Insight into the lateral ride discomfort thresholds of young-adult bus passengers at multiple postures : case of Singapore

Nguyen, Teron; NguyenDinh, Nen; Lechner, Bernhard; Wong, Yiik Diew

2019

Nguyen, T., NguyenDinh, N., Lechner, B. & Wong, Y. D. (2019). Insight into the lateral ride discomfort thresholds of young-adult bus passengers at multiple postures : case of Singapore. *Case Studies On Transport Policy*, 7(3), 617-627.
<https://dx.doi.org/10.1016/j.cstp.2019.07.002>

<https://hdl.handle.net/10356/151551>

<https://doi.org/10.1016/j.cstp.2019.07.002>

© 2019 World Conference on Transport Research Society. All rights reserved. This paper was published by Elsevier in *Case Studies on Transport Policy* and is made available with permission of World Conference on Transport Research Society.

Downloaded on 26 Apr 2023 20:56:19 SGT

Insight into the lateral ride discomfort thresholds of young-adult bus passengers at multiple postures: Case of Singapore

Teron Nguyen^{1,2,3*}, Nen NguyenDinh, Dr.-Ing.², Bernhard Lechner, Dr.-Ing.³, and Yiik Diew Wong, Ph.D.^{1,4}

¹TUMCREATE Ltd, 1 Create Way, #10-02 CREATE Tower, Singapore 138602. Email: teron.nguyen@tum-create.edu.sg

*Corresponding author

²TUMCREATE Ltd, 1 Create Way, #10-02 CREATE Tower, Singapore 138602. Email: nen.nguyendinh@tum-create.edu.sg

³Technische Universität München (TUM), Baumbachstraße 7, 81245 München, Germany. Email: bernhard.lechner@tum.de

⁴Nanyang Technological University (NTU), N1-01b-51, 50 Nanyang Avenue, Singapore 639798, Singapore. Email: CYDWONG@ntu.edu.sg

Acknowledgements

This work is a part of PhD study of the first author and financially supported by the Singapore National Research Foundation under its Campus for Research Excellence And Technological Enterprise (CREATE) programme. We thank our colleagues Mr Goran Marinkovic and Ms Penny Kong who provided insight and expertise that greatly assisted the research. We also thank NUS VENTUS for providing the complimentary bus ride.

Insight into the lateral ride discomfort thresholds of young-adult bus passengers at multiple postures: Case of Singapore

ABSTRACT

Ride comfort is an important serviceability attribute for bus passengers, of which bus operating under the influence of road layout in urban roads is a prominent contributory factor. Passenger posture is another influencing factor that has not yet been investigated comprehensively. In this case study, ride comfort from road-induced lateral acceleration and lateral jerk was assessed by correlating subjective evaluation with bus operation performance parameters as well as road layout in Singapore. In the first bus run, a sample of 26 participants classified in three groups: sitting, leaning and standing postures, rode on the same bus along a 45-minute route. Ride comfort was worst-off for standing passengers and least uncomfortable for sitting passengers. A strong statistical correlation was found between participants' subjective ratings with lateral acceleration and duration of turning movement. A second bus run was followed with a sample of 11 participants to collect additional passengers' ratings. Lateral ride discomfort thresholds were thus established for bus negotiating roundabouts, intersections and along links. The three levels of ride discomfort are *Uncomfortable*, *Very Uncomfortable* and *Extremely Uncomfortable* with average lateral accelerations of $a_y = 1.5, 1.75$ and 2.0m/s^2 , respectively. The lateral ride discomfort thresholds would be useful for several value-add applications which include better vehicle design including its interiors, and better vehicle handling about the road layout. With the advent of autonomous public transport (APT), the ride discomfort thresholds must also be considered as valuable input for APT vehicle operation.

Key words: Lateral ride discomfort; acceleration; passenger postures; human centric design; urban bus; Singapore

1. INTRODUCTION

Urban bus system plays an important role worldwide for sustainable transportation. Bus services not only contribute to relieving congestion (Nguyen-Phuoc et al., 2018b, 2018a) but also reduce traffic emissions and improve social benefits (Stjernborg and Mattisson, 2016). Improving bus service is one of the key measures to attract more passengers from car transport according to the pull-strategy (Lai and Chen, 2011). Different from intercity bus equipped with all sitting location for long distance travel, e.g. the bus model IK-301 in (Sekulić et al., 2018), urban city bus comprises higher proportion of standing location, e.g. 77 standing over 28 sitting locations on the Citaro bus (Mercedes-Benz, 2002). During peak hours, buses are often crowded, and standing passengers onboard at different locations and orientations would experience lower ride comfort when the bus negotiates sharp turning areas such as small-radius curves and roundabouts or making left-turn and right-turn at crossroad intersections. Indeed, standing passengers are the most vulnerable groups associated with various risk impacts (Asociación RUVID, 2012; Robert et al., 2007). This issue has called for better design of bus interior as well as improved bus driving behaviour towards passenger ride comfort as a recent human-centric design approach in transportation (Bogren et al., 2009; Mitchell et al., 2016).

Ride comfort is one of the main factors in attracting urban public transport ridership (Morton et al., 2016). However, ride comfort is difficult to evaluate due to various influencing factors: 1) objective factors from ambience such as temperature, air quality, noise, vibration, lighting, ergonomics; and 2) subjective factors like personal perceptions and assessment by Da Silva (2002). The effect of passenger load factor and in-vehicle time on ride comfort can be found in (Imre and Çelebi, 2017; Shen et al., 2016), and an overall bus comfort model can be found in (Zhang et al., 2014). Among the external stimuli, vibration and acceleration are considered as the main factors related to the effects of road infrastructure and vehicle condition on ride comfort. Evaluation of bus service quality has been often based on interview and questionnaire surveys at the end of the trips, and often without consideration of passengers' onboard position and orientation (Portouli et al., 2017; PTC, 2017). Therefore, information of discomfort might be missed about locations experiencing high acceleration and vibration levels. Better service for passengers is also provided nowadays given the emergence to autonomous public transport (APT) like autonomous bus (AB) worldwide. However, recent research has focused more on the technology development such as platooning control (Lam and Katupitiya, 2013), vehicle concept (Ginn et al., 2017), cost efficiency (Zhang et al., 2019), timetabling and scheduling (Cao and Ceder, 2019), experimental platform for vehicle control (Montes et al., 2017), mapping and path planning (Yu et al., 2018). Empirical evidence from passenger security on AB can be found in (Salonen, 2018), or public attitudes towards AB in (Portouli et al., 2017). There is still little knowledge on the point-of-view of passenger ride comfort to develop these AB systems.

This case study is a part of TUMCREATE project in Singapore to plan and design an innovative AB system not for an individual corridor but a larger part of the city-scale network, where conventional buses will be replaced by fully electrified APT (Rau et al., 2018). Passenger ride comfort is referenced

as a benchmarking parameter in bus transport. The study was granted ethics approval by NTU Institutional Review Board IRB-2017-19-058. Specifically, the study focuses on bus passengers' ride comfort in relation to lateral acceleration and lateral jerk while noting that ride comfort thresholds related to vertical acceleration/vibration can be determined in (ISO2631-1, 1997), while ride comfort thresholds related to longitudinal (forward) acceleration have been established by He et al., (2013). Furthermore, ride comfort associated to vertical vibration and road roughness is not a big issue for bus passengers in Singapore since its pavement system is consistently well-maintained in good condition (Tan, 2013), and the modern bus vehicles are well equipped with user-friendly air suspension system that greatly reduces vertical acceleration/vibration (Kowarska et al., 2014). For this case study, a special smart-phone application was designed to collect real-time subjective ride comfort ratings from 26 passengers along the first bus run and 11 passengers along the second bus run. Acceleration data, video recording of passengers' body movements and road conditions were collected and analysed accordingly. The relationship between subjective indicators (passengers' discomfort levels) and objective indicators (lateral acceleration, lateral jerk and duration of turning movement) were established at three levels of lateral ride discomfort: *Uncomfortable*, *Very Uncomfortable* and *Extremely Uncomfortable*.

