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Passengers Comfort Perception and Demands on Railway Vehicles: A Review

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Abstract

Trains are becoming a popular way of transportation driven by comfort and ecology reasons. Latest statistics showed an increasing of 40% on the number of passengers in the last decade. The development of new high-speed trains promoted an evolution on the coaches interiors, as to make railway transportation more attractive. To cope this objective, new requirements were set, namely high levels of comfort and safety. In complement, multiple long-term ride comfort evaluation methods have been developed. The aim of this work is to present a review on the passengers' comfort perception in railway vehicles. The standards ISO 2631, EN 12299 and the Sperling's method are the most used ones. They refer several factors, as the vibration (level, frequency and duration), temperature, noise and area of the train per capita. Additionally, the perception of reduced accidents delayed the studies of passive security. Therefore, recent works focus on reducing the consequences of the second impact in case of accident and minimize the biomechanics injury criterion, through new interiors design layouts.

Keywords: Railway vehicles, Passengers comfort, Posture, Ride evaluation, Passive safety

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1. Introduction

The development of new high-speed services worldwide allowed an increase of the high-speed trains passengers numbers. The last statistics by the International Union of Railways (UIC) showed that more than 3 million passengers used the train in the past 2017, representing an increase of 40% from relatively to 2007 [1].

Nowadays, the train is becoming a competitive move of transportation over the air travel, especially for short and medium distances, up to 800 km. Beyond its higher capacity, the train journey is revealed to be faster than the flight, mainly due to the time before and after boarding [2]. Also, the passenger can use better the time on board, not only to work, but also to make use of the train facilities, namely the bar. In addition, for those that have afraid of flying, or have special health requirements, trains are normally a better option.

However, the customer requirements are becoming more demanding, including technological features related to the use of mobile devices, more comfort, safe and accurate timetable, creating new challenges to the constructors [3–6].

Multiple definitions of comfort and discomfort can be found in the literature, the most accepted is the one developed by Zhang et al. in 1996. Zhang and his colleagues defined comfort and discomfort as two independent, individual concepts, associated with different underlying factors. Comfort is related with the feeling of well-being and relaxation, and it is influenced by the aesthetic impression of a product or environment. In opposition, the discomfort was associated pain, soreness, numbness and stiffness, and it is influenced by physical constrains in the product [7].

Train comfort is defined by multiple parameters such as, vibration, noise and temperature. Moreover, the highest cause of discomfort is related to the seat, if not designed in accordance with the passenger anthropometry. On the other hand, when designed according to the passenger anthropometry, the seat will provide low levels of fatigue and a generalised sense of comfort. Therefore, an ergonomic approach is crucial when considering the development of a new train seat. However, the activities performed by the user during the trip place an increasing challenger [8], [9].

In the present article, a review on train comfort will be performed. First, it will be introduced the most common postures and activities realized by the users on train journeys, following by the methods to evaluate the long-term ride comfort of railway vehicles and the evolution of the passive safety.

2. Postures and Activities

There are a few studies in the literature concerning to the relation between the activities performed by the passengers, their postures and comfort rates.

A research study with the goal to analyse the interaction between people's posture and activities during a train journey was conducted in [10]. The study involved the observation of 743 persons, 568 persons on a train journey in Germany and 175 persons on a train ride on the Netherlands. The top four activities performed during the train journeys were talking, relaxing, reading and sleeping. Regarding the postures, 40with the head free of support, trunk against the backrest, arms free from armrest and legs free with both feet on the floor; this posture was specially observed for medium and highlevel activities. The second most common posture (15.1%), especially associated with lowlevel activities is characterized by having the head against the headrest, back in a slump position, arms upon the armrest and legs free with both feet on the floor. In the third group, representing 12.5% of the train users, the passengers have a head free of support, trunk against the backrest, arms free from armrest and legs crossed.

A study conducted in [11] showed that while a large group of passengers travel with ends to work or study and perform activities like reading, writing or the use of computers, a smaller group of users performed activities like sleeping and make phone calls. The performed activities lead to different postures which consequently, can lead to higher levels of discomfort. The activity observed for a longer period of time was work on a laptop, followed by sleeping, reading and talking. However, when it comes to the comfort scores the highest rate was assigned to talking, secondly sleeping, reading and lastly, the less comfortable activity was work on a laptop. The four presented activities represented 78% of all observations. Concerning to the postures, this were defined based on the variations of head position, back posture and seat pan contact. Posture with head upright, trunk backwards and full seat contact was the only one observed for all the four activities, also it revealed to be the most comfortable posture for reading. The most comfortable posture for sleeping was unexpected an upright position with head upright, trunk upright and full seat contact. This posture was also observed for reading and working on laptop. Moreover, for work on laptop the posture with head forward, trunk upright and full seat contact was the most common. Lastly, for talking the posture with head sideward, trunk backwards and full seat contact was the one most observed.

