Deliverable D4.4
Track and ride quality monitoring technology based on train-borne measurements in standard vehicles

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TÜ-Delft

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Executive Summary

In deliverable D4.4, we present results on the development of smart technology solutions for lower density railway lines. The goal is to reach a cost effective inspection and asset management to minimize maintenance interventions time/cost without dedicated inspection vehicles. The proposed method includes axle box acceleration measurements installed in a passenger train. The technology is for the first time tested in passenger trains during normal operation, which bring new challenges in the processing and understanding of the data. In order to make use of the data, the data is interpreted and converted from monitoring information into management information. The most critical locations are detected, and a ranking of where the most relevant locations for maintenance are provided. Field test validation of the detection of welds and corrugation are presented as well. The tests were conducted in the railway line near Brasov, in Romania. Additionally, results from the measurement campaigns in Slovenia are discussed.

In this deliverable, first a short description of the axle box acceleration (ABA) system is presented and analysed in the direction to its implementation in the Romanian railway line, near Brasov. Then, preliminary results of the testing conducted in Romania are discussed. Then, results using the measurement system from the Slovenian railways are presented, which includes vertical and lateral acceleration. Finally, some conclusion and further research are discussed.

In this deliverable, the only deviation with respect to the grant agreement is the inclusion of tests from Slovenian railways, which were conducted without the TUDelft ABA system. The decision was taken due to the more chances of success and facilities provided by the Romanian partners for the testing conducted by TUDelft, in both Brasov with RCCF (as in grant agreement) and Faurei test ring with AFER (additional to the grant agreement). The results from the measurements in the test ring of AFER will be detailed in the final deliverable about demonstrations. The TUDelft ABA system was then focused on Romania, and it was not conducted in Slovenia or in Turkey.
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## Abbreviations and acronyms

<table>
<thead>
<tr>
<th>Abbreviation / Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABA</td>
<td>Axle box acceleration</td>
</tr>
<tr>
<td>LPP</td>
<td>Local Poor Places (of dynamic measurement)</td>
</tr>
<tr>
<td>RCF</td>
<td>Rolling Contact Fatigue</td>
</tr>
<tr>
<td>US/UT</td>
<td>Ultra-Sonic / Ultra Sonic Testing</td>
</tr>
<tr>
<td>S&amp;C</td>
<td>Switches &amp; crossings</td>
</tr>
<tr>
<td>SZ</td>
<td>Slovenske Zeleznice – Slovenian Railway Authority</td>
</tr>
<tr>
<td>TCDD</td>
<td>Türkiye Cumhuriyeti Devlet Demiryolları – Turkish IM</td>
</tr>
<tr>
<td>TUD</td>
<td>Delft University of Technology</td>
</tr>
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</table>
Introduction

Nowadays, railway lines across Europe face multiple interesting challenges: to further increase capacity, improve quality of services, shorten travel time, among many others. Particularly, in the case of regional underutilized lines, one of the greater challenges is to develop new technologies that allow a reliable service to be maintained based on a smart maintenance strategy, considering cost limitations, safety standards, and new concepts on sustainability and societal impact that go beyond the conventional economic analysis of highly utilized railway track.

A good track and ride quality are no luxury but an economic necessity, no matter what the railway line we are talking about. Quality can be assured by means of an optimal renewal plan and timely maintenance activities [1]. To optimally determine renewal or maintenance plans, Infrastructure Managers face decision problems that are inherently stochastic. Track behaviour depends on many factors, just to mention some of them: initial quality, state of the ground and formation condition (good drainage for instance), ballast quality, frequency of switches, traffic loading, type of track construction, curvature, type and quality of rolling stock among many other factors. Additionally, degradation of the components is affected by multiple sources which are difficult to control and some are exogenous such as weather conditions. Also, every monitoring system of the infrastructure relies on sensors which are affected by different type of noise. As a widely distributed ground infrastructure, railway infrastructures are distributed parameter systems evolving over time and dependent on the different locations. Thus, decision making in railway infrastructure is a complex problem. Short-term savings in terms of renewal or maintenance operations may end up increasing the total costs as those savings may severely affect the life cycle costs of the infrastructure [2].