The remaining paper is structured as follows. In the Related Works section, the relevant scientific literature is summarised. In the Methodology section, detailed steps in conducting the experiment are described. The Findings section reports the main results of this study, followed by a Discussion section. The study is summed up in the Conclusion and Outlook section.

2. RELATED WORKS

Several standards have been established for ride comfort evaluation. For comfort metrics due to whole-body vibration, (ISO2631-1, 1997) suggests a comfort criterion based on the frequency-weighted root-mean-squared acceleration ($\text{RMS } a_w$) of 3-dimension vibration while European standard recommends a comfort scale for train passengers in accordance to (BS EN 12299:2009, 2009). Standards like (BS 6841:1987, 1999; ISO2631-1, 1997) provide approximate indications of likely reactions of passengers to various magnitudes of overall vibration in public transport, but also recommend to use appropriate weighting curves for specific design purposes regarding ride comfort. It should be noted that ISO 2631's comfort criteria are focused mainly on whole-body-vibration with vibration frequency from 0.5Hz to 80Hz, which is mainly applicable to vertical acceleration excited by road roughness. A comprehensive summary of frequency-weighted acceleration and road roughness limit values based on measured vehicle vibration can be found in (Mucka, 2015) study. (Castellanos and Fruett, 2014; Lin et al., 2010) have adapted (ISO2631-1, 1997) approach for their studies on bus ride comfort. In-laboratory experimental study on the discomfort of standing people caused by vibration of a floor can be found in (Nawayseh and Griffin, 2006; Thuong and Griffin, 2012).

Regarding ride discomfort associated with longitudinal acceleration, (He et al., 2013) distributed questionnaires to 35 passengers to find discomfort thresholds due to bus braking and speeding-up, in which bus passengers are found to start to feel uncomfortable when the longitudinal acceleration $a_x > +1.5m/s^2$ and the deceleration/braking $a_x < -0.75m/s^2$. As for lateral acceleration, (Bodini et al., 2013; Maternini and Cadei, 2014) adapted certain railway ride comfort indicators for comfort evaluation of bus passengers notwithstanding the much different vehicle configuration and operations in rail-based vehicles. Their method was applied in a case study in Italy for ride comfort evaluation of standing passengers for buses negotiating roundabout areas where there are high levels of lateral acceleration. The comfort scale was based on the modified comfort index and transversal movements (or involuntary sway) of standing passengers. Another study in France by Beurier (2012) analysed the discomfort feeling of standing passengers about bus interior design as well as bus lane design. The study recorded passengers' feelings according to their responses (by pressing on buttons mounted on handlebars) at every incident of discomfort; data was collected concurrently on acceleration profiles and GPS locations along the journey. Besides, another ride comfort threshold used in (Shu et al., 2016; Xu et al., 2015) is more appropriate for car passengers, where lateral acceleration $a_y \leq 1.8m/s^2$ is acceptable, $1.8m/s^2 < a_y < 3.6m/s^2$ is bearable, and $a_y > 5.0m/s^2$ exceeds the human's bearing ability.

The recent and typical ride comfort thresholds in different directions and modes of transport are summarised in Table 1. Most of the approaches are based on established standards, guidelines and common practice, whereas to collect bus passenger perception only (He et al., 2013; Prashanth et al., 2013) used questionnaire after the bus run and (Beurier, 2012; Castellanos and Fruett, 2014) used push buttons during a bus run. However, the questionnaire method may not capture the timing of real-time discomfort feelings of bus passengers and push buttons are used on only a small sample, for example, 12 standing passengers (2 bus runs) were investigated based on 10 buttons assembled in 5 handles (Beurier, 2012). Passengers at sitting positions were not well investigated. The comfort scale used in (Maternini and Cadei, 2014) study was based only on passenger movements/sway via video observations but not from direct passengers' ratings.

In summary, there is no existing method that can concurrently collect passenger perceptions in the larger scale of urban bus such as those carrying more than 30 passengers comprising sitting, leaning and standing positions. Table 1 also shows that different ride comfort thresholds are applicable for different transport modes as well as different passenger postures. Therefore, it is necessary to understand the insight of bus passenger ride comfort at different postures. These gaps in the knowledge have provided a strong motivation: (1) to develop a new research method for large scale and real-time onboard survey, (2) to establish ride discomfort thresholds of bus passengers at multiple postures onboard, and (3) to provide recommendation for operating speeds of future AB system. This case study focuses on young-adult passengers and lateral ride comfort, but further application can be extended to larger sample sizes, age groups, and research contexts.

Table 1: Ride comfort thresholds at multiple directions

Source	Longitudinal acceleration a_x (m/s ²)	Lateral acceleration a_y (m/s ²) Acceleration rate of change or jerk C (m/s ³)	Vertical acceleration a_z (m/s ²)	Method to collect passenger ratings	Transport mode	Passenger postures
(ISO2631-1, 1997)	RMS a_{wx}	RMS a_{wy}	RMS a_{wz}	Guidelines	General vibration	Specific method
	RMS a_w includes three RMS a_{wx} , RMS a_{wy} , RMS a_{wz}					
(BS EN 12299:2009, 2009)	N_{MV} , N_{VA} , N_{VD} include three RMS a_{wx} , RMS a_{wy} , RMS a_{wz}			Guidelines	Rail	Specific method
(Parsons Brinckerhoff, 2012)	$a_x = +1.34$: max acceleration $a_x = -1.34$: max braking	$a_y = 0.98$ – 1.47 : uncomfortable		Guidelines	Light rail	Not specific
(Parsons Brinckerhoff, 2009)	$a_x = +0.58$: max acceleration $a_x = -0.54$: max braking	$a_y = 0.49$: uncomfortable		Guidelines	High speed rail	Not specific
(Shu et al., 2016; Xu et al., 2015)		$a_y \leq +1.8$: acceptable, $a_y = +1.8 \div 3.6$: bearable $a_y > +5.0$: bearing ability		Common practice adaptation	Car	Sitting
(AASHTO, 2011)	$a_x = -3.4$: comfortable braking	$a_y = 0.4$ – 1.3 : safety within spiral curve C = $0.3 \div 0.9$: comfortable rate of change		Guidelines	Car	Sitting
(Le Vine et al., 2015)		$a_y = 1.47$: uncomfortable on light rail $a_y = 0.49$: uncomfortable on high speed rail		Adapting railway	AV	Sitting
(ARUP, 2017)		$a_y = 0.6$ – 1.0 : uncomfortable C = 0.3 – 0.6 : uncomfortable		Guidelines, similar railway	Guided bus	Not specific
(Castellanos and Fruett, 2014)		RMS a_w includes three RMS a_{wx} , RMS a_{wy} , RMS a_{wz}		Adapting ISO2631, button push	Bus	Not specific
(Lin et al., 2010)		RMS a_w includes three RMS a_{wx} , RMS a_{wy} , RMS a_{wz}		Adapting ISO2631, phone sensing	Bus	Not specific
(Bodini et al., 2013; Maternini and Cadei, 2014)		N_{VD} includes three RMS a_{wx} , RMS a_{wy} , RMS a_{wz}		Adapting EN12299, video observation	Bus	Standing
Prashanth et al (2013)		RMS a_w includes three RMS a_{wx} , RMS a_{wy} , RMS a_{wz}		Questionnaire afterwards	Bus	Sitting, activities
(Eboli et al., 2016)	Acceleration thresholds = the average value of the accelerations + their standard deviation Comfort thresholds = acceleration threshold outliers/the total recorded points			Questionnaire onboard	Bus	Not specific
(He et al., 2013)	$a_x > +1.5$: uncomfortable $a_x < -0.75$: uncomfortable			Questionnaire afterwards	Bus	Sitting
(Beurier, 2012)	$a_x < -1.4$, $a_x > +1.5$: level 1 $a_x < -2.2$, $a_x > +2.5$: level 2	$a_y < -1.4$, $a_y > +1.6$: level 1 $a_y < -2.0$, $a_y > +2.0$: level 2	$a_x < +8.5$, $a_x > +11.3$: level 1 $a_x < +8.4$, $a_x > +11.6$: level 2	Handlebars buttons	Bus	Standing
Present case study		Uncomfortable, very uncomfortable and extremely uncomfortable thresholds		Mobile app	Bus, AB application	Sitting, leaning standing

