A Literature Review on Bus Comfort On-Board

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Abstract. According to the UN's 2030 Agenda, cities and human settlements aim to become inclusive, safe, resilient, and sustainable. In this context, cities are pivotal for social and economic development, serving as gathering places where everyone should enjoy a high standard of living and accessibility. Public transportation, particularly bus comfort on board, significantly influences the quality of urban transportation services. Measuring this comfort is essential for transportation providers to track, assess, and implement targeted improvements. Comfort is a complex concept influenced by factors like temperature, noise, vibration, acceleration, passenger load, and cleanliness.

The literature offers various approaches to measuring bus comfort, prompting this paper's review of existing research to establish a structured research base for future studies. Despite a wealth of literature on onboard bus comfort levels (OBCL), no methods yet establish graduated, dynamic comfort scales incorporating diverse passenger characteristics and real-time acceleration data. This gap prevents a comprehensive, real-time OBCL assessment that accurately reflects passenger experiences. Furthermore, extensive data collection is necessary to calibrate models and consolidate comfort scales effectively.

The insights from these studies help identify specific areas where comfort levels are inadequate, enabling transportation agencies to focus on targeted interventions for enhancing the passenger experience. While considerable progress has been made in understanding and measuring bus comfort, there remains a need for more sophisticated methodologies to develop comprehensive and dynamic comfort assessment tools aligned with the diverse needs of passengers and the dynamic nature of urban transportation systems.

Keywords: Comfort · Bus · Review · Approaches

1 Introduction

Public transportation (PT) plays a key role in creating sustainable and smart cities [1]. Indeed, PT helps reduce the carbon footprint by decreasing the number of private vehicles on the road, thereby lowering emissions of greenhouse gases and pollutants. This

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O. Gervasi et al. (Eds.): ICCSA 2024 Workshops, LNCS 14824, pp. 80–97, 2024.
https://doi.org/10.1007/978-3-031-65332-2_6

contributes to better air quality and helps combat climate change. Moreover, accessible and affordable public transportation ensures equitable access to essential services, education, employment opportunities, and recreational activities for all residents, regardless of their socioeconomic status or mobility needs. It fosters social inclusion and reduces transportation-related barriers to economic and social participation. Finally, a robust public transportation network stimulates economic growth by connecting people to job centers, educational institutions, healthcare facilities, and commercial areas. It attracts businesses, supports local economies, and enhances property values, driving overall prosperity in urban areas.

To achieve these goals, municipalities and public transportation agencies must provide reliable, accessible, clean, healthy, and comfortable transportation networks to encourage citizens to switch from driving private automobiles to public transit. In particular, on-board bus comfort (OBCL) appears to be a critical factor in achieving these improvements, and, moreover, offers a strategic advantage for public transportation companies (PTCs) [2–4]: improving OBCL conditions, driver performance may be raised, safety can be increased, and passenger discomfort can be decreased.

Today, public transportation systems can leverage technology and real-time data, such as location, digital payment options, and multimodal platforms, to streamline operations, improve efficiency and the overall passenger experience, as well as make public transportation more convenient, reliable, and user-friendly.

The OBCL of buses has received more attention by scholars in the past ten years, with an emphasis on measurement techniques and associated features. Research on passenger comfort primarily investigates technical factors such as space on board [5, 6], vibrations [7–14], noise [15, 16] and temperature [17–19]. Additionally, attention has been given to factors like driver behavior, which presents an intriguing aspect [20–25]. Therefore, exploring the relationship between driving style and passenger comfort is deemed beneficial. A smooth driving style ensures safety by reducing the risk of accidents among users, and discomfort. It, therefore, has a direct impact on customer satisfaction, encouraging positive feedback and repeat trips. Conversely, aggressive driving behavior may contribute to passenger discomfort, influencing their perception of the service quality.

Furthermore, adopting a smooth driving style is in line with environmental sustainability objectives, as it decreases emissions and enhances operational efficiency while reducing costs. Good driving practices enhance the public perception of public transportation services.

Again, a smoother driving technique leads to decreased fuel consumption and maintenance expenses. As a result, this relationship makes it easier to identify areas that need improvement and enhances the overall travel experience. Furthermore, customers worldwide usually provide feedback on their driving habits to PTCs, which inspires them to improve their driving practices in order to meet passengers' onboard comfort levels.