Vibration, ultrasonic, and eddy current measurements, together with video/pictures are common sources of information from railways and civil engineering structures in general. They can easily become several terabytes of data and their relation within a predictive maintenance decision making is an open challenge. The H2020 project NeTIRail-INFRA develops new models and technologies that are tailored to the needs of different railway systems. In this deliverable, the results on the development of smart technology solutions for lower density railway lines are presented including axle box acceleration (ABA) measurements.

A track irregularity like a squat or weld in bad condition causes an impact to a wheel, which induces forced vibration of the wheelset. The vibrations caused by the impact are then transmitted from the wheel-rail interface to the axle. In the case of longitudinal and vertical acceleration, axial symmetry of the wheel permits users to analyse some correlation between them and the local irregularity [3].

In the Dutch railways, ABA measurement has been used for the detection of rolling contact fatigue (RCF) [3-6], degradation monitoring of insulated rail joints [7-8], and for monitoring of railway crossings [9]. In other countries like Korea [10], Japan [11], Poland [12], Italy [13], ABA systems have also been implemented for analysis of railway track defects. The data is collected from accelerometers, a GPS receiver and either a tacho or speed-sensor for positioning. For the monitoring of the entire Romanian railway, the measurement would provide a data volume of several terabytes. The system was implemented in passenger trains (on-the-run measurement), which reduces the cost in comparison with using specialized measuring trains. The implemented system measures...
longitudinal and vertical ABA because the focus is on detection of short wave irregularities. Lateral ABA is applicable for longer wave track irregularities, out of the scope of this research.

In this deliverable, among all the components, the focus is on the detection of rail surface defects. We present detailed results on corrugation, and welds. Also a list of risk areas where the major energy peaks of the contact wheel/rail interaction were registered. Then after, based on the measurements from SZ in Slovenia, some conclusions about the use of lateral and vertical acceleration are drawn.
2 ABA measurement on the line Bartolomeu-Zarnesti in Romania

2.1 ABA system description

Data is collected from accelerometers, a GPS receiver and either a tacho or speed-sensor for positioning. In the field, GPS was obtained from the train system, via a direct communication with SATLOC. For ABA measurements, a number of accelerometers are mounted on the axle boxes of at least one bogie. Sensor cables are routed from the bogie frame to the measurement box in the train. GPS data is obtained from a receiver that is placed in the measurement box.

During the trial measurements, an operator was in the train to control the ABA measurement system and to check for error and warning signals. Once the system is automated/commercialized, this operator is not necessary. In Figure 2.1 is presented the train SNCF Class X 4500, which operates on the line Bartolomeu-Zarnesti. Figure 2.1(a) represents the train in the workshop of RCCF, Romania and Figure 2.1(b) represents the train during the measurement campaign in September 2016.

![Figure 2.1 - Passenger train employed for ABA measurements in the line near Brasov, Romania: (a) in the workshop of RCCF; (b) in Brasov station, during the measuring campaign.](image)

The ABA signal is greatly influenced by the train speed. In the implementation on a passenger train in operation, the speed varied from 0 km/h at stations to up to 80 km/h. The signals collected at nearly 0 km/h do not contain the necessary excitation for analysis of defects, while the ones around 70 km/h will have the more valuable information. In Figure 2.2(a) is the map of the railway track measured, and Figure 2.2(b) the speed profile at various measurement rounds (from Brasov to Zarnesti). Figure 2.2(b) indicates in green the areas where the signals will have the most information usable for detection of defects. The coverage is around 80% of the infrastructure. For the remaining rails (most of them at stations or near them), quantitative relationships with the signature tunes and maximum ABA can be incorporated using a regression model, to make full use of the data collected.
Figure 2.2 - (a) Map of the railway track between Brasov and Zarnesti, Romania. (b) Speed of the train during the measuring campaign (various rounds) with areas in green for rail where the train passed above 60km/h, yellow between 40 and 60 km/h, and red under 40km/h.
2.2 Analysis of train speed effect on defect detection

