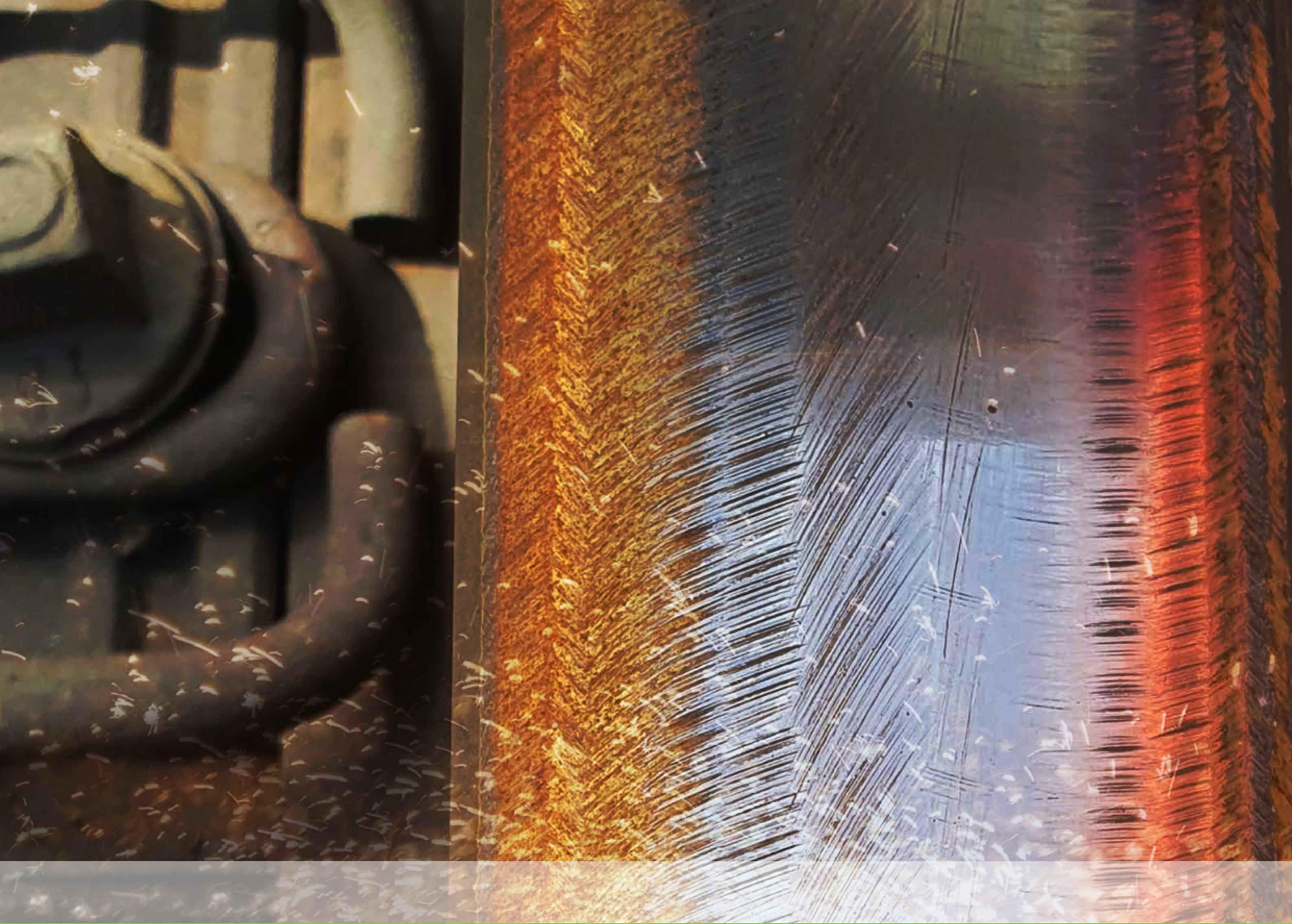

UIC SUSTAINABILITY DEPARTMENT

State-of-the-art report for on-board measurement systems

December 2025

ACORD

Acoustics of Reprofiling and Onboard Monitoring of Rail Roughness

INTERNATIONAL UNION OF RAILWAYS

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Contents

Executive summary

The ACORD project[1] addresses challenges around rail roughness as a critical factor in railway noise generation and maintenance efficiency. It aims to enhance the understanding and management of the acoustic quality of tracks, thereby supporting sustainable, low-noise railway operations across rail networks worldwide. The project has two complementary goals:

- Harmonised evaluation of the impact of rail reprofiling on noise, facilitating low noise grinding processes (WP1).
- On-board monitoring of the acoustic quality of tracks to better understand how roughness grows and the factors which influence it, enabling optimised noise reduction strategies (WP2).

Investment in on-board measurement systems is essential for achieving a modern, efficient, and environmentally compliant rail network. The evidence gathered from ACORD partners has led to the following conclusions:

1. **Noise compliance and public acceptance** – Continuous and accurate monitoring of acoustic rail roughness is important for the effective implementation of the EU Noise Directive. This monitoring allows more precise noise maps to be developed while also helping the implementation of targeted mitigation strategies. On-board systems provide systematic, network-wide data collection that enhances transparent compliance reporting.
2. **Asset performance and maintenance optimisation** – On-board monitoring enables detection of roughness growth and corrugation to be detected, allowing maintenance interventions to be planned based on the actual evolution of a track's condition. This approach supports more efficient use of resources, reduces costs, and helps extend asset life.
3. **Data-driven infrastructure management** – Integrating acoustic quality data with other track parameters helps foster predictive maintenance and informed decision-making. On-board systems capture large-scale, continuous datasets that are essential for digital twins and modern asset management frameworks.
4. **Operational efficiency and safety** – Modern on-board systems, equipped with vibroacoustic and laser sensors, can perform multiple functions on a single platform, ranging from roughness estimation to defect detection. This multi-purpose capability enhances monitoring coverage while reducing operational downtime.
5. **Supports innovation and research** – Continuous data from on-board systems provide a foundation for developing advanced models for noise generation and roughness development, supporting R&D efforts and facilitating innovation in noise control technologies.

Current practices and emerging trends

Among the infrastructure managers contributing to this report:

- Most already perform rail roughness measurements for specific purposes including regulatory compliance, grinding verification, noise monitoring, and research.
- Indirect monitoring systems with on-board measurements are increasingly preferred for large-scale, routine assessments due to their efficiency and integration potential.
- Leading networks now monitor up to 50% of their network annually, demonstrating the operational development of these systems.

