MAXBE
INTEROPERABLE MONITORING, DIAGNOSIS AND MAINTENANCE STRATEGIES
FOR AXLE BEARINGS

D6.4 – Final Wayside system

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• I-MOSS
• KRESTOS
• UoB
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1. INTRODUCTION

The safety of rolling stock and the economic implications of rolling stock maintenance have been of significant concern to the railway industry. In the last few years the maintenance strategy paradigm is significantly changing and the longstanding preventive time based maintenance is being progressively replaced by the condition based maintenance model. Also the early diagnosis of the rolling stock condition will allow the improvement of the definition of the maintenance strategies for railway vehicles. Condition monitoring technologies offer to the railway operators means to increase reliability and safety. Also by an earlier detection of potential failures the railway operator can better plan maintenance actions contributing to achieve financial savings.

In this context, the reliability and the safety of axle bearings in both passenger and freight trains have been a large concern to the railway industry since the axle bearing damage process and the consequent failures can cause severe delays or even dangerous derailments implicating human lives prejudice and significant costs for railway managers and operators.

Within the scope of WP4 and WP6 of the MAXBE project, four wayside systems based in different monitoring techniques and sensors were developed and installed in three different test sites in three countries (Portugal, Belgium and UK) in order to diversify the train types and the techniques used.

The wayside monitoring systems are based on a particular set of sensors installed in the track, connected to an acquisition module and to a data processor module. The raw data reis locally processed and the key performance indicators are as well as the raw data stored in a Station Data. The relevant data used for evaluating the evolution of the condition of the rolling stock is also sent to an upper level – the MAXBE integration platform - that gathers the information from the wayside stations and also from the on-board monitoring systems.

This document, integrated in WP6 (Testing and validation of systems), describes the testing and the validation of the developed wayside monitoring systems the site location and the monitored rolling stock. The results and tests performed in the period from May 2014 to April 2015 are also presented.

The Portuguese test site is located in the Northern Railway Line is a ballasted track with concrete sleepers and presents good geometrical track conditions besides the wide range of train speed. Furthermore, in this line it circulates and rolling stock from different operators, comprising both passenger and freight trains with a commercial speed range between 60 and 220 km/h which is very representative of a wide range of railway lines across Europe and the entire world. In this test site, two wayside monitoring systems are installed. The wayside vibration system, described in Section 2, is based on the measurements of strains in the rail. An acoustic emission system and its triggering system also installed in this experimental test site is described in Section 3.

In Section 4, the high-frequency vibration-based axle bearing fault detection system installed in the Antwerp depot of De Lijn is presented. Punt-Aan-De-Lijn is the northern tram and bus storage facility of the Belgium public transportation company ‘De Lijn’ at Antwerp, and the developed system intents to monitor light rail vehicles, in an embedded track subjected to car and bus traffic.
Regarding the acoustic wayside system to be installed in the UK (Section 5), the authorizations are still pending by the Network Rail. The system and its installation will be reported as an appendix to the present deliverable.

As mentioned before, the results and the raw data extracted from the monitoring systems are stored in a server which connects with the Integration Platform and its characteristics and technical details are presented in Section 6.
2. VIBRATION WAYSIDE SYSTEM – PORTUGAL

This section describes the vibration wayside system jointly developed by UPORTO and EVOLEO and installed in the Portuguese Northern Railway Line.

2.1. General Description of test site

The experimental test site in Portugal is located in the Portuguese Railway Northern Line, nearby Estarreja, at PK 291,991 (Figure 2.1 and Figure 2.2). This location was selected within the Task 2.9 of WP2. In short, the reasons for the selection of this site are: the proximity to a hot box and to a hot wheel detection system; the easy access from people to the equipment installed in the track; the existence of a power supply and a telecommunication interface; the good geometrical conditions of the track in the section. Moreover, in this site it circulates rolling stock from different operators (CP, COMSA), comprising both passenger and freight trains with a wide range of train speed. In the selected test site, the track is ballasted with concrete sleepers and 60E1 rails, and the maximum allowed speed is 220 km/h. Also, at the Estarreja site, the section is in a straight alignment with an insignificant slope and with no interferences nearby, allowing the trains to travel with a constant speed, which are satisfactory conditions to install a condition monitoring device. For more detailed information, on the description of the Estarreja site the deliverable 2.9 should be consulted.

Figure 2.1 – Location of Estarreja test site
2.2. Wayside system: general information

The general configuration of the vibration wayside monitoring system installed at the Estarreja site is presented in Figure 1. This system is composed by strain gages sensors. The raw data acquired from the sensors installed in the track are processed in the data processor unit through processing algorithms that may need to be feed up with information and data from other systems, such as the infrastructure manager data base (for instance, general information about the trains -geometry, references). The settings of the data processor unit (definition of the key performance indicators trending limits, sensitivity) are remotely defined/modified.