Note: RMS a_x , RMS a_y , RMS a_z : frequency-weighted root-mean-squared acceleration in vibrational direction x, y, z;

N_{MV} , N_{VA} , N_{VD} : mean comfort standard method; mean comfort complete method: seated passenger; mean comfort complete method: standing passenger;

Level 1, Level 2: uncomfortable and loss of balance; Specific/not specific method: method for individual/not differentiated posture

3. METHODOLOGY

Public bus service is one of the leading public transport (PT) means in Singapore besides Mass Rapid Transit and Light Rapid Transit. Bus ridership has a high share of 3.9 million passenger trips out of 7.9 million PT passenger trips per day (PTC, 2016), for a resident population of 5.5 million in the small (719 km² land area) island nation. Buses will continue to play a significant role, particularly in serving as feeders to the rail network for the future considering that *"eight in 10 households will be within a 10-minute walk to a train station"* by 2030 (LTA, 2013). Bus interior is designed with a high ratio of standing/sitting position such as 56/35 (single-deck MAN NL323F model), 51/83 (double-deck Alexander Dennis Enviro500s model) and 90/59 (articulated Mercedes-Benz O405G model) (Land Transport Guru, 2019). There are more than 400 bus services and a total fleet of more than 4,000 buses serving the dense residential areas, and their routes include numerous turnings and curves with small radii.

Since passengers' ride comfort is related to both subjective and objective factors, an experimental investigation was carried out involving a relatively large sample of participants. Data was collected over two experimental bus runs. Linear multiple regression and classification methods were used to establish the relationship between various indicators and to classify appropriate ride discomfort levels. It is noted that discomfort is the opposite of comfort; therefore, ride comfort can be inferred from ride discomfort thresholds and vice versa.

3.1. Selection of Participants

In the first bus run, a sample of 26 participants (17 female and 11 male) were involved in this study in which 11 were sitting, 8 were leaning, and 7 were standing, which essentially covered various combinations of location (front, middle, rear), posture (sitting, leaning, standing), orientation (facing forwards, backwards, sideways), and standee's support (holding grab-bar/stanchion, ceiling grip) on board the bus. There is no sideways-facing seat on this bus. Participants were recruited via an online platform as well as traditional distributed advertisements. The initial plan was 30 participants in total, but 4 of them did not show up on the day of the experiment. Participants' ages are in the range of 21-30 years old to ensure stamina of standing subjects on board the bus during the long 45-minute round-trip journey. The participants' onboard location, posture, orientation/support and age/gender characteristics are shown in Table 2 and Fig. 1. Participants must keep the same position and orientation (facing), but able to slightly change another hand to hold the handrail for the standing position.

In this study, the age group is not considered. The initial research idea is to divide the age group into the young and elderly, but it is not necessary since the elderly normally have their priority seat when boarding the bus, and for safety reason, they are only allocated at sitting position if being included in this experiment. However, from the preliminary study results, the sitting position does not expose much discomfort as compared to standing position.

Table 2: Passengers' posture, orientation/support, age and gender

Posture	Orientation (facing)/support	Code	Age	Gender
Sitting	Forwards	A1	22	Female
	Forwards	A2	27	Male
	Backwards	A3	21	Female
	Forwards	A5	24	Male
	Forwards	A6	21	Female
	Backwards	A7	23	Female
	Backwards	A8	24	Female
	Forwards	A11	22	Female
	Forwards	A12	24	Male
	Forwards	A13	22	Female
	Forwards	A14	26	Female
Leaning	Backwards	B1	22	Male
	Sideways	B2	20	Female
	Forwards	B3	22	Female
	Backwards	B4	24	Female
	Sideways	B5	33	Male
	Backwards	B6	23	Female
	Sideways	B7	23	Female
	Forwards	B8	23	Male
Standing	sideways/ ceiling grip	C1	30	Male
	sideways/ grab-bar	C2	21	Female
	forwards/ ceiling grip	C3	24	Male
	forwards/ grab-bar	C4	21	Female
	sideways/ ceiling grip	C5	23	Male
	sideways/ grab-bar	C6	25	Female
	sideways/ grab-bar	C7	29	Female

Fig. 1. Passengers' location, posture and orientation

3.2. Measurement Instruments

Different from conventional methods used for evaluating the quality of transit services such as SERVQUAL questionnaire (Sam et al., 2018) or in-depth interviews (Mah and Mitra, 2017), in this study a dedicated iOS and Android application “Timestamp datalogger” was designed for easy and portable use for a large number of participants. A 5-point rating scale (1 - not uncomfortable, 2 - a little uncomfortable, 3 - uncomfortable, 4 - very uncomfortable and 5 - extremely uncomfortable) was built into the data-logger. During the 45-minute bus ride, real-time subjective ratings on ride comfort were input into the data-logger by the participants. There is not any fixed time interval, and participants would rate their perception at any time of uncomfortable feeling. Then, at the completion of the journey, the participants used the same data-logger to evaluate (on the same 5-point scale) the overall ride comfort with regards to road condition, bus driver’s driving performance, and vehicle condition (Fig. 2.).

Fig. 2. Two user interfaces of the mobile application.

An onboard camera was installed to record the body movements of participants and another out-front camera installed to record road and traffic conditions. A commercial Svantek SV100A seat-pad accelerometer was laid on the seat cushion of participant A05 who was sitting directly above the rear wheel axle, and acceleration data was thus collected above the rear axle location. GPS information was collected by 4G data from a smart-phone. Meanwhile, it was found that a dedicated GPS device using an external antenna was not able to connect well with satellites whenever the bus is under tree and high building shadows, and the GPS device was thus not applied.

3.3. Experimental Procedures

The experiment was divided into four parts: (1) Preparatory stage: all participants were required to download and install the mobile application and practise to get used to it beforehand; (2) Briefing: before the onset of on-road experiment, participants were introduced again on the whole experimental process and the associated details; (3) Experiment stage: during 45 minutes of the bus run, participants pressed on the buttons at any occasion they felt uncomfortable due to vehicle's acceleration, braking, vibration and swerving. Later, these real-time discomfort ratings were matched with acceleration data from the accelerometer; and (4) Ending stage (after bus run): participants evaluated the overall ride comfort of bus run and answered questions regarding the vehicle's interior design.