A trend is emerging towards integrated, multi-purpose monitoring platforms capable of combining track geometry, defect detection, and acoustic roughness evaluation. This convergence supports cost-effective, preventive, and data-centric infrastructure management.

Investing in on-board measurement systems strategically drives sustainable, compliant, and cost-efficient rail operations. Such systems transform acoustic rail roughness monitoring from an R&D activity into a core component of modern infrastructure management. They provide the necessary basic data for achieving quieter, more reliable, and environmentally responsible rail transport.

1 https://uic.org/projects/article/acord

Abbreviations

List of abbreviations

ACORD	ACOustics of Reprofiling and onboarRD monitoring of rail roughness
UIC	International Union of Railways
IRS	International Railway Solution
EN	European Standard
END	EU Environmental Noise Directive 2002/49/EC
NMPB	Nouvelle Méthode Prévision Bruit - French road noise prediction method
ESV	Engins de Surveillance de la Voie – track monitoring devices
IM	Infrastructure Manager
RR	Rail Roughness
RMS	Root Mean Square
DB	Deutsche Bahn – German Railways
ÖBB	*Österreichische Bundesbahnen – Austrian* Federal Railways
SBB	Schweizerische Bundesbahnen – Swiss Federal Railways
SNCF	Société nationale des chemins de fer français – National Railways of France
SPOC	Single point of contact
HS2	High Speed 2 – UK high-speed railway, under construction
IP	Infraestruturas de Portugal – Railway Infrastructure Manager of Portugal
IoT	Internet of Things

Figures and Tables

Glossary

- **Rail roughness**
  Unevenness of the rail surface, which influences wheel-rail contact and generates vibration transmission and noise radiation. The relevant noise-related wavelengths typically cover the range from 0.5 m to around 5 mm.

- **Wavelength**
  A characteristic spatial scale over which variations in a signal occur. For a periodic signal, it is the interval over which the signal repeats.

- **Rail reprofiling**
  The process of reshaping a rail to restore its original cross-sectional profile.

- **Rail grinding**
  The process of removing the surface layer of the rail head to achieve the desired profile and remove any surface damage, via either rotating or longitudinally oscillating stones.

- **Acoustic rail grinding**
  Grinding procedure that reduces noise emissions related to rail roughness, by focusing on the small wavelength range of interest for rolling noise. An acoustic rail grinding procedure is obtained by optimising the grinding parameters (speed, type of grinding block, stone angle, stone surface, etc).

- **Rail milling**
  Rotational cutting process that removes a large, controlled layer of rail material.

- **Rail roughness monitoring**
  Process of measuring and tracking rail surface irregularities to assess rail condition, predict maintenance needs, and control noise and vibration.

- **Direct measurement**
  Rail roughness measurement via a device in contact with the rail surface to measure its irregularities.

- **Indirect measurement**
  Estimation of rail roughness based on rail–wheel interaction measurements (e.g. noise, rail vibration, or axle-box vibration).

- **On-board measurement**
  Collection of data directly from a vehicle in operation, using sensors mounted on the vehicle to monitor track condition in real time.

- **Rail defect**
  Physical irregularities or discontinuities in the rail material or geometry that can adversely affect the safe operation, performance, or lifecycle of the railway track. They may arise from manufacturing flaws, operational wear, environmental conditions, or mechanical damage, and can include, but are not limited to, cracks, head checks, corrugation, squats, shelling, and spalling.

1. Introduction

The ACORD project addresses rail roughness for noise reduction. The project emphasises:

- Harmonised evaluation of the impact of rail reprofiling on noise, facilitating low noise grinding processes (WP1).
- On-board monitoring of the acoustic quality of tracks to better understand how roughness grows and the factors which influence it, enabling optimised noise reduction strategies (WP2).

This report compiles and organises all relevant information provided by the ACORD project financing members for Task 2.1 of WP2. This information is related to the **acoustic monitoring approaches** and existing systems for **rail roughness measurement systems**. Focus is placed on the **use of on-board systems by infrastructure managers**. For this report, information was gathered from the following UIC members (principally infrastructure managers): BaneDanmark (Denmark), DB (Germany), HS2 (UK), Infrabel (Belgium), IP (Portugal), Network Rail (UK), ÖBB (Austria), ProRail (Netherlands), SBB (Switzerland), SNCF (France), Trafikverket (Sweden).

It is important to distinguish between *rail roughness* and *acoustic rail roughness*, as the latter focuses on the wavelength ranges that may generate noise.

1.1. Background

The most important source of noise from railways is rolling noise caused by wheel-rail interaction. Here, roughness on the wheel and rail running surfaces induces wheel and/or rail-structure vibration, leading to sound radiation.

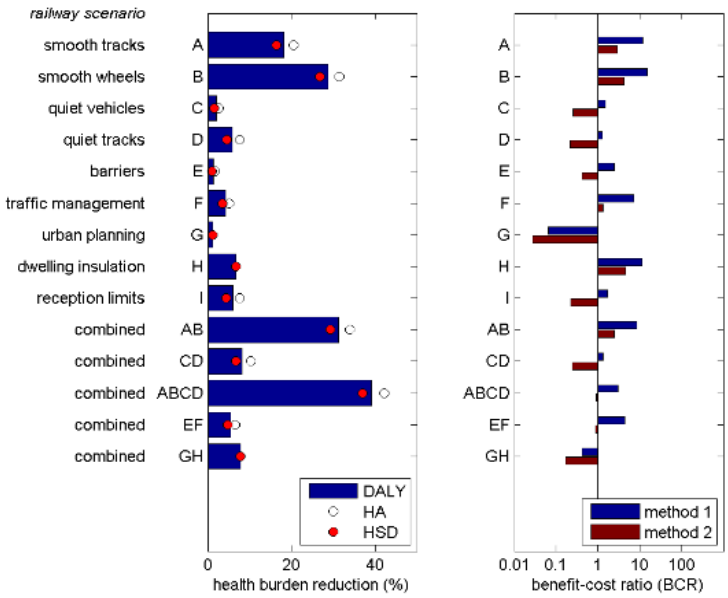

Figure 1-1: PHENOMENA project outcomes [1]

The PHENOMENA project (see Figure 11) [1] has identified reducing roughness as the most cost-effective way of decreasing rolling noise on the railways. Therefore, the UIC ACORD project targets roughness reduction by focusing on **acoustically optimised reprofiling processes** and **rail roughness monitoring**.

