Metronova – research on physical and perceived noise and vibrations from Oslo's metro trains

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ABSTRACT

The Metronova project is a research project about physical and perceived noise from Oslo's metro trains based on consultancy commissions and student assignments. Measurements of noise and vibrations from Oslo's metros since 2007 and an environmental monitoring program with yearly measurements since 2016 form the backbone of the project. In 2014 a survey questionnaire about perceived vibrations were added. In 2019 a study including qualitative research interviews in the homes of neighbors of the metro about their perception of noise and vibrations was added. In the same year we also added laboratory tests of the reactions of several test persons to field recorded sound from metro trains.

New ways of studying noise and its effects are added continuously. It started with traditional measurements of 1/3-octave and A-weighted noise. Since then we have added vibration measurements, survey questionnaires, qualitative research interviews, psychoacoustic parameters and finally laboratory listening tests correlated with A-weighted noise and psychoacoustic parameters.

It would seem that rich data from the project give a good insight towards an understanding of perceived noise from metro trains.

INTRODUCTION

The WHO environmental noise guidelines for the European region [1] give strong recommendations for railway noise. The values quoted for railway noise are L_{den} = 54 dB, L_{night} = 44 dB. These values are based on people being highly annoyed as the primary outcome. It is not obvious that noise from metro lines is perceived in the same way as the railways studied earlier. Sporveien, the publicly owned company that runs the metros of Oslo, has commissioned measurements of physical noise and vibrations for several reasons:

Control of the noise performance of newly constructed or upgraded line
Measurements of noise and vibration in houses where residents have complained
A yearly series of measurements of noise and vibrations as part of an environmental monitoring program.

The metro lines of Oslo transport more than 300,000 persons every day [2]. The metro system is the backbone of Oslo’s public transport. The trains are 115 Siemens MX trains delivered between 2006 and 2011.. Much of the metro lines run above ground. There are currently 5 lines serving 100 stops. Figure 1 shows a train running on one of the lines.

Figure 1, metro train on its way

Much of Oslo’s metro network consists of reconstructed tram lines. The power system is changed, and the superstructure is rebuilt to be able to support 6-car metro trains.

Figure 2 shows a map of the route network. One more line is currently in construction.

It is important for the city of Oslo to accommodate further growth without depending on the private car as a dominant mode of transportation. The metro is excellently suited, as it has an excellent safety record, takes little space and runs independently of other traffic.

Figure 2 – route network for Oslo’s metro. Downloaded from ruter.no

CORE CONCEPT OF THE METRONOVA PROJECT

There is a long history of measurements of standard physical noise and vibration parameters from metro trains in the Oslo area [3,4,5,6,7,8,9,10,11]. It has gradually become clear that measurement of physical noise and vibration is necessary, but not sufficient to prevent complaints about noise and vibration from the metro lines. Research about annoyance due to noise and vibration has gradually been introduced as the WHO guidelines are based on annoyance as the primary health outcome. The first attempt to acquire a better understanding of the perceived situation for the neighbours of the metro lines was a survey questionnaire about vibrations [10,12]. This survey has been kept running since it was first started in 2014.

An important factor in this type of research is relevance. There are no research grants as such included in the Metronova Project. The whole project is based on consultancy assignments and M.Sc. theses.

Experience from the initial survey of perceived vibrations has led to the design of a research program illustrated by figure 3.

