On-Board Comfort of Different Age Passengers and Bus-Lane Characteristics

Mauro Coni[1(✉)], Francesca Maltinti[1], Francesco Pinna[1], Nicoletta Rassu[1], Chiara Garau[1], Benedetto Barabino[2], and Giulio Maternini[2]

[1] Department of Civil and Environmental Engineering and Architecture (DICAAR), University of Cagliari, via Marengo 2, 09123 Cagliari, Italy
mconi@unica.it

[2] Department of Civil, Environmental, Architectural Engineering and Mathematics (DICATAM), University of Brescia, via Branze 43, 25123 Brescia, Italy

Abstract. Onboard bus comfort significantly depends on the bus lanes characteristics, such as horizontal curvature, pavement roughness, longitudinal, and transversal slope. A literature review shows a statistical relationship between acceleration level and passenger features, such as age and gender. A large number of onboard interviews have been collected and correlated to bus-lane geometry parameters, to evaluate the vibrational comfort of different passengers. Passenger's judgments are related to the lateral, longitudinal, and vertical shake. At the same time, a geometric investigation on bus-lane corridors, traveled during interviews, in the city of Cagliari in Italy allowed to extract infrastructure parameters in terms of numbers and density of turns, horizontal curvature radius, speed design, and acceleration variance. The paper analyzed the correlation between some geometric and cinematics road parameters that may affect the comfort and the different passenger's judgments on the three acceleration components by age classes and hourly day. The results generally show weak correlations between the selected parameters and passenger judgments. Conversely, travel speeds have significant correlation values. There is a moderate inverse correlation between the vibrational level and the age of the passengers. The younger age groups tend to have more severe judgments, attributable to their higher demand for comfort. The presence of preferential lanes increases the onboard comfort quality in terms of speed regularity, without private cars interferences.

Keywords: Bus comfort · Bus-lane · Vibrational level · Road geometric

1 Introduction

Passenger's onboard comfort (OBC) and satisfaction are critical factors of a bus-service quality and one of the best strategies to increase the bus users [1–3]. For these reasons, in recent years, the OBC of passengers in the public means of transportation received considerable attention in order to define appropriate parameters, efficient measurement systems, and procedures.

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The comfort level depends on several aspects related to vehicle and road characteristics, degree of crowding, traffic condition, internal microclimate, driver's behavior [1, 3–6]. Most of the investigations on OBC study the physical measurements of vibrations, and several studies [1, 2, 4] consider the subjective perception of the users. Also, many researchers investigated the correlation between judgment collected by the onboard questionnaire (qualitative and subjective) and contextual measurements of vibration (quantitative and objective) [1, 6–9]. The effect of whole-body vibration on balance, mobility and falls in older adults are well known and systematically reviewed in the literature [10, 11]. However, no specific studies are available on the bus passengers by age. Several studies [12–15] propose an innovative approach that allows the simultaneous measurement of subjective and objective of the OBC. The subjective measurements of the OBCL is an expensive activity due to time-consuming surveys and personal interviews. Thus, light and automatic vibrational collecting systems are desirable [1]. For these reasons, many recent studies involve the capability of the smartphones to gather acceleration values (longitudinal, lateral, and vertical accelerations), speed over the time with at the frequency of 1.0 Hz [1, 4, 12–14]. At the same time, the device can record instantaneous geographical coordinate (latitude, longitude, and altitude) from the global positioning system (GPS). However, many authors [17–21] pointed out how the automatic construction of a digital map is a considerable challenge, related to positioning errors, GPS noise and variability of speed, and the complexity of roads and urban streets. Therefore, many approaches are available to increase trajectory precision and consistency, classifiable into three categories [22–24]. In the "point clustering" method [17, 25], raw data are clustered in many ways (i.e., k-means clustering) to create a street segmentation. The "incremental track insertion" [18, 19] and [27] generates a road alignment by incrementally inserting trajectory data into an initially empty diagram. In the "intersection linking" method [20, 21], the intersection nodes of the road trajectory are detected and linked together.