Grinding marks may generate tonal noise, leading to annoyance and complaints. To design a reprofiling process optimised for acoustics, a dedicated indicator is required: this is the objective of WP1 of the ACORD project. To monitor the evolution of roughness after grinding, large-scale and efficient rail roughness measurement methods are required, for which on-board systems are the most suitable technologies: WP2 focuses on defining guidelines for their selection and use). Figure 12 illustrates the principal ideas of the ACORD project.

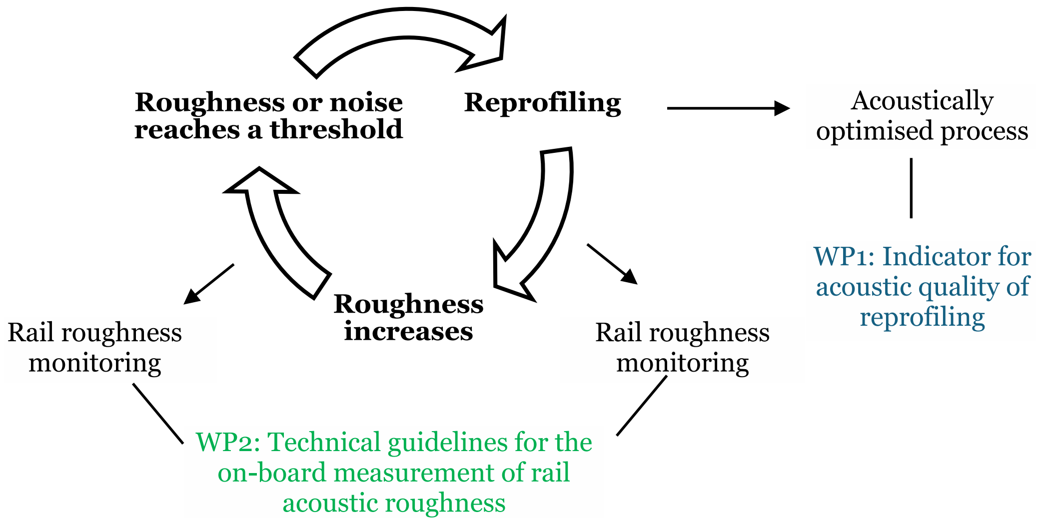

Figure 1-2: ACORD project outline [Credit: Infrabel]

1.1.1. Optimised grinding process – WP1

EN 13231-3 [2] (Figure 13) specifies the technical requirements and the measurements to be carried out for rail reprofiling work to be accepted. However, the standard does not currently cover acoustic rail reprofiling; its indicators are inadequate for evaluating the acoustic performance of the grinding process.

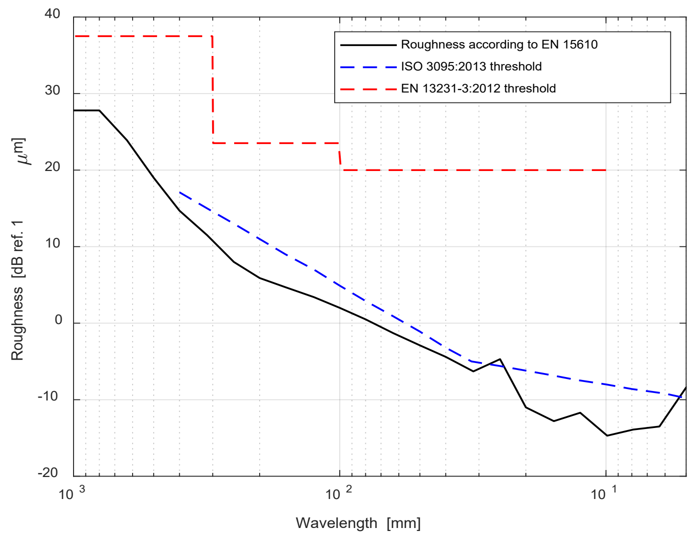

Figure 1-3: Application of standards EN 13231-3 and ISO 3095 [Credit: Vibratec]

The acoustic performance of a rail grinding process can be evaluated by analysing the acoustic rail roughness spectrum measured according to EN 15610 [3] and comparing it with the TSI limit curve defined in ISO 3095 [4] (Figure 13). However, this limit curve is difficult to interpret and is not well suited for this application. It has proved to be either too severe or not harsh enough for rails, thus leading to cost inefficient measures. Single-number metrics would simplify the interpretation of results and make the requirements clearer.

That is why ACORD WP1 develops a new roughness indicator which correlates with the annoyance caused by reprofiling.

1.1.2. Rail roughness monitoring – WP2

Nowadays, direct systems are the reference for rail roughness measurements. Direct roughness measurements estimate the vertical irregularities of the rail surface through fixed devices or mobile trolleys, that use displacement or acceleration sensors. The methodology is given in EN 15610 [3], with Figure 14 showing how to set up the measurements according the standard. Acoustic (i.e. short-wavelength) rail roughness should not be confused with other maintenance indicators and metrics, like the ones defined in EN 13231-3 [2].

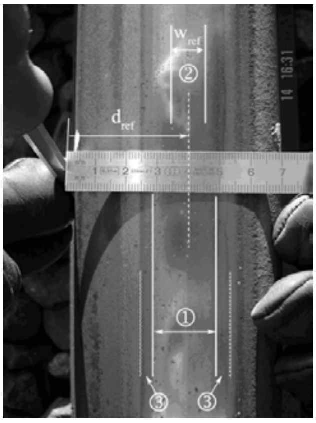

Figure 1-4: EN 15610 measurement procedure. [3]

Direct measurements (Figure 15) guarantee absolute roughness estimations in controlled conditions. Moreover, direct techniques are free from perturbations coming from the railway environment, and they also enable separation of rail and wheel. However, to perform direct measurements, tracks in the measurement area need to be accessed, which may only be possible when traffic is stopped. As the procedure is manual, this limits the length of rail that can be monitored.

Unlike direct measurements where sensors are applied directly to the rail surface, **indirect measurements** (Figure 15) focus on wheel-rail interaction data, such as noise in the bogie area or axle-box vibrations, from which the actual combined roughness is inferred. Indirect measurements can be performed in a fixed frame (pass-by measurement) or on the train itself (on-board measurement).

Figure 1-5: Rail roughness measurements - direct (left), indirect (right) [Credit: Vibratec]

Indirect on-board measurement systems are not limited by track length and therefore potentially enable measurements to be taken across an entire national railway network. On-board measurement systems not only help ensure better compliance with actual noise requirements but are also crucial for maintenance and grinding, as these can be optimised with the available information.

The ACORD project specifically focuses on the on-board measurement of rail roughness, a promising method for continuous, large-scale track condition assessments. The aim of WP2 is to facilitate and orient the development of such systems by defining comprehensive user specifications. Through this approach, WP2 supports the advancement of standardisation efforts.

