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Case Studies on Transport Policy

Towards a bottom-up estimation of a standard unit operating cost for bus operators: Methodology and policy implications in Italy

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A B S T R A C T

The paper proposes a bottom-up model for the calculation of unit operating costs of bus operators, with the aim of informing a more realistic calculation of standard costs in public transport. Standard costs are a key input for a more effective allocation of public resources to bus operators in Italy and allow for setting a virtuous circle towards more efficient public transport systems. Based on easy-to-collect data, an explicit dependence of some cost components upon relevant context/service variables faced by bus operators is introduced, ameliorating existing methods currently adopted. This enables bus operators to identify directions to improve their performance and public bodies to resort to more effective standard cost estimations. The viability of the proposed approach is showcased in the real case of *Azienda Napoletana Mobilità*, the biggest bus operator in the city of Naples (Italy), with examples of company-oriented and policy-oriented implications.

1. Background and motivation

Public transport systems design should compromise public-oriented and company-oriented objectives, given budget and asset constraints (Gentile and Noekel, 2016). Public-oriented objectives aim to ensure minimal levels of mobility for territories and citizens, achieve effective and sustainable modal split between individual and collective transport modes, preserve the environment and promote liveability (Mayer and Geller, 1982; Newman and Kenworthy, 2000; Mees, 2000; Intergovernmental Panel on Climate Change, 2007; Peña-Alcaraz et al., 2012; González-Gil et al., 2014; Gallo et al., 2015; Astarita et al., 2015; Fiori and Marzano, 2018; Fiori et al., 2019). On the other hand, the main company-oriented objective lies in the profitability of the transport service provided.

The main public-oriented objective, which translates into a primary requirement for public transport systems design, is to guarantee efficacy in matching transport demand (Cascetta, 2009; de Ortúzar and Willumsen, 2011), which means satisfying minimal levels of service in terms of performance (e.g., scheduling, geographical coverage) and not only in terms of quantity of service supplied (i.e., amount of vehicle·km), often with controlled tariffs. Consequently, optimisation of operating costs (usually expressed in €/vehicle·km) is bounded by level-of-service constraints, thus yielding heterogeneity of the latter costs across different travel demand contexts. On the one hand, this prevents

achieving company-oriented profitability and implies the need to resort to public subsidies to cover part of production costs (Hensher, 2020). On the other hand, this means that an equal quantity of public subsidies might yield appreciably different levels of service depending upon the context. A key non-trivial policy issue is the estimation of the total budget needed to subsidise/incentivise public transport and its distribution across bus operators (Gagnepain and Ivaldi, 2002; Marzano et al., 2018). Conceptually, this can be achieved by means of the quantification of a congruous unit cost to match the requested level-of-service, enabling the calculation of the budget needed for each specific travel demand context.

The unit operating cost has been extensively analysed in the scientific literature (see Section 2 for a literature review). In particular, allocation of public resources to bus operators is a longstanding issue in Italy, wherein budget allocation was traditionally proportional to their historical unit operating cost estimates (Law n. 42/2009; Law n.147/ 2013). Such an approach yielded a general inefficiency because public operators were not pushed to optimise the unit cost of their operations. In such a context, the calculation of the standard unit operation cost has been operationalised by the Italian Ministerial Decree 157/2018, as described in detail in Section 3.1. Although conceptually appealing, the standard cost is difficult to quantify because only some of its underlying causes can be ascribed to inherent inefficiencies of the bus operators. In fact, many context/service variables are crucial as well. For instance, the

commercial speed that impacts the productivity of the assets of the bus operator depends also upon variables outside the control of the bus operator, e.g., the slope of routes, percentage of trips with dedicated lanes and/or signal priority systems for buses, traffic conditions, the distance between stops, and so on. In addition, the structure of the demand might be characterised by inherent temporal and spatial unbalances – e.g., a remarkable difference between peak and off-peak demand volumes – yielding a timetable with bus shifts that prevent optimisation of drivers' work shifts. The prevailing methods for calculation of unit standard cost in Italy, which leverage the approaches by ASSTRA (2013) and Avenali et al. (2018), do not allow addressing entirely these aspects.

Based on the above, this paper tries to improve existing approaches for the calculation of the standard cost in Italy, by a more effective disentanglement of all relevant context/service variables, introduced as explanatory variables (*input variables*), from all other factors affecting the unitary costs, that should be treated as parameters (*standardised factors*). Input variables represent specific inputs of the methodology that may vary across bus operators, whilst standardised factors represent standardisable values of the methodology that can be averaged across operators. To preserve practical tractability and real-world applicability, relevant inputs for the proposed methodology include standard management control fundamentals, operations performance indicators, and data in the *General Transit Feed Specification* (GTFS), which embeds relevant information on the spatio-temporal characteristics of the service.

The methodology has been applied to the case study of Azienda Napoletana per la Mobilità (ANM), which is the main transport operator in the metropolitan area of Naples, and one of the main public transport providers in Italy in terms of quantity of vehicle·km provided.

The structure of the paper is the following. Section 2 reviews the literature and reports an overview of the unit operating costs sustained by transport companies in Italy; Section 3 illustrates both the current cogent methodology for the computation of standard unit costs and the proposed methodology; Section 4 describes an application to the real-world case of ANM in Naples (Italy) and discusses policy implications and scalability of the proposed approach; finally, Section 5 draws conclusions and research prospects.

2. Literature review of the Italian experience in public transport costing

2.1. Overview of the literature

Costing and econometric analysis of costs in public transport systems are well-consolidated and widely explored research streams, with contributions spanning over more than 50 years. The unit operating cost has been extensively analysed in different countries and contexts, also depending upon underlying contracts/regulations – e.g.Bhattacharyya et al. (1995), Cambini et al. (2007), Cambini and Filippini (2003), Cowie and Asenova (1999), Dalen and Gómez-Lobo (2003), Farsi et al. (2007), Fraquelli et al. (2001, 2004), Gagnepain (1998), Gagnepain and Ivaldi (2002), Kerstens (1996), Matas and Raymond (1998), Obeng and Sakano (2002), Ottoz and Di Giacomo (2012), Sinner et al. (2018), Wunsch (1996), de Borger and Kerstens (2007). Restricting attention to standard cost estimates, comprehensive reviews of the existing literature are provided, amongst others, by Daraio et al. (2016), Catalano et al. (2019) and Avenali et al. (2020). Dalen and Gómez-Lobo (2003) trace back a first documented experience on the application of standard cost contracts in Norway in the early '90 s and proposed a linear regression model with the total amount of vehicles·km as dependent variable. Hensher et al. (2013) used the Australian data to test a simplified model for the allocation of subsidies from the authority to single operators, whilst Sinner et al. (2018) proposed the use of a cost allocation model for both buses and train in Switzerland.

From a general standpoint, standard costs can be estimated with three approaches.

The first is usually termed *bottom-up* or *analytical* and attempts to estimate the standard cost as the sum of all relevant cost components for a bus operator. Inputs of the bottom-up approach are a set of context/service variables and a target value for each standardized factor. Target values can be defined based either on summary statistics (e.g., percentiles, maximum values, averages) on a set of observations from efficient bus operators, or from best practices. Overall, the bottom-up approach requires cumbersome data collection, and it is thus not commonly adopted.

The second is the more widely applied *top-down* or *synthetic* approach, wherein the standard cost is regressed on a limited set of aggregated input (context/service) variables. The regression is estimated on a sample of observations of output and input variables, that is unit operating costs of bus operators and context/service variables (e.g., commercial speed, average age of operated buses, proxies of the company size). In the practice, the standard cost for a real bus operator can be calculated by applying the regression to its related set of input variables. The main drawback of this approach is that the regression can only approximate the actual causal relationships amongst input variables and the unit cost of the bus operator. In addition, identifying the set of bus operators on which estimating the top-down regression is another relevant issue.

The third approach is termed *hybrid*, because it mixes top-down and bottom-up (usually drivers and rolling stock) calculations of some cost components (Avenali et al., 2018).

2.2. General overview of the unit operating costs of Italian transport companies

As mentioned in Section 1, the allocation of subsidies to public transportation companies has traditionally been based on their historical unit operating costs. The historical cost principle has fostered inefficiencies over the decades, which can be traced to several studies in the literature. This sub-section aims to show an overview of the main inefficiencies in the management of operating costs of transport companies in the Italian context, with a focus on different regions, referring mainly to the work of Papola et al (2017).

Fig. 1 reports the average unit operating cost for Italian bus operators – investigated by Papola et al. (2017) based on 2012 sample estimates – equal to 3.75 €/vehicle·km against an EU average of 2.80 €/vehicle·km, according to the Italian National Observatory for Local Public Transport. Significant differences arise between urban (4.42 €/vehicle·km on average) and interurban (3.25 €/vehicle·km on average) contexts, as well as across regions, ranging on average in between 2.56 €/vehicle·km of Abruzzo and 4.94 €/vehicle·km of Campania. Heterogeneity of unit operating costs is further magnified when looking at bus operators providing at least a million vehicle·km/year in urban contexts in Italy, as reported in the anonymised Fig. 2, yielding a range in between 1.63 and 8.18 €/vehicle·km.

