

## A Comparison Study on the Assessment of Ride Comfort for LRT Passengers

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**Abstract.** Ride comfort in railway transportation is very mind boggling and it relies on different dynamic performance criteria as well as subjective observation from the train passengers. Vibration discomfort from different elements such as vehicle condition, track area condition and working condition can prompt poor ride comfort. However, there are no universal applicable standards to analyse the ride comfort. There are several factors including local condition, vehicle condition and the track condition. In this current work, level of ride comfort by previous Adtranz-Walker light rapid transit (LRT) passengers at Ampang line were analysed. A comparison was done via two possible methods which are BS EN 12299 (2009) and Sperling's Ride Index equation. BS EN 12299 standard is used to measure and evaluate the ride comfort of seating (Nvd) and standing (Nva) of train passenger in three different routes. Next, Sperling's ride comfort equation is used to conduct validation and comparison between the obtained data. The result indicates a higher extent of vibration in the vertical axis which impacts the overall result. The standing position demonstrates a higher exposure of vibration in all the three tested routes. Comparison of the ride comfort assessment of passenger in sitting and standing position for both methods indicates that all the track sections exceeds "pronounced but not unpleasant (medium)" limit range. Nevertheless, the seating position at track section AU did not exceed the limit and stayed at the comfortable zone. The highest discomfort level achieved for both methods for seating position are  $3.34 \text{ m/s}^2$  for Nva and  $2.63 \text{ m/s}^2$  respectively, which is at route C uptrack that is from Chan Sow Lin station to Sri Petaling station. Meanwhile, the highest discomfort level achieved for both methods for standing are  $3.80 \text{ m/s}^2$  for Nvd and  $2.88 \text{ m/s}^2$  for  $W_z$  respectively, at uptrack section which is from Sri Petaling station to Chan Sow Lin station. Thus, the highest discomfort level was discovered to be at Route C.



## 1. Introduction

Nowadays, the factors affecting the satisfaction of passengers on public transport is becoming more complex. Consumers would become regular customers if they are fulfilled by the product or a certain service. The most vital stride in portraying and conveying top notch administration is to understand the expectations of the customers. The best method of evaluating the expectation and perception of the customers is via the service quality which is offered. Analysis could be conducted to define passenger satisfaction on the experience of transport service. The main concern of the business today is to maintain quality of service [1].

The concern for passenger satisfaction is not limited to the safety and travelling time but ride comfort of the passengers as well. In addition, ride comfort is not only evaluated based on the mental and physiological segments of the passenger. Nonetheless, there is a general perspective that the absence of negative attributes is the definition of comfort. Various degree of comfort is conceivable to obtain a positive riding experience. Assessment of comfort includes a great feeling or inversely, an awful feeling. It is possible to identify comfort via a set of questionnaires [2].

Vibration is the major factor that contributes to ride comfort. Vibration is either localised vibration or vibration that affects the whole body. Localised vibration occurs when an individual holds a vibrating object which only involves the arm and hand.. Whole body vibration is a result of vibration that would affect the whole body of the exposed person, which is usually transmitted through seats, backrests, and throughout the floor while standing or lying down [3].

In many countries, a variety of standard or criteria are used to evaluate the ride comfort of railway vehicles as it is extremely difficult to establish a universally applicable international standard on the factors of ride comfort. Many jobs require a range of tasks to be conducted, each with a different magnitude of vibration exposure. The ride comfort of a passenger is very important. It determines the satisfaction of the passenger throughout the ride [4].

Light rail transit (LRT) is a public transport that is heavily used by citizens in a country. In certain cities, LRT serves as major transportation for most people to get to work. They might have to travel from one end to another, where the journey is both long and tiring. During the journey, they might be exposed with vibration where most of it originated from mechanical disturbances and impacts of the rail when in motion [3]. When boarding the train, passengers would be exposed to vibration depending on the duration of their journey. When in standing position, passengers are primarily exposed to vibration from some altered structures (e.g. structures and walkways), where such exposures can cause distress to the person [5].

