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BUS NETWORK CHARACTERISTICS FOR PROMOTING SUSTAINABLE URBAN MOBILITY SYSTEMS

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Abstract. The present study deals with the systematic analysis of the bus network characteristics in many Italian cities and towns, characterized by a supply of public transport services mainly based on buses. The aim of the analysis is to derive the key characteristics for providing effective public transport services. The database built for the study is related to 54 municipalities, with a population from 80,000 to 360,000 inhabitants, and it is composed by a large set of indicators about supply and demand of the bus services network and of the territorial characteristics of the municipalities. The results of the analysis permit to underline the existence of very different condition about level of provided services, impacting on the level of demand using the public transport. These differences are not only related to the territorial characteristics but are also due to completely different characteristics of the supply.

Keywords: bus network, geographical characteristics, overall level of supply, built-up area, ridership.

JEL Classification: L91Transportation: General.

Introduction

Public transport services represent one of the main solutions for promoting a more sustainable urban mobility system but there are still many critical issues about the level and the effective quality of current services. A CIHT study (Chartered Institution of Highways & Transportation, 2018) confirms the need of providing high-quality bus services aa an essential part of an integrated approach to sustainable urban transport. Matas and Raymond (1998) clearly explain the presence of relationships between technical characteristics and efficiency of urban bus services. Moreover, Fitzová et al. (2018) show that bigger cities with greater population densities are more efficient than smaller cities and one of the key efficiency factors for public transport system is the structure of the city transport system. The literature analysis confirms the need of additional research efforts as stated by Daraio et al. (2016) after a critical review about efficiency and effectiveness of the urban public transport sector.

Starting from such issues, the present study deals with the systematic analysis of the bus network characteristics in many Italian cities and towns, characterized by a supply of public transport services mainly based on buses. The database built for the study is related to 54 municipalities, with a population from 80,000 to 360,000 inhabitants, and it is composed by a large set of indicators about: a) supply of the bus services network; b) ridership of the bus services; c) geographical and demographic characteristics of the cities and towns under investigation. The largest cities of the country (Rome, Milan, Naples, Turin, Palermo, Genoa and Bologna) with a multimodal public transport system, not only based on bus services, have been excluded from the database.

The aim of the analysis is to derive information about the key characteristics for providing effective public transport services. Specifically, the analysis is structured in different steps:

- first, there is the identification of the geographical and demographic differences among the Italian cities and towns;
- then, there is the study of the relationships between territorial characteristics and the overall level of supply of bus services for identifying eventual existence of common rules and standards;
- third, there is the study of eventual existing differences among the bus networks characteristics that can be impacting in the performances offered to bus network users.

The paper is structured in sections after an introduction part. The first one describes the construction of the database used for the study. The second section involves the analysis of the geographical and demographic features. The third section is instead related with the bus

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networks features analysis. The paper ends with a section of conclusion with some observations about the results of the study.

1. Database construction

This section deals with the construction of the database about the bus network supply on many Italian urban areas. The characterization of the cities and towns selected is also based on the collection of some geographical variables as the population, the area, the population density, the built-up area, the effective density of population as ratio between population and built-up area.

The different characteristics of many cities and towns within the selected sample need of better data about area. Such data in many cases include in a considerable extent not only the built-up areas. To avoid this issue, another territorial variable is collected: the built-up area for any city and town selected. This variable, also called land consumption, is monitored every year by ISPRA (Higher Institute for Environmental Protection and Research) and published every year on the national report "Land consumption, territorial dynamics and ecosystem services".

The database about the supply of public transport services is composed by the following data:

- the number of the bus lines of the network;
- the operating hours of each line;
- the daily frequency computed as the number of runs carried out during the day;
- the average headway of the runs computed as the ratio between the daily frequency and the daily operating hours;
- the number of runs carried out within the morning peak hour (7.00 – 8.00);
- the extension of the bus network within the urban area;
- the bus-km per year as the total amount of km offered by the bus services in the urban area in the last year.

These indicators have been collected from the websites of the operating companies or other documents as sustainability reports, Urban Mobility Plans and data disseminated by the Ministry of Infrastructure and Transport and Istat, the national institute of statistics. To overcome any problem with the heterogeneity of data, each single data has been taken from the same source. The data are related to year 2021 or year 2020, if this is the last year at disposal.

