Dynamics of Railway Infrastructures

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Abstract. Assessing dynamic performance for railway vehicles heavily relies on factors such as driving comfort. Various techniques in the literature exist for evaluating driving comfort in mixed traffic conditions and route geometry. The indices ride comfort (W_Z) and vehicle ride quality (W_R), formulated by Sperling, are commonly used in this research. Furthermore, experimental investigations have confirmed that driving comfort is influenced by speed and position within the bodywork. Vibrations stimulate the human body differently. The Sperling comfort index evaluates the effects of vibration on passenger comfort. The Sperling index is related to a scale of values and represents an objective value. The objection is that driving comfort could be a subjective parameter and therefore not measurable accurately; driving comfort may not be the only factor in assessing the dynamic performance of railway vehicles, as factors, such as weather conditions or railway maintenance, may affect driving comfort and the accuracy of the W_Z and W_R indices. This research validates the influence of velocity on ride comfort and the critical position of the car body from the ride comfort perspective.

1 Introduction

A track quality index obtained by direct track geometry measurements may not directly relate to passenger comfort conditions [1]. The Sperling index provides information on the dynamic behavior of the vehicle to improve the vehicle's dynamic performance in terms of driving quality and passenger comfort [2]. The research offers a method, derived from the Sperling method, of evaluating the comfort of passengers engaged in performing sedentary activities such as reading, writing, and typing on laptops during a journey by metro and train [3]. The proposed Sperling index can be an average value for long-distance sections of a train. The proposed index allows the overall assessment of the passenger's comfort subjected to mechanical vibration according to the three axes [4]. Kalman's filter filters the accelerations according to the three axes. Longitudinal vibrations can play a role in driving comfort in curves, elevation changes, and shared surfaces with urban road traffic. Existing regulations do not provide a universally recognized means of evaluating driving comfort. This study explores the interrelationships among Sperling's proposed comfort indices, using a rail transport case study to investigate the strengths and limitations of the Sperling approach. The parameters for assessing driving comfort rely on the filtering and processing

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acceleration data gathered within the railway vehicle. The research centers on the correlation between Sperling indices, designed to determine driving comfort.

2 Summarizing Previous Studies

Vehicles Locomotive E444, TGV carriage, Eurofima carriage, the ETR 450, AVRIL train electromotive engine have maximum speeds below 350 km/h [5]. Railway vehicles operate with a normal operating load [6]. The research examines the comfort of these vehicles as a function of speed up to 350 km/h. The Eurofima carriage has a high carbody. A high value of the carbody mass can increase the comfort of the vehicles. The locomotives E444 and ETR 450 have a similar value of the carbody. The reduction in passenger load decreases the comfort conditions of the E444 and ETR 450 railway vehicles [7]. Concerning the stiffness of the secondary suspension, the E444 locomotive has a high secondary stiffness value. The ETR 450 has low secondary stiffness. The TGV and Eurofima have similar secondary stiffness values. The E444 features a Sperling index of 3.82 close to the comfort range that is not always satisfactory at 350 km/h [8]. The 450 electric train offers the best comfort with a Sperling index of 1.85 at 100 km/h [9]. The other vehicles are between the above extremes (Fig. 1). Table 1 offers the vertical comfort index of rail vehicles with normal operating load. All Railway vehicles presented a satisfactory values of comfort index along vertical axis (Fig. 1). Table 2 proposes the secondary stiffness carbody and fundamental frequencies of railway vehicles. The AVRIL electric motor has an excellent comfort index at high speeds The AVRIL electromotive machine does not suffer from the creeping force of the bogies. The AVRIL electromotive machine has 2.56 as a comfort index at 320 km/h. On the other hand, the ETR 450, the carriage type TGV, and the Eurofima carriage have comfort ratings higher than 3 at 320 km/h (Fig. 2). The analysis of previous research highlights the parameters that affect the comfort of train passengers. The motion of a train on a railway track includes free and forced oscillations. Forced oscillations arise from irregularities in the track or damaged wheels of the train. Primary and secondary suspensions are employed to mitigate the impact of these oscillations on the transmitted bodywork. The frequency and intensity of these oscillations ultimately determine the train's vibrations, which can significantly affect passenger comfort.

