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Real-time evaluation of the on-board comfort of standing passenger in bus transit services

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Abstract

Bus on-board comfort may be intended as a multidimensional concept declined according to several attributes (e.g., vibrations, the load factor, the driving style, etc.) and represents a key factor of service quality. Thus, its measurement is crucial for public transport companies as it can support for the monitoring, evaluation and implementation of specific actions to improve their services.

The objective of this paper is to build a numerical scale for real-time measurement of bus on-board comfort. This is pursued integrating subjective measurements of the driving style provided by the passengers with objective ones of longitudinal and transversal accelerations data collected by Intelligent Transportation System tools.

The results are very useful because they represent a contribution to establish a comfort scale in a real operational environment, as a tool to regulate the driver's behavior: each driver is in the position of real-time monitoring the quality of a bus ride regarding on-board comfort level.

Keywords:

Bus on-board comfort, Real-time comfort scale, Driving style.

Introduction

Nowadays the interest in the service quality is quickly increasing for public transport companies (PTCs), given the deep conviction that a high-level of service can positively influence the choice of public transport *w.r.t.* the private transport. Indeed, it is believed that quality can represent the key factor that may affect the choice towards the use of public transportation. Among the various parameters of the service quality, the comfort on-board is a relevant one. Indeed, it may be related to the overall satisfaction perceived by passengers. Therefore, measuring the comfort on-board can support PTCs for the monitoring and the implementation of service improvements. Moreover, a good internal work environment can lead to better performance even by the driver, to improve the safety and reduce the annoyance of all passengers.

Over the past decade, the interest on the On-Board Comfort Level (OBCL) on buses has received an increasing attention regarding both attributes to measure and measurement methods, as shown in Table I. Regarding the attributes, most of the research is focused on the technical side of it (*e.g.*, [1], [2], [3], [4], [5]). This research included attributes concerning different facets including: the load factor and the available space on board (*e.g.*, [6], [7]), the cleanliness, the noise, the temperature (*e.g.*, [8], [9]), physical and kinematic components such as vibrations, lateral and longitudinal accelerations (*e.g.*, [10], [11], [12], [13], [14]) and so on. Conversely, the driver's behavior seems relatively few considered

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([15], [16], [17], [18]). Hence, it may be of interest to enlarge the research concerning the relationship between the driving style and passenger comfort.

Regarding the measurement methods, three different approaches have been adopted: 1) Subjective approach: the OBCL is measured by interviewing the passenger; 2) Objective approach: the OBCL is measured through technological devices; 3) Mixed approach: the OBCL is measured using both the subjective and the objective approach.

Table I: A list of comfort attributes and measurement methods

Authors, year, source	Comfort attributes	Measurement methods
Oborne and Clarke, 1975, [2]	Noise, vibrations, temperature, and posture	Subjective
Barabino *et al.*, 2012, [9]	Space on-board, cleanliness, driving style	
Kittelson & Associates Inc. *et al.*, 2003, 2013 ([6], [7])	Passenger Loads	Objective
Lin and Chen, 2011, [12]	Vibrations	
Sekulic *et al.*, 2013, 2016, 2018 ([3], [10], [11])	Vibrations	
Maternini and Cadei, 2014, [14]	Accelerations on the standing passengers	
Zhao *et al.*, 2016, [5]	Vibrations	
Af Wahlberg, 2006, [15]	Driving Style (Overall comfort, jerk, noise and safety, longitudinal acceleration)	Mixed
Castellanos and Fruett, 2014, [13]	Jerk, accelerations, and vibrations	
Zhang *et al.*, 2014, [4]	Noise, vibrations, thermal comfort, longitudinal acceleration	
Eboli *et al.*, 2016, [16]	Driving style and longitudinal and lateral accelerations	
Barabino and Di Francesco, 2016, [8]	Space on-board and cleanliness	
Barabino *et al.*, 2018, [17], [18]	Driving style and longitudinal and lateral accelerations	

The first approach is based on subjective measures of comfort, as a function of road conditions, vehicle type, internal vehicle conditions, *etc.* These measurements reflect the passengers' viewpoints on desires and perceptions as reported in the customer satisfaction surveys ([19]). For instance, the perception for a given comfort attribute is rated by passengers on a qualitative or quantitative scale, which may also be suitable for capturing opinions on a wide number of attributes. However, the subjective measure of the OBCL may be an expensive task regarding efforts, owing to survey and personal interviews. In addition, it may provide too varied judgments due to the passenger's characteristics the (*e.g.*, cultural level, mood, type).

