ANALYSIS OF TRAM COMFORT USING THE UNE EN 12299:2010 STANDARD AND SPERLING METHOD (WZ)

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ABSTRACT
Vibration is a main factor in the driving comfort contribution and can affect the human body by being transmitted through the seats and backrests. The vibrations produced in transport are transferred to the human body, affecting passenger comfort in terms of physical health (amplitude, duration, frequency range) and psychological health (type of population, sex, age). Transport comfort is governed by evaluation tests, ISO 2631-1:1997 standard evaluates human exposure to vibrations, UNE EN 12299 standard is based on the previous one, allowing the evaluation of user comfort by calculating the average and continuous comfort index. Acquisition of acceleration data on the x,y,z axes is weighted in frequency with respect to its direction and weighting curves as a rule. Root mean square values (continuous comforts) are obtained, and the 50th and 95th percentiles for the subsequent calculation of mean comfort. The Sperling method obtains the ride quality and users comfort according to weights. The data has been extracted by the Freematics One+ device at various tram locations. The EN 12299 standard studies the acceleration behaviour (x,y,z), time, latitude, longitude, speed. It is possible to calculate the comfort index of the tram by means of norms and the Sperling method. The data was processed in Matlab obtaining favourable values in the two experimental trials, indicating that the tram in the city of Cuenca, Ecuador is very comfortable and the vibrations produced are slightly perceived by users.
Keywords: acceleration, accelerometer, comfort, EN 12299, frequency, Freematics, percentile, railway, Sperling, tram, vibrations, weighing.

1 INTRODUCTION

Railway vehicles have become systems of great importance, causing designers to be interested in achieving safe and comfortable operation [1]. Important criteria within the sustainability of the urban transport network, including the railway, are passenger satisfaction, travel time and comfort [2]. A comfortable environment involves enriching the performance of drivers and therefore the safety of users [3]. Several factors such as humidity, noise, temperature, seat design, vibrations, among others, can affect the trip or journey, and therefore driving comfort. Over the years, vibration has been the most studied factor due to railway demand the development of both experimental and theoretical studies is required [4], [5]. The vibrations produced by different types of transport are transmitted to the human body, affecting not only the comfort of passengers or train drivers, but also their physical and psychological health. Vibrations caused by the railway vehicle are the cause of different diseases, whether physical (amplitude, duration, frequency range) or psychological (type of population, gender, age, level of consciousness) [6]–[8]. Prolonged exposure to high-frequency vibrations of small amplitudes leads to concentration problems, while short-term exposure to low-frequency vibrations of large amplitudes causes damage to muscles and internal organs [9]. Vibration is a primary factor in contributing to driving comfort and can affect the entire body, as it is transmitted through the seats, backrests [10], [11]. Frequency is an important factor considering human beings as vibration systems with resonances at certain frequencies, each part of the human body with its respective masses, natural

WIT Transactions on The Built Environment, Vol 213, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/CR220011

frequencies, shock absorbers and elastic elements that act when stimulated by oscillatory phenomena [12], [13]. Comfort when traveling in a railway vehicle has increased in recent years due to social demand [14], [15], a main objective for train drivers is to guarantee quality service. Comfort assessment encompass methods, standards, or criteria to determine how users feel about comfort [16]. Comfort varies in different countries due to vehicle conditions, road conditions, speed restrictions, curve radii, among others [17]. There are several methods that relate passenger comfort and acceleration levels in an unbiased way, being accepted to assess driving comfort [18]. The established methods to evaluate the mean comfort and, the most used are: ISO 2631, EN 12299 and the Sperling's method. The comfort index varies according to the method used and according to the way of extracting and processing the acceleration data [19]–[21]. The evaluation of the data is acquired with an accelerometer located in the center of the surface of the seat cushion and the surface of the backrest proposed in ISO 10326-1 [22]–[24]. The EN 12299 standard is considered accurate in multiple countries for calculating the comfort levels of railway vehicles by obtaining three comfort evaluation indices: mean comfort (N_{MV}), continuous comfort index (Ccx, Ccy, Ccz), and complete comfort (NVA) [25]. In order to obtain the corresponding vibrations, a weighted general vibration level is used as an exposure metric, most of these curves are derived from the ISO 2631 standard [26].

