# Wed 7.1 Severity of Road - Railroad Transport and Time Compression of Vibration Test

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## Abstract

In this work, we study the distribution of the acceleration levels of two modes of transport, European road and railroad. Then, we estimate the severity of these transports from the law of distribution of the vibratory signal, by calculating different indicators of severity /1/.

We supplement this work with a study led by D. Shires /2/. This paper deals with the time compression of broadband random vibration tests. Time compression is based on Basquin relation of fatigue. Generally, test intensity is increased and a value of k=2 is used (typically used in packaging) to reduce test time. We study the evolution of distribution of acceleration levels for different value of k and the severity associated to these new distributions. We shall present results obtained for real transports and for calculated distributions and we shall discuss results.

## Experimental set-up

For this study we record the vibration levels of two types of transport: rail transportation and truck transportation. Transportations are realized in Europe.

The train transportation is about 550 kilometres and the active journey duration is 9 hours and 59 minutes. The truck transportation is about 180 kilometres and the active journey duration is 2 hours and 56 minutes.

The same pallet equipped with a Lansmont saver 3X90 is used for both transportations. This pallet weighs about a ton. Acceleration data recorder is mounted on the wooden pallet in order to have the input signal. Figure 1 shows the installation of equipment on the pallet. On the scheme of the complete pallet the recorder is represented in red.

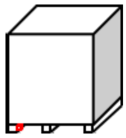

**Figure 1.** Scheme of the pallet and installation of data recorder

The data capture set-up is the following for both transportations:

| | |
|---|---|
| **recorder** | Lansmont 3X90 saver |
| **Measurement axis** | Vertical axis |
| **sampling frequency** | 500 Hz |
| **sample duration** | 2.048 s |
| **sampling interval** | 1 min |
| **Data retention mode** | Max overwrite |
| **Memory allocation** | 11881 events |
| **Full scale** | 20 G |
| **Filter** | 500 Hz |

**Table 1.** Data capture set-up

The truck transportation is realized by a vehicle with air ride suspension. The truck is fully loaded with same type of pallet. The measurement of vibration levels in the truck is located on pallet over rear (Figure. 2).

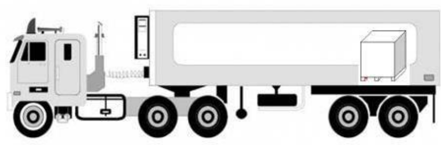

**Figure 2.** Set-up of the truck transportation and measurement location

For the train transportation, the pallet is located in the middle of the wagon. The wagon is fully loaded with the same type of pallet (Figure 3).

**Figure 3.** Location of the pallet in the train transportation

## Data and results

First we study and compare the severity of two mode of transportation.The data obtained from recorder were analyzed to determine the distribution of acceleration levels. We use the Gaussian and modified Gaussian to fit data. As S. Otari [1] shows it, modified Gaussian was the most relevant with the least number of parameters.

Here is the expression for the modified Gaussian fit:

$$p(x) = a\, exp\left[-\frac{1}{2}\left(\frac{|x-x_0|}{b}\right)^c\right]$$

Severity of the two modes of transport, road and railroad, can be compare with the root mean square value of the acceleration signal (RMS) σ. To characterize at best the transports, we used new indicators of severity available thanks to the model developed by S.OTARI. This model analytically calculate the full width at half maximum (FWHM) on the distribution curve of acceleration levels. So, we can calculate the FWHM indicator for a gaussian and a modified gaussian distribution. Ratio of the two gives an indicator of the transport severity, *S* :

$$S=\frac{b}{\sigma}(2\ln 2)^{\frac{1}{c}\;\frac{1}{2}}$$

Values of indicators of severity of the two modes of transport are presented in table 2. It shows that the railroad transport is tougher than the road transport.