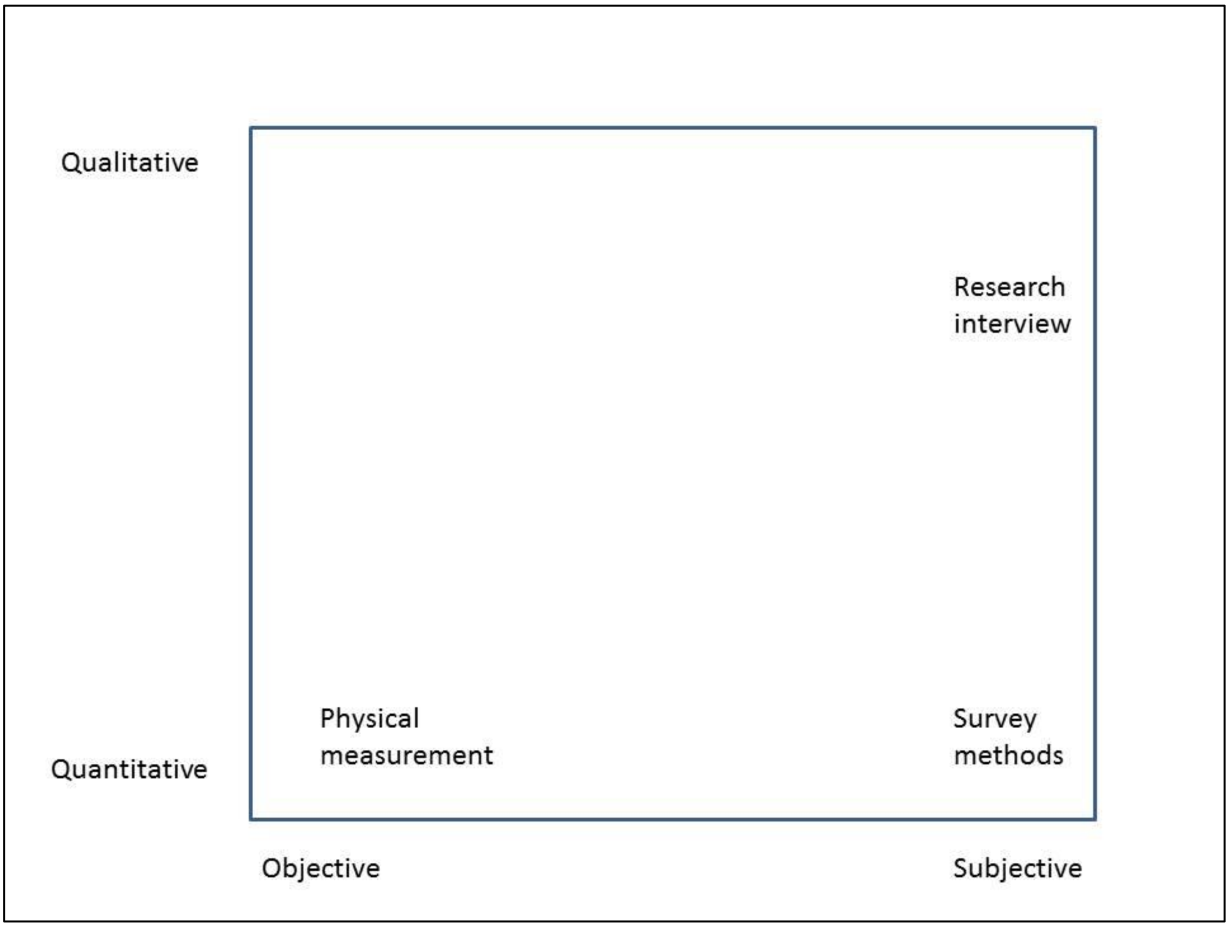

Figure 3 – overview of research programme

DATA ACQUISITION

There are three types of data acquisition that have been used to gather information for the Metronova project:

Quantitative – objective

Quantitative – subjective

Qualitative – subjective

Acquisition of quantitative objective data

The acquisition of quantitative objective data has been performed by 4 different paths:

1.Measurement of outdoor and indoor noise and vibration before and after major reconstruction of both suburban ends of metro line 3 – Montebello to Kolsås and Godlia to Mortensrud. Measurements were made in a large number of houses.

2.Measurement of outdoor and indoor noise and vibration in residences where the people have complained

3.The yearly environmental monitoring program with outdoor measurements at 11 sites once per year since 2016 [11]

4.Almost continuous measurement of noise every second since February 2018 near the track at Skøyenåsen on line 3

Points 1 and 2 have given data from around 100 measurement series. Points 3 and 4 give a way to monitor the trends over time in noise and vibration from the metro trains.

Acquisition of quantitative subjective data

The quantitative subjective data have been gathered using two different methods:

1.The running survey questionnaire about perceived vibration annoyance [10,12]

2.Rating of noisiness of metro sound events played back in the laboratory [13]. Calibrated headphones playing back the recorded signal from a recording made with an artificial head were used in the laboratory tests to ascertain that the signal reaching the listener was as close to identical to the one heard close to the track as possible.

Acquisition of qualitative subjective data

The qualitative subjective data have been gathered using two different methods:

1. Classification of metro sound events played back in the laboratory [14]

2. Interviews with residents living close to the metro in their homes [15]

DATA ANALYSIS - COMMENTS

Noise was originally only measured in 1/3-octave bands and A-weighted. For the yearly environmental monitoring program psychoacoustics parameters were also introduced in 2018 [16,17]. This was made possible by the introduction of recording of the noise and vibration signals. The introduction of recording of the signal also enables later introduction of further parameters for noise and vibration analysis.

