MAXBE

Interoperable monitoring, diagnosis and maintenance strategies for axle bearings – MAXBE

Integrating and strengthening the European Area

Co-operative Research Projects

Deliverable 2.2: Assessment of existing wayside equipment and on-board systems and operational requirements

Issue no. 1.0

Start date of project: 2012-11-01
Duration: 36 months

Organisation name of lead contractor for this deliverable: The University of Birmingham (UoB)
### Revision history

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Author</th>
<th>Description/Remarks/Reasons for change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>2013-04-21</td>
<td>M. Papaelias</td>
<td>First issue</td>
</tr>
</tbody>
</table>
1. SYNOPSIS
The European rail industry has been experiencing steady growth over the past decades, increasing gradually its economic importance for Member States whilst contributing to the sustainability of high mobility levels required in 21st century Europe. The policies adopted by the EC promote greener transportation and thus are expected to further underline the role of rail transport in the future. The rolling stock traffic density is increasing throughout the European rail network and therefore any operational disruption due to equipment failure is highly undesirable due to the associated costs and delays.

The reliability and safety of axle bearings in passenger and freight rolling stock has always been of concern to the rail industry. Wayside condition monitoring of in-service axle bearings has been based primarily on hot boxes and secondarily to acoustic arrays. These instruments use expensive infrared sensors and can only detect a problem once it has become critical and are prone to measurement errors. Moreover, due to their high cost hot boxes are usually spaced at relatively great distances from one another, hence faulty axle bearings can seize at anytime in between and result in a derailment. Acoustic systems are yet to prove their reliability and are also expensive.

Onboard measurement systems based on vibration and temperature sensors have also been developed but their commercial success has been so far limited. This is primarily attributed to cost-related reasons rather than anything else.

2. INTRODUCTION
Over the last 25 years traffic on European rail networks has been continuously increasing with rolling stock travelling at higher speeds and carrying more passengers and heavier axle loads than ever before. The rail industry in Europe as well as the rest of the world is set to continue to grow at a strong pace until at least the mid of 21st century. More high-speed lines are being designed and constructed constantly with an aim to connect not only major cities within Member States but also Europe with Far East Asia [1-2]. The increasing traffic density in the European rail network means that unexpected axle bearing and other wheelset faults and failures can cause severe delays and disruption of normal operations [3]. Furthermore, such faults can result in dangerous derailments involving human casualties, damaging the rail track and incurring substantial unnecessary costs for rail infrastructure managers and operators [4].

The technological advances in train design over the past few decades have enabled the extensive use of high speed trains [5]. The nature of rail freight operations has also been changing gradually with high-value goods being conventionally transported from the site of production to the site of consumption via rail [6]. The increasing trend for the rail industry’s business is forecast to continue up to at least 2050 since rail transport is steadily becoming a more attractive option over other means of transportation for both passengers and goods [7]. Train travel is generally cheaper than using a car, and usually the fastest option to reach a destination. It is also inherently safer and far more environmentally friendly in comparison to car travel, without compromising passenger convenience.

The immediate key challenges faced by the rail industry are: a) the improvement in the safety of the railway systems of EU member states, b) the development of new railways to accommodate the continued growth in demand, and c) contributing to a more sustainable railway, in both environmental and financial terms, by delivering further efficiencies and exploiting technological innovation [8].

In order to maintain economic growth, mobility and cooperation within Europe, it is absolutely necessary that the rail industry meets the operational, socioeconomic and environmental demands and expectations as described in the recently published White Paper for Transport by the European Commission. One of the fundamental milestones for sustainable surface transport across the continent is the significant improvement in the safety and reliability aspects of rail transport. The European Commission has set strict and specific objectives for the rail industry aiming to the significant reduction of delays, increased network capacity and absolute minimisation of accidents by 2020. The improvement of rail operations both in terms of punctuality and reliability will result in the continued growth observed annually in the numbers of rail passengers and freight. The environmental
benefits that can be achieved by maximising the efficiency of European rail transport and strengthening its growth are also considerable.

