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Testing and Improving Urban Bicycle Performance

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Abstract

The purpose of this study is to try to characterize the urban cyclability of the city of Bari (Italy) analyzing the data from the bike sharing system. The methodology used for the characterization is designed to be general so that, applied in different contexts, it could make it possible to compare cyclability in different cities. At the same time the aim of the paper is to provide a methodology that shows the strengths and weaknesses of a cycling system, providing a real support to decisions in order to properly allocate resources and to optimize the bicycle network.

Keywords:bicycle performance; bike sharing; bicycle travel time

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1. Introduction

Pursuing sustainable mobility, particularly in urban areas, has become a priority objective of national and global policies in the transport and environmental field [1]. In addition to communication and the development of reliable, comfortable and secure public modes of transport, the optimization of pedestrian and urban cyclability is one of the main useful tools in order to achieve sustainable urban mobility [2].

In the literature there are numerous studies that attempt to describe the facets of the bicycle mode that, by its nature, has proved not easy to schematize nor completely representable [3], [4], [5]. The collection of data related to bicycle demand and bicycle travel time, is actually more complicated than that relating to other modes of transport.

The existence of Bike Sharing systems in Europe's major cities [8] makes it possible to collect a valuable amount of data (use frequency and travel times) for the management and planning of urban cyclability. In the present paper, the main results obtained from the analysis of historical data from the first years of having a Bike Sharing system in the City of Bari (Italy) are described. With these data it was possible to analyze the urban

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cyclability in a city that is culturally linked to the use of private cars (even for short distances), and that has only recently begun to implement a bicycle infrastructure plan. In addition, in describing the bike sharing system in the city of Bari, the study has two main objectives: to seek a simple methodology that provides a tool for the prioritization of management and infrastructural actions to be taken to optimize urban cyclability and search for indicators able to characterize the cycling system, in a concise and efficient way.

The structure of the paper is organized in the following way: in the first part the state of the art of the guidelines and studies in the field of cyclability are summarized; the second part identifies the purpose of the study according to the state of the art; then the data obtained by analyzing the Bike Sharing system in the city of Bari is described; afterwards the bicycle travel time and the bicycle speed are analyzed; the work ends with conclusions and future objectives.

2. The state of the art

The study of cyclability cannot be separated from the interactions between management and planning of land use, from the policies aimed at environmental improvement and from health and the strengthening of tourism in the territory. Other essential elements that form part of the factors to be considered are the economic and financial ones, without of course neglecting the innate desire for mobility that has characterized man throughout time [7]. The available state of the art on cyclability can be summarized in the following macro areas:

- analysis of urban modal split in order to choose policies and infrastructure for sustainability [2], [8];
- analysis of the detected bicycle demand: usually using statistical studies that, conducted in different areas and on different levels, provide results in traveled miles, number of bicycle journeys, number of bicycles sold, etc. The methodology, although based on real data, is likely to be quite approximate, depending on the sample interviewed, its extension, or on the comparison of data from different realities [9];
- analysis of the estimated bicycle demand: generally the collected data is used in order to obtain estimation models for the future demand in the same analyzed contexts or in different contexts but with similar characteristics to those examined [10], [11];
- analysis of bicycle levels of service, usually related to a part of the bike path, to intersections or to entire cycling networks [12], [13];
- bicycle accident analysis (statistical studies and applications to mitigate situations of cyclists at risk) [14], [15], [16];
- analysis of physical and environmental benefits related to cycling [17], [18].

States that have invested in the cycling mode of transport, producing reports, manuals, scientific studies as well as planning and legislative tools, are those of Northern Europe, followed by some U.S. states (Oregon, N.Y). However, some reports and cyclability studies have been made in some Asian and African cities. The latest European act on the cyclability dates from 15 May 2009. The “Paper of Brussels” for the spread of cycling mobility (promoted as part of the Velo-City2009 project) is the common commitment of some Europeans cities:

- to implement appropriate policies to achieve at least 15% of trips by bike in its urban territory by 2020 (or greater if the limit has already been achieved);
- to reduce by at least 50% the risk of fatal accidents for cyclists by 2020;
- to enable appropriate action to increase the safety of bicycle journeys on bicycle paths between home-school and home-work.

The “Paper of Brussels”, however, is only the latest element of the European directives on cyclability. In recent years, in fact, European bicycle planning has not only been oriented to the urban areas but also to the idea, already partly realized, to connect the whole continent through real European cycling corridors. As part of the

ECF (European Cyclists' Federation), a special working group, which includes several European member countries, has drafted a proposal for a network of cycling routes across Europe (European Bicycle Route Network, commonly known as Eurovelo). The planning of this bicycle network has established 12 routes, which, as with the known transport corridors, establish the European cycling network. These routes were created by the merger of the national traits of existing bicycle routes, properly connected and expanded to include countries with no local networks, and have the dual purpose of facilitating the transit of tourists throughout Europe and to enhance the cycling mode of transport locally, as an alternative to motorized traffic.