Ride comfort is one of the main evaluation for the vibration level of the passenger. Thus, ride comfort assessment is important in order to maintain and monitor the services offered by the railway company. However, there are no universally applicable methods to evaluate the ride comfort since the railways, condition of vehicles, tracks and operations varies by country. Therefore, the evaluation for ride comfort has to be developed independently. Although it is difficult to make a universal evaluation method for ride comfort on account of local considerations, it is quite worthwhile to investigate the relationships between various ride comfort indices and conduct a comparison for the results from the evaluation of the level of ride comfort using different methods. Therefore, a study was conducted to evaluate the ride comfort of passengers by using Sperling's Ride Index. A comparison was made between two different methods which are Sperling's Ride Index and BS EN 12299 (2009) [11].

The objectives of this paper are to evaluate the ride comfort of the passengers based on whole body vibration via Sperling's method and to conduct a comparison between the ride comfort index of Sperling's and BS EN 12299 (2009) [11]. It is essential to evaluate ride comfort of the LRT passenger based on the whole body vibration. Besides, a comparison between the ride comfort index of Sperling's and BS EN 12299 (2009) [11] can be used to investigate the relationships between various ride comfort indices. In addition, a better and more accurate evaluation of ride comfort would be obtained.

## 2. Methodology

In an era where information and documents by specialists throughout the world are easily accessed, it is a common method to utilise existing information for researches. Thus, secondary data analysis is a common approach to conduct investigation on the information that were gathered by another researcher for another purpose. The usage of these information would greatly ease the researcher who may have constrained time and resources. Secondary analysis is an exact practice that applies an indistinguishable essential research standard from other studies. It uses essential information and has ventures to be taken similarly for any research methods. This research asserts that secondary data analysis is a suitable technique to be used for the procedure of request, and when a methodical procedure is taken after. This research commits to the discussion of secondary data analysis as a research strategy for ride comfort of LRT passengers using Sperling's method. A comparison between the Sperling's method and BS EN 12299 (2009) [11] was done to show the similarity and benefits of using different method analysis when analyzing the level of ride comfort for the LRT passengers.

### 2.1 Data Collection

The data was collected by using secondary data collection method and a comparison study was done. In this research, the data was obtained from Whole Body Vibration Analysis for Ride Quality of LRT Passenger by Ahmad Abqari Bin Abu Samah [12]. The collected data act as the primary data or original data which are gathered for a specific reason. There are two techniques for directing primary data, either through quantitative research or qualitative research. Quantitative research is directed in a high volume, for example, studies, while qualitative research is directed as a top to bottom research of a man or a certain circumstance. . Primary data is the first level of information in a research which is commonly completed under the bearing of the individuals who planned the study.

Secondary data is the re-analysis of the information with the end goal of noting the primary data inquiries with better factual strategies. Secondary analysis is done by researches who have entry to the first study information, yet most secondary analyst is not included in the outline of the original study [6]. This study serves to evaluate the ride comfort of the train passengers based on whole body vibration, and to identify the level of passenger satisfaction towards their experience during the ride.

### 2.2 Route of Experiment.

The Ampang line route was used to evaluate the ride comfort of the train passengers. In addition, the results of the previous study on the ride comfort via BS EN 12299 (2009) [11] would be used to be compared with Sperling's Ride Index method. The route in Figure 1 will start from Ampang Station and will end at two stations which are divided at Chan Sow Lin station with an overall distance of 27 kilometers. The two end of the station are Sentul Timur station and Sri Petaling station. Therefore, the route of this study was divided into three track routes, being labelled as Route A, B and C. Tables 1-3 list the detail of stations of Ampang line route.