In the first bus run, the bus route is a round-trip journey of shuttle service between NUS campus (Kent Ridge Terminal - KRT) and BTC campus with speed profile and typical road layout as shown in Fig. 3. The bus is a single-deck low-floor Volvo B9L model in very good condition. The speed values along the AYE highway and Farrer Road arterial are relatively higher than the origin and destination segments. There was no bus resting time at the BTC campus. The bus route includes various urban road horizontal alignments such as 3 small roundabouts (radius $R = 6$; 10 and 13m), 22 small-radius curves (radius $R < 100$ m) and 17 crossroad intersections (where the bus needs to turn left or right). Weather conditions were good with dry and good road surface during the bus run. The bus driver was not informed about the study, and he drove the bus as per normal operation. The bus was not crowded, and traffic was not congested as the experiment was conducted on a Saturday morning. The weekend is better timing for several reasons: 1) easier for the attendance of planned 30 participants; 2) enough available space to allocate all participants with absolute position and posture without much interaction with regular bus passengers; 3) the bus can run faster than on weekdays, resulted in higher levels of lateral acceleration and uncomfortable perception of participants.

Fig. 3. Speed profile along the bus round-trip journey with typical curves and turning movements

4. FINDINGS

After data collection, the locations of turning movements were identified based on the minimum value of lateral acceleration and minimum duration while the bus is turning. The primary subjective indicator is personal ratings of jury panels while objective indicators include lateral acceleration, lateral jerk and duration of turning movement, which was matched based on their timestamps. Linear multiple regression was used to investigate the relationship between various indicators but not to predict the subjective ratings. Thereafter, the classification method was used to classify three ride discomfort ranges according to passengers' ratings on different turning movements.

4.1. Ride Comfort Ratings concerning Passengers' Location and Posture

The first bus run resulted in 23 plausible datasets for analysis while data was not received from 3 participants (B2, B5, B8) due to errors in the data collection process (participants turned off their iPhone GPS location services accidentally). Real-time subjective ratings were analysed only for levels 3, 4 and 5 in the 5-level scale since level 3 marks onset of discomfort while levels 1 and 2, which covered comfortable feelings such as along straight road links, were included to provide contrast against discomfort feelings. The frequencies of pressing levels 3, 4 and 5, and the overall evaluation on ride comfort of each participant are shown in Fig. 4(a) and Fig. 4(b), respectively. Higher rating frequencies on levels 4 and 5 are seen for the standing group. It is evident that standing passengers experienced a higher level of discomfort compared to those in other postures, that resulted from the bus negotiating sharp turning areas such as small-radius curves and roundabouts or making left-turn and right-turn at crossroad intersections. This finding is consistent to the calculation of N_{VA} and N_{VD} index ($N_{VA} < N_{VD}$) for seated and standing passenger comfort in railway, respectively (BS EN 12299:2009, 2009), as affirmed in (Maternini and Cadei, 2014). Among sitting passengers, those in the rear positions A05, A06, A07 and A08 pressed levels 3 and 4 more frequently as compared to A11, A12, A13 and A14. The reason can be explained that the former ones were seated above the rear wheel axle where higher levels of vertical acceleration are to be expected.

Regarding overall ride comfort evaluation right after the bus run, 5 levels of ride comfort were considered (see Fig. 4(b)). Regression analysis resulted in greater correlation of overall ride comfort with driving condition ($R = 0.74$) than with road condition ($R = 0.59$) and vehicle condition ($R = 0.46$). The overall ride comfort is dependent on posture whereby levels 3 and 4 are seen more in the standing group while levels 1 and 2 in the sitting group, with the leaning group being in between. This is the main reason why 23/26 participants responded to sitting preference when answering the question after the bus run: *Do you prefer to sit, stand or lean when travelling on the bus?* The detailed distribution of the rating is shown in Fig. 4(b), in which the ratings on overall ride comfort are highlighted by the rated numeric levels.

Fig. 4. Subjective ratings of ride comfort levels for entire trip by individual passengers (n=23)

4.2. Correlation between Subjective and Objective Indicators

Turning movements of the bus along the journey were tracked and were classified into: turn left and turn right (at intersections); U-turn, straight and right turn (at roundabouts); curve left and curve right (on curved road segments). Ride comfort thresholds were established for these turning movements, by correlating subjective indicator of passengers' ride comfort ratings with objective indicators of bus lateral acceleration, lateral jerk and duration of turning movement. The maximum values of lateral acceleration and lateral jerk, as well as duration at each turning movement, were obtained from seat-pad accelerometer SV100A. Decimation smoothing was applied to reduce the data to 1Hz, given the high sampling rate of the accelerometer. The turning movements were double-checked with camera footage to avoid lane change movements which last for a short period from 2 to 3 seconds.

For the experiment, a participant may press the button on the mobile phone application several times over the duration of a given turning movement. The highest rated discomfort level (i.e. at levels 3, 4, 5) was selected for that participant for the particular turning movement. In this way, the aggregated discomfort level, denoted ' S_i ', for each turning movement was derived by summing up the individuals' highest discomfort ratings within that turning movement ' i '. In essence, the ' S ' value gives the overall perspective of the discomfort level of the given turning movement. In total, ' S ' value was determined at 48 turning movements. In the first bus run, the high ' S ' value can be about 50, for a rating panel of 23 participants. The greatest uncomfortable situation ($S = 53$) was for the bus making a U-turn at a roundabout which lasted 13 seconds. On the other hand, an on-road left turn that persisted over 3 seconds had a relatively low level of discomfort ($S = 6$).

Fig. 5a presents the results of linear correlation analysis (showing Pearson's correlation coefficient r and p -value (two-tailed test) for objective factors (lateral acceleration a_y , lateral jerk, RMS acceleration a_{wY} in lateral direction, a_{wV} in three directions, turning duration, and speed) and subjective factors (sum of comfort ratings of all participants). All variables were standardized (by subtracting its mean then divided by the standard deviation of the variable to have mean = 0 and sd = 1) resulting in the Pearson's r is equivalent to standardized coefficients or beta coefficients β as the slope of the linear regression line (Asuero et al., 2006; Rodgers and Nicewander, 2006).

In general, p -value is more significant for a_y and duration than jerk, speed and a_{wY} . The strength and positive direction of linear relationship can also be found between SumComfort and a_y and duration ($\beta \geq 0.5$, $p < 0.001^{***}$). The weaker linear relationship in a positive direction is found between SumComfort with jerk, and a_{wY} ($\beta < 0.5$, $p < 0.05^*$). Fig. 5b further shows the results of linear regression between SumComfort (dependent variable) and objective factors (independent variables). Again, the results confirmed that lateral acceleration (coefficient = 2.01, $p < 0.001^{***}$) has the strongest influence on the discomfort rating of passengers than the duration of turning movements (coefficient = 0.19, $p < 0.05^*$) and lateral jerks (coefficient = -0.18, $p = 0.84 > 0.05$). Due to not significant correlation of the intercept, jerk, a_{wY} and speed, they can be left out of the linear regression model.

Fig. 5. (a) Correlation analysis after standardization showing Pearson's r (or beta coefficient β) for objective factors and SumComfort, (b) linear regression between SumComfort and objective factors.

Furthermore, the factor loading can be interpreted from standardized regression coefficient β for which each subjective factor (comfort rating of individual group: sitting, leaning, standing; gender: female and male; facing: forward, backward, sideways; and location: front, middle, rear of the bus) contributes to the SumComfort. All data related to subjective is normalised per subject by an averaging process to mitigate the cumulative effects of participant number. The results in Table 3 have affirmed that standing is the most uncomfortable posture compared to sitting and leaning with the highest beta with SumComfort ($\beta = 0.89 > 0.82, 0.68$; $p < 0.001^{***}$), duration ($\beta = 0.60 > 0.33, 0.40$) and jerk ($\beta = 0.46 > 0.26, 0.23$); and second highest with a_y ($0.64 > \beta = 0.61 > 0.45$). Also, duration has higher beta and lower p -value (more significant) than jerk across all pairs, which was explored by the linear regression analysis (Fig. 5). There is not different in gender regarding comfortable ratings for almost

all correlation factors. Middle position is the least comfortable part onboard the bus ($\beta = 0.86 > 0.73$, 0.50 ; $\beta = 0.69 > 0.48$, 0.22 in the correlation with SumComfort and a_y , respectively), which is easily understandable that this is where all standing participants are located. Facing backward is the least comfortable position ($\beta = 0.85 > 0.79$, 0.65 in the correlation with SumComfort).