In 2018, based on a previous work developed in [11], it was realized a similar work on the Bangladeshi train passengers to observe the most used postures and activities on a train journey [12]. The experiment ran on two different trains equipped with the same type of second class seats. Two hundred persons were observed, 182 aged between 18-60 years old and 18 aged greater than 60 years old. Four main activities were observed, staring, sleeping, talking and listening to music or using mobile phone. As opposite of [11], in [12] it was considered the analysis of the foot contact, as a relevant parameter of the posture. The posture with head upright, trunk backwards, full seat contact and foot contact on floor was measured for the four activities, being considered the most comfortable for sleeping. For staring the most comfortable posture was considered the one with head forward, trunk upright, full seat contact and foot contact on footrest. The posture with head sideward, trunk upright, full seat contact and foot contact on footrest was the one considered more comfortable for talking. Finally, for listening to music or using mobile phone the most comfortable posture was head upright, trunk upright, full seat contact and foot contact on floor [12].

Comparing the three presented studies, it is possible to observe that sleeping, talking and reading are the top three performed activities by the train users. Concerning the passengers postures an evidence on the head upright, trunk backwards, full seat contact and both foot on the floor postures was common in all studies.

3. Methods to Evaluate the Long-term Ride Comfort of Railway Vehicles

The evaluation of ride comfort is vital to understand and assess the quality and experience of a passenger on a train journey. The passenger level of comfort is a combination of physical and psychological factors. Therefore, the ride comfort can be affected by parameters such as vibration, temperature, acoustic noise, humidity, smell, visual stimuli and design layout. Vibration is considered as the main parameter to affect the users' comfort, once it is caused by the train motion the passengers are subject to it throughout the trip due to the contact with the seat, backrest and the floor [13-16].

Due to the influence of vibration, the ride comfort evaluation methods are based on the passenger's exposure to it. The discomfort of the passengers will increase with the increasing time of exposure to vibration and the its level. The condition of the railway vehicles and the track conditions as railway profile, rail irregularities or curvature, influence the passenger's perception of comfort. Hence, once these parameters are not regular in all the countries it is difficult to establish a universal standard for ride comfort of railway vehicles. Three methods are commonly used, the R.M.S - based method, the statistical method and the Sperling's method [14].

The root-mean-square (R.M.S) method is an evaluation procedure proposed and revised by the International Organization for Standardization (ISO) on the ISO 2631 standard. This standard pretends to rate the human exposure to whole-body vibration. In its turn, the statistical method, developed in EN 12299, was created based on the R.M.S method. Considering the fluctuations in both acceleration and frequency levels that occur during a train journey, the ISO 2631 standard is appropriated for the evaluation of trips with small variations, while the EN 12299 method is more accurate for journeys with fluctuations and variations associated with passengers and also minimize the sensitivity to artefacts. When proceeding to a comparison between two or more train comfort rides, the more appropriated method is the Sperling's method. This method was introduced in the mid of the last century in Germany by Sperling, being currently used in countries like Sweden, China or India. The special characteristic of this method is the fact that it is determined for each direction using frequency-weighted accelerations which are different in three directions [13], [14], [17-20]. Even when the intensities for all frequencies of vibration are equal, the human feeling during its exposure to vibration varies depending on the direction of motion in different parts of the body. Thus, in order to convert the vibration into the human feeling a frequency weighting curve is used.

Higher levels of weighting factor correspond to the frequencies where humans are more sensitive. For ISO 2631 the sensitive ranges for vertical and lateral vibration are 4-12 Hz and 0.6-2 Hz, respectively. On the EN 12299 the sensitive ranges found are 4-16.5 Hz for vertical vibration and 0.6-2 Hz for lateral vibration. For the Sperling's method, both vertical and lateral vibration ranges are 3-7 Hz. Figures 1 and 2 show the frequency weighting curves for vertical and lateral vibrations [13], [14].