The scientific and regulatory effort in the scope of cyclability, therefore, is gaining importance that could eventually change, at least partially, the entrenched habits of "motorized" users and especially in urban communities. It is expected that funding for the realization of urban and extra-urban bicycle networks and for the systematization of cycling (with a direct estimate of demand, real time detection through GPS detectors, placed in safety critical points, etc.) will be increasingly significant in the next few years. Thus there is an even more evident need for practical methods to support decisions to be taken and resources to be committed to the optimization of existing systems or for the most appropriate implementation of those still lacking.

3. Bike sharing data collected supporting the existing state of the art

The bicycle mode, more than motorized modes, is affected by the human component. Freedom of the route to be taken (especially in areas without bike paths), freedom of choice of speed (only minimally affecting other cyclists), the mode of propulsion coming only from physical force, the extreme ease of usage and the cost of transport being almost zero are shown by the extreme heterogeneity of bicycle users (by age, sex, social and economic conditions).

The bicycle demand and accident models and the determination of levels of service can only be calibrated with data of objective input, representing a certain reality. Regarding the transposition of these models into other contexts, a new calibration method using statistical analysis (usually questionnaires) and estimation of demand is fundamental. However, the questionnaires almost always retain a degree of ambiguity (e.g. the travel time reported by respondents is often approximated to whole minutes). Among other things, the exact estimation of the bicycle demand involves the use of methods not always available or costly (e.g. GPS sensors) or, even worse, too vague (the classic counter or loops do not consider all the users who use an alternative bicycle route, different to that monitored).

For the reasons described above, the data from Bike Sharing systems are certainly more reliable, cheaper and more representative of reality. In a city with bike sharing stations spread all over it, so that the general user can reach the nearest one by walking a distance not exceeding 300 meters, and assuming that supply meets demand at any time, the data provided from bike sharing applications would directly provide the bicycle demand of that city, the busiest, most reliable and fastest routes as well as user preferences, etc. Of course, this ideal conditions is far from the reality in Italian cities, where bike-sharing stations are located only in the most important points and users of the service are only part of the total bicycle users. However, the frequencies and travel times recorded by the bike sharing cards show exactly the characteristics of the cyclability as a portion of reality. In this sense, although they cannot change the patterns of demand, nor of accidents or the calculation of service levels, the data from bike sharing can certainly be used for their proper calibration in a specific context.

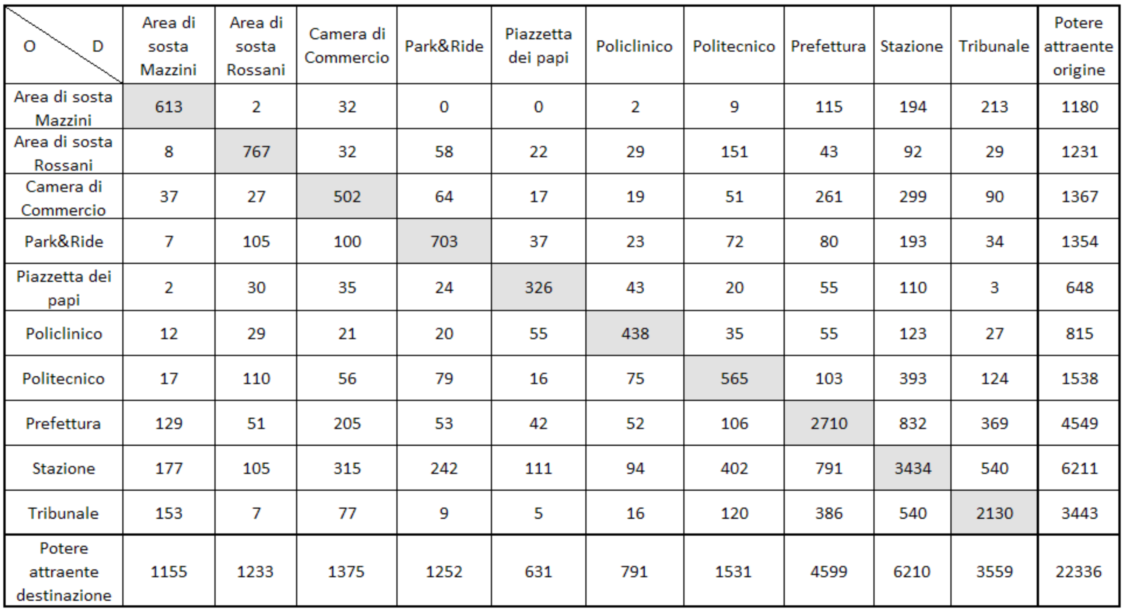
The study reported in next paragraphs is an example of the use of historical data of Bike Sharing for the representation (although partial) of the cyclability of the city of Bari and, above all, for the identification of methods of verification and optimization of urban bike paths. The negative factors related to the analysis of historical data could, however, be eliminated, since the data are collected by the system in real time. Creating a center for continuous monitoring, the same methodology could provide information on cyclability in almost real time, supporting or replacing the more expensive monitoring systems employing GPS detectors. The results described below may be considered relevant only for the city of Bari, while the processing method is undoubtedly applicable to any urban context with a shared bicycle systems.