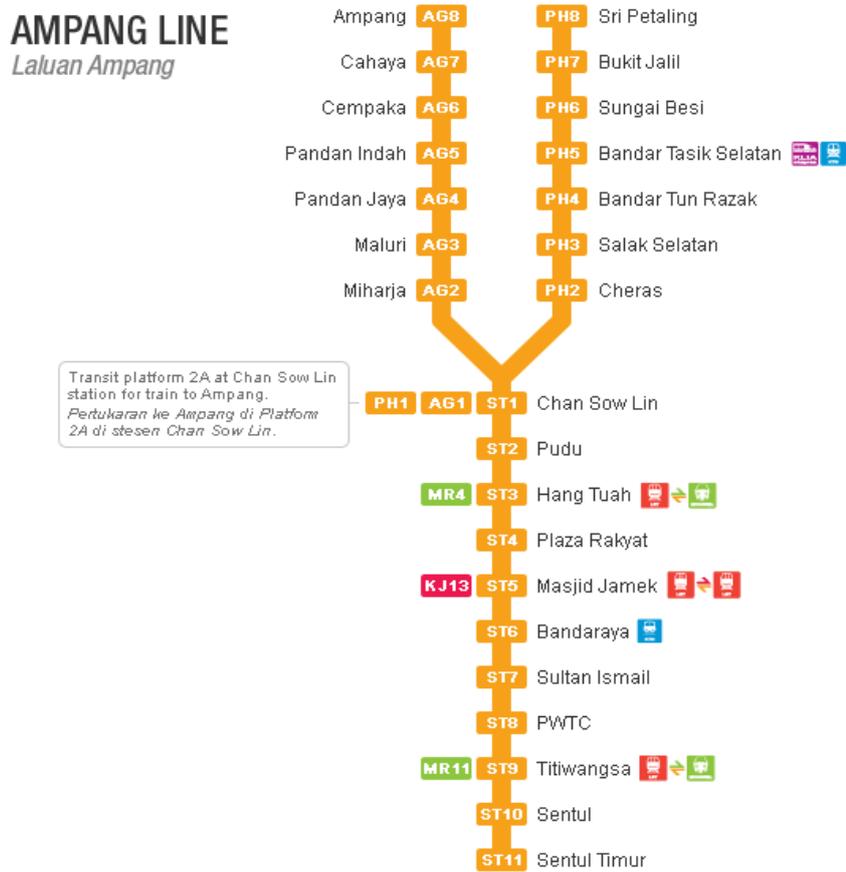


Figure 1: Ampang line route

Table 1: Track route between stations from Ampang to Chan Sow Lin

ROUTE	SECTION	STATIONS
A (Ampang – Chan Sow Lin)	AU1	Ampang to Cahaya
	AU2	Cahaya to Cempaka
	AU3	Cempaka to Pandan Indah
	AU4	Pandan Indah to Pandan Jaya
	AU5	Pandan Jaya to Maluri
	AU6	Maluri to Miharja
	AU7	Miharja to Chan Sow Lin
	AD1	Chan Sow Lin to Miharja
	AD2	Miharja to Maluri
	AD3	Maluri to Pandan Jaya
	AD4	Pandan Jaya to Pandan Indah
	AD5	Pandan Indah to Cempaka
	AD6	Cempaka to Cahaya
	AD7	Cahaya to Ampang

Table 2: Track route between stations from Chan Sow Lin to Sentul Timur

ROUTE	SECTION	STATIONS
B (Chan Sow Lin – Sentul Timur)	BU1	Chan Sow Lin to Pudu
	BU2	Pudu to Hang Tuah
	BU3	Hang Tuah to Plaza Rakyat
	BU4	Plaza Rakyat to Masjid Jamek
	BU5	Masjid Jamek to Bandaraya
	BU6	Bandaraya to Sultan Ismail
	BU7	Sultan Ismail to PWTC
	BU8	PWTC to Titiwangsa
	BU9	Titiwangsa to Sentul
	BU10	Sentul to Sentul Timur
	BD1	Sentul timur to Sentul
	BD2	Sentul to Titiwangsa
	BD3	Titwangsa to PWTC
	BD4	PWTC to Sultan Ismail
	BD5	Sultan Ismail to Bandaraya
	BD6	Bamdaraya to Masjid Jamek
	BD7	Masjid Jamek to Plaza Rakyat
	BD8	Plaza Rakyat to Hang Tuah
	BD9	Hang Tuah to Pudu
	BD10	Pudu to Chan Sow Lin

