Article

Not peer-reviewed version

Assessing Ride Motion Discomfort Measurement Formulas

Louis T Klauder, Jr *

Posted Date: 23 February 2024

doi: 10.20944/preprints202402.1363.v1

Keywords: vehicle-ride-motion; discomfort-measurement; discomfort-formula; motion-simulator; cross-match

Article

Assessing Ride Motion Discomfort Measurement Formulas

Louis T. Klauder Jr. †

Track Shape and Use LLC; lou@klauder.org
† Current address: Louis Klauder, 128 Eastman Ct, Marshall, MI 49068, USA

Abstract: After some context and motivation this article proposes gathering recordings of uncomfortable ride motions encountered in public passenger transport service and using a ride motion simulator to compare them. It explains how to adjust the amplitudes of the sample recordings so that they all cause equal discomfort. Then, if a formula is proposed for estimating the discomfort a vehicle ride motion would cause, it can be applied to each of the equal discomfort recordings, and the dispersion of the resulting discomfort scores will indicate the realism of that formula; the lower the dispersion, the more realistic the formula.

Keywords: vehicle-ride-motion; discomfort-measurement; discomfort-formula; motion-simulator; cross-match

1. Introduction

1.1. *A way to assess the realism of a ride motion discomfort measurement formula*

This article is generally about the discomfort that seated passengers feel when they are exposed to vibratory and jolting motions while traveling in common carrier vehicles such as planes, trains, and buses. The article takes note of ways that common carriers can make use of ride motion discomfort measurements. It also takes note of some discomfort measurement formulas currently in use for measuring such discomfort.

However, this article neither proposes nor evaluates any particular discomfort measurement formula. Instead, it sets forth a framework for evaluating and developing discomfort measurement formulas. Sections 1, 2, and 3 of the article provide context and motivation, and section 4 sets forth a procedure for establishing the framework.

This article will often speak in terms of travel by passenger railroad. However, what is presented will also be applicable to measurement of discomfort due to ride motions experienced by seated passengers using other modes of commercial passenger transport.

Literature on this subject often refers to "ride comfort". This article refers to "ride discomfort" because that is what passengers sometimes feel and what engineers can try to measure.

This article does not consider the discomfort referred to as motion sickness.

1.2. *The motivation for measurement*

Each of the major categories of vehicular passenger transport such as private auto, bus, train, and plane will have its own approach to passenger comfort. In the case of passenger rail service, if the service is governmentally mandated or has captive ridership it may seem that there is no business reason for measuring the discomfort of the service. As a practical matter, most passenger rail operations are operated with an intent to attract ridership. When passengers have a choice of travel mode, presence or absence of discomfort is a factor in their choice. Thus, a passenger rail service provider is well advised to measure the discomfort to which its patrons are exposed and, if discomfort is identified, to consider whether it would be profitable to take steps to reduce it.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 February 2024 doi:10.20944/preprints202402.1363.v1

1.3. Terminology

This article will use some terms with specific meanings. The ones that will be needed initially are:

- **discomfort** => the subjective discomfort felt by a seated passenger due to vehicle ride motions.
- **discomfort-estimate** => a single number intended to indicate how much **discomfort** an "average" passenger would feel if exposed to a given episode of passenger vehicle seat frame motion. (While some ride motion discomfort research has used measurements of accelerations at seat-surface to passenger-clothing interfaces, measurements on seat frames where they are bolted to floor beams is the most practical choice for ongoing measurements and particularly for those noted in sections 2.3 and 2.4.
- **discomfort-formula** => a numerical recipe for processing a segment from a digital recording of passenger vehicle seat frame accelerations to obtain a corresponding **discomfort-estimate**.
- **discomfort measurement procedure**, abbreviated as **DMP** => a procedure for recording passenger vehicle seat frame acceleration episodes and using a stated **discomfort-formula** to obtain corresponding **discomfort-estimate**s.