2 MATERIALS AND METHODS

2.1 Experimental overview

UNE EN 12299 standard mentions that the measurement points established will be according to the method used and the type of vehicle. In single deck vehicles, three measurement points will be established: a point in the center and one at each end of the passenger compartment, as shown in Fig. 1 [27].

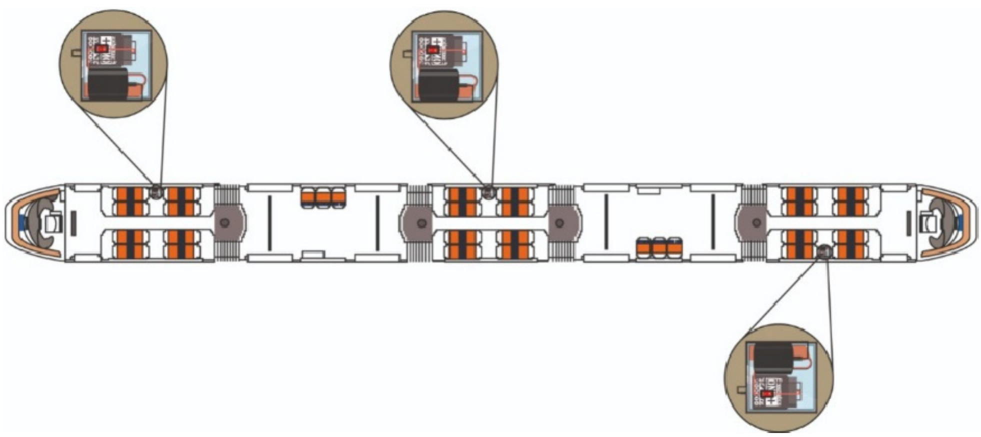

Figure 1: Measurement location points according to the UNE EN 12299 standard.

The UNE ISO 2631 standard establishes methods to quantify the vibration of the whole body in relation to human health and comfort, the probability of perceiving vibrations and the incidence of motion sickness [12], [28], [29] considering a frequency range of 0.5 Hz to

80 Hz for health and 0.1 Hz to 0.5 Hz for bad movement. Fig. 2 represents UNE ISO 2631 comfort analysis methodology.

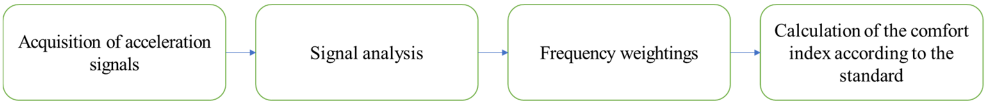

Figure 2: Comfort analysis methodology according to UNE ISO 2631-1, Vibrations and mechanical shocks.

2.2 Data acquisition

For data acquisition as mentioned in the EN 12299 standard, three Freematics One+ devices were organised as shown in Fig. 3. The acceleration data in the three axes extracted by the accelerometer measure with respect to the object inertial mass, allowing the movements of the railway vehicle to be identified during the journey, that is, the vibrations will be the Freematics One+ acquired data in addition to the maneuvers of drive and turns. The global positioning and location are acquired by means of the global positioning sensor (GPS) (M8030) obtaining data of latitude, longitude, altitude that allow knowing the route of the tram. The speed at which the tram circulated during the routes “Río Tarqui – Parque Industrial” and vice versa is obtained.

Figure 3: Freematics One+ and GPS devices used for data acquisition and Lipo battery power.

2.3 Data processing

Once the data is obtained, the microSD is connected to the computer to be able to process them. Freematics obtained data are stored in (.CSV) format, where eight files are obtained (round trip) for later processing in Matlab. By means of neural networks, a re-sampling of the GPS speed is performed to complete the speed matrix and relate these variables based on the accelerometers. The data of the three measurement points when applying the neural network are shown in Figs 4 and 5.

The latitude and longitude data sampled by the Freematics One+ device allow characterizing the behaviour of the tram route in Matlab using the Google Earth application, the green area indicates the route both outward and return.

