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Implementation of rail roughness control: how to deal with a non-ideal world

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ABSTRACT

At the end of 2014, rail roughness control was first applied on a significant scale on the Dutch conventional rail network. Due to a traffic increase between Groningen and Leeuwarden, the noise emission was expected to exceed the legal limits obliging ProRail to take counter measures. Traditional noise mitigation measures (noise barriers) were planned, but it takes some time before these are in effect. ProRail decided to use rail roughness control to bridge this timespan.

The grinding company, the infrastructure manager and the monitoring and consultancy company together shaped a program to control the roughness. In this paper, we will show the complete process of the implementation of a rail roughness control program in a real-life situation.

We specified the desired noise reduction, based on the legal requirements and translated this into a desired rail condition. We then devised and carried out a monitoring program: a combination of periodic stationary and dynamic (on-board) measurements. We will describe how we dealt with real-life situations such as changes in superstructure, bridges, switches, speed variations etc. and how the monitoring results can be communicated with the authorities, to show that the achieved rail condition is in compliance with the legal limits.

Keywords: Rail roughness control, noise ceiling I-INCE Classification of Subjects Number(s): 11.7.2

1. INTRODUCTION

Rail roughness control is an effective noise mitigation measure that works at the source. By reducing the rail roughness level, the total mechanical excitation of the wheel and the rail in the wheel-rail contact area is reduced and hence the rolling noise emission.

The working principle of rail roughness control is well-known and well-accepted (1). And although this measure is applied in several countries, the mitigation method is not (yet) widespread. When the mitigation method is applied, there are a number of practical issues that need to be dealt with, that is uncommon for other noise mitigation methods such as noise barriers or rail dampers. These issues are technical (How can we specify the desired result? What is the accuracy of the monitoring method?) and non-technical (When and how do I plan the large scale grinding activities? Who pays for the grinding: the projects or the maintenance department of the infrastructure provider?). Many infrastructure providers have little to no experience dealing with these issues. In this paper we will show how we dealt with these issues and share our experiences using a real-life example: grinding control on the railway line between Groningen and Leeuwarden.

2. THE PLANNING PHASE

2.1 Choice for rail roughness control

The Groningen-Leeuwarden line (see Figure 1) is situated in the North of the Netherlands and is about 53 kilometer in distance and consists of single and double track (80 km of single track in total). The passenger traffic on this line is operated by ARRIVA with Stadler GTW DMUs. There is a very

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small fraction of freight trains. This means that almost all vehicles that run on this line are disc-braked and hence that wheel- and rail- roughness play an equal part in the excitation of rolling noise on this line.

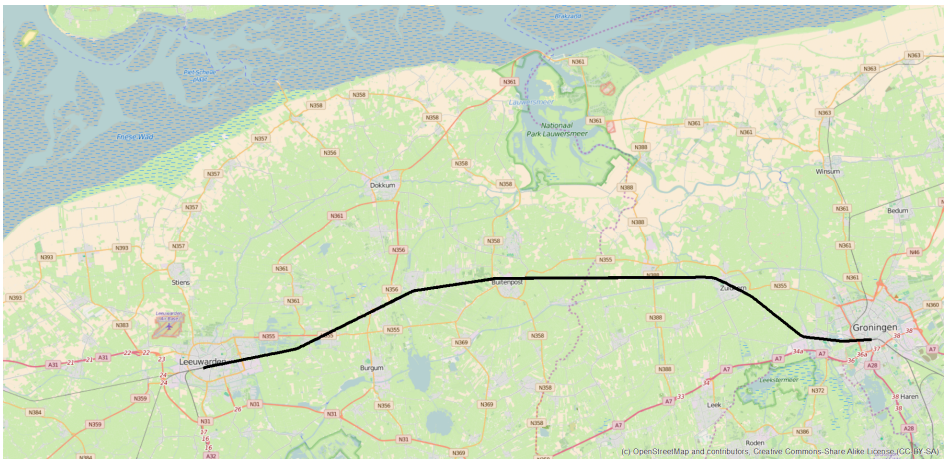

Figure 1 – The Groningen-Leeuwarden line. Chainage values start in Leeuwarden at kmp 26.8 and end in Groningen at kmp 80.1.

For the future, a significant increase in the passenger volume is foreseen. To accommodate this traffic increase, ProRail was obliged to take noise mitigation measures. For the long run, a combination of noise barriers, and exchange of wooden sleepers for concrete sleepers was chosen as a noise mitigation measure. However, the realization of these measures takes time and without measures, a traffic increase would lead to (temporary) exceedance of the so-called noise production ceilings. These ceilings are limit values for the noise immission in order to protect the surroundings of railway infrastructure against the negative noise effects of traffic growth.