Key attempts to reverse this trend were the Italian Laws 42/2009 and 147/2013, that replaced the ineffective approach based on the historical costs with a new system based on a *standard* unit operating cost, defined as the unit operating cost of an ideal, reasonably efficient bus operator. Consistently, resources for public transport are transferred from the central government to regional governments[1], and then to bus operators, in proportion to the standard unit operating costs (Avenali et al, 2014; Avenali et al, 2016; Avenali et al, 2018; Avenali et al, 2020). Overall, more efficient bus operators – that is, those with a unit operating cost lower than the standard cost – will receive an increased funding from the Region with reference to the previous year, whilst less

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[1] Consistent with the Constitution, the Italian system is characterised by a two-level approach, wherein regional governments act as a middle layer in between the central governments and the regional bus operators.
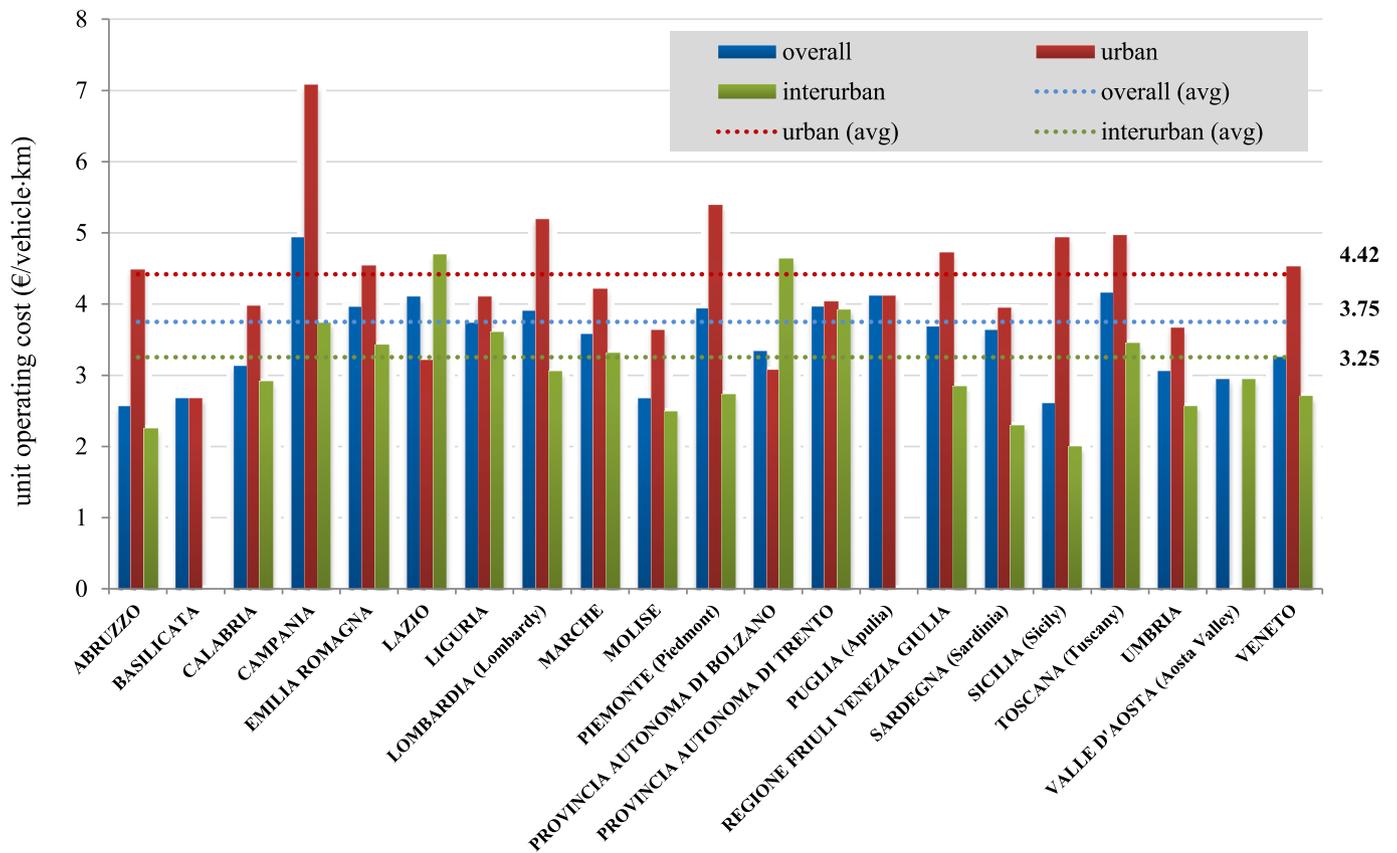
Fig. 1. Unit operating costs (€/vehicle·km) for public transport operators in Italy, by region and by context (urban/interurban). Source: Papola et al. (2017).
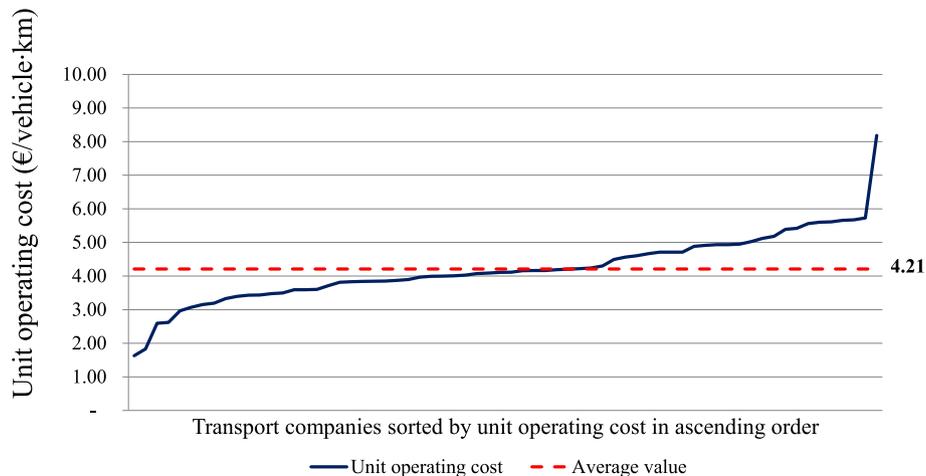

Fig. 2. Distribution of unit operating costs for public transport companies operating at least a million vehicle·km/year in urban contexts in Italy.

efficient bus operators will experience only a partial coverage of their costs.

In the next section, both the current methodology for the allocation of funding in the Italian context and an original methodology for its improvement will be shown.

3. Methodology

3.1. Current calculation of unit standard cost in Italian regulations

The concept of standard costs was introduced in Italy by the Legislative Decree 422/1997, without any methodologies for its practical calculation. The Italian Law 244/2007 established a National Observatory for Local Public Transport at the Italian Ministry for Sustainable Mobility and Infrastructures (MIMS)[2], to which public transit operators must transmit key aggregated economic and operations figures (Italian Law 228/2012), thus enabling calculation of standard unit costs. Specifically, the Italian Ministerial Decree 157/2018 operationalises the calculation of standard costs:

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[2] The Italian Ministry for Sustainable Mobility and Infrastructures (MIMS) was formerly termed Italian Ministry for Infrastructure and Transport (MIT).

- for tramway and subway operators, with an approach, termed *analytical method* by the Decree, resembling a model by ASSTRA (2013);
- for bus operators, with a top-down approach (termed *regression method* by the Decree) proposed by Avenali et al. (2014; 2016).

Avenali et al. (2018) proposed a further hybrid model to deal with the transfer from regional/local authorities to public transport operators.

Given their relevance for the objectives of the paper, the models underlying calculation of unit standard cost in the Italian regulation are described in the following. Calculation of the unit standard costs for bus operator imposed by the Italian Ministerial Decree 157/2018 leverages the top-down model by Avenali et al. (2014) and Avenali et al. (2016), subsequently refined by Avenali et al. (2020). It consists of a multivariate piecewise linear regression, wherein the dependent variable is the unit cost of production of the public transport service, that is the unit operating cost[3] c_{km}^{unit} [€/vehicle·km], expressed as a function of three explanatory variables:

- the *average commercial speed* v_{comm} [km/h], given by the ratio between the total yearly amounts of operated vehicles·km and vehicles·h excluding empty trips, e.g., those between depots and bus terminals at the end/beginning of a shift. Since most of costs by bus operators are available on an hourly basis, the commercial speed v_{comm} is the key parameter allowing for a conversion of these hourly cost in cost per kilometre c_{km};
- a proxy of the *company size*, given by the total amount of kilometres produced per year, excluding non-service runs, denoted with[4] $KM_{s,year}$ [Mkm/year], to capture the aggregate effects of economies (or diseconomies) of scale for bigger bus operators;
- the *degree of fleet renewal* c_{km}^{fleet} [€/km], calculated as the ratio between the yearly cost of the fleet (buses and/or rolling stock) and the total amount of kilometres run per year. The yearly cost of the fleet accounts for either depreciation or rent/leasing rates, over a 15-year conventional useful life. This variable aims to capture the effect of investments for refurbishment/renewal of the operated fleet, including improvements towards higher energy efficiency and technological enhancements.