The improvement in the efficiency of O&M processes and procedures can play a significant role on the way towards improving the competitiveness of European railways. It can also support the harmonisation of procedures and standards across the continent, satisfying the requirements of modern Europe for optimised and environmentally friendly mobility of people and goods.

Optimisation of capacity in European railways can only be achieved through reliable condition monitoring of infrastructure and rolling stock alike. If Europe is to meet the need for sustainable passenger mobility and transport of goods across the continent the rail industry must adopt the technologies that will enable it to achieve the objectives set for it.

To maximise safety efficiency in rail travel, the rail industry has applied a pro-active maintenance policy for axle bearings, combining online wayside monitoring for in-service rolling stock and inspections during maintenance.

3. RAILWAY WHEELSETS

Railway wheelsets consist of three key components; the wheel, axle and bearings. In order to predict fatigue life, wear resistance, corrosion resistance and all general mechanical and chemical properties of the wheels, the chemical composition of wheel material should be considered. Table 1 summarises the steel chemical composition used for the production of wheelsets.

<table>
<thead>
<tr>
<th>Element</th>
<th>Max/Min Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.52/0.36%</td>
</tr>
<tr>
<td>P</td>
<td>0.02/0.03%</td>
</tr>
<tr>
<td>Ni</td>
<td>0.11/0.30%</td>
</tr>
<tr>
<td>Cu</td>
<td>0.15/0.30%</td>
</tr>
<tr>
<td>H</td>
<td>1.1 ppm/2.0</td>
</tr>
<tr>
<td>Si</td>
<td>0.28/0.40%</td>
</tr>
<tr>
<td>S</td>
<td>0.012/0.025%</td>
</tr>
<tr>
<td>Mo</td>
<td>0.04%</td>
</tr>
<tr>
<td>Al</td>
<td>0.003%</td>
</tr>
<tr>
<td>Mn</td>
<td>0.81/0.70%</td>
</tr>
<tr>
<td>Cr</td>
<td>0.15/0.3%</td>
</tr>
<tr>
<td>Ni</td>
<td>0.04%</td>
</tr>
<tr>
<td>V</td>
<td>0.05%</td>
</tr>
<tr>
<td>Si</td>
<td>0.007%</td>
</tr>
</tbody>
</table>

Table 1: Steel chemical composition used in manufacturing of wheelsets [9].

Each of these elements can provide an improvement for wheel alloy compared to the original composition. The following alloying elements improve the performance of the wheel steel in the following ways:

- Mn: Providing better toughness
- Cr: Increasing hardening capacity
- Ni: Providing better toughness
- V: Making fine grained structure which leads to improved toughness and ductility

Reduction of S and P would most likely improve the mechanical properties especially regarding fatigue even more. Decreasing grain size of the improved material causes better fatigue resistance [9]. The schematic in Figure 1 shows the different parts of a train wheel.

Figure 1: 1 Rim - 2 Web - 3 Hub - L1 Hub-width [10].
4. WHEEL DEFECTS

There are several types of wheel defects that are expected to give rise to vibration and acoustic signals, including wheel flats, shells, metal build-up, ovality, rubbing flange, corrugation, stuck brakes and faulty axle bearings. Cracks propagating on the wheel might be detectable if the acoustic emissions generated by a crack growing are transmitted through the wheel to the rail.

Because of the stiff and small rail and wheel contact, heavy loads can cause high pressure on both wheel and rail. Therefore it might lead to the initiation or propagation of defects on the wheelset and rail. If the wear rate is bigger or equal to crack growth, surface cracks will be removed automatically. This phenomenon is not likely to occur due to the high wear resistant steels used in railways. The wheelset should be removed from service within 24 hours if any single cavity detected greater than 15 mm long or any multiple cavities separated by 50 mm having a total length of 15 mm circumferentially around the wheel [11]. The main wheel defects and their initiation mechanisms are discussed in brief next.

4.1 Wheel flats

A wheel flat is a flat area on the rolling surface of wheel tread caused by unintentional sliding on the rail. It can be formed when the wheel slides on the rail. The friction between rail and wheel will cause an extreme thermal loading on the wheel tread.