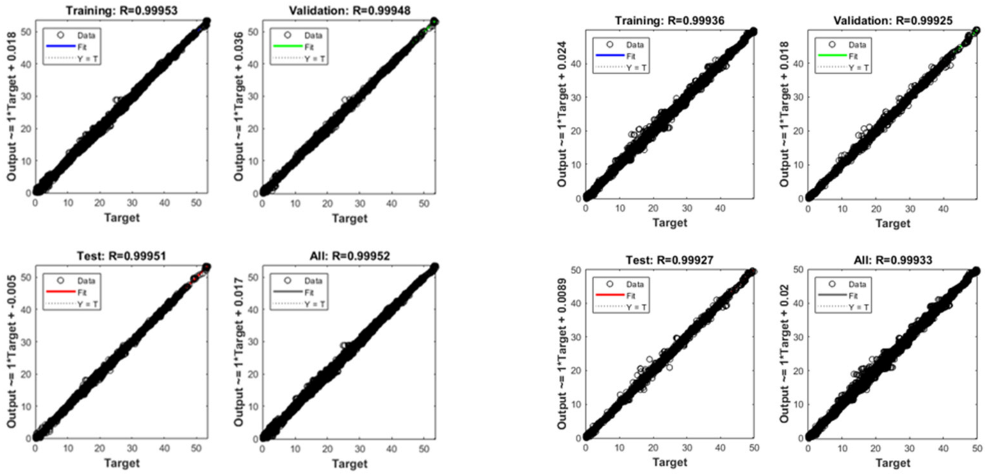

Figure 4: Neural networks: Front and middle measurement point respectively.

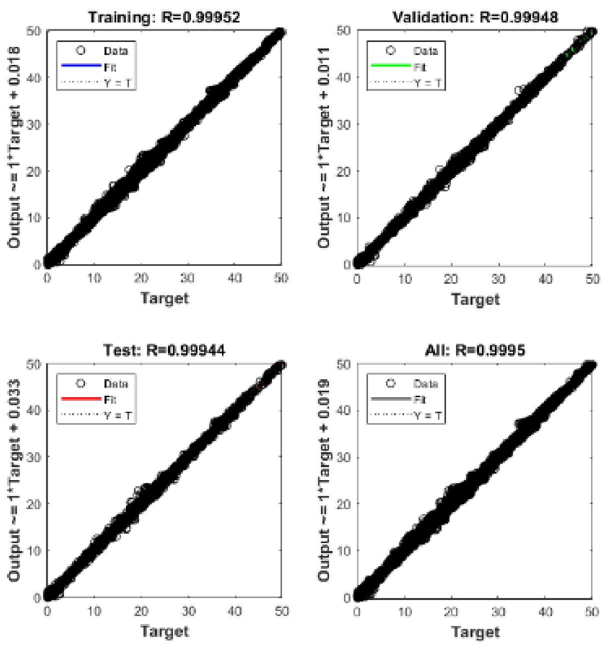

Figure 5: Neural networks: Front and middle measurement point respectively.

With the tram speed sampled on the route (tram routes are observed in Fig. 6), values of the maximum speed of the tram are obtained at the three measurement points, which oscillates around 48 km/h. The speed decreases when the tram is going to arrive at a station, therefore when the speed is equal to 0 km/h, that is, the tram has stopped because it has reached a station, as shown in Fig. 7.

Figure 6: Characterization of the route Rio Tarqui – Parque Industrial/Parque Industrial – Rio Tarqui.

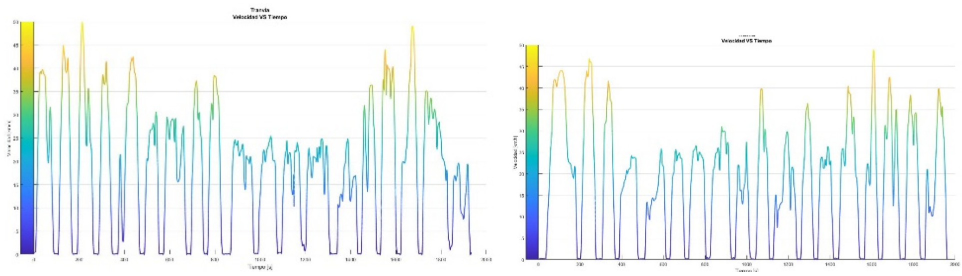

Figure 7: Round trip speeds respectively with measuring point forward.

