Pilot wheelset maintenance

Summarizing report

for ProRail's Innovation Program Source Approach Rail Vibrations ("Bronaanpak Spoortrillingen")

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Summary

This summary report describes the approach and results of the practical wheel maintenance trial conducted as part of the Innovation Program Source Approach Rail Vibrations ("Innovatieprogramma Bronaanpak Spoortrillingen", IBS). This practical trial focused on the influence of wheel roundness on ground borne vibrations and possibilities investigated for reducing vibrations through additional wheel maintenance based on new monitoring techniques. The quality of the track (substructure, superstructure, maintenance, innovations) was a separate area of research for the IBS which is reported separately[1]. Other aspects such as water management, measures for vibration transfer between the track and buildings, and structural aspects of buildings were outside the scope of this research and the IBS programme. For the reason behind the IBS and more background information, please refer to the appendix.

An extensive measurement programme was during the practical trial carried out at various locations, which yielded the following key insights:

- *Locomotives often determine the vibration level. However, locomotive wheels do not often contain deviations and there is therefore no relevant potential for improvement by carrying out additional wheel maintenance.*
- *Passenger trains do not have the highest vibration levels, but the positive influence of wheel maintenance on vibration levels has been demonstrated. There is no relevant potential for improvement regarding nuisance reduction by performing additional wheel maintenance.*
- *Freight wagons sometimes dominant for vibration levels. For some of the passages, this is caused by a measurable reduction in the wheel quality of these wagons. Calculations have shown that it is effective to carry out additional wheel maintenance ('vibration maintenance') in these cases to reduce rail vibrations (when the conditions mentioned below are met).*

The specific results per measurement location are also influenced by soil type, track construction and building characteristics. Train-related characteristics such as rolling stock type, axle load and train speed also play a role.

Various scenarios for vibration maintenance have been investigated specifically for freight wagons. This maintenance would then be carried out in addition to the maintenance that is already carried out based on European regulations. Three example scenarios have been developed for this purpose. Two of these scenario's only focus on iron/coal transport, since here the highest potential for improvement is foreseen. Feasibility and costs have been considered. In this order to make these maintenance scenarios feasible, several important preconditions must be met. For example, the commitment of many international parties is required, many mutual agreements must be made, and new processes must be set up. Additional shunting and maintenance facilities must also be built and reserve wagons and wheel sets must be made available. The scenarios outlined will result in cost increases for rail freight transport in the Netherlands ranging from several million to tens of millions of euros per year. This will negatively influence the desired modal shift. Price elasticity was used to determine the volume loss if these costs were to be borne by the rail freight sector itself. The table below summarises the estimated degree of reduction, the costs, the volume loss and the aspects of manageability, implementability and operational and commercial impact of three investigated example scenarios in comparison with the current situation.

[1] For a complete insight in the results of this IBS research programme is referred to [13]

Scenario	Degree of reduction	Feasibility	Implementability	Operational and commercial impact	Additional costs (in million euro/year)	Impact on transport volume in this sector
0- current situation	0	0	0	0	0	0
1 – preventive coal/ore wagons	0-9[2]	--	---	-	23.4	-35%
2 – corrective for all wagons, lower maintenance limit	0-20%[2]	---	----	----	47.6	-15%
3 – corrective coal/ore wagons, higher maintenance limit	0-5%[2]	-	--	--	4.1	-6%

The estimated costs and reduction in nuisance can be used to assess whether vibration maintenance to reduce nuisance is effective. This can be compared to the effectiveness of other source measures in the railway infrastructure, but also with measures in the transmission or the buildings. If vibration maintenance proves to be effective, it is recommended to investigate the possibilities with the necessary parties. If there is sufficient commitment from the parties involved, it is recommended to start with a small-scale pilot project, in which the new processes can be extensively tested. Even if it is not effective, the insights gained from the research can be used to ensure that wheels that do not meet the current maintenance standards are better detected.

[2] This is location-dependent; the range indicates what for different locations in the Netherlands has been determined. It concerns the estimated reduction in the average vibration level of the 10% of freight train passages with the highest vibration levels. For individual train passages, the vibration level can be reduced much more. The reduction in the total average vibration level at the location is negligible.

1. Introduction

This summary report describes the approach and results of the practical wheel maintenance trial carried out as part of the Innovation Program Source Approach Rail Vibrations (IBS). The trial was intended to provide more insight into the possibility of reducing rail vibrations through different wheel maintenance regimes. This trial was set up by ProRail and the Ministry of Infrastructure and Water Management together with other parties from the sector. These parties include the business organisations RailGood and Evofenedex, passenger transport operator NS, wagon owners Ermewa and VTG, shippers Sabic, Fibrant, Tata Steel and Nedmag, and freight transport operator RTB Cargo. The practical trial was carried out under the technical supervision of Ricardo Rail.

1.1 Objective of the practical trial

The aim of the trial was to:

- Gain more insight into the extent to which rail vibrations can be reduced through the international application of new maintenance rules for wheelsets, based on new monitoring techniques;
- Determine the impact of different wheel maintenance on the costs, availability and safety of rail transport.

1.2 Practical trial approach and report structure

In order to achieve the objectives set out above, the relationships shown in Figure 1 were investigated. First, the relationship between wheel roundness, rail vibrations and nuisance was investigated. To this end an extensive measurement programme was carried out, which is described in chapter 0. The results of the analysis are presented in chapter 3. We also examined whether wheel roundness can be measured using existing monitoring systems and whether these monitoring systems can be used to manage maintenance activities; see also chapter 4. Ultimately, wheel maintenance has an impact on the costs and availability of trains/wagons, and this was investigated in the final step of the trial. Chapter 5 describes the insights that emerged from this. Chapter 0 presents the main conclusions from the study.