Under the current national legislation, ProRail needs to comply with noise production ceilings at all times. This means that traffic is not allowed to grow until the noise reduction measures are in place. To overcome the timespan until the permanent noise mitigation measures are realized, ProRail decided to use rail roughness control as a temporary noise mitigation measure. The considerations for this choice were the following clear benefits:

- As a temporary measure rail roughness control is well-suited because it is implemented as a maintenance action. It can be started and stopped according to needs, without capital being wasted;
- The time to implement the measure is very short because:
    - rail grinding is already incorporated in the working process of the infrastructure provider;
    - there is no design and construct phase for this measure;
- It can be applied both to great track lengths and locally, whatever is required.

These benefits outweighed the following practical issues and skepticism:

- *Rail grinding will take away metal and hence decreases the lifetime of the rail and increases the life cycle costs*: the material removal for acoustic finishing is very small and insignificant when the acoustic finishing is combined with regular preventive and/or corrective grinding. Studies indicate that regular grinding increases the lifetime;
- *Rail grinding increases the total maintenance costs*: true, but it also decreases the investments in other noise mitigation measures. In practice, budget needs to be transferred from the project department to the maintenance department.
- *Rail grinding interferes with the regular grinding*: true, and it is very cost-effective when acoustic grinding is combined with regular grinding. The maintenance department has to integrate the acoustic grinding to its normal maintenance program (just as they have to change their maintenance when rail dampers are applied).
- *The effect of rail grinding is eliminated by freight trains*: true only when the majority of traffic has only cast-iron block brakes, but in case of disc-braked or LL/K-block braked (freight) vehicles, the effect is the same as for passenger trains (which are normally disc-braked). The

trend for the future is that more and more cast-iron braked vehicles are retrofitted with LL-blocks so the effectiveness of rail grinding as a noise reduction measure will increase.

- *It only works for rolling noise*: true. In this respect it is similar to wheel- or rail dampers. Noise barriers are also effective for other (low) noise sources (e.g. drive-train, compressor, HVC noise etc.).

The aim of rail roughness control as a noise reduction measure was to get a noise reduction of about 1 to 1.5 dB at critical sections on the line. In the next section we will show how such a requirement can be translated to a roughness parameter.

2.2 Defining the desired result

2.2.1 In terms of noise reduction

The Dutch noise calculation scheme (2) indicates how to express a noise reduction (or more precisely a change to the noise emission component) as a function of rail and wheel roughness. It is expressed as a coefficient that modifies the noise emission: $C_{\text{roughness},i,c}$ depending on frequency (octave band i) and vehicle category c as:

$$C_{\text{roughness},i,c} = (L_{\text{r},i,\text{track,actual}} \oplus L_{\text{r},i,\text{vehicle},c}) - (L_{\text{r},i,\text{track,reference}} \oplus L_{\text{r},i,\text{vehicle},c}) \quad (1)$$

with $L_{\text{r},i,\text{track,actual}}$ as the actual track roughness level, $L_{\text{r},i,\text{track,reference}}$ as the reference rail roughness level (i.e. the Dutch average roughness and $L_{\text{r},i,\text{vehicle},c}$ as the wheel roughness level. The index i denotes the frequency octave band, c denotes the vehicle category and $\oplus$ denotes energetic summation. This expression states that the noise reduction due to rail grinding depends on the difference between:

- the combined roughness of wheel and rail of the actual (ground) section
- compared to the combined roughness of the reference situation.

Because frequency and roughness wavelength are interlinked with the relation $f=v/\lambda$, it implicitly relates the noise reduction to the vehicle speed.

2.2.2 In terms of rail roughness spectrum

Equation (1) shows that if we would like to reduce the rolling noise in a certain wavelength by a number of decibels, we have to reduce the combined roughness with the same number of decibels. Given the vehicle's wheel roughness (which is an average for disc-braked wheels in the case of the Groningen-Leeuwarden track) we can derive a rail roughness to achieve this.

Since we require a different noise reduction at each part of the line, we could define a desired rail roughness for each part of the line. In practice this is difficult to use . In the Netherlands, we therefore use a standardized reduced roughness spectrum in the calculation scheme. Since the noise reduction depends on speed, there is a standardized spectrum for speeds below and speeds above 200 km/h (see Figure 1). In this case we use the standardized spectrum for speeds below 200 km/h.