**Table 2.** Indicators of transport severity

| | road | Rail road |
|---|---|---|
| **σ (g)** | 0.073 | 0.159 |
| **FWHM $_{\text{modified Gauss.}}$ (g)** | 0.106 | 0.276 |
| **FWHM $_{\text{Gaussian}}$ (g)** | 0.172 | 0.375 |
| ***S*** | 0.61 | 0.73 |

We can also compare the severity of the transport with the following mathematical model; it calculates the probability of acceleration levels greater than a fixed threshold (With *X* : acceleration level and *s* : acceleration threshold):

$$P[|X|\geq s]=\int_{-\infty}^{-s}p(x)dx+\int_{+s}^{+\infty}p(x)dx$$

For an acceleration threshold of 0.2 g, the probability to have extreme levels (> 0.2 g) for the railroad is about 20%. It is much more important than the probability for a road, which is 1.4 %.

The association of these indicators, i.e. σ (the root mean square value), S (the severity rate with regard to Gaussian of same σ value) and P[|X| ≥ s] (probability of exceeding the threshold), gives relevant information to evaluate the severity of transport in complement of usual frequential analyzes.

## Severity and time compression

The first part of this study allows us to evaluate the severity of a transport. It is important to know and characterize logistics roads in order to accurately simulate them in the laboratory. Many researchers have worked to improve simulation method of vibration test.

To complete this work, we apply a method developed by D.SHIRES /2/ which studies the contribution of fatigue of each class of acceleration Grms. From our data, the Grms values of each event are calculated for truck and train transportation. Figures 4 shows distribution of Grms for truck and train transportation.

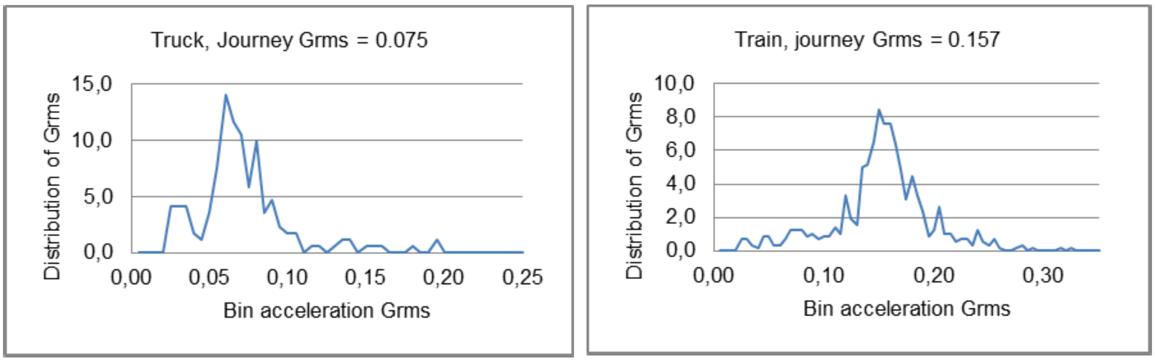


**Figure 4.** Distribution of Grms of truck transportation and train transportation

D.SHIRES /2/ proposes:

$$T_{test} = \sum_{i=1}^{n} t_i \left(\frac{a_i}{a_{test}}\right)^k$$

With : $t_i$ and $a_i$ which are respectively the duration and the acceleration Grms of each class representing the whole journey. $T_{test}$ is the fatigue life at acceleration test $a_{test}$.

This process will give us new distribution of acceleration Grms levels. It is possible to estimate the fatigue contribution of each class of acceleration Grms for different values of k. From this formula we find the expression of the new distribution, $\alpha_{i\,test}$:

$$\alpha_{i\,test} = \frac{t_{i\,test}}{T_{test}} = \frac{t_i \left(\frac{a_i}{a_{test}}\right)^k}{T_{test}} = \frac{t_i \left(\frac{a_i}{a_{test}}\right)^k}{\sum_{j=1}^{n} t_j \left(\frac{a_j}{a_{test}}\right)^k} = \frac{t_i}{\sum_{j=1}^{n} t_j \left(\frac{a_j}{a_i}\right)^k} = \frac{\frac{t_i}{T_{trajet}}}{\sum_{j=1}^{n} \frac{t_j}{T_{trajet}} \left(\frac{a_j}{a_i}\right)^k} = \frac{\alpha_i}{\sum_{j=1}^{n} \alpha_j \left(\frac{a_j}{a_i}\right)^k}$$

Figure 5 and 6 show respectively the fatigue contribution (%total journey fatigue) by bin acceleration Grms for k=2, 3, 4 and 5 for the truck and the train transportation. Distributions of Grms are shown in the graph for comparison.