The vibration measurements seem to give a very different result than those known earlier [4]. However earlier results were based on measurements made outside and a calculation of indoor vibrations. Our analysis is based on actual measurements of indoor vibrations [7,18] that give much lower values than those based on a combination of outdoor measurements and calculated indoor levels used earlier [4]. This means that our results cannot be directly compared to those used in earlier assessments of vibrations.

RESULTS

The results will be presented as correlations between subjective and objective data as far as conclusions can be drawn. Noise and vibrations will be treated separately.

Perceived noise

The research of Öqvist [15] on how the metro of Oslo is considered to influence the lives of those living nearby can be summarized in a few lines. Oslo's metro is a comfortable, convenient and reliable means of transport from the suburbs to the city centre or to "Marka", the forests surrounding Oslo. On the other hand, it makes so much noise it interrupts conversations outdoors, it makes people use their gardens less, it makes it difficult to entertain guests because it is perceived as noisy for those not accustomed to it. Those interviewed assume that the metro reduces the value of their property. There is only a 3 to 4 hour break between the last train at night and the first train in the morning, meaning that many of those exposed to the noise get interrupted sleep.

Both Monslaup [13] and Broks [14] have investigated the use of other parameters than LAmax, FAST to evaluate noise from metro trains. The parameters used were as follows [16,17]:

- Loudness
- Sharpness
- Roughness
- Tonality
- Fluctuation strength

Both found that loudness and sharpness were the best indicators. Loudness takes into account the different properties of the ear in different level ranges. It also takes into account the temporal variation of the sound. Sharpness depends on the bandwidth of different components of the noise. As a simplified way it can be said that a larger proportion of high frequency components gives a higher sharpness. The formal definition of loudness and sharpness is quite complicated, and there are different implementations of practical ways to determine those parameters. The quoted results are based on the solution built into the software package Artemis from head Acoustics [17]. Monslaup [13] found that a combination of loudness and sharpness gave the best fit to perceived noise when 53 listeners were asked to rate the noise of the metro played through headphones in a laboratory setting. The other psychoacoustic parameters were of little importance.

The regression fit is given in equation 1 below.

$$\text{Annoyance} = 0{,}052407 * \text{loudness} + 1{,}520169 * \text{sharpness} + 1{,}528752 \qquad (1)$$

There is no justification for the number of decimals. It is unlikely that the equation is valid for other noise sources than the metro lines of Oslo. It is given as one result which others can be compared to.

Figure 4 shows the expected annoyance from Monslaup's formula [13] plotted against measured maximal A-weighted level for the same signal.