The average and standardized reduced roughness spectra from the calculation scheme are to be interpreted as a time-average spectra. This means that to achieve a certain average, the roughness shortly after grinding should be lower than that average. Therefore, we also derived a roughness spectrum specification that should be realized shortly after grinding. This specification is also given in Figure 1. In the specification, we have taken into account that it is difficult to reach much lower roughness than the specification for the shorter wavelengths (i.e. below 1 cm), but that for the longer wavelengths, this can be achieved more easily.

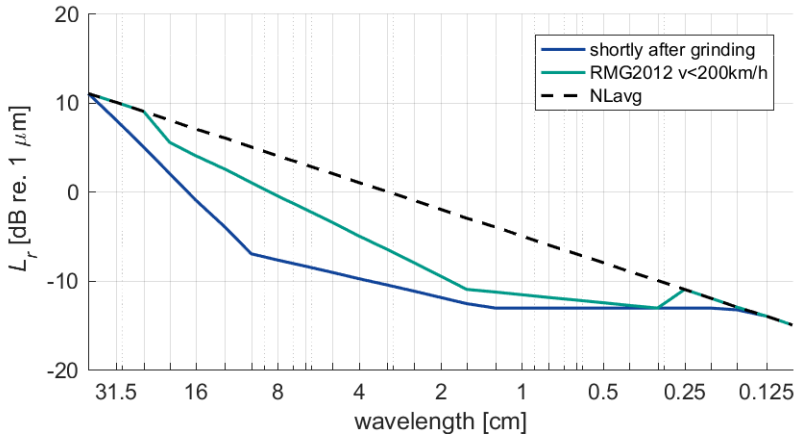

Figure 2 – Three typical roughness spectra: the average Dutch roughness (NLavg), the standardized lowered roughness for speeds below 200 km/h and the specification for the desired result for the Groningen-Leeuwarden line, which should be achieved shortly after grinding.

If these specifications are realized in practice, a noise reduction of 2.9 dB would be achieved shortly after grinding and a noise reduction of 2.5 dB would be realized on average. This is more than the required 1 to 1.5 dB, so not strictly necessary. However, using this specification provides some margin to allow further traffic growth or to have a longer time interval between grinding maintenance.

2.3 Monitoring plan

To study the time behavior of the ground track, we chose to monitor the rail roughness on the complete track using our (indirect) roughness monitoring system ARRoW (3,4). Two measurements were planned: one after 4 months and one after 11 months. In addition, one reference location was chosen where the rail roughness was monitored directly using a stationary measurement instrument, directly after grinding and also after 4 and 11 months.

3. THE PRODUCTION PHASE

3.1 The grinding

After specifying the desired result in terms of a roughness spectrum and contracting the grinding company, the complete line was reprofiled and an acoustic finishing was applied to get the track in the desired shape. The track was ground in December 2016 during a series of nightly out-of-service periods. On average a net production speed of about 7 km/h ground track was achieved (compared to 10 km/h that can be achieved without acoustic finishing).

The grinding was carried out using a grinding machine with rotating grinding stones. The same machine was used to perform the reprofiling and the acoustic finishing, albeit that the machine settings and vehicle speed were different in these cases.

3.2 Conformity of production check

The result of the grinding activities was monitored on a reference section (close to Leeuwarden at kmp 31.5). At this location, the roughness of the left and right rail was measured using a Müller-BBM m|rail measurement device and expressed as a roughness-wavelength spectrum. The results of the measurement are given in Figure 3. In the same figure, we present the result of the measurement at the same location, 4 months grinding.

Figure 3 shows that directly after grinding, the rail roughness for wavelengths longer than 2 cm is below the Dutch average and for wavelengths shorter than 2 cm, it is in the same range or above the Dutch average. However, this is not the final situation. A typical phenomenon that is observed for rotational grinding is that the roughness for short wavelengths will decrease. The grinding stone leave grinding marks in the rail head that manifest themselves as low wavelength roughness. This roughness will decrease during a run-in period where typically 0.5-1 MGT of traffic has passed (5).

Another typical aspect of rotational grinding is the distinct peaks for some larger wavelengths. These are due to oscillations in the grinding stone axle. The frequency of this peak can be manipulated

by changing the vehicle speed, the grinding stone rotational speed or both. The rather high amplitude of the roughness peak at 10 cm for this case was due to an (uncommon) instability in the grinding motor. This problem was only present in the first grinding shift and did not manifest itself in this amplitude for the other grinding shifts.