Previous studies examined the effects of movement variations (such as accelerations) on passenger comfort, using both subjective and objective approaches [26]. Subjective measures are labor-intensive because they involve surveys and interviews, whereas systems like [7], which focus on objective data, may prioritize the perspective of PTCs.

Consequently, an emerging approach [21, 22, 27] proposes measuring subjective and objective characteristics at the same time.

However, there is a need for real-time comfort scales that integrate these diverse measures to give drivers a tool to control their driving style [28, 29].

This paper aims to review the various studies conducted on OBCL to provide a thorough knowledge of both the characteristics impacting on users 'comfort and wide range of methods and relevant theories used to assess it, by considering research from several nations.

The rest of the paper is organized as follows. Section 2 describes and analyzes the models and methods used to calculate OBCL in bus services. Section 3 shows and discusses the results. Finally, Sect. 4 concludes the study and recommends new avenues of research.

2 Methodology

Articles from 1980 to 2024, indexed by Web of Science, Scopus, Google Scholar, IEEE, Semantic Scholar, Cambridge Core, and JSTOR, were used to evaluate the literature on passenger comfort on bus. This study's search strategy yielded a total of 55,000 articles. The studies were screened based on title and abstract, and after removing duplicates, manuscripts concerning medicine, occupational medicine, ergonomic, biology, etc., 70 eligible articles were included in this study. The selected studies dealt with the measurement of passenger comfort on buses by considering various attributes and subjective, objective, and mixed methodologies.

Initially, the research focused on identifying factors that influence the quality of public transportation. It turned out that service quality can be influenced by a variety of factors such as speed, travel time, convenience, reliability, cost, accessibility, maneuverability, safety, and comfort [30, 31].

OBCL is a critical factor, and several studies have attempted to delineate its characteristics. For example, Nguyen et al. [32] comfort (or being comfortable) can be identified as a sense of physical or psychological ease and ride comfort is defined as "*the overall comfort and well-being of the vehicle's occupants during vehicle travel*", in which noise, vibration, or both are the main source of [33, 34]. Hoberock [26] emphasizes that comfort in transit systems relies on passengers' experiences of motion in various directions and is also influenced by environmental factors. Faris et al. [35] define ride comfort as the vehicle's response to different road conditions. Recently, Roncoli et al.[5] associated passenger comfort with crowding in the post-COVID-19 era. Thus, comfort can be perceived as a multifaceted concept and several attributes can be used to evaluate the OBCL.

Furthermore, literature suggests that OBCL assessment is commonly conducted through three distinct approaches: subjective, objective, and combined.

Considering these observations, the decision was made in this study to rearrange the manuscripts according to two distinct classifications.

The first one categorizes the studies based on the attributes analyzed to assess comfort, while the second is based on methodologies (see Fig. 1).

In the following paragraphs, the classification is provided, and the contents and the results of the reviewed manuscripts are summarized.

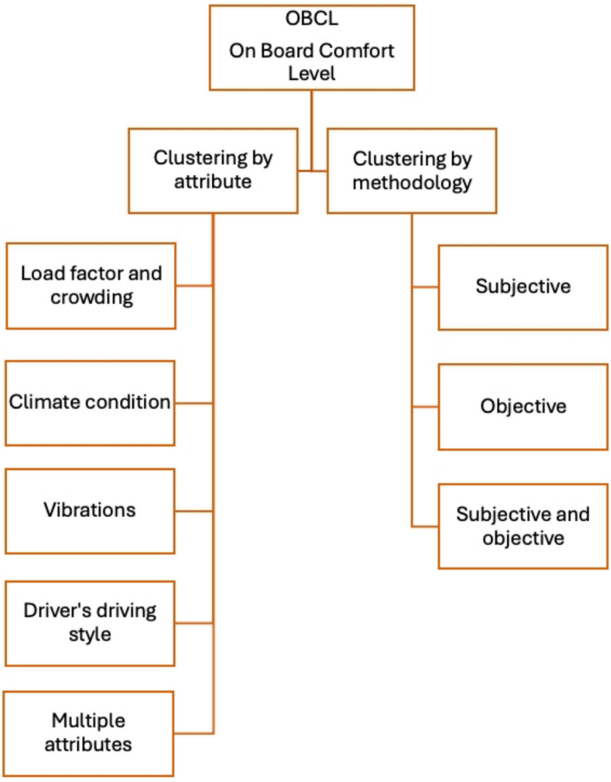

Fig. 1. Classifications for studies on on-board bus comfort level (OBCL).

