DOI: 10.61782/fa.2023.0204

H2020 RESEARCH PROJECT NEMO - IDENTIFYING HIGH NOISE EMITTERS FROM AUTOMATED TRACKSIDE RAIL MONITORING

Nathan Isert[1*] **Markus Naumann**[1] **Stefan Lutzenberger**[1]
[1] Müller-BBM Rail Technologies GmbH,
Helmut-A.-Müller-Straße 1 – 5, 82152 Planegg, Germany

ABSTRACT

The EU funded H2020 research project NEMO aims to lower emissions both from pollutants and noise by identifying 'high' emitters in road traffic, on railway lines and in shipyards. It approaches this task by applying the concept of remote sensing for a permanent and comprehensive monitoring as well as a fast and reliable detection method. This paper presents results drawn from a trackside railway monitoring specifically developed and adopted to the NEMO task. It was operated for 165 days on railway line 125 in the Netherlands. During this period all passing trains were recorded with rail-sensors and microphones. From their axle-patterns, trains were identified and separated into wagon/unit contributions. UIC-numbers were obtained from camera images and RFID. The brake-type label imprints on wagons were detected and recognized using an AI-model based on camera imaging. The monitoring data was merged with data from Quo Vadis systems. All wagons/units measured were classified for their noise emissions and train unit type. The analysis of the data shows that 60 percent of the 'high' emissions correlated with wheel flats. A second factor seemed to be the brake-type with wagons/units equipped with LL-brake blocks showing 2-3 dB(A) higher emissions than those equipped with K-brake blocks.

Keywords: *rail monitoring, rail noise, rail wheel irregularities, UIC-number detection*

1. INTRODUCTION

In their latest surveillance for Europe the EEA finds that approximately 6% of people living in urban areas are exposed to rail traffic noise levels above 55 dB (L_{den}) going up to 10% for some key transit countries such as Germany Austria and Slovakia [1]. The WHO guidelines on health recommends average noise exposures to not exceed 54 dB (L_{den}) overall and 44 dB (L_{night}) for night hours [5].

For rail traffic the main contribution to its noise emissions will often result from excitations and vibrations induced at the wheel-rail contact [6]. On a well maintained and straight track with no rail head irregularities the excitations stem from the roughness on the rail head and the wheels running tread. In the absence of surface irregularities i.e., wheel flats, the wheel tread condition is found to be strongly impacted by the brake type [2]. This is a direct consequence of the design of rail vehicle braking systems which for most brake types other than disc brakes uses brake blocks directly contacting the wheels running surface. Cast iron brake blocks were found to severely roughen the wheel tread causing higher excitations and increasing the rolling noise emissions by around 10 dB compared to smooth wheel running surfaces [2].

To protect its residents the European Commission and its member states have been taking various noise abatement actions. Noise limits were introduced in the TSI-N [3] such that newly approved Railway wagons/units would no longer be allowed to come equipped with cast iron brake blocks. Switzerland effectively banned freight wagons with cast iron brakes from its routes starting with a major retrofit of its own fleet in 2015 [7]. Germany followed suit with a legislation prohibiting cast iron freight wagons with the start of 2021 [8]. Legal actions being taken on national level had an impact on interoperability [9] as there is up to date no global ban of cast iron brake block equipped railway wagons/units across the EU and therefore not for all its railway operators. However, the introduction of 'quieter

---

[*] ***Corresponding author**: Nathan.Isert@mbbm-rail.com.*

routes' [4] on some of Europe's major railway lines effectively bans noisy wagons primarily on the so-called quieter routes in many countries by the end of 2024. This will almost mark the end of rail wagons/units equipped with cast iron brake blocks.

With the largest noise contributor being dealt with, the focus is shifted to other major noise sources that were formerly masked by the dominating noise emissions from freight traffic with cast iron brake blocks. The H2020 research project NEMO (Noise and Emissions Monitoring and radical mitigation) [10] seeks to lower noise emissions by offering solutions for a broad, reliable, and fast identification of 'high emitters' from remote sensing and track side rail monitoring.

