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Rail roughness surveys – a tool for effective environmental noise control

Lisette MORTENSEN[1]; Stig JUNGE[2]

[1] Banedanmark, Denmark

[2] Sweco Danmark A/S, Denmark

ABSTRACT

A mobile method developed by Sweco to estimate levels of rail roughness on a large scale is presented. The method is suitable for countrywide surveys and the data has proved to be very useful in the planning of track maintenance both in terms of environmental noise and rail quality. Roughness measurements were carried out twice on the Danish railway network in a two-year period, and all roughness data from these campaigns was been stored in Banedanmark's track measurement database. Banedanmark has developed a tool to rank track sections according to rail quality and population density in residential areas to most effectively reduce the amount of environmental noise from the track and to document the effect of noise reduction measures. The measurement method uses measurement of noise from the contact point between wheel and rail to derive an estimate of the rail roughness level and is based on the transfer function from rail roughness to acoustical noise. The method has been tested at measurement train speeds from 60 - 120 km/h and shows a high degree of reproducibility. Banedanmark has given these measurements a significant role in planning the large-scale maintenance operations of grinding and milling.

Keywords: Rail roughness, Environmental noise strategy

1. INTRODUCTION

Rail and wheel roughness is the main cause of rolling noise from passing trains. Infrastructure owners therefore have an interest in regular monitoring of the rail roughness. Methods for direct measurement of the rail roughness have been standardized (1,2) but they require direct contact with the rail head surface and only allow for measurement of very short rail sections. They are therefore not useful for overall surveys of the rail roughness on a complete railway network.

Indirect, i.e., contactless, measurement of rail roughness allows for measurement of longer track sections and has to some extent been performed on railway networks through the last years. Sweco has developed a method for contactless measurement using surface microphones mounted on a plate fixture. Two country-wide measurement campaigns have been done, one in May 2017 and the other in September 2018.

The results from these measurement campaigns are made available to staff responsible for handling noise complaints and the data is used to check if there are excessive roughness levels in the rail or local defects that may cause excessive noise – thus facilitating a clear and qualified response to the complainants.

Also, a tool for prioritization of noise reducing measures like grinding or milling has been developed which is based on the roughness measurements and which combine these measurements with information on population density along the railway.

2. METHOD OF MEASUREMENT

The contactless method uses surface microphones to measure the noise from the wheel/rail contact point. Using the transfer function from rail roughness to noise while taking the travelling speed into account an estimate of the rail roughness can be found.

[1] limo@bane.dk
[2] stig.junge@sweco.dk

Basically, the transfer function from roughness to noise, $L_{H,r}$ *(f)*, is subtracted from the noise spectrum, L_p *(f)* and then transferred from the frequency domain to the wavelength domain using the relation between roughness wavelength, noise frequency and train speed (2)

$$L_r(f) = L_p(f) - L_{H,r}(f) \quad (1)$$

$$L_r(\lambda) = L_r\big(f(V,\lambda)\big) \quad (2)$$

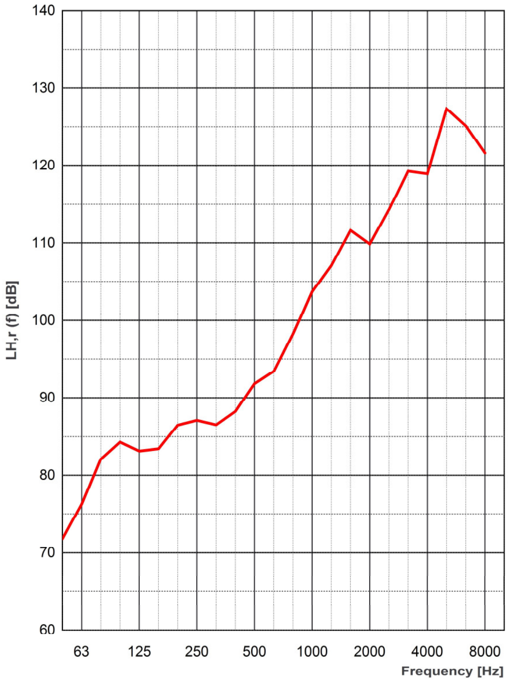
Figure 1 shows the microphone fixture fitted with two G.R.A.S. surface microphones with turbulence grid.