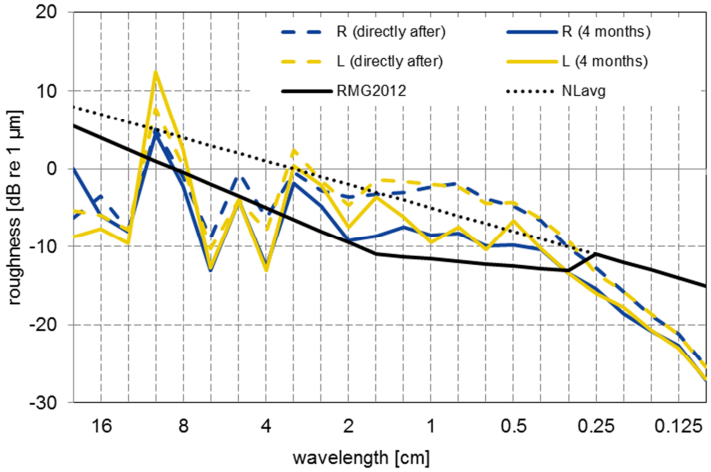

Figure 3 – Rail roughness spectra at reference location, directly and 4 months after grinding, compared to Dutch average roughness and standardized lowered roughness specification.

4. THE MONITORING PHASE

4.1 Monitoring with ARRoW

The monitoring of the rail roughness was carried out 4 and 11 months after grinding. For that purpose, the ARRoW system was installed in an in-service passenger DMU. Installation (mounting microphones, accelerometers and running cables to the inside of the vehicle) takes about 1 hour and measurements can be done without disturbing the normal passengers so the impact on the normal traffic is minimal.

The drawback of using a vehicle in service is that we do not know the wheel roughness of the vehicle so we cannot use equation (1) directly to relate noise changes to roughness changes and vice-versa. However, the direct measurements on the reference site can be used as a calibration to indirectly determine this relationship (see Figure 4 and reference (3)).

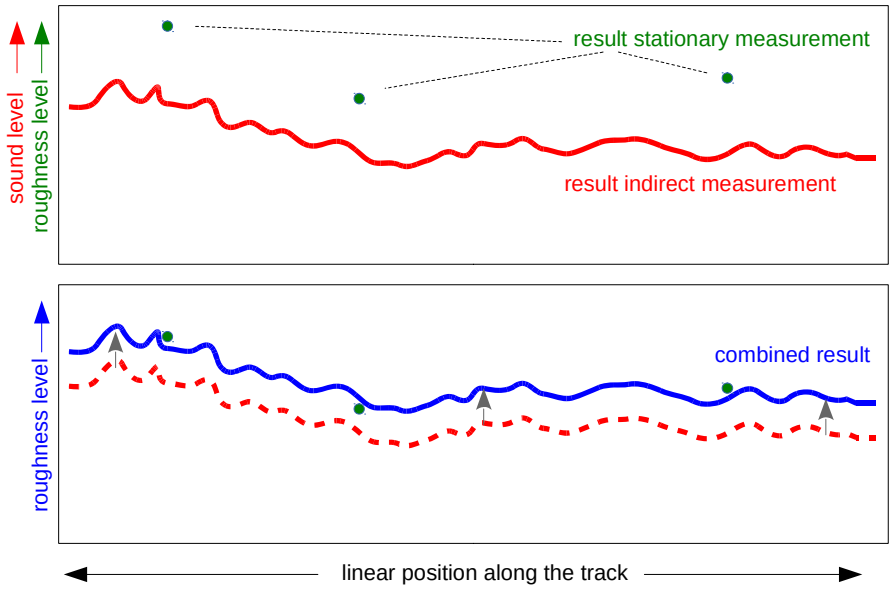

Figure 4 – The principle of calibration for indirect (ARRoW) measurements with stationary measurements.

A typical end-result of the monitoring is given in Figure 5: in this case the track condition 4 months after grinding. The noise emission change (with respect to standard track with average roughness) as a

function of chainage is displayed. for both slow traffic vehicles and express traffic vehicles, since the effect roughness depends on the vehicle speed. The used speed profiles are displayed in Figure 6. We found that the speed had little influence on the roughness-induced emission change. This is normally the case when the roughness spectrum has roughly the same gradient as the reference roughness. We therefore did not take traffic type into account in subsequent analyses

Overall we found that the grinding did result in a significant decrease of the noise emission and that rail grinding was thus effective as a noise mitigation method.

4.2 Dealing with real-life track

Figure 5 does not only show the emission change due to roughness (i.e. the $C_{\text{roughness}}$, but also changes due to change of superstructure properties and discontinuities such as switches and joints. This is because ARRoW uses microphones to measure the rolling noise difference and this difference is influenced by more than roughness alone. This has to be taken into account when interpreting the data.

