. (2007) identified economies of network density[7] and scale economies in studying LTP bus services, and especially for Italian urban context. Intercity LPT services shreds of evidence in support of both scale and scope economies were identified (Fraquelli et al., 2004). Filippini and Prioni (2003) find economies of scale comparing Italian and Swiss companies.

Conversely, Bhattacharyya et al. (1995), Levaggi (1994), Matas and Raymond (1998), Jha and Singh (2001) and Boitani et al. (2013) all find evidence of scale diseconomies.

Finally, Fraquelli et al. (2001) find that the average cost per seat-kilometers is U-shaped; similarly, also Avenali et al. (2016) find that the unit cost per vehicle-kilometers is U-shaped.

2.2. Rail services

Considering specifically the rail LPT services, researchers at first aimed at describing the industry and estimating the cost functions (Borts, 1960; Griliches, 1972; Meyer and Morton, 1975; Brown et al., 1979).

Other studies have focused on productivity efficiency (Caves et al., 1980; Dodgson, 1993; McGeehan, 1993; Loizides and Giahalis, 1995; Hensher et al., 1995). Finally, also methodological aspects in estimating the cost functions have been analyzed (Hasenkamp, 1976; Braeutigam et al., 1982; De Borger, 1991, 1992). Gradually, the focus moved to the study of scale economies, density economies (Harris, 1977; Keeler, 1974; Caves et al., 1980, 1981, 1985; Braeutigam et al., 1984; Preston and Nash, 1993; Savage, 1997), and scope economies (Kim, 1987). It is worth noting that many papers jointly evaluated passenger and cargo services and only relatively more recent papers have focused on passenger service only (Viton, 1981; Marumo, 1984; Miyajima and Lee, 1984; Filippini and Maggi, 1992, 1993; Mizutani, 1994; Nakamura, 1994; Savage, 1997). In the last decade, some studies have estimated the costs of passenger services by analyzing cost data provided different operators in some European countries, South Korea and Japan (Cantos Sànchez, 2000; Cantos Sánchez, 2001; Christopoulos et al., 2000, 2001; Cantos Sànchez and Villarroya, 2000; Cantos and Maudos, 2001; Loizides and Tsionas, 2002; Cowie, 2002; Mizutani, 2004; Mizutani et al., 2009; Daniel et al., 2010; Avenali et al., 2020). These studies mainly target the causes of inefficiencies and the cost structure of firms to identify the proper configuration of a network, or else they enquire to what extent the cost model and different type of regulatory contracts affect company performance.

2.3. Intermodal comparisons

Despite the vast amount of papers that analyze the cost of a single mode, the literature that compares costs and benefits of alternative modes is scarce. Notably, Tirachini et al. (2010) propose a model to compare the total performance, on a radial urban network, of light rail, heavy rail and BRT (bus rapid transit), with the aim of minimizing the total cost associated with public transport service provision by taking into account the users (demand) preferences (e.g. access time, waiting time, in-vehicle time). Li and Preston (2015) develop a spreadsheet cost model which simulates public transport modes (twelve different urban alternatives) operated on a 12-km route on UK context, considering the total social costs generated by each alternative and considering the effects produced by an endogenous demand. Grimaldi et al. (2014) applied the modes comparison to the Italian context, proposing a bottom-up model that analyzes the economic costs and benefits associated with an upgrade from an existing urban bus service to a light rail transit system. Somehow, the purpose of our paper is the opposite since we assume that the infrastructures costs (railways and motorways) are sunk and investigate on which mode is the most efficient under these circumstances.

3. Methodology

Fig. 1 summarizes our methodology framework to determine which of the bus or rail alternative is the most efficient to be activated on a specific scenario. The first step is the demand behavior analysis. It is assumed to analyze the transport service on a single binary origin-destination path. The demand is considered exogenous: externally fixed and not influenced by transport mode type and/or level of service. The transport mode services are required to totally cover the demand (i.e. unsatisfied demand is not acceptable). From the policy maker point of view, in applying our methodology, the demand behavior would be an input observed in a specific scenario. To different demand behavior would be associated different costs and results from the final comparison.

The demand is the input for the dimensioning of the service process; a minimum level of transport capacity needs to be activated to cover all the passengers' requests. Considering the distribution of the demand along the day (e.g. peak/off-peak percentages, the percentages on the two directions – "*A to B*" and "*B to A*" are important drivers), and fixing the load factor to a realistic average value,[8] the minimum required frequency and the efficient fleet's size are calculated, for each mode separately (e.g. the modes differ for vehicle's capacity and ride's travel time). In the literature the service dimensioning can be carried out through a theoretical approach (e.g. applying heuristic methodologies or vehicles routing and fleet size algorithms, while no formal optimization instruments are available; Nilsson, 2015), or expert based approach.

The calculated frequencies and fleet sizes are used as input for the costs' estimation. The overall social cost associated with each transport mode's service is then computed summing: standard costs for production, costs for the infrastructure usage, costs of externalities and proxy for the users' cost component (based on *value of travel time*). Table 1 displays the perimeter of costs, specifying for each one the unit of measure and the data sources used.

The comparison is performed by considering the resulting overall social cost values. The transport mode associated with the lower overall cost is then considered the most efficient to be activated in the considered scenario.

The considered costs categories can mainly be divided between: costs that increase with increment in traffic (unit of measure: *vehicles-km*; used for production and infrastructure costs), and costs which increase also with increment in load factor, even if the level of generated vehicles traffic does not change (unit of measure: *passenger-km*; used for externalities and users' cost component).

The standard costs for production, manly composed by costs associated to operation, fleet maintenance, administration and capital, also include the depreciation of the rolling stock. The cost of the net invested capital is considered only regarding the investment in transport operation activities, while the investments in infrastructure construction are assumed as sunk. The only costs associated with infrastructure included in our analysis are usage costs (i.e. payments to access to the infrastructure, infrastructure maintenance, operating infrastructure costs for lines and stations). Finally, the externalities impacts are considered, including the dimensions of air pollution, accidents, congestion, noise, climate change, well-to-tank and habitat damage. Also other categories of externalities are usually associated with transport services operation (such as landscape damage, soil and water

[7] Economies of network density exist when the total cost to transport passengers decreases by increasing the usage of the existing rolling stock and infrastructure within a defined network.

[8] For example, a typical value for load factor associated with rail services in the Italian context is 35%, for economically sustainable scenarios.