New or retrofitted rail wagons/units can come with various braking systems all having their own benefits and disadvantages [2]. Disc brakes are the least invasive on the wheel tread, but also the costliest to start with. Retrofitting old cast iron brake systems with composite brake blocks required a higher initial investment for K-brake blocks and more frequent maintenances for LL-brake blocks. Apart from cost, the overall noise emissions associated with these braking systems are distinct as is shown in the result section of this paper. Wheel tread irregularities (i.e. wheel flats) are shown to emerge as a major driving factor for noise emissions from rail wagons/units considerable exceeding TSI limits.

2. RAIL MONITORING

The research project NEMO's [10] main objective for rail traffic is the identification of 'high emitters' regarding noise emissions. This task was addressed by designing and implementing a novel remote sensing device for railway noise (N-RSD - based on the Train Monitoring System (TMS) from Müller-BBM Rail Technologies) capable of autonomously recording all train pass-bys and classifying them for their emissions.

2.1 Setup

The N-RSD had the following components for measuring key quantities (see **Figure 1**):

- 2 microphones (sound)
- 2 rail sensors (axle pattern, speed, wheel flats)
- 2 RFID readers (UIC number, NS numbers)
- 2 high speed cameras (UIC number, brake label)
- 1 weather station (windspeed, rain)
- Main station measuring PC (data collector)

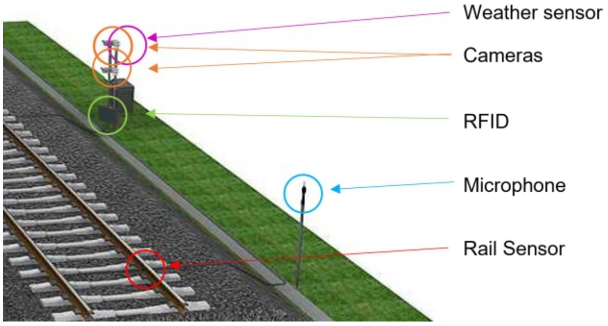

Figure 1. Schematic drawing of the setup with its key components.

Noise measurements were set up in accordance with ISO 3095 [11]. The noise measurements using the Train Monitoring Systems fulfill the highest accuracy class 3 of DIN 38452-1 [15]. Microphones were setup to measure across the neighboring track at a distance of 7.5 m to the center of the track. Two microphones were used that were setup 10m apart for redundancy and to detect disturbing noises not coming from train pass-bys.

The rail sensors were mounted at microphone position while the RFID readers and cameras were setup in the center with the height and distance from the track adjusted for its specific measurement purposes. The weather station was with the cameras and main station and continuously logged the meteorological conditions.

Figure 2. Onside installation of one of the two N-RSD systems for NEMO.

The rail roughness was measured prior to installation and found to be compliant with ISO 3095 limits for pass-by measurements for vehicle homologation. Compromises had to be made regarding the surrounding as the line is fenced with vegetation on both sides. This was deemed acceptable for the autumn and winter months of the measurement pilot.

2.2 Automated measurements

The N-RSD was put into operation during a pilot taking place between September 2022 and February 2023 in the Netherlands on line 125 between Tilburg and Boxtel. Two N-RSD systems were setup at the same location, one for each of the two tracks.

The measuring PC with its data collectors was configured such that it continuously grabs the sensors signals into memory but only saved them on a defined trigger signal. In this way the precious time right before a train pass-by could also be recorded. The signals were preprocessed in situ on the measurement PC and saved to a hdf5 file. The RFID information is stored with the microphone and rail sensor signals.

One camera is focused such that it captures UIC-number imprints in an area expected to cover most UIC-number imprints and at a framerate sufficient for the fastest trains to have travelled a maximum of half a frames width in the timespan between two successive frames.