ABA signals are taken based on different measurements over a single track. The magnitude of the ABA signal is dependent on train speed. In practice, the vibration amplitude is larger for higher speeds. To eliminate the influence of the train speed, measurements have been so far conducted within a range around 90 to 120 km/h in The Netherlands (where the train speed can be up to 140km/h). In the case of the track near Brasov, the measurement provided the speed profiles at different locations over the multiple runs. As depicted with three different colours in the Figure 2.2(b), the detection accuracy in terms of different speed ranges can be defined. For the track locations where the speed of the measurement train is above 60 km/h, the system is more excited and thus a better accuracy could be expected. This speed range in the figure is specified with the green colour. This typically occurs when the train is not near stations or stops. Once the train approaches stations, it has to reduce the speed first between 40-60 km/h (indicated with yellow) and then below 40 km/h (indicated with red) to stop at the zero speed track positions.

Within the speed range 40-60 km/h, a mapping between ABA measurements and speed can be carried out. Note that the frequencies related to rail defects are not affected by the train speed, but their PSD are influenced by the variance of the train speed. When the speed goes below 40 km/h, the energy values derived by the ABA signal drastically drops and detection of rail defects should be done differently. From Figure 2.2(b), the following table can be obtained presenting the length of the track covered by measurement within the different speeds.

<table>
<thead>
<tr>
<th>Track covered, m</th>
<th>&gt;60 km/h</th>
<th>40-60 km/h</th>
<th>&lt;40 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12515</td>
<td>12479</td>
<td>1959</td>
</tr>
</tbody>
</table>

Table 2.1 – Length of track with three different speed domains

Tractive effort and curving in the track are found to be potentially responsible for rail defects. In the literature, rail defects are associated with driving traction i.e. locomotives. Observations show a relationship between braking and defect occurrence. Thus, the traction performance of the rolling stock has a large influence on the initiation and growth of the defects over track. Moreover, the low speed is also influential, as more frequent activation of the Anti-lock Brake System (ABS) system occurs at lower speeds. Therefore, the most susceptible locations to the squat defects are those where low-speed running occurs with high wheel slip and low adhesion. Based on Figure 2.2(b), through different passages of the train over the track, there are certain locations with the train speed zero. It means that before and right after those locations, acceleration and de-acceleration play the role of traction. For the railway authority, it is valuable to have this information as it might have consequences on the appearance of rail defects and consequently rail degradation. In Figure 2.2(b), there are 11 train stop locations which not necessarily can be referenced to train stations. The train in some runs stopped nearby factories area, in a sort of “informal station” for dropping off passengers. Thus, it would be reasonable to claim that the track locations nearby those factories are also more prone to the influence of the speed variations and then the traction. Those locations can be seen from some measurements where the train does not stop at the same location. This brief investigation reveals that environmental/social and land use of the surrounding area of regional railway tracks play an important
role in the operation. In Figure 2.3, the areas that cover acceleration and de-acceleration are marked by dotted ellipses. Those zones with tractive efforts are interesting for further investigation.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{speed_profile}
\caption{The speed profile with the dotted markers for track areas with influence of traction}
\end{figure}

\section{2.3 Measurement results from ABA}

\subsection{2.3.1 ABA at welds}

In this section we discuss the results of condition monitoring of welds. In Figure 2.4 are three different welds, labelled as W3, W7 and W11. Side view and top view are shown. In Figure 2.5 the ABA responses on the welds are presented and the detection signal. Scaled averaged wavelet power is used to detect the welds. In the Figure 2.5 different measurements are shown. They were all obtained at a similar speed, so it is possible to estimate the severity of the welds based on the energy values or the maximum peak of the ABA signal in the time domain. W11 would be the more healthy weld, while W7 the one where the highest impact and the more energy are concentrated among the three welds. This example show that it is possible to create a ranking of the welds that will need more attention in the coming period. Visually they might look in a similar condition; however, by using their dynamic response it is possible to estimate in which ones the more energy is being dissipated during the wheel-weld-track interaction. In the example, the ranking sorted by the more healthy weld would be first W11, second W3 and third W7. In Figure 2.6 the responses on the weld for the left vertical sensors is presented.
Figure 2.4 - Three different welds.

