On the Parameters that Influence Road Vehicles Vibration Levels

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As the magnitude of the problems associated with excessive packaging and waste is becoming increasingly evident, it is critical that packaging systems are designed using environmentally responsible materials and optimised such that the least amount of material is used without compromising product integrity. One clear way to limit the impact of packaging waste is to minimise the amount of packaging used in the first place by applying engineering optimisation and risk management principles. A compromise between the costs associated with excessive packaging and those related with product damage needs to be carefully balanced. For this to occur, the prediction of damage rates for various packaging scenarios must be accurate and this can only be achieved by ensuring that realistic representations of distribution environments can be predicted and reproduced using laboratory-based simulation.

Today, the main approach taken to design and validate packaging systems for distribution relies on various vibration test protocols such as those published in standards including ASTM D4169 and ISTA 2, 3 and 4 series. These protocols specify average vibration rms (root-mean-square) levels and corresponding durations which the product is to withstand. However, rms levels for specific road transport scenarios (vehicle type, suspension, road type etc.) are not always known and, in such cases, the generic rms values published in standards are used and often lead to the use of excessive packaging material.

With the introduction of easy-to-use vibration data recorders, significant amounts of road vibration data have been recorded and numerous studies on the rms levels of truck vibrations have been published. However, the results available to date are typically from specific scenarios and do not provide comprehensive comparisons with similar published work. This article brings together the available information on road transport vehicle vibration levels to statistically reveal the influence of important vehicle and road parameters, namely suspension type, road type, payload and vehicle type. In addition to published mean rms levels, 32 values from vibration data previously measured but unpublished by the authors were added to the set making a total of 170 mean rms values representing the broadest range of road transport conditions collated to date.

To allow for the analysis of parameters which may influence road transport vibration levels, the mean rms data set was categorised into three groups:

- Payload: Due to a lack of detailed information, payload was grouped as a proportion of weight capacity in two halves.
- Suspension type: Two broad suspension groupings were used (where suspension type at the front and rear of the vehicle differed, the rear suspension type was used):
    - Steel leaf
    - Air.
- Road type: Two broad road types were used (records with mixed major/minor roads were not included):
    - Minor roads: Metropolitan and minor roads.
    - Major roads: Main roads, arterial roads, highways and motorways.

Once the rms values were categorised a statistical approach based on the use of the three-parameter Weibull distribution (1) was used to analyse the data.

$$p(x) = \frac{2}{\eta^2}(x - x_0)\cdot\exp\left[-\left(\frac{x - x_0}{\eta}\right)^2\right] \quad \forall \begin{cases} x \in \mathbb{R} \\ x_0 \le x < \infty \\ \eta \in \mathbb{R}^+ \end{cases} \tag{1}$$

, where: *p(x)* is the probability density, η is the scale parameter and x_o is the location parameter.

The results from the study show that distribution of the mean rms vibration level of the overall data set can be described by the Weibull distribution with the parameters: $x_o = 0.20$, $\eta = 0.97$ and $\beta = 1.43$. Figure 1 shows this distribution, with P50 (50th percentile) representing the average rms vibration level for a typical journey and P95 an extreme case (95th percentile).