2.4 Comfort evaluation

For the comfort evaluation according to the Sperling's method, vertical (Az) and horizontal (Ay) accelerations were used. The accelerations signals measured on the ground are transformed to cm/s^2. The power spectral density (PSD) is estimated through the vibration in each direction. It is weighted in frequency according to the vertical (passenger comfort) or horizontal (ride quality) direction. These weighting equations are:

Ride quality:

$$B\,(f) = 1.14\sqrt{\frac{[(1 - 0.056f^2)^2 + (0.645f)^2 * 3.55f^2]}{[(1 - 0.252f^2) + (1.547f - 0.00444f^3)^2](1 + 3.55f^2)}} \quad (1)$$

Passenger comfort:

$$(f) = 1.14\sqrt{\frac{1.911f^2 + (0.25f^2)^2}{(1 - 0.277f^2)^2 + (1.563f - 0.0368f^3)^2}} \quad (2)$$

where $k = 0.588$ for vertical vibrations and $k = 0.737$ for horizontal vibrations.

When calculating the Wz index and comparing with the limit tables of this method, the index is evaluated by means of the integral of the product of the power spectral density and the weighting modulus.

Evaluation of comfort according to UNE EN 12299 standard was established to the tram analysis comfort from the measurement of the accelerations on the railway vehicles ground with an antistep filter. Weighting the accelerations in frequency according to the direction of the vibration, the calculation of the mean square values (rms) every 5 minutes represents the continuous comfort. Calculate the 50th and 95th percentile. The value of the mean comfort index (N_{MV}) is obtained for each location of the measurement points and a global.

3 ANALYSIS OF RESULTS

3.1 Evaluation according to Sperling

The comfort is represented by the red curves representing the weighting in the horizontal direction while the green color represents the vertical direction, the driving comfort index is used to obtain the ride quality and is given by the blue color (Fig. 8).

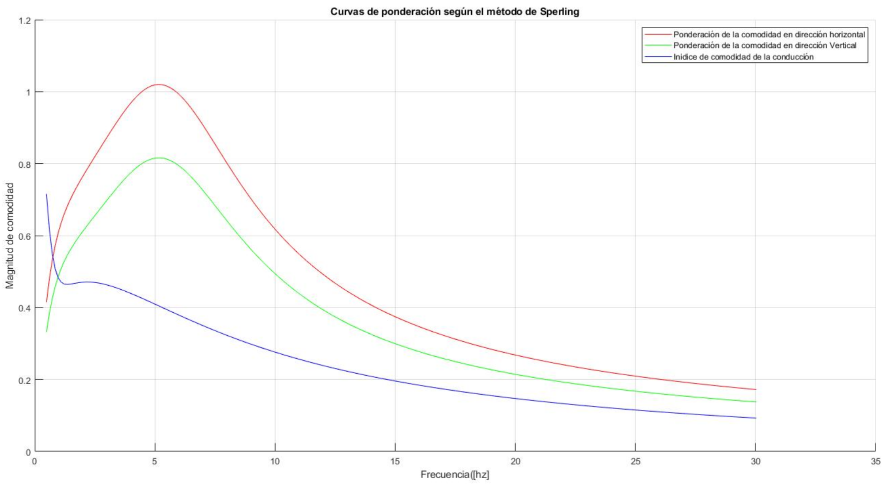

Figure 8: Sperling weighting curves depending on the measurement point forward, middle and back.

The Sperling method is evaluated according to the location of the measuring devices: forward, middle and at the other end of the tram. Defining as routes Río Tarqui – Parque Industrial (Route 1) and route Parque Industrial – Río Tarqui (Route 2). Comfort according to the Sperling method is reflected in Table 1. The values obtained are less than or equal to 1 in all directions and in the two study routes, according to the Sperling comfort index scale, the vibrations produced are “slightly perceptible” by tram users.

Table 1: Comfort index according to Sperling.

Route/Measurement point	Wzx	Wzy	Wzz
Route 1/Middle	1.01884	1.01884	0.82
Route 2/Middle	1.01793	1.01793	0.8147
Route 1/Back	1.01658	1.01658	0.8155
Route 2/Back	0.91862	0.91862	0.76
Route 1/Forward	0.9347	0.9347	0.761
Route 2/Forward	0.943	0.943	0.771

Gait quality according to the Sperling method is evaluated in Table 2. Ride quality results are the same for the three directions with values less than 1. According to the Sperling scale, driving is defined as "Very good".

Table 2: Driving quality according to Sperling (Wz).