The output of the data processor comprises registers and events in separate data packs. Every time that a problem is detected, an event is sent immediately to the operator. Thus, the event has strictly the critical and necessary information for the problem diagnostic.

Contrary to the event, the register includes all the information of the train and the key performance indicators (KPIs) which means that the register contains huge amount of data. For this reason, the data pack register should be sent in suitable time (during the day or the night), as defined in the communication system.

A MAXBE wayside server will integrate the data/measurements received from the monitoring systems (vibration and acoustic) as well as the KPIs, information that will be accessible to the operators and infrastructure managers,
2.3. Installation

For the successful evaluation of the condition of axle bearings a wayside system should have the capability of identifying and assessing all types of wheel faults in order to correctly recognising the development of axle bearing faults and its severity. For that reason, the vibration sensors are installed along an equivalent wheel perimeter length. In the present case, instrumented strain gages are placed over a total length of 3.6 m, that considers seven sleepers equally spaced in 0.6 m interval. For the identification of the geometry of the train, as well as for the evaluation of the dynamic loads, 28 strain gages were installed; these sensors have an internal compensation of the variation of the rail temperature (Figure 2.4). The sensors are protected against the railway adverse environment, with dust, ballast, water and all the heavy maintenance activities performed in this type of infrastructure with a robust mechanical system. The cables connecting the sensors to the acquisition system are underground cable ducts in order to ensure the safety and durability of the system after the maintenance activities. The system configuration (Figure 2.5) allows to weight in motion and to detect wheel defects in a speed range between 5 to 250 km/h, a wheel diameter between 350 and 1000 mm, and it is able to detect and to identify trains up to 300 axles with a range of load between 5 and 400 kN.
Figure 2.4 – Strain gages

Figure 2.5 - Wayside monitoring system: configuration
Figure 2.6 – Vibration wayside monitoring system: installation
2.4. RFID system

The identification of each carriage of the train is required to correlate the data measured in the wayside system with the train and carriage, and with the measurements acquired by the onboard system. Therefore, a radio-frequency identification system (RFID) was installed in the PCA and the UMEs trains that pass at the Estarreja site.

The RFID system is composed by tags attached to the train carriage to be identified. These tags send a signal to the reader system when the carriage crosses over the monitoring system as presented in Figure 2.7.

![Figure 2.7 – System architecture – Interface between RFID system and the Data identification System](image)

The Reader RFID UHF (Ultra-High Frequency) is TagMaster XT-3HD, (Figure 2.8) and it operates within a frequency range of 868 MHz allowing the identification of the passive tags UHF compatible with EPC G2 protocol and the standard ISO-18000-6C.

The Reader respects and supports the following international homologations for railways: ISO 18000-6C, EPC Gen2, CE, EN 50125, EN 50121. The reader is installed outside from the railway line and in parallel to the railway with a distance of 4 m away from to the outer face of the train where the tag is installed.
The tag RFID ST1456 HD (Figure 2.8) is a passive tag which means that it does not require external power. The tag operates within a frequency range of 868 MHz and due to its robustness it is suitable for railway applications. This Tag respects and supports the following international homologations for railways: (ISO 18000-6C, EPC Gen2, CE, EN302208-1, EN302208-2). The TAG will be installed in several trains within the measurement range of the reader as shown in the scheme of Figure 2.9.

Figure 2.8 – RFID system: (a) Reader RFID UHF G2, TagMaster XT-3HD; (b) Tag UHF ST1456 HD

Figure 2.9 – Schematic installation of the tags in CPA4000 (Alfa-Pendular train)
2.5. Acquisition System

The data acquisition is performed through a CompactDAQ Chassi from National Instruments, equipped with several modules that are connected to the strain gages sensors. Table 1 presents the acquisition modules used and the sensors connected to each module.

Table 1 – Acquisition system

<table>
<thead>
<tr>
<th>Acquisition Module</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAQ NI 9237 LINK</td>
<td>Connect to Strain gages DB37 connector</td>
</tr>
<tr>
<td>DAQ NI 9421 LINK</td>
<td>24V Sinking Digital Input, 8 Channel Module</td>
</tr>
<tr>
<td>DAQ NI cDAQ-9188 LINK</td>
<td>Chassis NI CompactDAQ Ethernet, 8 slot</td>
</tr>
</tbody>
</table>

The 28 strain gages that composed the monitoring system are divided in groups: 12 sensors in the external side of each rail and 2 sensors in the internal side of each rail. The designation of each group is:

- LE – Left External;
- LI – Left Internal;
- RI – Right Internal;
- RE – Right External.