Figure 1 – microphone fixture mounted with two surface microphones

Until now, two country-wide surveys have been carried out. The first was in May 2017 using a pocket car type Sggmrss with disc brakes. Due to problems with car rental the second campaign in September 2018 used an old car based on the Bpmz wagon type.

Before measurement, the cars had to be calibrated, i.e., the transfer function from rail roughness had to be found per 3rd-octave. The transfer functions were measured on both rails in three cross sections of the track and at three speeds covering the range from 60 to 120 km/h. The transfer functions were derived from simultaneous measurement of noise on the test wagon and of combined roughness from the wheel and track in the cross sections. All transfer functions were averaged resulting in the transfer function used in the subsequent roughness survey measurements. Figure 2 shows the average transfer function.

Output from the method is the average contact point filtered rail surface roughness level on the line that the measurement car's wheels follows on the rail. The noise from all irregularities in the track that are not rail roughness (switches, isolated joints, local defects etc.) are also interpreted as rail roughness and should rather be called equivalent rail roughness. On track sections where the transfer function is unknown (in tunnels, along platforms, on bridges) the measured roughness will not be correct but can in many cases point to some important track features that needs further investigation.



Freq. [Hz]	LH,r [dB]
50	71,8
63	76,2
80	82,1
100	84,3
125	83,1
160	83,4
200	86,5
250	87,1
315	86,5
400	88,2
500	91,8
630	93,4
800	98,3
1000	103,7
1250	107,1
1600	111,6
2000	109,9
2500	114,3
3150	119,2
4000	118,9
5000	127,3
6300	125,1
8000	121,6

Figure 2 – Average transfer function for car type Bpmz

Data sets are output per 1 meter track with each data set consisting of an average 3rd-octave roughness spectrum and a single value indicator, $L_{\lambda CA,v}$ (3) that relates to the environmental noise impact.

The reproducibility of the method is quite good. Figure 3 shows measured levels of $L_{\lambda CA,v}$ at three different speeds, 60, 90 and 120 km/h. The originally measured noise levels prior to conversion to rail roughness is shown in Figure 4.