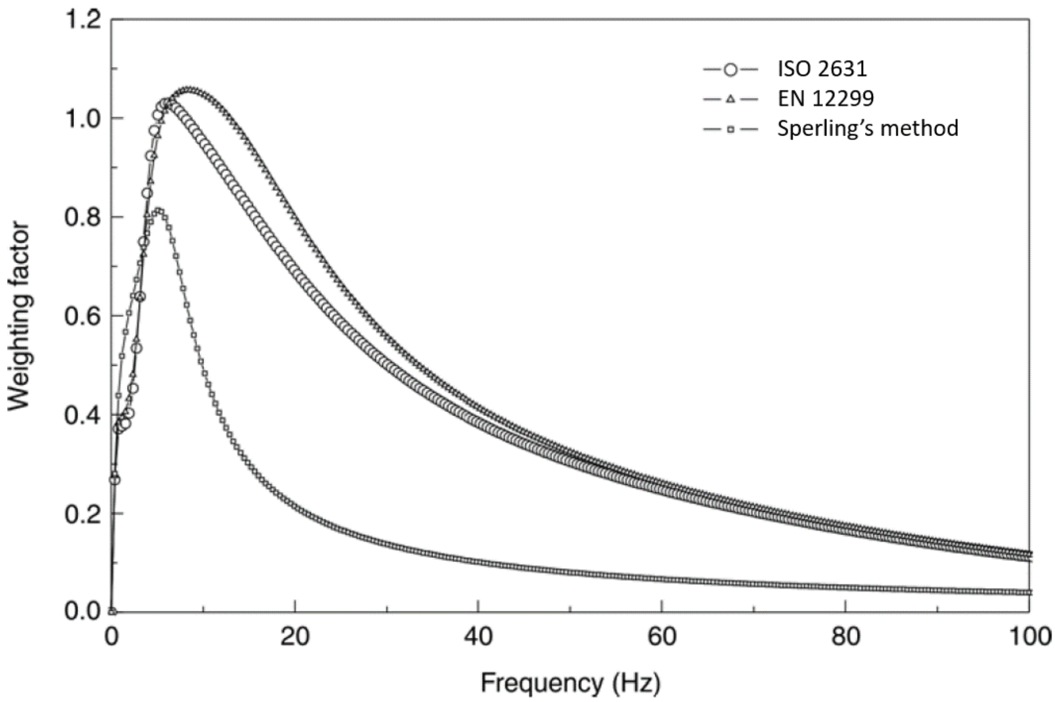

Figure 1: Frequency weighting curve for vertical direction [13]

The calculation of the ride comfort index for the three methods are as follow.

3.1. R.M.S-based method (ISO 2631)

To evaluate the railway vehicles comfort ride, the method proposed by the ISO 2631, given an arbitrary time interval, uses the R.M.S of the acceleration. The equation (1) shows the ride comfort level (RCL),