The second camera is focused on the lower part of the train for the detection of the smaller imprints of brake type labels. It may also be used for detecting axles.

After each train pass-by all records are send to a post processing server for analysis.

2.3 Data analysis

Upon receiving measurement files, the post processing server runs the analysis on the measurements and writes the result to a database.

2.3.1 Axle signal analysis

From the rail sensor signals the axle times and axle speeds are deducted and therefrom the axle pattern. An algorithm is applied that separates the trains axle pattern into individual wagons/units and their corresponding pass-by times at each of the two microphones. Wagon length, speed and the validity of its axle pattern are determined.

2.3.2 Sound emission analysis

For each train the TEL (transit exposure level), maximum sound levels $L_{Af,max,}$, the equivalent sound level over its pass-by time $L_{Aeq,Tp}$ and third octave band spectra are calculated. Train encounters are detected from the second N-RSD system but local disturbances or the use of the signal horn are being checked for on first analysis from comparison of the two microphone signals.

For each wagon/unit the equivalent sound level $L_{Aeq,Tp,wagon}$, max levels $L_{Af,max}$ and 1/3 octave spectra are calculated. A correction for noisy neighboring wagons is applied for each wagon from an algorithm numerically approximating the contributions from nearest neighboring wagons. The algorithm largely approximates the contributions from a noisy wagon to its neighboring wagons by assuming a level-distance relation of 30 times their logarithmic ratio with the main noise sources being located at the bogies. These contributions are then subtracted from the time-level curve measured for the neighboring wagons. Corrections were capped at 6 dB, as to not result in unrealistically low wagon emissions on those neighbors.

Each axle is assigned an equivalent sound level L_{Aeq} and 1/3 octave spectra over 10ms, corresponding to the smallest time interval from the signal preprocessing of the microphone signals. No audible microphone recordings were done during the pilot for privacy reasons.

2.3.3 Train and wagon/train unit identification

From the axle pattern and speed, trains are categorized into one of the categories: freight train, passenger train, service train / locomotive. Wagons/units are further separated into the categories defined in the current TSI-N [3]. Train units are deducted from symmetry of axle pattern, signal strength and train category.

2.3.4 UIC number reading

The images from the camera focused for capturing UIC number imprints are run through an AI detection algorithm and an OCR reading algorithm. The machine readability is highly dependent on the quality of the imprints. With a 12-digit number there need only be small parts unreadable to make the rest of the imprint worthless.

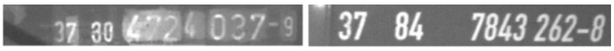

Figure 3. UIC-number imprints of different quality. bad quality (left), good quality (right)

UIC numbers are assigned to wagons from matching times of wagons, frames and object positions and wagon speed. The validity of the UIC number is checked through comparison to a database containing entries from the European Vehicle Register.

Two RFID readers were setup to collect UIC-numbers from RFID tags whenever these are installed and encoded in accordance with [13].

2.3.5 Brake type detection

Images from the camera focused on the lower train area are fed to an AI algorithm for detection and recognition of the imprinted labels for disc brakes, LL- and K-brake blocks.

Figure 4. Brake type labels for disc brakes, K- and LL-brake blocks

Brake type to wagon assignment is again done on matching times of wagons, frames and object position and wagon speed. Not all wagons had imprints for brake types. No label imprints exist for cast iron brakes.

2.3.6 Noise emission classification

All wagons/train units from valid measurements are classified regarding their noise emissions into one of the four classes listed below. The classification model is based on the current TSI limits for those train units. The sound level (L) used for reference could either be the actual measured sound level or the corrected sound level of the equivalent sound level $L_{Aeq,Tp,wagon}$

Table 1. Noise emission classes in reference to TSI limits.