2. Practical Uses for a Discomfort Measurement Procedure (DMP)

2.1. A DMP can assist in procurement of new rail passenger vehicles.

The irregularities in the geometry of any railroad track are random and complex and change with time. It is on such track that a new vehicle will be expected to afford good passenger ride quality. The track on which a new vehicle will be required to pass ride quality acceptance tests should be typical of the "roughest" track over which the vehicle is expected to carry passengers. Its exact geometry cannot be stated at the time the vehicle specifications are published, so it is not practical to specify **discomfort-estimate** values that the new vehicles should not exceed. However, the procurement specifications can designate an existing vehicle that the new car contractor can study and that is to serve as a standard of comparison. It can then be required that when the new vehicle and the comparison vehicle are both run according to a specified schedule over a specified section of track whose condition will meet the applicable geometric standards, the **discomfort-estimate**s generated by the new vehicle may not exceed a stated multiple of the corresponding **discomfort-estimate**s generated by the reference vehicle.

2.2. The discomfort-formula of a DMP can assist in the design of a new vehicle.

The concept here is that a **DMP**'s **discomfort-formula** can be employed during the design of a new surface transport passenger vehicle to tune resonant frequencies and suspension damping rates to minimize passenger **discomfort**. Internet searches on phrases such as "rail vehicle ride comfort analysis" can find numerous articles describing such studies. Among them are: Satari et al (2022) [1], Herrero (2013) [2], Dumitri & Stănică (2021) [3], Dumitriu & Cruceanu (2017) [4], and Dižo et al (2021) [5].

2.3. A DMP can be used to help prioritize passenger vehicle maintenance.

Ride **discomfort** to which passengers are subjected in passenger rail service can arise from defects in vehicle condition. Such defects in particular cars can be discovered when their **discomfort-estimate** s are compared with averages for the fleet. Some general effects of wear and tear over time can be recognized by looking at changes in a fleet average **discomfort-estimate** over time, but in this case possible changes in track condition with time must also be considered. In passenger services that do not employ conductors this use should be cost-effective. In a service where ride quality anomalies are systematically reported by conductors the cost-effectiveness of this use is open to question but may still be positive.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 February 2024 doi:10.20944/preprints202402.1363.v1

2.4. *A DMP can be used to help prioritize track maintenance.*

Ride **discomfort** to which railroad passengers are subjected in service can arise from local track defects. Such defects can be discovered when **discomfort-estimate**s are looked at as a function of track location. This application can provide a beneficial supplement to the basic track maintenance procedures that are in place to ensure safety, promote efficiency, and satisfy regulatory requirements.

3. Discomfort-formulas in Use and Their Inadequacies

3.1. *Discomfort-formulas for single axis pure sinusoidal motions*

The simplest kind of nonuniform motion is sinusoidal motion along or about a single axis. Procedures have been carried out to determine how **discomfort** felt by passengers exposed to such simple motions varies with frequency and with the choice of the axis of vibration or rotation.

The best-known reference where such results are set forth is the International Standards Organization's ISO 2631 - 1997 titled "Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration", Part - 1, "General requirements" [6], which will be referred to as just ISO 2631. This standard presents formulas and frequency dependent weighting factors for estimating the discomfort experienced by people exposed to single frequency, single axis sinusoidal accelerations. It also presents suggestions for estimating discomfort caused by more complex ride motions.

3.2. *Discomfort-formulas for complex motions*

Articles in the field of vehicle ride motion discomfort research commonly report estimation of relative discomfort using formulas defined in one or more of the following publications:

A) ISO 2631 Part 1 1997 [6], noted above. That standard has several other parts among which part 4 /cite[ISO 2631 Part 4][]BSISO26314 gives recommendations for estimation of discomfort engendered by ride motions of passenger rail vehicles.

B) British Standards Institution, BS 6841, Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock (1987) [7]. This elaborates on ISO 2631 with a British perspective.

C) BS EN 12299:2009, Railway applications - Ride comfort for passengers. Measurement and evaluation [8] is the English language version of a European standard. EN 12299 generally follows the recommendations in ISO 2631 but supplements them with additional detailed advice about how to record and process data. Illustrations of processing called for in EN 12299 can be seen in slides of a talk given in 2016 by Bjorn Kufver [9].