The model was estimated on a database encompassing observation from 54 Italian public bus operators, of which 26 operating less than 4 Mvehicles·km/year (labelled as small), 15 between 4 and 10 Mvehicles·km/year (medium) and 13 more than 10 Mvehicles·km/year (large), yielding:

$$c_{km}^{unit} = 14.07855 - 0.5923 v_{comm} + 0.50837 \delta_{VC17}(v_{comm} - 17)$$
$$+ 0.06827 \delta_{VC32}(v_{comm} - 32) - 0.18583(1 - \delta_{4Mkm})KM_{s,year} \qquad (1)$$
$$+ 0.01559 \delta_{4Mkm} KM_{s,year} + 1.46083 c_{km}^{fleet}$$

wherein δ_{VC17} takes 1 if $v_{comm} \geq 17$ km/h, δ_{VC32} takes 1 if $v_{comm} \geq 32$ km/h and δ_{4Mkm} takes 1 if $KM_{s,year} \geq 4$ Mkm/year. Avenali et al. (2016) modified slightly (1) by replacing the piecewise linear terms containing the variable v_{comm} with the hyperbolic term $-0.583/(v_{comm} - 5)$. Notably, the coefficient for the variable $KM_{s,year}$ for bus operators running ≥ 4 Mkm/year is positive, indicating that the bigger the company, the higher the chance of diseconomies of scale, as found by Boitani et al. (2013), Avenali et al. (2014; 2016). The model officially adopted by the

Ministerial Decree 157/2018 imposes a lower threshold for the commercial speed v_{comm} in equation (1), equal to 12.5 km/h for buses·km provided in areas with an average altitude greater than 400 m, and 14 km/h otherwise. Although conceptually simple and easy to apply, model (1) is inherently approximated because of its top-down approach.

The hybrid top-down bottom-up model developed by ASSTRA (2013) circumvents this shortcoming with an analytical breakdown of some of elemental service production costs, to account more properly for the context wherein the bus company operates and to distinguish the impact of context/service variables (commercial speed) and standardized factors (e.g., annual net driving hours per driver, average productivity of used vehicles). This comes obviously at the price of increased model complexity.

The logic of the ASSTRA model is illustrated in Fig. 3[5], that highlights the role of the number of drivers and buses as key inputs to calculate a significant share of the unit production cost, being the remaining part aggregated in a single component termed c_{others}. The number of drivers is calculated by dividing the total service kilometres/year $KM_{s,year}$ by the average commercial speed, to turn bus·km into bus·h, and then dividing by the average working hours/year by driver. The number of buses is calculated by dividing the total service kilometres/year $KM_{s,year}$ by a standard parameter expressing the average annual mileage of a single bus. Overall, the model can be applied from two different perspectives: on the one hand, it allows calculation of the standard cost of a bus operator, if fed with standardised values of the model parameters; on the other, it enables detection of the source of inefficiencies of a bus operator with respect to the standard cost, if fed with actual bus operator input parameters. The already mentioned Ministerial Decree 157/2018 largely resorts to the ASSTRA (2013) approach for the calculation of standard costs for tramways.

Different of (1), ASSTRA (2013) does not include company size. The rationale of the ASSTRA (2013) model also inspired the work by Avenali et al. (2018), who leveraged the top-down model (1) to develop a hybrid model with bottom-up calculation of the cost of workforce and of the economic cost of rolling stock, as illustrated in Fig. 4. However, despite their more appealing soundness, the ASSTRA (2013) and the Avenali et al. (2018) models still exhibit an important limitation: the commercial speed is the sole variable through which those models try to capture the heterogeneity of surrounding conditions, and thus their impact on the total cost, across application contexts.

The paper elaborates upon this limitation, by proposing a generalisation of the ASSTRA (2013) model, characterised by a wider set of input variables, capable to account more properly, even though at an aggregated level, for the surrounding conditions wherein a bus company operates. The goal is to make explicit the effect on the cost of some context/service variables, often outside the control of the bus operator. Mainly, the paper proposes to calculate the two key intermediate variables, that is the number of drivers and the number of buses, as a function of the service timetable, proxying the actual space–time structure of transit demand faced by the bus operator, rather than just based on standard values.

3.2. Proposed methodology: A new bottom-up specification of some cost components

The model proposed in the paper leverages the structure of models respectively illustrated in Fig. 3 and Fig. 4. The key difference is that the following further input variables inform the calculation of the number of buses and drivers: service timetable, number and locations of depots, age of buses, and insurance costs. Obviously, calculation of such additional variables should be simple and effective, to ensure practical

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[3] For the sake of readability, unit costs (e.g., per kilometre, driver, bus) are denoted with lowercase letters and total costs with uppercase letters throughout the paper.

[4] As for costs, unit times and distances (e.g., per driver, bus) are denoted with lowercase letters and cumulated times and distances with uppercase letters throughout the paper.

[5] Calculation of total cost in the ASSTRA (2013) model is linear in the number of vehicle·km, thus the unit operation cost in €/vehicle·km provided by the model does depend upon only the commercial speed.
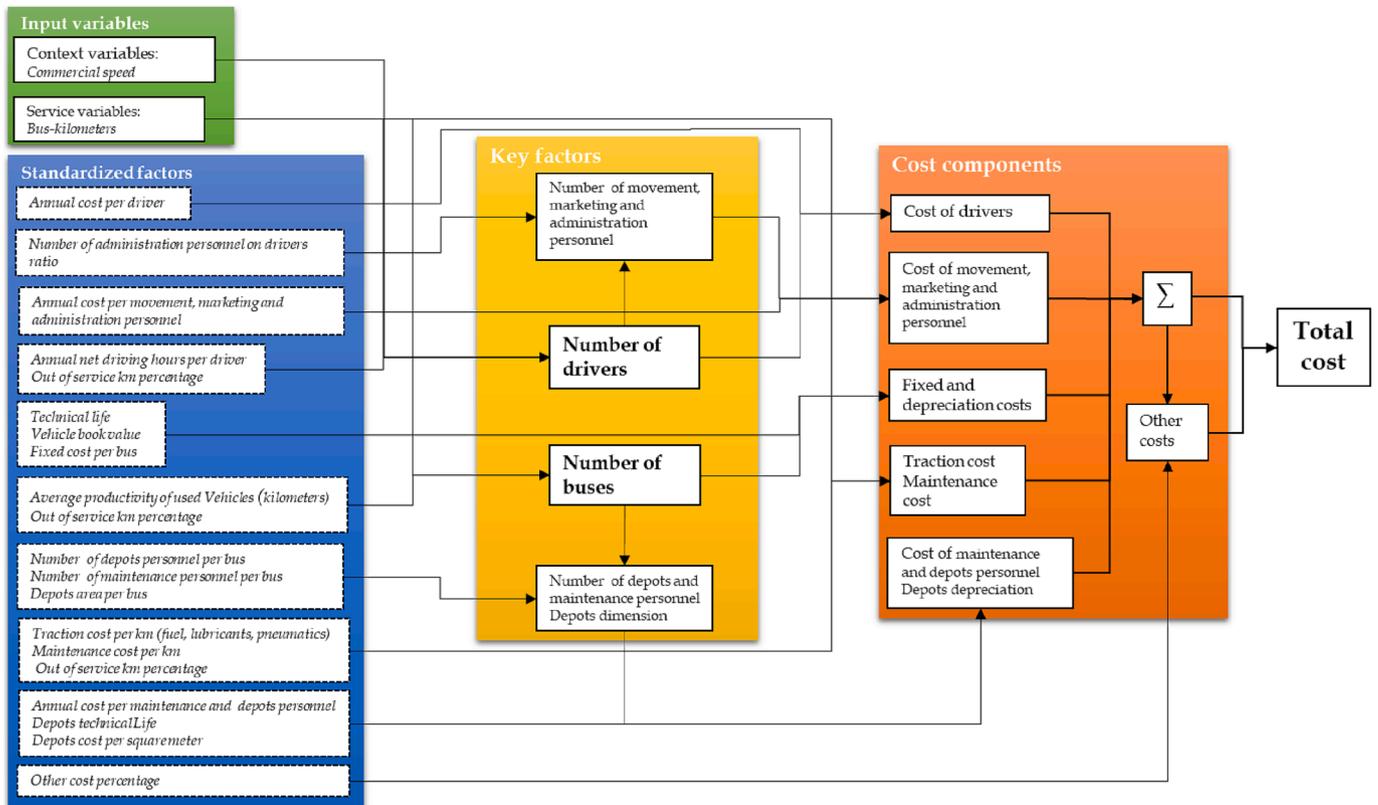
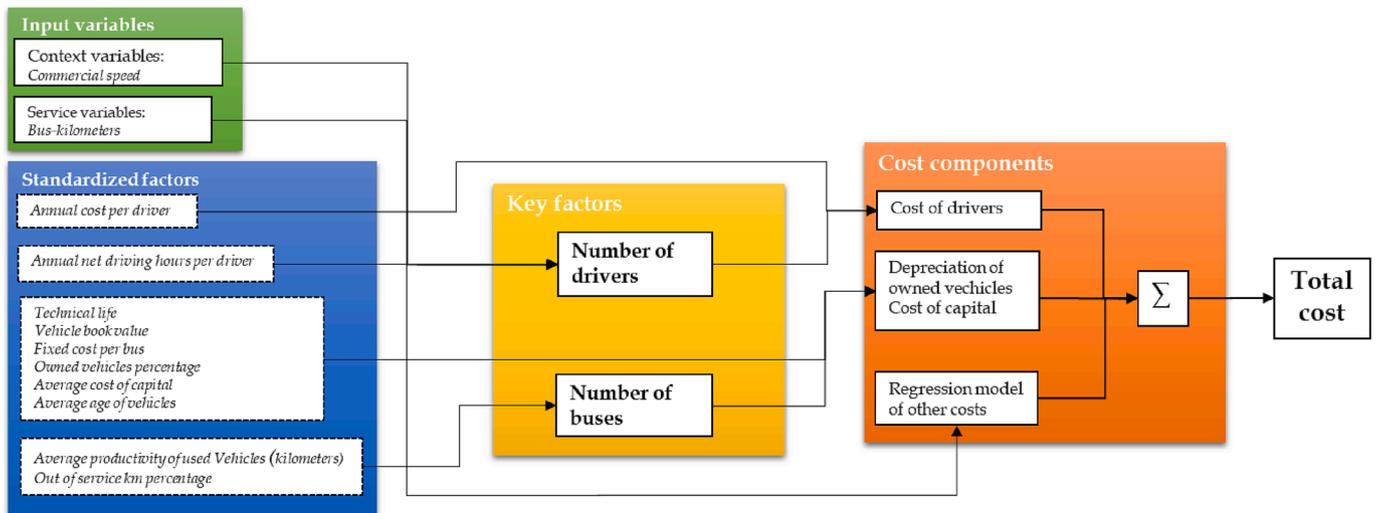**Fig. 3.** Schematic illustration of the ASSTRA (2013) model.