The acquisition unit is composed by seven NI9237 modules, each one acquiring the signal of 4 strain gages, as represented in the following scheme.
The support cabinet where the data processor unit and all the support equipment are installed can be observed in the following figure.
Figure 2.12 – Acquisition System (Cabinet and software)
2.6. Data Processor Unit

The data processor unit is responsible for acquiring the data during the passage of a train over the monitoring system and for processing the acquired data. The general architecture of the software is divided into three sections: the acquisition manager, the script manager, and the reports manager as represented in the figure below.

Figure 2.13 – MAXBE Software General Architecture

- **Acquisition Manager**
  - The acquisition manager considers three parts:
    - Trigger detection task
      - This task is responsible for detecting the start and the end of the vehicle. Based on these detections, the task tracks the status of the remaining tasks.
    - Acquisition task
      - The acquisition task is responsible for acquiring and controlling the flow of data between the hardware and the software. After each acquired sample, this task is responsible for delivering that data to the remaining tasks, using message queues and notifications for that purpose.
    - Log task
      - This task is responsible for writing all the data to the correct log files.

- **Script Manager**
  - This component is responsible for managing and organizing the log files that are sent for processing task "Script".

- **Reports Manager**
This component is responsible for generating the final report and submit the same to the server.

2.7. Data Processor Algorithms

The developed data processor algorithms unit considers five subsequent modules that are able to identify the train and its characteristics and to verify if any fault or failure is detected. The first module of the algorithm is responsible for processing the raw data acquired from the sensors installed in the track and from the data acquisition unit and to diagnose the operational condition of the system, i.e., verify if there is any failure in the sensors, in the acquisition system or even in the connections. If any problem is detected, the subsequent algorithms are adapted to the verified conditions and a message is sent to the operator in order to confirm and perform the adequate correction procedures according to the identified problem.

The train ID module allows the identification of the type of train and also each type of vehicle that composes that train, particularly in the case of freight trains, based on the axle load, axle count and the correspondent geometry. The following module is related with the measurement of the train speed and acceleration based on the average of each axle and vehicle data. This information is required as input of the subsequent modules, since both weight in motion measures and the failure detection are intrinsic and dependent on the type of train and also its speed.

The weight in motion module is responsible to measure the static weight of each wheel, axle, vehicle and the train based on the dynamic measurements collected with the moving train at a regular commercial speed. This information is relevant to the infrastructure manager in order to assess if trains are travelling with excess of load, or with an improper load distribution, which may cause problems in the railway infrastructure and also in the several components of the train.

In the final module, the algorithm processes the information available from the previous modules, and based in several key performance indicators, ratios and the respective thresholds defined in the standards and provided by the train operators, maintenance companies and infrastructure managers, the failures are detected along with the respective severity and priority level, which are transmitted to the relevant stakeholders.

The results are exported and stored in a server, which allows the historical analysis of the data and supports the development of new reliable maintenance strategy based on the real condition of the assets and the expected trend of deterioration and failure. In Figure 2.14, the information included in each module is presented in more detail. The KPIs are defined according to the standard EN 15654-1 [1] related with the measurement of wheel and axle loads.
2.8. Output file and communication with the integration platform

The monitoring systems developed within the project will be subsequently integrated into the MAXBE Monitoring System Integration platform, which is a global monitoring system that aggregates all the information generated by both the on-board and the wayside systems, such as the key performance indicators that results from the post processed data. The required general information that is provided by the infrastructure managers or by the rolling stock operators will also be included in the integrated system. Although the platform is developed based on the requirements of the project within the scope of WP5, it will be able to integrate different monitoring systems that can be developed in the future or that are already in the market, such as the hot box detector systems. The tool is able to simplify and to summarize the information gathered by the several monitoring systems and will be used by the infrastructure managers, by the rolling stock operators or by the maintenance managers as an aggregating tool correlating the data from the monitoring systems in order to get a more accurate and reliable monitoring and diagnostic tool that supports the decisions of the responsible stakeholders.
In order to achieve this goal, the wayside vibration monitoring system will extract the results to an output file such as the one presented in Figure 2.16. This output file contains all the information provided by the acquisition system and by the data processing algorithm, as described in the previous sections.

![Figure 2.16 – Results output file (example)](image)

The output file is then transformed in an XML file with the standard format defined within WP5, in order to be able to be directly integrated in the integration platform. An example of the XML file with the pre-defined structure is presented in Figure 2.17.
The wayside vibration monitoring system is installed in the Portuguese Northern Railway Line in a location that allows monitoring several types of trains in wide range of speeds. Regarding the freight trains, the average commercial speed is between 80 and 120 km/h according to the train characteristics and to the material that is transported. In this particular test site, the wayside system is able to monitor several freight train operators (Portuguese and Spanish), such as COMSA, Fertagus, CP Carga, Takargo, etc. In what concerns to the passenger trains, the Portuguese high-speed train, the Alfa-Pendular train that is used for passenger long distance transportation, circulates around 220 km/h which corresponds to the maximum commercial speed allowed in Portuguese railway line. This electrical railcar is a tilting train and it is formed by six vehicles and it has twelve bogies, in a total of 24 axles.