The following tasks are outlined for WP2:

- Task 2.1 - Documentation of existing systems
- Task 2.2 - Definition of comparison procedures
- Task 2.3 - Identify problems and suggest solutions
- Task 2.4 - Write an IRS

This report compiles and collates all relevant information for Task 2.1 of WP2, which relates to the documentation of existing systems.

1.2. Objectives

The primary objective of this document is to summarise available data on existing on-board measurement systems to monitor acoustic rail roughness. The document focuses on the uses of on-board systems by infrastructure managers, as well as their needs in terms of rail roughness monitoring. Technical information on the systems themselves is not the key focus of the present document, although some features are briefly outlined. This includes:

- Operational use cases: how and why infrastructure managers deploy such systems.
- Measurement strategies: frequency, coverage, and integration with maintenance planning.
- Sensor technologies and data outputs: types of sensors used and the nature of the data collected.
- Calibration and validation practices: how systems are verified and aligned with direct measurement methods.

By consolidating this information, the report lays the groundwork for future tasks in WP2, including the development of standardised guidelines for on-board measurement systems. Ultimately, the goal is to support harmonised, efficient, and acoustically optimised rail maintenance strategies across the railway sector.

1.3. Target audience

This report is addressed to infrastructure managers, rail maintenance and grinding companies and other interested parties involved in rail roughness measurements, noise regulatory measurements, and noise mitigation solutions.

2. State-of-the-art

Current information concerning rail roughness measurement systems mainly comes from three sources:

- The findings of a survey carried out in 2018 as part of the French research project Meequai (On-board measurement of the acoustic quality of the railway infrastructure) [5].
- Relevant information shared by the ACORD project members in previous meetings and documents [6].
- Information gathered from interviews with infrastructure managers during the ACORD project, providing updates to previous findings and highlighting practices from other users.

2.1. BaneDanmark (Denmark)

BaneDanmark is in charge of noise mapping for the Environmental Noise Directive 2002/49/EC.

Quantitative analysis of maintenance strategies allowed for interesting conclusions to be drawn:

- The probability of cracks in the rail head occurring increases with the rail roughness level, therefore ensuring low levels of rail roughness most likely reduces cracks.
- It is almost impossible to reliably predict rail roughness evolution with tonnage, and maintenance based on tonnage is ineffective. Tonnage-based grinding and milling are financially inefficient, as they increase environmental noise where the rail roughness level is already low, and can lead to high rail roughness levels on sections with less traffic. Instead, maintenance based on continued rail roughness monitoring should be significantly more effective.
- The density of housing units along tracks has changed over recent years: from 2019 onwards, a significant decrease in the number of homes located next to track sections with high rail roughness levels was seen, while residents seem to shift to areas where the track sections had low rail roughness levels (see Figure 21). This confirms the importance of rail roughness monitoring.

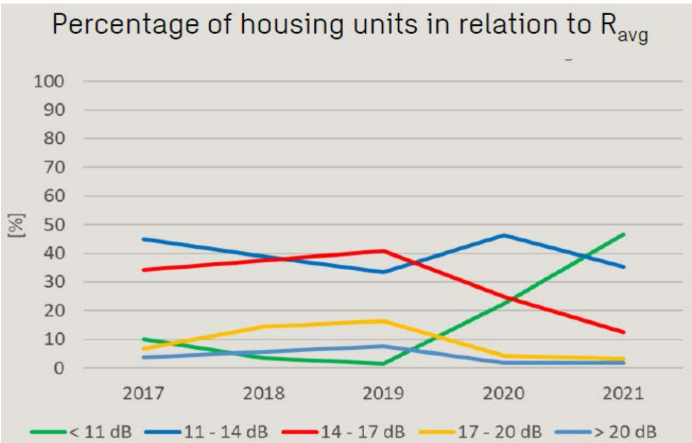

Figure 2-1: Percentage of housing units in relation to the average roughness [6]

Rail roughness measurements are performed once a year, following rail milling (on at least 50% of the network). Two milling campaigns are carried out during the year, with BaneDanmark now switching from corrective to preventive milling.

Measurements are performed by the subcontractor SWECO, with an on-board measurement system owned by the infrastructure manager. The measurement system is installed on one dedicated vehicle (Linke-Hofmann-Busch A.G., DB-type Bmpz with bogie type MD 52, see Figure 22) running at conventional speeds. An extra wagon is inserted at each end of the measurement wagon and acts as a spacer between the measurement wagon and the locomotive.

Figure 2-2: Dedicated vehicle for on-board measurements in Denmark [6]

Rail roughness measurements are also performed by the milling company for acceptance of work. In this case, the measurement does not cover the acoustic wavelengths.

BaneDanmark also owns a vehicle dedicated to track geometry measurements.

Technical characteristics of the on-board measurement system

The system has the following characteristics:

- Composed of microphones and accelerometers, see Figure 23.
- Outputs overall roughness levels, in the form of a single value indicator.
- Calibrated through direct rail roughness measurements on several tracks.
- Is not capable of identifying which track was measured.
- The speed range where measurements are valid is 50-120 km/h.
- Can detect short rail defects, that are not removed from the rail roughness measurement.

Operational conditions affecting measurement accuracy

- Wheel roughness should be low (reprofiling needed before the first measurement campaign, adapted braking). The wheel roughness on the other nearest bogies must also be low, and no wheel flats should exist.
- Noise sources other than the noise induced by rail roughness (engines, generators, exhaust pipes, rattling, turbulence) should be as low as possible.

Figure 2-3: SWECO On-board measurement system [6]

2.2. DB (Germany)

DB has a dedicated coach, the Schallmesswagen, to measure the acoustic quality of the German railway network. The inspected tracks are “Specially Monitored Tracks”, an important part of the German railway infrastructure noise abatement actions. The system measures the acoustic track quality (for the applicable legal requirements) but not rail roughness directly.

The DB system allows for fast noise mapping to be carried out, but is not yet used for trains in commercial service. Measurements are taken twice a year and cover approximately 12000 km of track.

Other test trains, mainly based on optical measurement systems, are used to measure the longitudinal rail profile.

Technical characteristics of the on-board measurement system

The system has the following characteristics:

- The measurement coach is used together with 2 adjoining dummy coaches and pulled by a locomotive.
- Consists of a microphone located in an absorbing cavity above a non-braked wheelset.
- The system measures equivalent overall pass-by noise levels at 25 m from the track centre; the indicator is measured every 10 m.
- The system is calibrated through pass-by noise measurements, averaged over various vehicles of the DB fleet.
- The speed range where measurements are valid is 80-200 km/h.