Fig. 4. Schematic illustration of the Avenali et al. (2018) model.

viability of the approach, and must resort possibly to as much homogeneous as possible data inputs. For this aim, the paper leverages the availability of transit data in the *General Transit Feed Specification* (GTFS), also considering that the National Observatory for Local Public Transport at the Italian Ministry for Sustainable Transport and Infrastructures (MIMS) does not collect all relevant information.

The following Section 3.2.1 illustrates how these additional variables can improve the calculation of the number of drivers and buses, whilst Section 3.2.2 highlights other minor differences and some relevant aspects for the application of Section 4.1.

3.2.1. Number of drivers and buses: The proposed approach

Existing approaches calculate the number of drivers by dividing the annual service mileage of the company $KM_{s,year}$, expressed in buses·km, by the average commercial speed v_{comm} and by the average number of annual working hours of a driver h_{year}^{driver}:

$$N_{driv} = \frac{KM_{s,year}}{v_{comm} \bullet h_{year}^{driver}} \tag{2}$$

Expression (2) indicates that the number of drivers depends upon a context variable (i.e., the commercial speed v_{comm}) and a parameter h_{year}^{driver}, which is regarded as standardisable and distinguishable amongst

urban and intercity services, according to Avenali et al. (2018). The paper deviates from this viewpoint and considers h_{year}^{driver} only partially standardisable, being in fact dependent mainly upon transit demand, and upon other both context and service variables such as the number and locations of depots. Specifically, the proposed formula for the calculation of h_{year}^{driver} is the following:

$$h_{year}^{driver} = \pi \bullet h_{year}^{driver,st} \tag{3}$$

where $h_{year}^{driver,st}$ represents a standardised number of driving hours per year and π is a context-dependent variable. In particular, $h_{year}^{driver,st}$ can be easily calculated from the maximum number of driving hours $h_{year}^{drivermax}$ allowed by relevant drivers' regulations and from a standard absenteeism rate α, yielding:

$$h_{year}^{driver,st} = (1 - \alpha) \bullet h_{year}^{drivermax} \tag{4}$$

On the contrary, π embeds two context-related parameters, that is:

$$\pi = \delta \bullet (1 - \varepsilon) \tag{5}$$

wherein δ is a [0, 1] parameter that quantifies the unavoidable inherent inefficiencies resulting from the match between work shifts and service timetable, and ε measures the incidence of empty trips, mainly related to movements from/to depots at the start/end of bus operations, hence depending upon their number and locations. In more detail, δ is context-dependent because the service timetable is a function of transport demand patterns and should usually also comply with constraints imposed by the funding public entity on the level-of-service of the bus operator (e.g., minimum frequency, number of runs/day, service paths). ε is context-dependent as well, because locations and number of depots can hardly be modified – usually not at all, because of space constraints in dense metropolitan areas, or only in the long term – or they might be imposed for instance as a given asset in a tendering procedure for the selection of bus operators.

That said, expression (5) is viable for the purposes of the paper only if δ and ε can be practically measured. In this respect, given the obvious unavailability to third parties of detailed company data, the paper proposes a novel methodology based on a timetable in GTFS format, usually easy to access and standardised across bus operators: details are reported below.

Calculation of δ, N_{driv} and N_{buses}

With reference to δ, availability of a GTFS timetable allows calculation of the number of buses in simultaneous operation throughout the day, consistent with a given daily service schedule: a visual representation of the daily service schedule is the blue line drawn in Fig. 5 for a hypothetical situation. The number of bus in simultaneous operation triggers a consistent drivers' work shift schedule, that can be designed based on heuristics or optimisation algorithms (see e.g,. Ernst et al., 2004 for a comprehensive review of the topic). In the hypothetical example of Fig. 5, the number of drivers in simultaneous service is depicted with an orange line, that should intuitively envelope the corresponding vehicles' line.

Areas below the blue curve and the orange curve represent the total amount of buses·h/day H_{day}^{buses} and drivers·h/day $H_{day}^{drivers}$ respectively, and the latter should necessarily be greater than the former, at least under fully manned operations. Thus, δ can be intuitively defined as:

$$\delta = \frac{H_{day}^{buses}}{H_{day}^{drivers}} \tag{6}$$

Importantly, the procedure illustrated for the calculation of δ provides also a reliable estimate of both the number of buses $N_{buses,min}$ and the number of drivers $N_{driv,min}$ needed to operate a typical working day, accounting for the already mentioned constraints on the timetable. For this aim, it suffices recognising that the maximum of the blue curve in Fig. 5 expresses the minimum number of buses needed contemporarily

to manage a given timetable and hence also the minimum number of buses $N_{buses,min}$ that a company must operate. This number can be improved by 10–15% to account also for a reserve and for buses in maintenance, yielding N_{buses}. Similarly, the overall number of work shifts needed to match the orange curve (i.e. to envelope the blue curve) indicates the minimum number of drivers $N_{driv,min}$ to operate a given timetable.

Interestingly, this also triggers a different approach for estimating N_{driv}, deviating conceptually from the average annual-based approach underlying equations (2)–(5). Indeed, the calculated minimum number of drivers $N_{driv,min}$ with the above described GTFS-based analysis related to the busiest day of the year, can be amplified with a percentage reserve α equal to the absenteeism rate, yielding a final number of drivers equal to $N_{driv,min}/(1-\alpha)$. In the practice, one might consider, at the end, the maximum number of drivers provided by the two approaches.

Calculation of ε

The parameter ε in equation (5) reflects the incidence of empty trips, that is:

$$\varepsilon = \frac{H_{day}^{busesempty}}{H_{day}^{buses}} \tag{7}$$

being $H_{day}^{busesempty}$ the total number of bus·hours/day related to the empty trips. ASSTRA (2013) regards (7) as a standardised parameter. Its actual estimation would require detailed data from the management control of the bus operator, however an upper bound can be estimated as follows. Let D and T be respectively a set of depots and a set of bus terminals (i.e., where service runs start/end) and let $dist(d,t)$ be the distance between a depot $d \in D$ and a terminal $t \in T$. Each bus terminal $t \in T$ is assumed to be served by the nearest depot $d_t \in D$, that is with a distance equal to $dist(d_t,t) = \min_{d \in D}\{ dist(d,t)\}$, and empty runs are allowed only between depots and terminals, i.e. direct bus re-allocation from a terminal to another is not possible. Letting $E[dist(d_t,t)]$ be the average distance between all terminals and their corresponding depots, it occurs:

$$H_{day}^{busesempty} = \frac{N_{depotruns} \bullet E[dist(d_t,t)]}{v_{comm}} \tag{8}$$

being $N_{depotruns}$ the minimum total number of empty runs between terminals and depots.

Thus, substitution of (8) into (7) operationalises the dependency of ε upon context variables, that is the number of depots and their locations, as well as the service timetable and the starting/ending stops for each service. This marks a difference with the approaches wherein incidence of empty trips is fixed independently of the application context. Like in the case of δ, the calculation of such variables is needed to be based on easily observable information, to operationalise the proposed approach. In particular, $N_{depotruns}$ can be computed based on the assumption that trips between terminals and depots occur only twice for each bus in service. Moreover, calculation of $E[dist(d_t,t)]$ requires knowledge of the locations of terminals and depots; the former comes directly from the service timetable in GTFS format, whilst the latter should be provided by the bus operator.

3.2.2. Other differences and relevant aspects

The main differences of the proposed approach lie in the calculation of the number of buses and drivers, already described in Section 3.2.1. As illustrated in Fig. 3 and Fig. 4, they represent the main input for many other cost components, whose calculation is performed in the same way as ASSTRA (2013) and Avenali et al. (2018), except for small changes highlighted below.