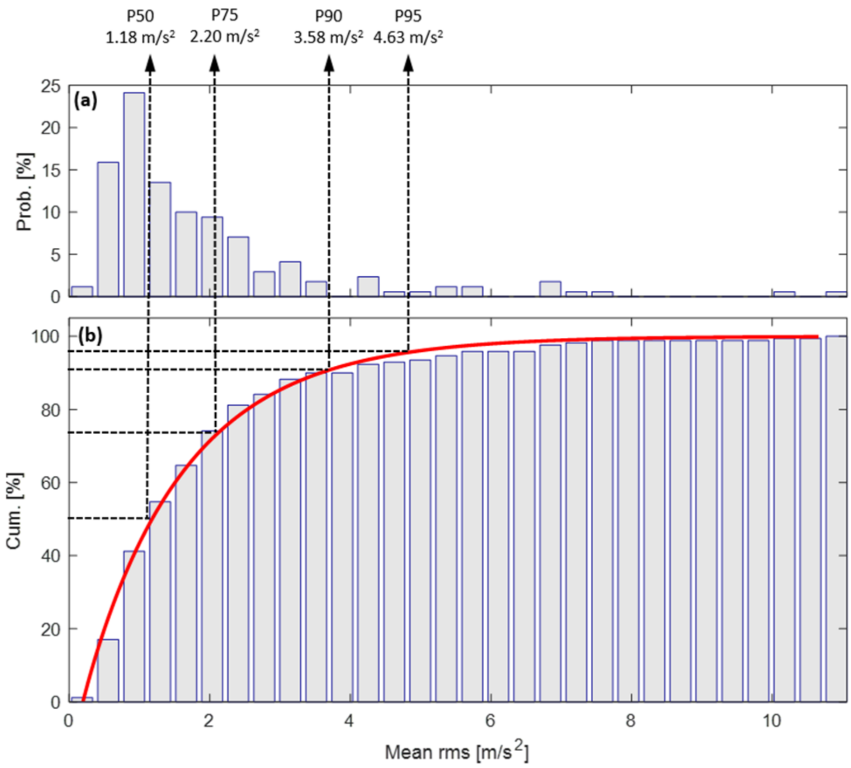


Figure 1: Distribution of mean rms levels for road transport (a) probability distribution (b) cumulative probability distribution with Weibull curve-fit in red.

Further statistical analysis was applied to the aforementioned categorised data to identify the correction factors that need to be applied to the values shown in the overall distribution based on the choice of suspension type, road type and payload. The results are presented in Table 1.

Table 1: Application of correction factors to obtain corrected mean rms values.

	Mean rms [m/s²]	**Suspension Type**		**Road**		**Payload**		**Combined Correction Factor**	**Corrected mean rms [m/s²]**
P50	1.18	Steel leaf	1.55	Minor	1.60	Low (< 50%)	1.22	3.03	3.57
						High (> 50%)	0.89	2.21	2.60
				Major	0.78	Low (< 50%)	1.22	1.47	1.74
						High (> 50%)	0.89	1.08	1.27
		Air ride	0.73	Minor	1.60	Low (< 50%)	1.22	1.42	1.68
						High (> 50%)	0.89	1.04	1.23
				Major	0.78	Low (< 50%)	1.22	0.69	0.82
						High (> 50%)	0.89	0.51	0.60
P75	2.20	Steel leaf	1.44	Minor	1.57	Low (< 50%)	1.26	2.85	6.27
						High (> 50%)	0.84	1.90	4.18
				Major	0.68	Low (< 50%)	1.26	1.23	2.71
						High (> 50%)	0.84	0.82	1.81
			0.57	Minor	1.57	Low (< 50%)	1.26	1.13	2.48

		Air ride				High (> 50%)	0.84	0.75	1.65
				Major	0.68	Low (< 50%)	1.26	0.49	1.07
						High (> 50%)	0.84	0.33	0.72
P90	**3.58**	**Steel leaf**	**1.38**	Minor	1.57	Low (< 50%)	1.33	2.88	10.32
						High (> 50%)	0.81	1.75	6.28
				Major	**0.62**	**Low (< 50%)**	**1.33**	**1.14**	**4.07**
						High (> 50%)	0.81	0.69	2.48
		Air ride	0.47	Minor	1.57	Low (< 50%)	1.33	0.98	3.51
						High (> 50%)	0.81	0.60	2.14
				Major	0.62	Low (< 50%)	1.33	0.39	1.39
						High (> 50%)	0.81	0.24	0.85
P95	4.63	Steel leaf	1.35	Minor	1.57	Low (< 50%)	1.44	3.05	14.13
						High (> 50%)	0.79	1.67	7.75
				Major	0.60	Low (< 50%)	1.44	1.17	5.40
						High (> 50%)	0.79	0.64	2.96
		Air ride	0.43	Minor	1.57	Low (< 50%)	1.44	0.97	4.50
						High (> 50%)	0.79	0.53	2.47
				Major	0.60	Low (< 50%)	1.44	0.37	1.72
						High (> 50%)	0.79	0.20	0.94

Using the results, a risk based approach for laboratory based vibration testing is recommended as follows:

[1] Select the probability percentile and record the corresponding expected mean rms based on the entire data set

[2] Select suspension type

[3] Select the road type

[4] Select the payload level

[5] Use Table 1 to find the combined correction factor.