Figure 2-4. Deutsche Bahn Schallmesswagen. [Credit: DB]

Operational conditions affecting measurement accuracy

- Wheel roughness should be low (reprofiling recommended).
- Short defects are not automatically detected.

2.3. HS2 (UK)

Rail roughness is a major consideration for HS2 because of the legal requirements set for noise and vibrations as part of the Parliamentary “hybrid bill” process.

HS2 is in the process of defining appropriate rail roughness limits and maintenance strategies, including considerations for on-board rail roughness measurement systems that can facilitate delivery of the noise and vibration objectives during the project’s operational phase. As part of this, HS2 has conducted a market engagement survey with rail reprofiling companies and other infrastructure managers via UIC.

2.4. Infrabel (Belgium)

Infrabel is not in charge of noise mapping in accordance with the Environmental Noise Directive 2002/49/EC, but contributes most of the input data, including rail roughness.

Rail roughness measurements are performed to map severe rail corrugation in curves, to investigate complaints, and for R&D projects (which include rail corrugation, rail roughness progression, and general infrastructure health and inventories).

Measurements are performed internally by Infrabel, with both a trolley and on-board measurement systems. Infrabel owns two self-developed on-board measurement systems, which are installed on track geometry and catenary inspection coaches. The trains run at conventional speeds and cover a combined 80000 km per year, with the most remote tracks being measured at least once or twice a year.

Technical characteristics of the on-board measurement system

The system has the following characteristics:

- It is composed of microphones and accelerometers, see Figure 25.
- It outputs:
  - Rail roughness spectra in 1/3 octave bands
  - Sound pressure spectra in 1/3 octave bands

- It is calibrated using conventional trolley measurements at certain locations.
- The speed range where measurements are valid is 40-120 km/h.
- The system can detect rail joints and short defects, that are not removed from the rail roughness measurement.

Figure 2-5: Infrabel on-board measurement system [6]

Operational conditions affecting measurement accuracy

- Wheel roughness on the current trains is too high to measure rail roughness outside of curves with severe corrugation. Their replacement is planned for 2026.

2.5. IP (Portugal)

IP owns two systems for the on-board measurement of rail corrugation:

- The lightweight RMF 2.3 device, manufactured by Vogel & Plötscher (Figure 26).
- The COR-005 inspection system, installed on a EM120 vehicle (Figure 27), produced by Plasser & Theurer, running on the whole network twice a year.

Figure 2-6. Vogel & Plötscher RMF 2.3 device. [Credit: IP]

Figure 2-7. EM120 inspection vehicle.

By default, both systems measure wavelength bands from 10 to 1000 mm, meaning that they are not used specifically for acoustic purposes and that they focus on track geometry and acceptance of grinding works (EN 13231-2).

The procurement of a new rail inspection vehicle is ongoing. Two systems will be installed for measuring rail corrugation: the Rail Corrugation Optical Measurement System (RCOMS) and the Rail Corrugation Inertial Measurement System (RCIMS). The first is a laser/optical system and the second is an inertial system for indirect rail corrugation measurement.

2.6. Network Rail (UK)

No specific legal requirements exist in the UK concerning noise from railways. Still, Network Rail has a legal requirement to provide noise mapping. These noise maps are developed through calculation using standardised rail roughness inputs.

Direct rail roughness measurements are occasionally carried out and mostly triggered by R&D projects, although measurements are also taken at specific locations with roughness issues.

Network Rail owns eight dedicated measurement trains, known as New Measurement Trains (NMTs), see Figure 28. The NMT is used to measure, scan and photograph the infrastructure for geometry maintenance and for maintenance and railway safety limits. The measurement system can be also installed on in-service trains.

Figure 2-8: Network Rail New Measurement Train [Credit: Network Rail]

Technical characteristics of the on-board measurement system

The NMT is equipped with a track geometry system, laser track scanners, a high-resolution video camera, unattended geometry measurement system, and overhead line inspection systems (see Figure 29).

The system has the following characteristics:

- A laser sensor gives information about the profile of the rail head, through optical measurements of the shape and movement.
- Transducers and accelerometers mechanically measure the vertical movement of the train as it travels along the track. This data provides information on track geometry: the shape and profile of the rail head and the twist of the track.
- A plain line pattern recognition (PLPR) system uses lasers and cameras to detect faulty track components as the train passes over them. Image analysis software uses an algorithm to compare what the cameras see with an image of how the track should look.
- Up until 2015, the system incorporated microphones in a system called NoiseMon, which measured sound pressure levels and could indirectly output overall roughness levels. This system was decommissioned at the end of its service life, and whilst capacity within the NMT still remains for an upgraded NoiseMon system, there is currently no immediate plan to replace it.

Figure 2-9: NMT sensor setup [Credit: Network Rail]

2.7. ÖBB (Austria)

The Austrian transport ministry is responsible for noise mapping in accordance with the Environmental Noise Directive 2002/49/EC, and ÖBB provides data for their mainline railway network (no light/urban railways).

At ÖBB, the conventional term *rail roughness* describes the longitudinal level in the wavelength range 30 mm to 300 (or 1000) mm, while *acoustic rail roughness* indicates the roughness as defined by EN 15160, i.e. at wavelengths down to 3 mm.

Rail roughness, as described above, is measured continuously in the framework of track inspection operations by the track inspection coach (type EM250), see Figure 210. With these inspection runs, numerous other data are also measured (such as vertical axle-box acceleration). Rail roughness is measured by a laser system dedicated to detecting corrugation, mounted on the track inspection coach, which contributes to planning maintenance works like grinding or replacing rails. Other measured parameters, e.g. through ultrasonic sensors, are used for planning grinding work.

Measurements by the track inspection coach are performed internally by ÖBB, as part of periodic track inspections for safety and quality assessments, with mainline tracks being measured two to four times a year.

Figure 2-10: ÖBB inspection coach [6]

Trials with indirect acoustic rail roughness measurements via onb-oard microphones, are also being conducted, see Figure 211. This system has been tested since 2012 but has not yet proven successful. It is currently planned to use it for comparisons to former runs but not for the exact determination of acoustic rail roughness.

Figure 2-11: On-board microphones for testing acoustic roughness measurements [6]

Acoustic rail roughness, corresponding to EN 15160, is measured once a year at the three permanent noise monitoring sites (see Figure 212) and on demand (e.g. R&D projects) at certain positions along the railway network. Measurements are carried out by direct systems.