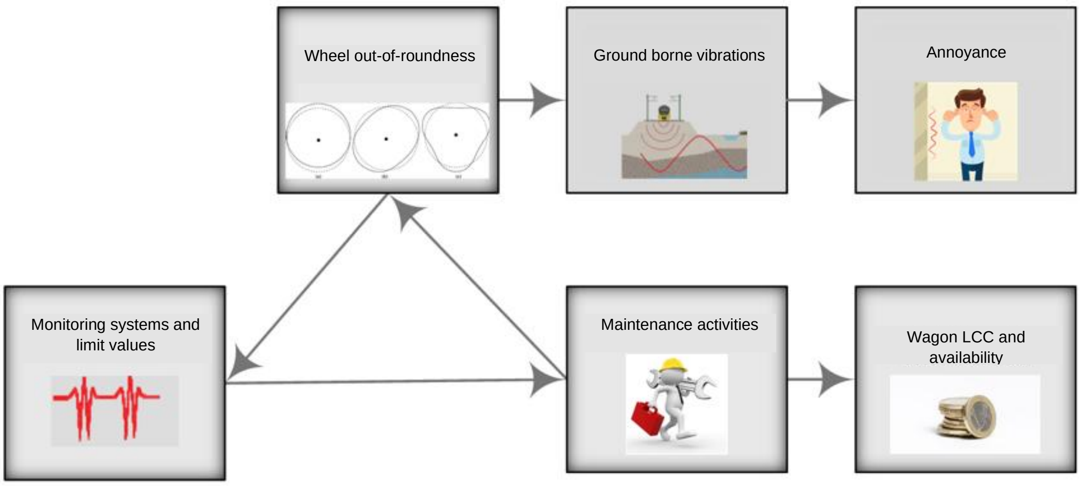

Figure 1 : Relationships between different parameters

1.3 International context of freight rolling stock

An important aspect that has been considered is the international context of rail freight transport. In the Netherlands, this is largely international, with rolling stock mostly belonging to foreign parties. In addition, there are many wagons that are only occasionally in the Netherlands because they mainly operate elsewhere in Europe. This rolling stock is maintained in accordance with international rules[3]. European legislation and regulations must be taken into account: rolling stock must, among other things, be able to operate unhindered throughout the European Member States. An approach that fits in with this international context is therefore an important prerequisite for arriving at a feasible and accepted approach.

[3] Before being put into service, each rail vehicle must be assigned to an entity in charge of maintenance (ECM). This entity is responsible for maintenance and ensures that the vehicle is in a safe condition. This includes compliance with maintenance records and applicable regulations, including the Technical Specifications for Interoperability (TSI).
The Technical Specification for Interoperability relating to freight wagons, known as the TSI WAG, is a European regulation that lays down the technical and functional requirements for the 'rolling stock – freight wagons' subsystem. This specification applies to freight wagons. The TSI WAG sets requirements for the maintenance and certification of freight wagons to ensure a high level of safety and reliability.

2. Data collection

To gain insight into the relationships as depicted in Figure 1, various types of measurements were carried out to collect data. These measurements are as follows:

- Wheel roundness measurements
- Track vibrations measurements
- Wheel-rail forces measurements

These measurements were carried out on passenger trains and regular freight trains from various transport operators with rolling stock from different owners for various shippers.

2.1 Wheel measurements

The wheel roundness measurements were carried out in two ways. For passenger trains, data from the wheel lathe was used. This machine restores the roundness of the wheels during wheel maintenance and measures the wheel roundness prior to maintenance. The wheel roundness of freight wagons was measured after a number of wagons were selected based on the measured track vibrations when these wagons passed the infra measurement locations of the project. Quo Vadis data has established that the measured wheels are a reasonably representative reflection of the entire fleet of freight wagons [9]. These selected wagons had to be taken out of service and set aside so that the wheels could be measured. Figure 2 shows an example of a wheel measurement on a freight wagon. The wheel measurements were carried out by M+P.

In addition, some freight wagons also underwent wheel maintenance during the trial. The wagon owners shared this data with the project so that it could be included in the study.

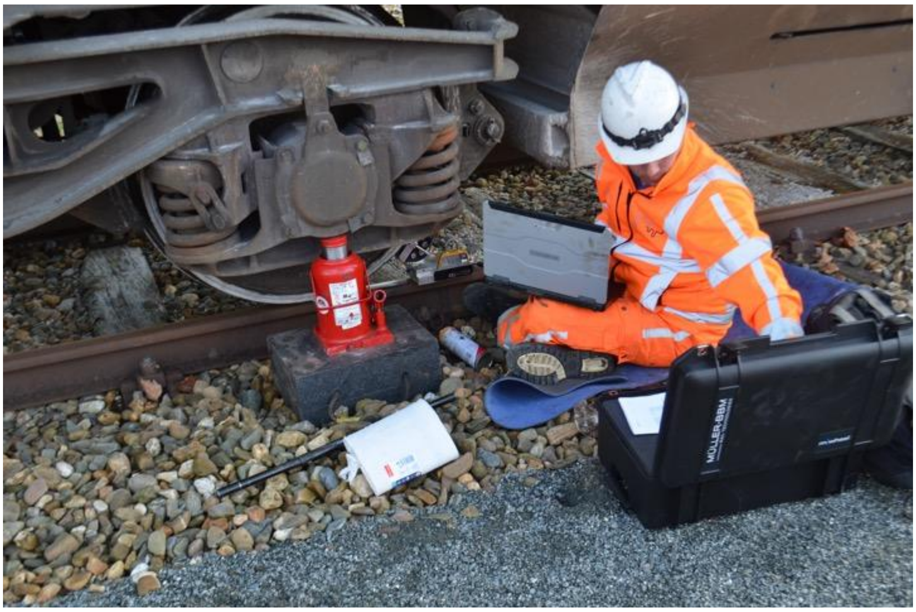

Figure 2 : Example of a wheel measurement on a freight wagon by M+P

2.2 Measuring stations

The rail vibrations were measured by Witteveen+Bos. They installed measuring stations at five locations, which were active for periods ranging from 1 to 12 months. Each measuring station measured the vibrations at distances of 4, 8 and 25 metres from the track. In addition, each measuring station also had a sensor in a building or dwelling at approximately 25 metres from the track. The water level in the soil was also considered. The measuring stations were located at the following locations, which have varying soil types and are used by different types of rolling stock:

- Heeze (sandy soil, relatively stiff)
- Weert (sandy soil, relatively stiff)
- Schalkwijk (peat soil, very soft)
- America (sandy soil, relatively stiff)
- Holten (sandy soil, relatively stiff)

Figure 4 gives an impression of the measurement location in Holten.

