BNAM 2018
Baltic-Nordic Acoustics Meeting
15-18 April 2018
Harpa, Reykjavík, Iceland

Environmental noise and vibration monitoring of Oslo's metro lines

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The environmental noise and monitoring program of noise and vibrations for the metro lines of Oslo started in the spring of 2016. The yearly program consists of measurements of noise and vibrations at 11 points on the metro network. On each site noise and vibration spectra for at least 20 trains are measured on one day per year. Noise and vibrations are measured at two distances on each of the 11 sites. On each site rail corrugation is also measured. The average speed of each train is measured with a stopwatch.

The data from these yearly measurements will be used as part of a continuing effort to accumulate knowledge of noise and vibrations from Oslo's metro lines. The measurements from 2016 were used to confirm the new input data for metro noise prediction. Two problems were discovered in this process:

Noise from switches are a bigger problem than has been anticipated earlier.
One part of Oslo's metro network has a particularly difficult geometry with steep vertical gradients and sharp horizontal curves, giving a characteristic noise with is not easily accounted for by current prediction methods.

1 Introduction

The noise and vibration monitoring program for the metro lines of Oslo has been shaped in the form of the tram noise monitoring program [1,2,3] that has been going on since 2007. The first year of the metro program was 2016, when noise and vibrations were measured at 11 sites along Oslo's metro network. This was the first part of the introduction of the program. The second part was a new series of measurements to update the a- and b- values to be as input in calculations of traffic noise for the metro according to the Nordic Prediction method for Railway traffic[4]. The third part was a comparison between measured values at individual points and predicted values using the new input data.

Results from the vibration monitoring part are shown as regression line in the three spatial dimensions.

2 Methods and results - noise

The three parts of the noise monitoring program will be described in the following subsections.

2.1 Yearly noise measurements

Experience from the tram monitoring program convinced us to start with two microphones on each site. There are several advantages to the use of two microphones. The obvious one is that twice as much data is collected. Another advantage is that it makes it easier to find a general distance attenuation using statistical methods. We also started the first year to measure rail corrugation on each site. A total of 11 points were used to achieve a reasonable cross-section of the conditions along the metro lines of Oslo. The measurements have been made at distances ranging from 4 to 18 meters form the centreline of the nearest track. As a general rule at least 20 train passages are measured on each site. The identity of each train is noted, and the average speed past the microphone is measured with a stopwatch. The local geometry is represented by the vertical gradient and the horizontal radius. Again the experience from the tram program has presented us with useful experience. So far only the distance attenuation and speed dependence for the overall program have been analysed by statistical means.

There are similarities between the noise monitoring programs for trams and metros. There are, however, also important differences. The metros are of the same model, a Siemens model called MX 3000 in Oslo. The metro trains are much newer than the trams, and the trams are of two different main models. Another difference is that the metro tracks are the same all over, ordinary ballast track, and only one line has other traffic crossing, in contrast to the tram that has three different types of track and has to coexist with other traffic in the city. There are 115 MX 3000 trains on Oslo's metro lines. Each train contains of 3 cars. They usually run two and two trains linked together as six-car trains. Usually the trains running together are not the same from day to day. Therefore there are some 6500 possible different six-cars trains.

Figure 1 shows the parameters from the first year of the metro noise monitoring program as taken from a multivariate linear regression. The regression is made using the logarithm of distance and vehicle speed as numerical predictors, the immission site as categorical predictor.

