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Comfort Index CI(bus): A methodology to measure the comfort on board

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Abstract

The presented work deals with the important topic of assessing the quality of public transport services. This research specifically addresses the performance of the service in terms of comfort. In particular, the study focuses on the definition of a comfort index (CI) that takes into account two dimensions (noise and vibration) measured on board the buses studied, both during motion and on a stationary vehicle. The methodology interprets how users perceive the comfort on board the public transport considered, with numerical data coming from high-precision measuring instruments. This methodology represents a further element of synthesis in the complex quantification of perceptions by an individual, precisely because of the extreme subjectivity of judgment.

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1. Related work

The quality of the service offered tends to affect strongly the use of public transport systems. In order to increase the attractiveness of these services and therefore reduce the use of the car, administrations in cooperation with transport companies should take steps to ensure high quality of services in the public transport system. Compared to a few decades ago, collective transport systems and, more generally, transport systems have been rapidly developing and a significant increase in the technologies available on the means of transport has been detected. These technologies have made it possible to design safer, more comfortable, quieter and less polluting transport systems. However, these measures are still not sufficient to achieve the objectives set by the European Community [1].

The quality of collective transport services is a feature of many aspects, some more easily identifiable and measurable, such as frequency of service, travel delay, travel cost, etc., while others are more subjective and therefore more difficult to locate and measure, such as on-board comfort, cleanliness, security etc.

Andaleeb et al. [2] study the satisfaction levels of regular bus users in Dhaka, Bangladesh. Using a factor analysis and multiple regressions, five of the eight selected factors were found to have significant effects on passenger satisfaction. In order to define the quality of the transport system, the most important factors for passengers are: comfort levels, staff behavior, number of buses changed to reach destination, supervision, and waiting facilities.

Cantwell et al. [3] examine the level of stress caused by commuting into Dublin city centre, determining the comfort value and the reliability of public transport services. An on-line survey, Stated Preference (SP) type, was subjected to users in order to collect data on movements, satisfaction levels and commuting. These data were processed using a multinomial Logit model, which showed that utility as crowding derived increases and decreases as reliability increases.

Another European study conducted by Friman [4] suggests a research based on the analysis of the effects of improvements to the quality of the collective transport system service, based on the satisfaction of regular service users. This study, conducted in Sweden, has shown how user satisfaction is not closely related to quality of service improvements.

The study conducted by Tyrinopoulos et al. [5] proposes a methodology for defining and controlling the quality of services offered to users of a public transport company. In this study, developed by the Hellenic Transport Institute, 39 indicators were analyzed and categorized into 7 categories.

Another methodology, proposed by Nathanail [6], was developed to monitor the quality of Hellenic railway services. The methodology is based on the estimation of 22 indicators grouped into 6 criteria: *safety system, cleaning, passengers comfort, maintenance, information to passengers, the accuracy of the itinerary.*

The study proposes a performance index, obtained by combining objective indicators and subjective judgments of users. These indicators are obtained through the use of qualitative and quantitative parameters derived from the railway operator's databases or obtained through a sampling survey to the users.

With the introduction of dynamic models, there have been several improvements in this research topic [7, 8, 9]. These studies do not define an index and/or a scale to define the acoustic comfort, but are limited to characterizing the problem and defining predictive calculation models.

As defined in other studies [10], the use of the same acceleration sensors can be helpful in determining on board comfort and users driving style, both in private and public transport systems. Furthermore, Astarita et al. [11] show that the combined use of two sensors in a smartphone, namely the microphone and the accelerometer, allows even road anomalies along the route to be determine, by means of a suitable calculation algorithm. The study conducted by Barone et al. [12] shows how the use of a high precision instrumentation, such as a noise dosimeter and a vibration dosimeter, allows the algorithm used to be greatly simplified for the identification of road anomalies. Finally, a speculative study was performed by Barone et al. [13] on board the trains, resulting in a CI (rail) comfort index.