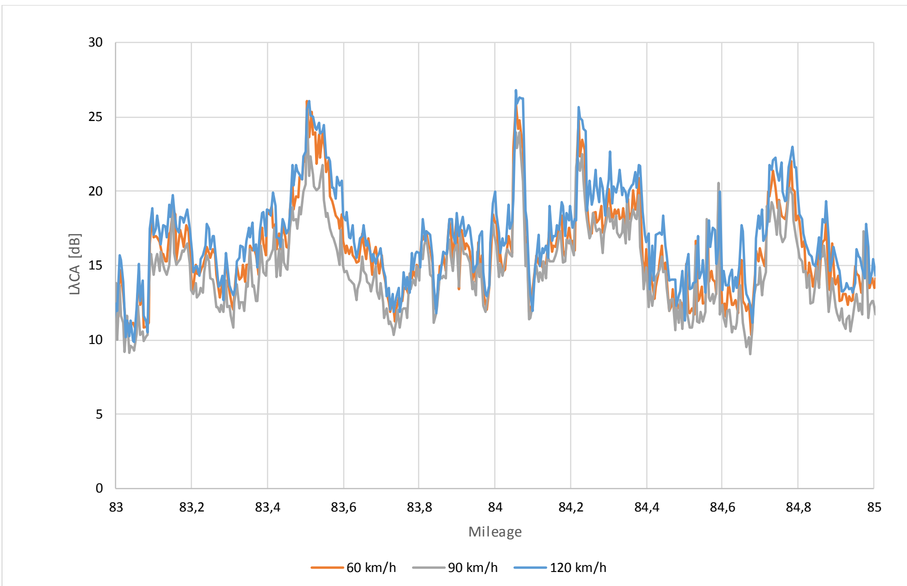


Figure 3 – $L_{\lambda CA,120}$ measured at three different speeds

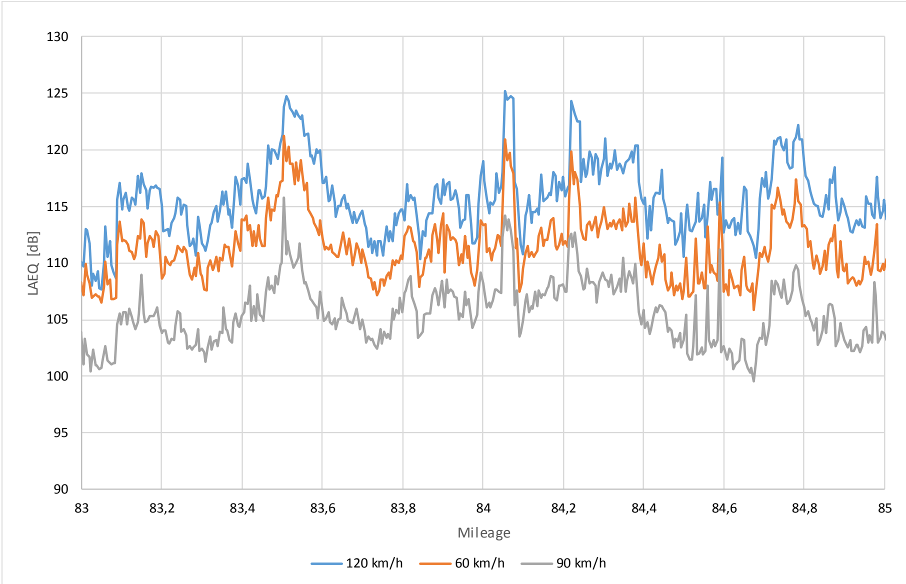


Figure 4 – Original noise levels, L_{AEQ} measured at three different speeds

Subsequent measurements have shown that the method yields valid data down to a travelling speed of 40 km/h thus making it possible to measure at stations where the population density typically is high.

3. NOISE COMPLAINTS HANDLING

Banedanmark regularly receives noise complaints from people living close to the railway. Until recently the staff responsible for handling these complaints had no detailed information about the track condition in terms of noise.

The roughness measurements have changed this since all roughness measurements have been made available to the staff responsible for answering the complainants. They now have a tool for assessing the track condition in general, and specifically if there are any track elements that cause excessive noise, and this enables them to give much more precise and qualified answers to complainants. An example of data presentation in GIS is shown in Figure 5. The roughness levels are colour coded with high levels shown in red or even pink. In this case high levels are seen at the switch in the upper part of the figure, at isolated joints in the middle and at the level crossing in the lower part.

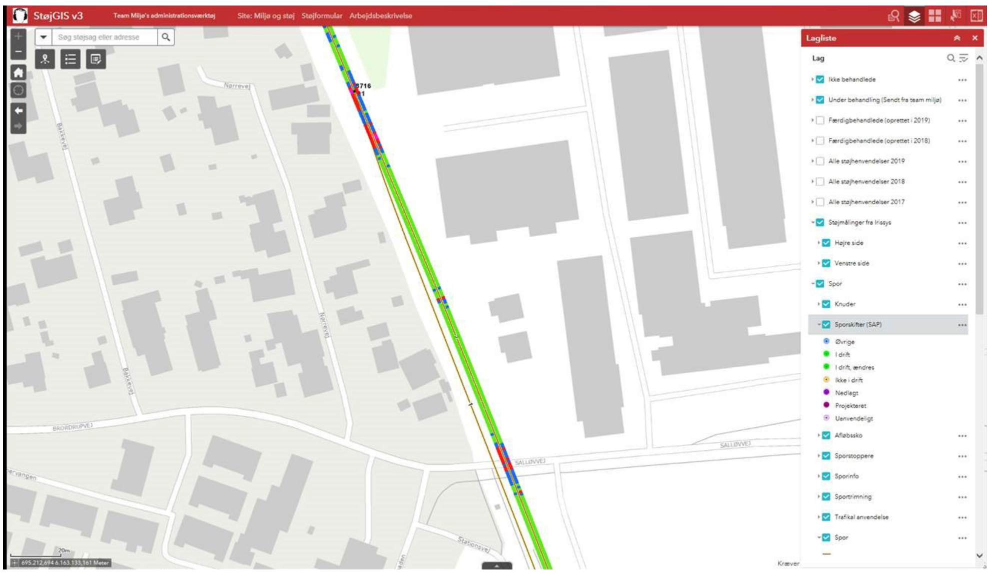


Figure 5 – Presentation of roughness levels in GIS

4. PRIORITAZION TOOL FOR ENVIRONMENTAL NOISE REDUCTION

Banedanmark has developed a GIS-based tool for prioritization and documentation of noise reducing measures along the railway lines based on rail roughness data. This tool helps Banedanmark to prioritize noise reducing activities like grinding and milling from a more socio-economic point of view and to document the environmental effect. General maintenance of tracks will naturally yield a reduction in noise levels along the railway, but the funds for maintenance and environmental issues are prioritized differently, and maintenance does not necessarily take place in densely populated areas.