The intercity train that in the location of the wayside monitoring device circulates between 180 and 200 km/h, is also used for long distances serving more cities. This train is composed by a locomotive as the motor carriage and a flexible number of passenger carriages that can
be combined according to the availability, the capacity level required at certain periods and with the operating rules applied in Portugal. In the example presented hereafter, the intercity train was composed by 7 passenger carriages, besides the locomotive. The regional and the urban trains of Oporto’s area circulate around 140 km/h. The urban train is articulated and it is composed by four carriages in a total of five bogies and ten axles, which means that the three middle bogies are shared between adjacent carriages. The registers with the raw data acquired for the different type of trains is presented in the following figures.

Figure 2.18 - Results – Freight Train: raw data

Figure 2.19 - Results – Alfa-Pendular: raw data
As an example, the results and KPIs related with the Alfa-Pendular train in the format of the output file of the algorithm are presented in Table 2.
Table 2 – Output information of the Vibration Wayside System for the Alfa-Pendular train

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axle Count</td>
<td>[24.0]</td>
</tr>
<tr>
<td>Speed per axle</td>
<td>[216.1, 214.9, 216.1, 216.5, 216.5, 217.8, 216.9, 216.9, 216.1, 215.7, 216.9, 216.5, 216.5, 216.9, 216.5, 217.4, 216.2, 218.2, 217.4, 218.2, 217.4]</td>
</tr>
<tr>
<td>Distance between axles</td>
<td>[0.00, 2.69, 16.29, 2.70, 4.24, 2.70, 16.38, 2.71, 4.23, 2.68, 16.30, 2.72, 4.19, 2.74, 16.32, 2.72, 4.21, 2.68, 16.27, 2.84, 4.23, 2.71, 16.40, 2.69]</td>
</tr>
<tr>
<td>Axle force</td>
<td>[140.35, 154.68, 129.69, 126.85, 136.77, 142.55, 135.57, 145.31, 146.41, 150.45, 131.53, 145.49, 143.01, 146.96, 151.00, 161.84, 127.86, 141.36, 138.42, 142.92, 125.47, 143.01, 143.20, 153.58]</td>
</tr>
<tr>
<td>Wheel right force</td>
<td>[70.17, 77.34, 64.85, 63.42, 68.38, 71.28, 67.79, 72.65, 73.21, 75.23, 65.77, 72.75, 71.51, 73.48, 75.50, 80.92, 63.93, 70.68, 69.21, 71.46, 62.73, 71.51, 71.60, 76.79]</td>
</tr>
<tr>
<td>Wheel right dynamic load</td>
<td>[8.96, 9.61, 7.98, 7.87, 9.13, 8.85, 8.49, 9.08, 8.99, 8.88, 7.92, 9.19, 9.02, 9.69, 8.91, 10.09, 8.34, 8.77, 8.51, 8.77, 7.73, 8.99, 9.08, 9.38]</td>
</tr>
<tr>
<td>Wheel right static load</td>
<td>[7.15, 7.88, 6.61, 6.47, 6.97, 7.27, 6.91, 7.41, 7.46, 7.67, 6.70, 7.42, 7.29, 7.49, 7.70, 8.25, 6.52, 7.20, 7.06, 7.28, 6.39, 7.29, 7.30, 7.83]</td>
</tr>
<tr>
<td>Wheel right ratio dynamic static load</td>
<td>[1.25, 1.22, 1.21, 1.22, 1.31, 1.22, 1.23, 1.20, 1.16, 1.18, 1.24, 1.24, 1.29, 1.16, 1.22, 1.28, 1.22, 1.21, 1.20, 1.21, 1.23, 1.24, 1.20]</td>
</tr>
<tr>
<td>Bogie count</td>
<td>[12.0]</td>
</tr>
<tr>
<td>Vehicle count</td>
<td>[6.0]</td>
</tr>
<tr>
<td>Vehicle length between axles</td>
<td>[21.69, 26.03, 25.93, 25.96, 26.01, 26.04]</td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>[215.9, 217.1, 216.3, 216.6, 219.8, 217.8]</td>
</tr>
<tr>
<td>Vehicle weight</td>
<td>[56.23, 57.11, 58.50, 61.45, 56.12, 57.62]</td>
</tr>
<tr>
<td>Train speed</td>
<td>[217.3]</td>
</tr>
<tr>
<td>Train acceleration</td>
<td>[0.1351]</td>
</tr>
<tr>
<td>Train length</td>
<td>[151.66]</td>
</tr>
<tr>
<td>Train weight</td>
<td>[347.02]</td>
</tr>
<tr>
<td>Average axle load train</td>
<td>[14.46]</td>
</tr>
<tr>
<td>Train ID</td>
<td>[Alfa Pendular]</td>
</tr>
</tbody>
</table>
Observing the results, it can be confirmed that the system is able to detect the 24 axles that compose the train, divided by twelve bogies, in a total of six carriages. In this register, the average speed of the train is around 217 Km/h, corresponding to a regular operational speed for this type of train in the location of the wayside device. It was also verified that the train was with a positive acceleration, around 0.13 m/s².