Figure 2-12: Permanent noise monitoring site [6]

Technical characteristics of the on-board measurement system

The system has the following characteristics:

- The measurement systems of the track inspection coach are mainly designed to measure track geometry (safety, quality), rail profiles, rail roughness, axle-box accelerations, laser clearance, driver's view, and track component videos.
- It contains inertial measurement units and contactless systems, e.g. laser scanning (rail surface laser system), video and line-scan cameras. A microphone system exists as an add-on, mounted for trials and data collection for comparison.
- Experience shows that the following factors have a significant influence on the on-board microphone measurements:
  - Speed of the measurement coach (not a simple linear or logarithmic dependence)
  - Trains passing or parking on the adjacent track
  - Noise barriers, including different distances to the track axis
  - Level crossings
  - Turnouts
  - Bridges
  - Curve squeal, from the beginning to end of the transition curve (irregular occurrence)
  - The signals' repeatability and reproducibility significantly suffer in many cases due to a wide range of possible wheel-rail contact points leading to a wide range of combined wheel-rail roughness measurements.
- It outputs axle-box acceleration. The laser system provides the root mean square (RMS) value for the selected wavelengths of the system.
- System calibration is not yet accurate enough (see above, in terms of repeatability and reproducibility), but on-board measurement results are compared with direct acoustic rail roughness measurements.
- The speed range of the measurements is up to 250 km/h.

Operational conditions affecting measurement accuracy

- Wheel roughness should be low. However, it is practically impossible to keep at this level. A great level of effort is needed for wheel reprofiling and grinding several times a year.

2.8. ProRail (Netherlands)

ProRail is not in charge of noise mapping in accordance with the Environmental Noise Directive 2002/49/EC.

The Ministry of Infrastructure and Water Management has defined an average rail roughness spectrum, based on a large set of measurements performed in the late 90s. These roughness levels are used as input for noise emission calculation models. In 2023, the Dutch network's average rail roughness values were checked with a temporarily installed on-board rail roughness measuring system.

Rail roughness is measured occasionally with a trolley or with a dedicated measurement coach. Generally, the need for rail roughness measurements is limited, as rail acoustic quality is good across most of the network.

Track geometry is measured twice a year on the entire network with a UMF 120 vehicle. The system covers the EN 13848-1 [7] wavelength domains D0, D1, and D2 (wavelengths from 1 to 70 m).

The Dutch high-speed line, managed by Infraspeed, has different and stricter noise requirements. Infraspeed uses an on-board rail roughness measurement system, developed by M+P, and provides measurement reports twice a year.

2.9. SBB (Switzerland)

The Environmental Noise Directive 2002/49/EC is not mandatory for SBB. Nevertheless, the Swiss regulation (VLE art. 7, 2016) provides a target value (10 dB) to be reached for the LλCA single-value indicator by 2020.

The single value indicator is calculated from acoustic rail roughness spectra according to EN 15610. Various filters are applied to the raw data, so that only wavelengths of up to approximately 40 mm contribute to the value. By 2017, the target value for the indicator had already been reached at several locations. Later with a sampling and statistical analysis approach, it was shown that it was possible to achieve the limit value gfor most of the network, except in certain locations immediately after grinding.

Rail grinding is performed every one to four years on the main lines, meaning that there is no need to measure roughness between two consecutive grinding operations. In other words, the SBB strategy for roughness management focuses on grinding quality (especially with respect to grinding frequency for each line), instead of rail roughness measurements. A need for rail roughness measurements may arise in the future, to check whether grinding operations guarantee the given threshold values.

Studies have been conducted attempting to link the surface quality of a newly ground rail with the occurrence of rolling contact fatigue. This effect, together with acoustic assessments, should be considered when choosing a parameter for rail surface quality after grinding.

Currently, rail roughness measurements are performed by SBB Infrastructure with a Vogel & Plötscher device for R&D purposes. The Swiss Federal Office of Environment is financing research at ETH Zürich on an on-board system for measuring rail roughness through laser triangulation, see Figure 213. The methods developed during the project were assessed through test bench measurements and very limited field tests. The current work underway also concerns the definition of requirements by SBB and wider-scale production of the system. The research project should end in 2025.

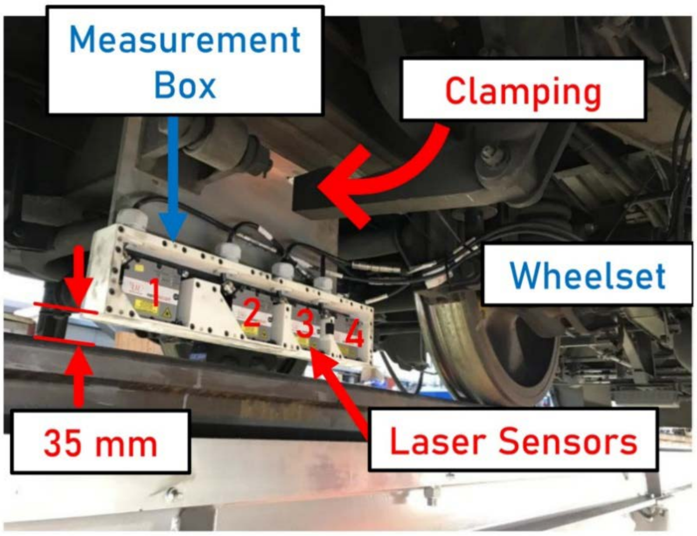

Figure 2-13: ETH experimental setup, including 4 laser triangulation sensors numbered 1 to 4 [6]

2.10. SNCF (France)

In France, grinding is currently not performed for acoustic purposes. However, new infrastructure specifications have introduced the need for acoustically optimised grinding, which involve high costs. Therefore, it is of great interest to determine where acoustic grinding is most needed, based on rail roughness and growth rate estimates.

Rail acoustic roughness is seldom measured, mainly within R&D projects and through direct methods.

Acceptance of work for grinding is based on indicators that grinding companies must provide to SNCF. Most acoustic problems are included in the Environmental Noise Directive 2002/49/EC framework. If this is not case, a finer NMPB model may be developed. Overall, the need for rail roughness measurement is currently limited.

SNCF owns a fleet of measurement trains (ESV, see Figure 214) dedicated to track geometry, but not noise or rail roughness monitoring. The ESVs are equipped with optical sensors and run on the national network two to three times per year.

Figure 2-14: SNCF ESV 702 [Credit: SNCF]

2.11. Trafikverket (Sweden)

Trafikverket is not in charge of noise mapping in accordance with the Environmental Noise Directive 2002/49/EC and currently does not measure roughness to monitor noise emissions from trains.