Figure 2.5 - ABA signal, energy and wavelet power spectrum, for welds W3, W7 and W11.
2.3.2 ABA at corrugation

In this section we discuss the results of condition monitoring at corrugation. In Figure 2.7 and Figure 2.8, pictures of the corrugation (located in the right rail) are presented. In Figure 2.9 is presented the ABA response with the right horizontal sensors, where the most clear response is obtained.

Figure 2.6 - Left vertical ABA signal, for welds W3, W7 and W11.
Figure 2.7 - Corrugation located between kilometers 9.015 and 9.04, after gentle curve.
Figure 2.8 - Corrugation located between kilometers 9.015 and 9.04, after gentle curve, right rail.
2.3.3 ABA estimations in the whole section

In this section we discuss the results of condition monitoring at a railway line level. In Figure 2.10 we show the 20 most interesting areas for inspection. Those places are where the most relevant variations in the energy level of ABA were obtained. Those locations might be related to joints in not good conditions, switches, and severe rail defects. Figure 2.11 shows the 98 most interesting locations for inspection.

In Figure 2.12, the places with a moderate variation of the ABA energy are displayed with an orange indication. In Figure 2.13, all locations, including light defects are displayed with yellow color. For validation of the 20 most interesting areas, a second round of measurements were performed. In Figure 2.14, it can be observed the 43 most interesting locations. When comparing to Figure 2.10 and Figure 2.11, most of the risk points appear, indicating a good repeatability of the signals in places with a high variation of energy.
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**Figure 2.10** - Locations of the top 20 places where the ABA signal show largest energy variations.

**Figure 2.11** - Locations of the top 98 places where the ABA signal show largest energy variations.
Figure 2.12 - Locations in orange indicate a moderate ABA energy variation.

Figure 2.13 - Locations in yellow indicate a light ABA energy variation.
Figure 2.14 - Locations of the top 43 places where the ABA signal show largest energy variations, using an independent measurement run.
3 Track measurement in Slovenia

3.1 Track quality monitoring technologies in Slovenia

In Slovenia, more measuring technologies are used to monitor the quality of rail tracks by means of measuring trains and using portable measuring equipment installed on standard track vehicles. Track quality tracking technologies based on measurements of the railway network with special measuring trains are as follows: measurements of track geometry, rail profile (cross-section) and corrugation of rails, ultrasonic and Eddy Current control of rails. The technology for monitoring (the quality) of rail tracks carried out in Slovenia with portable equipment on a passenger train is the measurement of dynamic parameters of lines.

In Slovenia, the following parameters or characteristics of the geometric position of tracks, track diagnostics and dynamic behaviour of the train on the tracks are carried out on the railway network:

- Measurements of the geometric parameters of the lines: stability, direction, cant, twist, gauge (extension, narrowing); calculation of quality parameter KT500;
- Rail diagnostics: ultrasonic control of rails, rail wear measurement, rail corrugation measurement, control of rails with Eddy Current (head check);
- Measurements of dynamic track parameters: lateral acceleration, vertical acceleration; calculating the coefficient of derailment.

In determining the quality of tracks, a review of the data and analysis of the detected failures (defects) is required. On the basis of permitted or limit values of certain parameters, the overrun of individual parameters is detected and local poor places on the lines are located. For the purpose of data review and analysis, for individual monitoring technologies the types of measurements use special viewers for graphical support to review the results of measurements.