2.10. MAXBE Software Interface

2.10.1. Data Storage

The data acquired for each train is stored in a folder that contains different files which structure is described in the following items. The defined structure allows an easier verification and visualization of the data taking into account its nature and type of information and it is more appropriate for the efficient performance of the data processing algorithm.

(1) LOG_FOLDER

The data is acquired and stored in the log folder. Therefore, each train that crosses the monitoring system creates a new log folder with the following structure:

- One folder per vehicle (ex: MAXBE___2014_05_11_10_29_16)
  - (1x) MAXBE___2014_05_11_10_29_16_S_LE.csv
  - (1x) MAXBE___2014_05_11_10_29_16_S_LI.csv
  - (1x) MAXBE___2014_05_11_10_29_16_S_RE.csv
  - (1x) MAXBE___2014_05_11_10_29_16_S_RI.csv
  - (1x) MAXBE___2014_05_11_10_29_16_rfid.csv
  - (1x) MAXBE___2014_05_11_10_29_16_weather.csv
  - (1x) MAXBE___2014_05_11_10_29_16_setup.csv

Each file created in the folder, respects to the same train and follows the structure defined below, for the strain gages (sensors) acquisition, for the RFID acquisition, for the weather station acquisition and also for the setup file, respectively.

Regarding the sensor acquisition, the file is identified based on the date and hour at which the train passed and also based on the position of a certain set of sensors, i.e., if the sensor is installed in the right or in the left rail, and if it is in the internal side or in the external side of each rail. In each file, several columns are displayed and each one refers to one sensor, ordered from 1 to n and each row is defined per acquisition.
**Acquisitions log file:**

- Name Definition:
  - MAXBE
    - #YEAR_#MONTH_#DAY_#HOUR_#MIN_#SEG_S_*CONFIG*
  - *CONFIG*:
    - LE – Left external
    - RE – Right external
    - LI – Left internal
    - RI – Right internal

- Data structure (without header):
  - 1 row per acquisition
    - Sensor 1 / … / Sensor n

The RFID log file name is defined according to the same structure of the acquisitions log file mentioned previously. In the file, 3 columns are presented, representing the timestamp, the ID tag and other relevant info, respectively.

**RFID log file:**

- Name Definition:
  - MAXBE___#YEAR_#MONTH_#DAY_#HOUR_#MIN_#SEG_S_rfid.csv

- Data structure (without header):
  - 1 row per acquisition
    - Timestamp / ID TAG / Other Info

In the weather log file is identified in the same way as the previous. In the file, the first column defines the timestamp of the register and the remaining columns represent the sensors 1 to n, in the respective order.
Weather log file:

- Name Definition:
  - MAXBE___#YEAR_#MONTH_#DAY_#HOUR_#MIN_#SEG_S_weather.csv

- Data structure (without header):
  - 1 row per acquisition
    - Timestamp / Sensor 1 / … / Sensor n

The setup log file is related with information and other details of the register such as the identification of the beginning and the end of the register, the rate of the acquisition, the details of the sensors, and other details. The information is organized in that file as follows:

Setup log file:

- Name Definition:
  - MAXBE___#YEAR_#MONTH_#DAY_#HOUR_#MIN_#SEG_S_setup.csv

- Data structure (without header):
  - Start/Stop Timestamp
  - Acquisition data rate
  - Sensors details
  - Setup details

2.10.2. MAXBE Software Interface

The MAXBE software interface allows the intuitive and easy interaction between the user and the monitoring system through a computer based platform. The front page of the interface allows the identification of the status of the system and the visualization of the information of the most recent event such as the train identification and characteristics and weather information.