2.1 Clustering Comfort on Board by Attributes

Hence, the initial phase of this study involved clustering the various studies based on the attributes used to evaluate comfort. Five groups were identified and reported in Table 1.

The initial group primarily comprises factors related to personal space that is available on board, including seating and personal space, passenger facilities usability, passenger loads, and load factor. The aspects related to climate conditions inside the bus, including temperature and cleanliness, are encompassed in the second category. The third cluster includes studies on vibrations experienced by passengers and generally on physical and cinematic elements related to road conditions and traffic. The fourth category involves elements of the driver's driving behavior, covering longitudinal acceleration resulting from acceleration and braking maneuvers, lateral accelerations influenced by road curves, and vertical accelerations stemming from pavement irregularities. Lastly, the fifth group comprises several characteristics that address various comfort aspects simultaneously as cleanliness, seat quality, staff behavior, level of crowding, security, temperature, sound pressure, acceleration change rate, speed; vibrations and noise effects on discomfort during travel while performing sedentary activities (reading a newspaper); space on-board, cleanliness, driving style; passenger facilities, seating

Table 1. Studies clustered by comfort attributes.

Comfort attributes	Authors, year, source
Load factor, crowding	Kittelson & Associates Inc. *et al.*, 2003, 2013 [31–36]
	Kumar *et al.*, 2004, [37]
	Vovsha *et al.*, 2014, [38]
	Shen *et al.*, 2016, [3]
	Więcek et al., 2019 [39]
	Zhou et al., 2021 [40]
	Roncoli et al., 2023 [5]
	Darsena et al., 2023 [6]
Climate condition	Pala, 2020 [17]
	Yunus et al., 2023 [18]
	Cigarini et al., 2022 [19]
	Volodkin et al., 2022 [41]
Vibrations	ISO 2631, 1997, [9]
	Coni, 1994 [42]
	Coni, 1995 [43]
	Strandemar, 2005 [44]
	Lin *et al.*, 2010, [10]
	Lin and Chen, 2011, [11]
	Heißing, and Ersoy, 2011 [33]
	Sekulic and Mladenović, 2016, [14]
	Zhao *et al.*, 2016, [8]
	Sekulic *et al.*, 2013, 2016, 2018 [7, 12, 13]
Driver's driving style	Hoberock, 1977, [26]
	Af Wahlberg, 2006, [20]
	EN 12299, 2009, [45]
	Castellanos and Fruett, 2014, [27]
	Maternini and Cadei, 2014, [46]
	Eboli *et al.*, 2016, [21]
	Meiping and Wen, 2017, [23]
	Barabino *et al.*, 2018, [22]
	Barabino *et al.*, 2019 [47]
	Barabino *et al.*, 2019 [48]

(*continued*)

Table 1. (*continued*)

Comfort attributes	Authors, year, source
	Chin, *et al.*, 2019 [49]
	Nguyen *et al.*,2019 [50]
	Wang *et al.,* 2020 [51]
	Karapetkov *et al.*, 2021 [25]
	Coni, *et al.,* 2020 [52]
	Fazio, *et al.,* 2020 [53]
	Nguyen, *et al.*, 2021 [32]
	Zeng, *et al.,* 2023[54]
Multiple attributes	Oborne and Clarke, 1973, [15] EN 13816, 2002, [30]
	AFNOR, 2005 [55, 56]
	Silva, 2002 [34]
	Eboli and Mazzulla, 2009 [4] Barabino and Di Francesco, 2016 [24] Barabino *et al.*, 2012 [57]
	Prashanth *et al.*, 2013 [58]
	Islam, 2014 [59]
	Zhang *et al.*, 2014, [16]
	Anik *et al.*,2020 [60]
	Deb *et al.,* 2022 [61]
	Zahra *et al.,* 2023 [62]
	Maltinti et al. 2020 [63]

and personal space, ride comfort, ambient conditions; noise, vibrations, temperature, and posture, vehicle condition & hygiene.