A first difference refers to the calculation of the depreciation cost of buses, given by the following expression:

$$C_{depr} = N_{buses} C_{depr}^u (1 - w_{age}) \tag{9}$$

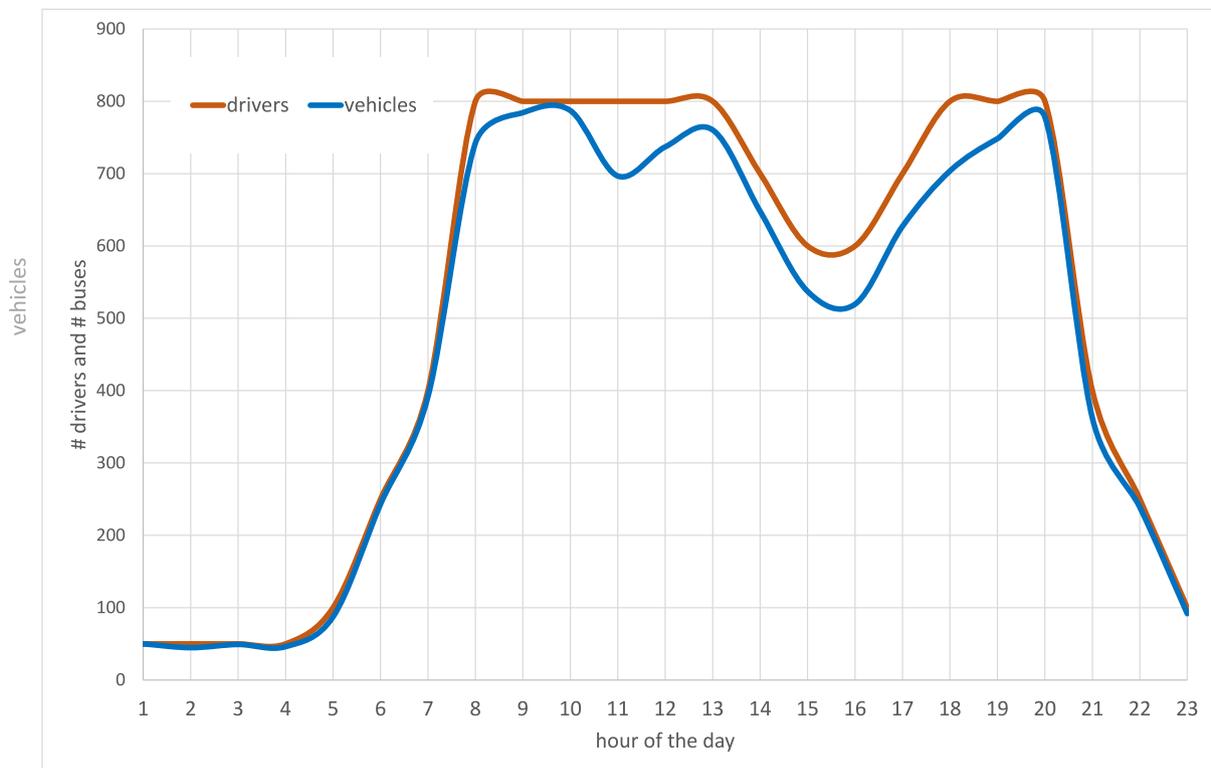wherein N_{buses} is the number of buses in the fleet calculated as

Fig. 5. Illustrative example of the within-day evolution of the total number of drivers' working and vehicles in operations.

illustrated in Section 3.2.1, C_{depr}^u is the average annual depreciation cost, given for a single bus by the ratio between its purchase cost and its useful life, usually standardised to 15 years, and w_{age} is a corrective factor that represents the percentage of buses in the fleet with an age greater than the (standardised) useful life in the fleet. This is conceptually sounder, because it assigns a null depreciation cost for buses still in service over their useful life. Notably, ASSTRA (2013) adopts equation (9) without the corrective factor w_{age}: this yields an overestimation of the depreciation cost and leads to the odd effect of pushing bus operators not to renew their fleet to "gain" in terms of standard costs, at the price of deteriorating the quality of service. As a side note, it would be desirable also to link maintenance cost to the age of fleet. However, this requires a specific analysis based on a sufficiently large data sample and is thus left as future research.

A second difference lies in the calculation of the insurance costs, that cannot be standardised, given their significant differences across regions in Italy, because of the heterogeneity in the average number of accidents per year. In this respect, the average insurance cost per bus should be provided by the bus operator or at least a correction factor of the average standard national value should be introduced, based on publicly available regional insurance values.

Finally, it is worth recalling, for the application illustrated in Section 4, that estimation of the number of drivers and of buses allows in turn, amongst other components, calculation of the corresponding number of non-drivers, through the following formula taken by the Italian Ministerial Decree 157/2018 for tramway and subway operators:

$$N_c = \gamma_{driv}^c N_{driv} + \gamma_{bus}^c N_{bus} \tag{10}$$

wherein N_c is the numerosity of non-driving personnel by category c, and γ_{driv}^c and γ_{bus}^c are proportionality parameters that take the values reported in Table 1, taken by ASSTRA (2013), which clarifies that the numerosity of some of the non-driving categories depends upon the number of drivers and some other upon the number of buses. Once known N_c from (10) the total cost of non-driving personnel can be straightforwardly determined as:

Table 1
Value of parameters in equation (10) for the calculation of non-driving personnel.

Category of non-driving personnel	ASSTRA (2013)	
	γ_{driv}^c	γ_{bus}^c
operations management/control	0.025	0
depots	0	0.12
maintenance	0	0.2
administration	0.14	0

$$C_{\text{no driv}}^{\text{TOT}} = \sum_c N_c * c_{year}^c \tag{11}$$

which, divided by the total annual service mileage, provides in turn the cost per kilometre per year.

The following Fig. 6 represents schematically the proposed model.

4. A real-world application: The case study of ANM in Italy

4.1. Model application

As illustrated in the introduction, the proposed methodology has a twofold objective: on the one side, it aims to support public bodies in a fairer quantification of the standard unit cost, by means of a more effective disentanglement between context/service variables and standardized factors; on the other, it helps bus operators to identify relevant weaknesses to overcome, in the attempt to match their target standard cost. This section showcases the viability of the proposed methodology by illustrating the real-world case study of *Azienda Napoletana Mobilità* (ANM), the main bus operator in the city of Napoli (Italy). Each cost component is calculated with the ASSTRA (2013) model and with the proposed approach to analyse relevant differences, and both are contrasted with the corresponding real ANM figures to highlight pros and cons of standardisation.
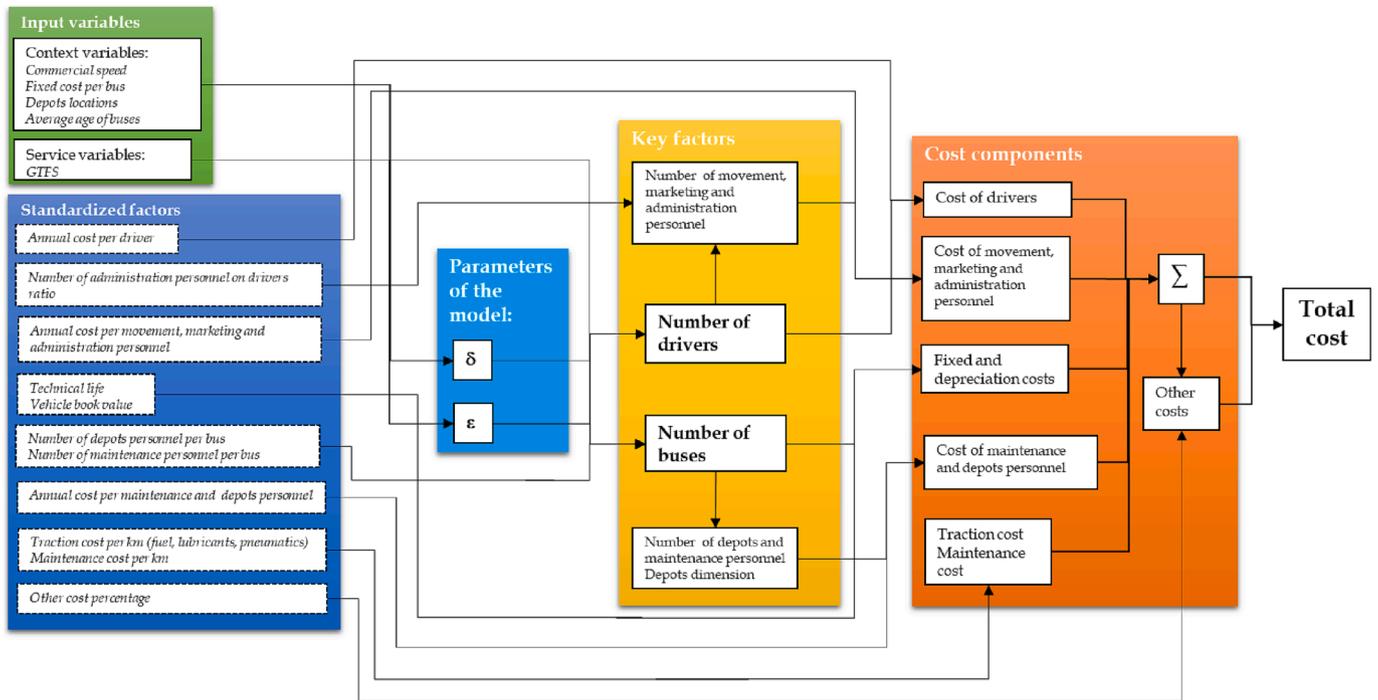
Fig. 6. Schematic illustration of the proposed model.