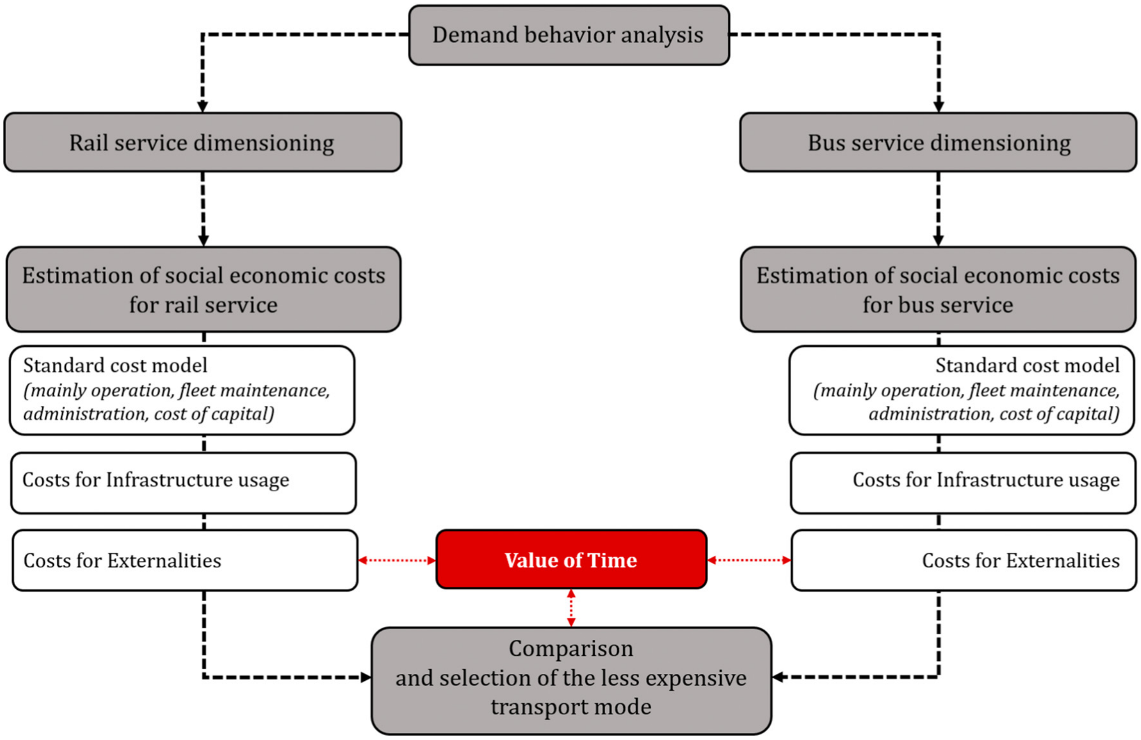

Fig. 1. The methodology flowchart.

pollution), nevertheless, the effect of these adjunctive external impacts are strongly related with the specific context of the application, and require specific data that are usually lacking. Since their inclusion would have not be associated with significant changes in our results, we decided to exclude them from our analysis. We also excluded from the perimeter of costs the effects generated on *land use* by transport systems. Indeed, the stations and stops position, the path itself and the demand level generated by the transport services have a clear influence on urban planning, household value, commercial activities position and so on. The inclusion of these types of effects requires a careful examination of the area interested by the transport service and thus beyond the scope of the present work. Nevertheless, it is an interesting element that could be considered in future works as an adjunctive feature for the developed tool.

In the next subsections, we provide details on the methodologies and data sources used in estimating each cost category.

3.1. Standard cost models

The standard cost for transport production is the first cost category included in the analysis, it encompasses:

(i) operation and maintenance (concerning the fleet's vehicles only);
(ii) administrative costs and other overheads; and
(iii) the pre-tax cost of capital.

The estimation is obtained applying the cost models proposed in Avenali et al. (2016) and Avenali et al. (2020). Avenali et al. (2016) estimate an average-efficient standard cost of local bus transport services if provided by Italian operators, given a specific level of demand. Similarly, Avenali et al. (2020) define a standard cost model to identify an average-efficient standard cost for regional rail public transport services production, under the same conditions.

Both the standard cost models do not include the costs for investments in infrastructure construction.

Operation and maintenance costs include labor costs, direct and indirect costs of spare parts, materials and goods, contracted services to third parties (e.g. outsourced maintenance), depreciation of fixed assets and the related capitalized maintenance. Overheads and general administrative costs mainly concern overall management, economic planning and control costs, business consulting costs and information systems costs.

Finally, the cost of capital represents the minimum money amount to reward the investments in rolling stock for the bus system, and the investments in rolling stock and maintenance facilities for the railway system.

The standard cost models have been developed through regression analysis by using certified economic data and real transport services information collected from Italian private and public-owned LPT operators. The data were gathered through questionnaires carried out by the National Observatory[9] on Local Public Transport Policies (from here on the Observatory) and covers overall >500 million of bus-kilometers (about 30% of the overall offer), and >220 million of train-kilometers (above 90% of the production of regional rail public transport services). The variable considered in the standard cost models evaluation represents both elements partially under providers' control (e.g. the fleet composition and quality) and elements endogenous to the scenario, on which instead the provider is mostly just subjected (e.g. the commercial speed).

3.1.1. Bus service standard cost model

In this section, we describe the standard cost model for local bus services production.

The model identifies the standard cost associated with the production of a single unit of bus transport and it was proposed by Avenali et al. (2016). For the bus services, the unit of transport considered as reference is the bus-kilometer (from here on bkm). The variables considered in the standard model are the following:

CSb (*km/h*): *Commercial Speed for buses*, a qualitative (hedonic) characteristic of the service, which can be barely controlled by the operator.

[9] The Observatory is in charge of building a complete, certified and constantly updated database to monitor of the Italian local public transport industry.

Table 1
Perimeter of costs description.

Costs categories		Unit of measurement	Source (rail)	Source (bus)
Standard cost models	Operation Fleet maintenance Administration and other overheads Pre-tax cost of capital	Vehicles-km	Avenali et al. (2020)	Avenali et al. (2020)
Infrastructure usage	Costs associated with the increment in infrastructure usage (e.g. access to the infrastructure, maintenance) and operation	Vehicles-km	*EU* (2019) and	*EU* (2019)
		Number of stations	Original methodology based on data from the Italian context	
Externalities	Total costs for externalities (accidents, congestion, air pollution, climate change, well-to-tank, noise, habitat damage)	Passengers-km	*EU* (2019)	*EU* (2019)
Users' cost	*Proxy:* Differences on trip duration, reported as saved time for passengers.	Passengers-km	*EU* (2019)	*EU* (2019)

BKM (*mln of bkm*): *million of Bus-Kilometers*, the overall transport capacity offered by the operator. In our specific case, *BKM* would indicate the overall bkm offered on the binary path A to B and B to A on a yearly base.

Abkm (*€/bkm*): *degree of fleet renewal*. This variable is defined as the ratio between a monetary value of the rolling stock (bus fleet) and the offered bus-kilometers (*BKM*). If the rolling stock is completely owned by the operator, the monetary value corresponds to the sum of all the depreciations of the owned vehicles (over an assumed lifetime of 15 years), including their capitalized maintenance. This variable identifies a qualitative characteristic, which can be controlled by the operator.

In the following lines, we report the equation used for *Abkm* calculation; for an extended description of how this equation is obtained and how it can be used (including practical examples), see Appendix A. Notice that, the monetary value of the rolling stock strongly depends on vehicles characteristics. The MIT has provided standard market values (including the expected capitalized maintenance through their life cycle) of several newly equipped bus types (*Annual depreciation*). These values are then adjusted to represent the costs associated with the single produced unit of transport (*Abkm*), that is then calculated as follow:

$$Abkm = \frac{Annual\ depreciation}{SMQ} \times NBS \times \frac{1}{Average\ annual\ BKM} \tag{1}$$

where,

SMQ (*seats/m*^{2}), is the number of seats per square meter for the bus vehicle type used to carry out the service. It is used to express the difference in bus types capacities (usually, it ranges between one and two);

NBS, number seats per bus (according to the type of vehicle);

Average annual BKM (*mln of bkm*), million of bus-kilometers produced on average by a bus vehicle in one year.