4.2.1 Changes in the superstucture

The influence of the superstructure can be filtered out of the results. For instance, we wanted to compensate for the influence of the emission change due to wooden sleepers instead of concrete sleepers. Track on wooden sleepers has a higher noise emission (2 dB according to the Dutch calculation scheme) and we can compensate for that by lowering the emission change with 2 dB for those parts of the track where wooden sleepers are installed. After compensation, we get the noise emission change displayed in Figure 7.

Instead of using a known relation between superstructure and sound emission, as demonstrated, one can also compensate for unknown superstructure influence. This can be done by using an additional set of calibrations on the superstructure of interest. In the ARRoW processing software, one can choose the calibrations to use, so it is straightforward to use the stationary calibration result obtained on wooden sleeper track, to calibrate all measurements on track with wooden sleepers. Then the emission difference with respect to standard track will be compensated for automatically.

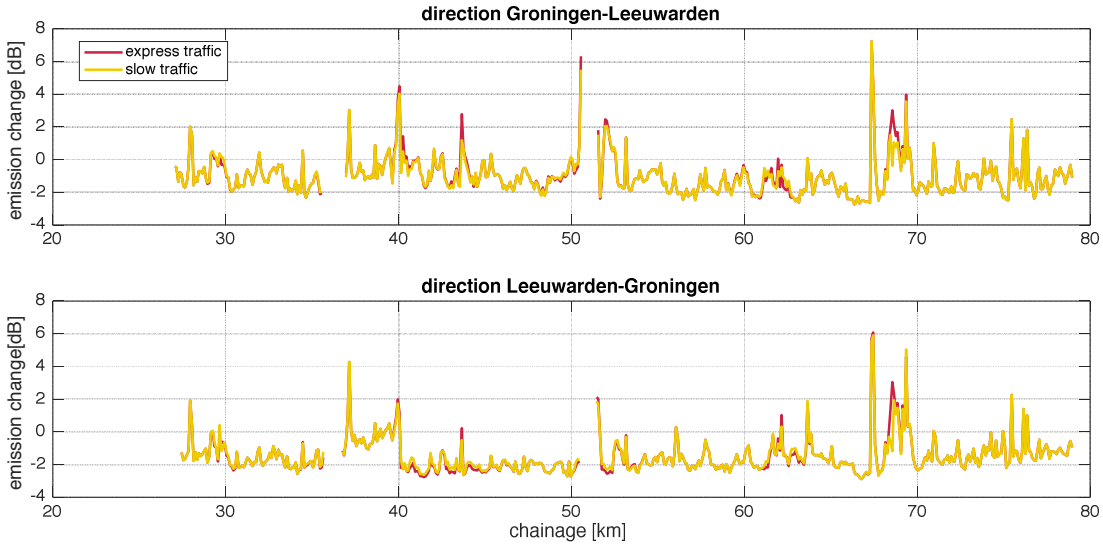

Figure 5 – Noise emission change measured in both directions on the line Groningen-Leeuwarden as a function of chainage.

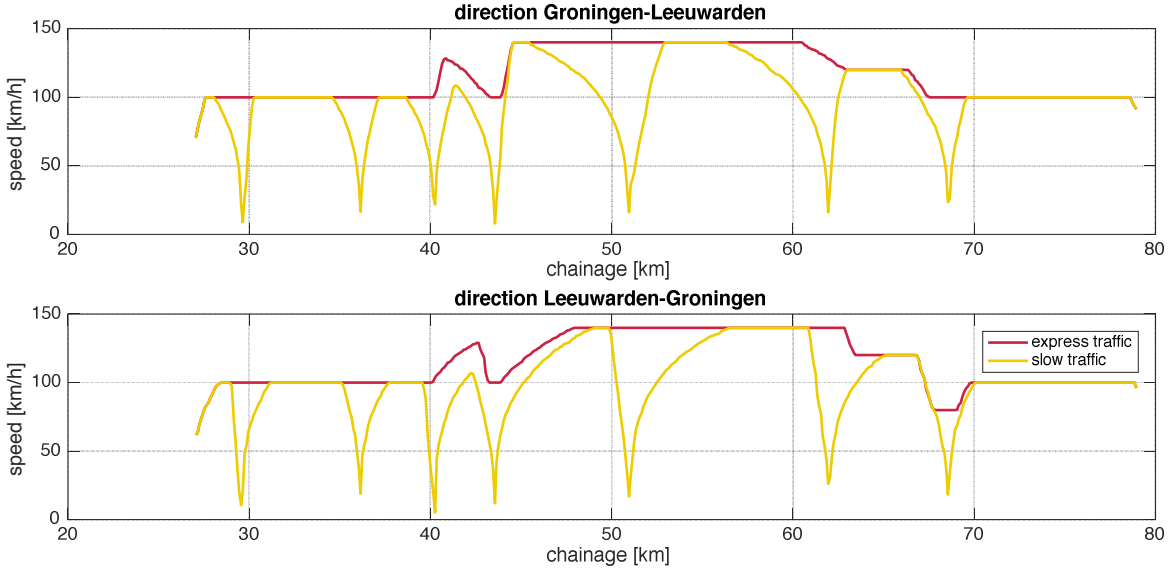

Figure 6 – Speed profiles for slow and express traffic in both directions on the line Groningen-Leeuwarden as a function of chainage.