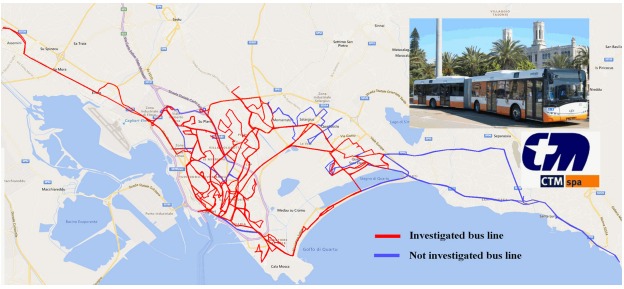

Fig. 1. The 25 of the 36 bus routes investigated in Cagliari.

In this paper, the point clustering of digital data from GPS operates in the key-point from the topographic survey and DEM (Digital Elevation Model) of the bus-lane based. Moreover, the polyline of the bus-lane axis has been segmented every 10 m evaluating for each point curvature radius, tortuosity, acceleration variance, and velocity diagrams.

The objective of this paper is to investigate the correlation between geometric and cinematics road parameters that may affect the comfort of passengers as well as the passenger's judgments of three acceleration components and class ages. The experimental investigation involves the public transportation network in the city of Cagliari (Italy) as shown in Fig. 1. During three weeks in July 2019, 755 questionnaires were collected in 198 bus rides, covering 25 of the 36 active lines in Cagliari. This study is essential for public transport companies needing to improve and certificate the service quality on routes according to European norms [28], also using ITS technologies, increasing modal shift, and urban social interactions [29, 30].

2 Data and Methodology

The structure of the research follows four levels: 1) data type, 2) data collection tools onboard, 3) bus-lane geometry and cinematic, and 4) data analysis (Fig. 2).

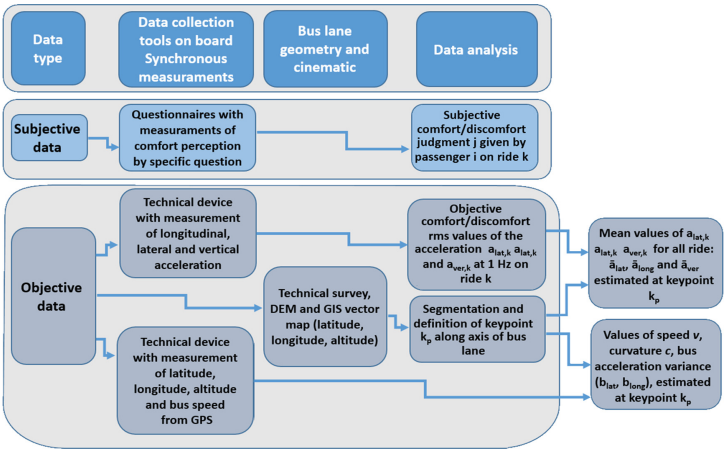

Fig. 2. The 4-level framework of the research.

Data Type

The study comprises two types of data: 1) "subjective data" regarding passengers' judgments on board comfort and, 2) "objective data" concerning vibration parameters, on ride k, along the route. The first assumption of the research considers the on-board comfort level as a function of passenger shaking, mainly due to the driver's behavior (braking, slowing down, accelerations and steering) and bus-lane characteristics (turns, pavements roughness, slope).

Data Collection Tools on Board

Two types of instruments have been used to collect the data. The subjective data were gathered through an on-board questionnaire, administered to passengers, in order to estimate their perception of the comfort level. In July 2019, during the periodical quality

survey collected by CTM. (the local public transport company) 8 new questions were submitted to passengers: 1) position during the interview; 2) position related to the direction of the travel; 3), 4) and 5) expected driving style for a) braking/acceleration; b) horizontal curves; c) vertical vibration; 6), 7) and 8) perceived driving style for a) braking/acceleration; b) horizontal curves; c) vertical vibration.

A total of 755 questionnaires were collected.

Several studies revealed the different roles of expectation for comfort perception evaluation [31]. The expectation is a factor associated with the environment, and it is strongly affected by the cultural/experience background of the passengers. For this reason, expectation and perception judgments were collected. Objective data refers to the kinematic parameters on ride k, which were measured through technical devices, in the longitudinal, lateral, and vertical directions at low frequencies. In general, frequencies ≤ 3 Hz depends by the vehicle age, materials and seats, road pavement roughness and bus engine and mechanic characteristics, whereas frequencies ≤ 2 Hz mainly depend on the bus weight, length, suspension type, traffic density, speed distribution, bus-route geometric characteristics and driving behavior [31–33].