2.2 Clustering Comfort on Board by Methodologies

Studies can also be categorized based on the methodology used to evaluate OBCL. Typically, OBCL assessment employs three main approaches: subjective, objective, and combined methods. Following this classification, Table 2 reports studies collected in this work.

Subjective Approach. The subjective approach captures passengers' viewpoints on various attributes through customer satisfaction surveys [64]. These surveys are conducted via questionnaire distribution [66] or through face-to-face interviews with passengers on board [32, 61].

Table 2. Studies clustered by methodologies.

Approach	Authors, year, source
Subjective	de Oña and de Oña, 2014 [64]
	Oboknb and Clarke, 1973 [65]
	Deb *et al.,* 2022 [61]
	Nguyen, *et al.*, 2021 [32]
	Islam, 2014 [59
	Zhang *et al.*, 2014, [16]
	Zahra *et al.,* 2023 [62]
	Silva, 2002 [34]
	Volodkin et al., 20 [41]
	Preston and Colman, 2000 [66]
	SAE, 2014 [67]
	Maltinti et al. 2020 [63]
Objective	ISO 2631, 1997, [9]
	Sekulic *et al.,* 2013 [7]
	Sekulic *et al.*, 2016 [12]
	Sekulic *et al.*, 2018 [13]
	Sekulic and Mladenović, 2016, [14]
	Lin *et al.*, 2010, [10]
Subjective and objective	Lin and Chen, 2011, [11]
	Wang *et al.,* 2020 [51]
	Zhao *et al.*, 2016, [8]
	Meiping and Wen, 2017, [23]
	Hoberock, 1977, [26]
	Maternini and Cadei, 2014, [46]
	Af Wahlberg, 2006, [20]
	Castellanos and Fruett, 2014, [27]
	Eboli *et al.*, 2016, [21]
	Barabino *et al.*, 2018, [22]
	Coni, *et al.,* 2020 [52]
	Karapetkov *et al.*, 2021 [25]
	Barabino *et al.*, 2019 [47]
	Nguyen *et al.,*2019 [50]

(*continued*)

Table 2. (*continued*)

Approach	Authors, year, source
	Anik *et al.*,2020 [60]
	Zeng, *et al.,* 2023[54]
	Chin, *et al.*, 2019 [49]

In such surveys, passengers evaluate their perception on a wide range of attributes (e.g., cleanliness, ride comfort, temperature) using either a qualitative or quantitative scale. In this way, it is possible to capture the passengers' perspective on desires and perceptions on public transport system. The authors differ in the way they approached data analysis, in the number and type of characteristics they chose for their investigations, and, of course, in the results of their findings.

The analysis of the subjective studies revealed that the main factor influencing customer satisfaction with bus services is safety, followed by comfort. Other significant indicators of public transportation quality encompass reliability, punctuality, seating availability, speed, cleanliness, accessibility of equipment and facilities at stations and on vehicles, as well as air conditioning. A study conducted by [63] focuses on the ratings provided by vulnerable users of public transport services and concludes that these users place significant importance on the courtesy of employees and the frequency of service.

Subjective studies can be further categorized by considering the rating scales employed.

Several studies, including [16, 32, 59, 62], and [34], used a four or five-point scale, with 1 denoting very poor or very unsatisfied and 4 or 5 denoting very good or very satisfied. This scale, known as the Likert scale, is a widely used psychometric tool in questionnaires, appreciated for its precision in estimating opinions, perceptions, and behaviors.

Other research utilized scales ranging from 1 to 9 or 10 points respectively [41, 62]. Specifically, Deb et al. [61] concurred with Preston and Colman [66] in advocating for scales with higher reliability, suggesting that 7, 8, or 9-point scales are more dependable compared to those with only 3 to 5 points. Indeed, scales with more response levels offer greater flexibility and may better capture respondents' attitudes while also exhibiting higher internal consistency. This approach, employing a scale from 1 to 10 in line with AE J1060 [67], is, in particular, adopted in studies conducted in Italy since akin to the scholastic rating system familiar to all citizens of the nation. Indeed, [47, 48], and [52] assume these scales for subjective ratings.