4. Bike sharing in Bari

The data available corresponds to the second year of activation of the bike sharing system in the city of Bari (from 13/10/2009 to 12/10/2010), when there were 10 bike sharing stations, the total of bicycle parking places was 110, there were 80 bikes available , there were 1000 users of the service and the urban bicycle network was practically nonexistent [19]. During the period under consideration the management of the system was characterized by the following limitations: an annual fee of only 10 Euros, which provided for unlimited use, and a fixed number of users.

Using data recorded with the Bike Sharing cards, it was possible to identify the exact times and frequency of trips for each of 45 possible O-D routes. In particular there were 22,336 uses, for a total distance of at least 18,500 kilometers (despite excluding 12,188 closed loop routes). The OD matrix is shown below.

Table 1 – OD matrix



O \ D	Area di sosta Mazzini	Area di sosta Rossani	Camera di Commercio	Park&Ride	Piazzetta dei papi	Policlinico	Politecnico	Prefettura	Stazione	Tribunale	Potere attraente origine
Area di sosta Mazzini	613	2	32	0	0	2	9	115	194	213	1180
Area di sosta Rossani	8	767	32	58	22	29	151	43	92	29	1231
Camera di Commercio	37	27	502	64	17	19	51	261	299	90	1367
Park&Ride	7	105	100	703	37	23	72	80	193	34	1354
Piazzetta dei papi	2	30	35	24	326	43	20	55	110	3	648
Policlinico	12	29	21	20	55	438	35	55	123	27	815
Politecnico	17	110	56	79	16	75	565	103	393	124	1538
Prefettura	129	51	205	53	42	52	106	2710	832	369	4549
Stazione	177	105	315	242	111	94	402	791	3434	540	6211
Tribunale	153	7	77	9	5	16	120	386	540	2130	3443
Potere attraente destinazione	1155	1233	1375	1252	631	791	1531	4599	6210	3559	22336

The relevant number of closed-loops routes could be related to the fact that bike sharing is not yet used in Bari on point to point journeys: home-work, home-school and home-university routes, which involve taking a bike from a station different from that of leaving it. The typical user of the system, more than 50%, picks up the bike near their residence, carrying out different tasks and then finally leaves it at the same station. Certainly the use of the system for traveling point to point should be encouraged with campaigns and support policies (incentives).

From the analysis of the time of possession of a shared bicycle, an important occurrence has emerged which reveals a misuse of bike sharing: 763 users kept the bike from 10 to 20 hours, 115 users from 20 to 30 hours, 43 users from 30 to 40 hours, 10 users from 40 to 50 hours, 9 users from 50 to 60 hours, 5 users from 60 to 70 hours, 5 users from 70 to 80 hours, 1 user from 90 to 100 hours and 3 users more than 100 hours. Higher performance of the service would be obtained by maximizing the number of daily uses or the number of traveled kilometers. In this perspective, if some users monopolize the shared bike for their own for a long time, the system becomes beneficial only for a fraction of the population. In order to limit this problem, the ideal solution might be to introduce an hourly rate from the second or third hour of use, a workable solution with the introduction of a prepaid card with a direct debit (currently the annual pass cost is € 10.00, including unlimited number of uses, regardless of their duration). A proper pricing policy could introduce a rate increasing proportionally with the bike possession time and in any case, the bike sharing should be implemented beside a bike renting system.

5. Bicycle travel time distributions

The data was used to plot the bicycle travel time distributions for each of the possible paths between the ten bike sharing stations. A selection of significant data has been carried out, excluding branches, corresponding to approximately V<10 km/h.