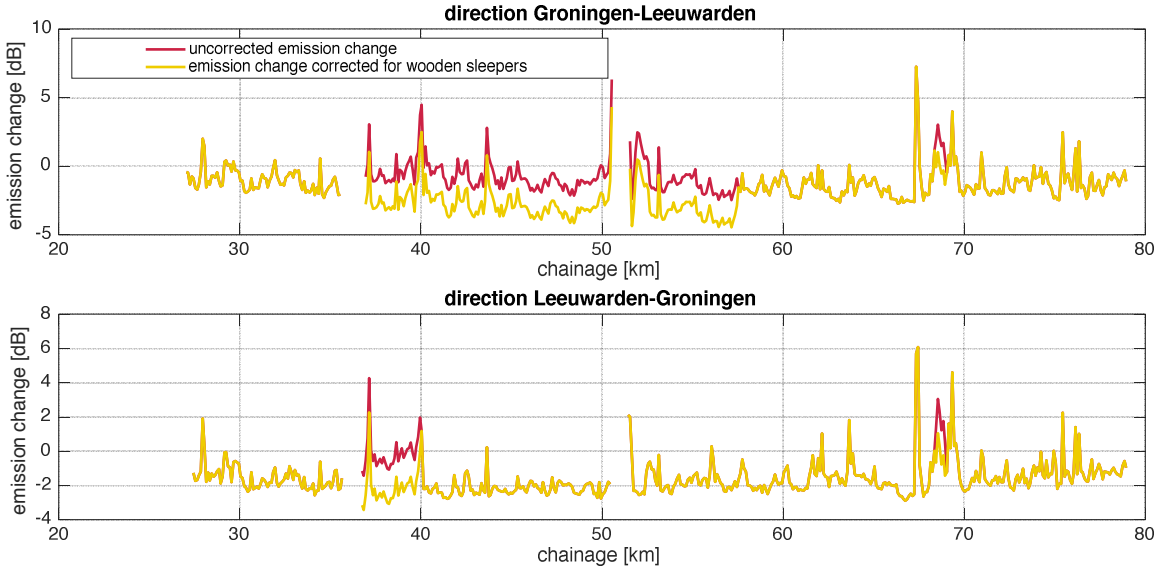

Figure 7 – Influence of correction for wooden sleepers on emission change.

4.2.2 Speed variations for the measurement vehicle

The measurements were carried out with a train in normal service. This means that the train stops at a number of stations. The train we used was running a slow train and express train service and we did one ARRoW measurement in each service type.

When there is a speed variation in the measurement, this will also influence the rolling noise emission. ARRoW can compensate for this variation in two ways. The simple compensation is to apply a $30 \cdot \lg(v/v_{\mathrm{ref}})$ law to adjust the measured sound levels. This is valid for small speed variations only (in the order of 5-10 km/h). However, for larger speed variations (that we see in the slow traffic service) we use a different, two-step, approach. First, we define a target speed and speed boundaries for a specific analysis. Then we analyze all sound measurements that fall within this speed range and apply the calibration principle using only calibration results that were obtained within that specific analysis speed range. This principle is in essence similar to the principle of using different calibrations for different superstructure types. Note that within the analysis speed range, one can still use the $30 \cdot \lg(v/v_{\mathrm{ref}})$ law to adjust to small speed variations and thus get the most accurate result. This analysis

is also automated in the ARRoW post-processing software.

What remains are locations for which the measurement vehicle speed was just too low. We can define a minimum speed in ARRoW and results that were obtained below that speed in a measurement run are disregarded. The averaging algorithm in ARRoW automatically takes care that only results obtained at a valid speed are taken into account. It may happen that there are no measurements taken at a valid speed for a certain part of the track. Then there is no result to be shown in the end result (see the left out areas in e.g. Figure 5). This happens e.g. close to train stations where a train in service always needs to approach at low speed. When using a dedicated measurement vehicle, one normally avoids these situations.