Four operators with smartphones collected objective data with the Android system, during each entire ride, concurrently with the passenger's interview. The smartphone's GPS device and 3-axis accelerometer MEMS provide geographical position (lat, long, alt), GTM time, accelerations (a_{lat}, a_{long} and a_{vert}) at the frequency of 1.0 Hz. A specific app (Torque) recorded the data of the several parameters a_{long} the bus ride k. Figure 3 shows some objective data record.

n.ord	Line-ride code	GPS Time	Longitude	Latitude	GPS Speed (Meters/second)	Altitude	G(x)	G(y)	G(z)	Bus number
1	1_OB_1	Fri Jul 26 13:13:07 GMT+02:00 2019	9.131383241	39.23754713	0.00	60.44	-0.68	1.05	9.40	344
2	1_OB_1	Fri Jul 26 13:13:08 GMT+02:00 2019	9.131383241	39.23754713	0.00	60.52	-0.21	1.24	8.95	344
3	1_OB_1	Fri Jul 26 13:13:09 GMT+02:00 2019	9.131383241	39.23754713	0.00	60.62	-0.47	1.22	9.67	344
4	1_OB_1	Fri Jul 26 13:13:10 GMT+02:00 2019	9.131459221	39.23752446	1.20	60.62	0.10	0.59	9.43	344
5	1_OB_1	Fri Jul 26 13:13:11 GMT+02:00 2019	9.131494824	39.23751886	2.11	60.64	-0.14	0.81	9.59	344
6	1_OB_1	Fri Jul 26 13:13:12 GMT+02:00 2019	9.131527964	39.23750744	2.63	60.64	-0.26	1.05	9.09	344

Fig. 3. Objective data record.

The smartphone's location inside the bus and its orientations affect the recorded vibrational level. All the smartphones were in the seat close to the driver, on a horizontal plane, and in longitudinal orientation (see Fig. 4).

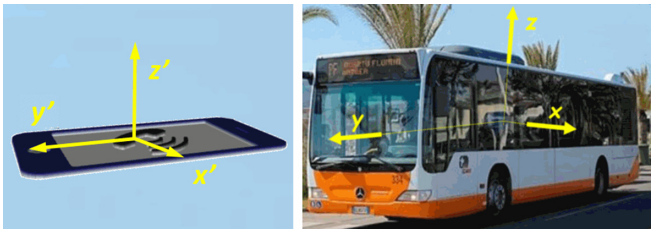

Fig. 4. Smartphone and bus coordinates systems.

Bus-Lane Geometry and Cinematic

The automatic polylines are drawable directly from the GPS data for each ride and show high variability related to noise and positioning errors. The mean value of the measured accelerations and speeds were associated with a key-point p in the real trajectory to enhance the trajectory precision and consistency between different rides. Figure 5 shows the GPS data-position compared to the real bus path.

The real trajectory was assumed the axis of the bus lane, derived from an official map database, DEM, and the topographic survey. The segmentation of the axis' polyline, every 10 m, allows extracting each key-point coordinates. The values of the GPS measured parameters (v, a_{lat}, a_{long}, a_{vert}) were averaged in the circular area of radius 10 m and assigned to the central key-point p.

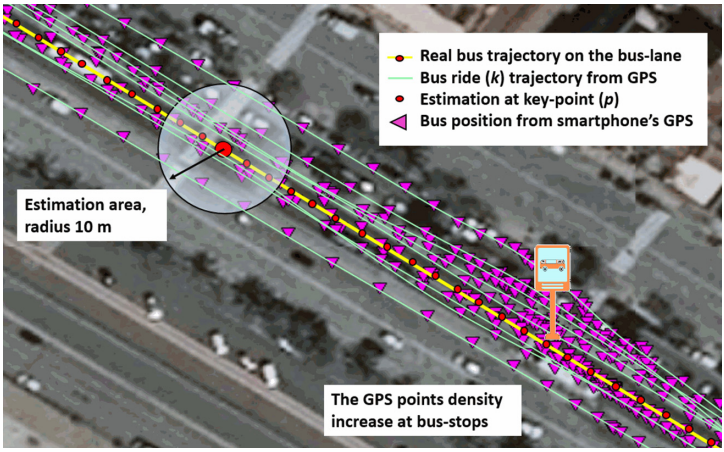

Fig. 5. Objective data position. The real bus trajectory and GPS data.

At key-point p, several parameters have also been calculated: curvature radius R; cornering speed limit v_l; tortuosity t; longitudinal speed v; lateral, longitudinal and vertical acceleration and lateral jerk (variation of acceleration over the time).