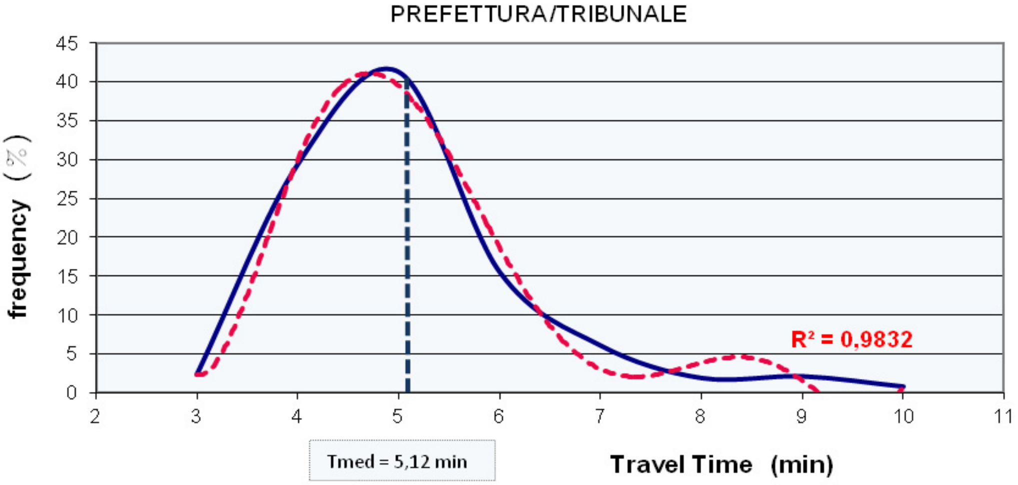


Fig. 1 – example of travel time distribution – Police Headquarters/Law Courts path - (purified data)

It is possible to verify that the ascending branch of most of the distribution curves is similar to a Gaussian distribution, whereas the descending branches are characterized by significant dispersion, which cause an increase in the average travel time. At a first analysis, it may be attributed to shortcomings in infrastructure and various interference with other modes of transport (including pedestrian). In this regard it is important to underline that a dedicated bicycle network is not present in Bari.

6. Ideal bicycle travel time distributions

In an ideal situation (more extensive data and proper use of the bike sharing system) the descending branch of the curves of distribution could also be assimilated to a Gaussian distribution that for a large number of samples, could well represent both the heterogeneity of the sample and also its different physical strength (different ages correspond to different speeds) and the different distribution of travel time (corresponding to daily peak or quiet hours). Therefore, based on this hypothesis, the ideals curves of time distribution have been built for each O-D path: the ascending branch of the curves has been mirrored on the vertical axis identified by the maximum frequency point (cfr. Figure 3). Then comparing the actual distribution curves with the ideal ones, have been identified the values of minimum, average and maximum travel times for each possible paths and for each pair of curves. The most significant results are summarized in Table 1. The comparison between real and ideal average times (or maximum) lets us estimate how close the distribution curve arising from the historical data collected is to the ideal situation. In the second analysis, the comparison tells us if the OD path is characterized by problems that, in fact, increase travel times.

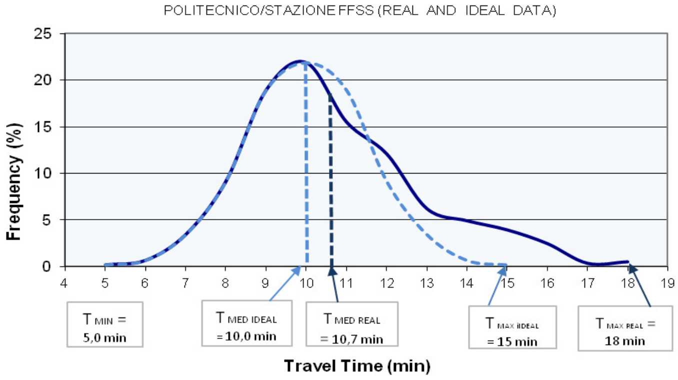


Fig. 2 - example of travel time distribution with real and ideal data

Table 2 –minimum, medium and maximum travel times for most travelled routes

	distance (mt.)	T med		T min (min.)	T max	
		real (min.)	ideal (min.)		real (min.)	ideal (min.)
Park&Ride-Politecnico-Park&Ride	780	4.7	4	2.2	6.8	6
Prefettura-FFSS-Prefettura	930	6.11	5.5	2.8	10	8.3
Prefettura-Tribunale-Prefettura	1,150	5.12	5	3	10	7
Tribunale-FFSS-Tribunale	1,675	8.96	8.5	4	16	13
Park&Ride-FFSS-Park&Ride	2,150	10	9.2	7	13	12
Politecnico-FFSS-Politecnico	2,340	10.7	10	5	18	15
Park&Ride-Prefettura-Park&Ride	3,000	16.32	12,2	8	22	16.4
Politecnico-Prefettura-Politecnico	3,250	18.6	13.5	9.5	26	17.5
Park&Ride-Tribunale-Park&Ride	3,800	20.75	19	10.8	33	27
Politecnico-Tribunale-Politecnico	4,000	18.36	18	11	34	25

7. The variability areas of bicycle speed

Pursuing the goal of identifying a methodology to briefly describe the cyclability of a specific reality (in this case the city of Bari) comparing it to a hypothetically "ideal" situation, the following chart has been plotted.

