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Tram noise monitoring

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The environmental noise monitoring program for the trams of Oslo has been going on since 2007. The program has been gradually extended and modified. The first attempts at using the data to create an empirical method for outdoor A-weighted noise levels from the Oslo tram based on a multivariate linear regression were presented at Internoise 2012. We have introduced several improvements to the model for A-weighted noise levels. In our latest regression analysis we have divided sharply between continuous variables and categorical variables. The continuous variables are distance, tram speed, rail corrugation, vertical gradient of the track and horizontal radius. The categorical variables are train type, track type, year of measurement, number of years since last grinding.

All the parameters came out with reasonable regression coefficients in A-weighted levels after the 2016 measurements, based on 1780 tram passages. The paper will show the regression coefficients in 1/3 octave bands after the 2017 measurements are included. The frequency range 50 Hz to 10000 Hz will be discussed. This is slightly wider than the usual building acoustics frequency range in order to include effects like curve squeal.

Limitations of our approach of using multivariate regression will be discussed as well as our investigations to remedy these limitations.

1 Introduction

Some status reports have been published earlier about the tram noise monitoring program of Oslo, [1,2,3]. These reports have been based on subsets of the data presented in current work. The noise monitoring program data analysis is now based on 2245 complete records up to autumn 2017 with all variables included.

A general overview of the effects of various parameters on A-weighted levels is presented in figure 1. Care has been taken to ensure that the mathematical representation is correct. Most of the parameters have also been analysed in spectrum.

Lastgrind is the number of years since the last grinding of the track, only analysed as a categorical variable. This parameter is also analysed by A-weighted values. It makes sense that the trams make more noise when more time has elapsed since the last grinding of the track.

Logdistance is the base 10 logarithm of the distance to the track centreline, a continuous variable

Loggradient is the base 10 logarithm of the vertical gradient given in ‰, a continuous variable

Logradius is the base 10 logarithm of the horizontal curve radius in m, a continuous variable

Logspeed is the base 10 logarithm of the vehicle speed in km/h, a continuous variable

Rsa is a single number rating of the rail corrugation, measured in dB rel. 1 µm, a continuous variable

Track effect is shown as a categorical variable, ballast track, city street or green track

Tram effect is shown as a categorical variable, SL 79 or SL 95, the two types of tram running in Oslo.

Year effect is a categorical variable and only analysed in A-weighted variable. It shows that a new maintenance program of both the rail and the rolling stock started in 2011 really has had effect. The noise reached a minimum in 2015. During the last two years we rather suspect that priority has been given to the works required to prepare for the new trams that will start replacing the old ones in a couple of years' time.