Table 3: Track route between stations from Chan Sow Lin to Sri Petaling

ROUTE	SECTION	STATIONS
C (Chan Sow Lin – Sri Petaling)	CU1	Sri Petaling to Bukit Jalil
	CU2	Bukit Jalil to Sungai Besi
	CU3	Sungai Besi to Bandar Tasik Selatan
	CU4	Bandar Tasik Selatan to Bandar Tun Razak
	CU5	Bandar Tun Razak to Salak Selatan
	CU6	Salak Selatan to Cheras
	CU7	Cheras to Chan Sow lin
	CD1	Chan Sow Lin to Cheras
	CD2	Cheras to Salak Selatan
	CD3	Salak Selatan to Bandar Tun Razak
	CD4	Bandar Tun Razak to Bandar Tasik Selatan
	CD5	Bandar Tasik Selatan to Sungai Besi
	CD6	Sungai Besi to Bukit Jalil
	CD7	Bukit Jalil to Sri Petaling

**2.3 Ride Comfort Evaluation.** An evaluation for ride comfort will be made based on EN 12299 and Sperling Ride Index, where the results will indicate if the vibration levels are within comfortable range. According to EN 12299 standard (EN), comfort is perceived in different ways by different people. Therefore, it is impossible to specify a unique assessment system which is valid for every passenger. As a result, the evaluation of Mean Comfort, made in this standard, is based on the relationship between the accelerations measured in a vehicle. The following formulas are being used for this research;

Comfort formula for seated:

$$N_{VA} = 4 \cdot (a_{ZP95}^{Wb}) + 2 \cdot \sqrt{(a_{YA95}^{Wd})^2 + (a_{ZA95}^{Wb})^2} + 4 \cdot (a_{XD95}^{Wc})$$

Comfort formula for standing:

$$N_{VD} = 3 \cdot \sqrt{16 \cdot (a_{XP50}^{Wd})^2 + 4 \cdot (a_{YP50}^{Wb})^2 + (a_{ZP50}^{Wb})^2} + 5 \cdot (a_{VP95}^{Wd})$$

Table 4: Scale for the  $N_{MV}$  comfort index. The index should be in one decimal (threshold of the passenger sensitivity) for each individual test zone.

Ride index	Ride comfort Level
$N_{Va}/N_{vd} < 1.5$	Very comfortable
$1.5 \leq N_{Va}/N_{vd} < 2.5$	Comfortable
$2.5 \leq N_{Va}/N_{vd} < 3.5$	Medium
$3.5 \leq N_{Va}/N_{vd} < 4.5$	Uncomfortable
$N_{Va}/N_{vd} \geq 4.5$	Very uncomfortable

According to Sperling Ride Index, the continuous whole body vibration exposure root mean square average vibration ( $A^{wrms}$ ) is the r.m.s value of the frequency weighted acceleration  $a^w(t)$  in  $m/s^2$ .

$$w_z = 4.42 (a^{wrms})^{0.3}$$

Where,  $a^{wrms}$  is the r.m.s value of the frequency weighted acceleration  $a^w(t)$  in  $m/s^2$

Table 5: Ride evaluation scale as per Sperling Ride Index [4]

Ride Index $W_z$	Vibration sensitivity
1	Just Noticeable
2	Clearly noticeable
2.5	More pronounced but not unpleasant
3	Strong, irregular, but still tolerable
3.25	Very irregular
3.5	Extremely irregular, unpleasant, annoying, prolonged exposure intolerable
4	Extremely unpleasant, prolonged exposure harmful

The  $W_z$  Ride Index (RI) is determined for each direction. One of the disadvantages for  $W_z$  is that the acceleration on different directions are treated separately. In this study  $W_z$  is calculated for all positions and directions separately. A  $W_z$  value of 2.5 is often compared with BS EN 12299(2009) [11] weighted r.m.s. acceleration value which is  $2.5 m/s^2$ . This value is often considered as an acceptable value for ride comfort on trains with respect to motions and vibrations.

EN 12299 is recognised as the most precise method, other than ISO-2631 which has been adopted by most country in evaluating ride comfort. However, in some cases, Sperling ride index ( $W_z$  method)

is much more convenient to be used because the result is in pure number. Therefore, it is more appropriate for comparison between two or more different situations.