Emission classes	**Level (L) [dB]**
low	$L \leq TSI - 3$
normal	$TSI - 3 < L \leq TSI$
medium	$TSI < L \leq TSI + 3$
high	$L > TSI + 3$

This classification model is interchangeable with any other one. The TSI reference was chosen as a basis because it makes the results best comparable to measurement done by others. The distinguishing between low and normal was made to see where the current TSI limits sits in relation to operational sound emissions from well-maintained train units.

2.3.7 Wheel flat detection

The rail sensor used for recognizing axles is based on the technology deployed on the Wheel Monitoring Systems (WMS) by Müller-BBM Rail Technologies [16] which is capable to detect defects such as flats or polygonization on the wheel treads of all passing vehicles. Only two rail sensors were equipped within NEMO since wheel defects were not in the focus of the project.

An algorithm was adopted to the N-RSD that analyzed the vibrational content of the rail sensor signals for the repetitive characteristics associated with wheel flats on each passing axle. Due to having only two sensors per track and because the demo system was missing a calibration for such an analysis the results are only indicative and only significant indication levels for wheel flats should be considered.

2.3.8 Quo Vadis data integration

ProRail provided data sets from two Quo Vadis systems operated on the same line but 20 km away from the NEMO pilot installation that saw much of the same rail traffic. The Quo Vadis data was integrated into the NEMO database based on matching UIC numbers, axle count, distance of locations and speed. This provided additional means to identify damaged wheels which could be used for linking these to noise emissions.

3. RESULTS

Over the course of 165 days of continuous, automated operation the two N-RSD registered more than 25k trains with 290k individual wagons/train units and about 1.1 million axles. For the further analysis all pass-bys with disturbances were removed from the data. By far the largest group of these are train encounters. Train encounters were checked for from comparing times of the two N-RSD systems on each pass-by. Since the classification uses the reference speed 80 km/h train going below 60 km/h were also ignored such as to not obtain too high of an impact from speed corrections. There were only few trains going below 60 km/h.

3.1 Average daily sound emissions

Figure 5 displays the distribution for the defined noise emission classes (2.3.6) for about 100k freight wagons going at an average speed of 90 km/h and 160k passenger cars and multiple units at an average speed of 130 km/h. The percentages of 'medium' and 'high' emitters directly correspond to the percentage of wagons exceeding their respective train unit TSI limits.

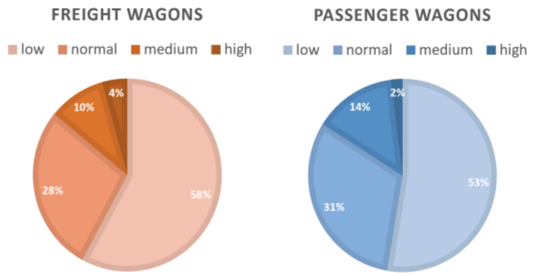

Figure 5. Distribution of noise emission classes for freight wagons and passenger wagons (incl. multiple driven units)

The average daily noise levels L_{den} for rail traffic from both tracks was 65.5 dB(A) – in 7.5m distance to the track. Freight and passenger wagons/units contribute to it according to the listed values in **Table 2**. Passenger traffic is dominating the emissions, largely due to its higher speed. The L_{den} was choses for its broad application in noise related studies and because it incorporated the emissions of all pass-by events in contrast to only focusing on night hours. On average there were 1-2 freight trains per hour with no increase during night hours while passenger trains still frequented the route in high numbers into the early morning hours.

Table 2. Average daily noise level (L_{den}) contributions from train units and emission classes in the NEMO pilot

Emission class	Passenger L_{den}	Freight L_{den}
low	56.4	55.8
normal	58.0	55.5
medium	56.8	53.3
high	51.5	53.5
total	62.3	60.7

Freight wagons classified as 'high' emitters made up only 4 percent of all freight wagons but contributed almost 20 percent of the total freight wagon noise emissions. If all freight wagons were made TSI compliant and assuming the given ratio between 'low' and 'normal' emitters, noise emissions from freight wagons would drop by 27 percent. For passenger wagons/units making all wagons TSI compliant would lower emissions by 25 percent.