3.2 Dynamic measurement technology

Dynamic measurements are carried out with portable measuring equipment of company Dewesoft. The sensors are mounted on a standard rail vehicle (passenger train) and are connected to a measuring system in the cabin which stores acceleration data. At the same time, the speed and the GPS train position are measured.

The measurement process involves the preliminary preparation of the measurement system, installation of equipment on the train, the execution of measurements, disassembly of equipment and office data processing. The preliminary preparation of the equipment includes inspection, calibration and functioning test of measuring software and sensors, and the establishment of a measurement file. When driving a train, the vertical and lateral acceleration of all sensors is recorded on the measuring system. System calculates the average lateral and vertical acceleration, lateral force, the derailment coefficient and train path. Subsequent processing of the measured results includes the calculation of kilometre position of the train and the analysis of local poor places where the permitted parameter values are exceeded.

Different sensors (accelerometers) are used for different purposes because the signals detect or discover various disorders. Descriptions and pictures present low-frequency and high-frequency
accelerometers which serve to detect different characteristics and a wider range of faults on the rail
lines or tracks. The Dewesoft measuring system includes the following sensors for measuring
acceleration:

- Low frequency accelerometers: four vertical and four lateral accelerometers (frequency
  range 80 Hz) emit signals comparable to the measured signals of the geometric parameters
  of the lines (see Figure 3.1).
- High frequency accelerometers: four vertical and four horizontal accelerometers (frequency
  range 2500 Hz) emit signals comparable to signals of diagnostic measurements of the state
  of rails (see Figure 3.2).

![Figure 3.1 - Low frequency accelerometers, Dewesoft 1221](image1.png)

![Figure 3.2 - High Frequency Accelerometers, Dytran 7504A6](image2.png)
3.3 Early diagnostics

The purpose of track quality monitoring is the detection of rail defects and the efficient and economical planning of maintenance work in order to eliminate track failures, thereby improving the condition of the railway lines.

With early diagnostics, with cheaper equipment and procedures, we can detect critical sites, where the state is approaching the limit of the permissible. Dynamic measurements with portable equipment on standard (passenger) vehicles can serve for early diagnostics of rail lines which can pre-indicate where geometric defects will occur. This can be demonstrated by comparing parameters of geometric and dynamic measurements.

By upgrading dynamic sensors to a wider frequency range, early diagnostics of rail lines can be extended to preliminary detection of rail failures, which is explained by the comparison of dynamic measurements with measurements of wear and corrugation.

3.4 Description of track quality monitoring technology

Monitoring technology includes graphical and numerical comparison of measured parameters of geometric and dynamic measurements. The procedure is described in the text below and in the next steps.

We look at the results of dynamic measurements (early diagnostics), where local poor places (LPPs) occur (deviations of lateral and vertical accelerations and coefficient of derailment) and how large their values are. So we get locations of dynamic LPPs. Then we look for these locations and the results of on-site geometric measurements, all measured parameters, if and to what extent they deviate from the allowed values. From the graphs we see which parameters reflect dynamic defects. We determine the correlation of dynamics with geometry, whether there is legality, a pattern that dynamics indicates a certain type or size of geometric defect. The question is at what size of a dynamic defect, with a high level of certainty, we can say that at the site of the dynamic defect a certain type of a serious geometric defect occurs. Additional attention is focused on the twist and the gauge, what does the dynamics on these geometric LPPs show, where there is a risk of derailment of the train.

Steps of monitoring technology for a particular line:

- We look at the graphs of dynamic local poor places (LPPs) and mark them: lateral, vertical acceleration, coefficient of derailment.
- For each location of the dynamic LPPs (within the considered section of the line) we display graphs of all geometric parameters in an enlarged scale and mark the locations of dynamic LPPs on them (with vertical lines).
- Especially in the graphs we look at the LPPs of the most critical twist and gauge if they occur on the segment and compare them with the dynamic parameters at these sites of LPPs.
- With the review and comparison of graphs on a larger scale (up to 2 km), we determine the correlation of dynamic and geometric parameters, and find out whether there is some pattern, does the dynamics (at a certain height / value of parameters) show some specific geometric defects.