Route/Measurement point	Wzx	Wzy	Wzz
Route 1/Middle	0.4	0.4	0.4
Route 2/Middle	0.4117	0.4117	0.4117
Route 1/Back	0.4132	0.4132	0.4132
Route 2/Back	0.45	0.45	0.45
Route 1/Forward	0.4517	0.4517	0.4517
Route 2/Forward	0.943	0.943	0.771

3.2 Evaluation according to UNE EN 12299 standard

Within the two tram routes there are different stations and each of them has been evaluated by means of the standard. Continuous comfort is calculated at the Río Tarqui – El Salado Interstation, considering the location of the Freematics One+: Forward. In Fig. 9, in the variable Ccx, values lower than 0.15 m/s^2 are obtained, the comfort in the transverse direction Ccy presents values of up to 0.17 m/s^2 except for the beginning of the route with a value of 0.33 m/s^2. Comfort in the vertical direction values range between 0.13 m/s^2, therefore, the preliminary scale defines it as "very comfortable" in that section.

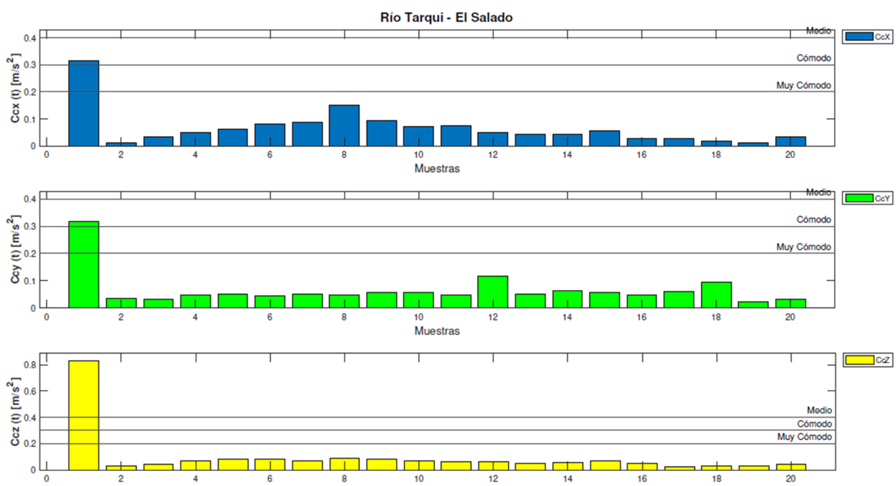

Figure 9: Continuous comfort: Ccx, Ccy, Ccz. Río Tarqui – El Salado. Measurement point: Forward.

The location of the measurement point was changed to medium as shown in Fig. 10. Obtaining a Ccx value of 0.16 m/s^2 and Ccy in the transverse direction of 0.18 m/s^2 establishing by the indices as "very comfortable". In the vertical direction Ccz, the first peak is identified as the starting moment with a value of 0.7 m/s^2 while the other values are less than 0.3 m/s^2, which according to the preliminary scale is "comfortable".

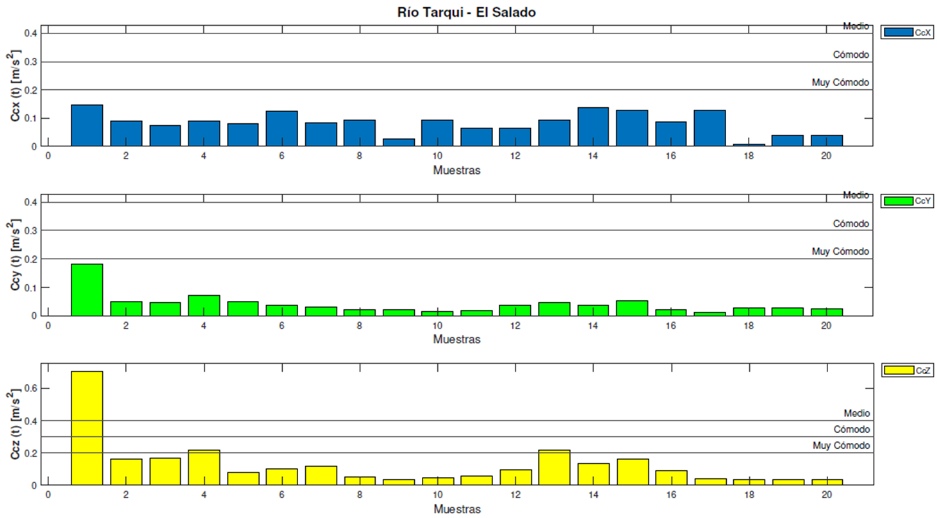

Figure 10: Continuous comfort: Ccx,Ccy,Ccz. Río Tarqui – El Salado. Measurement point: Medium

In Fig. 11, the location of the measurement point is modified to the back, where the values of both Ccx and Ccy take values less than 0.2 m/s^2, so according to the standard they are "very comfortable". In the vertical case, the same inconvenience is presented as in the previous case, where a value of 0.7 m/s^2 appears at the start, so that the other values satisfy the "very comfortable" scale.

