Calculating Sound Quality of the Outdoor Idling Noise of Diesel Powered Cars

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The sensation of loudness and the special character of diesel powered cars, the so called dieselness, are important factors influencing the assessment of sound quality of the idling noise of diesel powered cars. The close relationship between those magnitudes will be discussed by means of the results of psychoacoustic experiments. Hence, combining loudness and dieselness in the right way leads to good predictions for the estimated sound quality of idling cars. Calculated and psychoacoustically measured sound qualities will be compared.

1. INTRODUCTION

If subjects are asked to judge the sound quality of the outdoor idling noise of diesel powered cars, in former investigations [1, 2, 3] it appeared that mainly two magnitudes seem to be essential for the subjects' assessment of the sound quality, as there are the loudness of the noise and the typical sound character of the diesel engine, which will be called *dieselness* in the following. By means of eight sounds – one gasoline powered ("gp"), four diesel powered cars of different brands ("dp b1" to "dp b4") and three different motor adjustments of one diesel powered car ("dp a1" to "dp a3") - the correlations between the perceived sound quality and the loudness, resp. dieselness, will be assessed.

2. MODELING

To model the sound quality on the basis of the two sensation magnitudes loudness and dieselness, the relationship between those parameters and the sound quality will be regarded in more detail. The functions f(N) and f(D) will be linked as in Suchowerskyi [4] by a City Block Model:

$$SQ(N,D) = \sqrt{f(N)^2 + f(D)^2} \ , \qquad \text{(Gl. 4.1)}$$

with *SQ* sound quality, *N* loudness, and *D* dieselness.

Analogous to the work of Aures [5] we start with a rough estimation for the function between sound quality and the respective input magnitude f(N) and f(D). Then, an accurate connection will be determined by optimising the parameters.

2.1. Influencing Variables

Loudness

Figure 1 shows the relationship for the eight signals between the psychoacoustically measured magnitudes sound quality and loudness which can be approximated by the curve shown and characterized by equation 1.

$$f(N) = SQ(N) = a_{SQ} \cdot e^{-b_{SQ} \cdot N} \quad , \tag{1}$$

with parameters a_{SQ} and b_{SQ} for optimization.

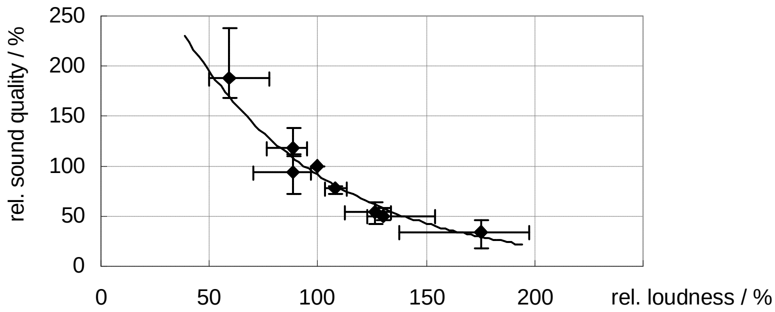

Figure 1. *Psychoacoustically measured sound quality and loudness.*

Dieselness

To acquire the influence of the dieselness on the perceived sound quality independent of the signals' loudness, the eight sounds were adjusted in loudness. Therefore level decreases of up to 5.5 dB and level increases of up to 4.3 dB were realized to get the same percentile loudness N_5 for all signals. Figure 2 shows the relationship obtained between dieselness and sound quality as measured in psychoacoustic experiments. It can be characterized by the plotted straight line according to equation 2:

$$f(D) = SQ(D) = c_{SQ} \cdot D - d_{SQ} \quad , \tag{2}$$

with parameters c_{SQ} and d_{SQ} for optimization.