The standard unit cost model combines the aforementioned three main variables in order to calculate CTS_{bkm}, the cost per produced unit of bkm (see the Appendix B for statistical details of the model). Then, the unit cost is multiplied for the produced bkm to determine $ACTS_b$, namely, the total cost associated with the production (Eq. 3):

$$CTS_{bkm}\ (€/bkm) = 1.538 + \frac{34.183}{CSb-5} - 0.186 \times DT_{b1} \times BKM + 0.015 \times DT_{b2} \times BKM + 1.651 \times Abkm \tag{2}$$

$$ACTS_b = BKM * 10^6 * CTS_{bkm} \tag{3}$$

Avenali et al. (2016) proved that the impact of the commercial speed on the production costs can be modelled through a hyperbolic function. The dummy variables DT_{b1} and DT_{b2} are introduced to model the nonlinear relationships that stands between the unit cost CTS_{bkm} and the scale of the service *BKM* (Eq. 4):

$$DT_{b1} = \begin{cases} 1 & if\ BKM \le 4\ mln\ bkm \\ 0 & otherwise \end{cases} \qquad DT_{b2} = \begin{cases} 1 & if\ BKM > 4\ mln\ bkm \\ 0 & otherwise \end{cases} \tag{4}$$

The standard cost model for bus services reports the existence of scale diseconomies after 4 millions of bkm. Indeed, according to the applied unit transport cost model (2), the minimum efficient scale for a LPBT services is about 4 million of bus revenue kilometers. In order to minimize the overall production cost in the case the scale of service is larger than 4 million of bus revenue kilometers, the service production has to be optimally allocated to two or more firms whose individual output vectors sum to the overall service size (for instance, it could be assigned to distinct operators of a temporary association of enterprises or to independent business units of a single operator; Braeutigam, 1989). However, a good proxy of the optimal (in terms of minimizing the cost) allocation consists of equally dividing the overall size of the service among the firms. Therefore, a rational policy maker would try then to avoid diseconomies by dividing the service in smaller fragments, to be assigned in separated contracts and/or to different operators. Therefore, we assume that if a service larger than four million of bus-kilometers per year is needed to satisfy the overall demand, the maximum subsidies payment recognized by the local public administration to the transport operator would be equal the one obtained with a fragmentation of the service into several service lots, each one with a size lower or equal to four million of offered bus-kilometers. For instance, the overall standard cost of a service of 15 million of bus-kilometers is equal to four times the overall standard cost of a service of 3.75 million of bus-kilometers. Thus, for real allotments of LPT services, the standard transport cost can be written as follows:

$$\overline{CTS}_{bkm} = 1.538 + \frac{34.183}{CSb-5} - 0.186 \times \overline{BKM} + 1.651 \times Abkm \tag{5}$$

$$\overline{ACTS}_b = BKM \times 10^6 \times \overline{CTS}_{bkm} \tag{6}$$

Variable $\overline{BKM} = \frac{BKM}{N}$ is used in the case of a service larger than four million of bus revenue kilometers, where $N = \lceil \frac{BKM}{4} \rceil$. Obviously, $\overline{BKM} = BKM$ for any service whose size *BKM* is lower than or equal to four million of bus revenue kilometers. Therefore, variable $\overline{BKM}$ is by construction lower than or equal to four million of bkm.

3.1.2. Rail service operating cost model

In this section, we describe the standard cost model for rail services production.

The model identifies the standard cost associated with the production of a single unit of transport and it was proposed by Avenali et al. (2020). For the rail services, the unit of transport considered as reference is the trainkilometer (from here on tkm). The main variables considered in the standard model are the following:

NTS: *number of seats per train (according to vehicle type)*.

CSt (*km/h*): *commercial speed*, a qualitative (hedonic) characteristic of a service, which can be barely controlled by the operator.

T: *rail turnover or network turnover*, indicating the intensity in the usage of rail tracks. If *skm* are the offered seat-kilometers (in millions) and *Rkm* are the kilometers of rail tracks used to produce the rail service, the rail turnover *T* is the ratio between *skm* and *Rkm*.

D_i: *percentage of seat-kilometers powered by diesel.* It is the ratio between the diesel-powered seat kilometers and the overall offered seat kilometers (*skm*), and it is used to model the existing differences in operating costs associated with diesel-driven or electric-driven train services.

Askm (*€/skm*): *degree of fleet renewal*. This variable is defined as the ratio between a monetary value of the rolling stock (train fleet) and the offered seat-kilometers (*skm*). If the rolling stock is completely owned by the operator, the monetary value corresponds to the sum of all the depreciations of the owned vehicles (over an assumed lifetime of 30 years), including their capitalized maintenance. This variable identifies a qualitative characteristic, which can be controlled by the operator.

We report the equation used for *Askm* calculation; for an extended description of how this equation is obtained and how it can be used (including practical examples), see Appendix A. Notice that, the monetary value of the rolling stock strongly depends on vehicles characteristics. The MIT has provided standard market values (including the expected capitalized maintenance through their life cycle) of several newly equipped bus types (*Annual depreciation*). These values are then adjusted to represent the costs associated with the single produced unit of transport (*Askm*), that is then calculated as follow:

$$Askm = \frac{\sum_i Annual\ depreciation_i * NTS_i}{\sum_i Average\ annual\ Skm_i * NTS_i} \tag{7}$$

The standard unit cost model combines the aforementioned variables in order to compute CTS_{skm} (€/*skm*), the cost to produce a unit of rail transport, measured as seat-kilometers (see the Appendix B for statistical details of the model). Then, unit cost is multiplied by *NTS* to determine CTS_{tkm} (€/*tkm*), namely, the cost per offered unit of tkm:

$$CTS_{skm} = 0.02716 + \frac{0.24975}{CSt - 28} - 0.00349 \times T + 3.52342 \times Askm + 0.02816 \times D_i^2 \tag{8}$$

$$CTS_{tkm} = NTS \times CTS_{skm} \tag{9}$$

Again, the impact of the commercial speed on the unit cost is modelled through a hyperbolic function. Furthermore, Avenali et al. (2020) showed the presence of scale economies[10] in the standard cost model.

Now, let TKM denotes the millions of offered train-kilometers (whatever the trains are powered). Obviously, TKM $= (Skm/NTS)$. Therefore, the standard transport cost for the train system is as follows:

$$ACTS_t = TKM \times 10^6 \times CTS_{tkm} \tag{10}$$

[10] Avenali et al. (2020) highlights that the model should not be applied to predict the cost of services with >10,000 million of seat-kilometers as it has been trained on a database where the largest-size instances have mostly 10,000 million of seat-kilometers.

3.2. Marginal infrastructure cost for usage

This section is dedicated to the marginal infrastructure cost description and estimation.

In our analysis, the marginal infrastructure costs for usage are defined as both the increment in costs due to the higher maintenance, repair, renewal and operation activities associated with an increment in vehicles traffic, and, in railway case, as the operating cost component for stations and tracks, associated with the service activation.

Even if there is not a univocal definition of the usage costs of the infrastructure in the literature, it is well established that part of the maintenance cost (that represents the main part of the infrastructure costs) have to be handled also in the absence of traffic. Nevertheless, the distinction between variable and fixed costs is rarely considered, preferring the assumption of a linear variation with the traffic volume. This output is usually expressed through vehicle-km or passenger-km (or gross-tons-km, for freight transport). We adopted this approach for the bus services marginal infrastructure costs.

The operating infrastructure cost category for railways, instead, is also composed of all the costs necessary to keep the infrastructure open for traffic. It includes, for example, lightning, signaling, expenses for stations activation (utilities, heating system, cleaning). Indeed, the costs associated with stations activation are also the main component, and the *number of stations* along the line can usually be used as unit of measures for this cost category, as approximation.

The measurement of the marginal infrastructure cost could be carried out using different methodologies, as described in Link and Nilsson (2005). As in other costs categories, it is possible to choose between *bottom-up* or *top-down* approaches. In general, different classes of vehicles have different impacts on infrastructure damages and also on the actual access capacity (i.e. associated with different minimum safe headway). For example, the difference in axle weight or types of tires in the road vehicles may affect the wear and tear in different ways (e.g. heavier vehicles tend to cause more damage). Similarly, passenger/freight service or high/conventional speeds for the trains may affect the magnitude of infrastructures' deterioration. The econometric methods often fail to represent in a significant way the described phenomena. A solution could be to create different models for each vehicle category, but this independent estimation risks to underestimate their joint impact (the interaction among different categories operating on the same infrastructure).

In the present paper, the marginal infrastructure costs are estimated referring to EU best practices, for the bus transport system, and referring to an original bottom-up estimation model that we proposed specifically for Italian LPT rail services. The EC (2019) reference included an indication of EU best practices also concerning the railway infrastructure usage, that we report in the following sub-paragraph. Nevertheless, the suggested marginal costs are national (or even European) average values; where possible, values specific for the context at exam could improve the estimation of the real external effects produced by the transport services.