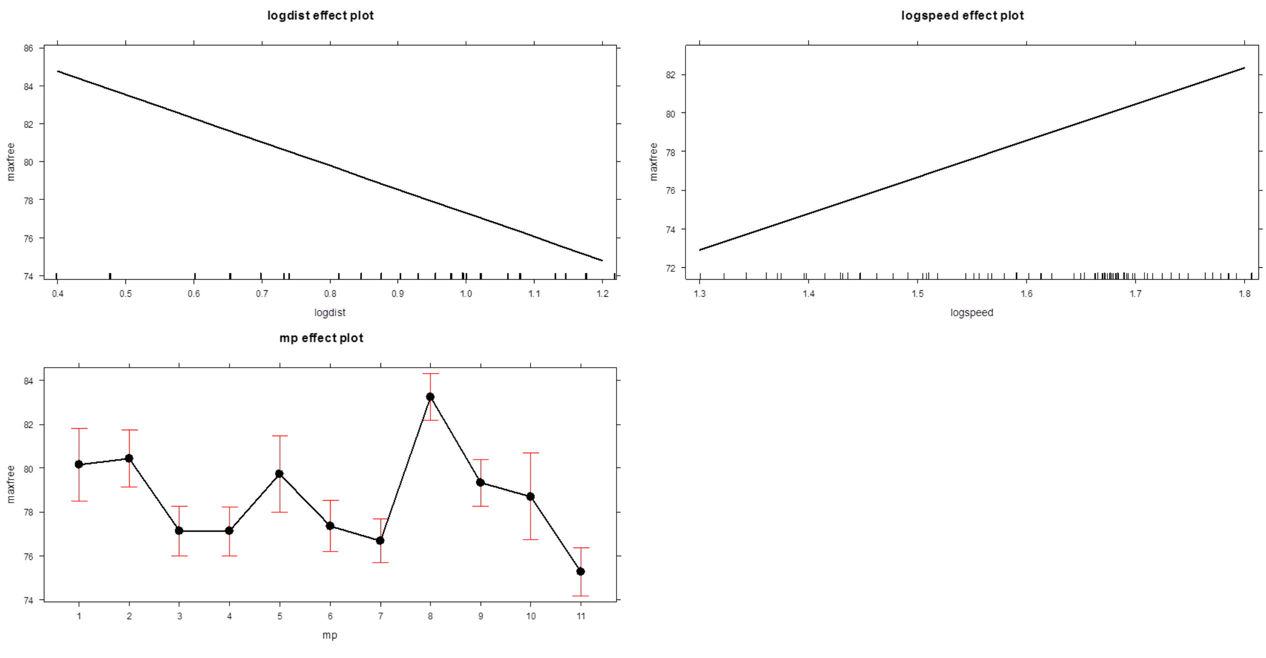

Figure 1, statistical analysis of maximal noise level expressed by distance, speed and immission point

The only facts that could be derived from the first year of the measurement series, was that maximal A-weighted level decreases with distance and increases with vehicle speed. In addition there is considerable variation between immission points. Our experience with the tram noise monitoring program tells us that more information will become available as the program is repeated through some more years. At the current stage the noise monitoring program in itself is insufficient to replace or even improve the standard prediction method [4].

2.2 New measurements of input to the prediction method

In the winter of 2017 new measurements of a- and b-values of the MX 3000 metro trains were performed. The measurements were made on two nights. On each of these nights two microphones and two metro trains were used. The measurements were made on a different site for each of these nights. Controlled speeds ranging from 20 km/h to 70 km/h were used. A total of 88 spectra were used for the analysis of the spectra.

The new measurements gave higher noise levels at low speeds and slightly lower noise levels at high speeds compared to the old values from 2006. The values from 2006 have been used for predictions of noise from the metro lines of Oslo according to the standard prediction method [4] since then. A change in levels was to be expected, as the old values were based on a single microphone and a single 6-car train in a single site and thus did not average out effects due to special properties of the train or the site. Figure 2 shows this difference given by A-weighted values.

Both series of measurements were made on 6-car trains.