The purpose of monitoring technology is to reliably detect defects (failures) and to find out what do larger signals (higher energy signals) of dynamic parameters show for geometric parameters and what do they say about the excess of their allowed values. The findings and comments in the conclusions
describe, what as can be seen on the graphs, and they try to explain the possible laws and correlation between dynamic and geometric measurements.

### 3.5 Comparison of measurement results

We want to prove that with dynamic measurements with portable equipment we can detect failures, local poor places, which are otherwise detected by measurements with a measuring train. A comparison of the results of dynamic and geometric measurements should show the same points of defects on the rail lines or rails.

For each measurement method, there is a data viewer that draws the graph of measurement results. Below is a comparison of geometric and dynamic graphs from the viewers (programs):

- DrezStac or. Drezyna for geometric measurements
- DEWESoft for dynamic measurements

Comparison of graphs is made for a certain section of the line in local poor places of dynamic and geometric measurements, where the graphs show a larger amplitude of signals or larger signal energy. All graphs display the same section of the rail line number 10 state border-Dobova-Ljubljana, left track.

#### 3.5.1 LPPs on the track section 10L 551.000-553.000 km

All local poor places (LPPs) of dynamic measurements on this section are located in 5 places where the average lateral acceleration is exceeded (see Table 3.1). A vertical acceleration is also shown on this section. The lateral force and the coefficient of derailment are not exceeded. The train was driven with a permitted traction speed (90 km / h). The speed of the train was 88 km / h.

<table>
<thead>
<tr>
<th>No.</th>
<th>Rail</th>
<th>Speed (km/h)</th>
<th>Lateral acceleration</th>
<th>Lateral force</th>
<th>Coefficient of derailment</th>
<th>Km position</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>L</td>
<td>87,655029</td>
<td>2,2962346</td>
<td>36,739754</td>
<td>0,21420425</td>
<td>551951,75</td>
</tr>
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<td>10</td>
<td>L</td>
<td>87,653244</td>
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<td>0,17141449</td>
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<td>0,17307292</td>
<td>552417</td>
</tr>
</tbody>
</table>

*Table 3.1 – Exceeding the lateral acceleration at section 10L 551.000-553.000 km*

A graphical comparison with geometric parameters is made for local poor places of dynamic measurements. We find similarities in the increased signals or even exceedance of the limit values between different charts, which represent failures on the tracks. In the first graph, Figure 3.3, the upper and lower limit values of the lateral acceleration are indicated by the red line. LPPs are surrounded by red ellipse.
Figure 3.3 - Lateral and vertical acceleration at 2 km section 10L 551.000-553.000 (DEWESoft), Aug. 2017

Figure 3.4 - Parameters of geometric measurements on 2 km section 10L 551.000-553.000 (DrezStac), May 2017

A line  B line  C line

Figure 3.5 - Longitudinal profile at 2 km section 10L 551.000-553.000
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Figure 3.6 - 55 geometric LPPs on 2 km section 10L 551.000-553.000

The table in the Figure 3.6 shows the numerical output of LPPs of geometric parameters where their values are increased. These are numerical values which are also visible on the previous graphs.

The graph presents 2 km section of rail line where higher values (signal amplitudes) of local poor places (LPPs) are evident and surrounded. A, B, C lines connect and illustrate the correlation between measured parameters in a certain km of rail track.