4.1 Background

In the period from 1986-2014 Banedanmark ran a noise abatement program, where all dwellings in Denmark with a façade noise impact higher than the specified noise limit have been protected with either noise insulation or/and noise screens. This strategy covered both noise from the track as well as from the railway operators. In 2015, Banedanmark changed this strategy and decided to focus on the noise from the track and wherever possible to reduce the noise at the source and not at the receivers. The aim was to lower the cost for noise reduction and thereby to be able to lower the noise for a lot more people but with the same economical costs. By setting higher standards for the infrastructure in terms of more smooth rails with less surface defects Banedanmark as the infrastructure manager has set a standard for the different operators which encourages them to strengthen their cooperation on this issue and this is expected to lead towards preventive maintenance replacing remedial measures. Some of the initiatives that have been taken have been the sharing of data from Banedanmark's different axle load stations around Denmark aimed at making the operators improve the quality of their wheels and the development of a management system that forces the different operators to run with a higher wheel and load standard than before. Another initiative is the use of roughness data for prioritization and documentation of noise reducing measures.

4.2 Parameters for optimization

The prioritization tool is based on several track parameters that have a profound influence on the noise level and on the population density along the railway. By establishing a model for the weighting of these parameters, all lines and track sections can be prioritized in relation to each other with the aim that in the case of repair/maintenance the most socio-economic noise reduction can be obtained in the most densely populated areas.

To assess the maintenance condition on the individual line it is necessary to know the "roughness level"/track quality of the average "normal situation" - where maintenance is not needed. By comparing the measured levels on the individual lines with the "normal situation" lines with a high roughness level can be identified. In combination with knowledge of the characteristics of the infrastructure (e.g. placing of welds, insulation joints, switches, etc.) and the cost of remediation a reduction in noise emission relative to the repair cost can be calculated.

The following parameters must be uncovered:

1. The roughness level for the "normal situation" in general and for selected track elements as isolated joints, switches, etc., where there will be differences as to what an acceptable level is.
2. The equivalent roughness level of the individual track elements – switches, crossings, isolated joints - that will trigger maintenance, i.e., the criterion level for triggering need of maintenance.
3. The effect of the various maintenance methods measured as a reduction in roughness level.

Staticical analyses of all results from the first campaign in 2017 showed that the average roughness level in terms of $L_{\lambda CA,line\ speed}$ is 11.9 dB. This covers a great variation of levels – some of them up to about 30 dB. Equivalent roughness levels for track components vary somewhat more with levels up to as high as 45 dB in single cases.

The effect of grinding and milling has been estimated for at 100-kilometer line by comparing roughness levels from the 2017 and 2018 campaign on sections where one of these activities had been performed. This analysis should be extended to more lines, but the first results are shown in figure 6.

