Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Critical components and systems – current and future monitoring

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Deliverable 41.1

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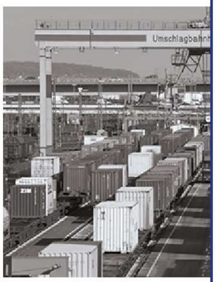

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Lead contractor for this deliverable:

- DB AG

Project coordinator

- International Union of Railways, UIC

Executive Summary

This report is the first deliverable for Work Package 4.1 of sub-project 4 (SP4) of the Capacity4Rail project. The task 4.1.1 of WP4.1 aims to identify components and systems critical for operation/deterioration of the railway infrastructure that should be monitored as well as to identify the current and future monitoring possibilities. The identification of the key operational parameters that govern deterioration of selected key components/systems and the translation of measured data to deterioration predictions for these collection strategies will be addressed in Task 4.1.2 and the related deliverable D4.1.2.

The overall objective of CAPACITY4RAIL is to increase capacity, availability and performance of the railway system. One of the required major step changes, amongst other areas like infrastructure design, freight operations, operations management, is the construction and maintenance part. In this respect, the incident recovery through real-time data management is a core part of maintenance, which can be ensured by advanced monitoring and non-intrusive inspection.

Particluar emphasize shall be given to the fact that this report provides an overview of current monitoring opportunities. The first chapter of this deliverable deals with the analysis the critical components within the railway operation. Focus is on switches and crossings (S&C), but also on other critical components and areas are covered. Since an overall approach is quite rare (or not published) in the European railway sector, the approach of a project launched at DB Netz is described as an initial situation, particularly because the objectives and the approach correspond to those of the entire Capacity4Rail project and the subproject SP4 Advanced Monitoring respectively. The described approach could also be useful to evaluate trade-offs between monitoring and diagnosis. In addition, other critical components and parts are indicated as typical areas to be suitable for monitoring. These include weak embankments in the neighborhood of the sea, rivers or hillslopes, peat lens under old or upgraded tracks, and cross wind sensitive bridges or exposed embankments. These systems need to meet higher requirements in terms of safety and therefore need to be avaliable for a daily self-diagnosis.

In chapter two current and upcoming monitoring strategies and the components/systems they target are investigated. One prominent example is monitoring of switches & crossings which relates to the most critical components in the infrastructure and has a major impact on the quality of maintenance. A major requirement when considering future monitoring solutions is that they should provide additional information regarding the frog-performance, e.g. forces during wheel passes and noise level.

Finally, the last chapter of this deliverable refers to monitoring gaps that need to be filled. It is stated, that the current trend in monitoring systems leans towards wireless systems, using low cost and low power consumption and wireless communication protocols. The key success of such networks/technologies lies in the low costs, low consumption (currently supported by batteries but the trend is towards energy harvesting) and their easy and rapid installation during the construction of the infrastructure and maintenance and oriented towards a cost-effective, easy and rapid sensor (including batteries) replacement/maintenance.

In order to establish the ground for an efficient use of the monitoring systems further steps are necessary for investigation of non-intrusive innovative monitoring techniques, like the definition of the functional and technical requirements, the technical and economic evaluation of monitoring solutions and the meaningful context of the technologies. These steps are dealt with in the subsequent tasks (4.2 and 4.3) of SP4.

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Abbreviations and acronyms

Abbreviation / Acronym	Description
6LoWPAN	IPv6 over Low power Wireless Personal Area Networks
GPRS	General packet radio service
IEEE	Institute of Electrical and Electronics Engineers
IM	Infrastructure Manager
IoT	Internet of things
LCC	Life Cycle Costs
LVDT	Linear Variable Differential Transformer
MEMS	Microelectromechanical systems
MTBF	Mean Time Between Failure
MTTR	Mean Time To Restore
PSD	Position Sensing Detector
RAMS	Reliability, Availability, Maintainability and Safety
RFID	Radio Frequency Identification,
SP	Sub-Project
USP	Under Sleeper Pad
WP	Work Package
WSN	Wireless sensor network
WTMS	Wayside Track Monitoring Systems
C4R	Capacity4Rail

1. Introduction

In principle, the current use of monitoring systems in the railway sector does not give any additional benefit. The reasons are that they are by default used only in certain (singular) locations and as stand-alone solutions. They are also specifically constructed for each individual case and region. In fact, monitoring systems provide essential input for a reliable condition and the main benefit of monitoring systems consists of anticipating defects and predicting performance of each asset type (degradation models) based on gathered real-time data and processing tools.

Capacity4Rail SP4 aims to develop monitoring systems for new and existing infrastructure with the associated strategies for non-intrusive and highly automated monitoring to meet with the general objectives of the C4R project and to meet the necessary criteria for the railway RAMS. Advanced Monitoring Systems can considerably contribute to increase Reliability and Availability of infrastructure thanks to early pre-failure detection and thanks to less failure and non-intrusive monitoring respectively (leading to reduction of the number of technical disruptions and delay minutes). It may also contribute to higher Maintainability of the infrastructure thanks to earlier and more accurate diagnosis.

The output of this deliverable sets out the components and systems that should be monitored since they are identified as critical for operation/deterioration of the railway infrastructure. However, this report also outlines current and future monitoring possibilities. This deliverable serves as input for the subsequent task and related deliverables e. g. Task 4.1.2, 4.2.1.

It is necessary to bear in mind, that the implementation of monitoring systems on the whole network clearly requires the analysis of financial return of investments. The focus should therefore not only be on the technical performance and advantages, but also on the economic performance of monitoring systems (this may be achieved by a business case).

2. Critical components and systems

In the following, an overview of the critical components in railway infrastructure is given.

Overview of the critical components:

- Infrastructure components: switches, signalling/interlocking, weak embankments etc.
- Critical parts of the network: critical nodes/bottlenecks, heavily loaded/operated track sections
- Vehicles as a critical component (motivates the need for WTMS)
- People and/or the human factor
- IT infrastructure and its critical parts

The **interlocking and signalling systems** are crucial for not only the safety, but also for its continuity, operational flow and reliability of the railway traffic. Seemingly minor failures on the interlocking side may imply severe consequences for the railway operations.

Bottlenecks are in this context physical infrastructure constraints such as heavy loaded/operated critical parts of the railway network, i.e. critical nodes, level junctions connecting different routes, heavily operated track sections, etc. Also some services/components which are commonly seen as complementary may constitute bottlenecks for the network – examples are maintenance depots, border stations, passenger convenience services, defrosting facilities etc.

Vehicles may be also seen as critical components of the railway system as a whole: the technical state and amount of vehicles is critical for the railway operations and its **operational flow**.