3.2 'High' emitter analysis

The broad set of data and information available from the various sensors and externally supplied information offers the opportunity to look for patterns and correlations which may reveal dependencies or even hint at root causes. Because NEMO targets 'high' emitters we will examine what the N-RSD offers in regard to identifying those.

3.2.1 Wheel tread irregularities

Looking at the percentage of freight wagons indicated to have wheel tread irregularities (i.e. wheel flats) both from NEMO's flat indication (only being a low key installation with the two axle sensors on just one rail) to Quo Vadis full axle measurements we find strong correlations to noise emission levels. 60 percent of all wagons in the class of 'high' emitters were also registered as having wheel irregularities.

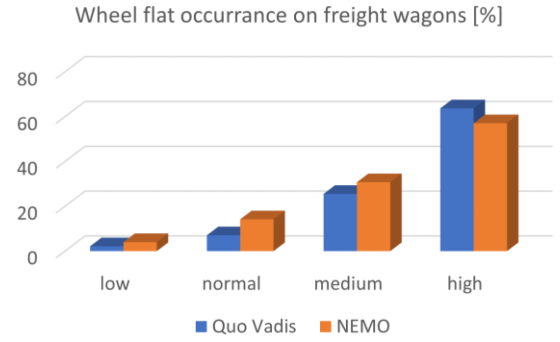

Figure 6. Occurrence of wheel flat indication in respect to noise emission classes from both NEMO and Quo Vadis.

For passenger wagons/units the percentage of 'high' emitters indicated as having wheel irregularities were still more than 50 percent.

3.2.2 Brake type

About 34 percent of all 'high' emitters were labeled as having LL-brake blocks but only 7 percent as having K-brake blocks. With overall three times as many freight wagons identified to have K-brake blocks than those with LL-brake blocks, this shows LL-brake blocks to be severely overrepresented in the 'high' noise emitter class. Due to only having access to the imprinted labels no distinguishing may be made between different types of LL- brake blocks as had been done in [12].

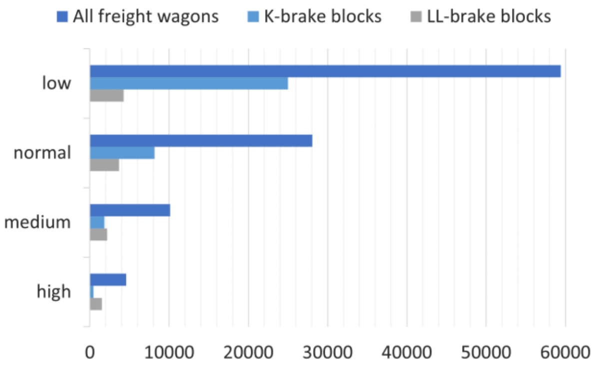

Figure 7. Total number of valid freight wagons measured and those registered with LL- or K-brake blocks.

In **Figure 7** the total number of freight wagons is plotted alongside the number of freight wagons registered with LL-brake blocks and K-brake blocks. In the class of 'high' emitters wagons with LL-brake blocks are overrepresented while wagons with K-brake blocks are clearly underrepresented.

3.3 Impact of brake type on noise emissions

Half of the registered freight wagons had readable brake label imprints. Almost 40k freight wagons had the K imprint and 13k wagons the LL.

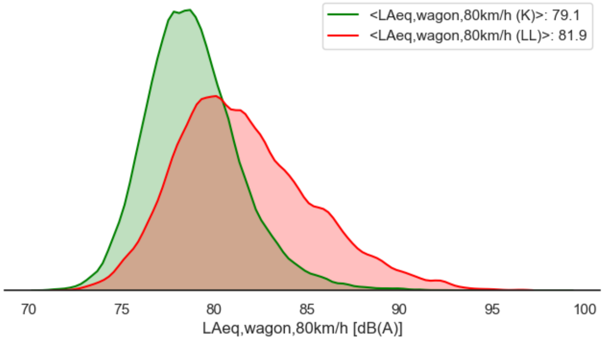

Figure 8. Density distributions of the $L_{Aeq,80km/h}$ from 40k freight wagon labelled K and 13k labelled LL.