Objective Approach. Objective measures can be used to assess comfort. They undoubtedly provide an unbiased evaluation of OBCL. Technical tools such as accelerometers, which offer unconditioned data, offer a means to monitor various comfort attributes. It has been noted that much of the research has focused primarily on vibrational comfort. This is explained by the fact that both drivers and passengers experience road surface vibrations during travel, which can impair driving ability and cause discomfort not only to drivers but also among passengers. The international standard ISO 2631 [9] is the

reference of numerous studies to establish a connection between objective measurements and subjective comfort experiences. This standard utilizes the Root Mean Square Weighted Accelerations (RMSWA) across the x, y, and z axes from passenger seats to quantify whole-body vibrations, assessing their impact on health, comfort, perception, and the likelihood of experiencing "seasickness".

Three main groups can be used to categorize studies directed towards objectively evaluating bus comfort depending on passenger involvement and adherence to [9]. Establishing threshold values that can elucidate the degree of comfort or discomfort experienced by passengers while traveling is their primary aim.

The first categories include studies that assess OBCL without direct passenger involvement.

Specifically, [7, 12], and [14] recorded acceleration signal recording using a tri-axial seat pad accelerometer and investigated the effects of vibrations on onboard bus comfort. [7] measured the vertical oscillation of the driver, passengers seated in the center of the bus, and the rear overhang, concluding that the least comfortable seats are those in the back overhang of a bus moving at 100 km/h. These findings were supported by other studies, including [12] and [14]. In [13], researchers evaluated the impact of vibrations on exposure time, noting that passengers in the front and rear overhang of the bus may experience vibrations for only a brief period.

Wang et al. [51] used a three-dimensional human-bus-road coupled vibration system to study the dynamic response and human comfort on buses. They introduced the annoyance rate index to quantify and evaluate the level of discomfort or annoyance experienced by passengers more accurately. They also carried out parametric analyses to explore the effects of road surface roughness, bus weight, bus speed, and seating location on human comfort, identifying road surface roughness as the most significant factor. Fazio et al. [53] conducted a comparison of onboard comfort levels between metro and buses. Utilizing kinematic data gathered from sensors and following [9], they assessed acceleration values and concluded that metro services provide superior comfort levels.

Studies in the second category utilized a passive approach to assess onboard comfort levels, which introduced a novel mode of passenger crowdsourcing. In these investigations, willing users collected acceleration data in all directions. For instance, in studies [10, 11], researchers developed systems that utilized passengers' mobile phones to gather data on their movements and measure vibrations associated with longitudinal, transverse, and vertical accelerations. These data were then transmitted to the systems via GPRS networks and analyzed according to established protocols [9]. The findings indicated significant variations in comfort levels along a trajectory, with smaller buses generally being reported as the least comfortable vehicles. [8] and [23] proposed analogous systems albeit utilizing WiFi as communication networks. The outcomes demonstrate that the experimental system's bus vibration comfort corresponds with the passengers' subjective perceptions, so validating the viability of this assessment technique.

In the third category are gathered studies that deviated from the international standard [9] or did not involve passengers in their assessments. For example, [26] indicated that steady accelerations between 0.11 g and 0.15 g are within the "acceptable" range while trigger values above 0.30 g are unlikely to be acceptable. Additionally, [46] introduced an objective scale for evaluating onboard comfort levels. This scale integrated dynamic

effects on standing bus passengers, a comfort index, and several route characteristics as the presence of roundabouts.

Mixed Approach. The emerging approach to assessing OBCL involves evaluating comfort aspects through both subjective and objective means. Studies can be categorized into three groups depending on models adopted to evaluate OBCL.

The first group, called descriptive models, comprises studies that utilize descriptive statistics to quantitatively evaluate OBCL. Using basic statistical methods such as correlation analysis and percentage values, these models seek to establish a connection between the subjective perception of comfort and objective parameters. This approach assists in defining comfort thresholds that correspond with passenger preferences. In Wahlberg's study [20] it was discovered that passengers perceived their bus journeys as less comfortable, noisier, and riskier after taking part in a driver training program focused on fuel efficiency.