3.2.1. Bus service marginal infrastructure costs for usage

As regards to bus services, we consider the method of estimation described in the European Handbook on the external costs of transport (EC - European Commission, 2019), that bases the cost evaluation on a study conducted on the structure of the traffic flow and variable cost composition in Germany for the year 2007 (Link et al., 2009).

In general, the magnitude of the generated effects differs by vehicle class, country (e.g. peculiar characteristics on construction road) and road type. For example, high quality roads are less affected by the damages due to the vehicles' operations, but their construction requires higher initial investments. To produce valid country-specific unit costs, EC (2019) applies some adaptation based on the price variation on average construction costs. As regards the technical characteristic of the roads, instead, it is assumed to be the same in all countries; even if this represents a strong assumption, it is considered acceptable respect to the aim of the present analysis. Table 2 reports the unit infrastructure costs (in €/vehicle-km) for buses. Values for

Table 2
Incremental roads and railways infrastructure costs according to EU (2019).
Source: European Commission – EC (2019).

	Italy (€/vehicle-km)	EU-28 (€/vehicle-km)
Buses	0.39	0.3575
Electric trains	6.129	1.81
Diesel train	6.129	2.075

marginal costs for infrastructure usage due to rail services are also added in the Table 2, as alternative reference (at Italian national level and EU average) to the methodology estimation proposed in this paper in the next subsection.

Thus, referring to the Italian case, the Standard Infrastructure usage Cost for the bus mode (SIC_b) is as follows:

$$SIC_b = 0.39\text{ €} \times bkm \times 10^6 \quad (11)$$

3.2.2. Rail service marginal infrastructure costs for usage

As regards rail services, we elaborated a simple model aiming to estimate the infrastructure usage marginal costs, making use of data gathered by the Italian MIT from 9 local railways operators. This methodology represents an original proposal for the Italian context.

It is well known that the estimated impact on the railways' assets could variate with the amount of traffic, the type of track (e.g. electrified or not), type of trains (e.g. passengers or freight, the latter being usually less expensive, according to Wheat et al., 2009 and Gaudry and Quinet, 2013) and speed regime. Our estimates find evidence that in the Italian context the number of produced tkm and the capillarity of the network (namely, the inverse of the average distance between two subsequent stations) represent the main drivers of the infrastructure maintenance unit cost (€/tkm). In particular, the capillarity of the network is an important factor due to its influence on the acceleration/deceleration needed in departing/approaching to a train station, to which are associated higher tracks wear and tear.

The operating costs due to circulation of traffic, instead, mainly depend on both the network capillarity and the total number of stations in the network. As already described, this category is composed by all the costs that are activated when at least one ride run on the infrastructure; including lightning, signaling, expenses for stations activation (e.g. utilities, heating system, cleaning). Table 3 reports the average values estimated from our dataset of 9 observations, where 3 observations are characterized by a high network capillarity (average distance between two subsequent stations lower than 2.9 km), 4 observations by a medium network capillarity (average distance between two subsequent stations higher than or equal to 2.9 km and lower than 4.8 km), and 2 observation by a low network capillarity (average distance between two subsequent stations larger or equal to 4.8 km).

More in detail, the Standard Infrastructure usage Cost for the rail mode (SIC_t) is modelled as follows:

$$\begin{aligned} SIC_t = {} & DI_{t1} \times \left(6.42\text{ €} \times tkm \times 10^6 + 292,500\text{ €} \times NStations\right) \\ & + DI_{t2} \times \left(2.44\text{ €} \times tkm \times 10^6 + 113,100\text{ €} \times NStations\right) \\ & + DI_{t3} \times \left(1.24\text{ €} \times tkm \times 10^6 + 113,100\text{ €} \times NStations\right) \end{aligned} \quad (12)$$

Table 3
Track maintenance and rail traffic unit costs for Italian context.

Network capillarity	Unit maintenance cost (€/train-km)	Operating infrastructure (€/station)
High (average distance < 2.9 km)	6.42	292,500
Medium (2.9 km ≤ average distance < 4.8 km)	2.44	113,100
Low (average distance ≥ 4.8 km)	1.24	113,100

where, dummy variables DI_{t1}, DI_{t2} and DI_{t3} identify the capillarity level of the rail infrastructure at issue (i.e. high, medium and low):

$$\begin{aligned} DI_{t1} &= \begin{cases} 1 & \textit{if capillarity is high} \\ 0 & \textit{otherwise} \end{cases} \\ DI_{t2} &= \begin{cases} 1 & \textit{if capillarity is medium} \\ 0 & \textit{otherwise} \end{cases} \\ DI_{t3} &= \begin{cases} 1 & \textit{if capillarity is low} \\ 0 & \textit{otherwise} \end{cases} \end{aligned} \quad (13)$$

while, parameter *NStations* represents the number of rail stations where passengers can get on or off the trains.

3.3. Costs of externalities associated with the transport services

A series of externalities are associated with transportation production. For example, a higher road traffic volume increases the congestion level and, consequently, the air pollution and the global warming, while trains and aircrafts generate noise. These types of effects generally do not burden only the transport users, but society overall. In outline, externalities occur when production and/or consumption of a good or a service imposes external costs to (generate external benefits on) third parties outside the considered market.

In this section, we present the methodology adopted to evaluate the external costs associated with the transport services.

Following EC (2019), we include in the cost perimeter environmental impacts: air pollution costs, fuel (*energy*) production external costs (*well-to-tank*), impact on habitat and on climate change. Furthermore, we consider the social costs associated with noise, congestion and accidents.

The most relevant component for the externalities costs are congestion, noise and air pollution. In particular, the latest generates broad negative effects on health and ecosystems (Kampa and Castanas, 2008). Despite positive improvements occurred in the last decades, the transportation sector still represents one of the principal air polluters, especially in urban areas with high traffic volume.

Table 4 collects the marginal external costs (in €-cent per passenger-km), divided in sub-categories, by mode. Since rail services run on dedicated infrastructure, in the limit of safety capacity (minimum headway between two subsequent rides in the same direction), congestion externalities are not generated. The marginal cost of climate change is null for electric-driven rail service, since the only generation of greenhouse gases associated with this type of vehicles would be caused by electricity production itself. The electricity production effects on climate change do not impact directly on the area where the service is run and are strongly related to the production sources mix, varying largely country by country (and year by year on the same country); for these reasons, it is not included in our analysis.

Notice that, to effectively run the bus services a number of bus-kilometers out of service are required. Referring to the Italian case, a 10% of total service BKM is considered an average reference value, while for regional rail services only 2% with respect to the number of TKM in service. Therefore, the external costs generated by bus and rail modes have to be computed also by taking into account vehicle-kilometers produced out of service.

Table 4
Costs for externalities by transport mode in €-cents per passenger-km.
Source: European Commission – EC (2019).

Cost category	Train (€-cent/pkm)	Bus (€-cent/pkm)
Accidents	0.343	0.472
Air pollution	0.007	0.780
Climate change		0.409
Noise	1.617	0.694
Congestion		3.833
Well-to-tank	0.679	0.177
Habitat damage	0.382	0.068
Total cost of externalities	**3.028**	**6.434**

3.4. Differences between transport modes on trip duration: users' value of time

As state in the introduction, in our analysis the demand is considered exogenous and not influenced by the transport mode. The assumption is that the demand could be considered captive with respect the public transport usage, so it would not significantly vary between the two transport modes, considered as mutually excluding alternatives. Nevertheless, the bus and rail transport modes cannot, in general, be considered as perfect substitutes, due to their possible high differences in terms of prices, comfort and time performance. The time performance element is usually also the most influential one. We decided to include part of this element in our analysis, assuming a certain level of discomfort for the users if forced to use a slower mode, considering it as a proxy for the users' cost component.