The wheel-rail forces were measured by ProRail's Quo Vadis monitoring system. These monitoring stations are located at several locations in the Netherlands and are intended, among other things, to detect wheels with reduced wheel quality. The rail vibration measuring stations, ProRail's Quo Vadis monitoring stations, freight trains that have been measured and the soil type are shown in Figure 3.

All this collected data has been used to map how often wheels with reduced quality occur and what the relationship is with vibration levels. In addition, the extent to which wheels with reduced quality can be detected by the monitoring stations and whether additional wheel maintenance, focused on wheels with reduced quality (here referred to as 'vibration maintenance'), can help reduce nuisance has been examined.

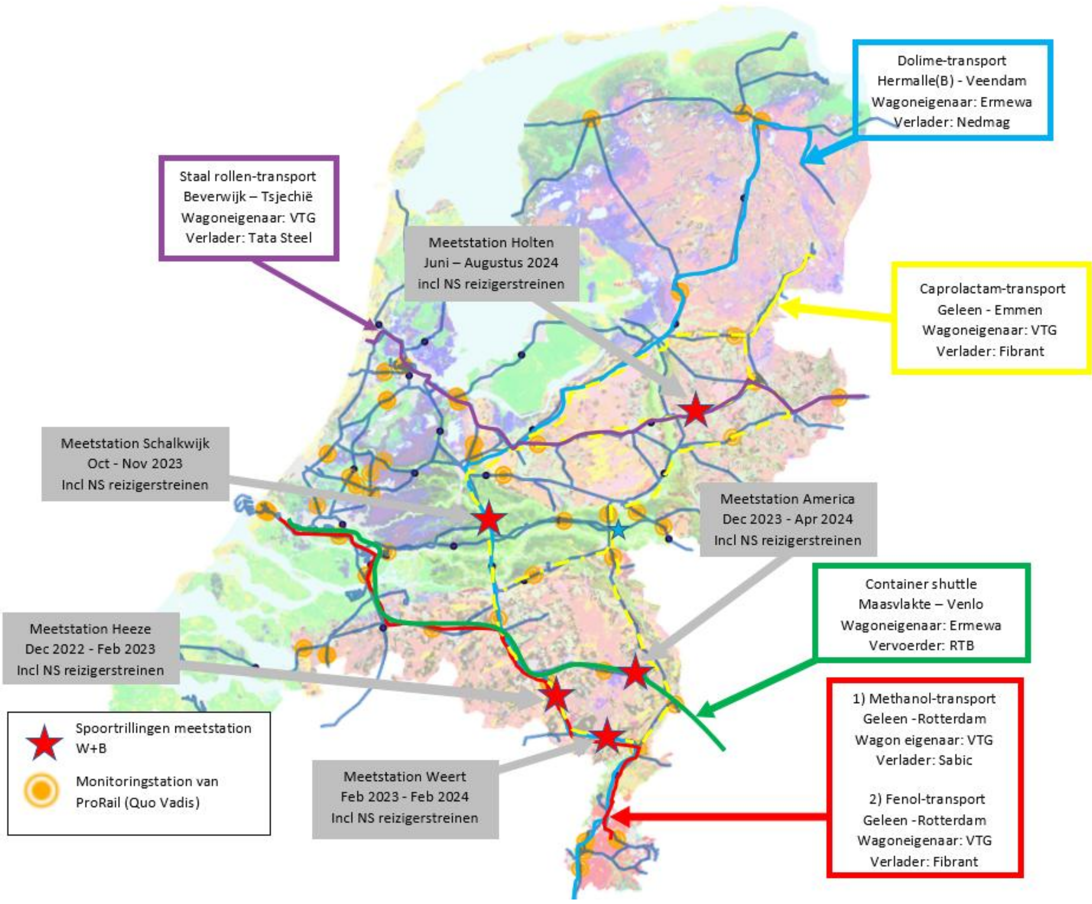

Figure 3 : Overview of rail vibration measuring stations, ProRail monitoring stations, trains and soil type

Figure 4 The measuring station at Holten with a randomly passing train (photo: Hans-Willem Vroon)

3. Influence of wheel roundness on vibrations and nuisance

The analyses carried out by Witteveen+Bos using the collected data have provided a number of important insights [2]. In general, it can be said that many different aspects influence vibrations and nuisance. Some of these aspects are:

- Train speed
- Axle load
- Type of rolling stock
- Soil type

This study focused on the influence of wheel quality on rail vibrations. The quality of the track (substructure, superstructure, maintenance, innovations), water management, transfer measures between the track and homes, and architectural aspects of homes fall outside the scope of this study. The quality of the track (substructure, superstructure, maintenance and innovations) was a separate area of research for the IBS.

3.1 Location dependency

The analyses showed that the influence of wheel quality varies per location. At the measurement location in Weert, wheel quality has the greatest influence on rail vibrations. The soil type in Weert is relatively stiff. To a slightly lesser extent, wheel quality influences the measurement location in America, and even less so in Holten. These locations have a similar soil type.

At the Schalkwijk location, the influence of wheel quality is almost invisible in the track vibrations. The soil at Schalkwijk is very soft and the aspect that has the most influence on track vibrations here is the axle load and the composition of the train. The higher the axle load, the higher the vibration levels. After axle load, the type of rolling stock and the speed of the train are the factors that influence vibration levels here. This means that vibrations cannot be reduced at this location by changing wheel maintenance practices.