The travel times described previously (minimum, average real, average ideal, maximum real and maximum ideal) have been included in a space/time graph. Each path, identified by its length on the vertical axis, is represented by the five travel times. The representative points of the minimum travel times for the examined paths were joined obtaining a broken line (in green). The same operation was performed for the other travel times, real and ideal. The five broken lines have been interpolated with second-degree polynomial trend lines which provided a coefficient R2 always higher than 0.92. The strong correlation clearly indicates that the bicycle space-time trend is well represented by a quadratic equation with the constant term equal to zero:

$$S(t) = a\,t^2 + b\,t \qquad (1)$$

The coefficients a and b can be used to represent the cyclability of a specific context in a summarized manner. In particular, the coefficient a (in m/s2 or km/h2) indicates the deceleration when the distance traveled increases, the coefficient b, (expressed in km/h or m/s) indicates the initial speed. The comparison of these coefficients calculated in different contexts could make it possible to rapidly compare the cyclability of different urban realities obtaining a benchmark that is both social and infrastructural. In practice, low "a" coefficients and high "b" coefficients, indicate both the propensity of cyclability of a population as well as good bicycle infrastructure in the same city.

In the case examined the following result is obtained:

$1.25 \cdot 10^{-4} < a < 1.25 \cdot 10^{-3}\ (m/s^2)$

$2.45 < b < 7.12\ (m/s)$.

The value of coefficients is valid only for the city of Bari and only for the time period of reference. A proper regression analysis useful to determine their correct variability and dependence will be conducted at a later stage, when more data are available. Comparing the same coefficients calculated for different urban reality, a good measure of comparison could be achieved, useful for representing the efficiency of the bicycle mode, depending on the network, its users and service management.

In addition to identifying a synthetic methodology useful to describe the cyclability with numerical parameters, the same chart can provide a practical tool for decision-makers and planners of the bicycle mode.

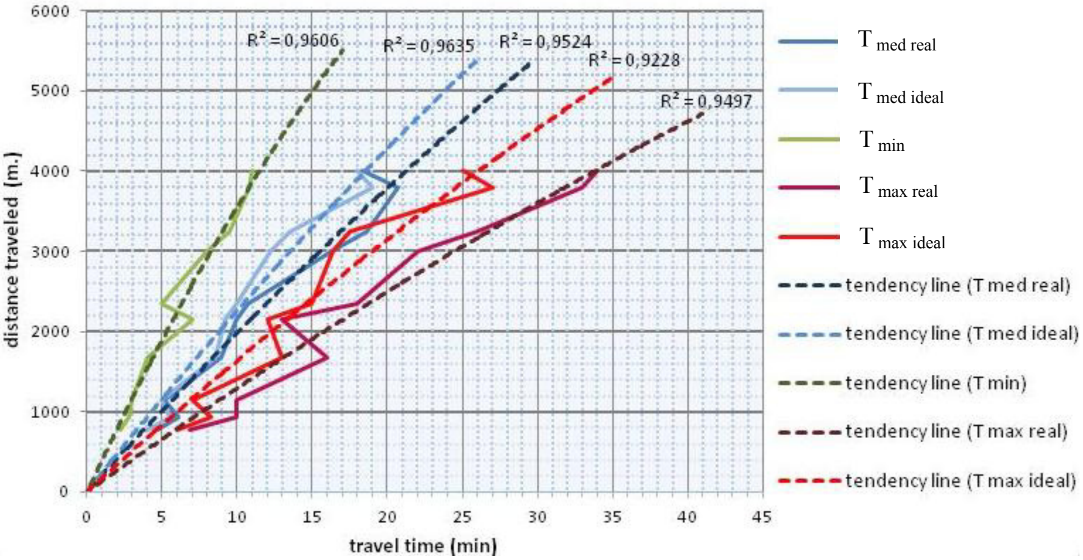


Fig. 3 – bicycle space/time graph

The areas between the trend lines have been called “the variability areas of cycling speed”. The area between the trend lines corresponding to the observed and the ideal maximum time is named the “low speed area” (in red in the figure). The area between the trend lines correspond to the observed and ideal average travel time is named the “average speed area” (in blue in the figure). In other words, the variability areas of cycling speed represent the field of variability of the situation detected with respect to the ideal: the more the areas are restricted, the more the entire bicycle network (or the management and use of bicycle sharing systems) can be considered efficient.