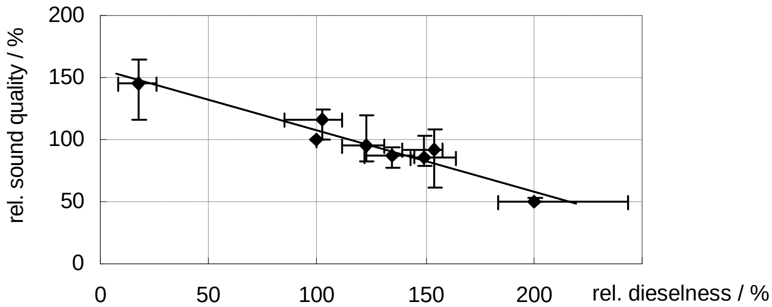

Figure 2. *Psychoacoustically measured sound quality and dieselness of the eight sounds with same percentile loudness N_5.*

2.2 Combining loudness and dieselness

To model the sound quality, the functional relations between loudness and sound quality (eq. 1), resp. dieselness and sound quality (eq. 2) are connected and the parameters a_{SQ} to d_{SQ} are numerically varied in such a way that an optimum agreement between psychoacoustically measured and calculated values is received.

$$SQ(N,D)=\sqrt{\left(a_{SQ}\cdot e^{-b_{SQ}\cdot N}\right)^2+\left(c_{SQ}\cdot D-d_{SQ}\right)^2}\ , \qquad (3)$$

with the optimum parameters a_{SQ}=717, b_{SQ}=0.023, c_{SQ}=0.175, and d_{SQ}=7.6.

Figure 3 shows the obtained calculated (stars) versus psychoacoustically measured sound qualities (rhombs). The correlation proves to be with a rank correlation coefficient according to Spearman of 0.98 as very high. Thus, for the eight signals the calculated values are very good in line with the measured values.

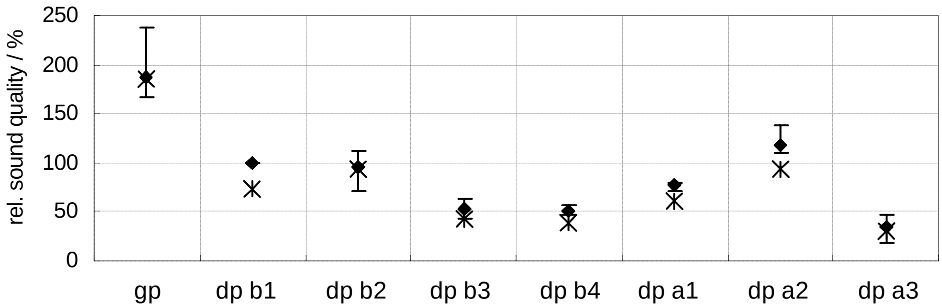

Figure 3. *Psychoacoustically measured (rhombs) and calculated (stars) sound qualities.*

2.3 Calculating dieselness

To implement the possibility of calculating the dieselness from the time signal, in the following connections between parameters of the time signal and the dieselness should be described.

Crestfaktor

The crest factor C is defined by the ratio of the peak value and the rms-value of a signal. The larger the difference between peak and rms-value is, the more impulsive is a sound. Thus, the crest factor can be seen as a measure for the impulsiveness of a sound.
Figure 4 shows the connection between the calculated crest factor C and the perceived dieselness D of the eight signals. The eight signals are mainly following the plotted curve (eq. 4) in figure 4:

$$f(C)=D(C)=a_D\cdot\ln(C)+b_D\ . \qquad (4)$$

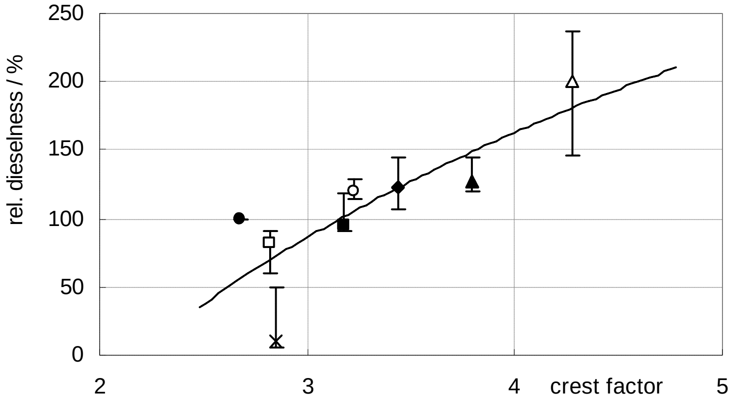

Figure 4. *Perceived dieselness versus the signals' crest factors. Star: gasoline powered car, open symbols: different motor adjustments of a diesel powered car, closed symbols: diesel powered cars of different brands.*