ANM operated 11.4 million bus·km in 2018 (i.e., the variable $KM_{s,year}$), of which 8.8 million bus·km of services within the city of Naples and 2.6 interurban million bus·km, with an average commercial speed v_{comm} observed by the company of 11.4 km/h.

Calculations of π via its components in equation (5), as illustrated in Section 3.2.1, implies the following:

- the real-world version of the conceptual diagram in Fig. 5 is reported for ANM in Fig. 7. The number of buses in contemporary operations by the time of day has been obtained, as mentioned in Section 3.2.1, using the *Google Transit* data in GTFS format provided by ANM.

Overall, following the methodology reported in Section 3.2.1, $\delta = 0.922$. A high δ (close to 1) is a natural consequence of the peculiarity of the ANM bus services, substantially flat across the day, whilst a greater heterogeneity between peak and off-peak service intensity might yield lower δ values;

- calculation of ε first requires the calculation of empty bus•h/day $H_{day}^{busesempty}$ through equation (8). Under the assumptions introduced in Section 3.2.1, $N_{depotruns}$ is calculated from Fig. 7, whilst the location of ANM depots and bus terminals, depicted in the left-hand side of Fig. 8, yields the frequency distribution of the distance between each
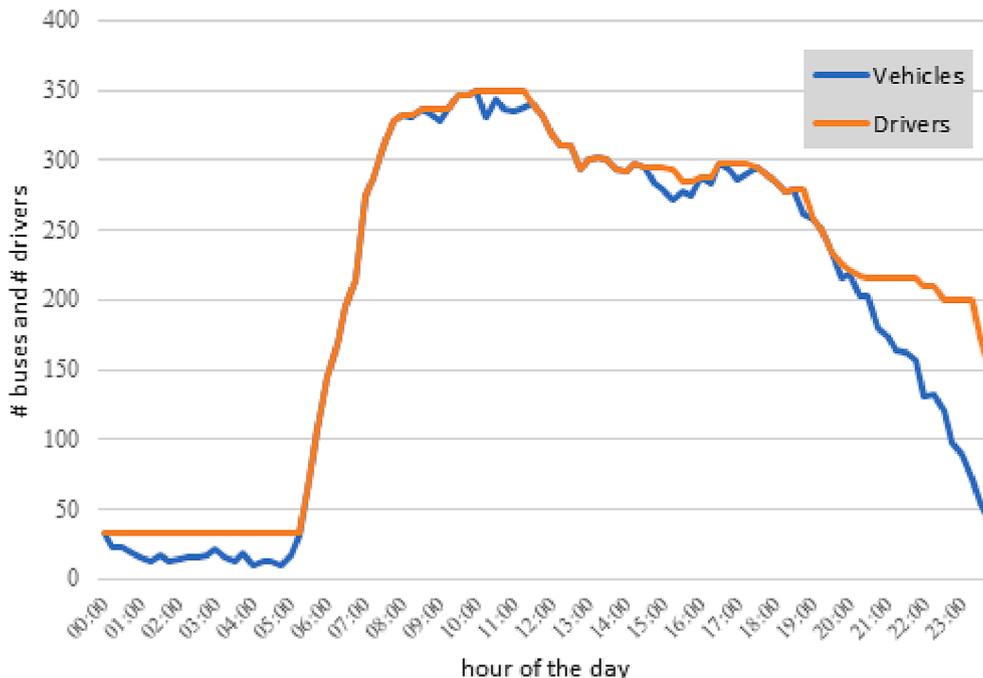

Fig. 7. Within-day evolution of total number of drivers and buses in simultaneous operation: the real case of ANM (Italy).
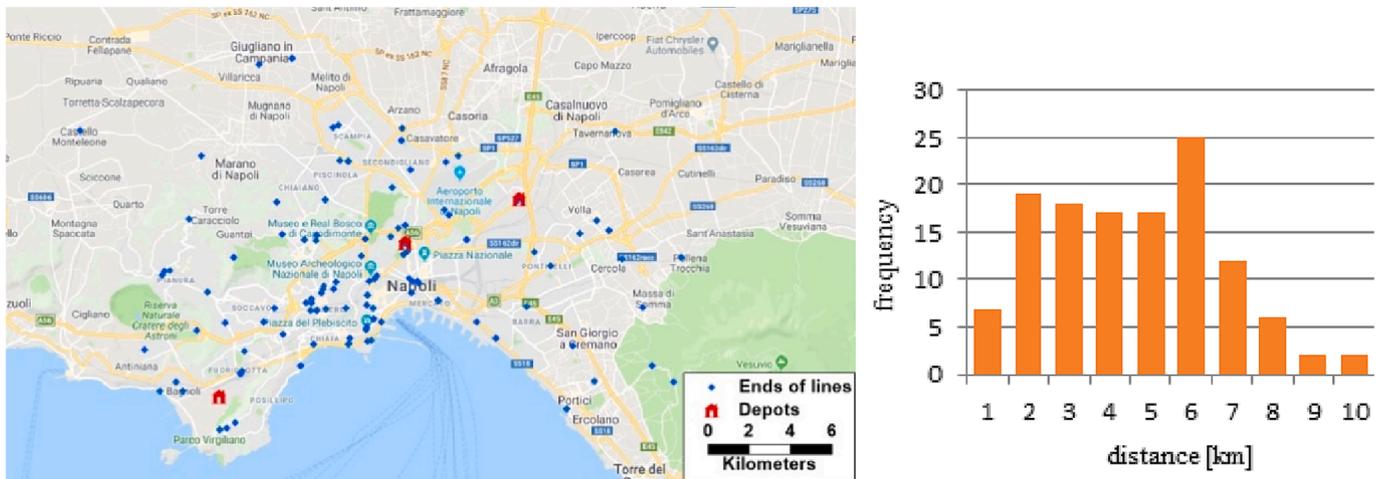
Fig. 8. Location of bus terminals (blue dots) and depots (red dots) for ANM (left) and frequency distribution of the distances between each bus terminal and the closest depot (right).

bus terminal and the closest depot reported in the right-hand side of Fig. 8, with an average of 3.05 km. Overall, substitution in equation (7) leads to ε = 0.052: this low value is a natural consequence of the urban nature of the ANM service.

As a result, equation (5) show that π = 0.922·(1–0.052) = 0.874, and accounting for an absenteeism rate α = 0.03, equations (2) yields 747 drivers, which corresponds to a driver unit cost of 2.77 €/km with the standard annual wage and 2.97 €/km with the specific ANM figure. GTFS-based calculation related to the busiest day of the year yields $N_{driv,min}$ = 721, corresponding to a final number of drivers equal to 721/(1–0.03) = 743. The ASSTRA (2013) model leads to 762 drivers, corresponding to a unit cost of 2.83 €/km with the standard annual wage and 3.03 €/km with the actual ANM figure.

Interestingly, the proposed approach matches more closely the actual ANM figure (see Table 1) with respect to ASSTRA (2013), whose overestimation comes from discarding the inherent mismatch between bus shifts and drivers' shifts. This is not reflected in a corresponding overestimate of drivers' unit cost only because the standard annual wage considered by ASSTRA (2013) is lower than the actual ANM figure. Furthermore, it is worth noticing that the GTFS-based approach perfectly matches the true ANM number of drivers. However, it is worth underlining that the objective here is not to check that the proposed approach fits better the specific figures of a bus operator, rather to showcase its robustness with respect to variations in service timetables, as illustrated in Section 4.2.

The GTFS data-based analysis previously mentioned also yields, as described in Section 3.2.1, a minimum number of buses equal to 349, leading to a final figure of 401 under the assumption of a 15% reserve which yields an annual mileage per bus of 29.162 km/bus/year. Both ASSTRA (2013) and Avenali et al. (2018) assume a standard annual mileage of 45.000 km/bus/year, not feasible in the light of the timetable that ANM should operate, as shown by the GTFS data-based analysis. Overall, this implies a significant underestimation of the number of buses - equal to 269 - and of all related costs. The real values for ANM – that is, 571 buses and an annual mileage of 20.479 km/bus/year – show a not-so-dramatic inefficiency as highlighted by ASSTRA (2013) and Avenali et al (2018).

Specifically, the number of buses impacts the following cost components, as illustrated schematically in Fig. 3:

- *fixed costs.* The ASSTRA (2013) model provides a fixed cost for ANM of 0.15 €/km, against the more than three times higher value of 0.55 €/km by ANM. The approach of Section 3.2 yield instead a more realistic value of 0.39 €/km, thanks to a more correct estimation of

the number of buses and also of the unit cost per bus, resulting from a tailored application of context-related variables (e.g., insurance costs);

- *depreciation costs.* The ASSTRA (2013) model leads to a cost of 0.35 €/km, resulting from a joint underestimation of the number of buses and an overestimation of the depreciation cost per bus. The proposed approach, accounting for the average age of the ANM fleet, equal to 14.2 years, yields a coefficient w_{age} = 0.53 in equation (10) and thus a depreciation cost of 0.28 €/km through equation (9). Importantly, ANM data provide a very low depreciation cost of 0.07 €/km, primarily due to the presence of a significant number of buses purchased via public grants and thus not accounted for in the company balance;

- *cost of maintenance and depots personnel.* The ASSTRA (2013) model leads to a cost of 0.39 €/km, while the proposed approach, accounting for a larger number of N_{buses}, yields a cost of 0,58 €/km.