2. Analysis of geographical and demographic characteristics

The geographical data are reported in Table 1. As clearly shown, the population varies from a maximum of 360,000 inhabitants in the city of Florence to a minimum of 80,000 inhabitants in the town of Varese. The average number of inhabitants in the cities is equal to 143,394 and a standard deviation in the sample selected equal to 63,708 inhabitants. Very large differences are also related to the extension of the cities that varies between the maximum value of 654 km^2 in Ravenna and the minimum value of 33 km^2 in Monza. The average extension is equal to 198.1 km^2. The comparison of these two sets of data permits to observe how the population level is not correlated with the extension of the city.

This observation is confirmed by analysing a further indicator, namely the population density that varies between the maximum value of 3,747 inhabitants/km^2 in Monza and 172 inhabitants/km^2 in the town of Grosseto with an average value of about 1195 inhabitants/km^2. These very large changes highlight the different characteristics of many cities and towns within the selected sample but also the population density's dependence on the extension of the city. The set of data produces an average value of the built-up area equal to 33.8 km^2. The city with the largest built-up area is Venice with 71.74 km^2, followed by Ravenna, while the one with the least extension is Como with 11.98 km^2. As clearly shown in Table 1, this variable presents values very different from the other variable area related to cities and towns extension.

The next figure clarifies the results of a grouping analysis with the identification of 4 different groups of Italian cities and towns using the average values of two set of data: the population and the built-up area density. Starting from the top on right and moving clockwise, the first group is related to the cities with largest population and highest built-up area density while the second one is related to the largest population level and the built-up

Table 1. Geographical indicators for the 54 Italian cities and towns selected

Variable	Maximum value	Minimum value	Average value	Standard deviation
Population (#)	359,755	80,039	143,394	63,708
Area (Km^2)	653.81	33.09	198.1	146.3
Population Density (people/ Km^2)	3,747	172	1,195	931
Built-up area (Km^2)	71.74	11.98	33.80	14.2
Built-up area (%)	51.4	6.3	23.6	12.25

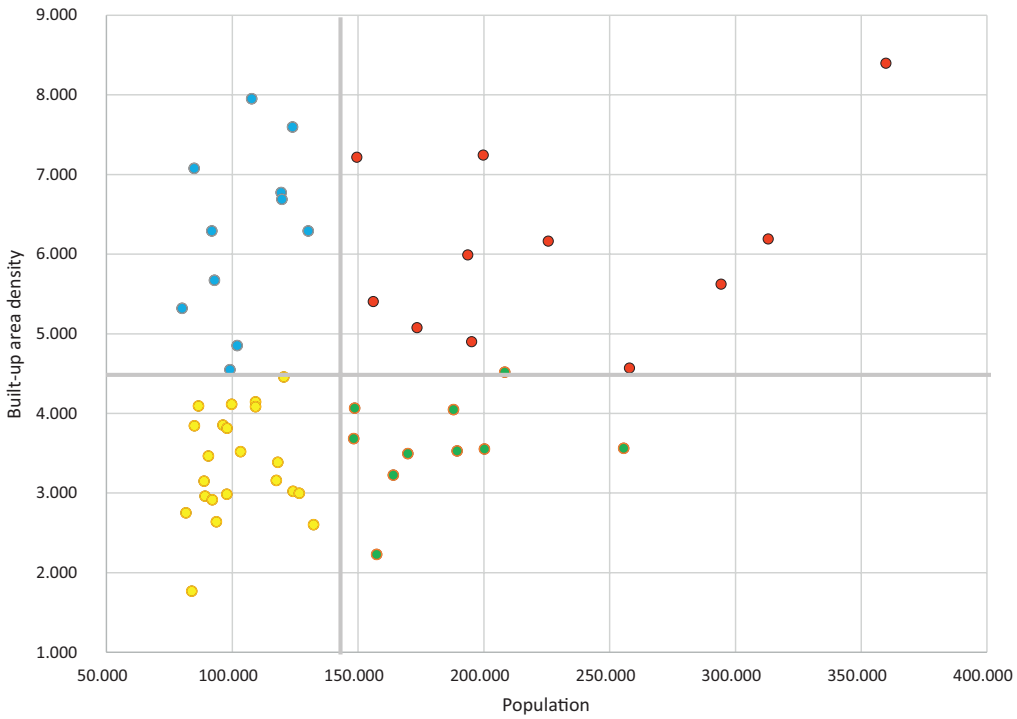

Figure 1. Grouping of the Italian cities and towns selected for population and built-up area density

area density indicator with values lower than the average. On the left, the third group is related to small towns with population and built-up area density lower than the average values. The last group is related to high built-up area density and limited population level.

