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STATISTICAL FACTORS AFFECTING MACHINERY NOISE EMISSION DECLARATIONS

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1.0 Introduction

Occupational noise-induced hearing loss is a significant public health problem in Canada. To help reduce workplace noise, purchasers of machinery need to be able to make meaningful comparisons of machinery noise emissions with: (i)emissions from other machines, (ii)purchase specifications and (iii)occupational noise limits. This can be achieved if technical specifications and instruction manuals for machinery contain noise emission declarations; realistic, but conservative, estimates of the sound pressure levels and sound power levels emitted by machine(s) under standard conditions.

Guidelines for machinery noise emission declarations in Canada are being prepared by the Canadian Standards Association (CSA). They are based, in part, on ISO 4871[1], one of a series of international standards that can be used as an efficient way to either meet European regulatory requirements for noise emission declarations or to verify declarations.

The purpose of this study was to examine the implications of using ISO 4871 for the declaration and verification of the noise emission values of machinery manufactured in batches. For measurement of noise emission values to be feasible, the values must be based on measurements of a relatively small sample of machines from the batch. From health and safety considerations, it is important that there be a reasonably high probability that the noise emission value of machinery purchased for a workplace will not exceed the declared value. For the benefit of the manufacturer, there should also be a relatively high probability that a noise emission declaration for a batch will be verified, either by a purchaser or a regulatory authority. Therefore, this study examined the dependence of these probabilities on three factors: (i) the number of machines used to determine a noise emission declaration, (ii) reproducibility of the measurements and (iii) the difference between the total standard deviation and the reference standard deviation of the measurements.

2.0 Calculation details

The statistics of the declaration were calculated based on the following model for the measured noise emission value L_i, for the ith machine in a sample from a batch:

$$L_i = \mu + \sigma_P X_i + \sigma_R Y \tag{1}$$

where μ, was the true mean noise emission value for the entire batch the X_i, and Y values were normally distributed random numbers with mean 0 and standard deviation 1, and σ_P was the true standard deviation of production for the entire batch. The value σ_P characterized the variation in the noise emission values due to production differences between machines. The remaining quantity σ_R, was the standard deviation of reproducibility. This quantity, normally obtained from a standard or test code, characterized the variation in the L_i due to random differences between the results of measurements of the same machine carried out under changed conditions of measurement. The value of σ_R normally includes repeatability differences but they were assumed negligible in these calculations. Except for the X_i, and Y all quantities in equation 1 are in decibels (dB). A new set of X_i and a new Y was generated for each trial.

The estimated mean noise emission value L_{avg} for the entire batch was calculated using[1]:

$$L_{avg} = \sum_{i=1}^{N} L_i \Big/ N \approx \mu \tag{2}$$

where i=1 to N, and N was the number of machines measured.

The estimated standard deviation of production s_P was calculated from the sample measurements and given by

$$s_P = \sqrt{\sum_{i=1}^{N} (L_i - L_{avg})^2 \Big/ (N-1)} \approx \sigma_P \tag{3}$$

The estimated total standard deviation s_t, for the batch was given by

$$s_t = \sqrt{s_P^2 + \sigma_R^2} \approx \sigma_t \tag{4}$$

where σ_t was the true total standard deviation for the batch. Note that σ_R would be obtained from the test code, or standard used to make the measurement, and was assumed to be the true value.

For each trial, the declared value for the batch , L_d, was obtained according to informative Annex A of ISO 4871from the equation

$$L_d = L_{avg} + 0.94\, s_t + 0.56\, \sigma_M \tag{5}$$

where σ_M was the reference standard deviation, a total standard deviation (as in equation 4) specified for a type of machine and considered to be typical for batches. A fixed value of $_M$ of 2.5 dB was chosen, as recommended in ISO 4871.

One of the quantities to be calculated was the probability that a noise emission declaration for a batch would be verified. This was obtained as the average, over 8000 trials, of the fraction of machines in a sample of three, that met the following criterion from ISO 4871

$$L_d - L_{avgV} > 0.56\, \sigma_M \tag{6}$$

where L_{avgV} was the estimated mean noise emission value measured by the verifier from a sample of 3 machines using equation 2. The values of L_i needed for L_{avgV} were obtained from equation 1. However, in each trial, the X_i and Y constants used to obtain L_{avgV} were uncorrelated with the constants used in the determination of L_d.