D) Sperling, "Contribution to the evaluation of ride comfort in rail vehicles" [10]. This publication appeared before the others, is different in detail but similar in approach, and remains popular in a number of countries.

Copies of the first three of these standards are offered for sale at fairly high prices. A reader who does not have access to the standards themselves can find summaries of their basic formulas in several of the references cited below such as Wawryszczuk et al (2023) [11] and Dumitriu & Leu (2018) [12].

3.3. *How current discomfort-formulas conceptualize ride motion*

The above four publications all approach ride motion discomfort under the influence of two main ideas.

The first is that when dealing with oscillatory phenomena it is customary to resolve them into their sinusoidal Fourier components. It is relatively simple to expose test subjects to sinusoidal motions and to record their judgments about the degree of discomfort that those oscillatory motions engender. Such results are well attested, stable over time, and widely accepted. Curves documenting the way that human sensitivity to sinusoidal motions varies with frequency for each choice of axis of translation or rotation are documented in ISO 2631 and in standards that are based thereon.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 February 2024 doi:10.20944/preprints202402.1363.v1

The second is the assumption that human response to an oscillatory motion as a whole can be satisfactorily estimated by the sum of the responses that would be engendered by each of the suitably weighted spectral components of that motion. The components are typically grouped into 1/3rd octave bands.

In line with those two ideas, these four standards begin their evaluation of a recorded ride motion by Fourier analyzing its acceleration signals into frequency bands. They then multiply the amplitude of each spectral component by a frequency and axis dependent weighting factor, raise each weighted spectral component to a stated exponent, and sum the results for all the spectral components.

As an example, ISO 2631-1997 Part-1 clause 6.1 calls for calculation of a basic single axis frequency weighted RMS acceleration measure defined as

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2(t)dt\right]^{1/2}$$

where $\mathrm{a_w(t)}$ is a modified time dependent linear or rotational acceleration wave form constructed from the Fourier components of the acceleration recording by multiplying each component by a weight appropriate for its axis and frequency. (When, as here, the square of the signal is being averaged, the result would be calculated in the frequency domain by summing the squares of the weighted Fourier components to save the step of converting from the frequency domain back to the time domain.)

At the same time, some of those standards suggest alternate formulas for motions that are far from sinusoidal. For instance, Clause 6.3 begins with:

"In cases where the basic evaluation method may underestimate the effects of vibration (high crest factors occasional shocks, transient vibration), one of the alternative measures described below should also be determined - the running r.m.s. or the fourth power vibration dose value."

Those alternate methods are given in clauses 6.3.1 and 6.3.2.

3.4. *Evidence that currently used discomfort-formulas can be unrealistic*

Papers by Araújo et al (2016) [13], Kaneko, Hagiwara, and Maeda (2005) [14], Maeda and Mansfield (2006) [15], and Maeda, Mansfield, and Shibata (2008) [16] describe investigations and comparison of results with the recommendations in ISO 2631 and conclude that those recommendations do not correlate very well with perceived discomfort caused by some motions that are not single axis and single frequency. Maeda, Mansfield, and Shibata (2008) [16] and Maaeda and Mansfield [17] also report that subjective responses to broad-band random ride motions correlate better with the RMS type measures defined in ISO 2631 if the frequency dependent spectral weightings recommended therein are omitted.

Plewa et al (2012) [18] reports that for seat accelerations experienced by operators of some forestry and mining vehicles the levels of discomfort reported by the operators showed almost no relationship to the discomfort scores calculated according to ISO 2631. The ride motions of that study are more abrupt and more uncomfortable than those normally encountered in even the least comfortable passenger rail vehicles.

4. Establishing a Framework for Evaluating Discomfort-formulas

4.1. *A logical approach*

The papers referenced in section 3.4 show that the ride measures commonly in use yield results that disagree more or less with passenger perceptions of discomfort due to ride motions encountered in daily life. In published investigations into how to measure ride quality, the general approach has been to consider one or more published or proposed **discomfort-formula**s and to compare its or their scorings of laboratory or revenue service ride motions with test subject scorings of the same motions.