The technical faults of railway vehicles in operation (both hauled and hauling) are a significant source of problems and often they cause **damage** not only on the vehicles and freight itself, but also on the infrastructure.

As the “**human factor**” influencing the railway operation we can generally see the following categories:

- Employees of IM – station masters, signal men, dispatchers, supervising staff and others
- Employees of RU or other organizations – engine drivers, onboard staff, station staff, etc.
- Passengers
- Unauthorized persons on the track, (linked with massive problem, at least in some European countries)

Information systems of the operational management, as well as some other systems, are **mission-critical** systems for controlling the train traffic. They cannot get along without a support of other underlying systems.

The following work is focused on technical monitoring solutions that prevent the sudden malfunction or failure of components. If all data are online and available in-situ, the support of traffic monitoring for dispatchers is also a further field of application.

2.1 Analysis of critical components within the railway operation – Initial situation

As technologies like monitoring become more and more fit for use, it is necessary to make a survey of the actual situation and solve questions such as

- Is the equipment, which should be monitored, "state-of-the-art" and compliant with the standard?
- Are there improvements available for upgrading the basic monitoring equipment?
- How economical is monitoring in relation to the failure costs?
- Is there an added value from the collected data?

An overall approach is quite rare – or at least not published – in European railways. Therefore the focus of this chapter is on the conditions at DB. The reason is that DB Netz launched a project (that will be described in detail in the following sections) where the objectives and the approach is the same as for the Capacity4Rail project and SP4 "Advanced Monitoring" respectively.

In the department "Technology and asset management" of DB Netz AG, a short-term and immediately effective availability management is aimed to be established. To this end, switches and crossings have been selected as starting basis.

Some data on why the system switches and crossings have been launched as starting basis: DB Netz has currently around 70,000 switches and crossings. Switches and crossings are crucial points in the network and require particular analysis. A high number of operational disruptions are caused by faulty switches. The components of the track switches represent the main cause for the disruptions that affect the availability and costs of the entire network. The cost share of a single fault recovery of a switch is more than 10 times as high as the current cost for failure prevention.

At present within DB Netz there are no consistent specifications related to the equipment standard depending on the operational needs (e. g. to answer the question which switch gets a heating system, diagnostic or closure compartment cover). Also measurements on availability of switches are currently not possible.

In this respect, it is considered as essential to define consistent criteria, which combines both technical and operational criteria and key performance indicators for controlling the availability. Furthermore, appropriate procedures and methodologies for the analysis, management and measurement of availability on the basis of defined key performance indicators are considered as vital.

In general, the main objectives of the project are to mitigate the number of technical disruptions and delay minutes as well as reducing the related life cycle costs of the switches. In detail, the defined tasks within the DB project to achieve the objectives are:

- Establishment of simple key performance indicators related to the availability for controlling substantial production means (performance measurement, analysis and monitoring system).
- Classification of all switches based on availability criteria
- Definition of equipment standard for the complete system switch (which switch category gets e. g. a heating system, diagnostics equipment, or closure compartment cover)
- Development of a strategy for the preventive maintenance and implementation concept

- Target-actual comparison regarding the equipment standard sharply outlined on the switch, i. e. the current situation is compared to the target state in terms of use of switch and its components based on the existing DB standard for the appropriate use of infrastructure equipments/components depending on few factors (load, speed etc.)

However, the tasks defined above should serve as main steps in order to achieve the overall goals of the project that is to increase the availability by reduction of the technical and operational disruptions, and also reducing the number of delay minutes caused by switches. By achieving these two goals the life cycle costs can be reduced as well.

2.2 Approach for Switches and Crossings

The approach mentioned above consists of data processing, data analysis and evaluation and generation of appropriate measures in terms of equipment standard and preventive maintenance.

Regarding the data processing

In the course of the status analysis it has been found that the needed data for analyses and assessments are already available. In addition, the required expertise, methodologies and tools are also available. These include root cause analysis, life time calculation, reliability analysis and life cycle costing. In this respect, the base for the defined tasks and associated goals set up for the project can be regarded as assured.

Regarding the classification of the switches

Firstly, the scope of the analysis and the technical structure of the switch have been determined by product breakdown structure. This is important not just to obtain a fairly good understanding of the complete switch system with its components and linked interfaces, but also to be able to identify cause-effect mechanisms by performing root cause analysis.

The next step was to classify the switches based on the answers to the following questions:

- What are the key elements and how these can be usefully categorized?
- Which switches have to be considered as operationally essential and which are crucial respectively?

The challenging aim is to identify the particular operational key points on the network of DB Netz, which are responsible for the high amount of delay minutes and require great deal of maintenance in an efficient manner.

Given that, the operationally essential switches were identified based on the following criteria:

(1) Number of trains operating the switch
(2) Operational loading (gross tons)
(3) Operational speed of passing trains
(4) Revenues (if needed)

Such being the case, the definition and the classification of the operationally essential switches have been successfully carried out. In this respect, the classification of the switches into quadrants allows a statement on which switches the main focus should be on. With the following diagram the switches can be classified by a clustering very well in the described quadrants (see Figure 1), taking into account the load and delay minutes as criterion.

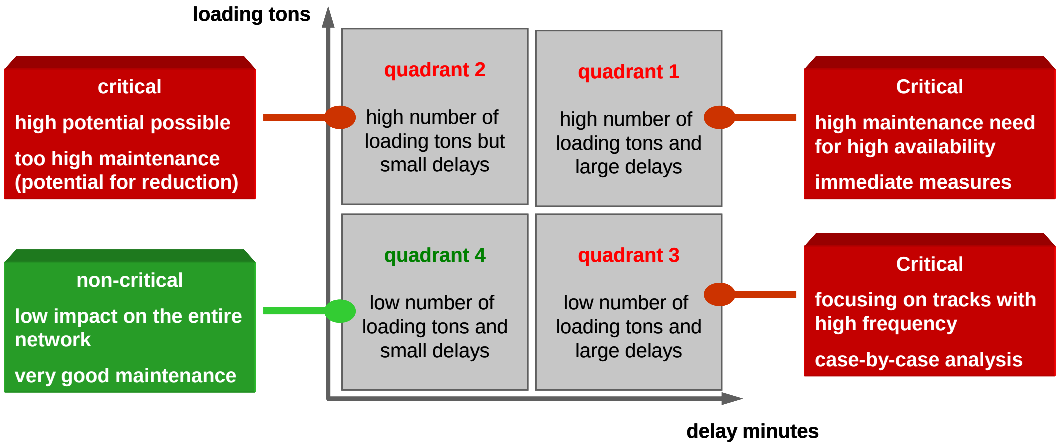


FIGURE 1 PRIORITIZATION CLASSIFICATION OF SWITCHES

Regarding the analyses based on available data

In the next step comprehensive analyses have been performed to identify the most frequently failed switches and their components, respectively. By identifying the most frequently failed elements (top failed switches and components) the applied approach followed the main steps described subsequently:

- Identification of correlations between the load data and the turnout characteristics
- Creating interdependencies and patterns to predict damage cases
- Categorization of assets according to elements and components respectively (base for further consideration)
- Identifying abnormalities or damage patterns according to elements and components with maintenance and repair needs
- Summation of the failure (number of incidents) and determination of a "accumulated damage" per turnout, which again represents an independent damage quantification (switch damage pattern)
- Identifying abnormalities according to switch damage patterns, comparison of structures and possibly prediction the development of existing switch damage patterns
- Calculation of the damage costs: the damage costs can be calculated as: Criticality = Cost per damage * Frequency of failure per (failure per time unit).
- Costs per damage include, but are not limited to: delay costs, costs for rerouting, repair and service costs, costs for spare parts, labour costs, ancillary costs
- Frequency of failure per time unit includes: number of repairs (repair rate) with the same damage code in a specified period (e. g. month) based on the switch identification number, repair date and damage code

- Decision support on the basis of technical and operational evaluation where a diagnosis and monitoring respectively is urgently needed and how much it may cost

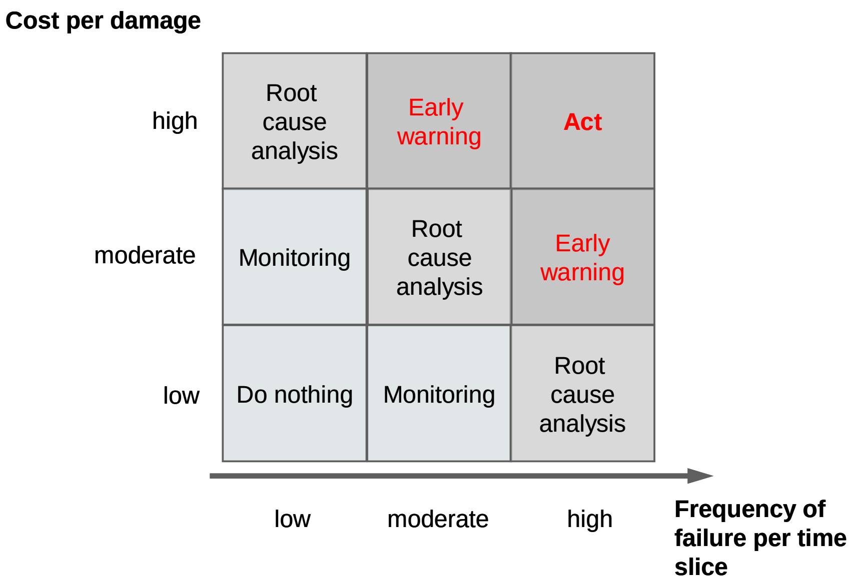


FIGURE 2 DECISION SUPPORT ON THE BASIS OF TECHNICAL AND OPERATIONAL EVALUATION

The main challenge to generate an essential benefit for the asset management in terms of increasing the availability is in answering the question: how are the needed values determined automatically to generate early warnings and risk figures etc. Further, how can this can be ensured by monitoring.

So at the end of the analyses the most frequently disrupted switches and components have been identified based on key performance indicators such as delay minutes and number of disruptions. One finding of the analyses was that the identified abnormalities and damage patterns of single switches show recurring failure causes.

By having these outcomes, specific switches dossiers have been created for the purpose of conducting root cause failure analyses in order to understand the cause-effect relationships. To verify the used data and outcomes, several workshops with the asset management teams tailored to each regional district have been conducted.

Regarding the definition of the equipment standard for the switches and crossings

So far within DB the technical equipment standard concerning the switches and crossings is based on speed and operational loading (tons). The technical equipment standard deposits rail type, closure compartment cover, heating system and diagnostic facilities are optional.

Given that, one of the targets is to extend the equipment standard such that each individual switch can be assigned to a uniform standard. This was achieved by considering:

- Issue of operationally essential/crucial switches

- Extreme weather: to answer the question to what extent the weather influences the incidents on specific switches with certain components, or which components respond, particularly sensitive to certain weather conditions (e. g. the most frequently failed latch tip locking reacts notably on temperature fluctuations)
- The impact on availability, reliability criteria and life cycle costs has been taken into account

Regarding the strategy for preventive maintenance and implementation concept

In addition to the provisions of the regulations, further issues in terms of maintenance have been taken into account, e. g. machine grinding process, holistic switch machining.

Further input is expected from the on-going workshops conducted with the asset management teams in terms of improvement measures from the perspective of technology and maintenance.

The concrete analyses of selected, particularly noticeable switches create the basis for the derivation of measures with regard to failure and robustness patterns.

Also the maintenance process itself and the linked data entry by the responsible persons are considered as areas for improvements, that need to be analysed.

Once the improvements measures have been generated they should be assessed economically. That is to say that one of the last steps is to assess the measures with regard to technology or/and maintenance by life cycle cost analysis (LCC) to get the economically best solution. It is worth to mention that there is a connection between the reliability, availability (RAMS) and economic efficiency (LCC) that should be accounted for. However, the technical specifications and the result data are supposed to be fed into the economical assessment.

The RAMS parameters (like MTTR, MTBF) influence each other and have an impact on the technical performance as well as on the LCC. However, many factors that influence technical performance and costs can only be considered by RAMS and LCC analyses.

In fact, the combination primary of investment, maintenance costs and costs for non-availability, determined by technical performance, result in the total costs of a product. This provides a base for decision making. Therefore not only the technical parameters but also follow-up costs over the life time of a system or component like maintenance costs should be taken into consideration.

An important question is how to achieve the required Availability of the system. The Availability depends on the technical performance of the system or component and the repair rate. Both parameters influence also the Life Cycle Costs of the system. Therefore the decision whether to change the technical performance of the component or to adjust the repair rate or to do both should be based on an LCC analysis.

The quality and the reliability of a transport service depend on the operation strategy which has many influencing factors. Through adopting an appropriate Maintenance regime the failure rate could be reduced. However, the Maintenance strategy includes the intensity, quality and budget of maintenance; availability and qualification of maintenance staff.