Figure 8 shows the density distributions of the equivalent sound pressure levels for freight wagons at reference speed of 80 km/h ($L_{Aeq,80km/h}$) for 40k wagon labelled K and 13k wagons labelled LL. The two distributions are clearly distinct with LL-brake block equipped wagons on average displaying 2-3 dB higher sound emissions.

3.4 UIC-number identification

Two complementary means of identification were tested within NEMO for retrieving wagon UIC-numbers. The camera system attempts to read UIC-number imprints from visual recording of each passing wagon, whereas the RFID reader setup retrieves RFID tag information sent during the wagon pass-by time interval. There were slightly different focuses and configurations for the two camera systems tested on the two N-RSD and two different sets of RFID readers installed.

The largest number of passenger wagons passing the NEMO pilots were from commuter trains operated by NS (Nederlandse Spoorwegen). Those largely had their internal 6-digit number encoded on the RFID tag. Readability of RFID tags on NS trains were very high (>95 percent) for one of the tested RFID solutions, indicating that the technique is viable at these pass-by speeds and distances.

The camera system was optimized for reading freight wagon UIC-numbers, which meant it was focus on the typical heights where UIC-numbers occur on freight wagons. It is much harder to assess how successful it is as a significant number of wagons in the test group that went into training the AI could hardly be read by the human labeling those. Looking at sets of freight wagons with high quality imprints the detection rate from the camera system was good and could even be improved when combined with the second camera initially meant for detecting brake type labels.

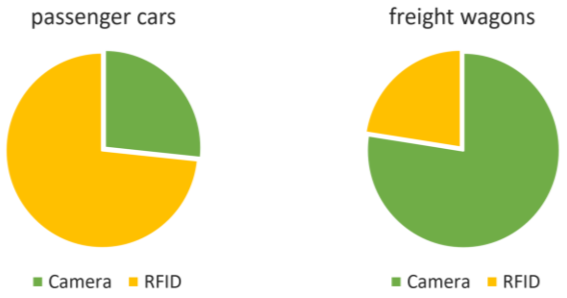

Figure 9. Proportion of the two complementary techniques contributing to the UIC-number detection from passenger and freight wagons.

From **Figure 9** we find that the larger portion of the passenger wagons identified with UIC-numbers could be found with the RFID systems. This comes as no surprise as the commuting passenger wagons were almost all equipped with RFID tags and the camera system was optimized for freight wagon imprints. Passenger car recordings had a higher percentage of images with reflections from the illumination blurring parts of the UIC-numbers. This could be improved by changing the illumination but was out of the scope and timeline of the research project.

For freight wagons **Figure 9** shows that the camera system is vital for retrieving the freight wagon UIC-numbers. This is likely the case due to a low percentage of freight wagons being equipped with RFID tags compliant with [13].

It should be noted that full UIC-numbers were only considered once a checking algorithm approved it as valid. This included comparison with a database table containing valid numbers from the European Vehicle Registry. This list had been found incomplete at some instances suggesting a slightly higher percentage of wagons could be identified by updating the information of valid UIC-numbers.

4. CONCLUSION

The NEMO approach of remote sensing and data integration could be proven to be very powerful tool. It allows for a fast and reliable identification of the largest noise contributors, while UIC-number detection from IR camera imaging and RFID combined allows to track down those wagons quickly. The collective information obtained from the remote sensing solution also allows to constantly evaluate the traffic and look for changing dependencies. This may be used to search for root causes or for deducting current state of the fleet or sub parts of it.