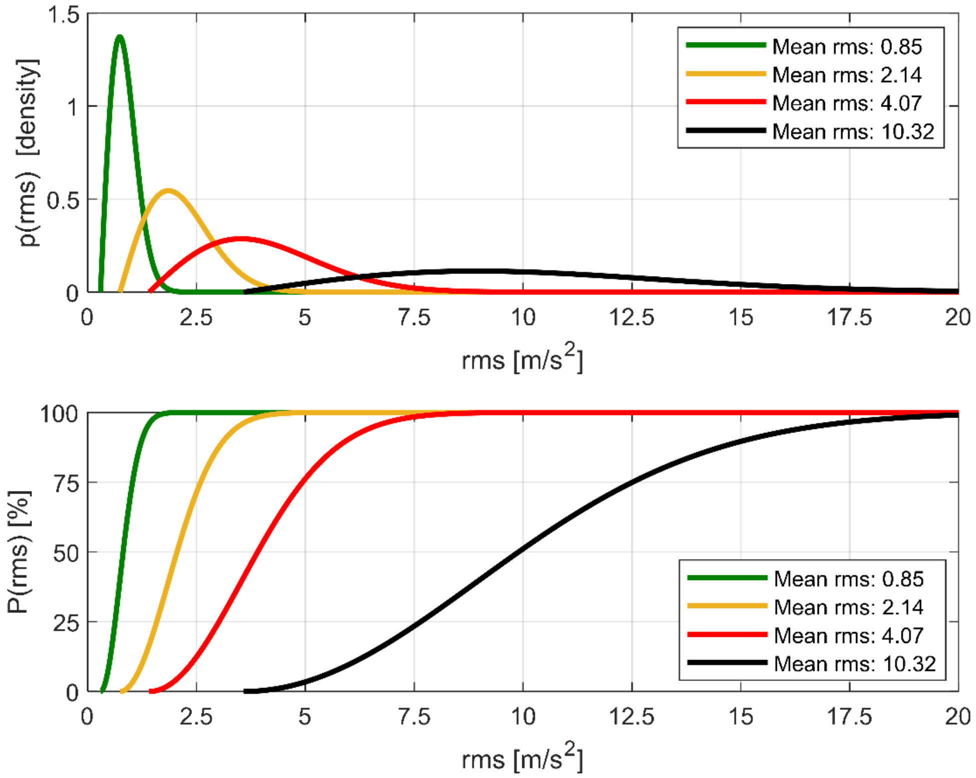
For example (following the highlighted values in Table 1), for a percentile level of 90% (P90), leaf steel suspension, major road and low payload level, the combined correction factor is 1.14. That is, the expected mean rms level is 1.14 times the expected, P90, mean rms level of the entire data set resulting in a new mean rms of 4.07 m/s^2.

Once a mean rms value is estimated for the specific journey, the relationships (3 & 4) established previously by the authors can be used to estimate the scale and location parameters. Using equation (1) these values can be used to estimate the overall rms distribution.

$$\eta = 0.735 \cdot \overline{rms} \tag{3}$$

$$x_o = 1.082 \cdot \overline{rms} - \eta \tag{4}$$

As an illustration, four scenarios for the 90th percentile – P90 – are given in Figure 2.



The four scenarios (taken from Table 1) represent:

- Air ride suspension with high payload on major roads (0.85 m/s^2 mean rms)
- Air ride suspension with high payload on minor roads (2.14 m/s^2 mean rms)
- Steel suspension with low payload on major roads (4.07 m/s^2 mean rms)
- Steel suspension with low payload on minor roads (10.32 m/s^2 mean rms)

Such distributions can be used to make risk-based decisions as to the maximum rms level expected for a particular road transport scenario and its probability of occurrence. In practical terms, costs associated with protective packaging (material, transport volume, disposal costs etc.) can be optimized against the costs associated with product damage.