In fact, the required Reliability depends on the operating conditions and is the results the demanded Availability. Furthermore the required Availability depends on the technical performance and the repair rate, which influence the LCC. However, there is a connection between maintenance and operating life through the failure rate. Therefore the relation between Maintenance actions and the operational life of components should be taken into account in terms of economical optimization.

Another important step is to develop a migration concept which links the implementation of the improvement measures with regard to technology (extended equipment standard) and maintenance (preventive maintenance) to the associated costs. This is recommended to be considered for a long-term period of at least five years to ensure the timely consideration of improvement measures in the planning control of the asset management.

For the purpose and tasks in SP4 of C4R the approach described above with the tasks to establish an availability management could be adopted and extended by the element of monitoring. By establishing a continuous monitoring, e. g. through switches equipped with sensors, deviations and potential risks respectively can be identified much earlier, the systems performance can be better measured and recommendations for correct actions can be driven.

2.3 Other critical components and areas

Regarding the Monitoring for critical areas in case of severe weather conditions:

In 1.2 the focus was on switches, since malfunctions or failures have an immediately influence on railway operations. Severe weather conditions also have a major impact on railway operations, but usually they are almost independent from maintenance. In that case, safety must be ensured. Typical areas which are suitable for monitoring are

- Weak embankments in the neighborhood of the sea, rivers or hill slopes
- Peat lens under old or upgraded tracks
- Cross wind sensitive bridges or exposed embankments

Different to the Monitoring for Maintenance, these systems must meet higher requirements in terms of safety. An alert is seldom triggered by such systems. For that reason, these systems must be able for a daily self-diagnosis. In addition, the data transmission to nodes and the integration into the company network must be reliable and secure, at least a SIL2 level is mandatory.

Monitoring for critical areas or structures

To allow an increased transport on railways, two approaches to deal with critical areas and old, weak structures are possible.

1) An increase of operational loads on an existing line, combined with monitoring to get an early warning if these loads are too high. (Often an opinion will be drawn based on single measurements, but these don't take the long-term behavior into account)
2) If the structure is at the end of life, monitoring may allow an extension of the lifetime (5–10 years). This is absolutely necessary to accommodate the planning and construction phases for a renewal.

For these applications in most cases a unique solution must be developed due to the vast variation in operational conditions.

3. Current and upcoming monitoring systems

3.1 Current Inspection and Monitoring Systems

This section highlights on-going monitoring concepts in progress and/or in full scale tests. While this deliverable mainly investigates the issue of “what we monitor today related to the critical components and systems” this section investigates what is already in planning and testing. The upcoming deliverable D4.1.2 takes a more futuristic approach and deals with the question of what we should monitor in an ideal situation. This includes identifying parameters that are governing deterioration of key systems/components and how these can be controlled by monitoring-based deterioration analysis and prediction.

3.1.1 Overview of monitoring systems as output from the D-RAIL project

In the EU funded project DRAIL, existing and innovative inspection and monitoring systems have been investigated from a safety perspective. In this regard, a detailed review and critical assessment of current (existing and emerging) inspection and monitoring techniques (including vehicle identification) related to derailment prevention and mitigation have been provided. A useful survey about current inspection and monitoring techniques that are used to prevent and mitigate derailments, for both rolling stocks and infrastructure, and the interaction between the vehicle and the track (the complete freight system) are given. The project focused on freight transport, but the survey also includes inspection and monitoring systems currently used for passenger trains, that could be adapted for freight traffic.

D-RAIL was the acronym for the EU Framework 7 collaborative research project: Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment. The project started in 2011 and ended in 2014. The main objective of the D-Rail project was to obtain a significant future reduction in freight derailments through an increased understanding of derailment causes, and to improve methods of predicting derailment critical conditions through measurement of appropriate system parameters. That is to say it the aim was to come up with cost-efficient measures to reduce derailments.

In tandem with various analyses, current monitoring systems (both wayside and vehicle-mounted) and developing technologies were assessed with respect to their ability to identify developing faults and potential dangers. Where current systems are shown to be deficient, the requirements for future monitoring systems have been specified. D-RAIL has also examined vehicle identification technologies, such as the standards- and interoperability-focussed RFID system being implemented by GS1 and Trafikverket.

The selected and most promising inspection and monitoring systems are:

- Axle Load Checkpoint (Q), type: wayside
- Axle Load Checkpoint (Y and Q, resp y/Q), type: wayside

- Hot Box Detection System (infrared based), type: wayside
- Hot Wheel Detection System, type: wayside
- Acoustic Bearing Detection, type: wayside
- Vehicle Profile Measurement, type: wayside
- Rail profile measurement (laser-based wear measurement), type: vehicle based
- Track Strength Testing, type: vehicle based
- Track Geometry Measurements, type: vehicle based
- Video Inspection of rail, sleepers and fastenings (rail failure), type: vehicle based
- Ultrasonic Rail Inspection, type: vehicle based
- Magnetic Flux or Eddy Current, type: vehicle based

Furthermore the overall effectiveness using all technologies on the parameters causing derailment including areas for improvement have been assessed. More details can be derived from the related deliverables and reports of this project, of which most of them are public and available on the project website http://d-rail-project.eu/.

3.1.2 Monitoring concepts launched at DB

Following the research outputs of D-Rail regarding inspection and monitoring systems, new concepts and developments of monitoring have been established meanwhile. Two of these measuring and monitoring concepts are described in the following section. One is a monitoring system based on acoustic measurement that implies a concept of collecting measurement data reg. rail traffic noise and rail related noise respectively by means of permanent measuring stations, which is described subsequently.

Concept regarding the Acoustic Monitoring at Deutsche Bahn

Basically the aim is to measure various physical quantities that are related to noise emission, e. g. wheel-rail forces or accelerations on the superstructure, by the permanent measuring stations.

A major requirement when measuring the physical quantities is to monitor the noise emitted by densely trafficked freight corridors. Three types of measurement devices have been designed with different level of complexity:

1. Basic device
2. Mobile device
3. Combination device

While the first type of the device collects only sound pressure data of passing trains, the second one also measures axle loads, allows precise vehicle identification and sound pressure level of passing vehicles. The third type of the device combines different track vibrations and a detection of out of round wheels with the acoustic entities, see Figure 3.