Under braking where there is insufficient adhesion to allow transmission of the braking between the wheel and rail, the wheel can lock up and slide leading to increased rolling noise levels, deterioration of ride quality and reduction of the service life for both wheelset and rail [12].

![Figure 2: Photograph showing the presence of a wheel flat on a freight rail wheel.](image)

The presence of wheel flats can result in damage to the axle bearings and therefore it is important to take this type of defect into consideration when assessing the condition of axle bearings. Wheel flats are also difficult to control and predict when they will occur. Wheel flats are expected to be found on the opposite wheel of the wheelset concerned as they normally occur in pairs. Table 2 summarises the maximum wheel flat length allowed per vehicle type and action required.
Table 2: Maximum wheel flat length allowed in mm per vehicle type and action required.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Maximum Wheel flat length allowed (mm)</th>
<th>Maximum Tread run-out (mm)</th>
<th>Vehicle to be taken out of service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any vehicle permitted to operated above 125mile/h and up to 140mile/h</td>
<td>&gt; 60</td>
<td>&gt; 1.3</td>
<td>Immediately On completion of the journey Within 24 hours</td>
</tr>
<tr>
<td></td>
<td>40 ~ 60</td>
<td>0.7 ~ 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 ~ 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger or personnel vehicles operating at speeds up to and including 125mile/h</td>
<td>&gt;60</td>
<td>&gt;3</td>
<td>Immediately On completion of the journey Within 24 hours</td>
</tr>
<tr>
<td></td>
<td>40 ~60</td>
<td>1.3 ~ 3</td>
<td></td>
</tr>
<tr>
<td>Non-passenger vehicles, locomotives, power cars, driving van trailers, on-track machines</td>
<td>&gt;60</td>
<td>&gt;3</td>
<td>Immediately On completion of the journey</td>
</tr>
<tr>
<td></td>
<td>40 ~60</td>
<td>1.3 ~ 3</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Hollow worn wheels
The change in the shape of the wheel caused by wear may result in thin wheel flanges and hollow worn wheels. Hollow wheels can destroy this natural steering by reducing the rolling radius difference and making resistance in rolling. This will lead to faster degradation, increased fuel use and increased wheelset wear. It can also increase the risk of rail rollover derailment [13].

4.3 Tread run out
Tread run out occurs when the wheel tread is no longer circular or concentric with the axle-bearing surface. A thermal effect due to braking or sliding and rolling contact fatigue will cause this problem [13].

4.4 Metal build up
This problem results as wheel, brake block, and/or rail debris is welded to the wheel tread due to heavy braking. Heavy braking results into a significant rise in temperature causing metal to accumulate on the surface of the wheel. This type of defect occurs more commonly in wintry and cold conditions and can also contribute to damage of the axle bearings as well as riding quality [9]. The photograph in figure 3 shows metal build up on a freight rail wheel.

Figure 3: Photograph showing metal build up on a freight rail wheel.
4.5 Other types of rail wheel defects
Cracking can occur on the wheel surface as well as internally. In most cases cracks present on the wheel are surface breaking in the tread area. The three main causes resulting in cracking in the thread are: a) thermal effects due to braking, b) rolling contact fatigue (RCF) and c) thermal effects due to sliding. Cracking due to thermal effects caused by braking are normally associated with the type of braking system incorporated on the train (normally block brake systems). RCF cracking can be dealt with provided that the wheel is turned at appropriate intervals so initiating cracks do not have sufficient time to propagate. Thermal effects due to sliding is more difficult to control and is dependent on the driving style and the conditions of the rails.

Shelling occurs due to rolling contact fatigue defects that have initiated subsurface. They initiate under the multiple action of tangential stresses at oxide inclusions in the wheel steel.

Corrugation normally appears on wheel treads that are block braked. Corrugation can contribute to excessive rolling noise as well as vibration. The rise in vibration levels can contribute to the initiation and subsequently evolution of axle bearing faults.