The software interface also allows the visualization of live data and the historical registers and also to define the settings of the system.
The tab related to the general settings of the system allows the configuration of the initial information of the system, during its installation or after any maintenance procedure or modification, by the end-user or the maintenance operator.
The MAXBE software can be accessed through the computer installed in the cabinet of the Estarreja test site and also remotely. This allows the modification or upgrade of any feature or information of the system without being required the dislocation of the technician, but also the verification in place of any problem.
2.10.3. Reports Viewer Software

Every time that a report is generated in the software, based on some self-diagnostic procedure or an event related with a certain train, the end-user is notified and can have a direct access to the report file through the reports viewer software interface, where all the report files are stored in a chronological order.

Further to the work previously described and as an extension to the DoW, a self-diagnostic tool pack is being developed in order to detect automatically any problem that may occur during the system operation.
3. ACOUSTIC WAYSIDE SYSTEM – PORTUGAL

The KRESTOS acoustic wayside system has been successfully installed in Estarreja by UOB, NOMAD TECH and MERMEC (trigger system). The acoustic wayside system is monitored remotely by KRESTOS using a 3G connection as shown in the following photographs. Two R50A acoustic emission sensors have been installed in the rail track as shown below. The system is triggered by the MER MEC optical system installed further down and further up from the sensor positions. The system is able to detect both wheel tread defects and axle bearing faults. Operation is entirely automatic and KPIs are calculated once a measurement is completed. If further analysis is required this is done by downloading the raw signals and processing them manually.

The photos below show the main aspects of the installation at Estarreja.

![Figure 3.1 – Acoustic system installation](image-url)
The first trains passing from the site have already been measured confirming the operational status of the system.

3.1. MERMEC Triggering system

The aim of the system is to trigger measuring equipment installed on the track. In the Framework of MAXBE project, its purpose is to trigger and send some needed information to the KRESTOS acoustic wayside system.

Regarding the requirement expressed to trigger the KRESTOS wayside monitoring system, the measuring equipment requires being triggered at least 2/3rd of second before train arrival on the measuring area. So, the Mermec system will be install approximately 80 meters away from the measuring equipment on each side of the track.

The Mermec triggering system is composed of 2 different kinds of sensors:

- Train detection sensors (Figure 3.4)
- Laser barrier (Figure 3.5)
Some equipment will be installed in the Electrical cabinet near the track (PC 4U and electronic rack 3U). This cabinet has been installed in a dry and air conditioned area, with 230Vac power supply. The maximum power consumption is 1500 Watts.

These sensors have be installed on a commercial track in Estarreja (Portugal).

The train detection sensors is used to detect the train arrival and then to count the number of axles.

The laser barriers is used to calculate the speed of the train. This sensor are installed on the each side of the track. This is composed of an emitter and a receiver; there are 2 sets on each sensor modules. The speed will calculated using the time and the distance between the 2 sensors of 1 module.

3.1.1. Track implantation

The Figure 3.3 presents the Mermec proposition for the triggering system implantation. In order to identify the cable length, estimation has been done considering the measuring equipment installed right in front of the shelter.

![Figure 3.3 – Mermec proposition for the triggering system implantation](image-url)
3.1.2. Train detection sensors

The tests have be carried out with partners that need to receive the information sent by Mermec system. These tests have be held with normal traffic conditions and with different train types and speed.
3.1.3. Interface between the MERMEC triggering system and the KESTOS wayside monitoring system

This section describes the interface between Mermec train detection system and the measuring equipment.

The train detection is done using the redundant sensors, once the train presence has been validated, a relay can be switched for each measuring system. If several monitoring system would be triggered, the electrical signal can be customized for each measuring system, as Mermec will only switch a relay.

The information about the speed, and axle count, are sent to the KRESTOS system (or to any other system, if needed) via an Ethernet connexion. The connexion uses UDP protocol and Mermec application is a server, sending messages to all connected clients.

The information about speed is updated and sent for each vehicle entering the measurement area. About axle counting the system is able to count entering and exiting wheels, which means the total number of detected axle, will be validated after the train leaves the area.

The Ethernet message sent via UDP to all clients contains the needed information about the train currently present in measuring area embedded in an xml formatted structure (see Figure 3.6).
Figure 3.6: Exemple of Maxbe measurement data interchange XML

The information embedded in the xml structure are the following:

- **Site_Code**: abbreviation of the site name which train pass
- **Train_Pass_Time**: local time when train was detected
- **Loco_ID**: considering that there is no possibility to identify the loco, the loco id will be the train detection time
- **Train_Direction**: this information will determined according to the first activated sensor on the track.
- **Train_Speed_In**: average speed of first bogie, this speed will be calculated on the four wheels of the first detected bogie when entering the measuring area
- **Train_Speed_Out**: average speed of last bogie, this speed will be calculated on the four wheels of the last detected bogie when leaving the measuring area
- **Train Length**: length of the train, measured between first and last axle, this length will be approximately calculated using the following information:
  - First axle entering time
    - Total axle count
    - Speed for every axles
    - Last axle leaving time
- **Number of Vehicles**: number of train’s vehicles, considered that one vehicle is made with two bogie and one bogie has two axles.
- **Number of Axles**: total count of train’s axles.
4. VIBRATION WAYSIDE SYSTEM – BELGIUM

This section describes the high-frequency vibration-based axle bearing fault detection system jointly developed by De Lijn, D2S, and I-moss and installed in the Antwerp depot of De Lijn. It has been demonstrated at the M30 MAXBE meeting on 2015-03-09.