Table 1. Vertical Comfort Index of rail vehicles with normal operating load

Speed	100	200	300	350	400
Railway Vehicle	[km/h]				
E444	2.1759	2.9724	3.5673	3.8236	4.0604
TGV	2.0166	2.7548	3.3062	3.3537	3.7631
Eurofima	1.8694	2.5537	3.0648	3.2850	3.4884
ETR 450	1.8488	2.5255	3.031	3.2487	3.4499
Avril	1.8536	2.5320	3.0389	3.2572	3.4589

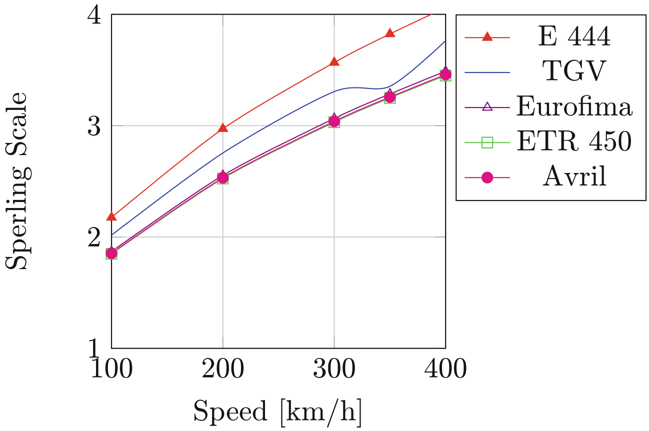


Fig. 1. Sperling Index of rail vehicles with normal operating load along vertical axis

Table 2. Secondary stiffness carbody and fundamental frequencies of railway vehicles

	E 444	TGV	Eurofima	ETR 450	Avril
Secondary Stiffness [daN/cm]	472	190	179	141	110
Carbody [tons]	33	28.4	37.2	33.2	27.5
f_1 [rad/s]	2.74	2.54	2.35	2.33	2.33

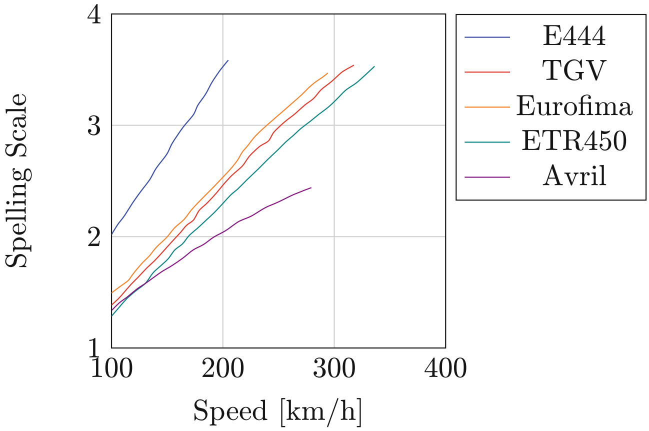


Fig. 2. Sperling Index of rail vehicles with normal operating load along lateral axis