Data Analysis

The fourth level of the research concerns the data analysis in order to evaluate the onboard comfort and bus-lane ride quality. First, the subjective and objective raw data have been gathered concurrently, and each questionnaire has been associated with smartphone measurements. During the interview, each passenger u rates the different aspects of the onboard comfort of ride k with average judgment j, from 1 to 10. For instance, the question on the satisfactions against braking/acceleration was formulated as follows: "On a scale from 1 to 10, how satisfied are you with the acceleration and braking of the bus operator concerning this route?". The judgments have been elaborated considering different characteristics: age, gender, profession, position during the interview, driving style for braking acceleration, curves and vertical oscillation, educational qualification, and trip time. The mean, the median, the mode, the standard deviation, and the coefficient of variation have been calculated for the subjective judgments:

Mean: $\bar{x} = \frac{\sum x_i}{n}$

Median: central data value. The data are sorted in ascending order, and the middle value is detected to obtain the median.

Mode: the value that occurs most frequently.

Standard deviation: $s = \sqrt{\frac{\sqrt{(x_i - \bar{x})^2}}{(n-1)}}$

Variance: $s^2 = \frac{(x_i - \bar{x})^2}{(n-1)}$

Coefficient of variation: $V = \frac{s}{\bar{x}}$

For the processing of the accelerometer data from MEMS, the authors compute the RMSWA (Root Mean Square) of the weighted accelerations in m/s^2 according to International Standard ISO 2631 [34] at the frequency of 1.0 Hz, by the following expression:

$$RMSa_{lat,j} = \sqrt{\frac{\sum_{d=1}^{n_j} \left(a_{lat,j,d}\right)^2}{n_j}} \quad \forall j = 1, \ldots j$$

$$RMSa_{long,j} = \sqrt{\frac{\sum_{d=1}^{n_j} \left(a_{long,j,d}\right)^2}{n_j}} \quad \forall j = 1, \ldots j$$

$$RMSa_{vert,j} = \sqrt{\frac{\sum_{d=1}^{n_j} \left(a_{vert,j,d}\right)^2}{n_j}} \quad \forall j = 1, \ldots j$$

$$RMSWA_j = \sqrt{\left[\left(k_{lat} RMSWAa_{lat,j}\right)^2 + \left(k_{long} RMSWAa_{long,j}\right)^2 + \left(k_{vert} RMSWAa_{vertj}\right)^2\right]} \quad \forall j = 1, \ldots J$$

where:

- d: index of the observation;
- n_j: total number of samples of a_{lat}, a_{long} and a_{vert} associated with judgment j;
- $a_{lat,j}$, $a_{long,j}$, and $a_{vert,j}$: transversal, longitudinal and vertical components of the accelerations for each judgment j;
- k_{lat}, k_{long}, and k_{vert} are the weight factors that reflect the importance of the acceleration along the x, y, and z axes, respectively.
- $RMSa_{lat,j}$, $RMSa_{long,j}$, and $RMSa_{vert,j}$: root mean square value of the accelerations along the transversal x, longitudinal y and vertical z axes for the judgment j;
- RMSWAj: root mean square of the weighted accelerations for the judgment j;

Some simplifications on the frequency range and the method of measurement are assumed. Unlike ISO 2631 (frequency range from 0.1 Hz–80.0 Hz), the authors consider only 1.0 Hz frequency, since the main annoyance to the transport passengers is between 0.5 and 5 Hz [32, 35]. Also, the maximum sensitivity of the human body for horizontal acceleration occurs at 1.0 Hz, and other frequencies are less relevant.

Finally, the following equations and procedures were used to calculate the kinematic parameters of the bus lane axis in the key-points.

Longitudinal Speed v at key-point p is estimated as a mean of GPS positioning data in a circular area of radius 10 m around key-point.

Acceleration at key-point p. The same procedure described above has been applied to lateral, longitudinal, and vertical accelerations.

Lateral Jerk. The variation of acceleration over time.