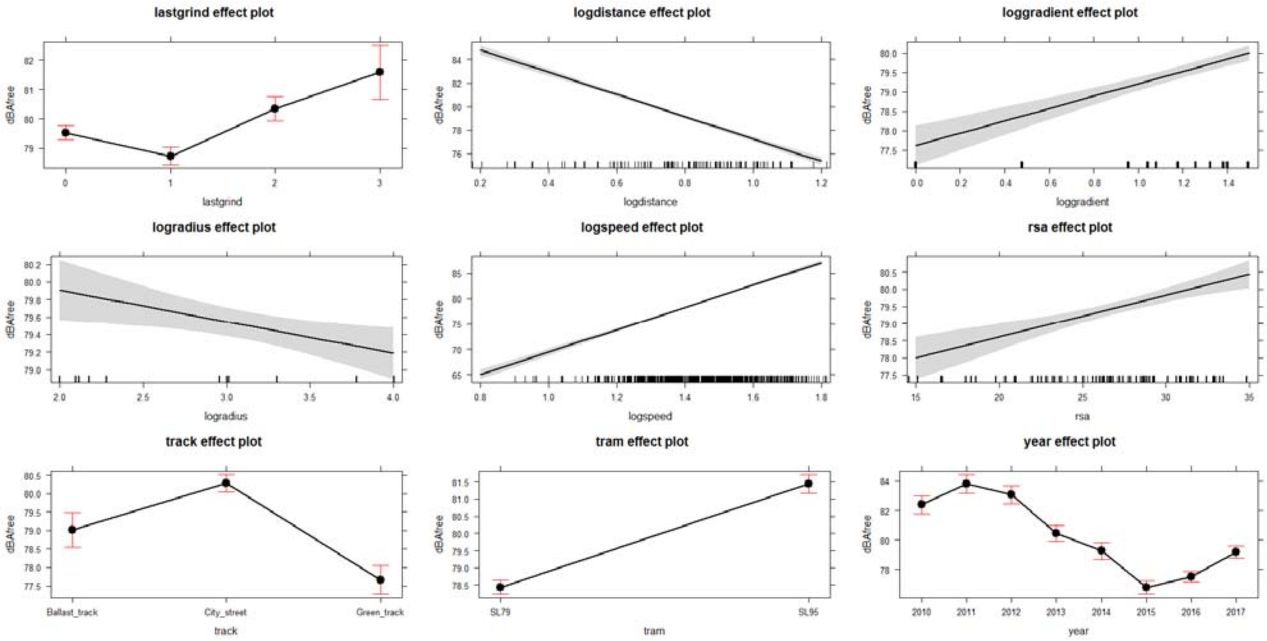

Figure 1 Overall effect on noise of different parameters

Last grind and year effect are not analysed in spectrum.

The measured sound levels have been corrected to free field in a simplified way. If there is reflection on one side of the street, 3 dB has been subtracted from the measured value. If there is reflection of both sides of the street, 6 dB has been subtracted from the measured value. A more comprehensive way of handling the sound field has been investigated [4].

2 Spectrum analysis of the parameters

In the following there will be a presentation of the spectrum variation of each of the 7 parameters where spectrum is relevant with a short discussion.

2.1 Logdistance

Figure 2 shows the spectrum of the effect of distance. 10 dB attenuation per decade would be a perfect line source, 20 dB/decade a perfect point source. Since the tram is a noise source that is only significant at short distances, all the immission points are in the near field.

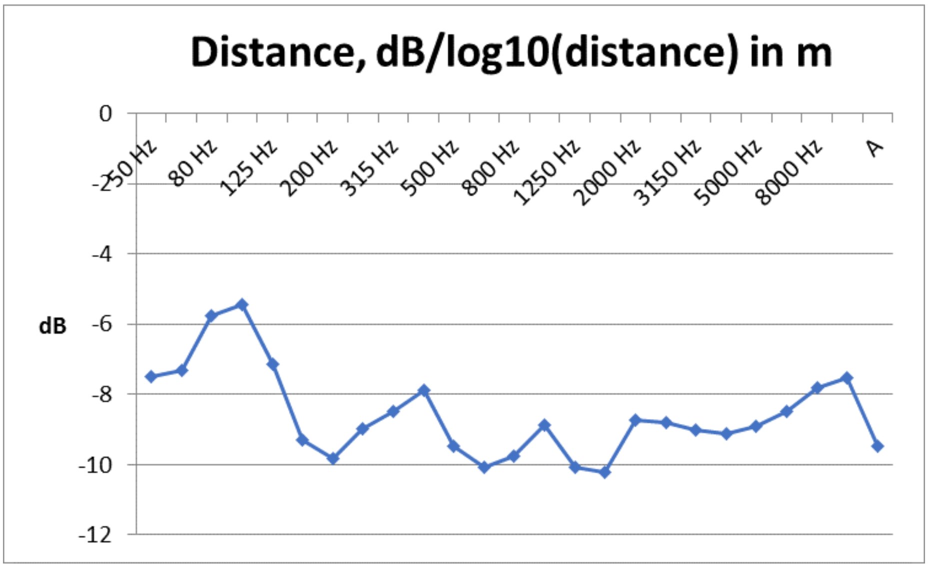

Figure 2 – spectrum of distance attenuation of tram noise

2.2 Loggradient

There is no tradition for including the vertical gradient as a parameter in calculations of noise from railbound sources. However there is every reason to include local geometry in analysis and prediction of noise from trams [5]. Figure 3 show the effect of the base 10 logarithm of the vertical gradient.