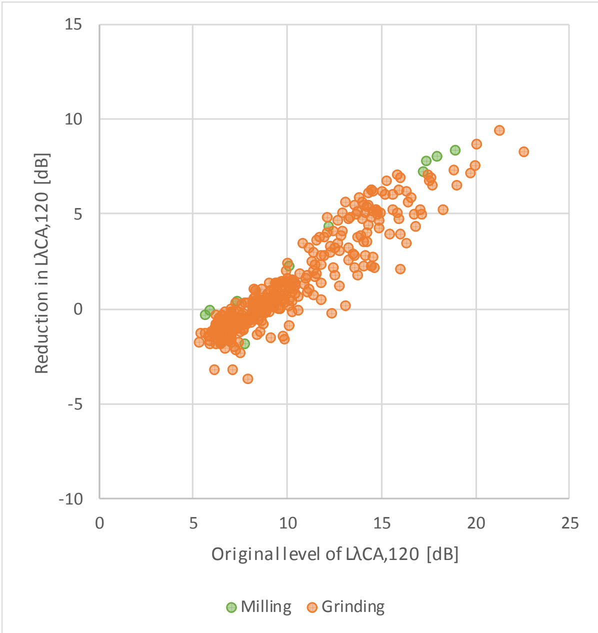


Figure 6 – Effect of grinding and milling

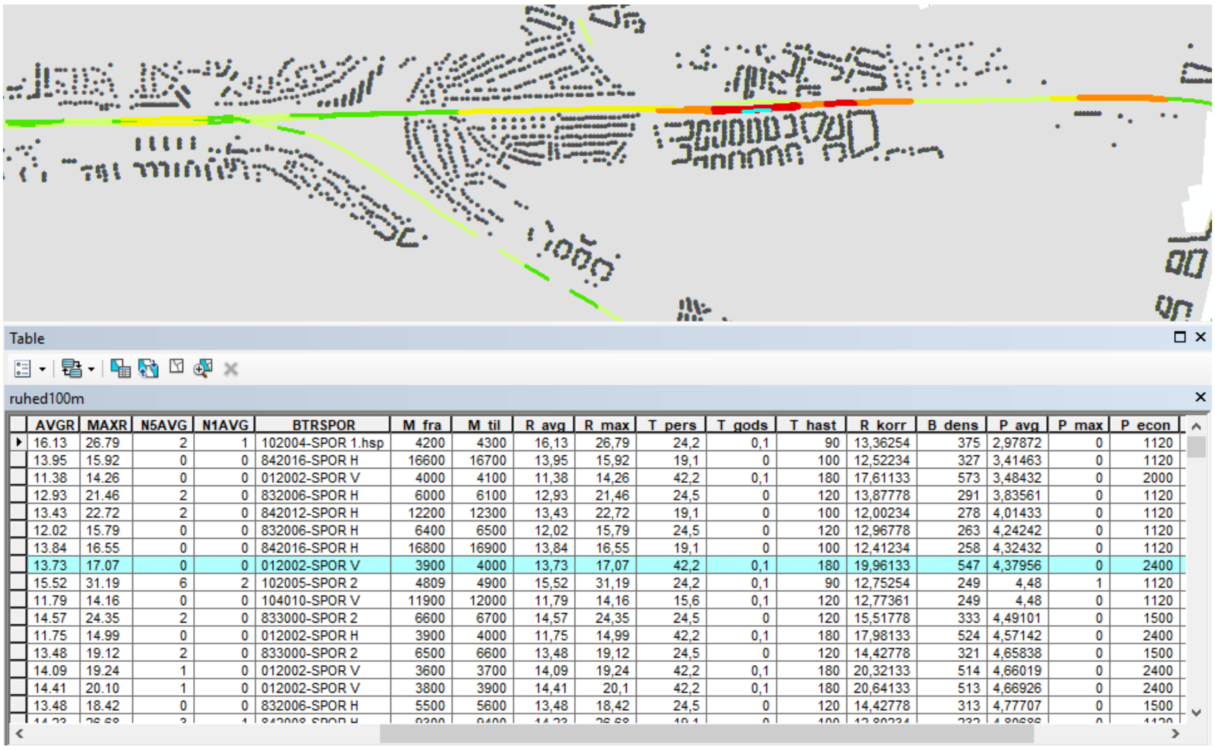
Grinding and milling is typically done on track sections of a certain length and an important thing to consider when planning maintenance is therefore to decide on the minimum section length that makes sense from an economical point of view. As a starting point, Banedanmark has therefore chosen to aggregate data at every 100 meters length of track.

Table 1 – Parameters included in the prioritization tool

Parameter	Description	Function
Roughness	Average roughness per 100 m track section	Input for calculating roughness compared with the average level
Maximum level	Maximum level and number of maximum levels per 100 m track section	Difference from average level is combined with placement of switches or insulations joints for identifying critical spots
Amount/mix of trains	Train length per 24 hours for passenger and freight trains	Included in the correction for roughness
Train speed	Line speed for passenger and freight trains	Included in the correction for roughness
Population density	Relative density of residential buildings and distance to the railway	Distance to dwellings combined with density scored in relevant intervals
Maintenance need	Effect of various maintenance methods	Scores at relevant intervals and is included in weighting
Maintenance costs	Cost for maintenance types	Includes weighting together with other parameters

4.3 Implementation in GIS

The prioritization tool is implemented in GIS, where it is possible to extract information with various levels of details. Figure 7 is a screenshot from the GIS showing a table with the track sections prioritized and a map where track sections are color coded according to priority.