$$RCL = 20\log_{10}(A_{rms}/A_{ref})(dB) \tag{1}$$

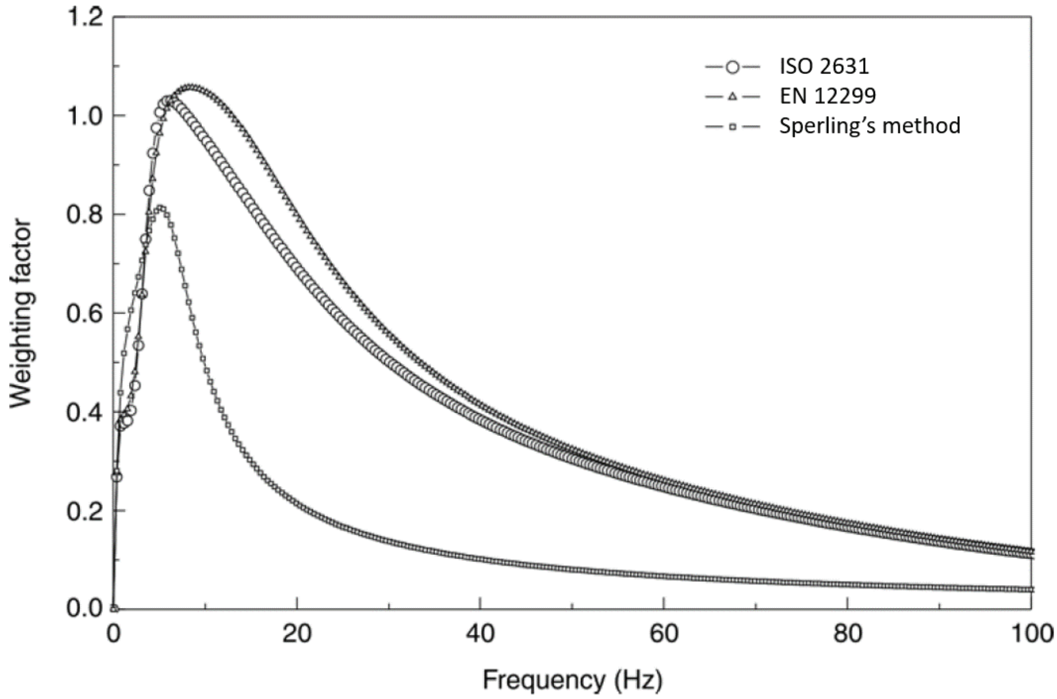

Figure 2: Frequency weighting curve for vertical direction [13]

where A_{rms} represents the weighted R.M.S. acceleration and, A_{ref} corresponds to the reference acceleration.

The evaluation of this method depends on the acceleration. Therefore, different accelerations lead to different evaluation scales, for example, while Korea uses 10-6 m/s2 as reference acceleration, the Japan uses 10-5 m/s2, which corresponds to a 20 dB larger RCL scale for the Korean scale when comparing whit the Japan one. While the ride is considered very comfortable for values under 103 dB and very uncomfortable for values above 118 dB in the Korean scale, the Japanese scale considers that a ride is very comfortable for values under 83 dB and very uncomfortable for values above 98 dB [13].

3.2. EN 12299 standard

The statistical method, propose a ride comfort indices (N_{mv}) calculation as

$$N_{mv_y} = 6A^w_{95_y} \qquad N_{mv_z} = 6A^w_{95_z} \tag{2}$$

where A^w_{95} represents the 95 percentile from 60 weighted r.m.s. values of acceleration, represents the lateral direction of the vibration and the vertical direction.

The evaluation of this method is based on a scale where a ride comfort index equal or under 1 is considered a very comfortable ride, while a value equal or above 5 is considered as very uncomfortable ride for the passengers [13].

3.3. Sperling's method

According with the Sperling's method, the ride comfort index (W_{zi}) can be calculated as follows

$$W_{zi} = \left[\int_{0,5}^{30} G_i(f) B_i^2(f) df \right]^{1/6,67} \tag{3}$$

where G_i corresponds to the double-side square acceleration $[(cm/s^2)^2]$ and B_i represents the frequency weighting curve. The evaluation of the presented method is also performed based on a scale. The passengers will not feel discomfort for values under 3 and, will feel extreme discomfort for results above 3.5 [13].

Some studies concerning the calculation of the ride comfort indices or performing a comparison between the results found with the different methods can be found in literature. Gangadharan et al. [21] performed a comparison between an analytical and an experimental ride comfort evaluation using the Sperling's method. The measurements took place at four different points located on the central line of the coach. An FE model was used to predict the analytical results. At a 45 km/h, the experimental results revealed a range from 2.21 up to 2.84 for ride comfort, while the predicted values were comprehended between 1.64 and 2.37.

Both experimental and analytical results are considered satisfactory on the Sperling's evaluation scale. The experimental results showed to be higher 10 to 30% than the analytical ones. This result can be explained due to the track irregularities not predicted on the FE model [21].

In a different study also based on the Sperling's method, [18] predicted through a numerical simulation, the ride comfort index and the effects of the velocity and train suspension on it. Using a velocity range between 20-300 km/h they found a relation between the increasing of the ride comfort index, which reveals lower levels of comfort, and the increasing of speed. The maximum obtained index was 2.5. For the suspension effect, using values of damping ratio of the suspension within the interval of 0.05 and 0.4, it was found that lower levels of damping will conduct to lower ride comfort index which means higher levels of comfort [18].