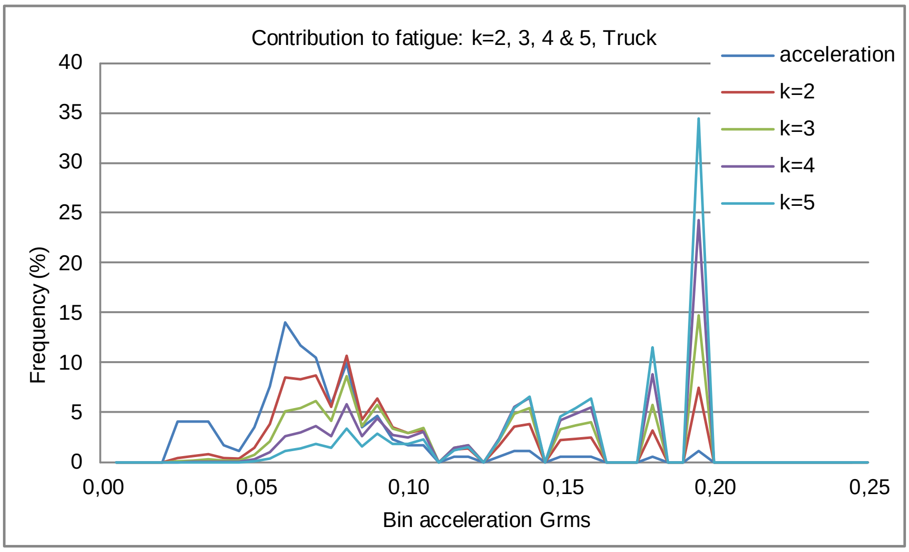


**Figure 5.** Distribution of Grms and fatigue contribution by bin acceleration, truck

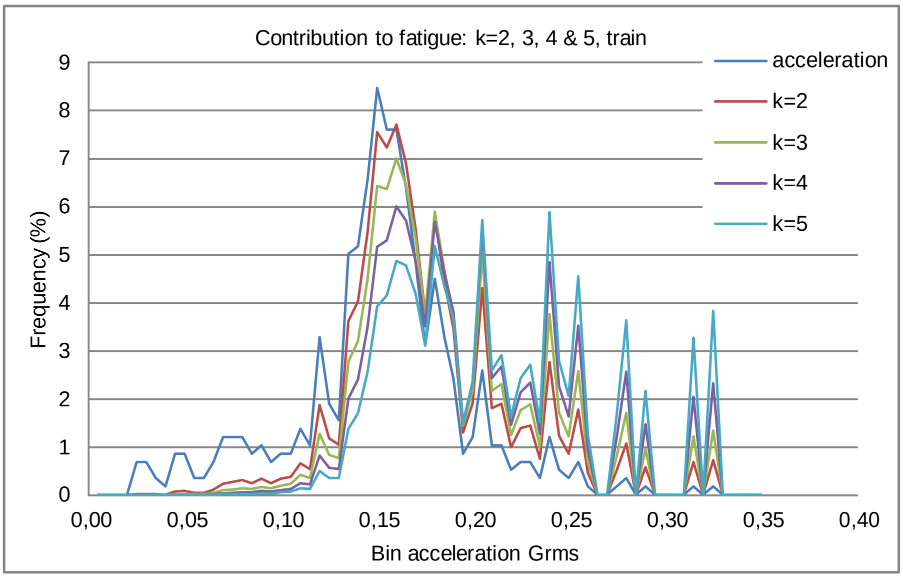


**Figure 6.** Distribution of Grms and fatigue contribution by bin acceleration, train

We can see in these graphs that the more the value of k increases, the more the high levels contribute to fatigue of the system (least for the lower levels). Once the new distributions obtained, we calculate the Grms values associated:

$$G_{rms} = \sqrt{\sum_i \alpha_i\, a_i^2}$$

The Grms values are presented in table 3.