The other quantity of interest was the probability that the true noise emission value of a purchased machine was less than the declared value for the batch, L_d. This was obtained as the average, over 8000 trials, of the fraction of machines that met the criterion

$$\mu + \sigma_P X_i < L_d \quad (7)$$

where the true mean noise emission value from the ith machine was modeled as $\mu + \sigma_P X_i$. In each trial, the comparisons in equation 6 and 7 use the same three machines. This means that for each trial, the X_i constants used in equation 7 were the same as used to obtain the L_{avgV} in equation 6.

For a given L_d, the probability of verification was also calculated using the Student-t distribution[2]. The Welch-Satterthwaite formula[2] was used to determine the effective number of degrees of freedom. Typically, this calculation and the simulation gave results that agreed to within 1%.

3.0 Results

The results are given in Table 1. The first line of Table 1 shows that the probability of verification was 95% and the proportion of machines with noise emission values less than the declared value was 93% if three conditions were fulfilled[3]: (i) there were a large number of machines in the sample used to obtain the noise emission declaration, (ii) there were no reproducibility differences between the manufacturer and verifier and (iii) the total standard deviation, σ_t, was approximately equal to the reference standard deviation, σ_M.

A realistic example using a survey grade measurement is given in the last line of Table 1. None of the three conditions were met, which resulted in reductions in both the probability of verification and the number of machines with noise emission values below the declared value. The effect of each condition is illustrated below.

If conditions (i) and (ii) were fulfilled but the total standard deviation exceeded the reference standard deviation of 2.5 dB, the percentage of machines with noise emission values below the declared value decreased. However, the probability of acceptance remained unchanged. This is shown by comparison of the second row of Table 1 with the first row. Here, exaggerated production variations (σ_P=10dB) make the total standard deviation much larger than 2.5dB, and the percentage of machines below the declared value dropped to 86%.

For the third row of Table 1, the measurement reproducibility condition (ii) was violated. This reduced the probability of verification, even though the total standard deviation, σ_t, was the same as in the first row. However, because σ_t was unchanged, the percentage of machines below the declared value remained the same. The likelihood of verification would increase if the manufacturer and verifier made measurements under identical conditions.

If conditions (ii) and (iii) were fulfilled but only 3 machines were used to calculate the declaration, the probability of verification was reduced and the proportion of machines with noise emission values below the declared value was also diminished. This is indicated by comparison of the first and fourth rows of Table 1. This resulted from the fact that, over the 8000 trials, the small sample size caused significant variations in the estimates of the mean and total standard deviation. This is shown by the wide range of differences between the declared and measured values in the fourth row of Table 1.

If, in each trial, the difference between the measured and declared values was doubled, the probability of verification would typically exceed 95%. The proportion of machines with noise emission values less than the declared value would also increase to over 93%.

4.0 Conclusions

To produce consistent declared values that allow simple comparisons between machinery, the CSA guidelines recommend the use of ISO 4871 and its informative Annex A. Declarations according to this standard are conservative estimates of the noise produced by the machines. To avoid difficulties when using declarations, manufacturers should be conservative in the estimation of errors. Purchasers should be aware that the declaration is a statistical upper limit, and some machines are expected to exceed the declared value.

References

[1] ISO 4871 (1996), "Acoustics - Declaration and verification of noise emission values of machinery and equipment"

[2] ISO GUM (1995), "Guide to the expression of uncertainty in measurement"

[3] ISO 7574 (1985), Part 4, "Acoustics - Statistical methods for determining and verifying stated noise emission values of machinery and equipment"

Table 1: Probability of acceptance for declaration, and percentage of machines less than declared value. Values are given for the number of machines used for declaration, N, the true standard deviation of reproducibility, sR, and the true standard deviation of production, sP. Note that the standard deviations are theoretical true values, not the approximate values from measurements. For reference, the difference between declared and measured value is also included, the values given represent the range for 8000 trials.

N used by declarer	σ_R dB	σ_P dB	declared - measured value, dB	probability of acceptance	% < declared value
∞	0	2.5	3.8	94%	93%
∞	0	10	10.8	95%	86%
∞	2.5	0	3.8	74%	93%
3	0	2.5	1 to 9	81%	87%
3	4	2.5	5 to 10	76%	88%