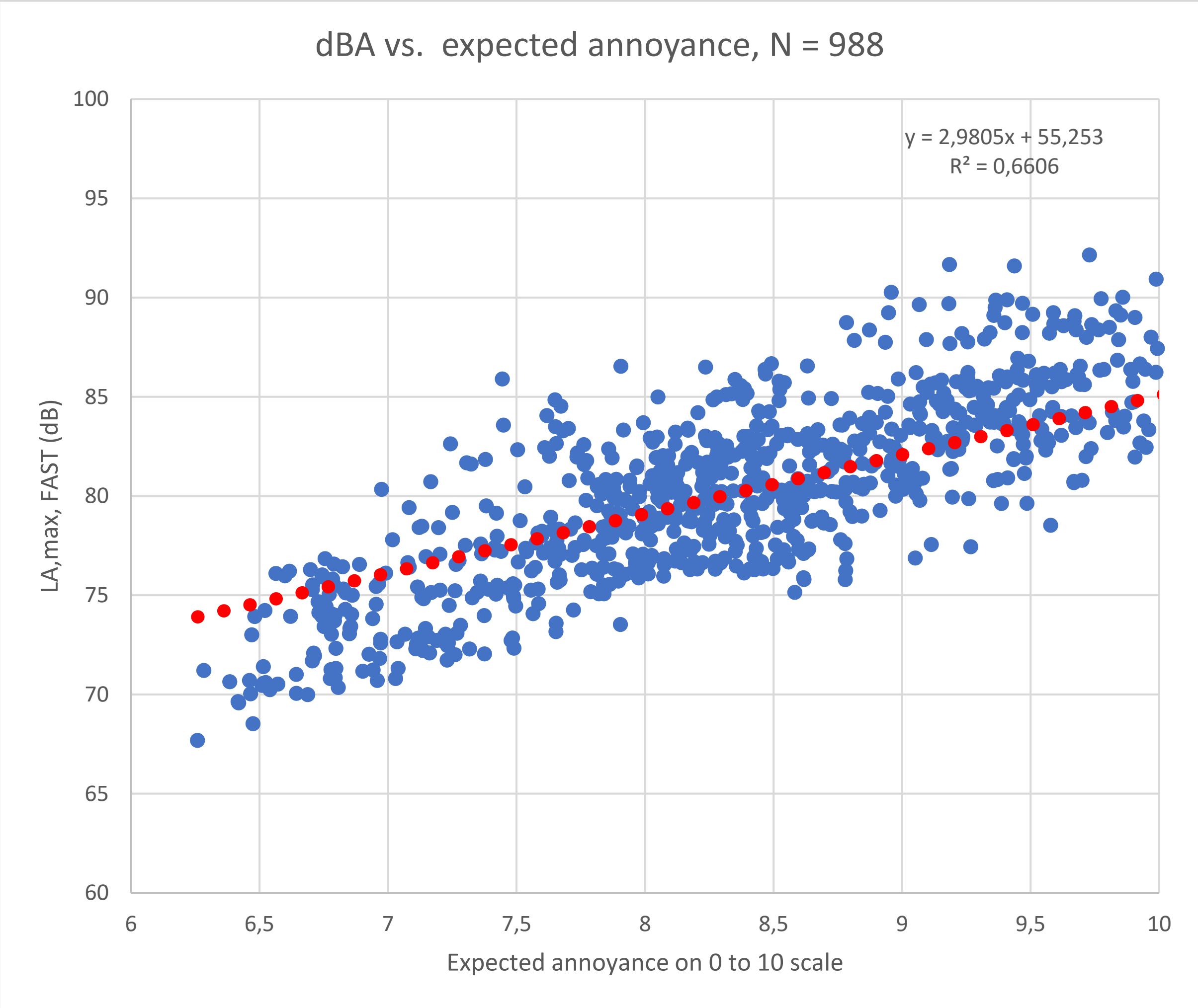

Figure 4, LAmax vs. expected annoyance

The work of Broks [14] is a continuation of a major investigation into description of road traffic noise by Hoffmann [18]. It is the start of a translation of Hoffmann's major work on road traffic noise into another type of transport noise source. Broks shows that sharpness is well suited to discriminate between perceived types of noise from metro trains. He found that roughness and fluctuation are of little importance, which agrees well with the findings of Monslaup.

Interestingly, Broks also found a clear difference between metro trains going uphill and downhill. There was a clear difference in the characterisation of sharpness in different directions for sites in a hill climb. His findings are confirmed by analysis of measurements of more than 3000 passing metro trains showing metro trains uphill and downhill to be two quite different noise sources. Unfortunately this last analysis has not yet been published, but may be made available on request.

Perceived vibration

The Norwegian standard, NS 8176, [4] gives a v_{w95} = 0,3 mm/s as a recommended normal limit for acceptable vibration levels for new situations when transport sources cause the vibrations. This level is meant to give a level which is found acceptable for 80 % of residents exposed to the given vibration.

Our own results based on sending a survey questionnaire to residents living in houses where comprehensive vibration measurement had been made show a quite different result [10,12]. The most updated situation even including some cases from 2021 is shown in figure 5.