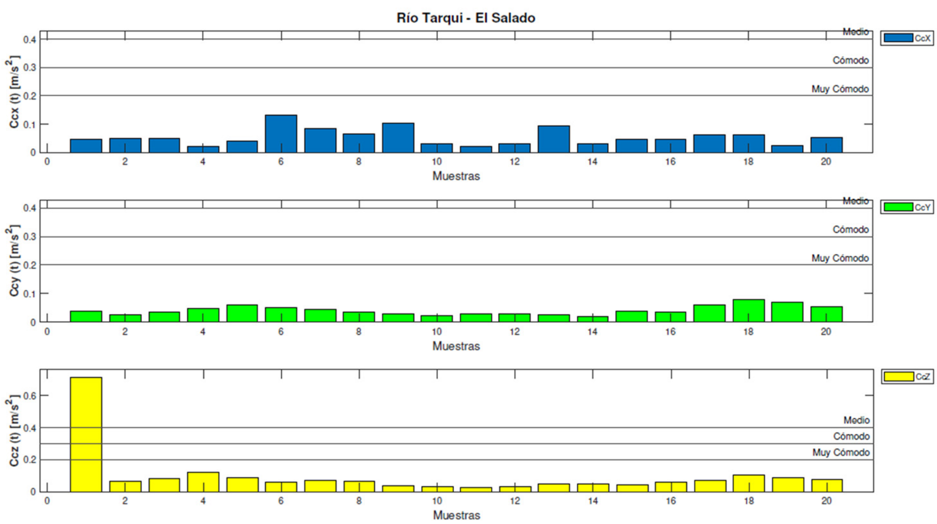

Figure 11: Continuous comfort: Ccx,Ccy,Ccz. Río Tarqui – El Salado. Measurement point: Back

The N_{MV} comfort index of standard EN 12299 is calculated by the normal method, the values were calculated for each direction (x, y, z). Table 3 shows that all the values of $N_{MV\ X}$, N_{MV} and y $N_{MV\ Z}$ are less than one. Therefore, according to the scale for the comfort index of standard EN-12299, it is "very comfortable". Similarly, the global average comfort values, N_{MV}, are less than 1.5. These values correspond to the entire journey of the two routes.

Table 3: N_{MV} comfort index according to EN 12299.

Route	Measurement point	$N_{MV\ X}$	$N_{MV\ Y}$	$N_{MV\ Z}$	N_{MV}
Route 1	Forward	0.7449	0.4915	0.9708	1.3187
Route 2	Forward	0.6351	0.5595	0.7635	1.1399
Route 1	Middle	0.6205	0.5161	0.5229	0.9617
Route 2	Middle	0.4874	0.6148	0.5478	0.9569
Route 1	Back	0.6268	0.6907	0.5775	1.097
Route 2	Back	0.6615	0.6047	0.521	1.0367

4 CONCLUSIONS

Railway vehicle comfort has been evaluated by different methods and guidelines applying the Sperling method and the UNE EN 12299 standard. Comfort index allows to obtain the quality of the ride from the Sperling method by identifying the road infrastructure while the EN 12299 standard evaluates the comfort of a user in discrete events. Both the Sperling method and the UNE EN 12299:2010 standard consider certain scales to assess the comfort of the railway vehicle, in this case they coincide in their evaluation of the tram as a comfortable transport. Data collection in low-cost devices such as the Freematics One+ compared to other more sophisticated equipment has shown similarity due to its fast and reliable data extraction for subsequent processing. The most influential extracted variables in the comfort analysis are given by the acceleration in the three axes, speed, time, altitude, latitude, among others. The level of comfort of the Cuenca tram is characterized as comfortable and safe after the evaluation of the indices by regulation.

As future work, a frequent data sampling can be applied in the tram, corridors, vehicle fleets and estimate a comfort analysis using the ISO 2631 standard, in addition to modifying the location of the data acquisition device in the Bogie.

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