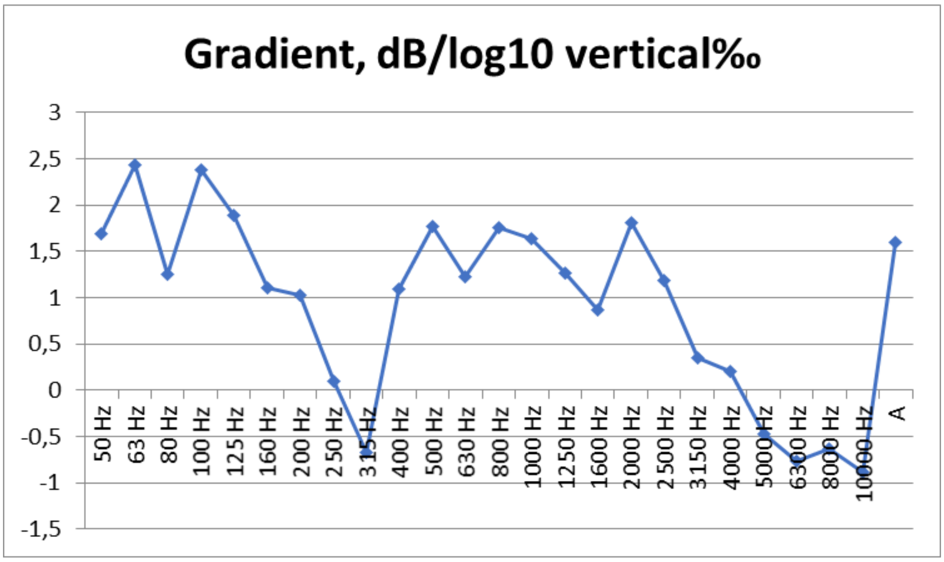

Figure 3, spectrum of effect of vertical gradient

There are some things in figure 3 that do not make sense. However it should be expected that some false data would come out of the analysis of a data set of this size. It does not seem reasonable that noise at 315 Hz and above 4000 Hz decreases as the gradient increases. Further investigations are clearly indicated as this does not seem credible.

2.3 Logradius

As with the vertical gradient there is no tradition in the Nordic countries for including horizontal curvature in the analysis of noise from railbound traffic. The trams run on tracks that have many sharp bends. In this analysis only bends with a radius of 100 meter or more have been included. Figure 4 shows the spectrum of the dependence on radius.

Straight lines have been included as 10000 m radius. Negative values mean more noise on curves with small radius. Figure 4 shows that the 160 Hz 1/3-octave band appears to be particularly sensitive to sharp bends. This may be a problem in Norway, as many recent types of window have a resonance frequency in that band with the consequence that outdoor noise in that band may give unexpectedly high indoor noise levels.

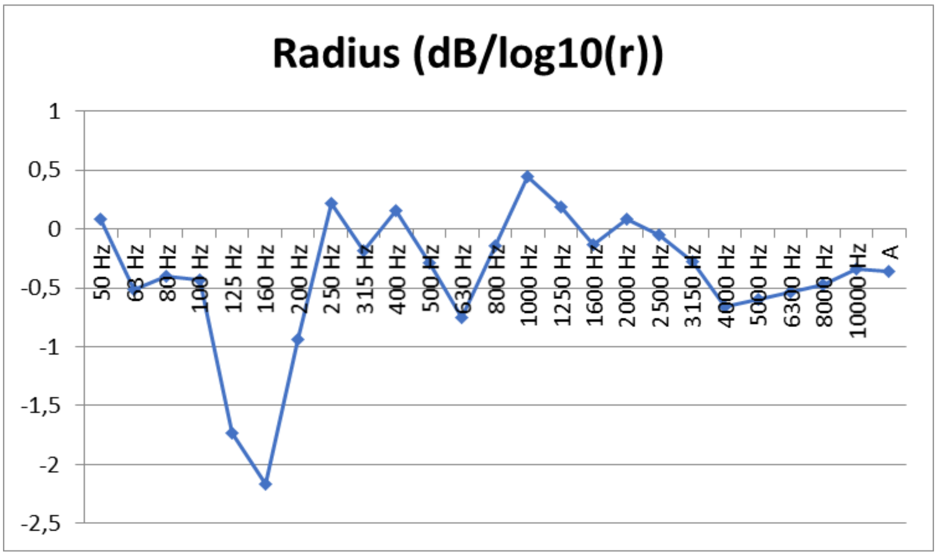

Figure 4, falling noise levels with increasing curve radius

2.4 Logspeed

The dependence of noise in 1/3-octave bands on vehicle speed is shown in figure 5.