5. AXLE BEARING FAULTS [14]
Axle bearing faults can be initiated from various mechanisms. Excessive loads can cause initiation of fatigue defects early followed by rapid growth resulting eventually in final failure.

Overheating of the bearing is another mechanism which can result in axle bearing failure. Higher than normal operating temperatures can result in loss of hardness and in extreme cases deformation. Moreover, the lubricant is also be degraded or even completely destroyed.

True brinelling can occur when the applied load exceeds the elastic limit of the ring material giving rise of increased bearing vibration and noise. Any static overload or severe impact can cause true brinelling of the bearing. False brinelling is usually related to excessive external vibration. The effect can be corrected by isolating the bearing from external vibration and using greases containing antiwear additives.

Fatigue failure or spalling is the result of continuous cycling loading of the axle bearing. This type of failure is progressive and once initiated will propagate as a result of further operation. Fatigue defects give rise to increased vibration levels as damage propagates.

Figure 4: Schematics showing defect evolution in axle bearing due to a) normal fatigue and b) contamination. Both schematics are courtesy of Wilcoxon Research.
Contamination is another important mechanism which can lead to axle bearing failure. Contamination results in high vibration and wear. Similarly lubricant failure causes excessive wear and overheating of the axle bearing which eventually leads to catastrophic failure of the axle bearing. Moisture present in the lubricant can cause rapid degradation of the lubricant’s quality.

Corrosion of the bearing can initiate early fatigue failures and is usually the result of exposure of the bearing to corrosive fluids or atmosphere.

6. ONBOARD CONDITION MONITORING

Onboard condition monitoring of axle bearings is primarily based on measurements of vibration, temperature and speed. A number of pilot studies have also considered the use of acoustic emission.

Vibration can be used to also monitor the condition of the wheel for the presence of flats, shelling and corrugation apart from the condition of the axle bearing. Temperature sensors are used to monitor the actual temperature of the axle bearing which if it exceeds a certain temperature then an alarm issued. It is important to monitor the actual speed during measurements in order to efficiently correlate the data.

The simplified schematic in figure 5 shows SKF’s IMx-R onboard condition monitoring for axle bearing condition monitoring [15]. Each axle bearing is fitted with an accelerometer, temperature and speed measurement sensor. The sensors are connected via cable or Wi-Fi to the main control unit onboard which collects the data. Once a defect is detected the system issues an alarm. The system can also employ acoustic emission sensors apart from accelerometers.

![Simplified schematic showing SKF’s IMx-R onboard condition monitoring system.](image)

Figure 5: Simplified schematic showing SKF’s IMx-R onboard condition monitoring system. The system incorporates vibration, temperature and speed measurement sensors on each axle bearing. The system can also incorporate acoustic emission sensors. The schematic is courtesy of SKF.

The schematic in figure 6 shows the overall operational principle of SKF’s IMx-R wheel and axle bearing condition monitoring system [15].
The schematic in figure 7 shows the onboard condition monitoring of the traction system. In this case a higher number of sensors is required [16]. The gearbox poses an extremely difficult problem for wayside equipment as it lies from the inner side of the wheelset. The SKF system meets TSI Directive 96/48 EC and EN15437-2.

Krestos together with UoB and VTG Rail Limited in the UK assessed the efficiency of onboard acoustic emission and vibration measurements using temporary installation. The sensors where...
mounted as close to the axle bearing using magnetic holddowns. Figure 8 shows the installation of the acoustic emission sensor and accelerometer on the axle box using magnetic holddowns.

![Figure 8: Acoustic emission sensor and accelerometer mounted on the axle box using magnetic holddowns. The photograph is courtesy of Mr Zheng Huang, The University of Birmingham.](image)

Figure 8 shows the raw AE signals acquired for a good and bad axle bearing using the above configuration.

![Figure 9: Onboard AE measurement from a) good bearing and b) bad bearing.](image)

Figure 9 shows the raw AE signals acquired for a good and bad axle bearing using the above configuration.

The photographs in figure 10 show the installation of an accelerometer using screws to attach it on the axle box in order to assess the condition of a wheel affected by shelling. One wheel of the train tested had shelling present on the tread as shown in the photograph of figure 11. Tests were carried out while the train was in normal service. The photographs are courtesy of EMEF.