In 2018, a work focused on the comparison between the EN 12299 and Sperling's method ride comfort indices was performed in [17]. It was also evaluated the influence of the velocity and the position of the carbody critical points on the ride comfort. Three reference points of the carbody were places at the carbody centre, above the bogie 1 and above the bogie 2. The ride comfort index above the bogies (index around 2.7) revealed to be slightly higher than the one at the carbody centre (index 2) when calculated with the Sperling's method, the same relation was not verified when using the EN 12299 method were the indexes were around 2. In agreement with the previous works, there was also found an increasing of the ride comfort index with the increasing of velocity [17].

A comparison study of ride comfort indices between Sperling's method and EN 12299 in Australian trains was performed in [14]. The complete acceleration time history signals were recorded by IPV system placed at both ends and middle of the trains. The test line has 267.38 km length where a speed of 120 km/h was reached. Finally, the data was processed in MATLAB to obtain the different ride comfort indices. For the longitudinal direction, the ride comfort index based on the Sperling's method was considered as clearly noticeable, while the one for the EN 12299 method was obtained as corresponding to very comfortable. For the lateral direction, the vibration was considered “More pronounced but not unpleasant” and “Clearly noticeable” with the use of the Sperling's method and “Very comfortable” and “Comfortable” for the EN 12299 method. From the results it was concluded that generally the journey was comfortable, however there were some track segments that need maintenance or improvement plans [14].

In a study reported in [22], it is presented a different methodology to calculate the passenger comfort benefits of railway travel. This method was based on the application of a Chinese one and consists in the measurement of 6 objective indicators and 5 subjective indicators. Besides being a methodology applied exclusively in China, all the indicators, objective and subjective, can be used worldwide.

The objective indicators are the area per capita in passenger coach, vibration, pressure changes, noise, temperature and passenger travel time. The subjective indicators are connected with the passenger feelings on the train trip and are highlighted the heath conditions, interior decoration of passenger coaches, information services, seat comfort and catering services [22].

Focusing individually in each of the objective parameters, it was possible to conclude that beside been associated with all the countries, different societies have different needs and different approaches to solve them. Starting by calculating the area per capita in the passenger coach, it affects directly the passenger comfort during the entire journey; the higher the area, the higher the comfort level. Different countries apply different standards of area per capita, e.g. in Great Britain is 0.85 m2, while the on Germany is 1.18 m2 [22].

As previously mentioned, vibration is the main factor associated with comfort/ discomfort levels. During a train ride, it is traditionally divided into lateral and vertical vibration. The humans are more sensitive to the lateral vibration. The transmission of vibration to the user will be higher if he/she performed a full contact with the seat. Therefore, the vibration felted by the passenger depends, mainly, on the vibration isolation performance by the seat. While authors of [25] claim that the vibration transmission depends on two factors, the impedance of the seat and the apparent mass of the seat occupant. Wijaya et. al., proposed a sliding seat to minimize transient vibrations. Their results showed that their proposed seat was capable of attenuate vibrations containing single transient vibration in the horizontal direction and, thus, after being in contact with the sliding seat and a regular train seat, the experiment participants preferred the new seat [16], [22-25].

Concerning to pressure changes, when travelling by train, it happens mostly due to the passage on tunnels. Changes in air pressure can cause aural discomfort and in severe cases rupture the eardrum [22], [26].

Relatively to the interior noise, it was defined by the UIC and by ISO 3381, that the noise in passenger train should not exceed 65 dB. Also, it can cause negative reactions on passengers as headache or neurasthenia. Moreover, noise and speed have a linear relationship during train journeys, for each 10 km/h increase of speed, the noise level will increase 1-2 dB [22], [27].

Nowadays, all passenger trains are equipped with air-conditioning systems. In European countries, the ISO 7730 is largely used to regulate the comfort temperature. It defines a human comfort for temperatures between 21-24oC. However, in the USA, a range from 20-23.6°C is regulated by the ASHRAE 55-92. In China the comfort temperature is considered to be 17-28oC. The lack of air-conditioning and poor ventilation can lead the passengers to manifest feelings of sneezing, dizziness, fatigue and in extreme cases memory loss [22].

Lastly, for the travel time, durations longer than 6 hours will induce discomfort [22]. Regarding the five subjective indicators, they should be evaluated based on questionnaires performed to high-speed train journeys during and after the end of the trip. Questions on the toilet hygiene, seat shape, decoration material and catering staff service, as example, should be performed [22].