In contrast to that traditional approach to studying **discomfort-formula**s, it would be both more logical and more effective to assemble a collection of digitally recorded samples of diverse

 doi:10.20944/preprints202402.1363.v1

representative episodes of uncomfortable real life ride motions and to adjust the amplitudes of those samples so that, on average, test subjects considered them all equally uncomfortable. With such an equal-discomfort ride episode collection available, the realism of any prospective **discomfort-formula** could easily be determined using just a personal computer. All that would be required would be to apply the **discomfort-formula** to each ride of the equal-discomfort collection and calculate the dispersion of the resulting scores. The smaller the dispersion, the more realistic the **discomfort-formula** . If the **discomfort-formula** had adjustable parameters, they could easily be optimized to minimize the dispersion of the scores on that collection.

In order to carry out this program there needs to be a procedure for bringing the rides of the initial collection to a common level of discomfort as perceived on average by test subjects. Such a procedure using seats attached to a motion simulating shaker table is spelled out below.

As far as the author is aware the only paper that has proposed this approach and explained how to go about it is the 1975 paper by Klauder and Clevenson [19]. That paper did not get much attention, perhaps because it was in the proceedings of a symposium rather than in a journal, was before the days of the internet, and started out with some non-essential theory that might have discouraged further reading. The **goal** of this paper is to give the core of that paper a second hearing and hopefully persuade the vehicle ride quality community of its utility.

4.2. *Additional terminology*

Use will be made of a few additional terms as follows:

- **sample** => a multi-channel digital recording of a short episode of passenger vehicle seat frame accelerations that cause significant **discomfort**.
- **sample-set** => a collection of **sample**s that are diverse representative examples of seat base acceleration episodes recorded on one or more passenger surface transport operations.
- **normalized-set** => a **sample-set** whose **sample**s have had their signal amplitudes scaled so that an "average" passenger would feel that they all caused the same level of **discomfort**.
- **scatter** => a value such as the dispersion or mean absolute deviation indicating the extent to which the **discomfort-estimate**s obtained by applying a **discomfort-formula** to the **sample**s of a **normalized-set** differ from their average.

4.3. *Assembling a sample-set*

The first step is to select the revenue services on which to make field recordings. The project will presumably aim to establish a framework for qualifying or developing a **discomfort-formula** for some specific type of passenger service. It might then seem logical to limit field recording to revenue services of that type. However, if additional recordings are made on other types of service, then it might be possible to show that a **discomfort-formula** optimized for the target type of service would also give realistic scores to disturbing ride motions found on other types of service.

Note at this point that when accelerations are reproduced by the motion simulator they are realized at its floor to which seat bases are attached. Thus the accelerations that need to be recorded to characterize revenue service ride motions are those of seat frame bases that are attached to the vehicle floor. That way they will correspond to accelerations that are reproduced by the ride motion simulator.

When contemplating the possibility that a **discomfort-formula** developed for one type of revenue service might give equally realistic scores when used with another type of service, account must be taken of the cushioning role of seating upholstery. Accelerations experienced by passengers seated on soft upholstery in long distance services will generally be lower than the associated seat base accelerations. In contrast, passengers on hard plastic seating in rapid transit services will feel the full brunt of seat frame accelerations. It would therefore seem impossible in principle for a **discomfort-formula** optimized for a service with hard seating to be the same as one optimized for a service with soft seating.

Related to the foregoing, it is important that the seating used on the motion simulator have cushioning and seat frame mechanical resonances that are representative of the target type of revenue service.

The transient and oscillatory motion signals that can be recorded are the linear accelerations in the vertical, lateral, and longitudinal directions and the angular yaw, pitch, and roll accelerations. As a practical matter, when dealing with long wheel base vehicles typically used for passenger rail service, the yaw and pitch accelerations are usually ignored leaving just the linear and roll accelerations. The longitudinal and roll accelerations may sometimes also be ignored.