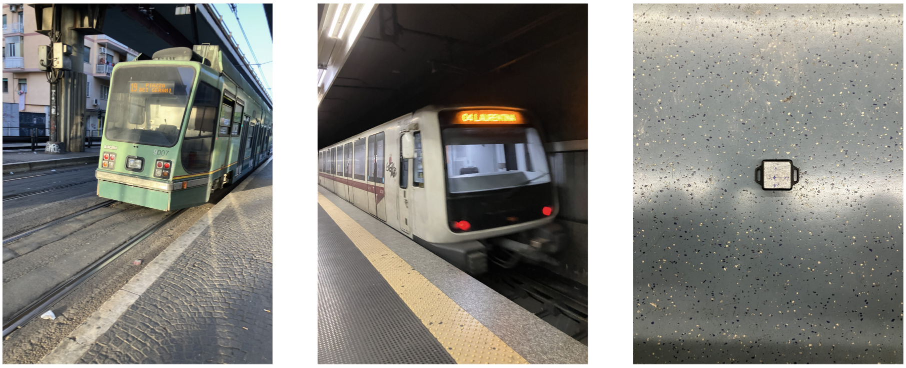
3 Methodology

Different traffic types, like urban, suburban, underground, and long–distance, require unique methods for evaluating driving comfort. The Sperling method, the Wz index, and ISO 2631 standards evaluate the driving comfort of railway vehicles. Sperling's W_Z index method is the best approach for assessing railway vehicle comfort W_Z and driving quality W_R. The International Union of Railways (UIC), the European Committee for Standardisation (CEN), and ISO have established standards like UIC 513R, EN 12299, and ISO 10056 to ensure consistent assessments [10–12] and [13]. The calculation methodology is developed and proposed in the publications edited by Sperling [14] and [15]. Current regulations do not offer a universally applicable method of assessing driving comfort. The salient point is to identify relationships between the driving comfort indices derived from different approaches to compare the results better and to know the strengths and weaknesses of each evaluation method. Each evaluation method has its different formulations. The parameters for assessing driving comfort depend on the processing of acceleration data. The correlation between the various methods of evaluating driving comfort is the subject of further study.

4 Results

4.1 Experimental Set–up

The MEMS Vibration Sensor acquires the accelerations on the platform of the underground and overground trains. The acceleration data concern the vibrations along the x– y– and z–axes. The X–axis identifies the lateral direction, the Y–axis represents the direction of travel, and the Z–axis indicates the vertical direction of the train (Fig. 3). Accelerations are weighted with the Kalman filter.



(a) overground train (b) underground train (c) MEMS accelerometer

Fig. 3. Experimental set-up

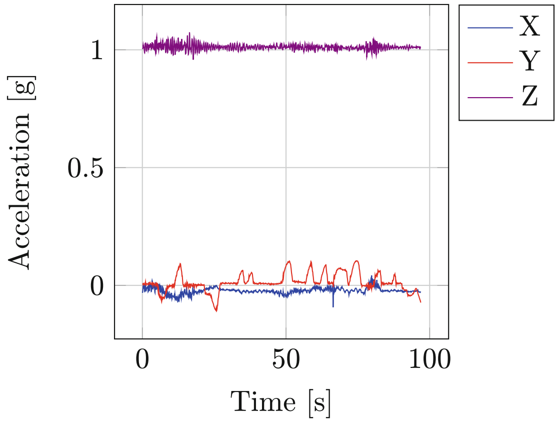


Fig. 4. Acceleration data acquired along x– y– and z–axis on the platform of the underground train

4.2 Experimental Investigations

The Fig. 4 and Fig. 5 show, respectively, the acceleration data acquired along x– y– and z–axis on the platform of the underground and overground trains. The Fig. 6 and Fig. 7 offer che Comparison of ride quality W_R and ride comfort W_Z for horizontal and vertical direction of acceleration between underground and overground trains.

5 Discussion

Sperling's index W_Z is more sensitive to the level of ride comfort. The Sperling's ride index W_Z is evaluated for each direction using the frequency–weighted accelerations, which are different along x– y– and z–axis [16]. The implementation of Sperling's index W_Z raises the following questions:

- How to address the potential bias in the Wz index caused by the weighting of accelerations along the x, y, and z axes.
- the W_Z index may not exhaustively represent the overall driving comfort experienced by passengers due to the use of frequency-weighted accelerations.
- The W_Z index has a mathematical complexity.

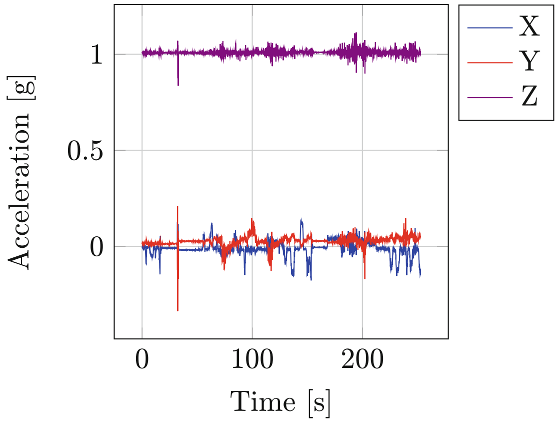


Fig. 5. Acceleration data acquired along x– y– and z–axis on the platform of the overground train