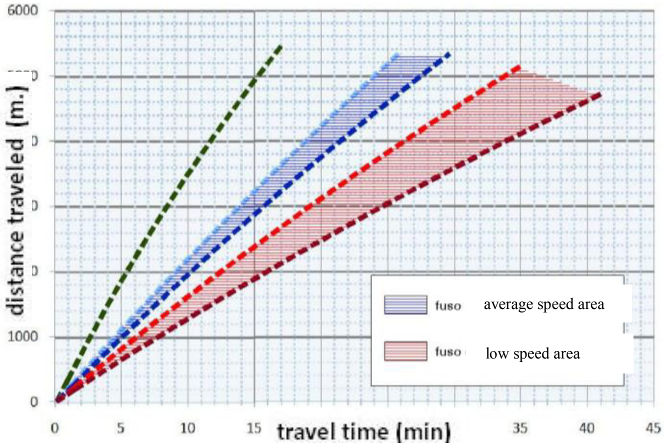


Fig. 4 – bicycle low speed area and average speed area

The variation speed areas can be used to evaluate the gain in time (and thus also the monetary gain) which would be achieved by optimizing the system through the selection of solutions to implement. The deviation of observed and ideal broken lines compared to spindles delimited by the trend lines, is an important indicator for the choice of allocation of resources, i.e. to obtain the best results related to the construction of a new bike path or the optimization of complex road/bike system. If for a specific path there is a high negative deviation between the broken line and the tendency line delimiting the slow speed area, specific solutions on the specific route or on some nodes of the same have to be found. For example, it is possible to obtain some conclusions from the analysis of travel time distributions, as follows:

- the Park&Ride-Politecnico and Tribunale-FFSS paths would need infrastructural measures in order to reduce their maximum travel time because they are higher than ideal values;
- the Politecnico-Prefettura path is one that suffers the most from the external conditions, given the considerable variability of travel time because real maximum and average travel times are respectively higher and lower than the ideal ones;
- the Park&Ride-FFSS path is the only one in which the TT is lower than expected (and is also the only one in which there is a bike path).

8. Bicycle speed distribution

The travel time is naturally directly related to the distance traveled, and consequently it cannot be used for the comparison of results between different paths. Therefore, an analysis regarding the bicycle speed has been conducted in parallel, after fixing a distance between the bike sharing stations. The analysis was conducted on three levels:

- obtaining the distribution of bicycle speed from the previous graph, depending on the distance traveled (maximum, real and ideal- average and ideal and real- minimum speed);
- unifying all purified data in order to obtain the accumulated distribution curve of the speed;
- modifying the starting data in order to obtain the speed distribution curve referred to each individual route.

The first level returned linear trend lines with a negative slope, interpolating the broken lines of maximum speed, average observed and ideal speed and minimum observed and ideal speed. The graph, evidently, confirms the above statements, and at the same time, describes the evolution of the speeds depending on the distance traveled, with this type of equation:

$$v(s) = d - c\,s \qquad (2)$$

with $0.34 < c < 1.16$ (km/h^2) and $25.7 < d < 9$ (km/h).

Therefore, in the analyzed situation the maximum speeds ranging from 25.7 km/h for short distances to 21.06 km/h for distances of 4 km; the detected minimum speeds starting at about 9 km/h for short distances to 7.03 km/h for distances of 4 km. The negative slope decreases going from maximum speeds to minimum ones, confirming the fact that going at higher speeds does affect physical tiredness.

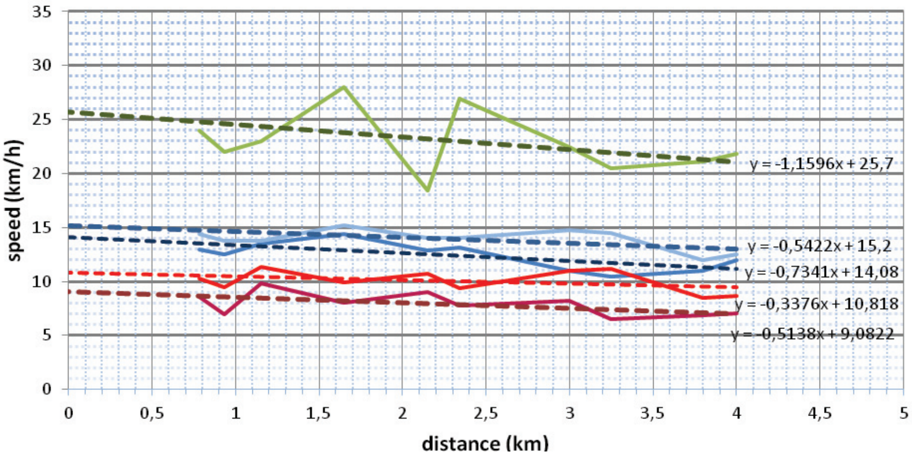


Fig. 5 - real and ideal bicycle speed

Accumulating all the available data, after their purification it was possible to obtain the speeds distribution of all the examined routes. The distribution shows that the bicycle average speed in Bari is equal to 12.51 km/h.