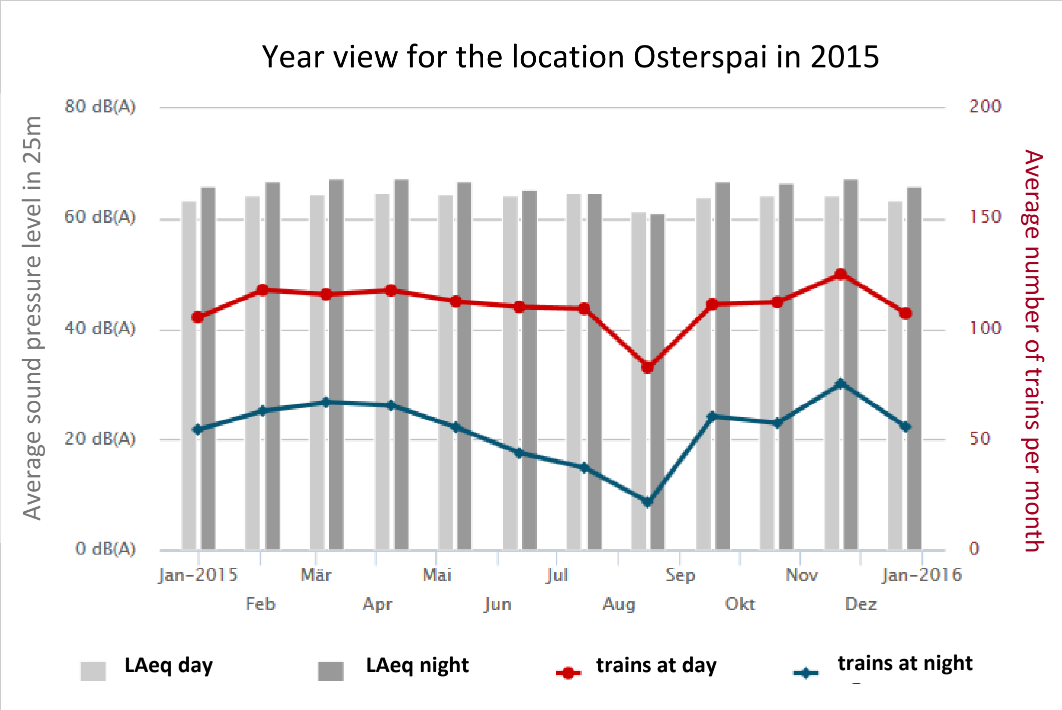
Basic device

Mobile Device

Combination Device

FIGURE 3 THREE-STAGE APPROACH OF THE MEASUREMENT DEVICES

However, results from two stations are published weekly for public interests, as shown in **Erreur ! Source du renvoi introuvable.**. The aim is to show a decrease of rolling noise levels achieved by retrofitting of cast iron to composite brake blocks of freight rolling stock. More details on this acoustic monitoring are shown in the deliverable D4.1.2.



LAeq…sound pressure level

Figure 4 Year view of the site Osterspai from 2015

The second concept employs monitoring by in-service trains, as carried out on two selected passenger lines at DB network. The monitoring technology is developed by DB and implemented on the ICE-2 for the purpose of monitoring of the track.

The measurement system is called CTM (Continous Track Monitoring) and is mounted on an ICE1 train that measures the accelerations of the axle bearings during the normal train operation. Based on these measurement data, the longitudinal level of the track is identified. Additionally noticeable switch and crossings with related parameters regarding their condition can be identified. The results are transferred by mobile communications to a central server and provided to the asset manager through weekly reports. The data can be used as asset condition data and transformed to actual and forecast usage information.

The concerned measurement technology corresponds to the technique that has been developed and analysed in the EU funded project AUTOMAIN. This measurement system is mounted on a train measurement vehicle (RAILAB) and measures the accelerations of the axle bearings during the measurement run. The collected data will be used for automated quality assurance of the inspection data of the RAILAB. The quality assurance is carried out online and the results are transferred by mobile communications to a central server.

AUTOMAIN is the acronym for the EU Framework 7 collaborative research project: “Augmented Usage of Track by Optimisation of Maintenance, Allocation and Inspection of Railway Networks”. The project started in 2011 and ended in 2014.

The high level aim of the AUTOMAIN project was to improve the movement of rail freight (more reliable, available, maintainable and safe) through the generation of additional capacity on existing networks. Through the widespread introduction of automation and improvement of railway infrastructure equipment and systems, modular infrastructure design, and far-reaching optimisation of maintenance, required possession time (downtime for inspection, maintenance and/or installation) of the railway can be reduced. Improvements are achieved through:

- Increased reliability
- Increased availability
- Increased maintainability
- Improved worker safety

The research areas range from a new methodology for analysing and optimising maintenance processes, new (high speed) inspection and maintenance methods to improvement of automatic maintenance scheduling and planning systems.

In fact, the additional effort needed for data processing increases the track maintenance efficiency substantially. For instance, the gathered data enable a continuous track monitoring, i.e., potential track failures become detectable at an early stage. Here, acceleration data gathered by low-cost units on in-service freight locomotives are used to recalculate the vertical track geometry. In addition, also fault tracing, i.e. the identification of the same fault in subsequent data records, is considered to analyse the fault progression reliably. Moreover, due to the increased number of data sets even a failure prediction can be put into operation. That is, the precursors of a track failure (tiny peaks in the displacement data) are evaluated to predict the remaining time until the expected track failure becomes critical. By knowing the remaining time until a track failure is expected, an optimised maintenance can be scheduled.

It is worth to mention that this monitoring technique can be considered as an independent system and does not disrupt the operation.

3.1.3 Additional monitoring concepts

Train loads

There are massive amounts of research in terms of maintenance related monitoring regarding vehicles and wheel/rail interaction. An overview of different track based systems around Europe was compiled within the UIC-funded projects Axle Load Checkpoint and HRMS. In the context of asset protection, Ansaldo STS has designed and developed an innovative monitoring system (named Weigh in Motion – WIM), which is able to measure weight and check load conditions of each train in transit. The system is based on fibre optic technology for detecting the weight and load imbalances of moving trains and the rolling contact fatigue based defects/wears.

In the context of asset management and maintenance planning, the Weigh in Motion (WIM) wayside monitoring system can be commonly applied in order to check the vertical load characteristics; the system is able to measure the wheel and/or axle loads (both for locomotives and wagons) and to detect the presence of critical conditions (e.g. overloading) for the running trains.

Wheel profiles

Wheel Profile Measurements System (WPMS) is a complement to the WIM system as it measures the wheel profiles. The data can be used as input to predictions of wear and damage to rail in curves, see e.g. [1]. The contact between rail and wheel depends on three major geometric factors, such as wheel profile, rail profile and curve radius (and indirect cant and speed). Note that a wheel profile in itself does not provide much information so it needs to be matched to the rail profile that it is traversing [1]. The issue of Rail profiles will be discussed in D4.1.2.