The second approach is based on an objective measure of it, which allows a more reliable evaluation. Different comfort attributes are measured through some technical devices such as accelerometers, which return the data free from any conditioning. The great majority of these studies analyzed the comfort regarding vibrations. Indeed, during the ride, drivers and passengers are also exposed to vibrations from the road surface, which may reduce the working ability and generate the feeling of discomfort. Moreover, to connect the objective measurement to the subjective feeling of comfort, the large majority of these studies relied on the international standard [20], which presented a comfort scale. However, this approach might be a drawback in state of the art. Indeed, this scale expresses vibration comfort under the fixed and controlled condition for one passenger; it was derived in ideal (static) conditions, measuring in the lab the effects of the exposure at a different frequency of vibrations on a human body sitting. However, especially in urban bus networks, passengers are subjected to real (dynamic) conditions and travel standing for a few bus stops.

The third approach is emerging and incorporates subjective and objective data on several comfort attributes collected together (*e.g.*, [4], [15], [16], [17], [18]). Subjective data are collected from passenger opinions using surveys, whereas objective data were collected by technical devices, manual measurements, and secret shopper surveys. Research on concurrently subjective and objective evaluations of bus comfort can be roughly divided into two categories. The first category includes studies which evaluate the OBCL using inferential models, *i.e.*, regression ones. The objective of these models is to look for variables explaining the OBCL [4]. The second category includes studies which use descriptive models to quantitatively evaluate the OBCL ([15], [16], [17], [18]). The objective of these models is to establish a relationship between the subjective perception of comfort and different objective parameters by simple statistics such as correlation analysis, percentage values, *etc*. Interestingly, one of the main outputs of this approach is to establish some comfort thresholds to recognize whether the OBCL is good from the passengers' viewpoint.

The objective of this paper is to develop a new method for the establishment of a comfort scale in bus transit services. This is in order to put bus drivers in the position of real-time monitoring the quality of a bus ride regarding OBCL. To this aim, the authors adopt two measures of comfort: a subjective and an objective one. The subjective measure considers the perception of passengers on comfort linked mainly to the driving style of the driver. The objective measure considers the instantaneous horizontal acceleration data recorded on the buses along each ride. Matching the subjective judgments with the objective ones, we found different thresholds of kinematic parameters that are representative of several levels of comfort. Each acceleration threshold corresponds to different average subjective judgments. By combining these thresholds, a comfort function is built. This function provides the trend of the acceleration values according to passengers' perceptions and helps measure the OBCL in real-time.

Following this introduction, Section 2 presents the method to build a comfort scale. Section 3 describes the experimentation of this method in a real environment. Finally, Section 4 provides conclusions and research perspectives.

Methodology

In this section, a practical, simple and holistic method is presented for the establishing an OBCL scale per the measurement of comfort in urban buses. As shown in Figure 1, the method is organized into three main levels: (A) Type of Data, (B) Tools of Data collection and (C) Analysis of Data. These levels will be discussed in what follows.