4.2.3 Impulsive noise due to switches and joints

The measurement microphones also record the sudden increase of noise when the wheel passes a turnout or a rail joint. These peaks are visible in the emission change result (see e.g. Figure 5). One could argue whether these belong to rail roughness and should or should not be filtered out of the data. We choose to leave them in the results and use the noise-event analysis option in ARRoW to locate all regions with impulsive noise. This helps us to distinguish regions with high roughness (which does not lead to impulsive noise) from areas with rail joints (that do show up as areas with noise events). For instance, in Figure 7, the track section km 68 and 69 seems to be an area with high roughness level. However, the noise-event analysis revealed this as a section with a lot of impulsive noise. Zooming in on the noise level at that section, we found that there were distinct peaks at an interval of 30 m apart (Figure 8). We thus found out that there was still an old section of jointed track that had not been replaced by continuous track yet.

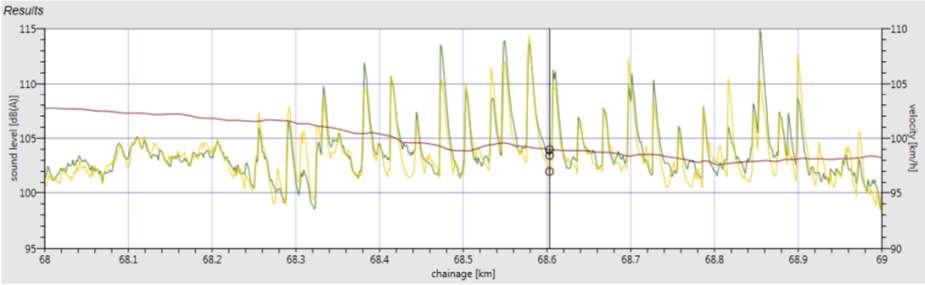

Figure 8 – Noise level at a track section with impulsive noise due to jointed track.

4.3 Practical evaluation of the grinding result

In principle, the ARRoW measurement results offer a resolution of a few meters. However, it is impractical to evaluate the grinding result on a meter scale because:

- it is difficult to display this level of detail for track sections of several decades of kilometers;
- grinding maintenance to bring the track in the desired state cannot be applied to only a few meters.

The practical approach we applied for this line is to split-up the complete line in a collection of verification sections and assess the grinding result as one average result for the entire verification section and decide on the follow-up action per verification section. The process of assessment and verification is given in Figure 9 and will be explained next.

For the verification of the Groningen-Leeuwarden line, the track was split up in sections of 100 m. For each section, we determine the average speed $\bar{v}$ and average rail roughness spectrum within that section. With that, we can compute the wavelength spectrum of the actual roughness coefficient $C_{\text{roughness, section}\bar{v},i}$ using equation (1). This spectrum is in fact the noise emission change due to grinding. We can also compute the required roughness coefficient spectrum $C_{\text{roughness, desired}\bar{v},i}$ using equation (1) and substituting for instance the standardized lowered roughness spectrum from Figure 2. If the actual roughness coefficient spectrum is below the desired roughness coefficient spectrum, then we can already conclude that the track condition is sufficient to obtain a lower noise emission.

If the actual spectrum is not below the desired spectrum (for all wavelengths) we cannot conclude the noise reduction is sufficient and we have to calculate the actual (time averaged) noise emission reduction (which is called $C_{\text{b,c}}$ in the Dutch calculation scheme and in Figure 9). In this scenario, the roughness for some wavelength bands can be higher than the desired value as long as this is compensated for by a lower roughness in other wavelength bands, such that the total (overall) noise emission is below the limit value.

A second aspect we have to take into consideration is the Dutch calculation scheme describes a time-averaged desired roughness so we also have to time average the sound reduction. So even if the

actual $C_{b,c}$ is above the desired value , grinding may not be required if the *time-averaged* $C_{b,c}$ (denoted with t) is below the desired value. To be able to compute the time-average, it is necessary to store the history of the roughness coefficient $C_{\text{roughness, section}\,\bar{v},i}$ in a database to be able to use it in the future.

When the actual $C_{b,c}$ is above the desired time-averaged value, then this is an indication that the track roughness has grown considerably and that grinding maintenance needs to be scheduled for the future. Using the history of actual $C_{b,c}$ values, it is often possible to predict the point in time when the average noise reduction will be insufficient. This means that the ARRoW results can be used in a predictive maintenance scheme to plan the maintenance in an efficient and cost-effective manner.