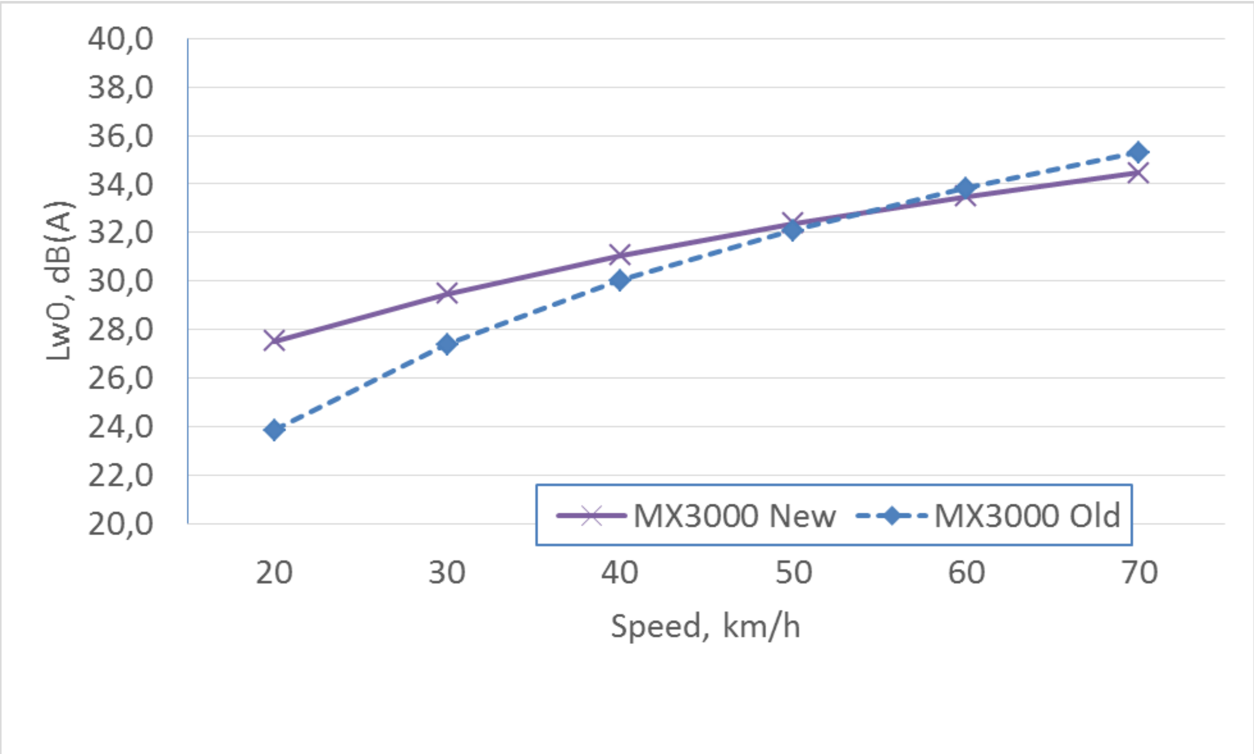

Figure 2, reference levels with old and new a- and b-values

2.3 Comparison between measured in the environmental monitoring program and predicted using new a- and b- values

The first possible test of both the environmental noise monitoring programme and the new a- and b-values was to compare results from the immision points. The test yielded some interesting results.

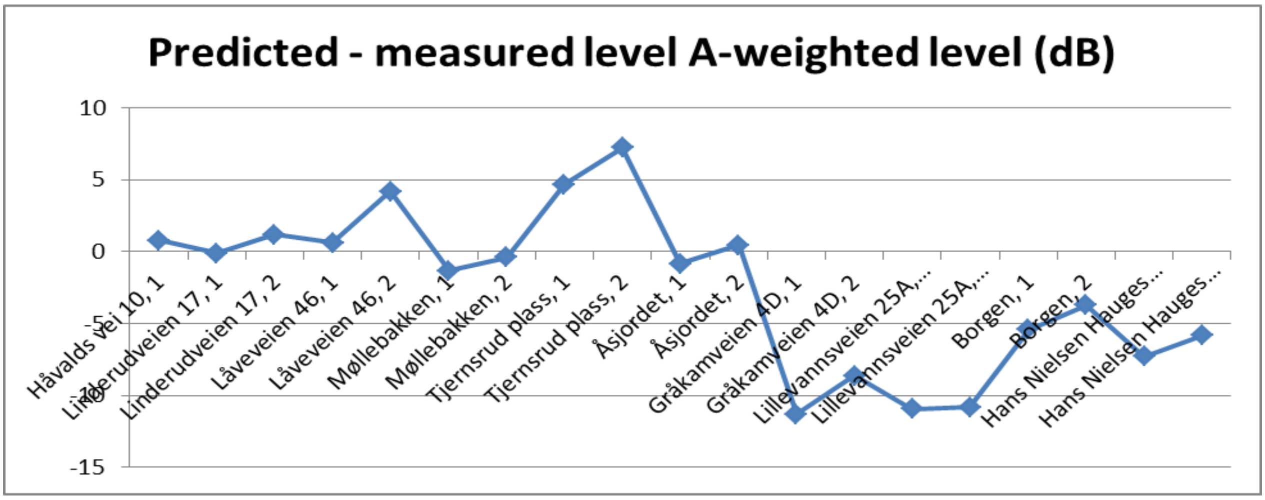

Figure 3, uncorrected difference between predicted and measured level

Figure 3 shows us some anomalies that can be explained and some that cannot easily be explained. We found no good reason for the deviation at Tjernsrud plass, where the new a- and b-values predicted higher values than we actually measured. On some of the other sites, however, we predicted substantially lower levels than we actually measured. Gråkamveien 4D and Lillevannsveien 25 both are along Holmenkollbanen, a line originally built in the early part of the 20th century for slowly moving trams. The geometry of this line is not optimal for a metro train like the Siemens MX, and on this particular line only single trains with 3 cars are used. On the other lines, that have a better geometry, double trains with 6 cars are normally used. At the sites Borgen and Hans Nielsen Hauges gate there are track switches.