In order to make a better comparison to see the LPPs more clearly in detail and to study them more precisely a bigger scale of graph has to be used. The following graphs of measurements show 1 km section of rail line (enlargement of track scale).
3.5.2 LPPs on the track section 10L 506.000-507.000 km

<table>
<thead>
<tr>
<th>STC</th>
<th>STP</th>
<th>STP</th>
<th>SPEED</th>
<th>VERTICAL</th>
<th>LAT</th>
<th>POT</th>
<th>v/d</th>
<th>Sla</th>
<th>keef</th>
<th>drom</th>
<th>v</th>
<th>km</th>
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<tbody>
<tr>
<td>10</td>
<td>L</td>
<td>L</td>
<td>100</td>
<td>50557</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>10</td>
<td>50</td>
<td>50</td>
<td>150</td>
<td>50600</td>
<td>1.94</td>
<td>0.5</td>
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</tr>
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<td>50</td>
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</tr>
<tr>
<td>10</td>
<td>50</td>
<td>50</td>
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<td>0.8</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.7 - Exceeding the lateral acceleration at section 10L 506.000-507.000 km

The table in the Figure 3.7 shows the numerical output of local poor places (LPPs) of dynamic parameters. All LPPs of dynamic measurements on this section are located in 44 places where the average lateral acceleration exceeds the permitted value. These are numerical values which are also visible on the graphs, from the Figure 3.8. A vertical acceleration is also shown for this section. The lateral force and the coefficient of derailment do not exceed the permitted values.
Figure 3.8 - Lateral and vertical acceleration at 1 km section 10L 506.000-507.000 (DEWEsoft), Aug. 2017

Figure 3.9 - Parameters of geometric measurements on 1 km section 10L 506.000-507.000 (DrezStac), May 2017

Figure 3.10 - Longitudinal profile at 1 km section 10L 506.000-507.000
In the figures: Figure 3.8, Figure 3.9 and Figure 3.10, the extended graphical comparison is made for 1 km track section. From the graphs of the measurements with the geometric parameters of the tracks and the dynamic parameters of the lines, a clear correlation is evident on the individual local poor places (LPPs), see Figure 3.9. It is reflected to be similar in the greater amplitude (energy) of the signals. Geometric failures of stability as well as of twist are also visible on the graph of vertical acceleration, see Figure 3.8. The geometric failures of the track direction, and partly the failures in the cant, are also shown mainly on the graph of lateral acceleration as shown in the Figure 3.8. The lower graph represents the main geometric elements of the track with technical data for the 1 km section of the track under consideration.

![Figure 3.11 - 41 geometric LPPs on 1 km section 10L 506.000-507.000](image)

The table in the Figure 3.11 shows the numerical output of local poor places (LPPs) of basis geometric parameters also visible on the previous graphs.

More detailed analysis can reveal even more characteristics of the faults and the geometric state of the tracks. Similar to geometric parameters, we can make a graphical comparison of rail corrugation measurements or some other rail diagnostic technology with dynamic parameters (accelerations) of the higher frequency range.

In order to validate the monitoring technology of dynamic measurements for the quality of tracks and rails in order to plan maintenance, it is reasonable to measure continuously and time comparison of parameters. More measurements and analyses will be made in the continuation of the project and presented in the final deliverable.
4 Remarks, future planning and conclusions

In this deliverable, a methodology for detection of short waves defects was used for estimating track quality: axle box acceleration measurements. The methodology is based on accelerometers mounted at the axle box. Coordination with other signals such as GPS, for positioning of defects is required. The information collected the system contains useful data for the infrastructure managers. With ABA, it is possible (among other applications) to rank the quality of the welds and also of other defects. A map with the places where the most energy is concentrated in the interaction wheel-rail was obtained. With this map, the infrastructure manager can check the condition of rail in those locations and the quality of the wheel/rail interface. Additionally, the use of lateral and vertical acceleration is proven useful in the Slovenian railways.

The collected data can be used for modelling, analysis, for supporting decision making of maintenance, but following a paradigm different from other traditional/old systems. From the theoretical and practical points of view, use of railway infrastructure information is challenging because it is multidimensional, spatially and temporally distributed, multi-scale, and it comes from heterogeneous data sources.

With adaptive and intelligent signal processing methods, it is possible to extract the key information needed for the decision-making process to anticipate the impact of degradation and determine the control measures needed to correct the problems in the infrastructure. Part of the further research is the generation of meaningful maintenance rules for the decision making of infrastructure managers using the collected track and quality information.
5 Bibliography