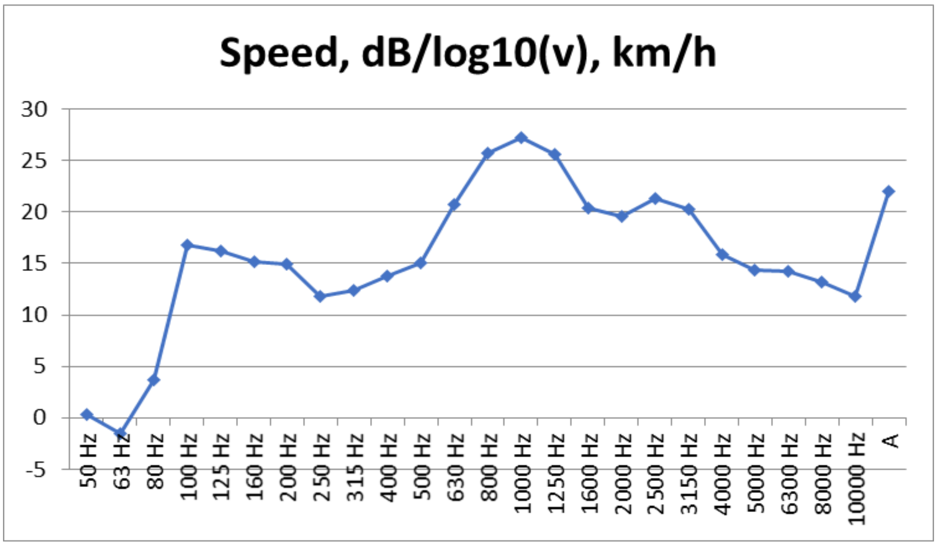

Figure 5, dependence of noise on tram speed

The vehicle speed dependence is highest around 1000 Hz. At low frequencies it seems that the speed dependence is limited.

2.5 Rail surface analysis

The rail surface analysis (rsa) is given as a logarithmic parameter. The rsa value is given in dB relative to 1 µm rail surface corrugation. The rail surface corrugation has most influence at low frequencies. The result is shown in figure 6.

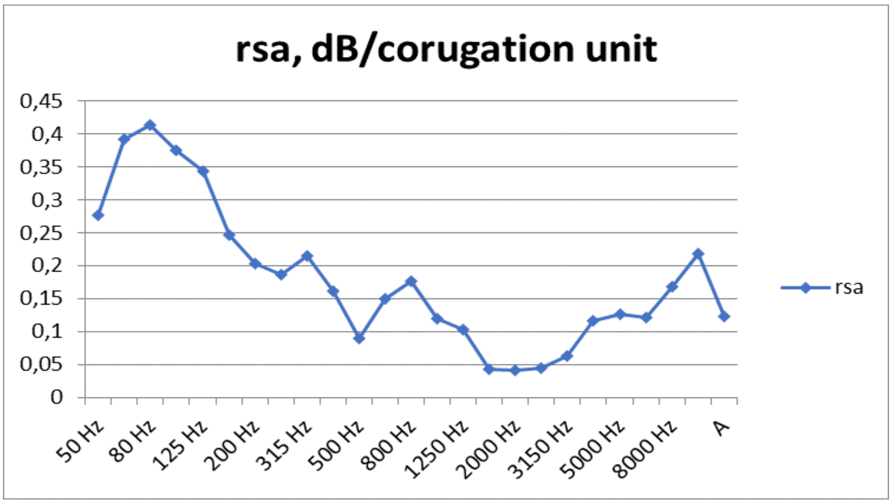

Figure 6, dependence of noise on rail corrugation.

2.6 Track effect

The effect of the three different types of track in Oslo is shown in figure 7.