The linear acceleration signals are typically band pass filtered to retain the spectral content between 0.4 or 0.5 Hz and 80 or 100 Hz with filtering that minimizes wave form distortion. This filtering can be incorporated in the recording process or applied after recordings have been gathered.

It is desirable for the the field recording instrumentation to include a voice channel and a channel for documenting the vehicle's location. On the voice channel the person conducting the recording can describe notable motion disturbances as they are encountered.

The initial field recordings of acceleration signals are likely to have durations in the range of 5 minutes to two hours. From the field recordings it is necessary to select episodes lasting for a chosen duration between 6 and 11 seconds that will constitute the **sample**s to be gathered into the **sample-set**. They should include examples of as many different types of ride disturbance as practical. The focus should be on selecting the most uncomfortable episodes. Having **sample** durations in the indicated range is to facilitate A-B comparisons using the motion simulator. The amount of disturbing motion should be relatively constant throughout each **sample**. Episodes of short duration abrupt disturbance may need to be duplicated to form **sample**s with the chosen length and relatively steady discomfort. Field recording voice commentary, location information, and computer display of acceleration wave-forms can help the person deciding where each **sample** should begin.

4.4. Converting a sample-set to an equal discomfort normalized-set

We come now to the question of how to convert a **sample-set** into an equal-discomfort **normalized-set**. Much of the material of this section is adapted from Klauder and Stevenson (1975) [19].

The author's thinking in this area was stimulated by a 1970 paper by C. Ashley [20]. Ashley used two side-by-side "shaker tables" as motion simulators and had test subjects stand alternately on:
A) a table driven by a broad band random signal and
B) a table driven by a sinusoidal signal.
As subjects experienced alternately the random motion and the sinusoidal motion they adjusted the amplitude of one of the signals to get the discomfort of the two motions to be the same. This was done for a sequence of sinusoidal frequencies in two stages. Ashley's paper gives details. Ashley's procedure constitutes a significant improvement over procedures which seek to have subjects verbally compare ride motions which differ in discomfort, and it is a model for that aspect of the procedure advocated here. Ashley referred to this technique of data collection as "cross matching".

Some of the concepts employed in this section are mentioned in Maeda and Mansfield (2006) [15]. Two later papers that describe A-B comparisons are Strandemar (2005) [21] and Zong et al (2000) [22]

It may be feared that singling any one motion out as the standard of reference for all of the others could cause some bias. (For example, repeated exposure to the reference motion could cause test subjects to become unduly sensitive to it.) Partly from fear of bias, and partly because of aesthetic dissatisfaction with the lack of symmetry if one motion is singled out as a standard, we suggest using the following moderately symmetrical procedure.

The procedure calls for use of a capable vehicle ride motion simulator on whose platform is mounted a seat module that is typical of the revenue service for which the **normalized-set** is being prepared. Electronic means need to be in place to:

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 February 2024 doi:10.20944/preprints202402.1363.v1

- alternately apply signals of **sample**s A and B to the motion simulator.
- allow test subjects to vary the amplitude of **sample** B.
- illuminate a sign to keep the subjects aware of which **sample** they are currently experiencing.

The test subjects are instructed that as they are exposed alternately to **sample**s A and B they are to adjust the gain of **sample** B to make its discomfort match that of **sample** A. In the testing reported in [19] each **sample** was presented for 10 seconds, and there was a 2 second pause between alternate **sample**s.

We expect that test subjects will sense motions with a little more acuity if the motion amplitudes are larger rather than smaller. Therefore, when two **sample**s are to be compared, We suggest that the **sample** with the larger RMS amplitude be assigned as **sample** A. Then, to bring about equal discomfort a test subject will tend to increase the gain with which **sample** B is presented. This approach sacrifices some symmetry with the expectation of slightly improving data collection consistency. Other researchers might prefer different approaches. Pursuing our preferred approach, label the **sample**s from 1 to n in order of increasing RMS amplitude. For each pair of **sample**s being compared via the simulator, present the one with the higher index as A.