3. Analysis of the bus services network

Table 2 and Table 3 present the characteristics of the bus network supply respectively for the largest cities and for the smallest cities. The first indicator is the bus-km and it is the most representative data about the quantity of public transport supply provided in each city and town. Such indicator is computed as the sum of the kilometres travelled by buses on the public transport network in a year. This value presents, as expected, very large variation from the maximum value of 18,047,739 km in Florence and a minimum value of 561,139 km in Barletta. The average value of the selected sample is equal to 4,264,037 km and the standard deviation is 3,585,475 km.

These data show large differences among the sample selected and these differences are wider than the population variation. In fact, the ratio between maximum and minimum value in one case is close to 36 while for the population, the ratio is about 4.5. A further analysis has been conducted by grouping the cities and towns into three classes relating to the macro-areas of Northern, Central and Southern Italy. It can be seen that the average value of bus-km is greater in the North, with an average distance of 4,787,331 km while Central Italy has the lowest average value with 3,269,006 km and Southern Italy has an intermediate value with approximately 4,336,077 km.

The second indicator, the bus-km per inhabitants, permits to analyse the overall supply level offered without considering the size of the cities and towns and such indicator confirms previous observations showing very different condition of the level of supply provided. It is also important to underline that the order of cities and towns in the two indicators changes and while the

Table 2. Bus network indicators about supply and demand for the 54 Italian cities and towns selected (group large cities)

Indicator	Maximum value	Minimum value	Average value	Standard deviation
Bus-km (#)	18,047,739	4,479,525	8,478,718	3,709,361
Bus-km per inhabitant (#)	84.3	24.4	42.3	15.2
# lines (#)	73	14	29	16.54
Daily runs (#)	5,437	421	2,044	1,409.73
Daily runs per line (#)	121	19	73	25.67
Annual ridership (#)	114,630,000	11,080,000	38,512,362	28,246,967

Table 3. Bus network indicators about supply and demand for the 54 Italian cities and towns selected (group towns)

Indicator	Maximum value	Minimum value	Average value	Standard deviation
Bus-km (#)	4,225,000	561,139	2,438,535	1,026,789
Bus-km per inhabitant (#)	45.9	6.0	22.0	9.7
# lines (#)	40	8	16	7.46
Daily runs (#)	1,586	145	647	347.22
Daily runs per line (#)	109	11	44	23.67
Annual ridership (#)	14,950,000	490,000	6,318,857	4,067,584

highest value of bus-km is in Florence, Cagliari presents the highest value of bus-km per inhabitant with about 84 km/inhabitant. Barletta instead has the minimum value in both the indicators about level supply with about 6 km/inhabitant. The average value of this second indicator is 28 km/inhabitant while the standard deviation is equal to 15 km/inhabitant.

The analysis of the indicators about the number of bus lines and the total number of daily runs carried out on the average weekday permits to identify the main characteristics about the public transport network in the cities and towns. First of all, the great variability of the indicator's values shows very different conditions with some cases where the bus network can be classified as intensive network based on a relative reduced number of lines with many runs and, in many other cases, as an extensive network based on a large number of lines with few runs. The maximum number of lines is present in Florence which has 73 bus lines while the minimum is recorded in Monza, Bergamo, Barletta and Como with only 8 bus lines. The average number of lines is 20 lines with a standard deviation of 12 lines. An interesting observation can be made by analysing the average number of lines in the 3 macro-areas of Northern, Central and Southern Italy. Southern Italy has the highest average number of lines with about 23.9 bus lines, followed by Central Italy with about 22.4 lines while in Northern Italy there is an average value of 17.2 lines. The comparison of the average values between number of lines and bus-km for the three geographical classes show that the number of lines is not clearly correlated with the bus-km. On the contrary, it is possible to see a completely different approach for the construction of the bus network (intensive vs extensive) given that in the Northern Italy there is the highest average value of bus-km but also the lowest average number of lines. The analysis of the indicator of the total daily runs reinforces this observation. The maximum number of daily runs is recorded in Florence and Trieste with more than 5,000 runs. These cities have a very high number of daily runs considering that the third city, Cagliari, has only 2,615 while the minimum number of daily runs is registered in Barletta with only 145 runs during a weekday. The average number is 1,082 daily runs and the standard deviation is 1,032 daily runs. Northern Italy is the macro-area with the highest average number of daily runs (about 1,218 runs), followed by Central Italy (about 1,103 runs) and Southern Italy with about 854 runs.