Trafikverket owns a track geometry measurement vehicle, equipped with triaxial gyroscopes and axle-box accelerometers, that allows short wavelength corrugation to be measured. The monitoring vehicle runs from six times per year to once every three years, depending on the track section tonnage.

Stockholm Metro uses a system that evolved from the European *Quiet-Track* project, which developed a noise related track maintenance tool, in the form of an on-board measurement system. A real-time condition monitoring system was built and mounted in Stockholm (Metro line 1) to validate the results. The system is now in full operation for the metro lines in Stockholm.

Additionally, a condition monitoring agreement exists between the contractor Tyréns and the Stockholm City Hall Transport Administration since March 2024. The idea is to install the system on seven of the Stockholm Local (SL) traffic metro trainsets, so that SL will receive continuous information about the status of all tracks on which the metro trains run.

Technical characteristics of the Stockholm Metro on-board measurement system:

The system has the following characteristics:

- It consists of microphones and accelerometers that measure and analyse the condition of the track. The solution is built on IoT (Internet of Things) technology and used together with IBM's Watson IoT platform.
- The monitoring solution not only checks the quality of the track but also examines the noise when trains run on tracks. The IoT technology uses microphones and sensors that digitally transmit track information to a centrally located server where the data is analysed, providing SL with suggestions for different maintenance workorder generation.

Operational conditions affecting measurement accuracy

- Accuracy depends on stable IoT connectivity and data transmission.

2.12. Summary

Table 1 summarises the general information provided by infrastructure managers concerning rail roughness monitoring policies. Some of the information contained in is graphically represented in Figure 215 to Figure 217. Table 2 and Table 3 outline the main technical characteristics of on-board measurement systems, with Table 4 focusing on the operational conditions affecting measurement accuracy. HS2 is not included in the following tables, as the infrastructure has not yet been built. However, HS2 does plan to measure rail roughness.

Table 1: Rail roughness measurement strategies – general

IM	Who performs RR measurements	Reasons for measuring RR[2]						Type of measurement system		Measurement frequency
		Rail grinding assessment	Compliance with noise laws	Corrugation monitoring	Complaints investigation	R&D projects	Noise monitoring			
BaneDanmark	Subcontractor	X						Indirect	On-board	1 / year
DB	IM		X[3]					Indirect	On-board	2/ year
Infrabel	IM			X	X	X		Indirect	On-board	At least 2 / year
								Direct	Trolley	*
IP		Does not perform RR measurement						*		
Network Rail	IM					X		Direct	*	On demand
ÖBB	IM & subcontractor						X	Direct	Trolley	1 / year
							X	Indirect Direct	On-board Trolley	On demand
ProRail	Subcontractor	X						Direct	Trolley	On demand
Infraspeed	Subcontractor		X					Indirect	On-board	2/ year
SBB	IM		X			X		Direct	*	On demand
SNCF	IM					X		Direct	*	On demand
Trafikverket		Does not perform RR measurement								
Stockholm Metro	*							Indirect	On-board	Continuously

* Parameter not determined during the investigation; further analysis is required.

2 "Acoustic rail roughness" in the wavelengths specified by the EN 15610 standard. None of the on-board measurement systems are currently EN15610-compliant.
3 Does not perform a full RR measurement, but acoustic measurements related to RR.

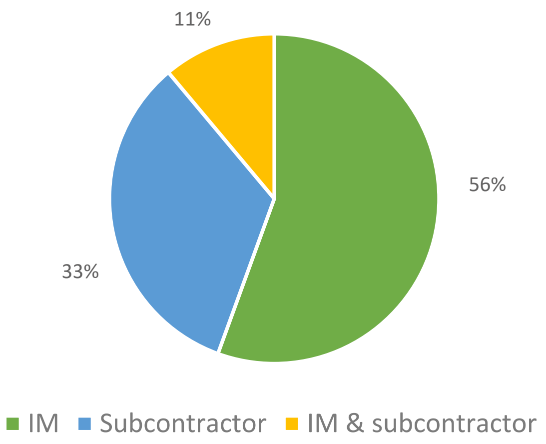

Figure 2-15: RR measurement strategies – who performs the measurements

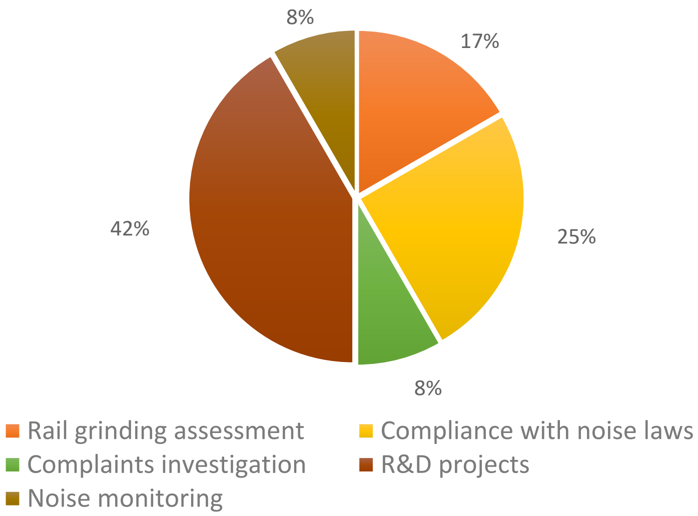

Figure 2-16: RR measurement strategies – Reasons for measuring

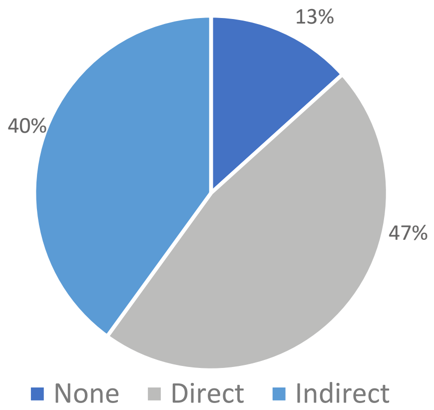

Figure 2-17: RR measurement strategies - Type of measurement system

Table 2: Rail roughness on-board measurement systems – general

Infrastructure manager	Number of systems4	Measurement train	System property	Measurements distance covered
BaneDanmark	1	Dedicated	IM	50% of the network
DB	1	Dedicated	IM	12000 km
Infrabel	2	Dedicated	IM	80000 km
ÖBB	2	Dedicated	IM	20000 km/year
Infraspeed	*More information will be shared in EU-RAIL financed QuieterRail project.*			
Stockholm Metro	*	Commercial	*	*

* Parameter not determined during the investigation; further analysis is required.