Let n denote the number of **sample**s of the **sample-set**. Let g_{ij} denote the gain value that when applied to **sample** j makes its discomfort equal to that of **sample** i. (That is inverse to the definition used in reference [19]) Moreover, define g_{ij} as a true gain factor that is not effected by inconsistencies in test subject responses. g_{ii} always equals 1 and would be of no interest except that $g_{nn} = 1$ plays a role below in the formula for the geometric mean of a group of gain factors. Thus, we are dealing with the $n(n-1)/2$ (ij) combinations in which $i > j$. However, the g_{ij} set possesses only $(n-1)$ degrees of freedom; namely all the g_{ij} values can be determined from the values $g_{n1}, g_{n2}, g_{n,n-1}$ via the relations, $g_{ij} = g_{in} g_{nj} = g_{nj}/g_{ni}$. Because human response to change of amplitude cannot be expected to be fully linear, the equality $g_{in} = 1/g_{ni}$ that was just asserted is not strictly true except in the limit that g_{in} tends to 1. We are ignoring that nicety but at the same time recommend that there be at least two rounds of A - B comparisons on the motion simulator and that results from one round be used to bring all the **samples** close to a common level of discomfort before carrying out the next round.

Coming back to the human subject responses that the testing will yield, let r_{ij} denote the average of the gains assigned by test subjects to **sample** j to make it as uncomfortable as **sample** i during a given round of simulator comparisons. In accordance with the way that we choose to present **sample** s to the subjects, all the r_{ij} values will have $i > j$. What we want to find is the set of g_{ij} values that provides the best fit to the empirical r_{ij} values. The variables to be determined are $g_{n1}, g_{n2}, \cdots g_{n,n-1}$, which we will abbreviate as $g_1, g_2, \cdots g_{n-1}$. ($g_n = 1$ by definition.) We find the best fit by minimizing an error function that measures the extent to which the g_i values fail to be consistent with the r_{ij} values. For the error function to be minimized we take

$$E = \frac{1}{2} \sum_{i>j}' \left[\frac{g_{ij}}{r_{ij}} - 1 \right]^2 = \frac{1}{2} \sum_{i>j}' \left[\frac{g_{in} g_{nj}}{r_{ij}} - 1 \right]^2 = \frac{1}{2} \sum_{i>j}' \left[\frac{g_{nj}}{g_{ni} r_{ij}} - 1 \right]^2 = \frac{1}{2} \sum_{i>j}' \left[\frac{g_j}{g_i r_{ij}} - 1 \right]^2$$

where the prime over the summation symbol indicates here that a given (ij) pair is not to be included in the sum if the corresponding r_{ij} happened not to be measured.

The g_i values which minimize E are found with the help of a simple computer code which uses Newton's method and iterates until the partial derivatives, $\frac{dE}{dg_i}$, are all close to zero.

With the $g_{ni} = g_i$ values in hand, each of the **sample**s can have its discomfort level adjusted to match that of **sample** n. To accomplish that one simply multiplies the signal values of **sample** i by g_i. The **sample**s as thus adjusted will constitute a **normalized-set**. The mean of the RMS values of the signals of that set will greater than the corresponding mean for the original **sample-set**.

The geometric mean of the factors by which the **sample**s of the foregoing **normalized-set** will have had their amplitudes adjusted is $g_{mean} = [g_1\, g_2 \cdots g_n]^{1/n}$. The **normalized-set** whose members

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 February 2024 doi:10.20944/preprints202402.1363.v1

have a comfort level matching the mean of the comfort levels of the **sample**s of the original **sample-set** is obtained by multiplying each original **sample** i not by g_i but rather by g_i/g_{mean}.

As noted above, determination of the g_i values should be accomplished by carrying out two or three rounds of A-B comparisons with each round serving to bring all of the ride samples closer to a common level of discomfort. That will make adjustments in subsequent stages smaller and will thereby minimize inconsistencies which can be expected due to non-linearity in test subject responses. Inconsistencies due to human variability will remain.

As a detail of procedure, the order in which **sample** i - **sample** j pairs are presented to the test subjects should be randomized. Techniques from the field of statistical design of experiments would enable optimization of the schedule of comparisons.