AVGR	MAXR	N5AVG	N1AVG	BTRSPOR	M fra	M til	R avg	R max	T pers	T gods	T hast	R korr	B dens	P avg	P max	P econ
16.13	26.79	2	1	102004-SPOR 1.hsp	4200	4300	16,13	26,79	24,2	0,1	90	13,36254	375	2,97872	0	1120
13.95	15.92	0	0	842016-SPOR H	16600	16700	13,95	15,92	19,1	0	100	12,52234	327	3,41463	0	1120
11.38	14.26	0	0	012002-SPOR V	4000	4100	11,38	14,26	42,2	0,1	180	17,61133	573	3,48432	0	2000
12.93	21.46	2	0	832006-SPOR H	6000	6100	12,93	21,46	24,5	0	120	13,87778	291	3,83561	0	1120
13.43	22.72	2	0	842012-SPOR H	12200	12300	13,43	22,72	19,1	0	100	12,00234	278	4,01433	0	1120
12.02	15.79	0	0	832006-SPOR H	6400	6500	12,02	15,79	24,5	0	120	12,96778	263	4,24242	0	1120
13.84	16.55	0	0	842016-SPOR H	16800	16900	13,84	16,55	19,1	0	100	12,41234	258	4,32432	0	1120
13.73	17.07	0	0	012002-SPOR V	3900	4000	13,73	17,07	42,2	0,1	180	19,96133	547	4,37956	0	2400
15.52	31.19	6	2	102005-SPOR 2	4809	4900	15,52	31,19	24,2	0,1	90	12,75254	249	4,48	1	1120
11.79	14.16	0	0	104010-SPOR V	11900	12000	11,79	14,16	15,6	0,1	120	12,77361	249	4,48	0	1120
14.57	24.35	2	0	833000-SPOR 2	6600	6700	14,57	24,35	24,5	0	120	15,51778	333	4,49101	0	1500
11.75	14.99	0	0	012002-SPOR H	3900	4000	11,75	14,99	42,2	0,1	180	17,98133	524	4,57142	0	2400
13.48	19.12	2	0	833000-SPOR 2	6500	6600	13,48	19,12	24,5	0	120	14,42778	321	4,65838	0	1500
14.09	19.24	1	0	012002-SPOR V	3600	3700	14,09	19,24	42,2	0,1	180	20,32133	514	4,66019	0	2400
14.41	20.10	1	0	012002-SPOR V	3800	3900	14,41	20,1	42,2	0,1	180	20,64133	513	4,66926	0	2400
13.48	18.42	0	0	832006-SPOR H	5500	5600	13,48	18,42	24,5	0	120	14,42778	313	4,77707	0	1500

Figure 7 – Screenshot with measured roughness weighted according to speed, traffic, density and economy

The aggregated roughness for the 100-metres sections therefore needs to be geocoded in relation to the track theme in GIS. Data can then be combined with data relating to train types (share of freight and passenger trains) and speed of the relevant track sections, as these parameters have an impact on the noise emitted to the surroundings.

Once the maintenance method has been selected the effect in terms of roughness reduction in relation to economical costs and building density along the railway can be assessed and prioritized.

5. CONSEQUENCES FOR GENERAL MAINTENANCE

Besides the obvious use of data to prioritize maintenance according to rail roughness in combination with population density these data have also proved to be of great use for planning of general maintenance (3). The data reveals a lot about the quality of the rail head surface and in combination with e.g. pictures of the railheads provided by the traditional measuring cars Banedanmark has been able to identify a substantial amount of rail defects not detected by other methods like e.g. ultrasound measurement. These include bad weldings, periodically spaced imprints from wheel flats, badly isolated joints, bad switches etc. Identifying and removing these faults at an early stage have great economic benefits.

6. SUMMARY

Over the past two years rail roughness surveys have become an important part of Banedanmark's strategy to reduce the environmental noise from the railway.

Staff responsible for answering noise complaints now have an efficient tool for assessing the track condition and can give more qualified answers to complainants.

The prioritization tool described here for the socio-economic optimization of noise reducing measures like grinding and milling etc. will ensure that the funds available for these activities are used in the most effective way. Documentation of the environmental effects of these measures is part of the tool and will strengthen the arguments for prioritizing funding of these activities in political decision-making.

Lastly, the roughness data have been used to plan the maintenance in terms of milling and grinding in 2019 and has also proven to be an effective tool in finding rail surface defects at an early stage resulting in financial savings.

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