Knowledge of wheel profiles of all trains gives the infrastructure owner a better understanding of the risk of wear and damage of rail and turnouts. Sweden has one WPMS that measures trains on the iron ore line between Luleå and Boden. An evaluation of the employed measurement system was done 2014 in the report “The wheel profile measurement system at Sunderbyn, Sweden" [2].

The following conclusions about the technology and handling the measured data have been drawn from this project 0[2]:

- The selection of technical solution and supplier was made on the basis of the technology level, reference installations, and operation and support possibilities, and not merely based on the price. A development project of this nature is not primarily a question of putting equipment into operation, but of transferring knowhow concerning possibilities and limitations associated with the technology in question.
- The information generated by the equipment installed is very useful for all parties working with the development of railway maintenance.
- The challenge with regard to utilizing the benefits afforded by the measurement system lies in the ability to process the generated condition data for the maintenance organizations concerned and integrate these data in the operations of these organizations.

The following parameters are directly measured (see Figure 5 for definitions)

- Flange height, Sh (Immediate Action Limit, IAL: 36 mm)
- Flange width, Sd (IAL: 22mm)
- Flange slope, qR (IAL: 6.5 mm)
- Thread hollow, Th (IAL: 2 mm, depends on the operating company)

The shape of the wheel profile can also be used to deduct if wear is too fast or uneven within the bogie, which indicates bad steering. By knowing the wheel profiles for all passing trains it is possible to predict where the rail will be worn or have problem with rolling contact fatigue, cf [1].

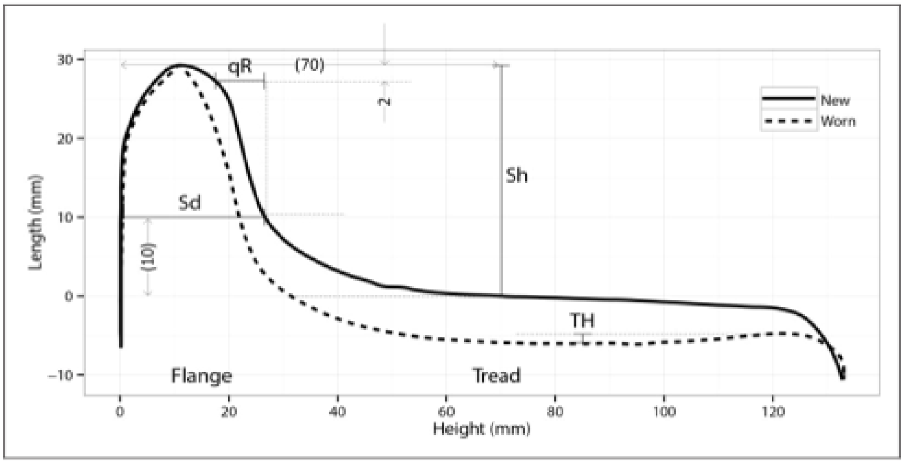


FIGURE 5 ORIGINAL AND WORN WHEEL PROFILES MEASURED BY THE WMPS (FROM ARTICLE REF 0)

Developing trends is possible for all measured parameters. If tread wear is dominating, which might be typical for the iron ore line, a need of reprofiling will occur when the maintenance limit for flange height, Sh, is reached (34 mm). If the maintenance limit is reached for other parameters it indicates that the wear is more aggressive than normal (or it is very many curves under 800 meters). A study by Li [3] showed found a wheel set (out of 32 studied axles) that was wearing twice the normal value. With a regular measurement this wheel set would not have been identified before it was at the end of its lifetime.

The wheel profile can be used to calculate the equivalent conicity and also to indicate where on the line the rail will be most worn and have the greatest problem of RCF 0[3].

Vehicle curving, traction and braking performance

Stratoforce is a lateral and vertical force measurements in a narrow curve (R~400 m), which has been implemented on the Iron Ore Line both on the Swedish and the Norwegian part of the railway. In USA (Truck Performance Detectors) and Austria (Argos) similar measurements are done. The measurements indicate conditions of bad steering (angle of attack), high dynamic vertical forces, high lateral forces and risk of derailment.

FIGURE 6 INSTRUMENTED TRACK SECTION

The following parameters are directly measured

- Vertical force (static and dynamic)
- Lateral force (static and dynamic)
- Angle of attack
- Number of axles
- Speed

More details will be provided in D4.1.2

3.2 SWITCH MONITORING

As discussed in section 1.1 switches and crossings are the most critical components in the railway infrastructure. Therefore new strategies have to be developed to reduce the operational impact of sudden failures.

With focus on the switches, it is worth to look at the variety of the countless variations in the types of interlocking connections. Usually in the course of switch monitoring just the interlocking system is taken into account that already has an IP connection, because necessary work platform is still available. Thus the base for monitoring is ensured which is also state-of-the-art. Therefore, it is always advisable to look at the hardware component in connection with the interlocking.

Current monitoring (since 2000) works quite good for new electronic interlocking. Up until today, each switch is connected directly by a wire through which the power for the motor is transmitted. The disadvantage of thick and expensive copper cables can be used as an advantage for the monitoring. The current which is necessary for the switch motion can be measured contactless in the interlocking. This simplifies the proof of non-interaction with the interlocking. The result is a current–time curve during a switch operation. An example is shown in Figure 7.

Figure 7 Traditional switch/point monitoring; Measurement of the current as a function of time

Each switch has its own target value curve, a deviation from the target is an evidence of sluggishness of the switch in operation. The timing of the sluggishness is also an indication of which components that are affected.

First strategic steps are the development for Open System solutions, bringing a variety of existing switches into the monitored family [4]. Second, the used algorithms can be added regarding the behaviour of the overall operating time over several years and different maintenance regimes. Using the example of the DB system DIANA, it has been shown that switch monitoring already has a high impact on the quality of maintenance. Figure 8 shows a time-line from one switch. It is clearly indicated that a maintenance intervention changed the performance from low (yellow) to bad (red). The bad (red) performance indicates high switching forces, but up to now the switch didn't fail in this example!

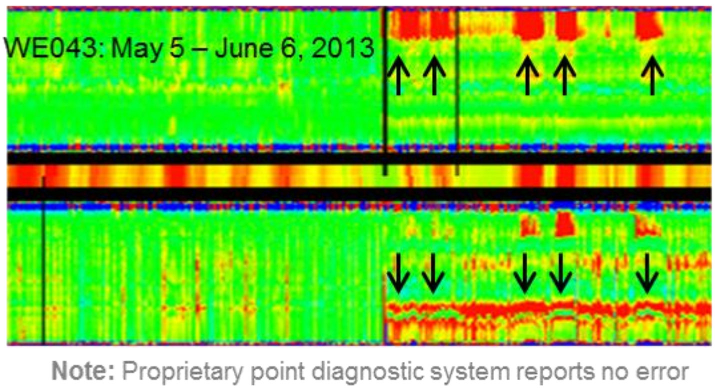


Figure 8 Long term behavior of a point machine. Indication of an increasing switching force due to wrong adjustment during last maintenance. Point machine shows temperature-induced anomalies

Future monitoring solutions should give additional information about the frog-performance, e.g. forces during wheel passes and noise level.