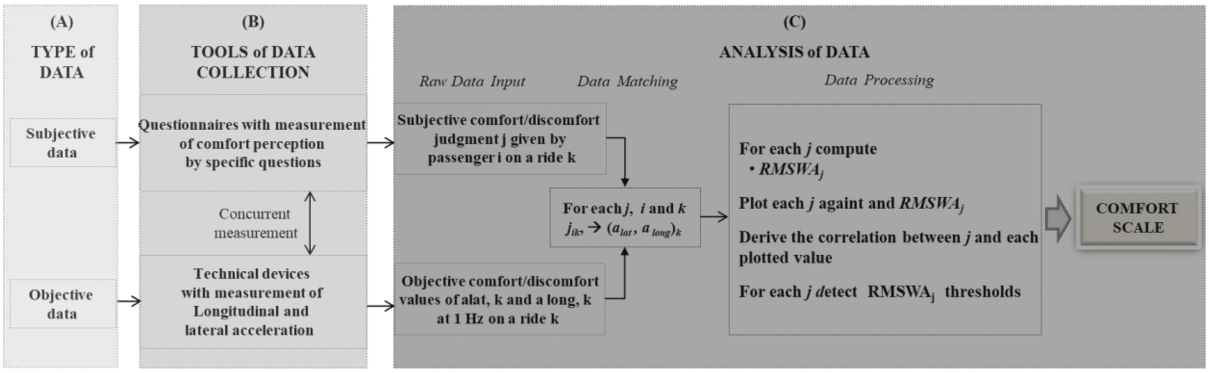

Figure 1: Flowchart of the proposed method

(A) Type of Data

Two types of data are considered: subjective and objective data. The former represents the subjective judgment of the perceived comfort on-board rated by bus passengers. The latter represents the values of the kinematic parameters (*i.e.*, acceleration data) that are usually used to measure the driving style (*e.g.,* [16], [17]). It is worth noting that the basic assumption of this method mainly considers the OBCL as a function of passenger shake due to driving behavior on slowing down, braking, steering, and accelerations. Thus, some kinematic parameters need to be considered as affecting passengers' feeling of comfort/discomfort on-board

(B) Tools of Data collection

Since the two types of data must be collected, two different tools will be used. Subjective data may be collected through questionnaires. Objective data may be collected by devices able to continuously record bus location and kinematic parameters. In this paper, the kinematic parameters considered are the longitudinal and lateral accelerations. Indeed, they are usually adopted for measuring the driving style ([15], [16], [17], [18]). More precisely, location-at-time data (*i.e.*, the bus location at the arbitrary time when it is polled) on accelerations are recorded continuously along the bus route. As a result, the OBCL can be assessed according to the spatial characteristics of the route. It is worth noting that subjective and objective data need to be collected concurrently, to avoid temporal mismatches and biases in the measurement. This may be done by interviewers and technicians simultaneously. Indeed, for each ride, interviewers administer the questionnaire (or use a self-administered survey) to a group of users, and concurrently technicians detect the kinematic measures with the devices.

(C) Analysis of Data

To be able to determine the passenger's tolerance to accelerations, the collected data must be analyzed and combined. This analysis can be summarized as follows: (i) raw data input; (ii) data matching and (iii) data processing. First, subjective and objective raw data input is collected as follows. Each passenger i rates with judgment j the on-board driving style along with a ride k. Personal judgment can be provided using qualitative or quantitative scales. Simultaneously, the technical device collects raw data on lateral a_{lat} and longitudinal along accelerations, respectively. Thus, for each ride k, one can interview several passengers on their perception on driving style and collect several location-at-time data of a_{lat} and along.

Second, data matching between judgments and transversal and longitudinal accelerations is performed. More precisely, for each judgment j, a list of k rides which have obtained that judgment is built. Thus, one builds as many lists as many items have the judgments scale. For example, if judgment j is given by both passenger i on ride k of route r and passenger $i+1$ on ride $k + 1$ on route r_1, judgment list j will contain objective data on both rides (k and $k + 1$).

Third, data processing follows. The comfort experience on the bus can be complex and difficult to evaluate. Thus, in this method, the authors assume the Root Mean Square Weighted Accelerations (RMSWA) along the horizontal plane at 1.0 Hz as an indicator of shake comfort mainly due to acceleration, braking, and turns. The OBCL may be related to the vertical component of the instantaneous values of accelerations. However, in this method, we consider the horizontal components, as passengers rate the driving style only. In addition, in cases like speed bumps, the comfort of the passenger may be directly related to the driver's driving style and vertical acceleration.

However, in this paper, we disregard the vertical component of the instantaneous values of accelerations, as we suppose that is more related to pavement roughness rather than the horizontal driving style. Let:

- $RMSWA_j$ be the total value of root mean square of the weighted accelerations in m/s^2 for each judgment j;
- $RMSWAa_{lat,j}$, and $RMSWAa_{long,j}$ be the root mean square value of the weighted accelerations along the transversal x and longitudinal y axes in m/s^2 for each judgment j;
- $a_{lat,j}$, $a_{long,j}$ be the transversal and longitudinal components of accelerations for each judgment j;
- k_{lat}, k_{long} be weight factors which reflect the importance of the acceleration along x and y axes.