Vibration measurements were carried out on a good and a bad wheel. In both cases the accelerometer was attached using screws on the axle box. The results from both wheels are shown in figure 12.
Figure 10: Photographs showing the temporary installation of an accelerometer on the axle box in order to assess the condition of the wheels. The photographs are courtesy of EMEF.

The photograph in figure 11 shows the damage present in the bad wheel tested using the accelerometer mounted on the axle box.

Figure 11: Shelling on the wheels of the test vehicle due to braking. The photographs are courtesy of EMEF.

Figure 12 shows the FFT of the acceleration signal for both the good and bad wheel indicating the presence of a fault in the bad wheel.
Figure 12: FFT for a) good condition and b) deteriorated wheel condition.

7. WAYSIDE SYSTEMS
Wayside systems for axle bearing fault detection are commonly based on hot box detectors which are based on temperature measurements. Infrared cameras have also been considered as a cheaper solution to hot boxes. Alternative non-thermographic systems are based on acoustic monitors (e.g. RAILBAM systems) which employ acoustic arrays placed on either side of the track in order to capture the noise from a defective bearing. An alternative approach is the installation of high-frequency acoustic emission sensors which are physically attached on the rails and monitor the wheelsets of passing rolling stock (e.g. SAFERAIL Belém system).

7.1 Hot box detectors
Wayside detection monitors are based primarily on hot boxes can check rolling stock for poorly performing axle bearings, inefficiencies in the braking system and blocked wheels. The main purpose is to detect critical axle bearing faults just before they result in a catastrophic failure.

Hot box detectors can detect the heat emitted by the bearing and report its imminent failure. However, wheelset bearings can heat up and seize extremely rapidly causing derailment before the train passes over a hot box detector and triggers an alarm in time to receive a warning to stop.

Moreover, the output of existing online hot box detectors is not fully reliable and can lead to misinterpretation of the data acquired and may frequently miss significant faults if the temperature of the axle bearing has not risen sufficiently at the time that the train passes over a checkpoint.

Maintenance inspections can help reduce the occurrence of faulty axle bearings however, they require that the rolling stock is removed from service and the axle box opened for visual inspection. Even then an axle bearing can start deteriorating rapidly and become faulty between inspection intervals.

Current hot box wayside detection systems can be connected to a railway’s computer network to provide the information they acquire on axle bearing performance but their software in most cases does not use trending from checkpoint to checkpoint but independent measurements from each site. Thus, rapidly deteriorating axle bearings may be missed even if there is time to go over several checkpoints before failure occurs simply because the temperature has not exceeded yet the preset alarm threshold. Hot box measurements are also prone to false alarms.

Approximately 80% of trains stopped after a hot box alarm are found to have absolutely healthy axle bearings and therefore the disruption caused to the network’s operation has been unnecessary. The cost of an individual hot box system is usually in the range of 70-100k Euro per measurement site.
making very expensive the installation of hot boxes at sufficiently frequent intervals. Figure 13 shows the principle of operation of a hot box detector.

![Figure 13: Hot box operational principle [17].](image)

### 7.2 Acoustic detectors

Acoustic bearing defect detectors based on air-coupled acoustic arrays have been developed in recent years as an alternative to hot boxes. Acoustic systems are generally more expensive than hotboxes. RAILBAM more specifically has been costed at just below half a million Euros per site instrumented. The photograph in Figure 14 shows an instrumented site using the RAILBAM axle bearing fault acoustic detector.

![Figure 14: RAILBAM axle bearing fault acoustic detector. The photograph is courtesy of VIPAC Engineers.](image)

Acoustic bearing detectors can monitor wheel bearings of passing trains at speeds between 30km/h and 130km/h. The system tries to differentiate between the various sounds in order to identify a faulty axle bearing and wheel related defects. However, the acoustic measurement can be affected by
environmental noise significantly thus leading to either missed faults or false alarms. Acoustic detectors do use trending to increase the reliability of the measurement but with the existing signal processing methodology is very difficult to ensure that the signal has arisen from a faulty axle bearing and not from a different type of wheel defect.