For the monitored line 125 the ‘high’ noise emissions were found to be strongly correlated with wheel tread irregularities. There was also a stark indication that freight wagons equipped with LL-brake block emit on average higher noises than freight wagons equipped with K-brake blocks. Wagons with LL-brake blocks were also overrepresented in the group of wagons classified ‘high’ emitters. No correlations could be made regarding the age or maintenance of the wagons. The UIC number information provided with the classification in NEMO should make this a feasible task if incorporating registries.

The machine readability of wagon imprints such as UIC-numbers is very diverse and in no way comparable to the standardized number plate readability in road traffic. RFID tags were only found in relevant number on passenger trains. This makes the visual number identification a vital component identifying freight wagons. A combination of the two techniques is recommendable.

Apart from the aspects discussed in this paper a remote sensing devise such as presented can offer further benefits. Complains from residents could be directly linked to certain trains, the traffic distribution and levels over time are easily retrievable for real emissions and in relation to each other. It also provides the means to update data for calculation models or for their validation. One of the missing features in many noise assessment studies for rail traffic noise is the inclusion of intermittency [14]. Monitoring solutions can provide input data for accounting for intermittency.

By the end of 2024, the quieter routes will come into force. From this point on, cast-iron braked wagons will largely phase out. Remote sensing solutions as the one presented in this paper can support the authorities in monitoring the rolling stock on the quieter routes and identify non-permitted wagons.

5. ACKNOWLEDGMENTS

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Grant Agreement n° 860441.

6. REFERENCES

[1] EEA Report, “Environmental noise in Europe - 2020” No 22/2019.

[2] G. van Blokland, S. Lutzenberger: "Progress report on measures on rail traffic noise in the EU" EPA Network meeting in Riga, 2014.

[3] Commission Regulation (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU

[4] Commission Implementing Regulation (EU) 2019/774 of 16 May 2019 amending Regulation (EU) No 1304/2014 as regards application of the technical specification for interoperability relating to the subsystem 'rolling stock — noise' to the existing freight wagons.

[5] WHO: "Environmental Noise Guidelines for the European Region", 2018

[6] J. Nielsen, A. Pieringer, D. Thompson, P. Torstensson: "Wheel–Rail Impact Loads, Noise and Vibration: A Review of Excitation Mechanisms, Prediction Methods and Mitigation Measures." 10.1007/978-3-030-70289-2_1. (2021)

[7] Fredy Fischer: "Lärmsanierung des Bahngüterverkehrs: Die alten Klötze haben ausgebremst", www.bafu.admin.ch/magazin2015-1-15, 2015

[8] Gesetz zum Verbot des Betriebs lauter Güterwagen (Schienenlärmschutzgesetz - SchlärmschG), 2017

[9] P. Bucsky: "Noise Related Rail Access Charges in Europe: Aspects of Interoperability and Competitiveness." Periodica Polytechnica Transportation Engineering. 49. 10.3311/PPtr.14269. 2019

[10] H2020 research project website: Nemo | (nemo-cities.eu)

[11] ISO 3095: "Acoustics — Railway applications — Measurement of noise emitted by railbound vehicles.", 2013

[12] F. Létourneaux, F. Aubin: "Acoustic Specification of Composite Brake Blocks for Railway vehicles", EuroNoise, 2015

[13] BS EN 17230:2020: "Information technology, RFID in rail", 2020

[14] J. Wunderli, R. Pieren, C. Cajochen, N. Probst-Hensch: "Intermittency ratio: A metric reflecting short-term temporal variations of transportation noise exposure", Journal of Exposure Science & Environmental Epidemiology, 2015

[15] DIN 38452-1:2022-08; Long-term measurement of railway traffic noise - Part 1: Emissions

[16] Müller-BBM Rail Technologies homepage: Wheel Monitoring System (WMS) - www.muellerbbm-rail.com/products/wheel-monitoring-system