### 3. Result and Discussion

Vibration assessment towards ride comfort of LRT passenger was carried out at different travelling routes. The routes have been divided into three which are route A, route B, and route C, which is as shown in Table 6.

Table 6: Number of track segments by different travelling route

Route	Track section	Station	Track Segment
A (Ampang – Chan Sow Lin)	A Uptrack	Ampang- Chan Sow Lin	7
	A Downtrack	Chan Sow Lin- Ampang	7
B (Chan Sow Lin-Sentul Timur)	B Uptrack	Chan Sow Lin-Sentul Timur	10
	B Downtrack	Sentul Timur-Chan Sow Lin	10
C (Chan Sow Lin – Sri Petaling)	C Uptrack	Chan Sow Lin - Sri Petaling	7
	C Downtrack	Sri Petaling – Chan Sow Lin	7
Total			48

#### 3.1 Comparison on the Level of Ride Comfort between Routes via Sperling’s Method

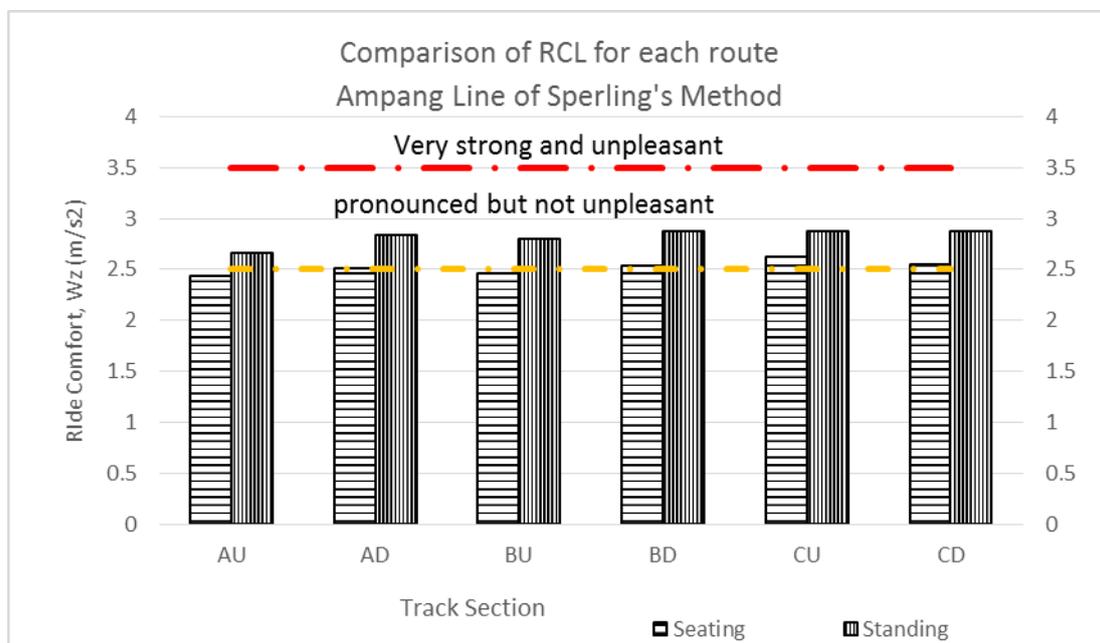


Figure 2: Comparison of seating and standing ride comfort level for Ampang line route

Figure 2 shows the comparison on the level of ride comfort between standing and seating position for Ampang line. Each line consists of track sections which are uptrack and downtrack section. The graph shows the range for the limit of ride comfort within pronounced but not pleasant as well as very strong and unpleasant. The value of the acceptable range is below 3.5 m/s<sup>2</sup>. According to the graph, it