3.2 Direct measurement of the effect of wheel maintenance on passenger rolling stock

As mentioned earlier, the wheel roundness measurements on the passenger trains were carried out just before wheel maintenance was performed. This made it possible to compare the passages of these passenger trains before and after wheel maintenance. This comparison showed that improving wheel quality has a positive effect on rail vibrations. This is because vibration levels decrease after wheel maintenance has been carried out. The track vibrations were measured at various distances (4, 8 and 25 metres) from the track. The 25-metre distance is decisive for nuisance, but the greater the distance from the track, the smaller the decrease in vibration levels. The average decrease in vibration levels at 25 metres from the track is almost negligible, but the differences between vibration levels (the spread) do become smaller. This means that the occasional peaks (causing high vibration levels) have disappeared after wheel maintenance has been carried out. This is an important conclusion because it demonstrates that improving wheel quality can reduce vibration levels. However, reducing vibration levels does not necessarily mean that there is also a noticeable positive effect on nuisance. For this, we refer to the RIVAS study [7], which describes that a reduction in vibration levels of at least 25 to 40% is only noticeable to humans. Such differences have not been observed at a distance of 25 metres from the track for these passenger trains.

3.3 Model for the effect of wheel maintenance on freight trains

The practical test showed that vibration levels for trains pulled by a locomotive (both passenger trains and freight trains) are generally higher. To this end, research was conducted into the passages where the locomotive determines the vibration level. These vibration levels are not influenced by the wheel quality of the locomotive, as locomotives with reduced wheel quality are rare. The explanation for the higher vibration levels is the higher axle load of a locomotive.

Another observed effect is that the differences in vibration levels between freight trains (the spread) are much greater than between passenger trains. This is partly related to the observation that there are passages where the carriages determine the vibration level and not the locomotive. Whether these vibration levels caused by carriages are influenced by wheel quality has been extensively researched. Because freight trains are never serviced in their entirety, and the train composition often changes afterwards, it is not possible to make a direct comparison between train passages before and after wheel maintenance. Models were therefore used to determine the influence of wheel quality on vibration levels. This is shown in Figure 5. In the first step, these models were fed with all the collected data to teach the model the relationships between wheel roundness, wheel-rail force and track vibrations. In the second step, the models were used to predict the influence of wheel quality on vibration levels. Such a model was created for each measurement location.

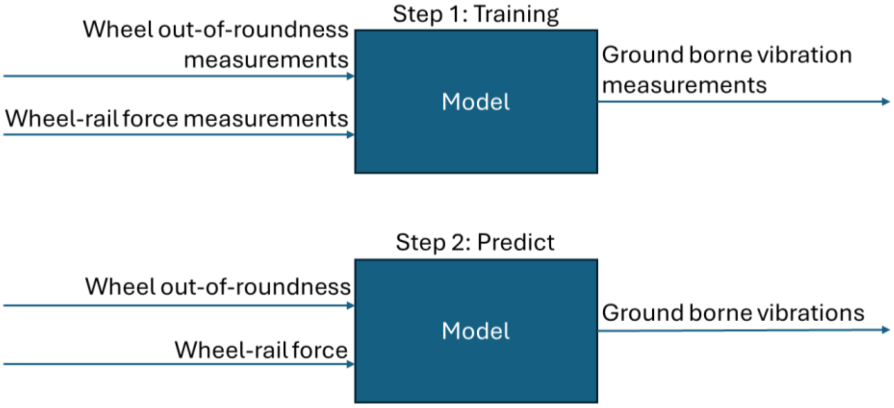

Figure 5 Schematic representation of the use of models

3.4 Insights from the measurements

The models show that for the group of passages with the highest vibration levels, where the carriages are the determining factor, a reduction in vibration levels is possible. However, this depends on the location and the carriage types. For the various measurement locations, the calculated reduction has been mapped out when some of the carriages, with dynamic wheel-rail forces above a certain value, additional receive vibration maintenance. The results for the measurement location in Heeze have not been quantified because this was a trial location for testing the measurement methodology. However, it has been established that wheel maintenance has a positive effect on vibration levels at this location.

The results are summarised in Table1. The second column indicates what happens when wheels with a dynamic wheel-rail force (RMS_Low) above 7.5 kN[4] receive vibration maintenance. It shows how the average vibration level at 25 metres from the track, of the 10% of train passages with the highest vibration levels, decreases. It can be seen that, depending on the location, a reduction of a few percent to approximately 25% is achievable. The third column indicates which part of the carriages at that location is affected. The fourth and fifth columns provide similar information when only wheels with a wheel-rail force (RMS_Low) above 15 kN[4] receive vibration maintenance.

The last column indicates the possible reduction (approximately 1 in 100,000 wagon passages) for the largest outliers. At busy locations such as America , this occurs several times a year, at other locations less often. Only in these very rare cases can a reduction of this level be achieved.

The conclusion of the Witteveen + Bos study is that in order to reduce nuisance, it is effective to carry out vibration maintenance on this limited group of wagons. These conclusions are confirmed by other studies conducted within the framework of the IBS. Analysis of complaints [12] and research into the perception of nuisance by residents living near the railway [11] have also established that there are links between wheel damage reported in Quo Vadis and complaints and the perception of nuisance.

Table1 : Summary of results - Average and maximum reduction in vibration levels for the 10% of passages with the highest vibration level at 25 metres from the track and the proportion of wagons (of the total number of passages) where the measured dynamic wheel-rail forces (RMS_ Low) exceed. [2]

Location	Decrease in vibration level (RMS_Low > 7.5 kN)	Proportion of wagons at location (RMS_Low > 7.5 kN)	Decrease in vibration level (RMS_Low > 15 kN)	Proportion of wagons on site (RMS_Low >15 kN)	Maximum possible reduction for largest outliers
Weert	14 - 24 %	50 – 75 %	10 %	7 - 12 %	Up to approx. factor 2.5
America	5 - 19 %	23 – 63 %	< 5 %	1 – 7 %	Up to approx.. factor 3.5
Holten	< 5 %	20 – 32 %	< 1 %	< 1%	Up to approx. factor 1.25
Schalkwijk	< 5 %	20 – 23 %	< 1 %	2%	Up to approx.. factor 1.5