7.3 SAFERAIL Belém system
Feldman Enterprises Limited, together with Krestos Limited, the University of Birmingham and EMEF S.A. developed a wayside system based on high-frequency acoustic emission which has been installed on the Lisbon-Cas-Cais line (Belém station, direction to Lisbon). The system can detect wheelset defects as well as axle bearing faults. This system will be upgraded during the MAX-BE project. The system uses high frequency acoustic emission sensors which are physically coupled on both rails of the rail track. In this way much more information can be received from the sensors in comparison to acoustic arrays. The installed system is based on an 8-channel system with 4 AE sensors installed on the rail track. The remaining channels are used for other purposes, such as operating the triggering system, etc. The basic system architecture of the SAFERAIL Belém system is shown in the schematim of figure15.

![Figure 15: Schematic showing the SAFERAIL AE Belém system architecture.](image)

The photographs in figure 16 show the on-site measurement unit and the installation of the AE sensor on one of the rails using magnetic holddowns. The system consists of the following components: a) AE sensors coupled on the rail, b) pre-amplifiers, c) amplifiers, d) 4-channel measurement hub, e) data acquisition board, and f) onsite server.

The onsite server analyses the data automatically and transmits them via fibre optic connection to the Amadora Control Centre managed by EMEF.

The trains passing through the check-point have been tagged using Radio Frequency Identification (RFID). Along the ID of the train the system logs all the axle numbers, therefore whenever a defect is found the system approximates through analysis the exact location of the defect. Whenever the threshold is exceeded the supervising engineers are automatically alerted.

The system also maintains historical trends for each of the trains travelling on this particular line (suburban passenger trains only).
Figure 16: Photographs showing a) the onsite control unit of the SAFERAIL Belém system and b) AE sensor attached on the rail onsite.

The signal shown in figure 17 is the raw AE data acquired during the passage of a train from the check-point at Belém.

Figure 17: Raw AE data acquired by the SAFERAIL Belém system.

Further tests based on the Belém system have been carried out at Long Marston in collaboration with VTG Rail Limited. In this case the AE sensors have been complemented using accelerometers which are also attached on the rails using magnetic holddowns. The photograph in figure 18 shows the installation of the sensors at Long Marston.

A train consisting of one engine and two freight wagons was used during the trials at Long Marston as shown in the photograph in figure 19. The tank wagon contained two axle bearing faults artificially induced. At a later stage during the trials an artificial flat was also induced to assess its effect.
Data were collected during passages of the test train at speeds of 25km/h at either direction. The flat and axle bearing faults were successfully detected during the tests proving the capability of the system in detecting various types of faults. The results were verified with onboard measurements carried out simultaneously with the AE tests. Figure 20 shows the RMS of the raw AE data indicating the presence of the axle bearing faults and flat.
Figure 20: RMS of raw AE data indicating the presence of axle bearing faults together with the wheel flat.

7.4 SAFERAIL Antwerp system
A SAFERAIL vibration based system has been installed at De Lijn’s depot in Antwerp. The system has been developed by APT Rail in collaboration with De Lijn and monitors the wheels of the trams leaving and returning to the depot for the presence of defects such as flats, ovality and broken wheel gummies. The system uses high-frequency accelerometers to record the vibration signature produced by the trams travelling over it. The photograph in figure 21 shows the system installation. The system provides real-time alert for bad wheels detected whilst the collected data measurements can be checked using a web page.

Figure 21: Photograph showing the SAFERAIL vibration system at De Lijn’s depot in Antwerp.
7.5 Other types of detectors for railway wheelset monitoring

The shape and size of flat or shell, axle load, vehicle speed and rail pad stiffness influence the impact loads sustained by the rail. Rail pads, originally called “sole” plates or pads, are used in order to reduce vibrations and noise generated by rolling stock, minimise impact damage on the rail track and prevent cracking of the ties.