can be seen that the standing position shows a higher ride index value when compared with the seating position. This is due to the direct exposure of vibration magnitude from the train floor to the body parts. Besides, there are other elements such as the body weight that would have an influence on the force acting on the body. A standing position would have a relatively high value when compared to seating, and this would eventually cause a feeling of discomfort. In a standing position, the vibration magnitude will increase. Thus, discomfort would be increasing as it is dominated by the sensations in the legs. Therefore, there is less vibration being transmitted to the upper body as compared to a seated position [5]. All track section exceeds pronounced but not unpleasant limit range except for the seating position in two track sections which are AU and BU. The highest ride comfort level in a seating position was  $2.626 \text{ m/s}^2$  which is at uptrack of route C, originating from Chan Sow Lin to Sri Petaling. The highest ride comfort level when standing was  $2.880 \text{ m/s}^2$  at downtrack of route B which originated from Sentul Timur to Chan Sow Lin.

### 3.2 Comparison between RCL of Sperling's Equation and BS EN12299

The data analysis for Sperling's RCL was compared with the data analysis for BS EN 12299:2009. The graph shows the limit for the range of ride comfort within pronounced but not pleasant (Medium) as well as very strong and unpleasant (Uncomfortable). The range of the acceptable range is below  $3.5 \text{ m/s}^2$  for both cases. The results for both RCL of Sperling's equation and BS EN12299 show that the ride comfort level for both standing and seating are about the same which is below the range of  $3.5 \text{ m/s}^2$ . Thus, it can be deduced that the ride comfort is acceptable. Nevertheless, some of the results from BS EN12299 exceeded the uncomfortable limit at several track sections. Although EN 12299 was recognized as the most precise method other than ISO-2631 which has been adopted by most country in evaluating the ride comfort, Sperling's equation was to be chosen in certain cases if appropriate comparison would like to be done on the findings [4].

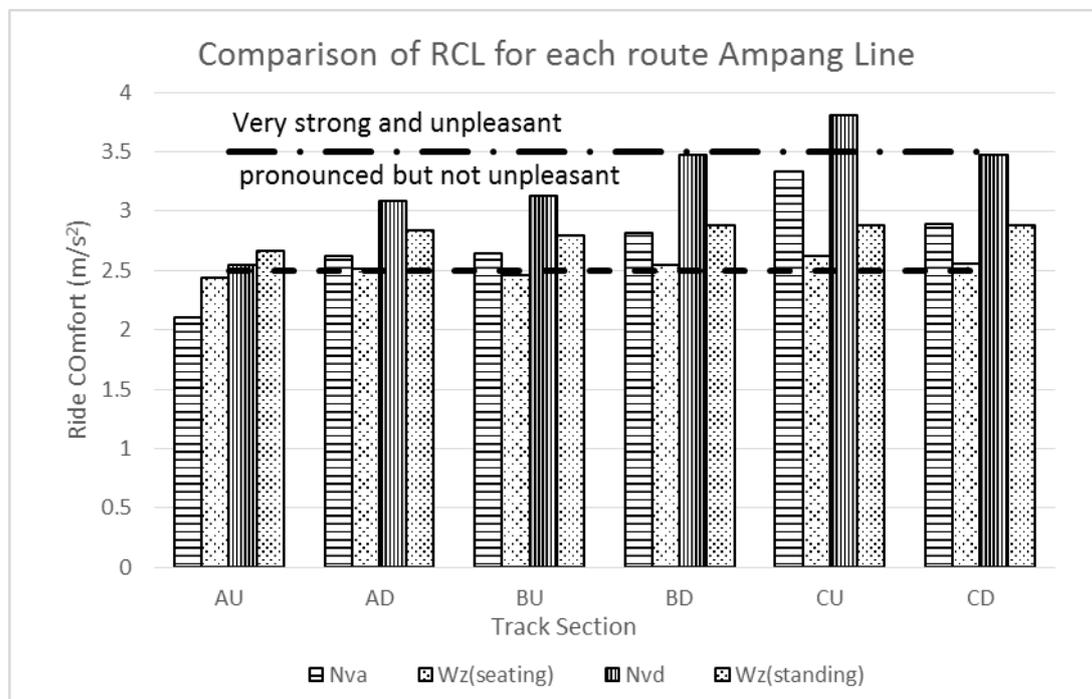


Figure 3: Comparison on the level of ride comfort for standing and seating position for both methods