An ad hoc solution has been chosen to cope with this problem. The line Holmenkollbanen has patches of sharp curves and steep gradients where the rail is worn down rapidly. We have made measurements in many houses along the line, and in many houses there is a strange noise. Until further knowledge has been gathered we have added a +10 dB correction for the sites along Holmenkollbanen.

For the two sites with track switches the familiar correction of +6 dB has been added. There are two different types of track switches on the metro line of Oslo. It has been assumed that the most recent one of them is quieter than the older type. The experience after the first year does not yet seem to confirm this assumption. After the corrections have been introduced, the difference between predicted and measured level become as shown in figure 4.

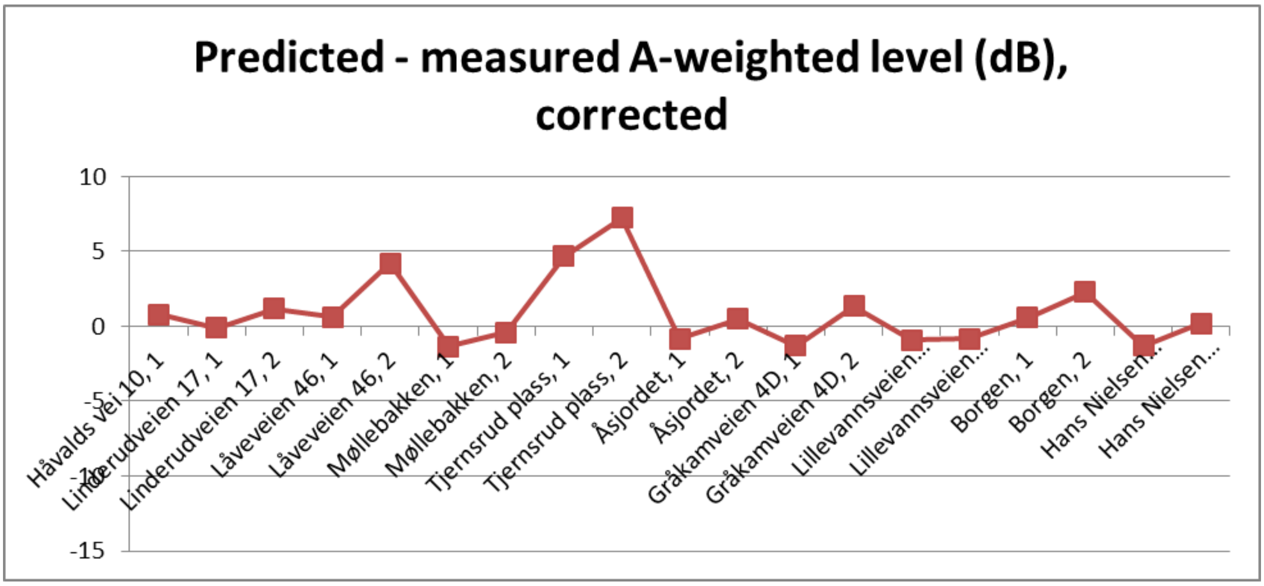

Figure 4, corrected difference between predicted and measured level

3 Method and results – vibrations

Measurements of vibration were made with triaxial geophones placed on the ground under the microphones measuring noise. So far only general trends can be detected. Figure 5 shows vibrations in the x direction (horizontal perpendicular to the track), figure 6 shows vibrations in the y direction (horizontal parallel to the track), and figure 7 shows vertical vibrations, the z direction.