Curvature Radius R. To determine the radius of curvature, triplets of key-points p were considered in sequence. The radius of the circle circumscribed to this triplet is given by $R = \frac{abc}{4S}$ while a, b and c are the sides of the triangle and S its area, according to the following expressions:

$$a = \sqrt{\left(x_{p-1} - x_p\right)^2 + \left(y_{p-1} - y_p\right)^2}$$

$$b = \sqrt{\left(x_p - x_{p+1}\right)^2 + \left(y_p - y_{p+1}\right)^2}$$

$$c = \sqrt{\left(x_{p-1} - x_{p+1}\right)^2 + \left(y_{p-1} - y_{p+1}\right)^2}$$

$$S = \sqrt{sp(sp-a)(sp-b)(sp-c)} \text{ where } S = \frac{a+b+c}{2}$$

Tortuosity. The tortuosity has practical relevance in many aspects of transportation: for road design, cost of the journey, passengers' comfort, accessibility and, fuel consumption. It can be defined as the rate between real length (L) of the path and the distance of the ends (D), as shown in Fig. 6. If the lane is defined as a poly-line connecting key-point p, the total length L is the sum of each segment.

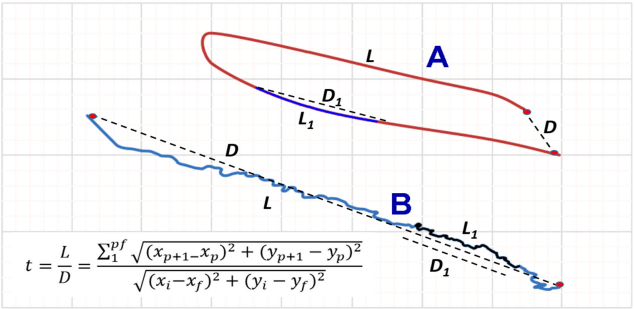

Fig. 6. Local and global tortuosity of a pathline.

Cornering Speed Limit. The two main hazards of excessive cornering are tire slip and rollover [36, 37]. Before the cornering, the speed limit can be evaluated by the equation: $v_{Lim} = \sqrt{gR(f_t + tag\beta)}$ m/s or $V_{Lim} = \sqrt{127R(f_t + tag\beta)}$ km/h.

A precautionary values of the skid coefficient f_t of 0.15 and transverse slope *tag* $\beta = 0$ are assumed.

Lateral Jerk (acceleration variation over time). It is necessary to limit the maximum jerk to avoid vehicle passengers' losing control over body movements and, to allow muscles to adapt to tension changes during sudden acceleration.

However, high jerk values are uncomfortable. The roads are designed to limit the jerk at $0.4 \div 1.4$ m/s^3 as a maximum as a function of the speed, which has been assumed c = 50.4/V according to Italian Regulation DM 6792/2001 (c [m/s] and V [km/h]).

3 Results

The survey saw a total of 130.1 h of accelerometric recordings on buses, which covered 2,393.9 km with an average travel speed of 18.4 km/h. The peak speeds are 87.8 km/h, and for 25.3% of the time, the bus was stopped (mostly at the bus stop and traffic light). Figure 7 shows the distribution of travel speeds.

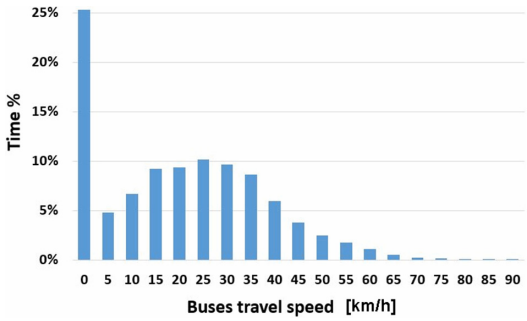

Fig. 7. Distribution of travel speeds.

Some observations concern the objective acceleration values linked to the subjective judgments (Fig. 8). The lateral accelerations a_x has values between −12.2 and 12.7 m/s^2, the longitudinal accelerations a_y between −4.0 and 10.5 m/s^2, and the vertical accelerations a_z between −10.2 and 21.0 m/s^2. Interestingly, the longitudinal accelerations are concentrated in the range between −4 and +4 m/s^2. A plausible interpretation is that they are linked to the characteristics of the bus braking system, which automatically introduces gradual braking (Fig. 8).

Figure 9 shows the trend of the geometric and kinematic parameters estimated along route 1OB, which was selected as an example.

The correlation matrix among all the analyzed variables shows that the parameters are generally not correlated with each other, with some exceptions (Fig. 10).