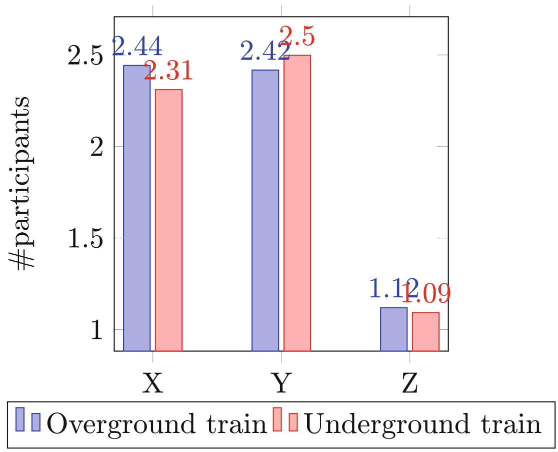


Fig. 6. Comparison of ride quality W_R for horizontal and vertical direction of acceleration between underground and overground trains

ISO 2631 offers a further contribution to the deductions offered by the Sperling index. ISO 2631 supposes the human body is sensitive at a level of acceleration and velocity [17]. Exposure limits are a function of the frequency and time of exposure to a given level of acceleration. Human exposure limits propose a gradual reduction in comfort. The reduction of comfort begins at a level of 10 dB lower than the exposure limits. The constant 3.15 divides the acceleration value. If the acceleration threshold doubles, mechanical vibrations can cause irreversible damage to humans. An acceleration of 6 dB higher than the exposure limit may damage the human body organs. The exposure limit is $1.2\,\text{m/s}^2$ for an exposure time of 1 h. The efficiency of the human body decreases slowly until the

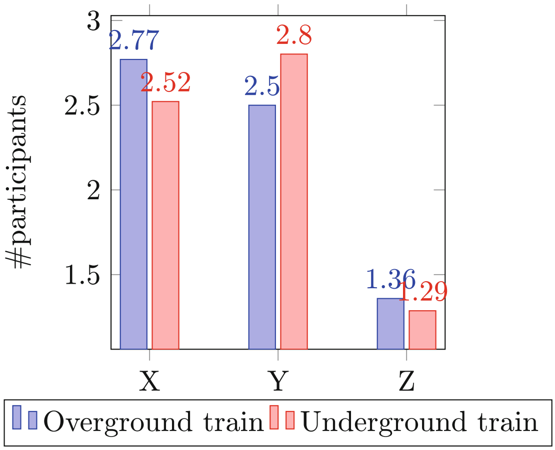


Fig. 7. Comparison of ride comfort W_Z for horizontal and vertical direction of acceleration between underground and overground trains

total loss. The efficiency decreases with an acceleration value of $1.2/3.15 = 0.38$ m/s^2 with 1 h of exposure. An acceleration of $1.2 \times 2 = 2.4$ m/s^2 at 4–8 Hz can physically damage the abdominal organs with 1 h of exposure [18]. If the breaks interrupt the mechanical vibrations, a recovery phenomenon increases the total exposure time. If the spectrum response is lower at level h of the exposure limits, the passenger is tired after h hours of exposure. Approximate methods define the hours of exposure limits when the acceleration spectrum of the biodynamic response is higher than the exposure limit of h hours at frequency f, and the remaining acceleration spectrum of the biodynamic response is lower [19]. Lateral comfort differs from vertical comfort at low speeds and high speeds. The axial snaking effect, generated from the differences in altitude and floor plan of the railway line, plays a fundamental role.

6 Conclusion

This research introduces the method of comfort of the running gear and the Sperling method to evaluate the driving comfort in railway vehicles. The experimental investigation identifies a scale to link the values deduced with the two approaches. Horizontal axes are the worst axes for comfort. Regardless of the assessment method of driving comfort, the results of the experimental surveys show that the comfort index increases in correspondence with rectilinear geometric profiles of the route and decreases in the presence of mixed urban traffic. The critical points of driving comfort are near the trolleys.

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