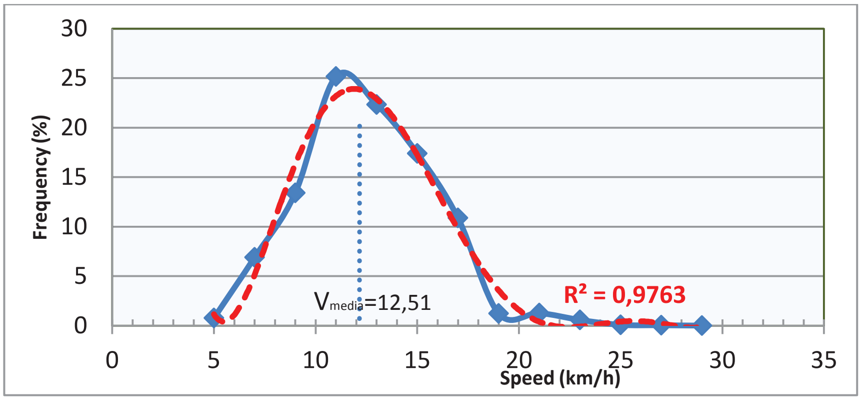


Fig. 6 - cumulated speed distribution

Plotting the value of the average speed in the chart of Fig. 5 and intersecting the trend line corresponding to the real average speeds, a distance of 2150 m is obtained, corresponding approximately to the average distance travelled by the generic user of the Bike Sharing system.

The last analysis carried out produced the curves of speed distribution for each bicycle path considered, which is shown below by the overlap (the most used routes are shown in the graph).

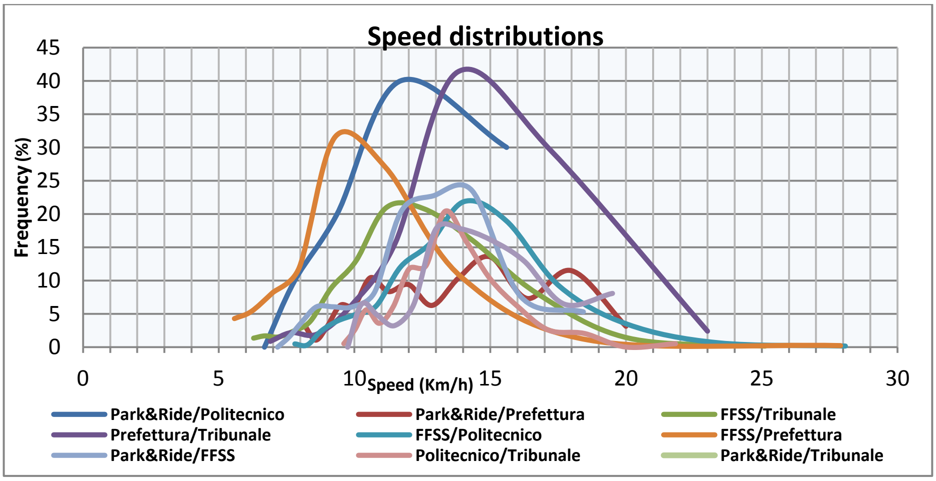


Fig. 7 - speed distribution of the 10 paths

In spite of the results regarding travel times, analyzing the speed distribution it is possible to compare the functioning of paths in a direct way, from the same graph. It is visible that the curves are generally more steeper for low values of speed and, in most cases, with irregular ascending branches.