The "value of time" is a concept broadly used in transport appraisal, and could be seen as the "value of changes in travel time": monetary evaluation for the discomfort in using an additional hour travelling, or for the increase in utility of having an additional free hour for leisure or consumption (ARUP, 2015). We take as reference for the monetary value of time the one proposed by EU (2019) for Italy, displayed in Table 5.

For public transport, the journey time can be decomposed into in-vehicle time, waiting time, access and egress time, boarding and aligning time and time for possible interchanges (Preston, 2015). Our analysis will concentrate mostly on in-vehicle time, which is usually the most relevant component.

We include the value of time in the total social cost estimation, as adjunctive users' cost for the slower mode of transport (that usually is the bus). In Eq. (14) we calculate this cost as:

$$Users'cost = \left[\frac{(travel\ time_b)}{km_b} - \frac{(travel\ time_t)}{km_t}\right] \times psk \times (Value\ of\ time) \quad (14)$$

4. Results obtained applying the methodology on an Italian case study

In this section, the proposed methodology is applied to a case study. Specifically, we considered as a scenario a real intercity transit system active in a Region of southern Italy. This section aims to verify if the rail service at the moment active in the scenario is still economically sustainable from the Local Authority point of view, or if a transport service completely carried out through bus operators would be preferable and more efficient. To this end, our comparison tool seems appropriate. In particular, for the case at study we show that it is convenient to substitute the rail service with the bus service given that passengers are highly concentrated in the peak hours (e.g. over 20%) while demand is very low during off-peak hours.

First of all, the technical characteristic of infrastructure and service path is reported. The case study considers a two-directional path that connects two cities; from here on we referred to those two cities as *A* and *F*. On the path, both rail-based service and bus-based services are active.

The railway track directly connects A to F with four intermediate stations stops (from here on called: B, C, D and E). Overall, the head station A is 84 km far away from the head station F, of which 11.9 km are considered passing through urban areas, while 72.1 km are considered as carried out in an interurban (rural) area. Table 6 reports the distances on tracks between consecutive stations along the path.

Similarly, the road path directly connects A to F, and presents stops in the same intermediate locations (B, C, D and E). Nevertheless, the road path is longer (92 km) and characterized by 13 km of local roads (that we can consider as urban) and 79 km of trunk roads (that we can consider as interurban).

Table 5
Value of time associated with trips for commuting or personal purposes.
Source: European Commission – EC (2019).

	Commuting or business travelers (€/hour)	Leisure travellers (€/hour)
Value of time	12.8	5.9

Table 6
Distances between consecutive stops.

Consecutive stops	Distance
A➔B	6.0 km
B➔C	10.0 km
C➔D	23.0 km
D➔E	15.5 km
E➔F	29.5 km

Concerning the vehicles powering type, the railway line at exam is entirely electrified (i.e. D_i, the percentage of *skm* produced with diesel-driven vehicles used in the standard cost model, is equal to 0). The bus service, instead, is carried out exclusively through diesel-driven vehicles. Concerning the time of travel, the rail service is characterized by a commercial speed of 74 km/h, while the bus service runs at 49 km/h.

The first step of our methodology is the *demand analysis*. For this case study, the service providers active in the transport system at exam made available to us real data on passengers behavior. The demand served by the transit system overall is on average equal to 7730 daily passenger-kilometers, distributed along the peak hours, and 37,342 daily passenger-kilometers, distributed on the service range overall.[11] The service is running every day from 6:00 am to 10:00 pm. It is possible to identify, essentially, two peaks per day in the direction AF (one hour long each, respectively on the early and late morning) and a single two hours long peak in the direction FA (on the late afternoon). All these characteristics are displayed and summarized in Fig. 2, that reports the real distribution of the daily demand along the service slots, considering both directions (A to F and F to A). On a yearly base, about 11,389,310 passenger-kilometers travel on the path.

4.1. Fleet sizing and degree of renewal estimation

The second step of our methodology, require to quantify the service characteristics: frequencies, fleet dimension, number of vehicle-kilometers to be produced. As simplification, we assume that each fleet has to be sized in order to guarantee the service during the peak hours. Some redundancy is then added, to taking into account the necessary vehicles substitutions due to breakdowns or planned maintenance. Notably, the fleets' sizes assumed in the case study reflect exactly the real case at exam: both for bus and rail services, technicians from the transport providers active on the transport system dimensioned the fleets by analyzing the hourly demand in every direction (i.e. the expert based approach was adopted). Nonetheless, when it is not possible to have access to a realistic or specific information, heuristic methodologies or optimal routing techniques could be applied to obtain representative approximations (i.e. theoretical approach).

Considering the bus services, an efficient fleet (including breakdowns and planned maintenance) requires 6 diesel powered buses, characterized by 55 seats (NBS) each and 1.83 seats per square meter (SMQ), to satisfy in total the assumed daily demand. This fleet would be able to produce at most 413,289 bkm per year; with every bus offering 68,881.5 km per year, on average. Notice that, the service presents a size under 4 million bus-kilometer, hence it is not affected by the diseconomies of scale. Therefore, applying Eq. (1), the degree of renewal is equal to:

$$Abkm = \left(\frac{520.56\ €}{1.83} \times 55 \times \frac{1}{68,881.5}\right) = 0.2271\ €/bkm$$

Considering the rail services, a fleet that could serve (efficiently) the demand should be composed by 4 identical single-decker electric-powered trains, with 144 seats (NTS). This fleet would be able to produce at most

[11] Average percentage of passenger-kilometers served on peak hours is equal to 20% of the daily demand.

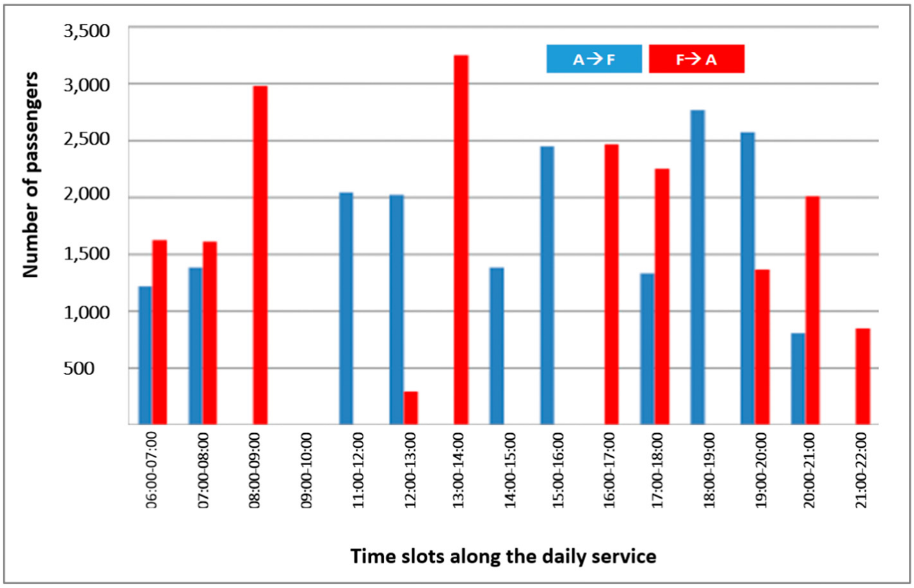

Fig. 2. Distribution of daily passenger-kilometers at different hours in both directions.

326,503 train-kilometers per year; with every train offering 81,625.75 km per year, on average. Therefore, following Eq. (7), the degree of renewal is equal to:

$$Atkm = \left(\frac{840.78\ € \times 144}{81,625.75 \times 144}\right) = 0.0103\ €/pkms$$

The calculated level of degree of renewal will be used as input for the standard cost calculation, in the next paragraph.

4.2. Overall social costs estimation

The third step of our methodology is dedicated to the evaluation of the costs associated with transport services production. Table 7 reports all the case study's parameter useful for costs estimation.