For each judgment j = 1,..., J, the total value of *RMSWAj* is calculated as follows:

$$RMSWAa_{lat,j} = \sqrt{\frac{\sum_{q=1}^{N_j} \left(a_{lat,j,q}\right)^2}{N^j}} \qquad \forall j = 1, \ldots J \qquad (1)$$

$$RMSWAa_{long,j} = \sqrt{\frac{\sum_{q=1}^{N_j} \left(a_{long,j,q}\right)^2}{N^j}} \qquad \forall j = 1, \ldots J \qquad (2)$$

$$RMSWA_j = \sqrt{\left[\left(k_{lat} RMSWAa_{lat,j}\right)^2 + \left(k_{long} RMSWAa_{long,j}\right)^2\right]} \qquad \forall j = 1, \ldots J \qquad (3)$$

Next, each judgment j is plotted against the values returned by eqn. (3), thus a relationship between the subjective judgments and the objective values of acceleration is sought. Regression analysis is adopted to find this relationship. This *modus operandi* helps provide a comfort scale associated with each judgment j. The range between two consecutive judgments marks the thresholds between two values of RMSWA.

Real world experiment

The context

This method was tested in the urban bus transport system on the metropolitan area of Cagliari, a coastal area with 0.4 million inhabitants, located in the island of Sardinia (Italy). This area includes eight municipalities and represents that with the highest demographic density of the Sardinia. In addition, it is the main administrative and commercial hub of the island, attracting tens of thousands of commuters daily. The local PTC manages public transportation with 271 vehicles (*i.e.*, buses and trolleys) and serves around 38.9 million journeys a year. Moreover, these vehicles travel over 12.3 million kilometers per year along 32 urban routes [21]. CTM collected data for this experimentation on a pool of 8 routes. These are representative of the general bus network regarding lengths (6÷13 km), vehicle types (7÷12m) and capacities (29÷105 passengers) as reported in Table II.

Table II: Sample of routes and buses for the experiment

Route name	Overall length [km]	Overall bus stops [#]	Bus length [m]	Bus Capacity [passengers (seats)]
L1	24.39	81	12.00	105 (27)
L2	19.03	70	12.00	105 (27)
L3	12.86	48	7.90	58 (10)
L4	9.94	31	9.23	85 (15)
L5	18.49	49	12.00	83(25)
L6	9.21	28	7.00	29 (10)
L7	19.30	68	12.00	105 (27)
L8	21.02	58	12.00	105 (27)

Data types and collection tools

Data were collected during some days in July 2017. The sampling was done from 7:00 AM to 7:00 PM from 3 to 6 consecutive hours. No distinction has been done between standing and seated passengers. However, according to the last column of Table II, it can be reasonably assumed that the representative sample is precisely that of standing passengers. Moreover, standing passengers are supposed to experiment the most critical condition regarding OBCL.

Subjective data were collected by trained surveyors. The interviewers directly interviewed passengers both to minimize the bias due to possible misunderstandings of some questions and to collect the largest number of questionnaires since the sample needs to answer only. The questionnaire was organized according to four sections. The first section is a general one and contains contextual information, including date, time, route investigated as well as a question about the availability of passengers to agree on the survey. The remaining three sections are organized as follows: Socio-demographic attributes (i.e., gender, age, educational qualifications, employment, car availability and the reason for using the bus); Trip-related attributes (i.e., trip purpose, in-vehicle time, other transit systems use, bus use frequency); Quality rating on the OBCL. The OBCL was evaluated according to the Italian school assessment method on a scale of 1 to 10 using the following question: "On a scale of 1 to 10, how satisfied are you with the driving style of the bus driver regarding this route?" Pre-test and piloting were also conducted. As a result, some questions were slightly adjusted regarding the order; moreover, formatting and data entry errors were pointed out and addressed before starting the full survey.

Objective data were collected by trained technicians, using a Smartphone equipped with a GPS device and a 3-axis accelerometer. At a frequency of 1 Hz, a specific app (Torque) recorded location-at-time data of several parameters along the bus route during a ride *k*. Vbox is professional equipment that may be adopted to record the measurements. However, in this paper, the Smartphone has been used both since it is less bulky than the Vbox and easier to install on-board. The most relevant parameters for this study are: the GPS time (in hh:mm:ss), the bus location (in latitude and longitude), the speed (in m/s), and the lateral - a_{lat} - and longitudinal - a_{long} - accelerations (in m/s^2). A crucial choice was the location of the Smartphone to record reliable data. It was located inside the bus, close to the driver and on a horizontal plane. This choice can result in an approximation on the perceptions of comfort levels from passengers. Indeed, several passengers can station quite far from the Smartphone (e.g., in the middle or the rear of the bus). However, to limit this effect, interviews were administered close to the Smartphone.