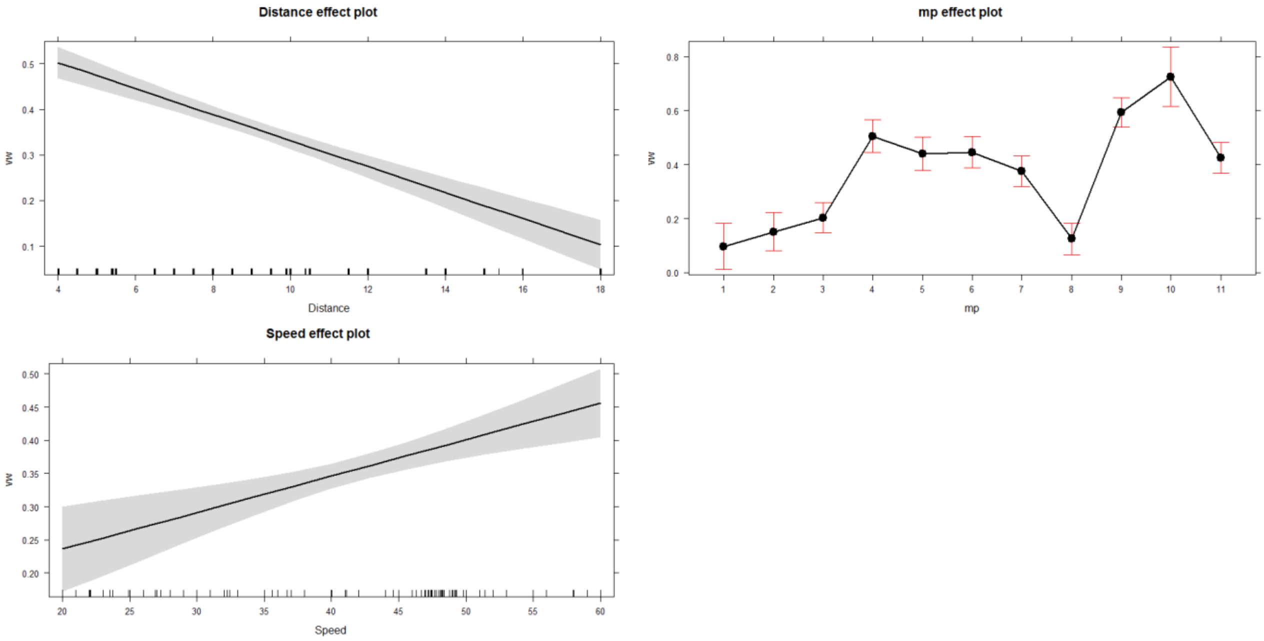

Figure 5, vibrations in the x direction

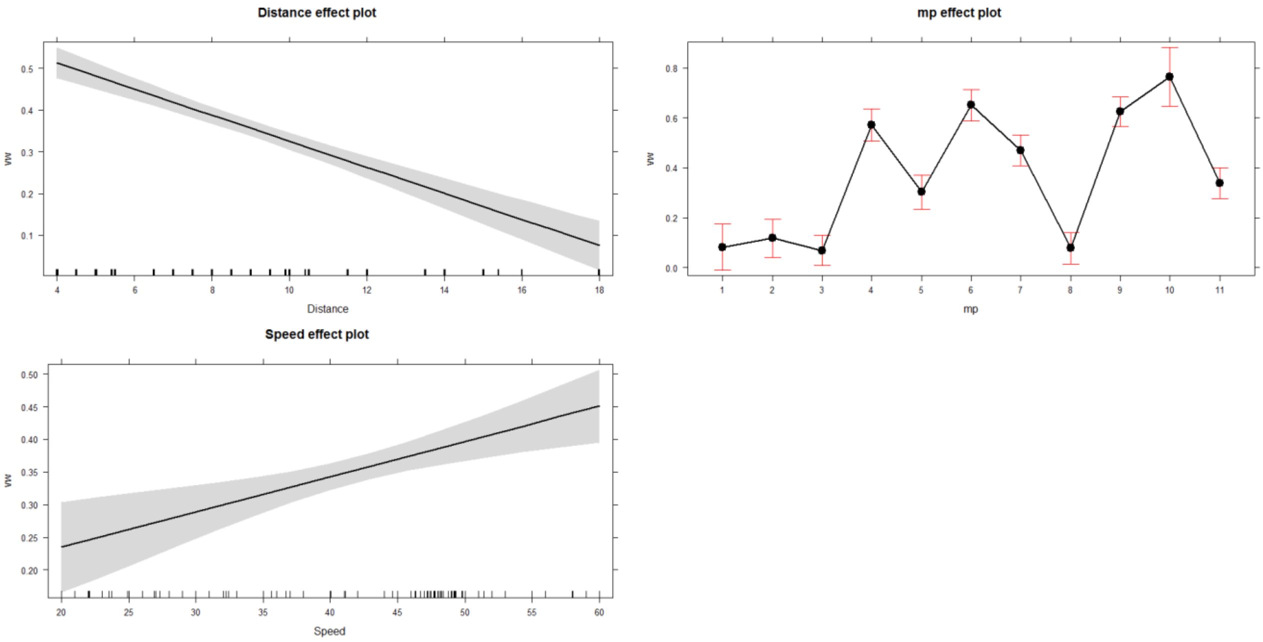

Figure 6, vibrations in the y direction

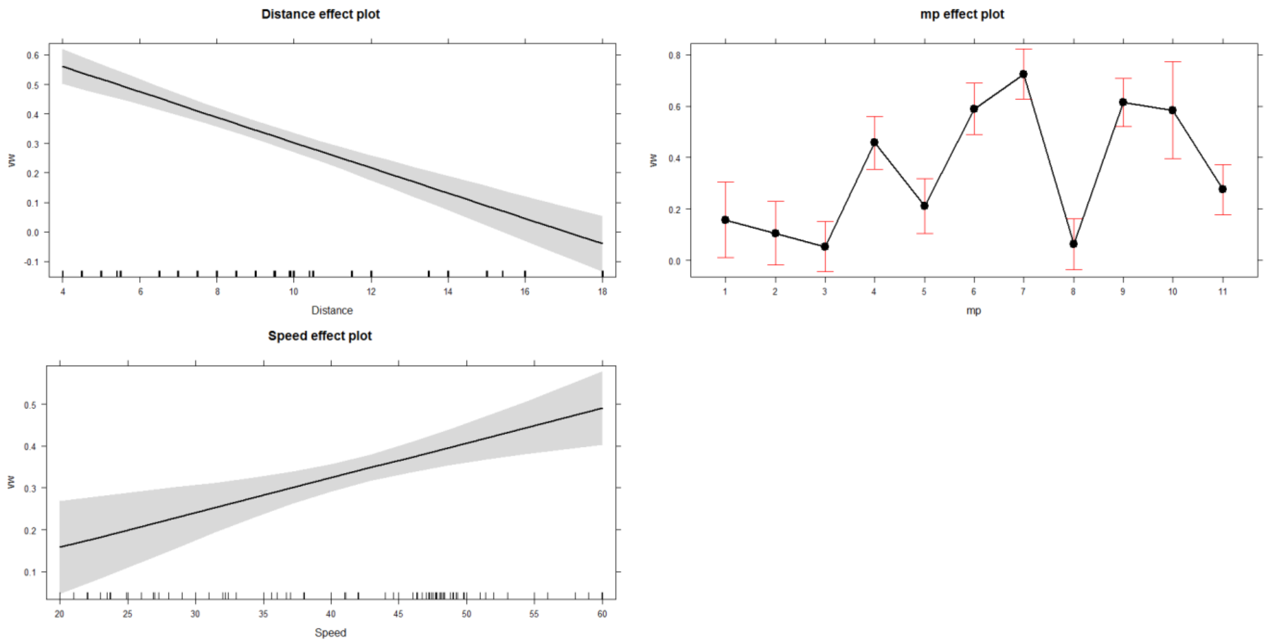

Figure 7, vibrations in the z direction

The presented values are made as effect plots from the statistics program R. It seems there are the same general trends in all dimensions, with vibrations being dependent on train speed and distance in roughly the same way in three dimensions and in the same way at each immission point.

4 Future work

Our main inspiration has been the tram noise (and vibration) monitoring program. We expect to present much more detailed information about Oslo's metro after a few more years. Measurements on the metro have been made in 2017 and a similar series is planned for 2018. There will be more analysis and better conclusions as more data are entered in to the statistics program. This presented paper is based on roughly 200 events at 11 sites, which is only sufficient for a rough overview. We will present updates when we have enough data to present a more complete empirical model including spectrum information for both noise and vibration.

5 Acknowledgements

Our sincere thanks go to Sporveien, the publicly owned company that runs the trams and metros of Oslo. Sporveien has commissioned the consultancy assignments that form the basis of our research.

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