4. Monitoring systems

Managing maintenance differently means, among other things, that suitable wheel monitoring systems (WDD – Wheel Defect Detection) are needed to reliably and consistently identify wagons with reduced wheel quality. In the Netherlands, ProRail has installed the Quo Vadis WDD system. This system was supplied by

[4] This study develops scenarios based on low RMS maintenance limits of 7.5 kN and 15 kN, respectively. These two values were arbitrarily chosen and used here to compare two scenarios: one with a relatively high maintenance limit (less maintenance effort) and one with a relatively low maintenance limit (greater maintenance effort).Witteveen + Bos proposes to carry out vibration maintenance at dynamic wheel-rail forces (RMS_ Low) higher than 10 to 20 kN. It is also proposed to compensate the Quo Vadis measurement values for axle load and speed, so that the assessment of the wheel does not depend on this [2]. A final, meaningful choice for a maintenance value based on RMS_low should be based on a good balance between benefits (nuisance reduction) and costs.

Voestalpine. Data analysis by Witteveen + Bos (see chapter 3) has shown that the Quo Vadis system is well capable of detecting wheels that also cause extra vibration nuisance.

4.1 Innovation

Voestalpine is currently developing improvements to the system. Together with Voestalpine, a practical trial was conducted to investigate whether an alternative analysis method could detect wheels that generate vibrations even more effectively [3]. According to the analysis by Witteveen + Bos, this did not yield any significant improvements compared to the current analysis method [2].

In the context of innovation in monitoring systems, collaboration was also sought with ProRail's FOAS project. FOAS stands for Fibre Optic Acoustic Sensing, which is a fibre optic cable that runs underground along the track and can be used to detect vibrations. There are various possible uses for this. One of the uses that has emerged is the detection of low wheel quality. The practical wheel maintenance trial investigated whether this innovative measurement technique can help detect wheels that cause extra vibration nuisance. To this end, data on rail vibrations and wheel roundness collected during the measurement period at Holten was shared with the FOAS project. Unfortunately, too little data was collected from measurements with the fibre optic cable to validate wheel defects such as out-of-roundness, cracks and spalling. The FOAS project has therefore not yet concluded whether this innovative technique has added value in detecting wheels of reduced quality.

4.2 Monitoring systems in Europe

In connection with the international context of freight traffic, Professional in Transportation has mapped out which other monitoring systems are in use in Europe [4]. The situation is different in every country. In Austria and Switzerland, for example, similar systems have been installed on the track by the relevant infrastructure managers. However, this has not been done in Germany and Belgium, for example. In Germany, there is a private initiative for a monitoring system called Railwatch. Railwatch uses acoustic signals to detect flat spots, unlike Quo Vadis, which measures wheel/rail forces. In the practical trial, a limited benchmark was created based on measurement data from the same trains that also passed the vibration measurement stations, in order to see whether the data from the Quo Vadis and Railwatch monitoring systems are suitable for the same purpose. This did not reveal a clear correlation between Railwatch and Quo Vadis, so this was not investigated in further detail [8] .

4.3 Limitations

In addition to the fact that monitoring systems are not installed everywhere, there is also no international harmonisation and standardisation of the output of these types of systems. This means that wagon owners may receive different information from different countries, with different consequences. Given the international context of rail freight transport, these are two relevant disadvantages. It is therefore recommended that, in a European context, efforts be made to further develop, roll out and standardise these types of systems.

Given the current situation is the consequence now that the insights gained from this practical trial can currently only be applied based on monitoring wagons on the Dutch rail network. Until a more comprehensive and harmonised monitoring system is in place in Europe, this is an important limitation that must be considered.

5. Feasibility and costs maintenance measures

In the chapter 3 was concluded that vibration maintenance can help to reduce nuisance for a limited group of freight wagons [2]. Professional in Transportation has investigated in further detail whether and how it is feasible to implement vibration maintenance with additional requirements for maintenance intervals and procedures based on monitoring systems. Bridgecraft Strategy and Corporate Finance ("Bridgecraft") has conducted an economic analysis of this approach.

5.1 Focus on outliers

It was decided to distinguish between different types of rail freight transport, as they all have different characteristics and conditions. Differences in the extent to which wheels of reduced quality occur were also examined. This was done to focus on vibration maintenance on sectors where it is most useful. The following sectors are distinguished:

- Chemical transport, which takes place using tank wagons. This accounts for 11% of transport volume and is fairly stable.
- Coal and ore transport; this takes place using heavily loaded bulk wagons with high axle loads. The current transport share is 34% [5], but this will decrease in the future due to the energy transition.
- Car transport, that takes place using relatively light wagons with an open structure. The transport share is 2%.
- Container trains, which consist of different types of container wagons. The share of transport is 43%, and an increase is expected in the long term.
- Other types of transport, such as wagons for transporting steel coils and sliding wall wagons. Transport share is 10%.

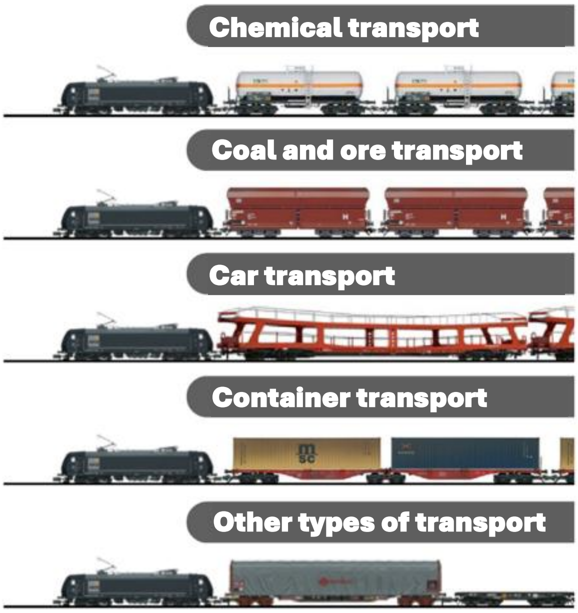

Figure 6 Different types of freight transport [10]

Figure 7 shows how these sectors relate to each other in terms of their share in the annual number of tonne-kilometres and the number of wheels detected with dynamic wheel-rail forces (RMS_Low) above 15 kN. It can be seen that coal and ore transport in particular accounts for a relatively large share of wheels with reduced quality, also in relation to transport volume. With container trains, the opposite is true. According to research by Professional in Transportation, the age of the wagons used is very likely to play a role here. With ore/coal trains, the wagons are relatively old, while with container trains they are relatively new.