Analysis of data and results

A total of 26 hours distributed on 42 complete runs was investigated. Final data resulted in 294 completed questionnaires and more than 142,000 raw records of kinematic parameters. For the sake of easy and to have more objective data for each judgment, the 10 judgments were merged into pairs. Thus, an adjusted scale is obtained, ranging from 1 to 5. More precisely, judgments 1 and 2 have been fused into judgment 1, judgments 3 and 4 into 2, and so on. Results are shown in Figure 2. It shows that 96% of passengers are satisfied with the driving style. Therefore, we expected that they are not exposed to quite high values of accelerations.

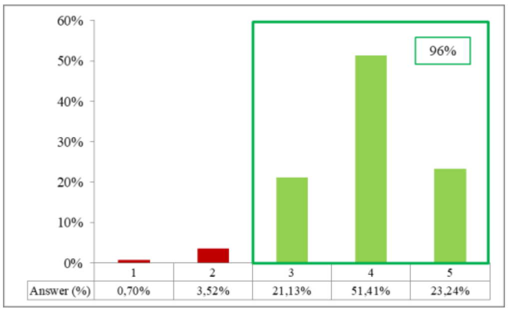

Figure 2: Judgment distributions about the driving style

Next, acceleration data have been fused according to the adjusted 5-point scale. Thus, for each judgment *j*, the list of the corresponding *k* rides was built, and the actual values of a_{lat} and a_{long} were associated as shown in Figure 3 (A). A total of 198,710 raw records of kinematic parameters resulting from the matching between judgment/ride and accelerations data are considered.

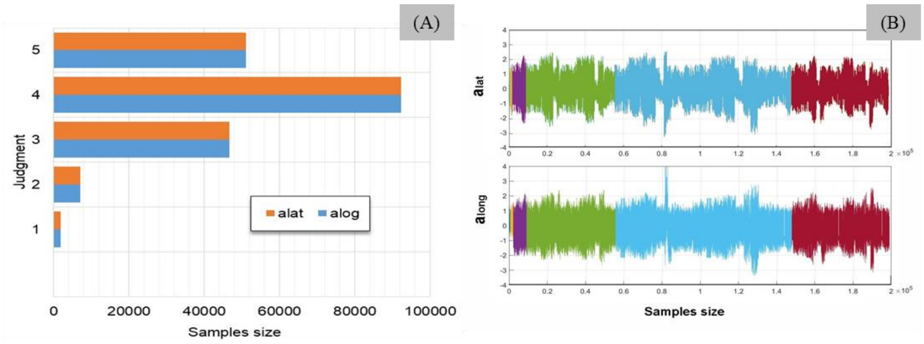

Figure 3: Sample size and values of a_{lat} and a_{long} for each judgment

Figure 3 (B) reports the elementary value for each a_{lat} and a_{long} associated with each judgment. Each color highlights the values of a_{lat} and a_{long} associated with judgment *j*. For instance, the values of a_{lat} associated with judgment 5 are shown in purple. Figure 3 (B) shows that even if there are differences between the max and minimum values of a_{lat} and a_{long}, these are not significant at 5% significance level, *i.e.*, the thresholds in the ranges of a_{lat} and a_{long} may be considered quite similar. Indeed, the result of two-sample *t-test* shows that the calculated value (*i.e.*, 0.285) is within the acceptance range of *T* (*i.e.*, $-2.12<0.285< 2.12$). Therefore, the comfort perception depends both on acceleration and braking actions due to traffic conditions and/or transversal movements due to the route characteristics

Figure 3 shows that judgment 1 contains few data. Therefore, before data processing, the acceleration data linked to this judgment were neglected, to preserve statistical consistency and uniformity of data. This means neglecting about 2% of the data, a value that does not affect the results obtained.