3.3 Monitoring for critical areas and Structures

Available on some test sites but not state-of-the-art is monitoring for critical areas and structures. Outside of some test-sites, these applications usually are used for monitoring of in-service tracks beside larger construction work. Here, it is necessary to observe the influence of buildings, e. g. ramming or sheet piling, on the stability of track.

A typical example is the monitoring of a tunnel construction site between Network Rail and DLR tracks. The entrance of the tunnel was stabilized by sheet piling on both sides in the direct relation to tracks which are still in operation. For safety it is absolutely necessary to observe small movements of the track.

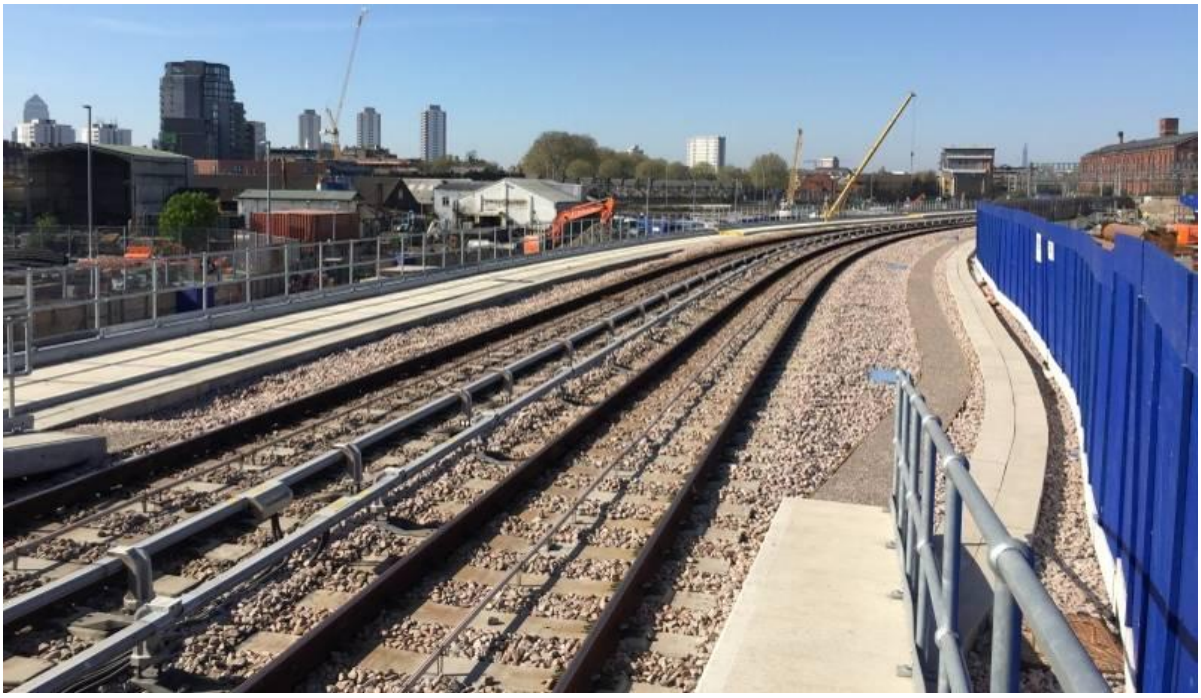


Figure 9 London Construction site of Morgan-Sindall; track monitoring close to sheet piling

In this example two different and independent monitoring technologies were applied. One is a traditional automatic optic system from Leica, which is state-of-the-art and comparable to what is used at other construction sites [5]. The disadvantage of optical systems is the dustiness of construction sites. At least every two weeks all optical prisms have to be cleaned, otherwise incorrect measurements are obtained and the monitoring system reports movements of the track – up to 40 miles as reported by an engineer!

The second system is a set of highly sensitive inclinometers from Senceive Ltd. [6]. A huge number of sensors were applied in the track, powered by long lasting batteries and using wireless data transmission featuring a network mesh. This system runs without any maintenance and delivered high precision data of track movements.

Similar systems will be used within C4R to establish a monitoring of a critical track to prove the feasibility.

Monitoring of track geometry and ballast enclosure

Soft soil in combination with a strong protection layer leads on a line between Ulm and Friedrichstadt to high dynamic reactions of the track over a length of 30 m during the passing of trains. This causes lateral movements of the ballast, degradation of the track geometry and as a consequence a speed reduction for the trains. The reconstruction of the effected track section and the transition zones would cost several millions of Euros. To avoid the expensive reconstruction in front of the complete rebuilding of the line and to increase the speed to the planned value, the following approach was used:

On the outer side of the track a simple wall was installed to prevent the lateral ballast movement (see Figure 10). Because this wall has to be founded in the soft soil the position of the wall has to be monitored by several inclination sensors to ensure the stability and safety.

In addition to these monitoring devices the loading, dynamic reactions of the track and the pore water pressure are measured (see Figure 10).

.

FIGURE 10 ADDITIONAL SENSORS TO MEASURE FORCES, ACEELERATIONS AND PORE WATER PREESURE AT THE CRITICAL SECTION

All sensors are connected to a measurement computer which is installed in a concrete box at the section (see Figure 10). The computer stores and evaluates the measurements and allows the remote control of the system and a real-time view on the results.

FIGURE 11 MEASUREMENT SYSTEM AND POWER SUPPLY AT THE CRITICAL SECTION

After installation of the monitoring system several measurements were carried out for different speeds and different types of trains to analyze the dynamic behavior of the section, as an example shows the application of energy for different trains and speeds. Further investigations and results from Sweden for similar boundaries show that the selected technical solution (enclosure of ballast) allows a safe operation as long as the ballast wall works proper.