The Wheel Impact Load Detector (WILD) is a device based on strain gauges. It is used for the protection of the structural integrity of rails. Wheel defects such as flat, out-of-roundness or shelling can cause high impact loads which can be detected using WILD systems. When a train passes over a WILD site the system reads the impact load of each wheel on the rail and determines their location.

The system also records additional information about axle loads, train speed, weather information, total train length and weight etc. In particular, whenever a wheel’s impact exceeds the threshold an alarm is issued [12]. The schematic in figure 22 shows the operational concept of WILD systems.

![Schematic showing the operational principle of WILD systems](image)

Figure 22: Schematic showing the operational principle of WILD systems [18].

The plot in figure 23 shows data typically collected by WILD systems. Once a measurement exceeded the present load threshold the system issues an alarm.

![Load data recorded by WILD](image)

Figure 23: Load data recorded by WILD [19].
7.6 Profile measurement system
The profile measurement system is a real-time method using a combination of lasers and video cameras to automatically profile and measure the wheel. Mounted wayside in the track area, the system acquires all major wheel parameters. System’s analysis and reporting software provides wheel performance and predicting of faulty components. Data expected from profile measuring is, Wheel full profile and wear, Wheel diameters, Height and thickness of the flange, Back-to-back distance and wheel inclination.

7.7 Infrared thermographic camera
The use of infrared thermographic cameras in the place of hot boxes provides a cheaper solution. The installation of the system can be temporary or permanent depending on the requirements of the infrastructure manager. The system can be moved around relatively easily due to the portable nature of the infrared camera. In comparison to hot boxes infrared cameras achieve relatively poorer resolution whilst the maximum speed where they can be applied is also lower. Figure 24 shows the resulting infrared image generated by a camera-based detector [19].

![Infrared Thermographic Image](image)

Figure 24: Thermographic image generated by an infrared camera used to monitor the axle bearings of a freight train.

8. Technical Specification for Interoperability
The railway interoperability Directive (2008/57/EC) sets out a number of essential requirements to be met for interoperability, which cover safety, reliability and availability, health, environmental protection and technical compatibility along with others specific to certain sub-systems. The Directive also requires the production of mandatory Technical Specifications for Interoperability (TSIs) which define the technical standards required to satisfy those essential requirements. The development process for TSIs, as set out in the Interoperability Directive and managed by the European Railway Agency (ERA), is a complex one and can be challenging for those individuals who are involved in it. The TSIs are managed by ERA, who works with representatives from the National Safety Agencies (NSAs) and
other national railway representation to produce the drafts documents. A number of the TSI requirements may be satisfied by the requirements set out in the appropriate European Norms (ENs). The ENs are produced and managed by CEN/CENELEC and develop new standards where requested by the ERA, in support of the TSIs.

The key stages in the process for development of a TSI are:

- Drafting and development of the TSI by the ERA;
- Recommendation of the draft TSI by the Railway Interoperability and Safety Committee (RISC);
- Adoption of the TSI in a decision by the European Commission (EC);
- Notification of the EC decision to Member States (by formal letter);
- Publication of the TSI in the Official Journal (OJ);
- The TSI ‘becoming applicable’ (i.e., coming into force).

The rolling stock TSIs include requirements for axle bearing condition monitoring that set out the general requirements and direct to the appropriate European Norms (ENs) for the specific requirements to be satisfied.

According to the requirements as these have been set by the European Technical Specification for Interoperability (TSI) Directive 96/48 EC for bogie condition monitoring, the evaluation of the running stability should be continuous or at a frequency to provide reliable and early detection of damage for high-speed rail applications. The TSI Directive 96/48 EC defines different classes of rolling stock: a) Class 1 which includes rolling stock having a maximum speed equal to or greater than 250 km/h (i.e. high-speed), b) Class 2 which includes rolling stock having a maximum speed of at least 190 km/h, but less than 250 km/h. The above specification should be considered when designing onboard or wayside condition monitoring equipment for railway wheelsets.