In [27] the authors developed a system consisting of hardware, firmware and software for to identify inadequate driving styles and road surface problems. By two algorithms they detected acceleration and jerk magnitudes out of the comfort range. The results revealed that 0.7 g, 0.8 g, and 1.4 g for lateral, longitudinal, and vertical events, respectively, represent the maximum accelerations above which users experience discomfort. Eboli et al. [21] focuses on analyzing the comfort levels on board a bus service, particularly related to route roughness and driving behavior such as slowing down, braking, steering, and accelerations. They established thresholds for determining good or poor comfort levels and by analyzing frequency distributions, they developed a straightforward and simple method for evaluating comfort levels. Similarly, Barabino et al. [22] identified a comfort domain based on horizontal accelerations to facilitate the recognition of instances where passengers experience comfort or discomfort related to the bus drivers' driving style. In [52], how passenger assessments on three-axis acceleration components in relation to road factors varied by age and time is examined. The study found modest correlations, indicating that passengers did not differentiate among the three accelerations.

The second classification comprises research that evaluates OBCL through various formulations of inferential models. These models illustrate how different variables affect the perception of OBCL and consider users' subjective perception as the dependent variable and the attributes observed during bus trips as independent variables. These models have the capability to assess the impact of individual factors on OBCL and adhere to a generalized linear assumption.

In [16], a model was created to gauge OBCL by incorporating physical factors such as noise, vibration, thermal comfort, and acceleration, as well as personal characteristics like age, gender, and health. Karapetkov et al. [25] segmented passengers by age and gathered assessments on turns to construct an OBCL forecasting model for each age category, achieving prediction accuracy levels of up to 98%. Additionally, they introduced a straightforward dashboard to prevent driver distraction during driving. Barabino et al. [47] presented a progressive scale for real-time OBCL assessment combining objective acceleration data with subjective assessments of driving style. The spatial linkage of OBCL allows bus drivers to monitor the ongoing quality of the bus journey. Nguyen et al. [50] utilized a smartphone application to measure accelerations to examine annoyance

experienced on buses, pinpointing most discomforting factors like lateral acceleration and duration of turns, and standing being.

Lastly, a framework study [60] proposes structural equation model to observe the effect of observable and non-observable variables on public bus comfort in Dhaka. The authors identified 'jerking', 'sound pressure level', 'fan/AC quality', 'inside temperature', 'security', 'cleanliness' as the most significant observed variables. To determine how commuters' perceptions of comfort vary depending on trip features, socioeconomic factors, and demographic attributes, an ordinal logistic regression model was developed. The findings of this study showed that 'gender', 'car ownership' and 'income' of passengers have significant relationship with comfort.

The final classification comprises studies that utilized machine learning models (MLMs) to assess OBCL. MLMs represent functional relationships between inputs and outputs of a system, with parameters lacking physical interpretation. Employing MLMs provides a chance to catch the intricate, frequently nonlinear interactions between comfort and its influencing factors.

Classification and regression tree method was used in [49] to correlate kinematic motion characteristics with ride comfort. The authors found that passenger discomfort was primarily linked to sharp turns in conjunction with changes in elevation or sudden turns.

An artificial neural network algorithm was created by Nguyen et al. [32] and showed good performance and output-to-input correlation. Instead of weighted acceleration magnitude, they utilized vibration dose value and maximum transient vibration value, emphasizing the impact of horizontal-direction acceleration and speed.

Zeng et al. [54] determined the factors affecting ride comfort via a questionnaire, focusing on velocity, longitudinal acceleration, and yaw rate. They utilized long short-term memory models to forecast these factors and evaluate driver behavior. Their findings led to the development of an application program offering real-time driving recommendations based on speed, acceleration, and yaw rate.

3 Results and Discussion

The reviewed literature showed a wide array of characteristics, systems, models, and methodologies for evaluating OBCL all of which are highly interesting. These investigations have highlighted the multidimensional nature of comfort and showcased various approaches to its assessment, owing to the complexity of the concept. However, despite the extensive research in this area, several gaps remain.