**Table 3.** Grms value associated to the different distributions

| Distribution of Grms | TRUCK, Grms value | TRAIN, Grms value |
|---|---|---|
| Real transport | 0.075 | 0.157 |
| k=2 | 0.108 | 0.181 |
| k=3 | 0.127 | 0.192 |
| k=4 | 0.145 | 0.203 |
| k=5 | 0.159 | 0.216 |

In fact, the new distribution sets the Grms value of test. It now remains only one unknown value, the test time. It may be obtained by calculating the time compression factor, $\beta$.

$$\beta = \frac{T_{trajet}}{T_{test}} = \frac{{a_{test}}^k}{\sum_{i=1}^{n} \alpha_i {a_i}^k}$$

Table 4 presents the value of time compression factor considering the value of k for both transportations.

**Table 4.** Time compression factor considering k for truck and train transportations

| Distribution of Grms for | Time compression factor $\beta$ | |
|---|---|---|
| | Truck | Train |
| k=2 | 1.98 | 1.30 |
| k=3 | 3.51 | 1.59 |
| k=4 | 6.38 | 2.06 |
| k=5 | 10.70 | 2.84 |

The calculation of time compression factor, $\beta$, is coherent with what we expected. For example, if we take the truck transportation with k=2, the value of Grms is set at 0.108 and the time factor compression is set at 1.98. The real duration of the truck transportation is 2 h 56 min, with a time factor compression of 1.98, the duration of a test in a lab is about 1 h 30 min. The time compression factor $\beta$ varies from 1.98 to 10.7 for the truck when k varies from 2 to 5 while $\beta$ varies from 1.3 to 2.84 for the train. It is coherent with the indicators of severity found previously (0.61 for the truck and 0.73 for the train). Indeed, the severity of the train transportation is higher than the severity of the truck transportation : It seems reasonable to find a time test compression lower to simulate the train transportation.

This method sets the value of k, the Grms value and the duration of the test.

So, can we apply the new distribution in the lab from the PSD of our real transportation ? To try to answer this question, we realized tests on our vibration table by increasing the Grms value of our PSD in order to obtain the same Grms value corresponding to a severe distribution (k=2, 3...).

We take the distribution of train and truck for k=3 and we take the respective PSD to carry out our tests. We compare the distribution of Grms given by the distribution calculated for k=3 and the distribution of Grms given by the vibration table for an equivalent Grms. (Figure 7-8)