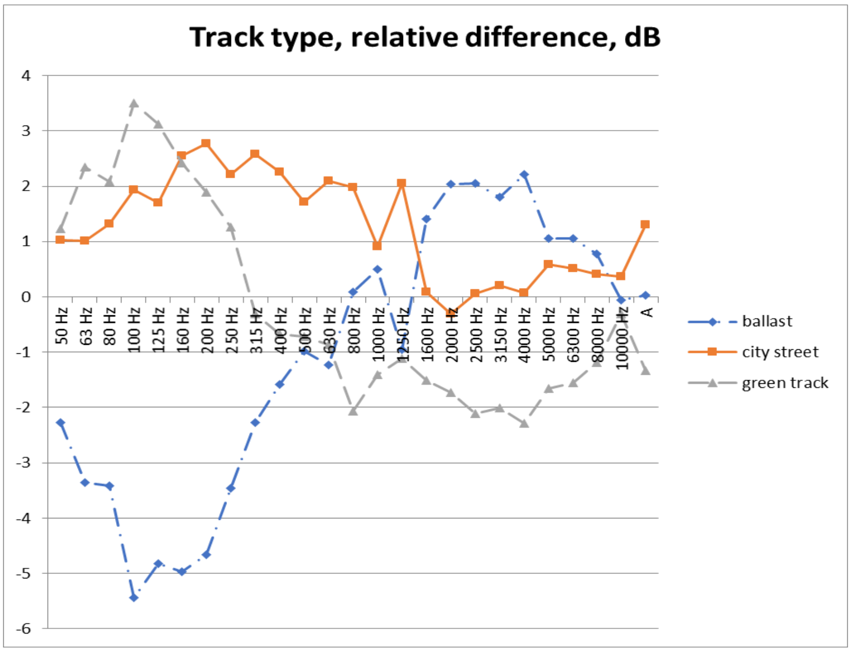

Figure 7, effect of different track types.

The difference between track types is relative, in each band the sum of effects is zero. The analysis includes 474 cases of ballast track, 1388 cases of city street and 433 cases of green track. We can see that the ballast track contributes sound absorption at low frequencies. The green track is noisy at low frequencies. It would seem that the green track is a radiator of low frequency sound, while at high frequencies the grass is a good absorber of sound.

2.7 Tram effect

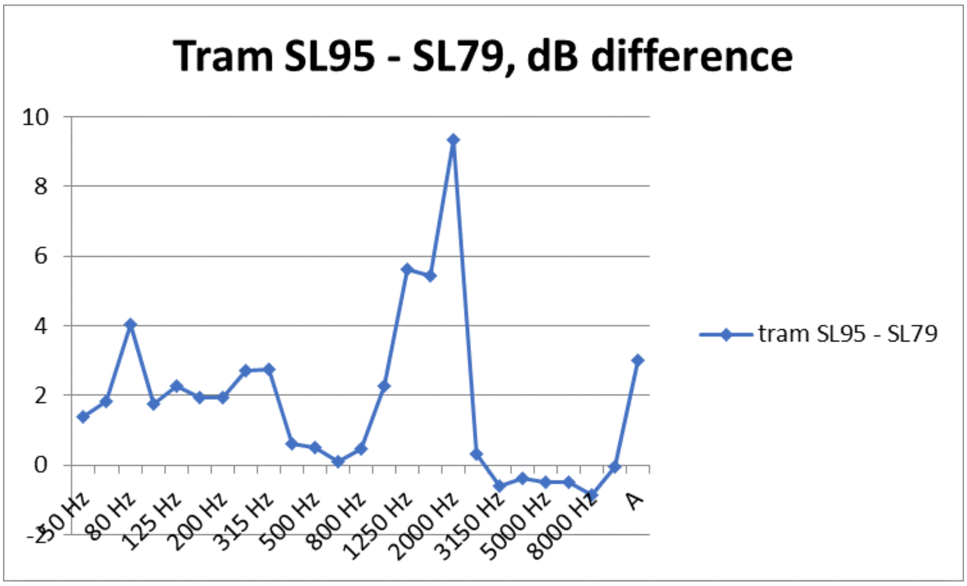

Figure 8, effect of different tram types

In the analysis 1441 spectra from SL79 and 804 spectra from SL95 have been included. The SL95 trams have been known to be noisy since they first arrived in Oslo around 2000.Figure 8 shows that the noise is most important in a limited frequency range, 1250 Hz – 2000 Hz. This difference in noise emission also shows up in a more detailed investigation in Storgata in Oslo[4].

3 Further work

Two obvious details are already investigated or under investigation. The first is the sound field in narrow street canyons. This task was covered by the M.Sc.thesis of Oskar Andreas Sivertsen [4], which is also due to be presented at BNAM in Reykjavik. Another task is a more direct investigation of distance attenuation. There is a double M.Sc. thesis under way at Chalmers University of technology about distance attenuation over grass in parks based on measurements in Oslo and Gothenburg, and one on attenuation by vegetation at Norwegian University of Technology and Science based on measurements just outside Oslo.

Future work will mostly be about the new trams of Oslo. The type of analysis presented in the current paper will be redone at intervals as the new trams start running and the current ones are taken out of traffic.

4 Acknowledgements

The work presented has been commissioned by Sporveien, the publicly owned company that runs the trams and metros of Oslo. The seed of the idea of using multivariate regression to analyse a large and confusing data set came from Rani Lill Anjum, lecturer in philosophy at Norwegian University of Bioscience in Ås outside Oslo. She is coauthor of a book devoting a whole chapter to considering multiple causes as vectors [6].

References

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