4.2.1. Standard cost models associated with transport services production

The estimation of standard cost models (operation, fleet maintenance, administration and other overheads, pre-tax cost of capital), is carried out making use of the procedures described in Section 3.1.

First, we consider the ***bus mode***. The values of all the variables included in the standard cost model are displayed in Table 7 (commercial speed - *CS*, *Abkm* that has been calculated in paragraph 4.1 and number of seats per ride – *NTS*). The standard cost associated with the bus services are then calculated applying the formulas to the total BKM that need to be produced, according to the level of daily demand. Following the (5) and (6), we calculate the standard cost per unit of produced bus service, and the total standard cost:

$$\overline{CTS}_{bkm} = 1.538 + \frac{34.183}{CS_b - 5} - 0.186 \times \overline{BKM} + 1.651 \times Abkm = 2.61\ €/bkm$$

$$\overline{ACTS}_b = BKM \times 10^6 \times \overline{CTS}_{bkm} = 1,079,906.27\ €$$

As regard the ***rail mode***, the values of all the variables included in the standard cost model are, again, displayed in Table 7 (commercial speed – *CS*; rail turnover, *T*; *Atkm* that has been calculated in paragraph 4.1; number of seats per ride – *NTS*). The standard cost associated with the rail services are then calculated applying the formulas to the total TKM that need to be produced, according to the level of daily demand. Following (8) and (9), we calculate the standard cost per unit of produced rail service, and the total standard cost:

$$CTS_{tkm} = NTS \times \left[0.02716 + \frac{0.24975}{CS_t - 28} - 0.00349 \times T + 3.52342 \times Atkm\right] = 9.63\ €/tkm$$

$$ACTS_t = TKM \times 10^6 \times CTS_{tkm} = 3,146,746.51\ €$$

Table 7
Values assumed by parameters in the case study.

Parameters	Description	Values (bus)	Values (train)
CSb, *CSt* (km/h)	Average commercial speed (bus, train)	49 km/h	74 km/h
BKM, *TKM*	Annual average million of vehicle-kms	0.413289	0.326503
Fleet	Fleet dimension	6	4
NBS, *NTS*	Number of seats per ride	55	144
Depreciation (€)	Annual depreciation	520.56 €	840.78 €
Abkm, *Atkm* (€/skm)	Degree of renewal of the fleet	0.2271 €/bkm	0.0103 €/skm
EC_{pkm} (€-cent)	Externalities costs per pkm (€-cent)	6.434 €-cent	3.028 €-cent
Rail only			
skm (train-km)	Annual average million of seat-kms		47.016
Rkm (km)	Kms of rail tracks		84 km
T (adimensional)	Rail turnover		0.5597
D_i	% of seat-kilometers diesel powered		0
NST	Number of train station		6
DI_{t1}, DI_{t2}, DI_{t3}	Dummies for the rail network capillarity		0, 0, 1
Bus only			
SMQ	Number of seats per square meter for bus	1.83	
DT_{b1}, DT_{b2}	Dummies for bus-service size	1, 0	
Both modes			
pkm	Million of passenger-kms	11.38931	

Table 8
Social economic cost associated with rail and bus modes.

Cost categories		Rail mode	Bus mode
Standard cost models	Cost per unit of transport produced (*vehicles-km*)	9.63 €/*tkm*	2.61 €/*bkm*
	Total cost per transport production	3,146,746.51€	1,079,906.27€
Infrastructure usage	Total costs for infrastructure usage	1,083,463.7€	161,182.71€
Externalities	Total costs for externalities	344,853.09€	732,775.91€
Users' costs	Discomfort due to a slower mode	–	1,000,561.49€
	Social economic cost	**4,575,078.5€**	**2,974,438.69€**

4.2.2. Marginal infrastructure cost estimation

The estimation of marginal infrastructure costs for usage is carried out using the procedures described in Section 3.2.

First, we consider the ***bus mode***. The path connecting A to F replicates the same stops of the rail service, the only variable needed for the estimation is BKM; then, from (10) the marginal cost for road infrastructure usage is:

$$SIC_b = 0.39\ € \times 413,289 = 161,537.8\ €$$

As regard the ***rail mode***, for the estimation we from (11) and (12), for which the variable needed are TKM and NStations. The average distance between two consecutive rail stations is >4.8 km (i.e. the capillarity is low; $DI_{t1} = 0$, $DI_{t2} = 0$, $DI_{t3} = 1$), since six stations are open to the public (NStations) and the length of the line is 84 km. Then, we have that:

$$SIC_t = (1.24\ € \times 326,503 + 113,100\ € \times 6) = 1,083,463.72\ €$$

4.2.3. Marginal costs for externalities

We estimate the costs associated with externalities using of the procedures described in Section 3.3. Table 4 displays the externalities included in the analysis and reports the calculated total marginal cost for each externalities, with respect to each transport mode. The unit of measure for these marginal costs is the number of passenger-km (for the considered case study, the *pkm* value is reported in Table 7).

Considering these information, we estimate the costs for externalities for each mode.

As regard the ***bus mode***, we have:

$$EC_b = pkm \times 10^6 \times 0.06434\ € = 732,775.91\ €$$

As regard the ***rail mode***,

$$EC_t = pkm \times 0.03028\ € = 344,853.09\ €$$

4.2.4. Users' cost: difference in travel time

We estimate the costs associated with users' value of time by following the procedures described in Section 3.4. Table 5 displays the monetary value of time associated with trips for commuting or personal purposes. In our analysis, as an approximation and considering it representative with respect to the context of our case study, we assume that the daily demand is composed mainly by commuters. The discomfort for users is considered as adjunctive cost for the bus service, that is the one presenting the longest in-vehicle time. The users' value of time cost is calculating using (13) and the parameters displayed in Table 3:

$$Traveltime = \left[\frac{1.88}{92} - \frac{1.14}{84}\right] \times 11.38931 \times 12.8 = 1,000,561.49\ €$$

4.3. Overall social costs comparison

In this section, we firstly compare the total costs of providing the transit services by considering the actual level of service provided under both the rail and bus modes. We then provide a simulation in order to compare the costs of the two alternatives when the amount of passengers-km increases.

Table 8 gathers all the cost categories outlined in the previous paragraphs, reporting finally the overall social economic cost for each transport service.

The analysis highlights that for the existing level of demand the bus mode should be largely preferred over the rail one. In particular, the low level of demand does not justify the high lump investments for the rail rolling stock. Moreover, the (incremental) rail infrastructure costs are higher than the bus ones. In fact, on one hand, the Italian law requires that any rail station has to be controlled and managed by at least one employee and thus personnel expenses are in the rail mode much higher; while, on the other hand, the number of bus-kilometers necessary to serve the demand are just moderately larger than the offered train-kilometers.

Starting from this point, we have then performed a simulation where we let the amount of passengers-km to increase in order to understand if a more saturated rail service (where peak and off-peak demand gets closer and trains run with a high percentage of occupied seats), could reverts the observed results. In the simulation, we assume unaltered the rail service characteristics and we let the pkm increase to the point the service provision is still feasible, but saturated. In other words, we increase the demand until the yearly amount of pkm equals the amount of seats-km offered by the rail service. Thus, the production cost and infrastructure usage costs of the rail service are constant, since constant is the amount of tkm that is provided. Conversely, since the external costs increase when the amount of passengers-km raise, the total social cost of the rail service grows.