Table 3: Standardized regression coefficient β between subjective factors and objective factors

	Posture			Gender		Facing			Position		
	Sitting	Leaning	Standing	Female	Male	Forwards	Backwards	Sideways	Front	Middle	Rear
SumComfort	0.68***	0.82***	0.89***	0.87***	0.86***	0.79***	0.85***	0.65***	0.73***	0.86***	0.50***
a_y	0.45*	0.64***	0.61***	0.61***	0.62***	0.70***	0.58***	0.41*	0.48**	0.69***	0.22
Duration	0.40*	0.33*	0.60***	0.47**	0.5**	0.53***	0.35*	0.49**	0.40*	0.47**	0.32*
Jerk	0.23	0.26	0.46*	0.28	0.44*	0.38*	0.24	0.40*	0.38*	0.40*	-0.06

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.3. Ride Discomfort Threshold for Bus Passengers

A second bus run, using a different route and on a weekday, was conducted to obtain additional passengers' ratings. In this case, fewer participants (6 sitting, 4 leaning and 1 standing) were included to minimise interaction with crowded passengers during weekday operation. Bus interior is the same design and all the experimental procedures were the same as the first run. From the 2 experimental bus runs, 258 data samples were collected in total from 34 responded participants (17 sitting, 9 leaning and 8 standing) as shown in Table 4 and Fig. 6. These data samples were used for classification analysis using boxplot as described in the following section. Concerning the distribution of age groups, there are in total 20 participants in the "early working age" (from 15-21 years old) and 14 participants in the "prime working age" (from 25-54 years old), who are frequently travelling and commuting using bus transport service during the peak periods.

As shown in Table 4 and Fig. 6, level 5 rating contains the fewest data samples, but it is understandable that the extremely sharp turning movement does not happen frequently. The discomfort thresholds are slightly different among the 3 posture groups. Standing and leaning participants start to feel uncomfortable at $a_y = 1.5 \text{ m/s}^2$ while sitting participants is at $a_y = 1.55 \text{ m/s}^2$. At $a_y = 1.75 \text{ m/s}^2$, standing participants feel extremely uncomfortable while leaning participants feel very uncomfortable, but sitting participants' perception is still in uncomfortable level. The extremely uncomfortable rating was not observed from sitting participants. The effects of turning duration (range of 5-8s) and lateral jerk (range of $0.6\text{-}0.9 \text{ m/s}^3$) are clearly not proportional to different levels of ride discomfort.

The objective indicators were inferred from the median value of the boxplot with the main focus on lateral acceleration which has the most significant correlation with subjective ratings as noted in the investigation in the linear regression model (Fig. 5). The ride discomfort was further characterised by three individual levels: *Uncomfortable*, *Very Uncomfortable*, and *Extremely Uncomfortable*). Average lateral accelerations of $a_y = 1.5$, 1.75 and 2.0 m/s^2 were found for three thresholds, respectively. Fig. 6

shows the boxplots overlain with original data points in which the distribution of data in the box-plot diagram was presented after removing all outliers beyond the upper limit and lower limit.

Table 4: Ride discomfort threshold classification

	Discomfort (3)	Great Discomfort (4)	Extreme Discomfort (5)	Sum of samples
Sitting (samples)	79	3	0	82
Leaning (samples)	31	17	6	54
Standing (samples)	37	63	22	122
Median (standard deviation):				
Turning duration (s)	5 (2)	6 (2.5)	7 (3)	
Lateral acceleration (m/s^2)	1.5 (0.4)	1.75 (0.5)	2.0 (0.5)	
Lateral jerk (m/s^3)	0.6 (0.2)	0.75 (0.3)	0.9 (0.3)

Fig. 6. Classification of lateral ride discomfort levels when the bus is turning. The box-plot diagram, after removing outliers beyond the upper and lower limit, is overlaid with original data points.

5. DISCUSSION

The linear regression model (Fig. 5b) expresses the relationship between subjective ratings with lateral acceleration and duration of turning movement, with adjusted $R^2 = 0.54$. This shows that lateral acceleration as well as duration of turning movement are important factors that affect ride comfort of bus passengers. The intercept, jerk, a_{wY} and speed can be left out of model since they are not statistically significant ($p\text{-value} > 0.05$). The low adjusted R^2 can be explained by other human factors that were not taken into account such as: the inconsistency of ratings (even for the same lateral acceleration but a

participant mistakenly pressed a different button), the interaction during bus run (normal passengers boarded and interacted with participants), tiredness during the 45-minute bus run and other factors. For example, participant A02 pressed 59 times on an uncomfortable level and 5 times on a very uncomfortable level, but he evaluated the overall ride comfort as being not uncomfortable. The main reason is that he compared and considered this bus run as "the best ride in his entire 6 years". This contrasted with C02 when she pressed 40 times on not uncomfortable and little uncomfortable, but the overall ride comfort was uncomfortable. This is the outcome of "tired standing up the whole time" as her comments. In fact, in human behavioural science, R^2 as low as 0.59 is considered good (strong to very strong) since humans are harder to predict than physical processes (Harms and Groen, 2017; Lemke et al., 2016; Sawaya et al., 2017; Van den Bulck et al., 2018). The primary goal for this model is not to predict the dependent variable but it is an intermediate step to investigate the relationship between the subjective factor and objective factors (Moksony, 1990).

Regarding three levels of ride discomfort, the *discomfort* threshold at $a_y = 1.5\text{m/s}^2$ is similar to $\max(a_y) = 1.4\text{m/s}^2$ when passengers feel uncomfortable; and the *extreme discomfort* threshold $a_y = 2.0\text{m/s}^2$ is the same as $\max(a_y) = 2.0\text{m/s}^2$ when there is the start of balance loss, as compared to the study in (Beurier, 2012). The average lateral jerks $d_y = 0.6; 0.75$ and 0.9m/s^3 in 3 discomfort levels are within the range from 0.3 to 0.9m/s^3 as an empirical value for ride comfort and safety recommended in (AASHTO, 2011) for the design of spiral transition curves. Such consistency has demonstrated the fidelity and relevance of the methodology and devices used in this study. It is noted that the exact S value of subjective ratings of passengers would not be replicable in future experiments due to the inherence of field study. However, the objective indicators (lateral acceleration, later jerk and duration of turning movements) associated with 3 levels of ride discomfort will be unchanged or be only slightly different.

Besides the collected objective indicators (acceleration, jerk and time duration), the maximum root-mean-square value of frequency-weighted lateral accelerations (a_{wy}) within the 48 turning movements were also calculated according to (ISO2631-1, 1997). The $a_{wy} = 0.11\text{-}0.37\text{m/s}^2$ is in the range of "not uncomfortable" to "a little uncomfortable" and did not correspond well with the rated levels of discomfort. Therefore, this a_{wy} index is not suitable for evaluating the ride comfort of bus passengers within the turning movements. The main reason is that lateral sway within turning movements does not occur as frequently as vibration which causes discomfort to passengers (frequency from 0.5Hz to 80Hz). The lateral sway at very low-frequency oscillation from 0.1Hz to 0.5Hz (or even lower) is, hence, more related to motion sickness. This is probably the reason why (Bodini et al., 2013; Maternini and Cadei, 2014) studied the adaptation of railway ride comfort thresholds for application to roadway public transport. The more appropriate ride comfort scale in (ISO2631-1, 1997) for vertical acceleration rather than longitudinal and transversal directions was also investigated in (Castellanos and Fruett, 2014) or the experiment for bus driver by Fichera et al. (2007).