[5] This concerns the transport volume, because these trains are relatively heavy, the share of coal/ore trains in train kilometers/train passages is lower.

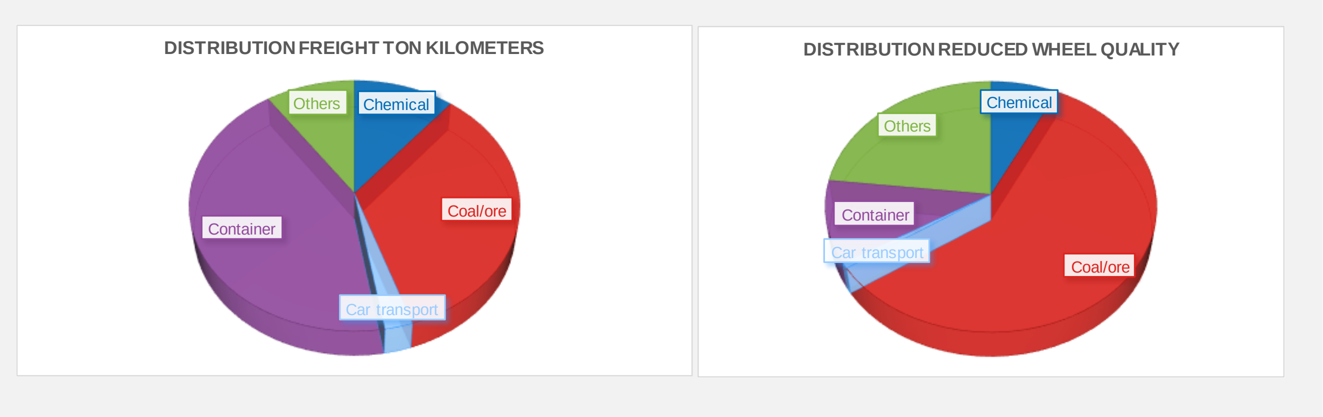

Figure 7 : Distribution of different sectors [4]

In addition, it was also investigated whether different types of brake pads on freight wagons have an impact on the number of wheels of reduced quality. After all, one of the causes of out-of-round wheels is related to abrupt braking. Analyses show that, on average, the type of brake pad has no significant relationship with vibration levels [6][4]. However, when zooming in on wagons with poorer wheels, it appears that wagons with so-called LL brake blocks more often have wheels of reduced quality than wagons with K brake blocks [6] [4].

5.2 Current maintenance processes

Freight wagons travel throughout entire Europe, which is why the current maintenance processes and rejection standards for wheels are based on European standards and agreements. Various parties are also involved. The railway undertaking operates the wagon and is responsible for operational safety. This party is therefore also responsible for the internationally agreed inspections of the wagons, including the daily safety checks of the wheels. The keeper is the legal owner of the rolling stock. The ECM (see also[3]) is responsible for drawing up the maintenance programme and implementing it. Together, these parties are responsible for the safe operation and maintenance of the rolling stock. European standardised agreements regulate the division of roles and costs and the efficient handling of processes.

The current standard maintenance processes for wheels are not designed for the use of data from monitoring systems such as Quo Vadis. Nor do they provide for vibration maintenance. New processes will therefore have to be set up for this purpose.

The practical trial did not investigate the extent to which it would be legally possible under European regulations to impose the implementation of additional vibration maintenance by means of regulations. Therefore, the further elaboration is based on voluntary contributions to vibration maintenance by the relevant parties. This means also that if such a system is to be introduced, commitment and additional contractual agreements between the various international will be necessary.

5.3 Maintenance concepts

In order to investigate the feasibility, in document [2] it was opted to study various concepts for how vibration maintenance could be organised. Subsequently, it investigated in detail what the implementation of these maintenance concepts would mean in comparison with the current situation.

[6] LL and K brake blocks are both composite brake blocks that are now used instead of cast iron brake blocks to reduce noise emissions. LL brake blocks are intended for wagons that previously used cast iron, while K brake blocks are intended for newly built wagons. Both brake block types are not interchangeable.

The following maintenance concepts for vibration maintenance were considered:

- Corrective maintenance, whereby vibration maintenance is carried out on the basis of measurement results from Quo Vadis. In concrete terms, this means that when an exceedance of a certain limit value is detected in Quo Vadis, the wagon is taken out of service and undergoes maintenance.
- Preventive maintenance, whereby vibration maintenance is carried out preventively and systematically on all wagons (regardless of wheel quality) and the frequency of this maintenance is adjusted as necessary based on Quo Vadis.

5.4 Example scenarios for vibration maintenance

In this study, three example scenarios have been selected for further elaboration. The scenarios focus on the part of the European freight wagon fleet that is regularly used on the Dutch railway network. This is to enable the effectiveness of these scenarios to be assessed in the Dutch context, on the one hand, and to take into account the limited availability of monitoring data for wagons outside the Dutch railway network, on the other. Furthermore, these are scenarios that are feasible in the European context. The aim was to find scenarios with the greatest possible reduction in nuisance, the lowest possible costs, the least possible operational and commercial impact and the greatest possible manageability and implementability. Because it is also clear that the number of wheels with reduced wheel quality is relatively high in ore/coal transport, it was decided to focus on this to some extent (maximum reduction in nuisance). Ultimately, these example scenarios were worked out in detail in terms of feasibility and costs:

- Scenario 0: The current situation;
- Scenario 1: A preventive scenario, in which all ore/coal wagons regularly used in the Netherlands undergo preventive vibration maintenance;
- Scenario 2: Corrective scenario, in which all wagons regularly used in the Netherlands undergo corrective vibration maintenance when Quo Vadis measures a dynamic force (RMS_Low) above 7.5 kN[4] more than 10 times (lower maintenance limit);
- Scenario 3: Corrective scenario, in which all ore/coal wagons regularly used in the Netherlands undergo corrective vibration maintenance when Quo Vadis measures a dynamic force (RMS_Low) above 15 kN[4] more than 10 times (higher maintenance limit);.