Distribution of the impulses' heights

In the following a closer view on the distribution of the impulse maxima will be done. Therefore, the heights of all maxima appearing in an interval of one second of the signal were analyzed. The standard deviation of the distribution of the impulses' heights S can be seen as a measure for the regularity of the impulses. In figure 5 the relation between the perceived dieselness D and the standard deviation of the impulses' heights S is plotted. Thus, the logarithmic function (eq. 5) displayed in figure 5 by the curve can approximate the relation to the perceived dieselness of the signals.

$$f(S) = D(S) = c_D \cdot \ln(S) + d_D \quad . \tag{5}$$

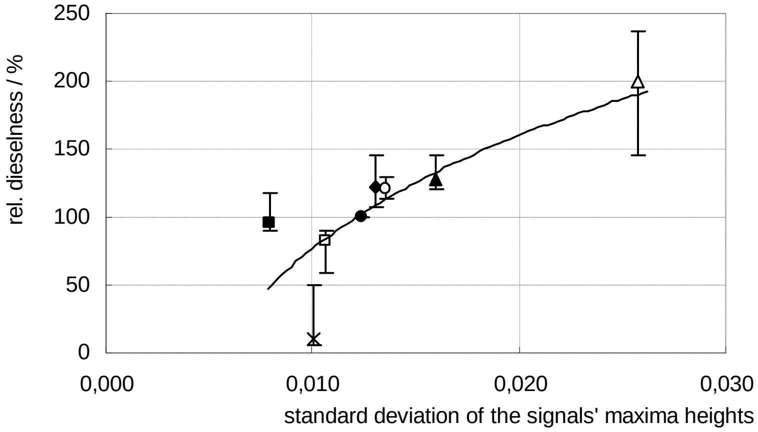

Figure 5. *Perceived dieselness versus the standard deviation of the signals' maxima heights. Star: gasoline powered car, open symbols: different motor adjustments of a diesel powered car, closed symbols: diesel powered cars of different brands.*

Modeling dieselness

If equations 4 and 5 are connected in the same way as described in chapter 2.2, equation 6 results and the psychoacoustically measured values of dieselness can be reproduced with a rank correlation coefficient of 0.88 as displayed in figure 6.

$$D(C,S)=\sqrt{\left(a_D\cdot\ln(C)+b_D\right)^2+\left(c_D\cdot\ln(S)+d_D\right)^2}\,, \qquad (6)$$

with a_D=146, b_D=-94, c_D=149, and d_D=714.

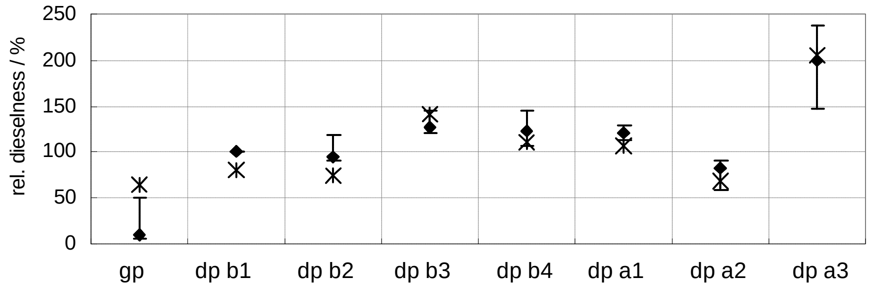

Figure 6. *Psychoacoustically measured (rhombs) and calculated (stars) dieselness.*

3. VERIFICATION

In the following by means of several additional outdoor idling noises of diesel powered cars, the quality of the modeling will be verified. Therefore, the values of the percentile loudness N_5, the crest factor C and the standard deviation of the signals' maxima heights S are measured physically and are inserted in equations 3 and 6. Figure 7 opposes the thus received calculated sound qualities (stars) and the psychoycoustically measured values (rhombs). In more than 50 % the calculated value is lying within the interquartile ranges of the subjective judgements. The rank correlation coefficient according to Spearman amounts to 0.74.