The ratio between drivers and non-drivers, included in equation (10) in Section 3.2.2, represents undoubtedly one of the most critical elements for the case study. Indeed, ASSTRA (2013) yields a non-driver/driver ratio of 0.28, against an actual much higher value from ANM of 0.84, corresponding to an incidence of 0.75 €/km for ASSTRA (2013) and 2.82 €/km for ANM. Inserting into equation (10) the number of drivers and buses calculated with the proposed approach yields a ratio of non-driver/driver equal to 0.34, corresponding to an incidence of 1.14 €/km.

The remaining cost components depend only upon total mileage, namely:

- *traction costs.* The tested models yield a similar[6] value of around 0.50 €/km, also consistent with actual ANM data. It is also worth recalling that ANM operates in an urban context, wherein the commercial speed is inherently lower and fuel consumption is higher, whilst an extra-urban context would likely magnify differences across approaches.

- *maintenance costs.* ANM data yield 0.093 €/km – not including maintenance-related workforce – a remarkably lower figure with respect to the literature, also considering the average bus age. The proposed model utilizes the ASSTRA (2013) value, thus the two figures coincide.

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[6] The slight difference between ASSTRA (2013) and the proposed model lies in the different calculation of the non-service mileage in buses·km.

Overall, the proposed approach yields the values of the cost components reported in Table 2.

The proposed bottom-up approach has the further advantage, with respect to the ASSTRA model, to make explicit further input variables and hence to identify the real inefficiencies of a company more properly. In particular, the application of the proposed method to the real case study of ANM reveals that internalisation of some context/service variables allows a more realistic calculation of the number of drivers and buses, and their related costs, thus ameliorating the effectiveness and the equity of a standard cost approach.

4.2. Model sensitivity and policy implications

The application of the method presented in Section 3.2 to the case of the bus operator ANM in Naples (Italy), presented in Section 4.1, showed its viability and its capability to account easily for both context and service variables. This section illustrates how the proposed approach can help identify effective actions to reduce the unit operating cost per kilometre, by quantifying the elasticity of the model output - i.e. the unit cost - with respect to key inputs. Relevant inputs are discussed separately in the next sub-sections.

4.2.1. Demand-oriented timetable

The first analysis deals with the service timetable the company must operate, which enters the calculation of Fig. 3 and Fig. 4 for the real case of ANM. In general, the proper design of a service timetable depends upon the underlying transport demand – see e.g., Cascetta (2009) and de Ortúzar and Willumsen (2011) – and thus it should be regarded as an input variable. In addition, companies operating under public subsidies should often comply with a timetable designed by the subsidising public body also to match social objectives (e.g., minimal levels of mobility) not necessarily consistent with service efficiency. In this respect, the proposed approach allows estimating the impact of different timetables on the unit operating cost per kilometre.

By way of example, Fig. 9 depicts a variation of the timetable in Fig. 7, built by keeping the total KM_{year} constant and changing only the within-day allocation of services, to match more closely the common bimodal peak/off-peak transport demand curve.

Interestingly, designing drivers' work shift on such timetable reduces δ from 0.92 for the timetable in Figs. 7 to 0.82 for the timetable in Fig. 9, again in the absence of split shifts. Assuming no changes in commercial speed, this corresponds to a change in π in equation (3) from 0.872 to 0.777, implying in turn an overall unit cost of drivers of 3.34 €/km, that is a 12.5% increase with respect to the current situation (Table 2), and with a consistent increase in other linearly-related cost components.

4.2.2. Location of depots

Another application deals with changes in the number and in the location of depots. The context under analysis does not represent a very significant test bed in this respect, because bus operators in urban services are usually characterised by depots close to bus terminals.

Table 2

Absolute values and percentage incidence of cost components [€/km] for ANM (Italy) calculated with the approach proposed in Section 3.2.

	ANM data	ASSTRA	proposed model
Quantity	[#]	[#]	[#]
N_{buses}	571	269	401
$N_{Drivers}$	742	762	747
Cost component	€/km	€/km	€/km
Drivers	2.95	2.83	2.77
Non-driving personnel	2.82	0.75	1.14
Depreciation	0.07	0.35	0.28
Fixed costs	0.55	0.15	0.39
Maintenance	0.09	0.16	0.16
Traction	0.50	0.53	0.52

Anyway, a scenario with the removal of the most western depot in Fig. 9, named *Cavalleggeri*, has been hypothesized, leading to an increase in the average distance between depots and bus terminals from 3.05 km to 4.03 km, corresponding to an increase of ε from 0.052 to 0.067, yielding a not appreciable increase of + 1.2% of the total cost.

4.2.3. Fleet size and age

The impact of interventions on fleet size can be evaluated straightforwardly, by resizing the fleet to N_{buses}, computed as described in Section 3.2.1. This would correspond for ANM to an overall cost reduction of only 6%, resulting of a reduction of the fixed costs of 2.4% and a reduction of the cost of maintenance and depot workforce of 3.6%. A simultaneous resizing and renewing of the fleet – leading to an average useful life of 7.5 years and a correspondent $w_{age} = 1$ – would yield in any case a 2.5% reduction, because of an increase in depreciation costs.

4.2.4. Staff costs and effects of commercial speed

This is an interesting analysis, generally allowed by all bottom-up models, because the workforce accounts for 64% of the total unit cost (Table 2). As already mentioned in Section 4.1, the incidence of non-driving personnel is very high for ANM with respect to the average national data. If the ratio between the number of drivers and the number of non-drivers were aligned to the ASSTRA (2013) value γ = 0.28, instead of the current value γ = 0.84, a 15.6% reduction of the total unit operating cost would be achieved.

The other key factor impacting on staff costs is the commercial speed v_{comm}: as expressed by equation (2), the relationship between the total unit cost in the model and the commercial speed is hyperbolic in the range of commercial speeds normally experienced in urban contexts[7], yielding a relationship between commercial speed and cost reduction depicted in Fig. 10. This implies a remarkable elasticity of the total cost to the commercial speed in its usual range in urban contexts: by way of example, an increase for ANM of v_{comm} from the current value to 13.5 km/h would reduce the unit operating cost of about 10%, and a further increase to 16.5 km/h would correspond to a 20% cost decrease.

GTFS data used in the study allow drawing an interesting policy consideration on how to improve the commercial speed, usually depending upon factors exogenous to bus operators, such as average traffic conditions, presence of reserved lanes, bus signal priority systems, and so on. In this respect, the left-hand side of Fig. 11 illustrates the structure of the network of bus services run by ANM in the average workday, corresponding to the vehicles·km by road depicted in the right-hand side of Fig. 11; overall, only 550 km of road infrastructures are covered by ANM services. Based on such data, a Pareto diagram of the distribution of vehicles·km has been elaborated, as reported in Fig. 12.

Interestingly, 10% of the total vehicles·km cover only some 2% of the overall ANM network (i.e., summing up to 550 km) corresponding to 11.5 km of the road network, whilst 20% of the total vehicles·km cover 5.3% of the network, corresponding to 29 km. This means, in the practice, that public investments aimed to improve the commercial speed to 20 km/h along those 11.5 km, e.g., by means of reserved lanes, would lead to a reduction of the cost via the proposed model of 6.3%, that is about 6.5 M€/year. Similarly, an upgrade of the commercial speed to 20 km/h on the aforementioned 29 km would lead to an 11.6% saving.

5. Conclusions and research prospects

This paper has generalised some aspects of the bottom-up approach by ASSTRA (2013) and Avenali et al. (2018) for the estimation of the