6. CONCLUSIONS AND OUTLOOK

A full-scale experimental study has been conducted with 34 responded passengers (over 37 invited participants) onboard buses to establish lateral ride discomfort thresholds for bus passengers in an urban road context. Standing passengers experience much more discomfort levels than sitting and leaning groups. Facing backwards and middle location on bus are also associated with high uncomfortable ride. Turning movements are associated with 3 levels of discomfort (*Uncomfortable*, *Very Uncomfortable* and *Extremely Uncomfortable*), which were defined based on the relation between passengers' ratings and lateral acceleration, lateral jerk and duration of the turning movements from a linear multiple regression. The a_{wy} index is not consistent with that of (ISO2631-1, 1997) as related to human whole-body vibration. The main findings of the three levels of ride comfort thresholds of bus passengers will assist bus drivers in their driving behaviours to ensure passengers' ride comfort as well as to design the speed and acceleration profiles of autonomous vehicles given the state-of-the-art steering control along vehicle trajectories (Kozłowski et al., 2015; Tan and Huang, 2014).

The three levels of lateral acceleration (a_y) in Table 4 can be used for back-calculation of APT speed (V in km/h) based on turning movements and curved radius (R in m): $V = 3.6\sqrt{a_y R}$. This estimation is inferred from the basic equation that governs vehicle operation on a curve following the laws of mechanics (AASHTO, 2011). The effects of a lateral jerk and turning duration have been neglected in this simple back-calculation (Le Vine et al., 2015). The proposed speeds can be used as the speed limit for APT timetable planning as well as for APT operation along the network to ensure passengers' ride comfort. The logic is that for new innovative APT systems, passengers' locations and orientation can be easily detected by sensors which, coupled with the development of navigation technology, APT will be able to detect road geometry, curves and turning movement trajectory at any location along its route. Therefore, the vehicle speeds at discomfort threshold (uncomfortable at $a_y=1.5 \text{ m/s}^2$) could be suggested when there is a high number of standing passengers while the vehicle speeds at great discomfort threshold (very uncomfortable at $a_y=1.75 \text{ m/s}^2$) could be suggested in case of all seated passengers. In any case, the vehicle speeds at extreme discomfort threshold (extremely uncomfortable at $a_y=2.0 \text{ m/s}^2$) must be avoided. The lower bound discomfort threshold is similar to railway ride quality (LRT) when considering leisurely or productive activities as for driver and passenger comfort in case of autonomous cars (Le Vine et al., 2015).

The new method of using a smart-phone application to collect passengers' responses has demonstrated its ability to cover a large number of subjects on the same bus run. As a result, the correlation between ride discomfort with lateral acceleration and turning movement duration has been established. This is different from the previous study by Beurier (2012) when pressing buttons were assembled in the bus vehicle body that limits the number of subjects as well as requiring the engineering input of bus manufacturers. Furthermore, the smart-phone application enables the capture of real-time discomfort feelings of passengers which is advantageous than the questionnaire method in the previous

study (He et al., 2013). The usage of the portable seat-pad accelerometer in this study does not require the interference with Controller Area Network (CAN bus) system as often used in traditional methods (Bodini et al., 2013; Maternini and Cadei, 2014).

Regarding bus interior design, there are points of improvement towards passenger-centred design such as ergonomics aspects of expansion of seat width and legroom space (Park et al., 2014; UITP, 2008); provision of more leaning surfaces, more accessible grip support in every part of the vehicle as in findings (Beurier, 2012). Furthermore, there are other interior design features that can be configured to improve ride comfort by providing Wifi network, charging ports, and trip information announcements (Beirão and Sarsfield Cabral, 2007; Daimler Global Media Site, 2019).

While this study has provided important insights into the lateral ride discomfort of young-adult bus passenger onboard, several limitations need to be acknowledged. First, the case study was conducted with two bus runs in an urban road context with a small sample size, good vehicle conditions, very good road surface and good driving manoeuvres of the bus driver. The study is at first designed to target the young-adult participants in the “early working age” and “prime working age” groups, who are frequently travelling and commuting using bus transport service during the peak periods (also the more congested periods). The missing “mature working age” group can be a target for further study. Second, the level of passenger ride comfort can vary in other countries, particularly in Europe or America. Further research can be extended to cover larger sample sizes, age groups, and research contexts based on the method developed in this case study. Recently, Volvo launched the “world first” driverless electric bus in Singapore with a capacity of 80 passengers per bus as regular transit (CNA, 2019), which is a potential scenario to extend the experiment once the AB opens for public use. A comparison study between two scenarios: conventional bus and AB, will be expected to gain interesting results on passenger ride comfort on the real AB as the research gap pointed by Le Vine et al. (2015).

Lastly, the further study will also focus more on the application of the three ride discomfort thresholds in other bus routes to detect high uncomfortable locations for diagnosing bus drivers’ driving behaviour such as in-vehicle telematics system of Tower Transit (Koh, 2017). Thus, a new ride discomfort warning mobile application can be designed based on the proposed ride discomfort thresholds and the ratio of standing passengers on the bus shall be established as an input, especially during peak hours.

REFERENCES

AASHTO, 2011. A Policy on Geometric Design of Highways and Streets, 6th ed. American Association of State Highway and Transportation Officials, Washington, D.C.