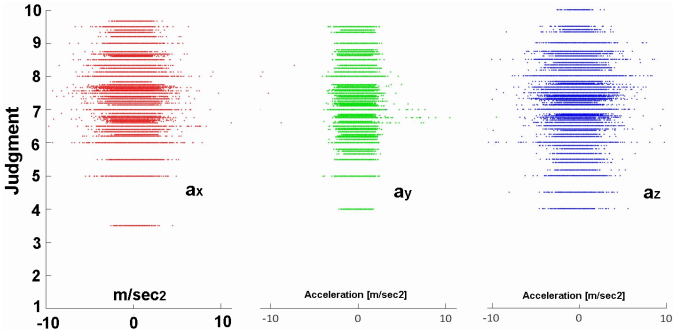

Fig. 8. Acceleration range as a function of judgments.

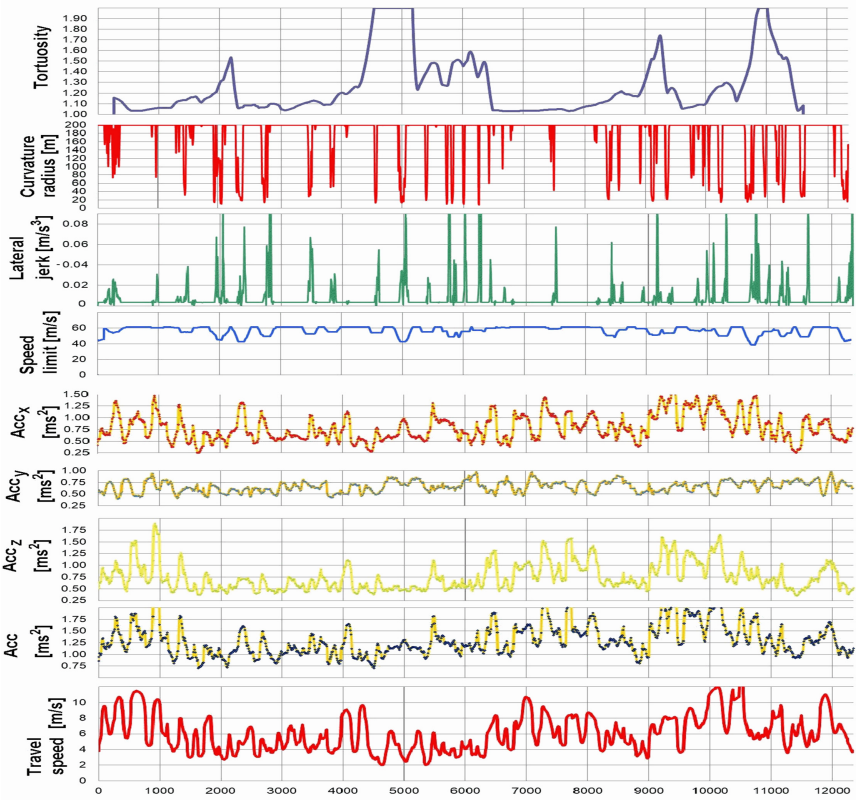

Fig. 9. Geometric and kinematic parameters estimated along the Line 1OB.

They concern the accelerations with the travel speed, the kickback with a radius of curvature. Perhaps high trivial correlations mutually abated among the three components of accelerations.

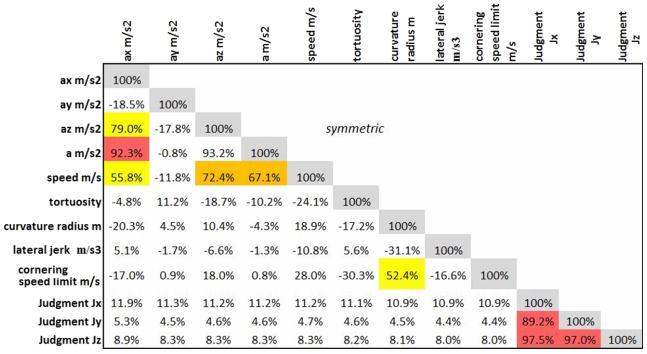

Fig. 10. Correlation matrix of the considered parameters

The subjective investigations were conducted mainly between 10:00 and 20:00 and mainly involved women (63% of the interviewees). Almost 40% of the interviewees are young people aged between 18 and 25, and over 75% are under the age of 35, mainly composed of students of first and second-grade schools. The movements are mainly short-lived, 88% with travel times of less than 15' (Fig. 11).