4 Number of on-board measurement systems owned by each IM

Table 3: Rail roughness on-board measurement systems – technical characteristics

Infrastructure manager	Sensor configuration	Primary outputs	Wheel roughness	Calibration	Speed range	Rail defects
BaneDanmark	Microphones and accelerometers	Overall roughness levels, single value indicator	Low[5], no flats	Direct measurements on several tracks	50-120 km/h	Detected
DB	Microphone	Normalised SPL	Low, reprofiling recommended	Normalised pass-by measurements	80-200 km/h	Not detected
Infrabel	Microphones and accelerometers	Rail roughness spectra Sound pressure spectra	Not fitted outside curves[6]	Direct measurements at certain locations	40-120 km/h	Detected
Network Rail	Laser systems, accelerometers, cameras (no active microphones)	Track geometry, rail profile, twist, PLPR defect detection	Not applicable (no active acoustic module)	Visual/optical calibration	*	Detected
ÖBB	Accelerometers, laser scanner, microphone add-on	Acceleration spectra, laser SOF-single value, geometry, rail profile, roughness, axle-box acceleration	Low, frequent reprofiling required	Comparison with direct measurements at one location	Up to 250 km/h	Detected
Infraspeed	*More information will be shared in EU-RAIL financed QuieterRail project.*					
Stockholm Metro	Microphones and accelerometers (IoT-based)	Acoustic and vibration diagnostics; maintenance suggestions	*	IoT analytics platform	*	Detected

* Parameter not determined during the investigation; further analysis is required.

5 Low wheel roughness means that it is negligible with respect to rail roughness and therefore does not alter the rail roughness estimation. To achieve low wheel roughness, disc-braked wheels that have been reprofiled just before the system's operation should be used.
6 Wheel roughness on current trains is too high to measure rail roughness except in curves with severe corrugation. Their replacement is planned for 2026.

Table 4: On-board measurement systems - operational conditions affecting measurement accuracy

Infrastructure manager	Operational conditions affecting measurement accuracy
BaneDanmark	■ Wheel condition must be maintained, as flats or irregularities reduce accuracy. ■ Background noise from propulsion, generators, turbulence, or rattling must be minimal. ■ Speed outside 50-120 km/h affects measurement reliability. ■ Short defects included in roughness indicator.
DB	■ Variations in background noise affect pass-by measurements. ■ Use of dummy coaches and locomotive influences system response. ■ Wheel reprofiling needed for low roughness ■ Short defects not automatically detected.
Infrabel	■ Excessive wheel roughness currently limits measurement accuracy. ■ Short defects and joints contribute to outputs. ■ Accuracy depends on trolley calibration location and track condition. ■ Valid speed range 40-120 km/h.
Network Rail	■ Optical and laser systems require a clear line of sight. ■ Lighting, weather and contamination influence accuracy. ■ Wheel roughness not directly measured.
ÖBB	■ Measurement affected by speed, adjacent trains, noise barriers, crossings, turnouts, bridges. ■ Curve squeal produces irregular high-noise events. ■ Reduced wheel roughness difficult to maintain: repeatability and reproducibility limited.
Stockholm Metro	■ Accuracy depends on stable IoT connectivity and data transmission. ■ Background metro noise and operational variability affect diagnostics. ■ Data completeness is critical for reliable analytics.

Practices among infrastructure managers

Among the infrastructure managers analysed:

- 83% perform rail roughness measurements
- 40% use on-board measurement systems
- Some rely entirely on internal resources, while others employ subcontractors

The **reasons** for performing these measurements include:

- Compliance with noise laws
- Assessment of rail grinding opearations
- Corrugation and noise monitoring
- Complaint investigation
- R&D activities (a wide range of activities, often related to the development of standard applications)

These varied objectives demonstrate that rail roughness measurements play a key role both in **regulatory assurance** and **network asset management**.

Measurement system characteristics

The two main categories of systems used are:

- **Indirect on-board systems**, used for routine and large-scale monitoring
- **Direct systems**, preferred for localised investigations and research

The measurement frequency varies depending on network size and operational needs:

- Once or twice a year for regular monitoring
- On demand for specific studies
- Continuous monitoring in advanced setups

Most infrastructure managers who have on-board systems operate **dedicated measurement trains**, covering distances between 12000 km and 80000 km per year, in some cases up to 50% of the network.

Their systems are equipped with:

- Vibroacoustic sensors (microphones, accelerometers)
- Occasionally laser sensors

Some systems can also detect rail defects, expanding their functionality beyond roughness assessment.

Overall, infrastructure managers conduct comprehensive track geometry and acoustic monitoring using on-board systems installed on dedicated test vehicles. Only a few possess on-board systems capable of the indirect estimation of acoustic rail roughness.

3. Conclusion

The collected information shows that rail roughness measurements are being progressively integrated into broader noise management, maintenance, and research frameworks. Infrastructure managers are increasingly seeking to perform multiple types of measurements with the same tool, promoting **shared use of monitoring systems for a variety of purposes**. This evolution reflects a growing emphasis on efficiency, **preventive infrastructure monitoring**, and data-driven management across European rail networks.

This document summarises current acoustic monitoring approaches and rail roughness measurement systems, collected from the ACORD project partners. Emphasis was placed on the use of on-board systems by infrastructure managers. Although technical specifications for the systems are not the main subject, selected features were briefly described.

It is important to distinguish between *rail roughness* and *acoustic rail roughness* as they relate to different wavelength ranges and should not be used interchangeably. Periodic rail surface unevenness is usually called corrugation and broadband unevenness is called roughness. Corrugation issues are connected to maintenance procedures and does not usually concern noise mitigation. [8]

Acoustic rail roughness measurements are generally limited to R&D projects, typically on small track sections and using direct systems such as beams or trolleys. The direct measurement method for characterising rail roughness associated with rolling noise is specified in standard EN 15610.

Few infrastructure managers own on-board measurement systems for indirect estimation of acoustic rail roughness. These systems scan a representative part of the network once or twice per year and are installed on dedicated measurement trains. The measurement setups are essentially based on vibroacoustic sensors such as accelerometers and microphones, that are seldom coupled with laser sensors.

On the other hand, infrastructure managers carry out comprehensive track geometry measurements, with on-board systems installed on dedicated test vehicles.

This study has been conducted in close cooperation with the EU RAIL-funded QuieterRail[7] project, with the ACORD Steering Group contributing to the Advisory Board of QuieterRail Work Package 3, ensuring that users' perspectives are taken into consideration and avoid duplication of efforts.

7 https://www.quieterrail.eu/

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