2. The instrumentation

The instrumentation used during experimentations was provided by the 01 dB Acoem company. Instrumentation is represented by those reported below: vibration dosimeter VIB 008, noise dosimeter WED 007, dodecahedron FOUR and amplifier PHON-X Mark I.

3. Preliminary sample survey

An SP (Stated Preference) survey was preliminarily conducted on a sample of 100 users who habitually use the public transport system, with the aim to involve users in the referencing process of transport service quality, overturning the concept of customer satisfaction currently used by public service operators.

A sounds set, previously recorded inside the buses running along the reference test site, was defined and encoded according to the equivalent sound level (Leq (A)). Interviewees have listened, through Dodecahedron Four, 7 different recordings (shown in Table 1), with predetermined equivalent sound levels (with a tolerance of ± 2 dB):

These recordings have a span of 3 seconds and were heard by the user in random sequence. In particular, at the stop-bus located along the reference test site, we asked users to match the level of perceived noise with the dodecahedron FOUR connected to the amplifier PHON-X Mark I, through a scale from 1 (highly comfortable) to 5 (extremely uncomfortable).

Results obtained from the preliminary sample survey on 100 users are summarized in Table 1.

Table 1. Preliminary sample survey results to detect the perceived noise level

Leq (A) [dB]	Noise perceived									
	1		2		3		4		5	
	n°	%	n°	%	n°	%	n°	%	n°	%
60	99	99.0	1	1.0	0	0.0	0	0.0	0	0.0
65	98	98.0	2	2.0	0	0.0	0	0.0	0	0.0
70	17	17.0	68	68.0	15	15.0	0	0.0	0	0.0
75	5	5.0	11	11.0	52	52.0	32	32.0	0	0.0
80	0	0.0	0	0.0	1	1.0	4	4.0	95	95.0
85	0	0.0	0	0.0	0	0.0	3	3.0	97	97.0
90	0	0.0	0	0.0	0	0.0	1	1.0	99	99.0

The survey shows that for as many as 98% of regular users, noise below 65 dB is highly comfortable. Instead, noise above 80 dB, for about 95% of regular users, is extremely uncomfortable. These two values were identified as minimum and maximum thresholds in the definition of comfort index.

Similar considerations were defined to determine the thresholds for vibrations perceived by the users on board the vehicle. The survey was conducted with a private vehicle (Land Rover Freelander 2) on a reference test site located on Viale Principe in Rende (CS) with the collaboration of 100 users because it is complicated to simulate a set of vibrations with predetermined thresholds to be subjected to the collective transport users.

Starting from the study [14] in which the relationship between the traveling speed of vehicles and the acceleration a_v (overall whole-body vibration acceleration) is demonstrated, specific speed thresholds were defined allowing to obtain certain values of acceleration. Each user was asked to give, by means of a scale from 1 (highly comfortable) to 5 (extremely uncomfortable), the level of vibrational comfort perceived on the vehicle that runs with predetermined speed (with a tolerance of ± 2 km/h):

- *Vm= 20 km/h*: determines an acceleration value (a_v) of about 0.20 m/s^2;
- *Vm= 30 km/h*: determines an acceleration value (a_v) of about 0.35 m/s^2;
- *Vm= 35 km/h*: determines an acceleration value (a_v) of about 0.50 m/s^2;
- *Vm= 40 km/h*: determines an acceleration value (a_v) of about 0.65 m/s^2;
- *Vm= 45 km/h*: determines an acceleration value (a_v) of about 0.90 m/s^2;
- *Vm= 50 km/h*: determines an acceleration value (a_v) of about 1.20 m/s^2.

Parameters used to determine vibrational comfort on board are: the a_w (frequency-weighted R.M.S. acceleration in m/s², along the three axis x, y, z) and the a_v, overall whole-body vibration acceleration, determined using the following formulation:

$$a_v = \left[(K_x \cdot a_{wx})^2 + (K_y \cdot a_{wy})^2 + (K_z \cdot a_{wz})^2\right]^{0.5} \quad (1)$$

where:

- a_{wx}, a_{wy} and a_{wz} are the weighted R.M.S. accelerations with respect to the orthogonal axes *x, y, z*, respectively;
- K_x, K_y, K_z are multiplying factors with respect to the orthogonal axes *x, y, z*, respectively.