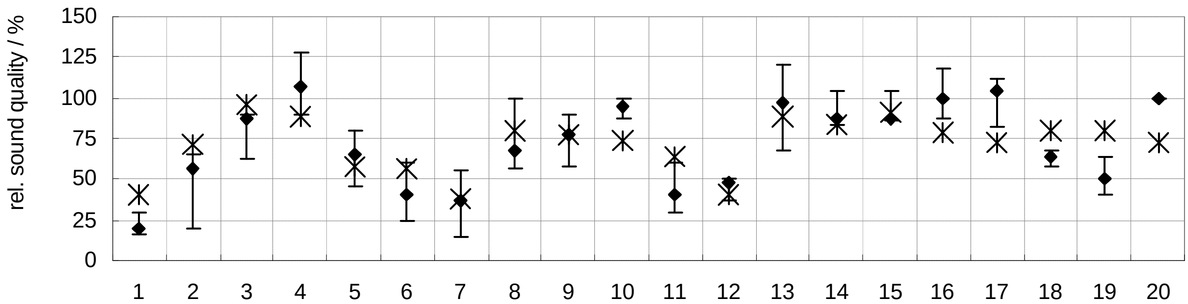

Figure 7. *Psychoacoustically measured (rhombs) and calculated (stars) sound qualities.*

To describe the quality of the model's prediction, the arithmetic mean of the interquartile ranges shall serve as measure. A value of $\pm$14 % is calculated for the subjective judgements shown in figure 7. If the calculated sound qualities are lying within those $\pm$14 %, the prediction can be seen in the context of the interquartile ranges of the subjective judgements as sufficiently accurate. According to this consideration, 60 % of the sounds are within this tolerance band of $\pm$14 % plotted in figure 8.

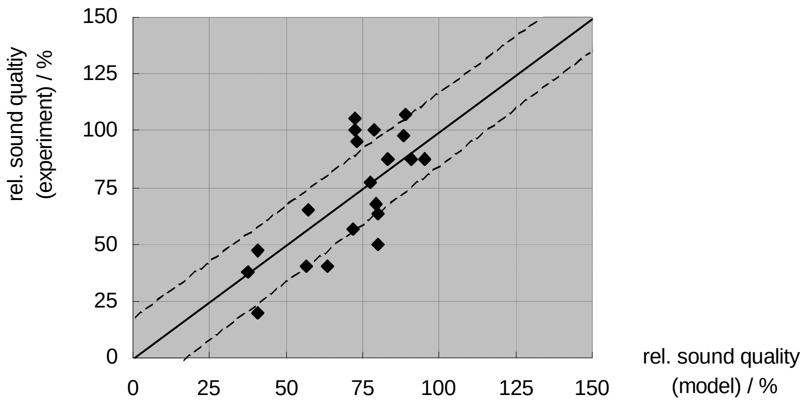

Figure 8. *Psychoacoustically measured versus calculated sound qualities. Tolerance band according to the mean of the interquartile ranges of the subjective judgements.*

4. CONCLUSIONS

For the sound quality assessment of the outdoor idling noise of diesel powered cars, the loudness and the typical sound character of the diesel engine, the so called dieselness, are important magnitudes. A city block model combining those two parameters reproduces the perceived sound quality with a rank correlation coefficient of 0.98.

To calculate the perceived dieselness, physical and statistical parameters of the time signal were analyzed. In addition to the crest factor, the standard deviation of the signals' maxima heights seems to be in strong relationship with the perceived dieselness. The higher the crest factor and the more irregular the distribution of the maxima, the larger is the dieselness. A combination of those two magnitudes can reproduce the typical character of the diesel cars with a rank correlation coefficient of 0.88.

By means of 20 additional outdoor idling noises the modeling was verified. The prediction succeeds with a rank correlation coefficient of 0.74. As measure for the quality of the prediction the arithmetic mean of the interquartile ranges is calculated. Within these boundaries of $\pm$14 %, a large number of the sounds (60%) were predicted correctly.

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