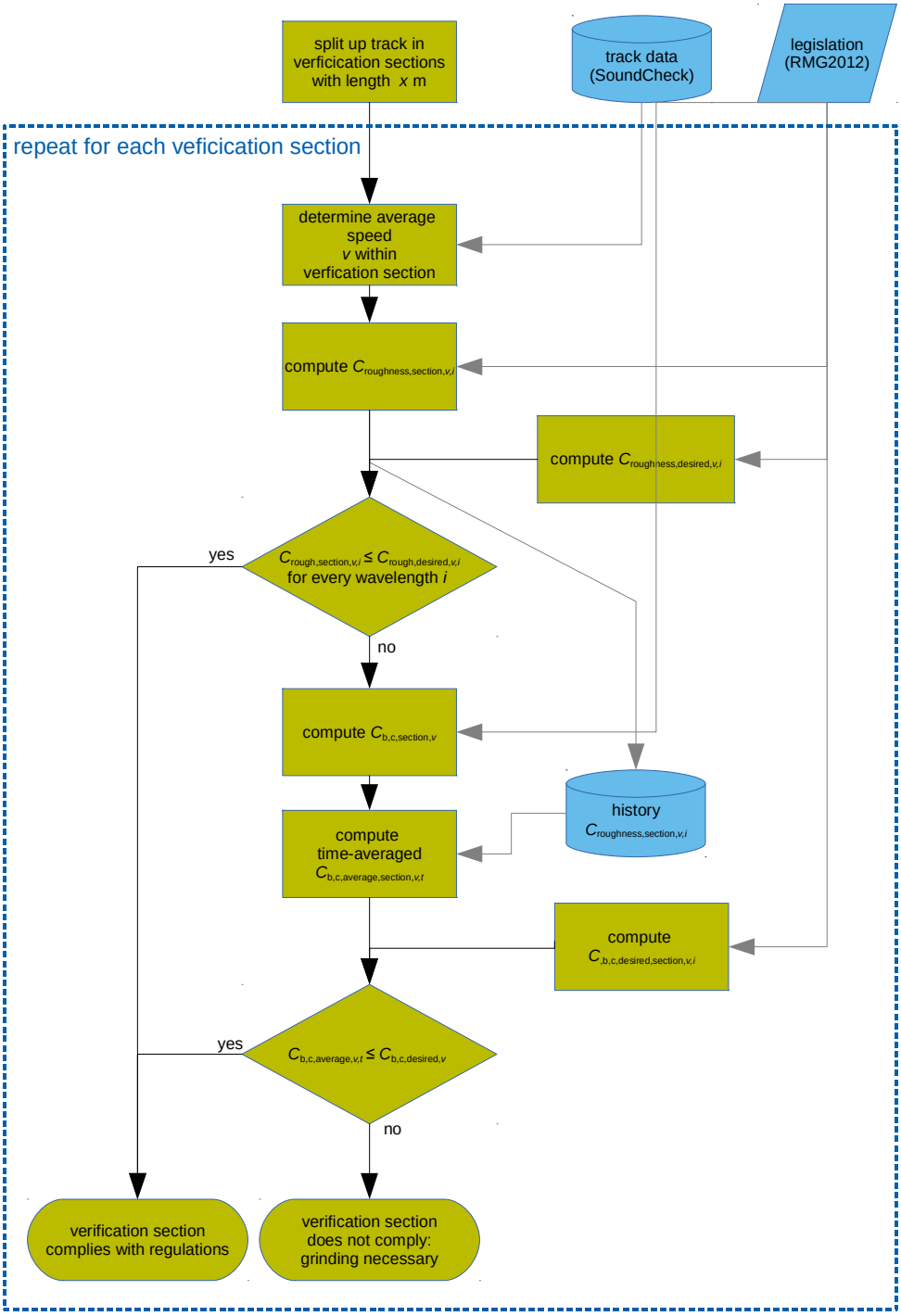

Figure 9 – Flow-chart for the assessment and verification of the rail roughness condition based on verification sections.

5. SUMMARY

In this paper, we have shown how rail roughness control is applied in a real-life application case at the Groningen-Leeuwarden line. From the legislative context we have derived a desired result in the form of a desired roughness spectrum. After grinding, we were able to assess the condition of the track and the result of the grinding using ARRoW measurements on an in-service vehicle. We have presented alternatives for dealing with practical issues such as change in superstructure, varying measurement speed, switches and rail joints and shown how these issues are dealt with in ARRoW. Based on these measurements, we have shown how to evaluate the acoustical performance of the ground track based on verification sections. This concept has been tested and approved by ProRail in the Netherlands and we believe that it could serve as a template for other infrastructure providers that want to use rail roughness control as a noise mitigation measure.

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