Results obtained from the preliminary sample survey on 100 users are summarized in Table 2.

Table 2. Preliminary sample survey results to detect the perceived vibration level

a_v [m/s^2]	Vibration comfort perceived									
	1		2		3		4		5	
	n°	%	n°	%	n°	%	n°	%	n°	%
0.20	97	97.0	3	3.0	0	0.0	0	0.0	0	0.0
0.35	13	13.0	85	85.0	2	2.0	0	0.0	0	0.0
0.50	0	0.0	28	28.0	70	70.0	2	2.0	0	0.0
0.65	0	0.0	26	26.0	69	69.0	5	5.0	0	0.0
0.90	0	0.0	0	0.0	1	1.0	4	4.0	95	95.0
1.20	0	0.0	0	0.0	0	0.0	1	1.0	99	99.0

4. Sample survey on bus transport

After setting the thresholds for defining the comfort index from the preliminary results, a second survey on public transport vehicle (buses) was carried out, in order to define the level of vibration and acoustic comfort perceived by users on board the vehicle and to identify which component between noise and vibration is more significant.

The survey covered about 100 regular passengers of the public transport system, to which a questionnaire was administered. Users of the transport service were asked to express a unified judgment on which of the two factors (noise and vibration) has greater effect in the definition of on board comfort, with the aim to define the weight to assign to each variable. In addition to socio-economic questions useful to identify the sample interviewed, the same users were asked to assign a unique value from 1 to 10 to the perceived comfort on board the vehicle. This value allowed obtaining a corresponding perceived comfort CP(*bus*) on the route.

Following the elaboration of answers provided by users in the 100 survey forms, it was possible to determine the weights (α_n e α_v) attributable to the two variables in the comfort definition.

Starting from these indications it was possible to assign a weight (α) to the noise component (α_n) and vibration component (α_v) in the definition of the Comfort Index (CI). Therefore the parameters are: $\alpha_n = 0.35$ and $\alpha_v = 0.65$.

5. The Comfort Index CI(bus)

In order to determine the on board comfort in public transport systems we have studied a Comfort Index CI(*bus*) useful to uniquely identify the comfort level of the considered transport system. This CI(*bus*) was studied starting from two variables: *noise measured* on board the vehicle during the trip and *vibrations measured* on board the vehicle during the trip. In defining the CI(*bus*) formulation, a weight was assigned to each measured variable, starting from indications emerged from the 100 survey forms submitted during the investigation on public transport. Specifically, the CI(*bus*) was determined for the rail transport system.

The formulation used to define the CI(*bus*) is the following:

$$CI(bus) = x_n \cdot \alpha_n + x_v \cdot \alpha_v \quad (2)$$

where:

- x_n, x_v: noise and vibration coefficient;
- α_n, α_v: weight assigned to the noise and vibration class;

  The weights α_n e α_v, were set equal to: $\alpha_n = 0.35$ and $\alpha_v = 0.65$.

  The values x_n e x_v dependent from noise and vibrations measured on board the vehicle are shown in Table 3.

Table 3. Identification of parameter x_n and x_v

Leq (A) [dB]	**Leq (A) ≥ 80**	**80 > Leq (A) ≥ 75**	**75 > Leq (A) ≥ 70**	**70 > Leq (A) ≥ 65**	**Leq (A) < 65**
x_n	1	0.75	0.5	0.25	0
a_v [m/s^2]	**$a_v \geq 0.90$**	**$0.90 > a_v \geq 0.65$**	**$0.65 > a_v \geq 0.35$**	**$0.35 > a_v \geq 0.2$**	**$a_v < 0.2$**
x_v	1	0.75	0.5	0.25	0

Through the thresholds defined in Table 3 it is possible to determine the level of measured comfort CI(*bus*), shown in Table 4, concerning the considered transport. In Table 4, are also given the thresholds useful to define the perceived comfort CP(*bus*) identified by interviewees in the survey on transport.