Report [4] describes in detail how these scenarios can be set up and what needs to be considered. Ultimately, each scenario is feasible, but the implications and complexity differ. The various scenarios were assessed on the following aspects:

- <u>Degree of reduction</u>
  Scenario 2 has the highest potential in this regard. This scenario focuses on a broad group of wagons with a relatively high number of reports. Based on the generic results inTable1, depending on the location, the 10% most vibrating passages will decrease by a maximum of 20%. Scenarios 1 and 3 focus only on coal/ore transport, which generates approximately half of the reports. In Scenario 1, a maximum reduction of 9% is expected to be achieved. Scenario 3 focuses only on the large outliers exceeding 15kN, achieving a maximum reduction of 5%.
- <u>Manageability</u>
  This looked at the number of wagons that will undergo vibration maintenance under the new maintenance regime. In scenarios 1 and 3 (coal/ore trains only, involving approximately 4,500 and 1,000 wagons per year respectively), this is much more limited than in scenario 2 (involving 16,000 wagons).

- Implementability
  The number of actors required to make this scenario a success was examined. In scenarios 1 and 3 (coal/ore trains only), implementability is much better because it focuses on a single type of transport, with a limited group of wagon types and parties involved. Scenario 2 is the least implementable due to the wide variety of rolling stock and parties involved.
- Operational and commercial impact
  In scenario 1, this is estimated to be moderate. It involves plannable interventions, but requires the removal of wagons from fixed sets. This has an impact on capacity and planning. In scenario 2, this impact is very significant: the maintenance actions are difficult to plan, with many shunting operations and disruption to logistics. In scenario 3, planning is also less straightforward, but it concerns a much more controllable group and is therefore more manageable than scenario 2.

Table 2 in chapter 0 provides a complete overview of these assessments.

5.5 Economic assessment of vibration maintenance

Bridgecraft has conducted an economic analysis of the three example maintenance scenarios described. This analysis looked at the additional costs of the scenarios compared to the current situation.

The three important cost components were considered:

- the additional costs for the supplementary vibration maintenance itself;
- the additional costs for renting extra wagons, which are necessary to maintain transport capacity at the current level despite the larger number of rolling stock withdrawals;
- savings due to overlap between existing maintenance and vibration maintenance.

The calculations show that the additional costs associated with scenario 3 are the lowest: €4.1 million per year. The additional costs incurred in scenarios 1 (€23.4 million per year) and 2 (€47.6 million per year) are much higher.

The question which is not discussed within the scope of this study is which party should pay these costs. Bridgecraft has determined the expected effect of these scenarios on the volume of goods transported by rail, if these costs were to be borne by the rail freight sector itself. In that case, the higher costs and resulting higher market prices will lead to a loss of transport volume. This loss of volume has been estimated using price elasticity. The analysis shows that in scenario 1, the transport of coal and ore by rail will decrease by almost 35%, falling from 9.8 to an estimated 6.4 million tonnes. In scenario 2, the total transport volume will decrease by an estimated 6.0 million tonnes (-/- 15%). In scenario three, there will be a volume loss of 0.6 million tonnes in the transport of coal and ore (-/- 6%).Table 2 in chapter 0 provides a complete overview of these assessments.

It is clear that if the sector were to face such cost increases , its competitive position would be disadvantaged , thereby significantly reducing the transport volumes of rail freight transport. Such a scenario would therefore have a negative impact on the desired modal shift.

5.6 Important preconditions for feasibility

Research conducted by Professional in Transportation [4] shows that these scenarios for vibration maintenance are only possible if several important preconditions are met. These include:

- Monitoring data from Quo Vadis has be made available in a suitable and useable format for the relevant parties. This means the relevant wagons will need to be fitted with RFID tags. ProRail will have to ensure that the data is made available in a usable form, with details still to be worked out regarding the exact type of notification, frequency, response period, communication channel, etc. It has already been established that a correction per Quo Vadis measuring point and a correction based on axle load are relevant [2].
- The processes required for this type of vibration maintenance, including the handling of Quo Vadis reports, will differ from and be implemented in addition to the current European processes and agreements. This is only possible if the necessary parties are willing to cooperate on a voluntary basis and through separate agreements. First and foremost, the cooperation of the wagon owners and ECMs of the rolling stock is required. However, the cooperation of transport operators is also considered necessary for the effectiveness of these scenarios. Wagon owners and their contracted ECMs will need to make additional procedural and financial agreements with their customers (often shippers) and operators regarding the organization, handling, registration, and settlement of this wheel maintenance. Agreements between the relevant stakeholders regarding the financing of vibration maintenance logically play a key role here as well. Part of this involves accepting Quo Vadis signals as a trigger for wheel maintenance to be carried out by various parties. A digital alternative to the current physical labelling of wagons will have to be developed, accepted and implemented in the transport operators' production systems.
- Sufficient funding must be available to cover the additional costs incurred. Part of this will have to be invested in resources: sufficient spare wagons and spare wheel sets must be made available to prevent the implementation of these processes from reducing transport capacity. This will also require additional sidings. Investments will also have to be made in the necessary expansion of equipment for changing and/or turning wheels (such as lifting tracks, cranes, wheel lathes and/or underfloor wheel lathes) and sufficient repair tracks and shunting capacity. In the case of underfloor wheel lathes, this involves 3 to 32 units, depending on the scenario. The cost estimate for the scenarios assumes that these facilities are sufficiently available and that the shunting and repair processes can be carried out more efficiently than is currently the case. It is recommended that service stations be set up at relevant hubs (such as Kijfhoek) where wagons can be efficiently exchanged in trains and wheels in wagons. Whether parties are willing to invest in such facilities will determine whether this is feasible. The construction time for such facilities will determine the time frame within which the scenarios can be implemented.
- Finally, sufficient personnel must be recruited and trained to carry out the necessary additional shunting, wheel set change and wheel machining.