Subjective analyses of OBCL in public transportation are crucial as they offer user perceptions essential for transportation agencies to enhance services. Understanding passenger expectations through subjective feedback enables agencies to make improvements that align with passenger preferences, consequently attracting more users to the service. However, users' socio-economic background, the diversity in tastes and attitudes towards public transportation, personal comfort thresholds and, nevertheless, mood, past experiences, and external conditions can influence subjective ratings [64]. So, it might be restrictive to focus only on passenger views, particularly when dealing with non-representative samples and outside factors like fare hikes.

Objective measurements guarantee accurate and quantifiable data enabling consistent and repeatable assessments of comfort in a variety of settings and conditions ensuring reliability in the evaluation process [44]. They allow direct comparisons between different modes of transportation, routes, or vehicles, so that transportation planners and operators can make well-informed decisions. Data acquisition can occur under static conditions in the laboratory or directly on the vehicles as they operate in service. The latter option provides a more accurate representation of the dynamic nature of real-world bus networks. Moreover, findings from analogous studies conducted on rail vehicles cannot be transferred to buses due to the vastly different driving phenomenon: consider, for instance, traffic interruptions or changes in road conditions [46].

Objective measures alone, while easy to acquire and evaluate, may not be sufficient to measure comfort because they lack the human element of subjective experience. Noise levels, vibrations, and accelerations provide quantifiable data but do not capture the nuances of individual passenger's feelings and preferences. Table 3 summarizes advantages and disadvantages of subjective and objective analyses.

Table 3. Summary of advantages and disadvantages of subjective and objective analyses.

Analysis	Advantages	Disadvantages
Subjective	They offer user perceptions	Users' background and their diversity in tastes and attitudes towards public transportation can influence subjective ratings
Objective	They guarantee accurate and quantifiable data They allow direct comparisons between different modes of transportation, routes, or vehicles	They do not capture the nuances of individual passenger's feelings and preferences

Therefore, combining subjective assessments with objective data is essential for a comprehensive understanding of OBCL in public transportation. This hybrid approach takes into account both quantifiable indicators and subjective sensations to provide an exhaustive understanding of comfort levels.

Indeed, this bibliographic research indicates a notable shift towards this direction in recent studies.

At this juncture, further and broader opportunities of investigation can be identified.

Expanding the sample size in terms of monitored bus routes, the number and characteristics of surveyed passengers, and measured accelerations is necessary. Indeed, some authors study one or two route, others interview only students [21, 32, 50], others measure only longitudinal and transversal acceleration [47]. Moreover, there is a lack of algorithms designed to handle large volumes and data complexity [20–22, 27, 32, 50, 60]. Working with limited data can introduce a significant level of empiricism and

unpredictability, as it involves overly localized analysis and narrow conclusions. Consequently, the results may lack generalizability. In contrast, using a huge amount of data for the measurement helps build comfort scales that are more consolidated.

Moreover, it is crucial to consider the vertical component of acceleration, as it has a significant impact on OBLC. Long-term exposure to high levels of vertical acceleration can cause discomfort and, in some cases, trauma, which can engender in physical problems and cause pain by affecting the general well-being of travelers both during and after travel. Vertical motion greatly influences stability especially for standing passengers also playing a crucial role in safety.

Finally, the evaluation of driving style should differ based on the age of the passengers.

Indeed, younger passengers may tolerate more dynamic driving styles since their physical performance allows them to react immediately to any abrupt changes in direction or acceleration and braking. Whereas older passengers, who may have health issues as mobility limitations (joint pain or balance problems), often prefer smoother, gentler driving for increased comfort and safety. Therefore, if the driving style could adapt to the different needs of passengers, the well-being of all passengers would be ensured.

Based on the above observations, the following flow chart (see Fig. 2) suggests a methodology for applying the mixed methodology that can help transit operators in design more reliable surveys and experimental investigations on OBCL.