The possible qualitative analysis was finally correlated with a quantitative analysis of the distributions: the values of speed corresponding to the 15th and 85th percentile and the coefficients α and β, described below, were calculated. The two coefficients indicate how the low and high values of speeds are dispersed in relation to the average value of the distribution.

$$\alpha = \frac{|v_{\max} - v_{85}|}{v_{\max} - v_{med}} \tag{3}$$

$$\beta = \frac{|v_{15} - v_{\min}|}{v_{med} - v_{\min}} \tag{4}$$

The more the coefficients are close to unity, the lower data dispersion will be related respectively to the ascending or descending branch of the distributions. In particular:

- if the coefficient β is low, it means that the curve is no dispersed at the low speed values (effect due either to external conditioning, such as traffic and interaction with other modes of transport, or to the infrastructure level of the path); in this case the real and ideal maximum values of travel time in Figure 3 are quite distant;

- if the coefficient α is low, on the contrary, it means that the curve is no dispersed at the high speed values (apparently positive) and so the path is characterized by greater variability of high-speed (the external conditions are more problematic than the level of path infrastructure); in this case the minimum values of travel time in Figure 3 are quite variable.

	Vmin	V15	Vmed	V85	Vmax	$\alpha(V_{85})$	$\beta(V_{15})$
Park&Ride-Politecnico-Park&Ride	7,80	9,65	12,01	13,57	18,60	0,76	0,44
Prefettura-FFSS-Prefettura	5,58	8,72	9,75	13,83	27,90	0,78	0,75
Prefettura-Tribunale-Prefettura	6,90	12,48	14,14	19,05	23,00	0,45	0,77
Tribunale-FFSS-Tribunale	8,85	10,15	11,84	16,18	25,12	0,67	0,43
Park&Ride-FFSS-Park&Ride	8,21	11,25	12,95	15,48	18,42	0,54	0,64
Politecnico-FFSS-Politecnico	8,80	12,02	13,70	19,65	28,08	0,59	0,66
Park&Ride-Prefettura-Park&Ride	8,18	10,65	13,16	18,55	20,00	0,21	0,50
Politecnico-Prefettura-Politecnico	9,25	10,93	13,35	19,33	22,50	0,35	0,41
Park&Ride-Tribunale-Park&Ride	9,12	10,88	11,95	13,94	16,28	0,54	0,62
Politecnico-Tribunale-Politecnico	9,60	11,45	13,32	15,68	21,81	0,72	0,50

Table 3 – speed values, α and β coefficients

The speed values and the coefficients α and β, shown in the previous table, describe the speed distributions of the various cycling routes in a concise and effective way. Examining these values it is possible to select the priorities of management or infrastructural intervention in order to optimize the urban cyclability and make it uniform.

In the examined case, the β coefficient shows that the Park&Ride-Politecnico, Tribunale-FFSS and Politecnico-Prefettura paths are the critical ones, confirming the results obtained from the graph in Figure 3. The FFSS-Prefettura path is characterized by lower speeds, and a high variability of the speed (even if distributed properly): in this case the criticism does not appear to be linked to external interference (good values of α and β) but to the level of infrastructure of the path. While in the first case external influences should be limited, in the second the construction of a bike path seems essential.

9. Conclusions

Data analysis of Bike Sharing in the city of Bari has identified a methodology that, in its general approach, can be considered useful to describe the cyclability of a generic urban environment and to provide an effective tool for its planning and management. It is important to underline that the methodology could be carried out with other survey methods , able to give data on travel time and path of the journey.

Comparing the situation detected with a hypothetical ideal situation (the presence of a protected bicycle network; the widespread use of the bike sharing system; the point-to-point use of the system, etc.) it has been possible to describe the efficiency of the bicycle links and the entire network. In particular, the joint analysis of space-time diagrams and speed distributions of the bicycle mode, has highlighted the routes that are most in need of infrastructure or management action to optimize their operation.

From the analyzed data it appears that the trend of the space-time curves seems to adhere to a quadratic equation with the constant term equal to zero. The coefficients a and b of the quadratic equations corresponding to the minimum, average and maximum travel time (real and ideal) are a summary indicators of cyclability. The comparison of these parameters for different realities could be able to provide a scale of variability of cyclability as a function of spatial location, user customs and habits and management of cycling paths.

The space-time graph and the detection of the "variability areas of bicycle speed" provide a valuable support to optimize the cyclability of the examined situation :

- experimental curves presenting points somewhat below the trend lines underline the need for localized improvements;
- minimizing the "variability areas of speed" means being able to optimize the entire network, reducing the differences of the real data compared to those ideals. The value of the areas can be taken as a measure of performance of the bicycle network.

The analysis of city bicycle speed also provides others general indicators of cyclability (variability of minimum, average and maximum speed), and confirms and/or supplements the space-time analysis.

It remains desirable to deepen the analysis conducted to more extensive networks of bike sharing, comparing situations previous and subsequent to the implementation of bike lanes, also examining cases in which the distances exceed 5 km. In fact, the use of a greater amount of data and a greater number of paths could validate the method which, among other things has demonstrated in this first approach that it is useful for the representation of a complex system, at low cost and is fundamental for choosing the paths to be taken for a sustainable future.

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