More details about the background to these preconditions can be found at [4]. How exactly this will be implemented will have to be worked out further, also depending on the chosen form and scope of any implementation.

6. Conclusions regarding vibration maintenance for additional freight rolling stock

The study has shown that in freight trains, the locomotive often is the determining factor for vibrations. For other freight trains, the wagons are the determining factor, and for some of the passages this is caused by a measurable reduction in the wheel quality of these wagons. Vibration maintenance on the wheels of these wagons can reduce vibrations for some of the passages. The effect is strongly influenced by the local soil type, track construction and building characteristics, and train-related characteristics such as rolling stock type, axle load and train speed also play a role.

Three example scenarios to implement the vibration maintenance have been elaborated. The degree of reduction varies per scenario, as does the complexity. The additional costs of the scenarios have been determined. Price elasticity has been used to determine the volume loss if these costs were to be borne by the rail freight sector itself. The three scenarios investigated are summarised in the table below.

Table 2 : Overview feasibility, effect and costs of different scenarios – based on [4] and [5]

Scenario	Degree of reduction	Feasibility	Implementability	Operational and commercial impact	Additional costs (in million euro/year)	Impact on transport volume in this sector
0- current situation	0	0	0	0	0	0
1 – preventive coal/ore wagons	0-9[7]	--	---	-	23.4	-35%
2 – corrective for all wagons, lower maintenance limit	0-20%[7]	---	----	----	47.6	-15%
3 – corrective coal/ore wagons, higher maintenance limit	0-5%[7]	-	--	--	4.1	-6%

These results make it possible to assess the effectiveness of vibration maintenance as a measure against vibration nuisance and to compare it with other measures in infrastructure, transmission and buildings. The effectiveness also differs for the three scenarios developed.

If it proves to be effective, it is recommended to further investigate the possibilities of vibration maintenance. However, for this approach to succeed, sufficient funding is needed. Broad commitment from many (mostly international) parties is necessary as well. This applies to freight wagon owners, the parties responsible for organising or carrying out maintenance (ECMs), parties wishing to invest in repair facilities and rail freight operators. Support for this will not come easily, so investment will first be needed to secure this commitment.

[7] This is location-dependent; the range indicates what for different locations in the Netherlands has been determined. It concerns the estimated reduction in the average vibration level of the 10% of freight train passages with the highest vibration levels. For individual train passages, the vibration level can be reduced much more. The reduction in the total average vibration level at the location is negligible.

If this commitment is obtained from a number of parties, it is advisable to start with a small-scale pilot involving a limited number of parties and wagons, in which the new processes can be extensively tested. This helps to minimise risks, better control costs and increase the chances of success in a larger-scale implementation.

It is possible that the implementation of vibration-based maintenance, as outlined in the scenarios, is not sufficiently effective or feasible. Even then, it is valuable to examine how the insights from this study can be used to detect wheels that do not meet the existing European limit values at an earlier stage using Quo Vadis or similar systems and to carry out maintenance. This is possible if the output of Quo Vadis can be linked to current international maintenance standards and/or new international standards for Quo Vadis-like systems are agreed upon. This can contribute to preventing the larger wheel deviations that cause the most additional nuisance as much as possible within the current maintenance agreements and processes.

7. References

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Appendix – Motivation and background

Motivation for the project

Ground borne vibrations can sometimes be felt around the railway tracks. These can cause nuisance and complaints. In addition, new housing construction along the railway tracks is difficult with the current vibration levels and regulations. There are few tested measures and solutions available to combat railway vibrations and nuisance. Measures at source, which prevent the occurrence of railway vibrations as much as possible, may be more effective than shielding vibrations or modifying homes. Because vibrations are so complex, it is desirable to investigate the effect of possible measures in a structured manner.

Innovation Program Source Approach Rail Vibrations

To investigate the effects of source measures, the Ministry of Infrastructure and Water Management has decided to make funds available for the implementation of the Innovation Program Source Approach Rail Vibrations (IBS). Within the IBS, various parties from rail freight transport, passenger transport and ProRail are working together to investigate the effects of possible source measures.

The IBS consists of a mix of fundamental research, practical trials and mutual knowledge exchange. Practical tests focus on both different maintenance methods and innovations, for both infrastructure and rolling stock. A selection of possible measures has been made based on expected outcomes and potential. In addition, the data analysis of complaints from recent years carried out within the IBS has also been considered. A uniform measurement protocol has been drawn up for the IBS and all measured data is stored in an overarching database.

Influence of wheel maintenance on rail vibrations

One of the potential measures we are investigating within the IBS is the effect of wheel maintenance. Train wheels can become out of round due to uneven wear or abrupt braking. This can take many different forms (example in Figure 8). This reduces wheel quality.

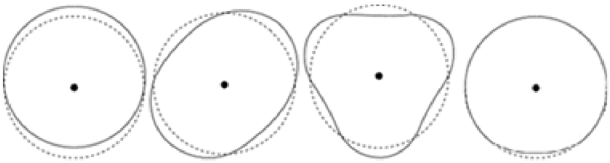

Figure 8 : Different forms of wheel roundness (enlarged)

The question is whether out-of-round wheels can lead to higher levels of track vibration that cause nuisance to residents. New monitoring techniques are making it increasingly possible to detect wheels with reduced wheel quality in good time. These techniques could potentially be used to intervene in maintenance. Wheel maintenance, in which the wheel is turned round again on a wheel lathe, for example, improves wheel quality. This project investigates whether wheels that cause specific nuisance could be maintained earlier to prevent nuisance where possible.

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