Figure 3 shows the comparison on the level of ride comfort for both standing and seating positions for Ampang line. Each line route consists of two track sections which are uptrack and downtrack

sections. The graph shows the range of limit for the ride comfort within pronounced but not pleasant as well as very strong and unpleasant. The range of the acceptable range is below than  $3.5 \text{ m/s}^2$ . Thus, if the value exceeds this limit, it will be considered as uncomfortable (based on BS EN12299) or very strong and unpleasant (based on Sperling). According to the graph, the standing position for both methods show a higher ride index value as compared to the seating position. This is due to the direct exposure of vibration from the floor of train to the body parts. All the track section exceeds the pronounced but not unpleasant (medium) limit range except for the seating position at track section AU, which does not exceed the limit and is within the comfortable zone. The highest discomfort level for both methods are  $3.34 \text{ m/s}^2$  for  $N_{va}$  and  $2.63 \text{ m/s}^2$  for  $W_z$  respectively. This occur in the seating position at uptrack of route C, which originates from Chan Sow Lin to Sri Petaling. The highest discomfort level for both methods in the standing position are  $3.80 \text{ m/s}^2$  for  $N_{vd}$  and  $2.88 \text{ m/s}^2$  for  $W_z$  respectively. This occurs at the uptrack section which originates from Sri Petaling to Chan Sow Lin. Therefore, the highest discomfort level was at Route C for both methods.

### *3.3 The importance of the comparison between Sperling's RCL and EN 12999 Ride Comfort*

One of the significance of this study is to conduct a comparison between the methods that was used in the previous research and another established method. For evaluation of the ride comfort, there are various standards that are commonly used. This is because there are no universally applicable international standards to evaluate ride comfort. Ride comfort can be evaluated via human feeling. Besides, there are several other elements such as vibration due to tracks, vehicle and the operations which may vary by different countries [7]. There are a couple of researches that discussed on the number of different analysis involving the measurement of the acceleration at the seats of the train with the model of human response to the acceleration in terms of ride comfort. In addition, several researchers used the magnitude of vibration to calculate the expected ride comfort of the passengers. As a result, most of the calculations indicate that the vibration exposed to the passengers is not severe and is within the tolerable range [8].

Although it is difficult to make a universal evaluation method for ride comfort on account of local considerations, it is quite worthwhile to investigate the relationship between various ride comfort indices [4]. Nevertheless, in order to have a generally established ride comfort evaluation, many factors should be considered including several non-motion factors which may have a relatively high cost. Next, in order to obtain a better and higher accuracy of evaluation for ride comfort, a comparison study by using various methods could be done.

## **4. Conclusion**

This research discuss on the secondary data analysis for ride comfort of LRT passengers via Sperling's method. A comparison between the Sperling's method and BS EN 12299 (2009) [11] was done as well in order to show the similarity and benefits of using different methods of analysis for level of ride comfort for LRT passengers. Sperling's RCL was used to evaluate the ride comfort of the passengers in both seating and standing positions. Next, the results are compared with ENV 12299 (2009) [11]. BLAZE software is used to conduct a synthesis on the value of raw acceleration in three different axes for each track section. The level of WBV exposure for the passengers in three different routes along three different axes in both seated and standing position were analysed. All the track sections exceeded the range of pronounced but not unpleasant (medium) limit except for the seating position at the track section of AU, which does not exceed the limit and is within at comfortable zone. The highest discomfort level achieved for both methods are  $3.34 \text{ m/s}^2$  for  $N_{va}$  and  $2.63 \text{ m/s}^2$  for  $W_z$  respectively. This occurs at the uptrack of route C, which originates from Chan Sow Lin to Sri Petaling. In addition, the highest discomfort level achieved for both methods when standing are  $3.80 \text{ m/s}^2$  for  $N_{vd}$  and  $2.88 \text{ m/s}^2$  for  $W_z$  respectively. This occurs at the uptrack section which originates from Sri Petaling to Chan Sow Lin. Therefore, it can be concluded that the highest discomfort level was at route C for both methods.

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