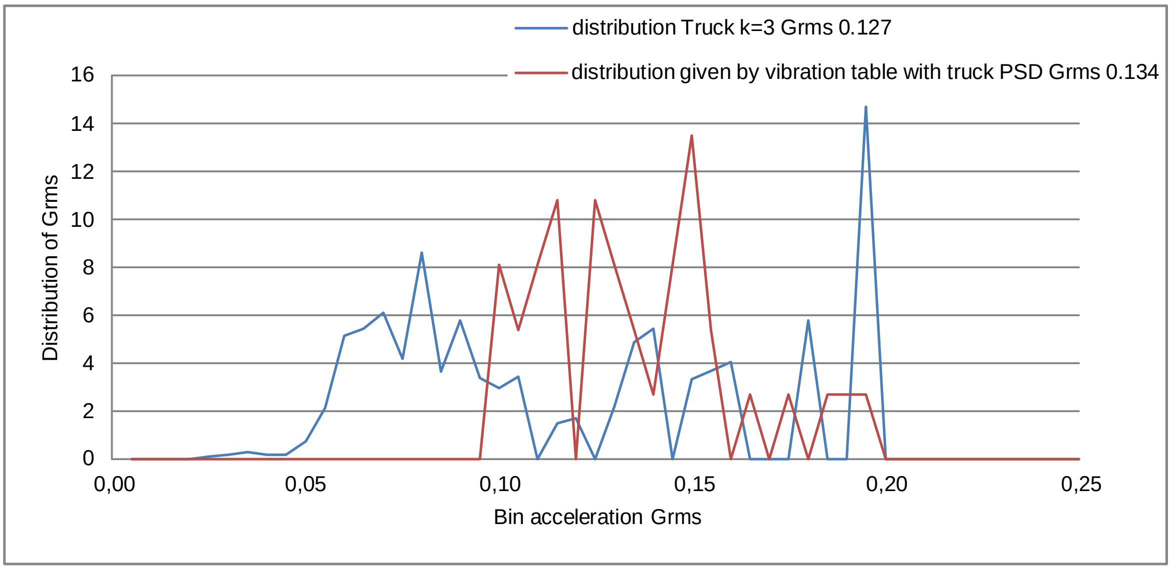


**Figure 7.** Comparison of distribution of Grms-Truck

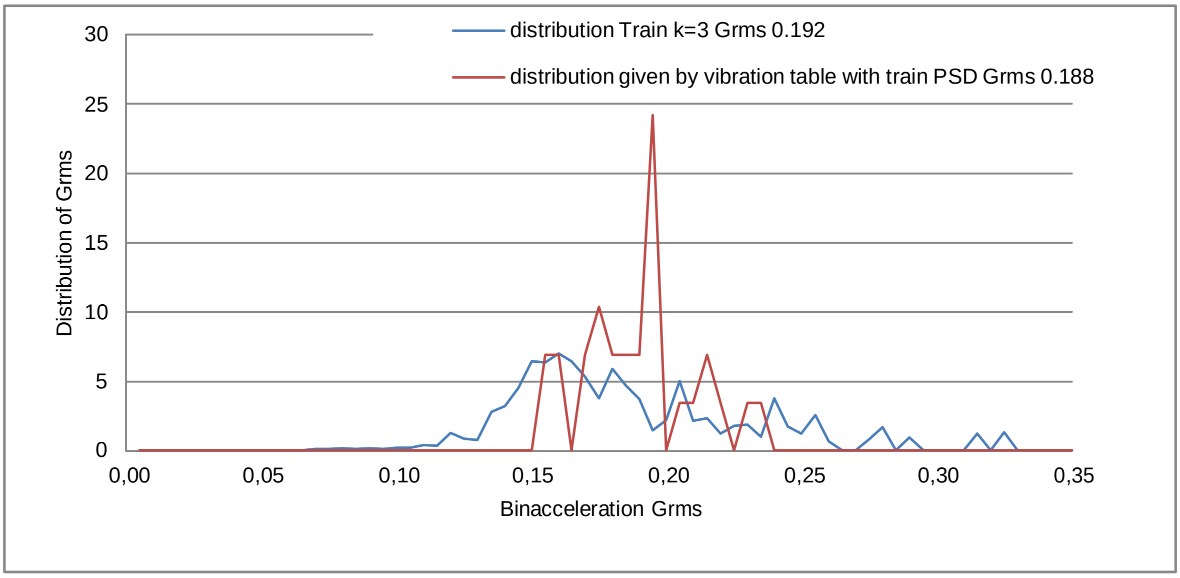


**Figure 8.** Comparison of distribution of Grms-Train

On these graphs, we observe that for both cases (truck and train) the distributions given by the vibration table did not match with distributions for k=3. This is even more pronounced for the truck.

It may be the construction of the signal, how to change the distribution of the vibration table (Gaussian and modified Gaussian distribution) ?

It may also be that the number of events given by the distribution table is too low.

But a random vibration signal obtained from a PSD of higher severity should provide a distribution of Grms similar to the distribution calculated theoretically. It is very likely that the difference obtained comes from excessive simplification of the process: acceleration levels are averaged by the calculation done with Grms and the calculation does not take into account the frequency distribution.

## Conclusion

In this work, we caracterize severity of transportations with new indicators. We study how to obtain distribution with a higher severity starting from the Basquin equation and how to reduce test time. However, we still have problem with the distribution of Grms.

The next step of this work is to develop a method allowing a calculation of factor of time compression robust.

## References


1. Otari S, Odof S, Nolot J.B, Vasseur P, Pellot J, Krajka N, Erre D, *Statistical Characterization of Acceleration Levels of Random Vibrations during Transport*, Packaging Technology and Science, 2011; 24(3), pp 177-188.

2. D. SHIRES, *On the Time Compression (Test Acceleration) of Broadband Random Vibration Tests*, Packaging Technology and Science 2011; 24; pp75-87.