4. Passive Safety

Safety is one of the mayor concerns of passengers and train producers. In the case of trains, as they move usually in their own tracks, without interaction with other transportation modes, and reduced interaction with other trains in time and space, they are considered to have a high level of safety. Historically, train crashes are a relatively seldom event. Nevertheless, during many decades the research in passive safety was a very active area [28]. A train crash has some particularities. During a crash it can be distinguish two different impacts, the primary and the secondary impact. The primary impact occurs during the first part of the crash and, once it occurs during an abrupt deceleration of the train it is defined by the absorption of the kinetic energy by the train and its systems. Later comes the secondary impact where, once the passengers travel without any restrain system, they are projected with the initial velocity of the train, until they collide with the interior of the vehicle, objects or against other occupants [28-30].

The first engineering approach was to solve the absorption of the kinetic energy by the train during the primary collision. Therefore, the TRAINCOL project was ended with this problem by proposing structural solutions where the passenger compartment was preserved by a structural deformation from the exterior to the interior of the train with main concerning to the front and rear parts of the vehicle [30-32]. However, there was a need to solve a higher problem, the secondary collision effects. Statistics of railway accidents showed that the higher number of deaths are resulting from the secondary impact. The SAFEINTERIORS project was the first one that have developed the criteria for the protection of passengers and also studied the injury criteria and their thresholds. The thresholds are grouped according with the body regions by head, neck, thorax, upper leg and lower leg and, are scaled according the severity level. Thus, three thresholds are defined, moderate, serious and severe. A moderate injury threshold corresponds to the limit for the onset an injury requires hospital treatment, a serious injury threshold characterises an injury associated with long-term consequences and, the severe injury threshold represents an injury that poses a significant threat to life [28], [33].

As part of the SAFEINTERIORS project, [34] presented a systematic approach to the improvement in the passive safety in railway interiors. Using Anthropometric Test Devices (ATD), or dummies in short, a numerical model of the interior train layout was developed using MADYMO software with the goal of investigate potential sources of injury and suggesting new improvements. The interior layout consisted in three rows of 2 seats per row and three dummies placed two in a row, one in another row and being the first row empty. To consider a more realistic scenario, dummies with different body structures were considered. Then a secondary impact crash scenario was simulated. The results showed that initially there's a contact of the dummy legs with the back of the front seat followed by the impact of the head with the top of the back of the front seat. It was observed that most of the injury thresholds were moderated. Therefore, results showed a safe seating inline scenario. Also, it was concluded that smaller passengers are subjected to higher risk of leg injuries. The same conclusions were obtained in the 2017 study developed by the same authors but conducted with a finite element model in LS-DYNA. Moreover, the results comply with ones experimentally obtained for the same conditions [28], [29].

A few years later, in 2016, [30] presented a work developed with the goal of improve the optimal interior train design and minimize the passenger's injuries by modifying the seat structure. Therefore, it was proposed a methodology for improve the train interior where the biomechanical injury criteria form the spaces of the objective functions approximated by second-order polynomial functions. The observed data revealed that a variation of 10% on the thickness of the seat frame tubes and on the lower back seat plate lead to a 13.2% improvement on the injury criterion of head and neck [30].

In 2019, in the way to reduce the head and neck critical injuries occurred in crash scenarios connected with the death of passengers, [34] proposed the introduction of a foam pad at the top of the backseat. The foam pad goal was to control the energy absorbed by the seat during the collision of the head, with the consequent reducing of the biomechanical injury indices. The results showed that when comparing the new seat with the foam pad with a traditional regular seat without the foam pad, the injury risk was reduced by 59% and the injury value become below the moderate injury threshold [34].

5. Conclusion

The recent improvements of high-speed trains converted this transportation mode in a competitive alternative to the air transport. Therefore, it is observed an increase of the train passenger number. The greater advantage of the train transportation is that it allows a use of the travel time to work, business and relax associated with low levels of fatigue. Therefore, the passenger's requirements are becoming more demanding about comfort and safety.

A critical evaluation of the current market offer is needed. Therefore, methods to evaluate the long-term ride comfort were created. Depending on the assessment evaluation required, there are three different methods that can be applied, the ISO 2631, the EN 12299 and the Sperling's method.

Safety is one of the producer's major concerns. Multiple studies are conducted to realize the passengers' impact during a train collision and minimize their injuries. The TRAINCOL project solved the main issues during the first collision. Besides many efforts to reduce the secondary impact effects, there is no solution so far and, new work should be developed to fulfil the passengers' requirements.

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