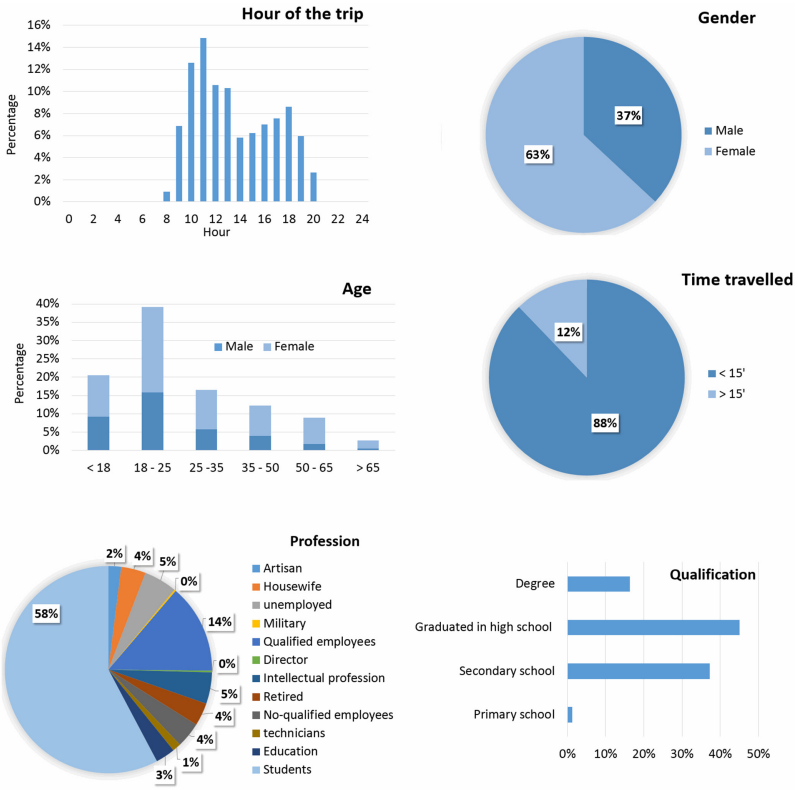

Fig. 11. Descriptive statistics of the surveys

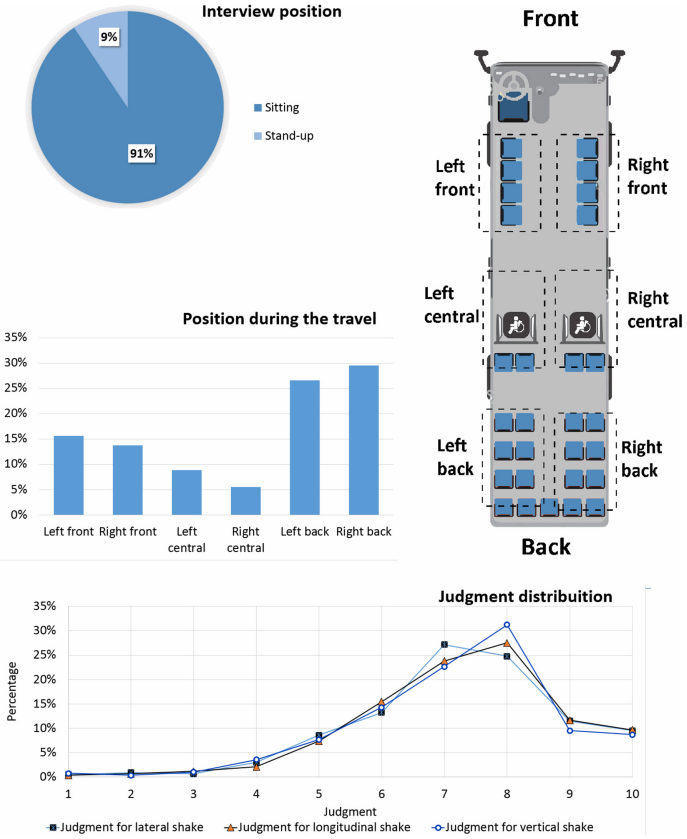

Fig. 12. Positions during interviews and judgment distribution

During the journey, 55% of the interviewed were positioned in the back of the bus. The passengers during the interview were 91% standing, and only 9% were sitting, In 75% of cases, the judgments are above 7. Judgments 7 and 8 exceed 55% (Fig. 12). These results clearly show that most of passengers rate the comfort on board along the three acceleration axes in the same manner, thus they seldom distinguishing among braking/acceleration actions, characteristic of the route and vertical vibrations mainly related to the pavement roughness.