Considering the bus service, instead, we have to take into account that each bus has capacity of 55 seats. Thus, when the average number of travelling passengers exceeds the bus capacity, the fleet size must raise accordingly to cover the adjunctive demand, causing an increment in the amount of bus-km offered and a stepwise increment[12] in the production costs, infrastructure usage costs and external costs. Fig. 3 shows that the rail service gets less expensive from the production costs point of view when the amount of passengers-km is more than tripled with respect to the base scenario, namely when passengers-km is above 37 millions and trains travel with a load factor of 80%. Things change when external costs are included (Fig. 4); in this case the rail service produces lower total costs with respect to the bus mode when the amount of passengers-km exceeds 22 millions, namely trains travel with a load factor of 47%. Fig. 4 also displays the total social costs for bus service both not considering the proxy for users' cost component (black line, squared indicators) and including it in the overall social costs (red line, rounded indicators). If the users time value is included, then a switch to rail service would be preferable for a slightly lower amount of yearly passenger-km (17,5 millions), corresponding to a load factor of 35,6%.

5. Discussion and concluding remarks

In the recent past, the Italian Ministry of Transportation chose the standard costs as tool for implementing the yardstick competition in the LPT industry. Local authorities should correspond to service providers a compensation that covers the costs of a (hypothetical but realistic)

[12] The step increments in costs occur when the passengers saturate entirely the bus fleet capacity, and it is necessary to increase the fleet dimension with a new vehicle. The step in costs is caused by the fixed capital costs needed for the new vehicle acquisition.

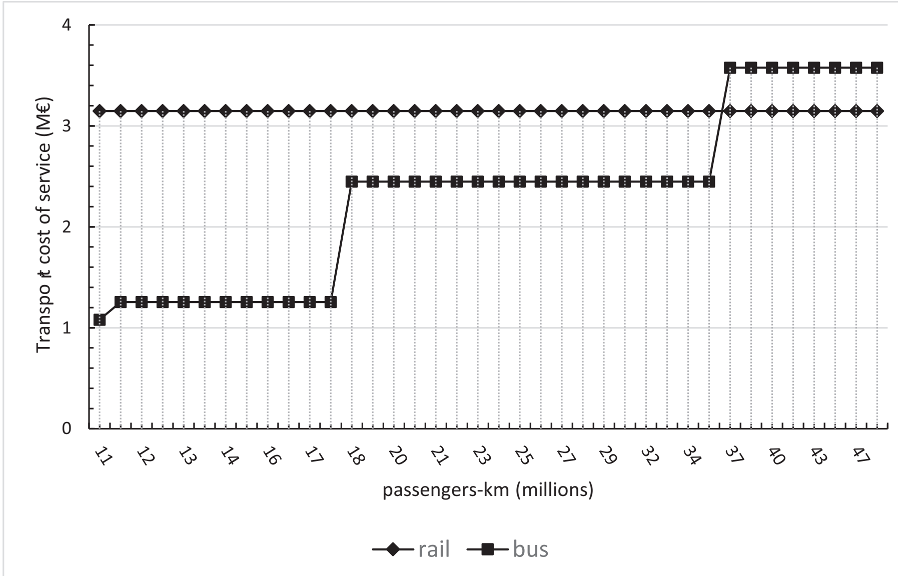

Fig. 3. Transport costs simulation associated with standard cost models.

reasonably efficient operator, (partly) disregarding the actual cost of the supplying firm. In this framework, Local Authorities should be induced to use more efficiently public funds and re-program current services by taking into account the opportunity of a switch to less socially expensive transport modes, while preserving passengers' mobility and service quality. Indeed, for an overall good performance, Regions should select the most efficient and effective alternative, according to the path and demand characteristics. This opportunity would be particularly relevant for several Italian local railway routes, where the collapse in the level of demand of last decades could justify a switch from rail to bus services.

In this framework, this paper suggests a methodology that compares the social costs of LPT bus and rail services, as alternatives in providing rides on a single path with exogenous demand (and infrastructures investment costs assumed as sunk). By using comparable cost models, the paper is able to provide a simple tool that may support a policy maker in selecting the most preferable mode, from the efficiency and effectiveness points of view. In order to test it, the paper applies the proposed methodology to the real case study of an Italian local service. The obtained results would suggest, given the existing levels of demand, to plan a substitution of the rail service with a bus service. In fact, the analysis shows that the bus mode is able to serve the demand at a much lower social cost, preserving almost the same service quality. Then, simple simulations suggest that for the case at study rail service should be preferred only when the level of daily demand doubles and the difference between peak and off-peak almost disappears. In any other circumstances, the bus service appears to be more efficient even when including external costs related to air pollution, congestion and accidents.

It is finally worth noting that the proposed approach might also induce, in the medium-long term, a change in local transport infrastructure investment policies. Indeed, in the case that Italian local routes based on isolated

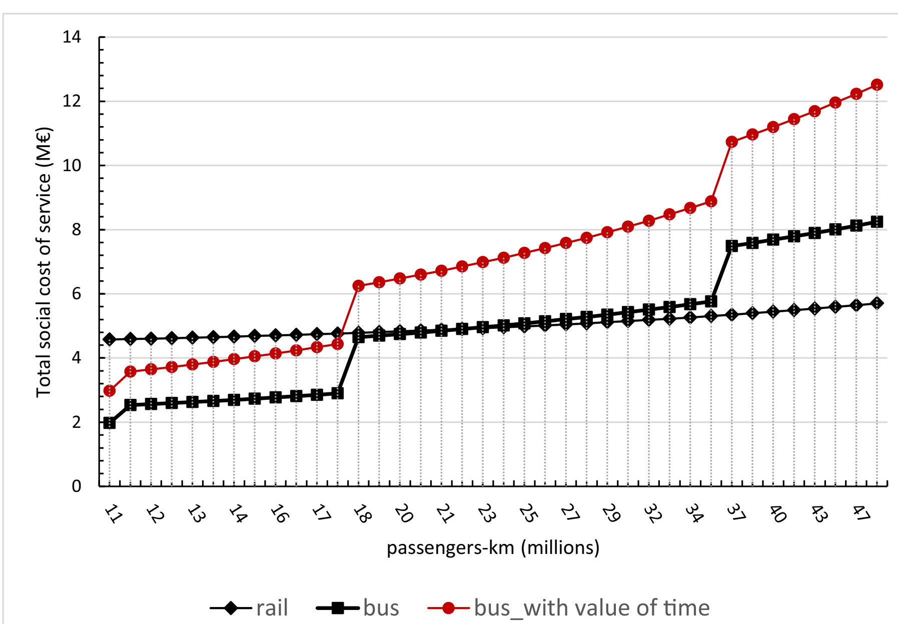

Fig. 4. Total social costs simulation (standard costs, infrastructure usage, externalities).

or terminating railroad tracks should switch from rail to bus service, the tracks might be substituted for example by roads dedicated to (electric) Bus Rapid Transport (BRT) lanes, which represent an intermediate transport mode between bus and rail ones in terms of capacity and flexibility to adapt to market developments.

Further work may contribute to the literature by designing and implementing a set of simulations aimed at identifying the crucial aspects which can make the bus system economically more desirable than the rail one and vice versa. In particular, crucial extensions would regard the introduction of an endogenous demand, the inclusion in the analysis of the positive and negative externalities generated by a possible diversion from public transport to private mode due to the level of the activated services, and, finally, the introduction of a deeper analysis of the geographical and economical context (land use component).

CRediT authorship contribution statement

Alessandro Avenali: Conceptualization, Methodology, Formal analysis, Writing - Original Draft
Giuseppe Catalano: Conceptualization, Project administration, Supervision
Martina Gregori, Data Curation, Writing - Review & Editing
Giorgio Matteucci: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Writing - Review & Editing

Appendix A. Extended description of the variables Abkm and Askm

The degree of fleet renewal is a crucial variable in the standard cost models adopted (Avenali et al., 2016; Avenali et al., 2020), both for bus services and rail services. In Appendix A, we better describe the variable role, meaning and way of calculation.

A.1. Degree of fleet renewal in standard cost model for bus services

Abkm (*€/bkm*): *degree of fleet renewal*. This variable is defined as the ratio between a monetary value of the rolling stock (bus fleet) and the offered bus-kilometers (BKM).