- 1 ARUP, 2017. Guided Busway Design Handbook. The British Cementitious Paving Association,
2 Wokingham, Berkshire.
- 3 Asociación RUVID, 2012. Safety of standing passengers in urban buses [WWW Document].
4 ScienceDaily. URL www.sciencedaily.com/releases/2012/10/121022080357.htm (accessed
5 5.11.19).
- 6 Asuero, A.G., Sayago, A., González, A.G., 2006. The correlation coefficient: An overview. *Crit. Rev.*
7 *Anal. Chem.* 36, 41–59. <https://doi.org/10.1080/10408340500526766>
- 8 Beirão, G., Sarsfield Cabral, J.A., 2007. Understanding attitudes towards public transport and private
9 car: A qualitative study. *Transp. Policy* 14, 478–489.
10 <https://doi.org/10.1016/j.tranpol.2007.04.009>
- 11 Beurier, G., 2012. Analysis of the Discomfort Feeling of Standing Bus Passengers on the TEOR T1
12 Rouen Bus Lane. *Procedia - Soc. Behav. Sci.* 48, 425–434.
13 <https://doi.org/10.1016/j.sbspro.2012.06.1022>
- 14 Bodini, I., Lancini, M., Pasinetti, S., Vetturi, D., 2013. Techniques for on-board vibrational passenger
15 comfort monitoring in public transport. 12th IMEKO TC10 Work. Tech. Diagnostics New
16 Perspect. Meas. Tools Tech. Ind. Appl. Proc. 3, 118–123.
- 17 Bogren, L., Fallman, D., Henje, C., 2009. User-centered Inclusive Design: Making Public Transport
18 Accessible, in: International Conference on Inclusive Design–Royal College of Art.
- 19 BS 6841:1987, 1999. Measurement and evaluation of human exposure to whole-body mechanical
20 vibration and repeated Shock. British Standards Institution.
- 21 BS EN 12299:2009, 2009. Railway applications - Ride comfort for passengers - Measurement and
22 evaluation. British Standards Institution.
- 23 Cao, Z., Ceder, A., 2019. Autonomous shuttle bus service timetabling and vehicle scheduling using
24 skip-stop tactic. *Transp. Res. Part C Emerg. Technol.* 102, 370–395.
25 <https://doi.org/10.1016/j.trc.2019.03.018>
- 26 Castellanos, J.C., Fruett, F., 2014. Embedded system to evaluate the passenger comfort in public
27 transportation based on dynamical vehicle behavior with user's feedback. *Meas. J. Int. Meas.*
28 *Confed.* 47, 442–451. <https://doi.org/10.1016/j.measurement.2013.08.068>
- 29 CNA, 2019. Driverless electric bus launched by NTU and Volvo in “world first” [WWW Document].
30 CNA. URL [https://www.channelnewsasia.com/news/singapore/driverless-electric-bus-launched-](https://www.channelnewsasia.com/news/singapore/driverless-electric-bus-launched-by-ntu-and-volvo-in-world-first-11311838)
31 [by-ntu-and-volvo-in-world-first-11311838](https://www.channelnewsasia.com/news/singapore/driverless-electric-bus-launched-by-ntu-and-volvo-in-world-first-11311838) (accessed 4.23.19).
- 32 Da Silva, M.C.G., 2002. Measurements of comfort in vehicles. *Meas. Sci. Technol.* 13, R41–R60.
- 33 Daimler Global Media Site, 2019. World premiere:Mercedes-Benz Future Bus with CityPilot – a
34 milestone on the way to the autonomous city bus, and a revolutionary mobility system for the
35 future [WWW Document]. Daimler. URL
36 <https://media.daimler.com/marsMediaSite/ko/en/12776336> (accessed 5.14.19).
- 37 Eboli, L., Mazzulla, G., Pungillo, G., 2016. Measuring Bus Comfort Levels by using Acceleration
38 Instantaneous Values. *Transp. Res. Procedia* 18, 27–34.
39 <https://doi.org/10.1016/j.trpro.2016.12.004>
- 40 Fichera, G., Scionti, M., Garesci, F., 2007. Experimental Correlation between the Road Roughness
41 and the Comfort Perceived In Bus Cabins. <https://doi.org/10.4271/2007-01-0352>
- 42 Ginn, M., Amuna, F., Colmenares, J.E., Stewart, A., Diong, B., Wang, Y., Yang, J., 2017. Conceptual
43 design and prototyping of a Slim Semi-autonomous Bus Rapid Transit Vehicle, in: Conference
44 Proceedings - IEEE SOUTHEASTCON. IEEE, pp. 1–6.
45 <https://doi.org/10.1109/SECON.2017.7925292>
- 46 Harms, R., Groen, A., 2017. Loosen up? Cultural tightness and national entrepreneurial activity.
47 *Technol. Forecast. Soc. Change* 121, 196–204. <https://doi.org/10.1016/j.techfore.2016.04.013>

- 1 He, Y., Yan, X., Wu, C., Chu, D., Peng, L., 2013. Effects of Driver's Unsafe Acceleration Behaviors
2 on Passengers' Comfort for Coach Buses. *Improv. Multimodal Transp. Syst. Safety, Integr.*
3 <https://doi.org/10.1061/9780784413036.220>
- 4 Imre, Ş., Çelebi, D., 2017. Measuring Comfort in Public Transport: A case study for İstanbul. *Transp.*
5 *Res. Procedia* 25, 2441–2449. <https://doi.org/10.1016/j.trpro.2017.05.261>
- 6 ISO2631-1, 1997. Mechanical vibration and shock - Evaluation of human exposure to whole-body
7 vibration (Part 1: General requirements). International Organization for Standardization,
8 Switzerland.
- 9 Koh, V., 2017. Device on Tower Transit buses helps cut down bad driving habits, accidents [WWW
10 Document]. TODAYonline. URL [https://www.todayonline.com/singapore/device-tower-transit-](https://www.todayonline.com/singapore/device-tower-transit-buses-helps-cut-down-bad-driving-habits-accidents)
11 [buses-helps-cut-down-bad-driving-habits-accidents](https://www.todayonline.com/singapore/device-tower-transit-buses-helps-cut-down-bad-driving-habits-accidents) (accessed 5.14.19).
- 12 Kowarska, I., Korta, J., Kuczek, K., Uhl, T., 2014. Fully Equipped Dynamic Model of a Bus. *Shock*
13 *Vib.* 2014. <https://doi.org/10.1155/2014/201952>
- 14 Kozłowski, M., Choromański, W., Kowara, J., 2015. Analysis of dynamic properties of the PRT
15 vehicle-track system. *Bull. Polish Acad. Sci. Tech. Sci.* 63, 799–806.
16 <https://doi.org/10.1515/bpasts-2015-0091>
- 17 Lai, W.T., Chen, C.F., 2011. Behavioral intentions of public transit passengers-The roles of service
18 quality, perceived value, satisfaction and involvement. *Transp. Policy* 18, 318–325.
19 <https://doi.org/10.1016/j.tranpol.2010.09.003>
- 20 Lam, S., Katupitiya, J., 2013. Modeling and control of a platoon of autonomous buses, in: *IEEE*
21 *Intelligent Vehicles Symposium, Proceedings.* IEEE, pp. 958–963.
22 <https://doi.org/10.1109/IVS.2013.6629590>
- 23 Land Transport Guru, 2019. Land Transport Guru - Singapore Transport Information at a glance!
24 [WWW Document]. L. Transp. Guru. URL <https://landtransportguru.net/> (accessed 5.14.19).
- 25 Le Vine, S., Zolfaghari, A., Polak, J., 2015. Autonomous cars: The tension between occupant
26 experience and intersection capacity. *Transp. Res. Part C Emerg. Technol.* 52, 1–14.
27 <https://doi.org/10.1016/j.trc.2015.01.002>
- 28 Lemke, M.K., Apostolopoulos, Y., Hege, A., Sönmez, S., Wideman, L., 2016. Understanding the role
29 of sleep quality and sleep duration in commercial driving safety. *Accid. Anal. Prev.* 97, 79–86.
30 <https://doi.org/10.1016/j.aap.2016.08.024>
- 31 Lin, C.-Y., Chen, L.-J., Chen, Y.-Y., Lee, W.-C., 2010. A comfort measuring system for public
32 transportation systems using participatory phone sensing, in: *Proceedings of PhoneSense.*
33 Zurich, Switzerland.
- 34 LTA, 2013. Land Transport Master Plan 2013. Land Transport Authority Singapore, Singapore.
- 35 Mah, S., Mitra, R., 2017. The effects of a free bus program on older adults travel behaviour: A case
36 study of a Canadian suburban municipality. *Case Stud. Transp. Policy* 5, 460–466.
37 <https://doi.org/10.1016/j.cstp.2017.05.003>
- 38 Maternini, G., Cadei, M., 2014. A comfort scale for standing bus passengers in relation to certain road
39 characteristics. *Transp. Lett. Int. J. Transp. Res.* 6, 136–141.
40 <https://doi.org/10.1179/1942787514y.0000000020>
- 41 Mercedes-Benz, 2002. Technical information The new Citaro, Mercedes-Benz. Mercedes-Benz,
42 Mannheim, Germany.
- 43 Mitchell, D., Claris, S., Edge, D., 2016. Human-Centered Mobility: A New Approach to Designing
44 and Improving Our Urban Transport Infrastructure. *Engineering* 2, 33–36.
45 <https://doi.org/10.1016/j.eng.2016.01.030>
- 46 Moksony, F., 1990. Small is beautiful: the use and interpretation of R2 in social research. *Szociológiai*
47 *Szle.* 130–138.