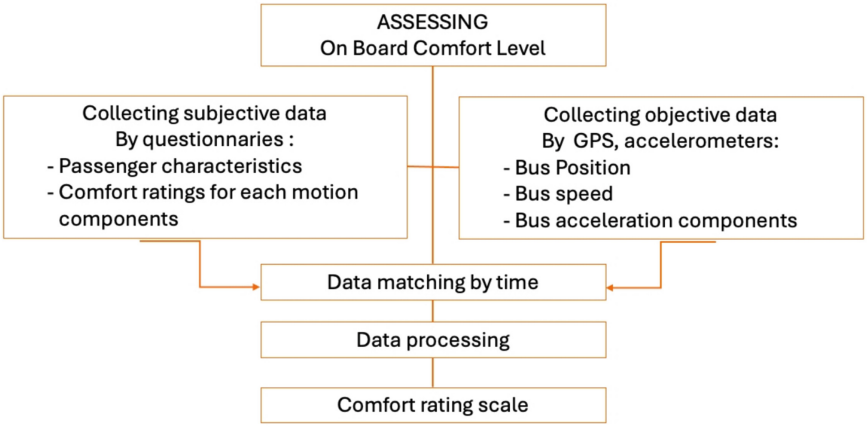

Fig. 2. Flow chart suggesting a methodology for applying the mixed methodology.

4 Conclusion

This paper aims to report a review of the research conducted on bus comfort on-board to date and to provide an ordered research base for those who wish to try their hand at these studies.

After an initial filter through all the searches across different databases, which totaled approximately 55,000 papers, 70 searches relating to the engineering aspects of comfort were identified.

These were categorized according to the attributes considered by the authors for analyzing comfort. Subsequently, the studies were clustered based on the methodologies used to analyze comfort.

For the first classification, five groups were identified: load factor and crowding; climate condition; vibrations; driver's driving style and multiple attributes.

Whereas, for the second classification, three methodologies were identified: subjective, objective, and mixed. The contents and results of the revised manuscripts were summarized.

Although there is a particularly large body of literature available on OBCL, there are still no methods for establishing graduated and dynamic comfort scales that incorporate different passenger characteristics (such as age and seating position) along with real-time acceleration data. This limitation, to date, has prevented the creation of a comprehensive, real-time assessment of OBLC that accurately reflects passenger experience. Moreover, there is a need to collect a huge amount of data for the measurement to calibrate models and to build comfort scales more consolidated.

The findings from these studies facilitate the pinpointing of precise areas where comfort levels are insufficient. This enables transportation agencies to concentrate on specific areas requiring improvement and to enact targeted interventions aimed at enhancing the passenger experience.

In addition, in competitive transportation markets, these comfort analyses can serve as a valuable benchmarking tool, allowing companies to differentiate themselves based on superior comfort offerings.

Acknowledgments. This study is supported by the MIUR (Ministry of Education, Universities and Research [Italy]) through the project entitled: SMART3R-FLITS: SMART Transport for TRavellers and Freight Logistics Integration Towards Sustainability (Project protocol: 2022J38SR9; CUP Code: F53D23005630006), financed with the PRIN 2022 (Research Projects of National Relevance) programme; and project e.INS – Ecosystem of Innovation for Next Generation Sardinia" funded by the Italian Ministry of University and Research (MIUR) under the Next-Generation EU Programme (National Recovery and Resilience Plan – PNRR, M4C2, INVESTMENT 1.5 – DD 1056 of 23/06/2022 , ECS00000038)- SPOKE 8 - CUP F53C22000430001. We authorize the MIUR to reproduce and distribute reprints for Governmental purposes, notwithstanding any copyright notations thereon. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors, and do not necessarily reflect the views of the MIUR. Moreover, the authors are grateful CTM SpA, which made its data available for this study.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

Author Contributions. Conceptualization: Francesca Maltinti, Nicoletta Rassu, Mauro Coni, Benedetto Barabino. Methodology and formal analysis: Francesca Maltinti, Nicoletta Rassu, Benedetto Barabino, Roberto Ventura, Mauro Coni. Introduction and literature review: Francesca

Maltinti, Nicoletta Rassu, James Rombi. Writing-original draft preparation: Francesca Maltinti, Nicoletta Rassu, Benedetto Barabino. Writing review and editing: Francesca Maltinti, James Rombi. Visualization, all. All authors have read and agreed to the published version of the manuscript.

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