The monetary value of the rolling stock strongly depends on vehicles characteristics. The MIT has provided standard market values (including the expected capitalized maintenance through their life cycle) of several newly equipped bus types. For instance, a twelve meters-diesel powered urban bus is estimated at 242,050 €; an eighteen meters-hybrid powered urban bus is estimated at 365,650 €; a twelve meters-diesel powered interurban bus is estimated at 221,450 €. Based on these values, a general upper bound value for the Italian operators' degree of fleet renewal (diesel-driven) has been estimated and assumed as representative for production scenarios in the country. When adjusted through a conversion factor related to the vehicle capacity (expressed in seats per square meter available to passengers), the upper bound is assumed to be 7808.33 €.

This upper bound value is then adjusted to represent the costs associated with the single produced unit of transport (*Abkm*), that is then calculated in Eq. (1.A) as follow:

$$Abkm = \frac{Annual\ depreciation}{SMQ} \times NBS \times \frac{1}{Average\ annual\ BKM} \tag{1.A}$$

where,

Annual depreciation, is assumed to be equal to 520.56 €, since the standard depreciation life is assumed equal to 15 years;

SMQ (*seats/m*^{2}), is the number of seats per square meter for the bus vehicle type used to carry out the service. It is used to express the difference in bus types capacities (usually, it ranges between one and two);

NBS, number seats per bus (according to the type of vehicle);

Average annual BKM (*mln of bkm*), million of bus-kilometers produced on average by a bus vehicle in one year.

Essentially, the value of any single seat of a newly equipped bus is assumed equal to 7,808.33 €/SMQ.[13] Since the standard depreciation life is assumed equal to 15 years, the standard depreciation for any diesel-powered bus with *NBS* number of seats is: NBS * (7,808.33 €/SMQ)/15, that is equal to NBS * (520.56 €/SMQ). For example, let us suppose that a bus interurban service is provided by using one twelve meters-diesel powered bus (NBS = 55, SMQ = 1.83) that produce at most 30,000 bkm per year, and one ten meters-diesel powered bus (NBS = 43, SMQ = 1.72), that produce at most 50,000 bkm per year. Then, the standard degree of renewal Abkm for this fleet would be:

$$\frac{\frac{55 \times 520.56}{1.83} + \frac{43 \times 520.56}{1.72}}{30'000 + 50'000} = \frac{15'645.25 + 13'014.00}{30'000 + 50'000} = 0.36\ €/bkm.$$

A.2. Degree of fleet renewal in standard cost model for rail services

Askm (*€/skm*): *degree of fleet renewal*. This variable is defined as the ratio between a monetary value of the rolling stock (train fleet) and the offered seat-kilometers (*skm*).

The monetary value of the rolling stock strongly depends on vehicles characteristics. The MIT has provided standard market values (including the expected capitalized maintenance through their life cycle) of several newly equipped train categories. For instance, a 144 seats diesel-powered train value is estimated at 4,162,500 €, a 810 seats electric-energy powered train value is estimated at 12,262,500 €. Based on these values, a general upper bound (*Annual depreciation*, reported below) for Italian operators' degree of renewal have been estimated.

This upper bound value is then adjusted to represent the costs associated with the single produced unit of transport (*Askm*), that is then calculated in Eq. (2.A) as follow:

$$Askm = \frac{\sum_i Annual\ depreciation_i * NTS_i}{\sum_i Average\ annual\ Skm_i * NTS_i} \tag{2.A}$$

where,

i, for each trains categories involved in the production;

Annual depreciation, is assumed to be equal to 840.78 € per every seat of single-decker trains (either diesel or electric powered), and 532.32 € per every seat of double-decker trains (either diesel or electric powered). The standard depreciation life, as already specified, it is assumed equal to 30 years[14];

Average annual Skm, million of offered seat-kilometers produced on average by a bus vehicle in one year.

[13] For example, the value of a twelve meters-diesel powered bus with 29 seats (NBS) and 0.97 seats per square meter (SMQ), including the present value of their expected capitalized maintenance through their life cycle, is estimated equal to $\frac{29 \times 7{,}808.33\ €}{0.97} = 234,249.83\ €$. Instead, the value of an eighteen meters-diesel powered bus with 44 seats (NBS) and 0.98 seats per square meter (SMQ), included the present value of its expected capitalized maintenance through its life cycle, is estimated equal to $\frac{44 \times 7{,}808.33\ €}{0.98} = 351,374.75\ €$.

[14] For example, the value of a (whatever powered) train with 180 seats on one floor (NTS), including the present value of its expected capitalized maintenance through its life cycle, is estimated equal to $180 * 840.78 * 30 = 4{,}540{,}212.00$ €.

For example, let us suppose that a regional rail service is delivered with one (whatever powered) single-decker train with 180 seats (NTS_1) that runs at most 70,000 tkm per year, and one (whatever powered) double-decker train with 480 seats (NTS_2) that runs 90,000 tkm per year. Then, the standard degree of renewal *Atkm* for this fleet would is equal to:

$$\frac{180 \times 840.78\ € + 480 \times 532.32\ €}{180 \times 70,000 + 480 \times 90,000} = 0.007291\ €/skm.$$

Appendix B. Regressions element from the standard cost models estimation

For the sake of the reader, we report from Avenali et al. (2016) and Avenali et al., 2020 in Tables 1.B and 2.B, respectively, the details of the estimated models applied in (2) and in (8).

Table 1.B
Unit cost model for bus services: regression results

Regressor	Coefficient	Estimates (*std. err*)
Constant: 1	α_0	1.538[a] (0.232)
$\frac{1}{CSb-5}$	β_{VC}	34.183[a] (2.903)
$DT_{b1} \times BKM$	γ_{KM1}	−0.186[a] (0.067)
$DT_{b2} \times BKM$	γ_{KM2}	0.015[a] (0.004)
Abkm	σ	1.651[a] (0.528)
n. obs. = 54 Adj R^2 = 0.81		

[a] Significant at 1% level.
[b] Significant at 5% level.
[c] Significant at 10% level.

Table 2.B
Unit cost model for rail services: regression results.

Regressor	Estimates (*std. err*)	Asy. p-value	Bootstrap p-value
Constant: 1	0.02716[a] (0.009)	0.007	0.000
Commercial speed: $\frac{1}{CSt-28}$	0.24975[b] (0.060)	0.000	0.048
Network turnover: *T*	−0.00349[a] (0.001)	0.003	0.010
Degree of renewal of the fleet: *Askm*	3.52342[a] (0.804)	0.000	0.009
Percentage of diesel-powered seat kilometers: Di^2	0.02816[b] (0.013)	0.053	0.047
n. obs. = 29 F = 42.81 Adj R^2 = 0.856		Breusch-Pagan test for heteroskedasticity: LM = 9.05 p-value:0.059 Schwarz criterion (BIC): −141.419	

Based on HC2 standard errors and 9999 wild bootstrap replications.
[a] Significant at 1% level.
[b] Significant at 5% level.
[c] Significant at 10% level.

Appendix C. Abbreviations list

Table 1.C
In Table 1.C we display the abbreviations used in the text.

Abbreviation	Meaning
bkm	Bus * kilometers
BKM	BKM would indicate the overall bkm offered on the binary path A to B and B to A
LTP	Local Public Transport
LPBT	Local Public Bus Transport
MIT	Ministry of Infrastructure and Transport
NBS	Number of seats in a bus (according to the type of vehicle used to produce the service)
NTS	Number of seats in a train (according to the type of vehicle used to produce the service)
NStations	Number of stations along the considered railtrack path

(continued on next page)

Table 1.C (*continued*)

Abbreviation	Meaning
Observatory	The Observatory on Local Public Transport is an institution in charge of building a complete, certified and constantly updated database to monitor of the Italian local public transport industry
skm	Seat * kilometers
tkm	Train * kilometers
TKM	TKM would indicate the overall tkm offered on the binary path A to B and B to A

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