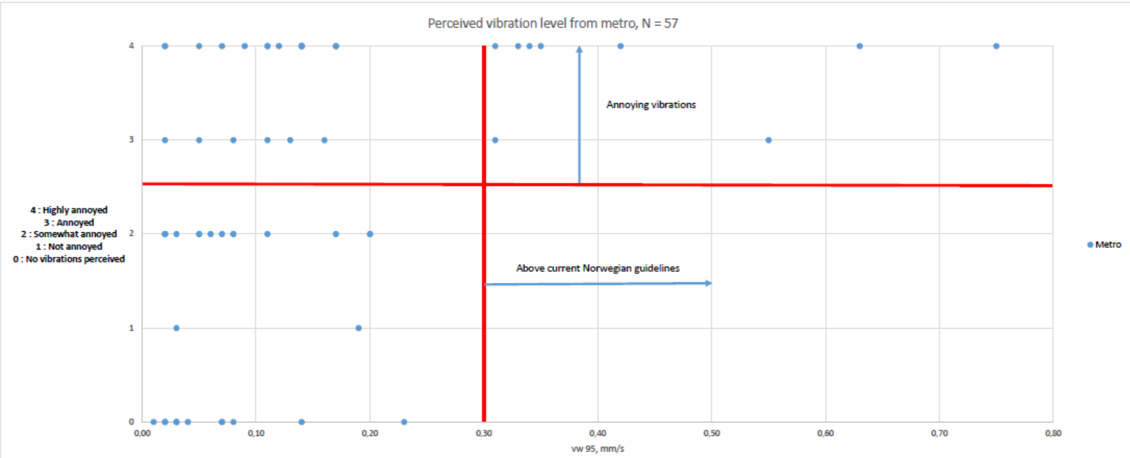

Figure 5 – perceived vibrations from Oslo's metro

The points above the horizontal red line represent respondents annoyed by vibrations. The points to the right of the vertical red line represent measured levels higher than current Norwegian regulations. Our results indicate that all respondents exposed to vibrations above these guidelines are annoyed. A significant proportion of respondents having lower vibration levels also complain about vibrations.

Our result may seem in conflict with the current Norwegian guidelines. The results from the running survey indicates that people are annoyed with vibration levels much lower than expected. There are possible explanations for the discrepancy. For one thing we have used lower vibration levels than those making the basis for NS 8716 [4]. NS 8716 is based on measurements of outdoor vibrations and an assumed amplification in the building. Our measurements indicate that buildings are usually attenuators of vibrations [7,10,19]. This could explain why the respondents in the current study report more annoyance with less vibrations.

There is also the possible uncertainty incurred by the fact that we have been in people’s homes with sufficient instrumentation to map outdoor and indoor noise and vibrations in detail. It would be reasonable to expect that the measurement itself will change the resident’s impression of noise and vibration. There is no way to know how this influence would change the response to a questionnaire. We suspect, without documentation, that one possible effect of a visit could be that people feel that they have been taken seriously. This may be similar to the socalled Hawthorne effect [20], although that effect occurred in a very different situation.

There is even the possibility that the frequency of the metro train passages might change the annoyance. All the metro lines in Oslo have at least 4 trains per hour in each direction. The parameter v_{w95} only takes the statistical distribution of the maximal vibration level during the passage into account, the number of trains are not taken into consideration.

The questionnaire also revealed other factors contributing to annoyance. The only clear message is that vibrations increase in hard winters. It would seem that there is an increase in vibration levels that occurs when the frost has gone down to a certain level. This level is very local. We cannot confirm this by sufficient measurements, but residents have been unanimous.

FURTHER WORK

The metro is excellently suited for research into effects of noise on health. It gives negligible amounts of other types of pollution, no exhaust, minimal wear on rails and wheels, and it presents almost no risk of accidents. Health effects along a metro line could safely be assigned to noise and vibrations.

This is a status report of a project aiming to improve the knowledge of the correlation between physical and perceived noise and vibration from the metro trains in Oslo. The collection of “rich data” in the form of detailed measurements in many points of the physical noise and vibration combined with qualitative in-depth interviews has given valuable insights and will be continued. It would seem that laboratory listening tests and survey questionnaires also have a place in a complete investigation.

Similar projects are just starting for road traffic, urban throughfare and motorway, as well as for the trams of Oslo.

Hopefully the databases acquired can also be of use in future research into the correlation between noise, vibrations and health.

Caution should be exercised in transferring our results to other noise sources and other geographical areas. Norway is not a densely populated area, and it would make sense to assume that Norwegians are particularly sensitive to noise.

Acknowledgements

My sincere thanks are due to Sporveien, the company that runs Oslo's metro lines. Sporveien has commissioned the measurements that form the basis of our research. And of course my thanks go to my colleagues at Brekke & Strand, in particular Teresa Fernández Espejo, Tore Fodnes Killengreen and Alice Hoffmann. Teresa and Tore have both contributed valuable comments to this paper, and they have taken part in literally all aspects of the research, from the field measurements to the analysis of results and the writing of reports. Alice introduced us to psychoacoustical methods and contributed to the design and supervision of the M. Sc. theses that form part of the background for this paper.

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