About the operating speed monitored by Istat in the annual report of year 2018 on Urban Mobility, it is possible to observe that there is an average value of 19 km/h with a standard deviation of 3 km/h so presenting quite similar conditions in all the cities and towns selected. The maximum operating speed is recorded in Ravenna with a speed of 26.6 km/h while the lowest value is recorded in Salerno with 13 km/h. A more detailed analysis of the situation in the three macro-areas shows that Southern Italy presents lower speed (about 16.6 km/h) than Northern Italy (average value equal to 19 km/h) and Central Italy (about 19.5 km/h).

As for many other indicators, Florence is the place with the highest number of ridership (114.63 million), followed by Trieste with 67.6 million passengers per year. The town with the lowest value of ridership is Barletta with 490,000 passengers per year. In general, as already seen for the supply-related indicators, this indicator related with the level of demand transported by the urban bus network, shows a very wide range of variation within the sample of cities and towns selected. The average value of ridership is 15.28 million passengers per year with a standard deviation of 20.38 million passengers. Northern Italy has the highest average value of ridership with 19.92 million, followed by the Central Italy with 14.22 million passengers and, finally, the Southern Italy with an average value of 9.04 million passengers.

The last indicator shown in Table 2 and Table 3, the average trips per inhabitants, is computed as the ratio between the annual ridership and the population of the city or town analyzed and it can be seen as a proxy variable describing the propensity to use public transport or to evaluate modal split. Trieste has the highest value equal to about 338 trips per year per inhabitant, followed by Florence with about 319 trips per year per inhabitant. Syracuse presents instead the lowest value about 4 trips per year per inhabitant. The average value of the sample selected is approximately 89.7 trips per inhabitant, with the Northern Italy characterized by the highest average value of demand, about 124 trips per inhabitant per year, followed by Central Italy with 72 trips per inhabitant and from the Southern Italy with 50 trips per inhabitant. These figures therefore highlight a large difference among the various cities and towns selected and,

in many cases, it is possible to say that the public transport system is marginal as transport mode for satisfying the everyday mobility needs.

Conclusions

In conclusion, it is possible to underline that collected data has been sufficient for the macro analysis of public transport services. The study shows that the bus network indicators describe a much-diversified situation among the cities and towns selected with significant wide variations recorded. These differences are larger than the expected ones only due to the different characterization by the geographical point of view.

In other words, both a level of quantity and quality of the supply provided as well as the level of demand satisfied, prove that it is very difficult to recognize any common feature among the sample selected. As previously highlighted, the indicators of Northern Italy seem to underline, in almost all of the analyses carried out, better condition of public transport system than Central and Southern Italy.

Disclosure statement

There are not competing financial, professional, or personal interests from other parties.

References

Chartered Institution of Highways & Transportation. (2018). *Buses in urban developments*. CIHT.

Daraio, C., Diana, M., Di Costa, F., Leporelli, C., Matteucci, G., & Nastasi, A. (2016). Efficiency and effectiveness in the urban public transport sector: A critical review with directions for future research. *European Journal of Operational Research*, *248*(1), 1–20. https://doi.org/10.1016/j.ejor.2015.05.059

Fitzová, H., Matulová, M., & Tomeš, Z. (2018). Determinants of urban public transport efficiency: Case study of the Czech Republic. *European Transport Research Review*, *10*, 42. https://doi.org/10.1186/s12544-018-0311-y

Istat. (2018). *Indagine Istat sulla mobilità urbana*. Retrieved April, 2022, from https://www.istat.it/it/files//2020/06/tavole20210406.zip

Istat. (2022). *Databank about population in Italy*. Retrieved April, 2022, from https://dati.istat.it

Matas, A., & Raymond, J. L. (1998). Technical characteristics and efficiency of urban bus companies: The case of Spain. *Transportation*, *25*(3), 243–264. https://doi.org/10.1023/A:1005078830008