Figure 13 shows that 1) the difference between couple of judgments is never greater than 4, 2) the 55% makes the same judgment and 3) approximately 88% differ only by one point.

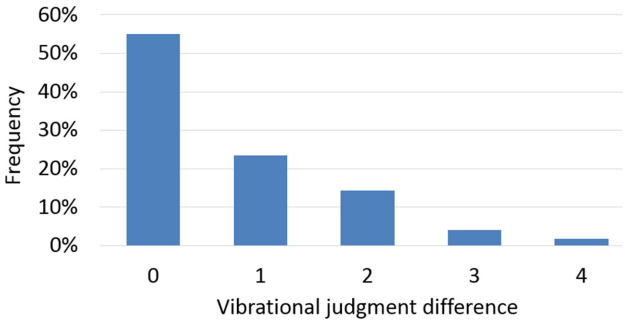

Fig. 13. Vibrational judgment difference between the component x, y, and z for each interview

Finally, it is interesting to observe the differences in judgments according to gender and age (Fig. 14a). Females tend to give a decreasing judgment with age while males show an opposite trend. Another trend observed in the group of interviews, decidedly marked in the female population, is a correlation between the average opinion expressed and the peak traffic hours (Fig. 14b).

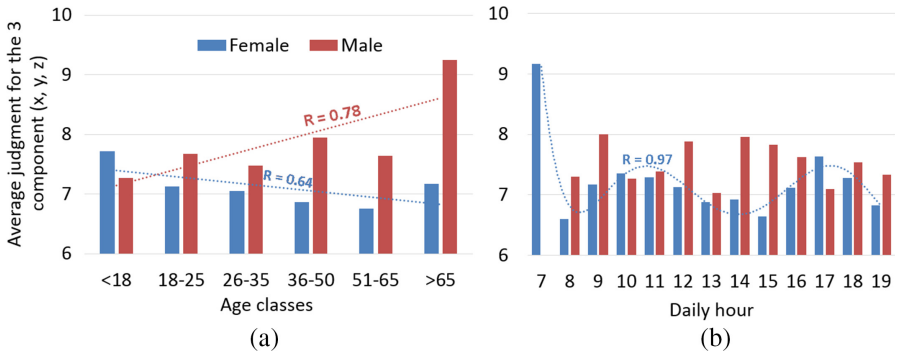

Fig. 14. a) On the left: average judgment vs. age classes; b) average judgment vs. daily hour

4 Conclusions and Remarks

The survey highlights how the perception of vibrational comfort on board in public transport can be particularly complex. A multiplicity of physical and subjective parameters can modify passenger perception. Objective measurements, such as the three distinct acceleration components, the speed, and the characteristics of the track, are felt very differently depending on the sex, age, and position inside the vehicle during the journey.

Trivial, predictably high correlated, have been obtained between the x, y, z acceleration components, and between the judgments Jx, Jy, and Jz. Users tend to judge the travel experience overall without discerning the three components. The interviewees attribute values very similar to the three components (lateral, longitudinal, and

vertical ones) even in the presence of significant variability of the road condition and in the presence of considerable difference in the levels of the three components. The difference between couple of judgments of each acceleration component differs only by one point for the 88% of the interviewed.

The results generally show weak correlations between the selected parameters and passenger judgments. Conversely, travel speeds have significant correlation values. There is a moderate inverse correlation between the vibrational level and the age of the passengers. The younger age groups tend to have more severe judgments, attributable to their higher demand for comfort. Another trend observed in the group of interviews, particularly in the female population, is a relationship between the average opinion expressed and the peak traffic hours. The presence of preferential lanes increases the onboard comfort quality in terms of speed regularity, without private cars interferences.

These results are a preliminary step in the authors' agenda, and thus, further research is suggested. It has been shown how many objective parameters can affect the comfort. In addition, passengers rated the perceived comfort along the three axes. Therefore, an advanced econometric model may be calibrated to examine the impact of objective measurements on the overall judgment. In this way, a gradual comfort scale may be perfectioned building on [1]. It can be part of a real-time dashboard, which shows to the bus driver when driving in comfortable/uncomfortable conditions, thus also improving the measurement of the service quality [37].

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