4.1. Installation site at Punt-Aan-De-Lijn Antwerp

Punt-Aan-De-Lijn is the northern tram and bus storage facility of the Belgium public transportation company ‘De Lijn’ at Antwerp. The system is installed at the exit of the facility, indicated on the picture below.

![Figure 4.1 - Entrance Punt-Aan-De-lijn, installation site](image)

The installation on an LRV network has some specific characteristics: embedded track, car and bus traffic, speed and weights different from mainline, etc. The hardware setup chosen in the De Lijn demonstrator takes this requirement into account.
4.2. System specifications

The complete system is composed of 8 high frequency accelerometers, mounted on the rail feet, field side. All these accelerometer are connected to a processing unit through a cable duct. The Processing unit is located in the vicinity of the accelerometer, in a weatherproof casing.

A raw schematic of the setup is given here:

The accelerometers are high frequency and have a sensitivity of 10 mV/g and are equipped with an integrated cable, to protect them from moisture and dirt. A mechanical protection system is installed over the accelerometer for protection and isolating it from other vibrations.

Spacing between the accelerometers is 52 cm, this is approximately one fourth of the wheel circumference.

The processing unit is composed of signal conditioning cards, a data acquisition card and an embedded computer. The system also features a GPRS system to allow remote connection.

The in-house built signal conditioning cards have been tuned for high frequency signals, since will be measuring signals of up to 40 kHz.

At the installation site the rails are embedded for mixed tram and bus traffic, so special precautions are required to ensure a well-functioning and stable system. This includes: underground cable ducts, accelerometers with integrated cabling, mechanical protection systems.
Figure 4.3 - Wheel dimensions
4.3. Installation

For the MAXBE project, the right rail has been instrumented. The installation required 8 hours of track access.

Figure 4.4 - Removal of pavers and stabilization layer to access the rail foot

Figure 4.5 - Removal of pavers and stabilization layer to access the rail
Figure 4.6 - Preparing and cleaning rail base surface for installation

Figure 4.7 - Installing accelerometers and mechanical protection
Figure 4.8 - Installation of accelerometers and mechanical protection complete

Figure 4.9 - Processing unit and cable duct
Figure 4.10 - Placed pavers and stabilization layer back in position
4.4. Vehicle identification

All vehicles are identified by a unique number. A magnetic loop reads the vehicle number. As a backup system, also a synchronized picture is taken from a high-definition, high-speed camera.

Figure 4.11 - Vehicle identification through magnetic loop and high-definition camera
4.5. Automated processing and fault criterion

Each wheel’s high-frequency vibration is measured by 4 sensors sampled at 80 kHz. This time signal is enveloped and on the spectra a peak-to-average norm is taken as a basis for anomaly alerting. Based on the measurement database, also trending is possible.

Figure 4.12 shows the raw measured signals for all 4 sensors. Figure 4.13 shows a detail of the enveloped signal.

![Figure 4.12 – Raw vibration signals of a vehicle passage measured by the system](image)

![Figure 4.13 – Enveloped signal (detail)](image)
4.6. Reporting

In the next paragraph we will discuss the interface to the WTMS, which allows for an integrated reporting of the measurements from this individual wayside monitoring system.

In this paragraph, we discuss the GUI built-in as a webserver in the vibration-based systems and which allows this system to be used in a stand-alone operation. This will be the case for smaller (e.g. urban) operators or in a degraded mode operation when the integrated system is not functional.

The vibration-based system is based on a generic vibration monitoring system developed by I-moss. It continuously monitors all vibration on all sensors. This can be reported for example in a 24-hours overview graph. Each peak corresponds to a vehicle passage. The software allows for a flexible configuration of loggings and alarms. The I-moss Wheel Flat detection and Out-of Roundness Monitoring (WORM) system is also based on this platform and is in integrated in the system presented here.

Figure 4.14 - I-moss monitoring system GUI, 12h measurement
Figure 4.15 presents the MAXBE GUI developed for the vibration-based system. Each measurement is shown as a single line on the screen, with a schematic drawing of the train. Axle bearings that reach warning levels are shown orange, when they reach alarm levels they are show red. (Note: levels on the screenshots are mock values and are not in relation with actual vehicles).