9. COMPARISON OF ONBOARD WITH WAYSIDE CONDITION MONITORING SYSTEMS

In general onboard systems are more likely to detect an axle bearing fault particularly during the earliest stages of evolution. This is due to the fact that the sensors are much closer to the axle bearing and also measurements can be carried out repeatedly. Onboard systems can also detect other faults such as wheel flats, ovality, shelling, and other wheel defects although the sensitivity exhibited to these particular faults is likely to be comparable to the sensitivity achieved by wayside systems.

In contrast to onboard systems, wayside equipment relies in the detection of a signal which can be generated far away from the sensors when an axle bearing fault is concerned. When wheel flats, ovality or shelling are concerned the source of the signal lies near the sensor and therefore the sensitivity achieved is comparable to that of an onboard system.

Nonetheless, the data management and signal processing is not necessarily the same and it depends on what other factors influence the raw signal (e.g. motorised wheel, speed, severity of defect, etc.)

Each wheel needs to be instrumented when considering the use of onboard systems. This means that the overall cost of the onboard system although it may be lower than that of wayside system is a factor which needs to be taken into account seriously.
The onboard system due to its architecture makes use of a large number of sensors. A permanently installed system will require that these sensors operate at very harsh operational conditions.

This means that at least in certain cases the sensors may be damaged and require replacement for the onboard system to continue to operate normally. Sensor replacement or maintenance is very likely to increase further the cost of onboard systems.

It is more likely, that the onboard systems will be financially viable only for passenger trains. In the case of freight trains, apart from the locomotive, it is very hard to achieve an onboard system cost which is low enough in order to be financially viable.

Nonetheless, portable onboard systems could be employed to assess the condition of axle bearings and wheels during ad hoc maintenance evaluation measurements.

A possible combination of onboard systems with wayside equipment could be as follows. Once wayside equipment detects a fault, portable onboard equipment can be mounted on the wagon or train concerned in order to assess its wheelsets.

In this way, the presence of a defect as well as its severity can be verified rapidly and without the need to remove the wheelset in order to be visually checked.

Wayside equipment is at the moment of more interest to the rail industry but of course it poses more significant technical challenges and higher costs in comparison to onboard systems. Wayside equipment should be integrated in order to increase the value of the data recorded and increase the reliability of the measurements.

One of the key concerns in wayside condition monitoring is the train identification. Unless RFID is readily available alternative methodologies should be used in order to identify the trains passing through a checkpoint. Possible alternatives could be the information fed to axle counters (where these are used), optical identification or information fed by the infrastructure manager directly to the system.

The situation is more straightforward in onboard systems as identification is readily available. However, the conditions under which the sensors are required to operate is a factor which needs to be addressed. Similarly wayside sensors should be able to withstand adverse weather conditions as well as excessive vibrations from passing trains. Wayside sensors that are physically coupled on the rail should also be ensured that they do not affect the track circuits.

Installation of wayside or onboard sensors should be rapid and cause minimal interruption to normal operations. In case of failure of a sensor the problem should be identified quickly and the sensor concerned should be replaceable immediately requiring minimum intervention.

Nonetheless, an integrated acoustic emission and vibration system is likely to cost significantly less than a hotbox or acoustic array thus enabling more frequent check points to be installed on a rail line at a fraction of the cost. Results up to date, show that integrated AE and vibration approach may offer a realistic step change in wayside condition monitoring technology of railway wheelsets by the time the MAX-BE project is concluded.

10. CONCLUSIONS
This document discussed the onboard and wayside systems that are currently used by the rail industry for wheel and axle bearing condition monitoring. Each system has its own advantages and disadvantages. The sensitivity of the systems should be taken into account but also the cost of installation. All systems should be as easy as possible to install requiring minimum maintenance during their operation. Onboard systems will be more difficult to justify their financial viability. Nonetheless, the technology involved remains exciting and as long as their cost can be justified there will be a market for them. The real question is what scale this market will have. The wayside equipment is in general favoured by the rail industry as overall it results in lower costs. In any case the efficiency of the wayside systems needs to be clearly assessed. Both onboard and wayside systems should comply with the relevant TSI and EN standards.
11. REFERENCES