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[7] In fact, in urban contexts the fuel consumption diminishes when the commercial speed increases, and an increase of fuel consumption can be observed only moving to appreciably higher commercial speeds, typical of extra-urban contexts.
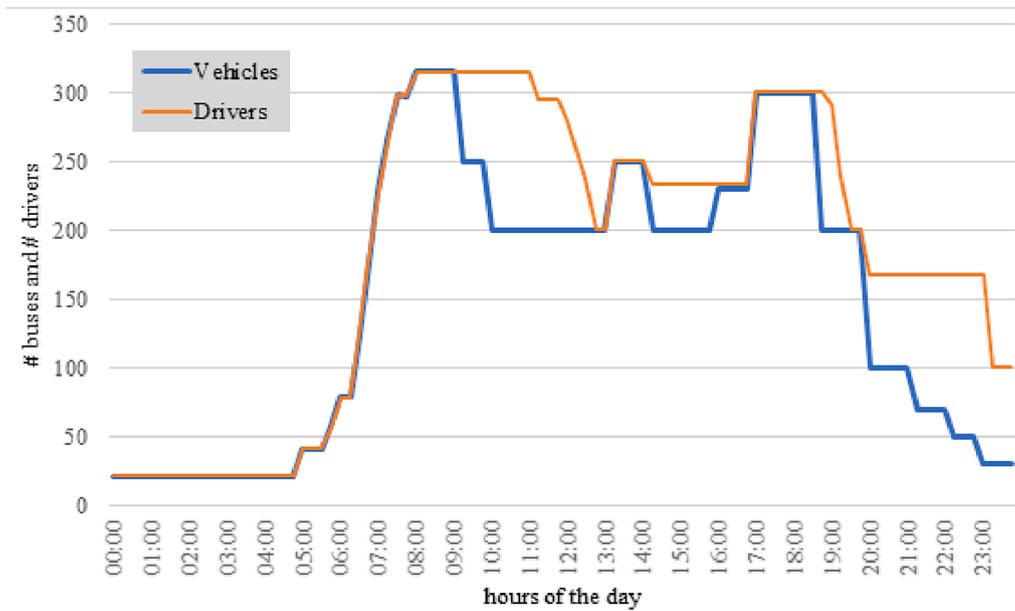
Fig. 9. Alternative assumption on within-day evolution of the total number of drivers and buses in simultaneous operations for ANM, keeping the total KM_{year} unchanged.
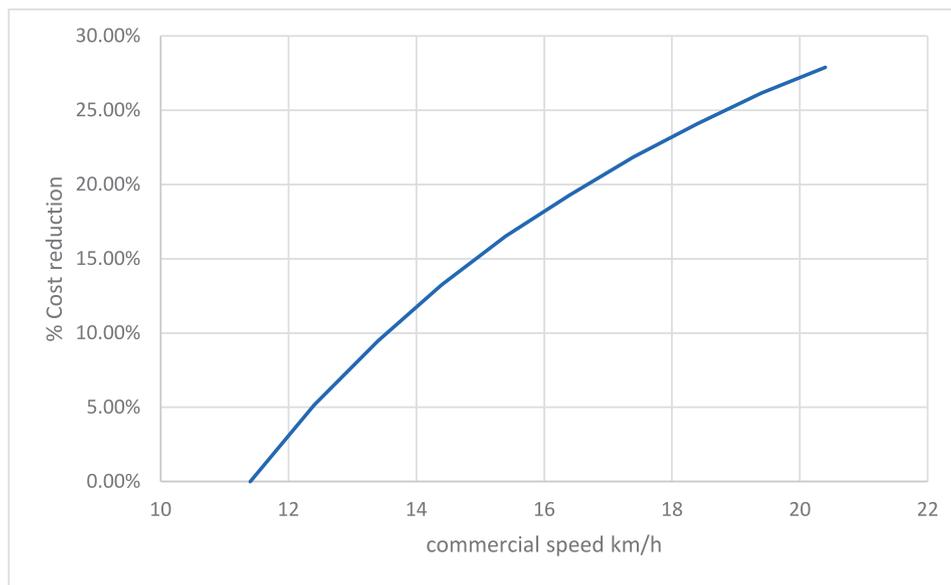

Fig. 10. Relationship between commercial speed and total unit cost [€/km] for ANM (Italy).

unit cost for bus operators. The proposed approach leverages standard management control fundamentals, operations performance indicators, and data in the *General Transit Feed Specification* (GTFS) by Google format. This enables bus operators to identify suggestions for improvements of their performance and public bodies to apply standard cost principles more effectively. For instance, the proposed approach allows estimating the impact of different timetables, depots location, and fleet age on the unit operating cost/km via the parameter δ in equation (6): this might help public bodies to quantify the inherent inefficiency of their timetables and thus take it into consideration in the estimation of the standard unit cost. On the contrary, the models proposed by Avenali et al. (2014) and Avenali et al. (2016) and by ASSTRA (2013) are rigid with respect to such timetable change.

The model has then been applied to the real case of *Azienda Napoletana Mobilità* (ANM), the biggest bus operator in the city of Naples (Italy). Results of the application showcased the viability of the

proposed approach to identify the correct standard cost on the one hand and the real inefficiencies of a bus operator on the other, based on relevant context/service specific variables.

Furthermore, company-oriented, and policy-oriented (specifically, a demand-oriented timetable, see Section 4.2.1) implications enabled by the proposed approach have been discussed as well.

It is worth pointing out two straightforward and interesting research prospects. The former is based on recognising that bottom-up models need a clear distinction between urban and extra-urban services, due to their inherent differences (commercial speed, within-day distribution of the demand, higher incidence of empty trips): thus, it is needed to extend the proposed approach to bus operators belonging to this segment. The latter refers to the need to specify in a more disaggregate manner other cost components, with the objective of better disentanglement between context/service variables and standardized factors: by way of example, the research showcased the importance of relating
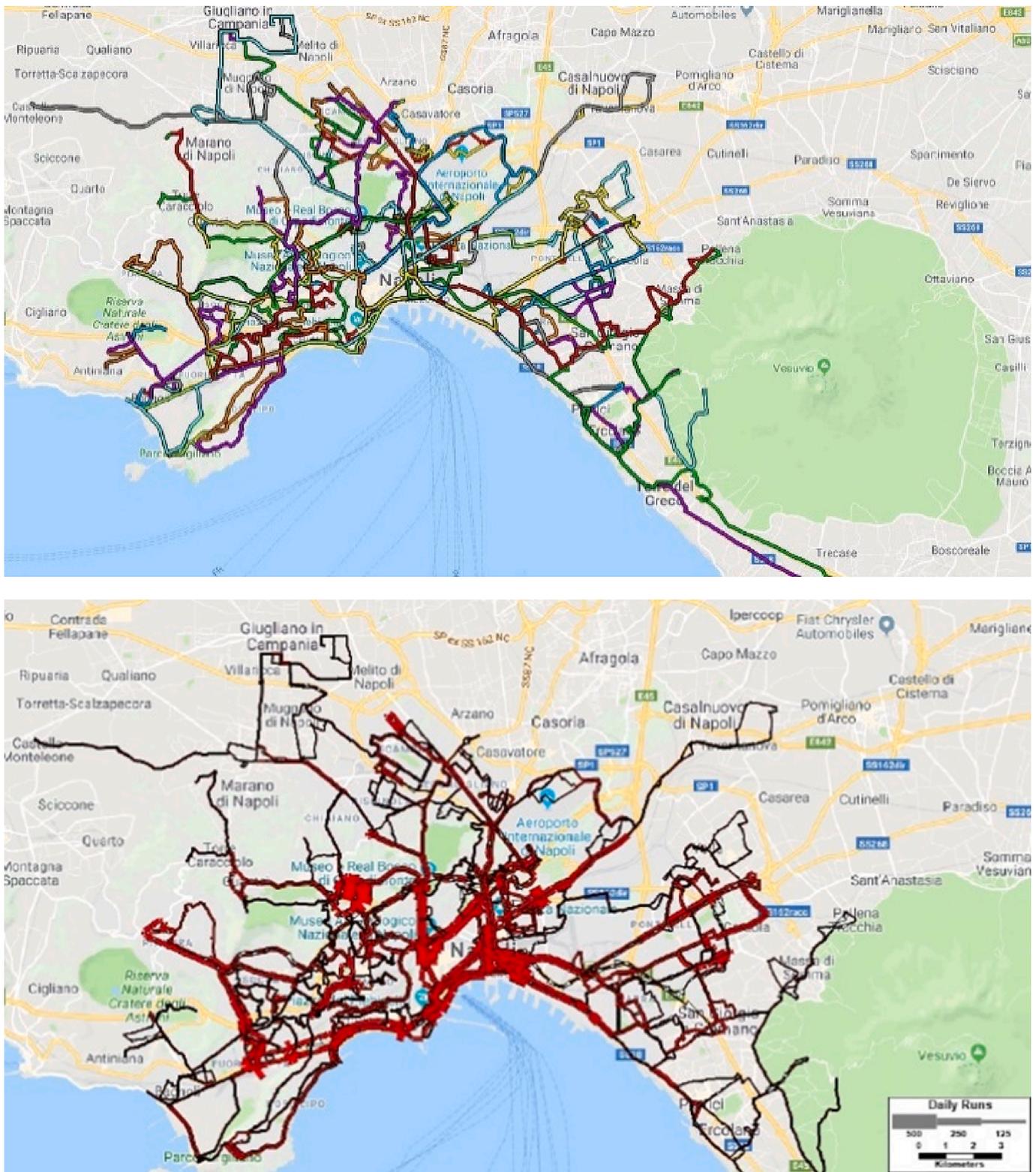
Fig. 11. Representation of the services run by ANM in the average working day in Naples (Italy) based on GTFS data: service routes (top) and vehicles·km by road (bottom).

maintenance costs to the average life of buses.

CRediT authorship contribution statement

Fulvio Simonelli: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Software. **Andrea Papola:** Conceptualization, Writing – review & editing, Supervision. **Fiore Tinessa:** Resources, Writing – review & editing. **Daniela Tocchi:** Writing – review & editing. **Vittorio Marzano:** Conceptualization, Writing – original draft, Resources, Funding acquisition.
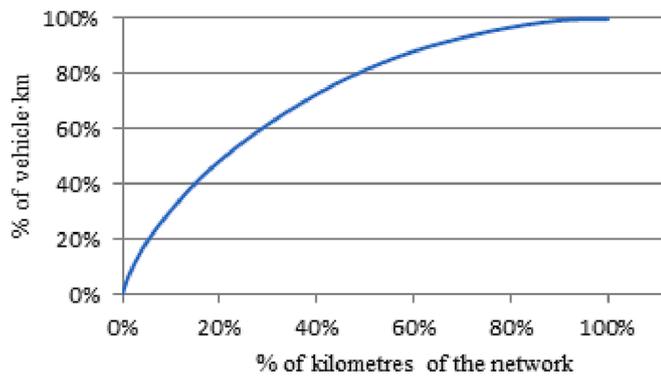
Fig. 12. Distribution across the ANM network of vehicles·km run by ANM in the average workday.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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