Table 4. Determination of Comfort Index CI(*bus*) and Perceived Comfort CP(*bus*)

CI(*bus*) Comfort Index	1 ≥ CI ≥ 0.90	0.90> CI ≥ 0.75	0.75 > CI ≥ 0.50	0.50 > CI ≥ 0.25	0.25 > CI ≥ 0
	Extr.Ucomfortable	Uncomfortable	Avg.Comfortable	Comfortable	High.Comfortable
CP(*bus*) Comfort Perceived	CP ≤ 2	2 > CP ≥ 4	4 > CP ≥ 6	6 > CP ≥ 8	8 > CP ≥ 10
	Extr.Ucomfortable	Uncomfortable	Avg.Comfortable	Comfortable	High.Comfortable

6. Testing and validation of the Comfort Index CI(bus)

To validate the proposed methodology, an experimental campaign on a reference test site was conducted. In the case of buses, the test site considered, is the stretch from Cosenza Vaglio Lise station to the Cittadella Regionale Germaneto (CZ) for a total of about 110 km. Bus types, affected by the measurements, used by the Ferrovie della Calabria along the Cosenza Vaglio Lise - Catanzaro Germaneto section, in four specific courses considered for testing, are: *Setra S 415 HDH* and *Iveco France SFR 160*

6.1. Validation of the Comfort Index CI(bus)

15 external measurements and 15 return measurements were performed for each of the two transport systems described, for a total of 60 measurements. Each measurement was georeferenced and exported to GIS, for processing data, including graphs, using the Open Source Quantum GIS software.

Starting from photometric and accelerometer measurements carried on board the buses, the CI(*bus*) was calculated according to the scheme described in the previous paragraph. The comparison between the comfort index CI(*bus*), determined by the formulation (2), and the perceived comfort CP(*bus*), calculated by the average of scores given by users in the survey forms and shown in Table 5, highlights a good correspondence between the values of CI(*bus*) and CP(*bus*).

Table 5. Comparison CI(bus) and CP (bus) on the test site Cosenza Vaglio Lise – Germaneto (CZ)

	CI (*bus*) $_{\text{average}}$	CP (*bus*) $_{\text{average}}$
Setra S 415 HDH	0.4775	6.54
Iveco France SFR 160	0.5151	5.60

In the case of buses, the Setra is generally more comfortable than the Iveco bus, on each of the three test sites considered (urban, highway and state road). The most comfortable section of the test site is the urban stretch where bus proceeds at low speeds, effectively reducing the accelerations transmitted to the onboard users and the noise perceived by the users themselves. It should be noted, however, that the highway section, on average, appears to be the least comfortable with reliefs that in some cases were "uncomfortable".

The highway section under consideration is being modernized with modifications of the current track that include numerous curves with bending radii too small for a highway, thus decreasing the comfort on board perceived by users. A chi-square test Chi-$sq_{(4-0.95)}$, was applied to determine whether there are no significant differences (*Setra S 415 HDH = 2.38 and Iveco France SFR 160 = 2.24).*

7. Conclusions

The study started from a sample survey on regular users of the transport service, with the aim of determining a perceived noise level and vibration and identifying their thresholds. The next step was to start a vehicle sampling survey that allowed the perceived environmental factors to be detected, such as noise and vibration, and the degree of incidence of the same factors on perceived comfort. For this purpose, a CI comfort index, specific to the collective transport (bus), acceleration function and noise measured on board the vehicle during the journey was specified, calibrated and validated. The validation of this index (CI) was carried out on two types of buses (Setra S 415 HDH and Iveco SFR 160) along the Cosenza Vaglio Lise - Germaneto (CZ) section. Research led to a new idea of service quality indicators. In fact, starting with objective measures such as noise and acceleration measured on board the vehicle, it was possible to determine accurately the acoustic and vibrational comfort on board the means of transport considered.

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