Raw signals of the sensors can be downloaded, and it is possible to listen to the vibration signal by clicking on the loudspeaker icon.

The GUI allows also to select only measurements that have found anomalies. It is also possible to view the history of one vehicle and do trend analysis. The data can also be downloaded as CSV for to do custom interpretation in Excel or to develop interface to an automated maintenance management system.
Figure 4.15 - GUI for vibration-based axle bearing fault detection system
4.7. WTMS synchronization

The system stores the processed measurements in an SQL relational database. The two main tables are the “passage” table and the “axle bearing” table. The passage table identifies each measurement of a passing vehicle. It corresponds to the “Measurement_identification” XML file that is exchanged with the MAXBE WTMS server as defined in D5.1. The axle bearing table defines the measurement of an individual bearing during its passage (and is therefore related to the passage table. It corresponds to the “Bearing_event” XML file as sent to the MAXBE WTMS server.

4.8. Conclusion

The final system is in continuous operation for more than six months at the time of this writing. The installation has thus proven to be robust in a very adverse environment, with braking sand and busses passing from the De Lijn depot. This robustness of sensors is a major advantage over other methods of detection. The wayside electronics containing the data acquisition, processing and transmission to the wayside has been proven in the field for more than 1 year.
5. **Acoustic Wayside System – UK**

The installation in the UK is still pending due to the intervention arrangements required and to be confirmed by Network Rail. The software for the UoB system is ready and its installation will be reported in due time as soon as the Network Rail completes the necessary arrangements. The preparation of the site has already been reported in the previous MAXBE deliverable.
6. MAXBE WAYSIDE SERVER

The results and the raw data extracted from the monitoring systems are stored in a server which connects with the Integration Platform accessible to the operators and to the infrastructure managers developed within WP5. The characteristics and the technical details of the server are presented hereafter.

The original specifications for the wayside server provided by REFER are:

- Quad-core processor with frequency $\geq 2$ Ghz;
- Memory $\geq 8$ GB;
- Hard disc $\geq 2$ TB with an adequate redundancy system;
- Operating system was left to REFER option and in accordance with REFER technical requirements;
- The database manager was left to REFER option with the possibility to choose between open source and proprietary solutions;
- The server will receive information from the different monitoring systems installed in Estarreja connected through REFER telecommunications network.
- It will have the possibility to create and run web applications to consult and visualize the data;
- It will allow interconnection with the others partners servers / sources of information (information from the on-board and Antwerp site);

REFER has create a server with Centos 7.x64 in run level 3. It will hold FTP and SSH services.

A general overview of the system is presented in Figure 6.1. The server HMI is presented in Figure 6.2.
Figure 6.1 – MAXBE System Overview
Figure 6.2 – MAXBE Server Interface
7. CONCLUSIONS

In the present document, a description of the several wayside monitoring systems developed within MAXBE project is presented.

The systems were developed, installed, tested and validated through WP2, WP4 and WP6, since the beginning of the project in November 2012 until April 2015. A vibration wayside system is installed in the Portuguese Northern Railway Line at Estarreja (PK 291.991). From the measurements of the rail accelerations, several KPIs are calculated and evaluated such as the wheel force, dynamic and static load, several ratios as indicative parameters and the weighing in motion and wheel defects indicators.

An acoustic wayside system is also installed at Estarreja in the Portuguese Northern Railway Line. The system is composed by acoustic emission sensors. The system is triggered by the MER MEC optical system installed further down and further up from the sensor positions. The system is able to detect both wheel tread defects and axle bearing faults. Operation is entirely automatic and KPIs are calculated once a measurement is completed.

The installation of the acoustic wayside system in the UK is still pending on the confirmation by the Network Rail. The system and its installation will be reported in an appendix to the present deliverable.

In Belgium, a high-frequency vibration-based axle bearing fault detection system was installed in the Antwerp depot of De Lijn, Belgium public transportation company, located in the northern tram and bus storage facility. The system monitors the light rail vehicles, in an embedded track subjected to car and bus traffic. The system measures each wheel’s high-frequency vibration thought 4 sensors sampled at 80 kHz. This time signal is enveloped and on the spectra a peak-to-average norm is taken as a basis for anomaly alerting.

The MAXBE wayside server which connects with an Integration Platform accessible to the operators and infrastructure managers is installed in the REFER services. This server stores the results and the raw data extracted from the monitoring systems installed in Portugal.

The final monitoring systems will be co in operation during the next six months, until the end of the project, to demonstrate to the potential end-users, the viability and the technical feasibility of these systems.
8. REFERENCES