Next, according to eqn. (3), the value of $RMSWA_j$ associated to each judgment *j* was calculated. Coefficients k_{lat}, k_{long} have been set to 1 because we supposed that accelerations on the horizontal plane have the same weigh. Moreover, we plot each judgment *j* against $RMSWA_j$. The results are reported in Figure 4 (A)**Errore. L'origine riferimento non è stata trovata.**. After fitting these distributions using different functional forms, the best results have been obtained using a linear trend. Indeed, a high correlation between judgments and RMSWA have been obtained (R^2 = 0.917). Moreover, extending this trend towards judgment 1 (and 0), a comfort scale is obtained as shown in Figure 4 (B). Indeed, the resulting eqn. (4) returns the value of human judgment, according to the value of RMSWA. Nevertheless, in order to obtain judgment ranging from 0 to 5, eqn. (4) should be considered in the following ranges of RMSWA:

$$J = \begin{Bmatrix} 0 & if\ RMSWA > 2.0756 \\ -17.34 * RMSWA + 35.99, & if\ 1.7872 \leq RMSWA \leq 2.0756 \\ 5 & if\ RMSWA < 1.7872 \end{Bmatrix} \quad (4)$$

More precisely by inserting in eqn. (4) the value of the RMSWA returned by eqn. (3), the corresponding value of the subjective comfort is obtained.

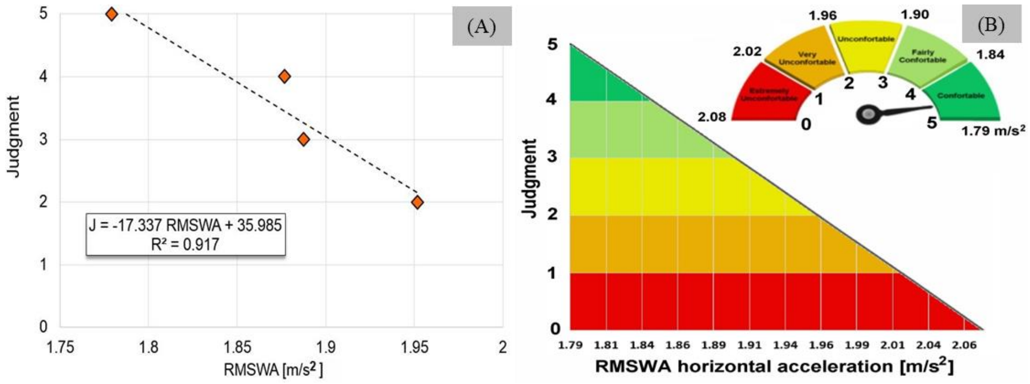

Figure 4: Estimation of the RMSWA and judgments according to each judgment (on the left). The comfort scale for the horizontal acceleration RMSWA (on the right)

The range of acceleration values concerning the judgments is very narrow. The homogeneity of bus routes selected for the survey and the short average passenger travel distance (less than 10 stops) reduce the variability of the all possible accelerations. Interestingly, Figure 4 (B) shows that this scale can be used to identify comfort/discomfort conditions in real-time. Indeed, this scale may be part of a real-time dashboard, which shows to the bus driver when driving in comfortable/uncomfortable conditions. A clear example is shown in the top-right of Figure 4 (B). It shows the dashboard with the judgments expressed qualitatively (*e.g.*, J = 4.86 falls within the *comfortabl*e range -in green-).

Finally, it may be of interest to perform further experimentation providing separate estimates of the mean values of a_{lat} and a_{long} distinguishing between positive and negative components, for each judgment *j*. These components are denoted by $\widehat{a_{lat}^{+}}^{j}$, $\widehat{a_{lat}^{-}}^{j}$, $\widehat{a_{long}^{+}}^{j}$ and $\widehat{a_{long}^{-}}^{j}$, respectively. Although this analysis may go beyond the paper aims, it may be useful to observe if the perceptions of the passengers on the driving style mainly depend on acceleration or braking actions due to traffic conditions, or to the lateral movements due to the route characteristics (*e.g.*, roundabouts). Therefore, for each judgment *j* the values of $\widehat{a_{lat}^{+}}^{j}$, $\widehat{a_{lat}^{-}}^{j}$, $\widehat{a_{long}^{+}}^{j}$and $\widehat{a_{long}^{-}}^{j}$ were calculated, and plotted against each judgment *j*. Next, we fitted four distributions (two per the positive components of acceleration, and two for the negative ones) using several functional forms. The best fits have been obtained using linear-log regressions, since they present the highest R^2. The results are shown in Figure 5, in which triangles represent values of a_{lat} and circles that of $a_{long.}$ Although only four points are available to estimate the components of accelerations, they are indicative of its trend. Indeed, each point of $\widehat{a_{lat}^{+}}^{J}$, $\widehat{a_{lat}^{-}}^{J}$, $\widehat{a_{long}^{+}}^{J}$ and $\widehat{a_{long}^{-}}^{J}$ was derived by averaging 39,742 raw data.