5. Conclusion: How discomfort-formulas can be evaluated

Given a **normalized-set** and a prospective **discomfort-formula** the number that indicates the realism of the **discomfort-formula** with respect to the type of revenue service represented by the **normalized-set** is the **scatter** of the **discomfort-estimate**s obtained when the **discomfort-formula** is applied to each of the **sample**s of the **normalized-set**. The lower the **scatter**, the more realistic the **discomfort-formula**. As noted previously, that same procedure can be used to optimize any adjustable parameters present in a prospective **discomfort-formula**.

6. Discussion

Reference [19] includes an example of use of the **normalized-set** described therein to optimize one hypothetical **discomfort-formula** that included 14 adjustable parameters. Even when optimized That particular **discomfort-formula** did not give realistic results. A little subsequent exploration found that an exceedance type **discomfort-formula** [Catherines, Clevenson, und Scholl (1972) [23], Vinje (1972) [24]] gave very consistent scores to those **sample**s of the **normalized-set** that represented motion episodes recorded in revenue services. However, it did poorly on the one **sample** that consisted of an artificial sinusoidal motion. That subsequent exploration was not published, and unfortunately, organizational and computer resource changes that occurred shortly after that work was done lead to loss of the underlying **normalized-set** data.

The poor performance of the exceedance count style formula on the sinusoidal motion suggests by hindsight that in order to have comprehensive applicability a **discomfort-formula** might need to begin with a Fourier decomposition to identify the possible presence of a strong sinusoidal component and to handle such a component differently than the rest of the motion.

Hopefully some research group will take up the procedure described herein so that more concrete progress can be made. It would be most helpful if ISO 2631 could be extended to document some open access downloadable **normalized-set**s representative of the major types of commercial passenger ground transport. That would establish a basis for development and validation of realistic **discomfort-formula**s.

Funding: “This research received no external funding”.

Acknowledgments: The author thanks Prof. Setsuo Maeda for his encouragement.

Conflicts of Interest: “The author declares no conflicts of interest.”.

Abbreviations

The following abbreviations are used in this manuscript:

DMP discomfort measurement procedure

References

1. Graa, M.; MohamedNejlaoui, M.; Houidi, A.; Affi, Z.; Romdhane, L. Mechatronic Rail Vehicle Design Based on the Passenger Comfort. *JOURNAL OFEngineering Science andTechnology Review* **2016**, *9*, 176–186.
2. HERRERO, ADRIÁN. Towards Optimization of a High Speed Train Bogie Primary Suspension. Master's Thesis in the International Master's programme Applied Mechanics, CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden, 2013.
3. Dumitriu, M.; Stănică, D.I. Study on the Evaluation Methods of the Vertical Ride Comfort of Railway Vehicle—Mean Comfort Method and Sperling's Method. *Applied Sciences* **2021**, *11*. doi:10.3390/app11093953.
4. He, Y. Design of Rail Vehicles with Passive and Active Suspensions Using Multidisciplinary Optimization, Multibody Dynamics, and Genetic Algorithms. PhD thesis, 2003.
5. Dižo, J.; Blatnický, M.; Gerlici, J.; Leitner, B.; Melnik, R.; Semenov, S.; Mikhailov, M.; Kostrzewski, M. Evaluation of Ride Comfort in a Railway Passenger Car Depending on a Change of Suspension Parameters. *Sensors (Basel)* **2021**. doi:10.3390/s21238138.
6. ISO 2631-1:1997(En) Mechanical Vibration and Shock — Evaluation of Human Exposure to Whole-Body Vibration — Part 1: General Requirements, 1997.
7. BS 6841:1987 Guide to Measurement and Evaluation of Human Exposure to Whole-Body Mechanical Vibration and Repeated Shock, 1987.
8. BS EN 12299:2009 Railway Applications. Ride Comfort for Passengers. Measurement and Evaluation, 2009.
9. Kufver, B. EN12299-Evaluation of Ride Comfort For Rail Passengers (Alternative To ISO2631). 2016.
10. Sperling, E.; Betzhold, C. Beitrag Zur Beurteilung Des Fahrkomforts in Schienenfahrzeugen (Contribution to the Evaluation of Ride Comfort in Rail Vehicles). *Glasers Annalen* **1956**, *80*, 314–320.
11. Wawryszczuk, R.; Kardas-Cinal, E.; Lejk, J.; Sokołowski, M. Methods of Passenger Ride Comfort Evaluation—Tests for Metro Cars. *Sensors (Basel)* **2023**, *23*, 5741 ff. doi:10.3390/s23125741.
12. Dumitriu, M.; Leu, M. Correlation between Ride Comfort Index and Sperling's Index for Evaluation Ride Comfort in Railway Vehicles. *Applied Mechanics and Materials* **2018**, *880*. doi:10.4028.
13. Araújo, P.; Duarte, M.L.M.; Horta, F.; Penna de Carvalho, L.A.; Arenales, G.G.R. The Effect of Exposure Duration on Whole-Body Vibration Comfort. American Conference on Human Vibration 2010, 2016.
14. Kaneko, C.; Hagiwara, T.; Maeda, S. Evaluation of Whole-Body Vibration by the Category Judgment Method. *Industrial Health* **2005**, *43*, 221–32. doi:10.2486/indhealth.43.221.
15. Maeda, S.; Mansfield, N. Evaluation of Whole-Body Vibration Comfort. 2006.
16. Maeda, S.; Mansfield, N.J.; Shibata, N. Evaluation of Subjective Responses to Whole-Body Vibration Exposure: Effect of Frequency Content. *International Journal of Industrial Ergonomics* **2008**, *38*, 509–515.
17. Mansfield, N.J.; Maeda, S. Subjective Ratings of Whole-Body Vibration for Single- and Multi-Axis Motion. *The Journal of the Acoustical Society of America* **2011**, *130*, 3723–3728. doi:10.1121/1.3654014.
18. Plewa, K.M.; Eger, T.R.; Oliver, M.L.; Dickey, J.P. Comparison between ISO 2631–1 Comfort Prediction Equations and Self-Reported Comfort Values during Occupational Exposure to Whole-Body Vehicular Vibration. *Journal of Low Frequency Noise, Vibration & Active Control* **2012**, *31*.
19. Klauder Jr, L.T.; Clevenson, S.A. Evaluation of Ride Quality Measurement Procedures by Subjective Experiments Using Simulators. 1975 Ride Quality Symposium; NASA, Washisngton, DC: Williamsburg, VA, USA, 1975; Vol. NASA TM X-3295, pp. 217–265.
20. Ashley, C. EQUAL ANNOYANCE CONI OURS FOR THE EFFECT OF SINUSOIDAL VIBRATION ON MAN. THE SHOCK AND VIBRATION BULLETIN; Office of The Director of Defense Research and Engineering: Air Force Academy. Colorado., 1970; Vol. 41, p. Part 2.
21. Strandemar, K. On Objective Measures for Ride Comfort Evaluation. Technical Licentiate degree, Royal Institute of Technology, STOCKHOLM, SWEDEN, 2005.
22. Zong, C.; Guo, K.; Guan, H. Research on Closed-Loop Comprehensive Evaluation Method of Vehicle Handling and Stability. SAE 2000 World Congress. SAE International, 2000. doi:10.4271/2000-01-0694.
23. Cutherines, J.J.; Cleuenson, S.A.; Scholl, H.F. A METHOD FOR THE MEASUKEMENT AND ANALYSIS OF RIDE VIBRATIONS OF TRANSPORTATION SYSTEMS. Technical Report NASA TN D-6785-, Lungley Research Center, 1972.

doi:10.20944/preprints202402.1363.v1

24. Vinje, E.W. ANALYTICAL AND EXPERIMENTAL EVAUJATION OF PROPOSED RIDE COMFORT CRITERIA. SYMPOS!0M ON VEHICLE RIDE QUALITY; NASA Langley Research. Center: Hampton, Va. 23365, 1972; Vol. NASA TM X-2620, pp. 115–129.