- Montes, H., Salinas, C., Fernández, R., Armada, M., 2017. An experimental platform for autonomous bus development. *Appl. Sci.* 7, 1131. <https://doi.org/10.3390/app7111131>
- Morton, C., Caulfield, B., Anable, J., 2016. Customer perceptions of quality of service in public transport: Evidence for bus transit in Scotland. *Case Stud. Transp. Policy* 4, 199–207.
- Mucka, P., 2015. Road roughness limit values based on measured vehicle vibration. *J. Infrastruct. Syst.* 23, 1–13. [https://doi.org/10.1061/\(ASCE\)IS.1943-555X.0000325](https://doi.org/10.1061/(ASCE)IS.1943-555X.0000325).
- Nawayseh, N., Griffin, M.J., 2006. Effect of frequency, magnitude and direction of translational and rotational oscillation on the postural stability of standing people. *J. Sound Vib.* 298, 725–754. <https://doi.org/10.1016/j.jsv.2006.06.027>
- Nguyen-Phuoc, D.Q., Currie, G., De Gruyter, C., Kim, I., Young, W., 2018a. Modelling the net traffic congestion impact of bus operations in Melbourne. *Transp. Res. Part A Policy Pract.* 117, 1–12. <https://doi.org/10.1016/j.tra.2018.08.005>
- Nguyen-Phuoc, D.Q., Currie, G., De Gruyter, C., Young, W., 2018b. Congestion relief and public transport: An enhanced method using disaggregate mode shift evidence. *Case Stud. Transp. Policy* 6, 518–528. <https://doi.org/10.1016/j.cstp.2018.06.012>
- Park, J., Lee, H., Choi, Y., Park, K., Kim, M., You, H., 2014. Development of an ergonomic bus seat profile design protocol, in: *Proceedings of the Human Factors and Ergonomics Society*. pp. 1825–1828. <https://doi.org/10.1177/1541931214581382>
- Parsons Brinckerhoff, I., 2012. Transit cooperative research program report #155: Track design handbook for light rail transit (Second edition). <https://doi.org/10.17226/22800>
- Parsons Brinckerhoff, I., 2009. Technical memorandum: Alignment design standards for high-speed train operation. California High-Speed Rail Authority, California.
- Portouli, E., Karaseitanidis, G., Lytrivis, P., Amditis, A., Raptis, O., Karaberi, C., 2017. Public attitudes towards autonomous mini buses operating in real conditions in a Hellenic city. *IEEE Intell. Veh. Symp. Proc.* 571–576. <https://doi.org/10.1109/IVS.2017.7995779>
- Prashanth, A.S., Saran, V.H., Harsha, S.P., 2013. Study of subjective responses on ride comfort in public transport Uttarakhand State buses. *1st Int. 16th Natl. Conf. Mach. Mech.* 236–240.
- PTC, 2017. Commuter satisfaction with public transport continues to improve, Public Transport Council, Singapore. Singapore.
- PTC, 2016. Commuters at heart on recommendations to improve commuter's journey, Public Transport Council, Singapore. Singapore.
- Rau, A., Tian, L., Jain, M., Xie, M., Liu, T., 2018. Autonomous road transit (DART) for use-case capacity more than bus, in: *Mobil.TUM 2018 "Urban Mobility – Shaping the Future Together"* - International Scientific Conference on Mobility and Transport.
- Robert, T., Beillas, P., Maupas, A., Verriest, J.P., 2007. Conditions of possible head impacts for standing passengers in public transportation: An experimental study. *Int. J. Crashworthiness* 12, 319–327. <https://doi.org/10.1080/13588260701433552>
- Rodgers, J.L., Nicewander, W.A., 2006. Thirteen Ways to Look at the Correlation Coefficient. *Am. Stat.* 42, 59. <https://doi.org/10.2307/2685263>
- Salonen, A.O., 2018. Passenger's subjective traffic safety, in-vehicle security and emergency management in the driverless shuttle bus in Finland. *Transp. Policy* 61, 106–110. <https://doi.org/10.1016/j.tranpol.2017.10.011>
- Sam, E.F., Hamidu, O., Daniels, S., 2018. SERVQUAL analysis of public bus transport services in Kumasi metropolis, Ghana: Core user perspectives. *Case Stud. Transp. Policy* 6, 25–31. <https://doi.org/10.1016/j.cstp.2017.12.004>
- Sawaya, Y., Sharif, M., Christin, N., Kubota, A., 2017. Self-confidence trumps knowledge: A cross-

- cultural study of security behavior. *Proc. 2017 CHI Conf. Hum. Factors Comput. Syst.* 2202–2214. <https://doi.org/10.1145/3025453.3025926>
- Sekulić, D., Rusov, S., Dedović, V., Šalinić, S., Mladenović, D., Ivković, I., 2018. Analysis of bus users' vibration exposure time. *Int. J. Ind. Ergon.* 65, 26–35. <https://doi.org/10.1016/j.ergon.2018.01.017>
- Shen, X., Feng, S., Li, Z., Hu, B., 2016. Analysis of bus passenger comfort perception based on passenger load factor and in-vehicle time. *Springerplus* 5, 62. <https://doi.org/10.1186/s40064-016-1694-7>
- Shu, H.B., Shao, Y.M., Lin, W., Xu, J., 2016. Computation-based dynamic driving simulation for evaluation of mountain roads with complex shapes: A case study. *Procedia Eng.* 137, 210–219. <https://doi.org/10.1016/j.proeng.2016.01.252>
- Stjernborg, V., Mattisson, O., 2016. The role of public transport in society-A case study of general policy documents in Sweden. *Sustain.* 8, 1–16. <https://doi.org/10.3390/su8111120>
- Tan, H.S., Huang, J., 2014. Design of a high-performance automatic steering controller for bus revenue service based on how drivers steer. *IEEE Trans. Robot.* 30, 1137–1147. <https://doi.org/10.1109/TRO.2014.2331092>
- Tan, J.Y., 2013. International Roughness Index – Concept and Application in Singapore, in: Singapore Symposium on Pavement Technology (SPT 2013). Pavement Engineering Society, Singapore (PES), Singapore.
- Thuong, O., Griffin, M.J., 2012. The vibration discomfort of standing people: Relative importance of fore-and-aft, lateral, and vertical vibration. *Appl. Ergon.* 43, 902–908. <https://doi.org/10.1016/j.apergo.2011.12.011>
- UITP, 2008. EBSF: designing the future of the bus. The International Association of Public Transport (UITP).
- Van den Bulck, S.A., Hermens, R., Slegers, K., Vandenberghe, B., Goderis, G., Vankrunkelsven, P., 2018. Designing a patient portal for patient-centered care: Cross-sectional survey. *J. Med. Internet Res.* 20, e269. <https://doi.org/10.2196/jmir.9497>
- Xu, J., Yang, K., Shao, Y., Lu, G., 2015. An Experimental Study on Lateral Acceleration of Cars in Different Environments in Sichuan , Southwest China 2015.
- Yu, L., Kong, D., Yan, X., 2018. A driving behavior planning and trajectory generation method for autonomous electric bus. *Futur. Internet* 10. <https://doi.org/10.3390/fi10060051>
- Zhang, K., Zhou, K., Zhang, F., 2014. Evaluating bus transit performance of chinese cities: Developing an overall bus comfort model. *Transp. Res. Part A Policy Pract.* 69, 105–112. <https://doi.org/10.1016/j.tra.2014.08.020>
- Zhang, W., Jenelius, E., Badia, H., 2019. Efficiency of semi-autonomous and fully autonomous bus services in trunk-and-branches networks. *J. Adv. Transp.* 2019, 1–17. <https://doi.org/10.1155/2019/7648735>