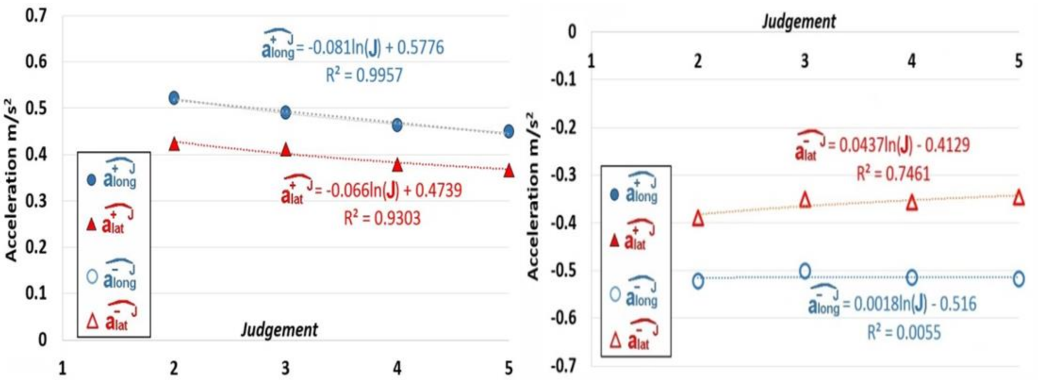

Figure 5: Estimation of , (on the left) and , (on the right) vs judgments.

Figure 5 deserve three considerations. First, the OBCL perceived by passengers may mainly be attributable to the positive components of the longitudinal and transversal acceleration, whereas negative components affect less the OBCL. Second, while accelerations strongly affect the OBCL, braking does not seem to have any effect. This may be explained considering the strong acceleration from the bus stops and confirms the result of [15], since also in CTM drivers were trained in a full-blown fuel-efficient driving style. Third, the values of $\widehat{a_{lat}^{+}}^{J}$, $\widehat{a_{lat}^{-}}^{J}$, $\widehat{a_{long}^{+}}^{J}$ and $\widehat{a_{long}^{-}}^{J}$ present OBCL thresholds stricter than those of [15].

Conclusions

Bus comfort is a key factor of transit service quality. Measuring the on-board comfort level (OBCL) can support public transport companies for the monitoring, evaluation, and implementation of specific actions to improve their services. In this study, the OBCL related to driving style is evaluated using about 300 subjective judgments and 200,000 raw acceleration data collected on different routes of an Italian bus operator. Moreover, these data are combined to build a real-time on-board comfort scale. This represents a pioneering output of this framework. Although this scale has been developed and calibrated combining the subjective judgments with the objective ones, it allows evaluating the comfort only through kinematic data recorded during the bus ride. Therefore, it results in two impressive advantages: 1) a bus driver can regulate her/his driving style and 2) the bus company may save many economic resources the evaluation of OBCL as there is not the need to perform surveys.

The first benefit of this research is the high degree of applicability for public transport companies needing to improve the OBCL on their routes. The second benefit is the possibility to development new bus on-board instruments together with bus manufacturing. Indeed, buses may be equipped with a new dashboard that real-time shows when the bus driver is driving in comfortable/uncomfortable conditions. This dashboard may be added to traditional ones such as the one, which measures the level of fuel.

Nevertheless, this research is a preliminary step in the authors' agenda, and thus, further developments are suggested. First, in this experiment, no distinction was made between young and old passengers, and those sitting and standing in the sample. Since it is believed that these facets could affect the OBCL, in future research, they could be considered to achieve a complete comfort scale. Second, the subjective evaluation of the vertical component of acceleration by passengers needs to be considered. This is to take mainly into account the roughness of the pavement.

Acknowledgements

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