Reference measurements in combination with the absolute inclination of the ballast wall are the basis for the monitoring. For each train the measurement system compares the results with given limits or the reference measurements. If the measured values are above the limits the system generates a warning which triggers the following actions:

1. Check of the measurement using the remote access
2. Visual control of the track section if the first step does not show measurement errors
3. If necessary send message to asset owner for further actions

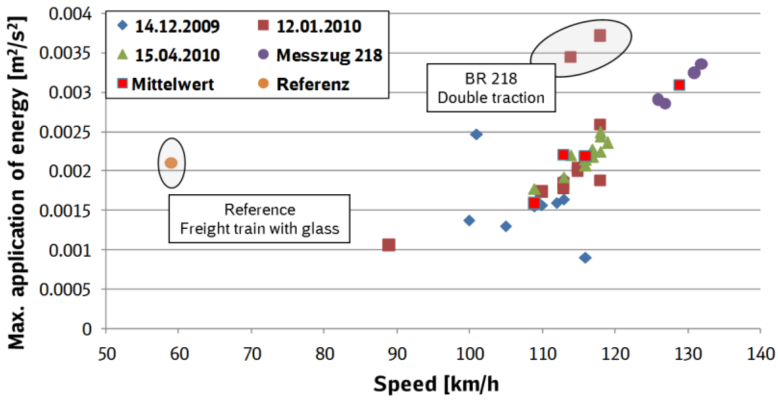


FIGURE 12 MAXIMUM APPLICATION OF ENERGY IN BALLAST FOR DIFFERENT TRAINS AND SPEEDS

The described monitoring system works absolute sufficient for long time and ensures a safe operation without improvement of the soil in the critical track section. On one hand it reduces the cost about more than factor 20 and on the other hand the measurements increased the knowledge about soil dynamics and behavior under real boundary conditions which were used for the rebuilding of the track.

The chosen technical solution in combination with the permanent monitoring of the wall inclination is a suitable way to improve the long-term behavior of sections with soft soil at lowest cost.

3.4 Monitoring of Structures

Although many of Europe's 300,000 railway bridges are close to or exceeding their planned service life, it would not be economically feasible or realistic to envisage their replacement on a large scale. Thus, an extension of the service life of bridges should be a major priority.

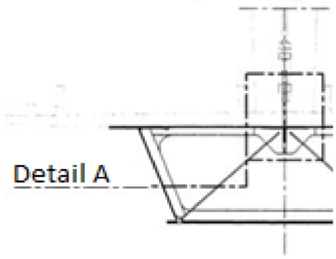
Fatigue is one of the main causes of severe damage in the case of railway bridges. Within the framework of the European project FADLESS – Fatigue damage control and assessment for railway bridges – a long-term monitoring system was recently applied to assess fatigue damage at critical details of the bridge of the new railway crossing of the river Sado, located at the Lisbon Algarve railway line, in Portugal (Figure 13).

The bridge is prepared for freight trains with up to 25 t per axle and operated by conventional and tilting passenger trains with speeds up to 200 km/h and 220 km/h, respectively.

a) Location b) Overview

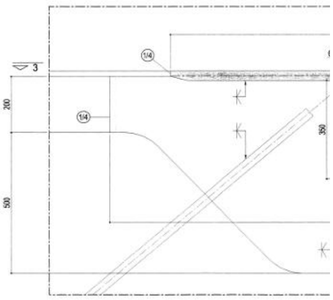
Figure 13 Bridge of the new railway crossing of the river Sado

At each hanger-to-deck connection, the deck has a steel diaphragm and two diagonal strings that transfer the suspension loads from the hangers to the deck (Figure 14). Detailed fatigue analyses showed that connection of the diagonals of each diaphragm and the cope hole at the top connection of the same elements (Figure 14) are critical details to fatigue.



a) Location of details

b) Diaphragm and diagonals



c) Detail A – Design

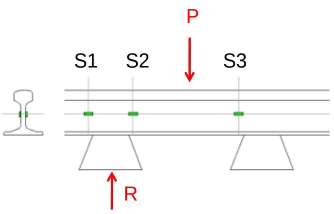
d) Detail A - Construction

e) Detail B – Design

f) Detail B - Construction

FIGURE 14 DECK DIAPHRAGMS CRITICAL DETAILS

A permanent monitoring system was developed in order to characterize the railway traffic and its effects on the critical details of the structure. The traffic is characterized both quantitatively and qualitatively. The quantitative evaluation is performed using 3 rail sections instrumented with 3 full Wheatstone bridges (Figure 15). Each full Wheatstone bridge results from welding 4 shear strain gauges at the neutral axis of the rail. Both sensors and cables were protected against potentially harmful maintenance operations, to be performed later, on the track.



a) Relative location of the 3 different sections

b) Welding of strain gauges

c) Protection

FIGURE 15 STRAIN GAUGES IN THE RAILS

The qualitative information is provided by an IP Camera placed at one hanger of the bridge (Figure 16).

a) Alfa Pendular passengers train

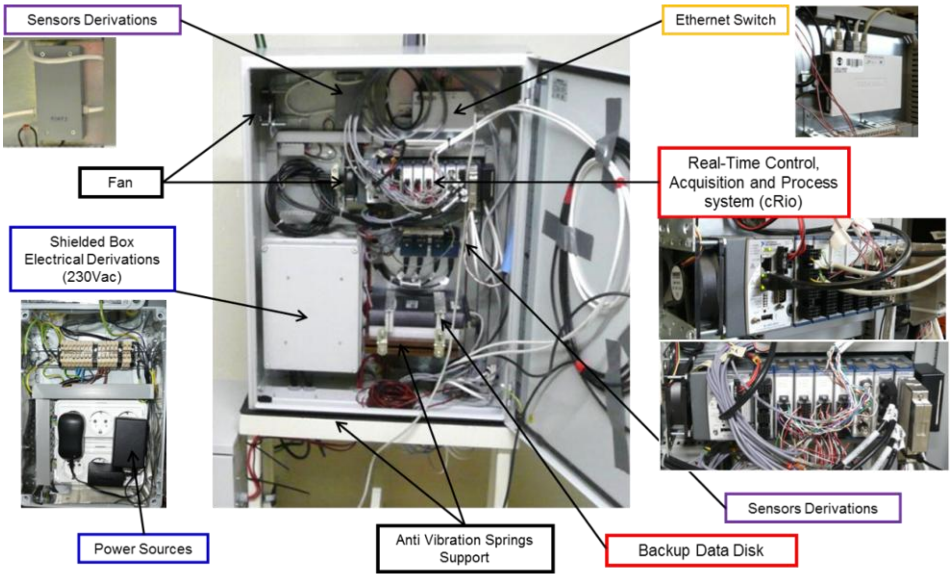
b) Intercity passengers train

c) Freight train

FIGURE 16 TYPES OF TRAINS CROSSING THE BRIDGE

A total of 32 strain gauges, were installed on critical details of the structure.

The acquisition and control system adopted is the National Instruments cRIO-9024. The strain gauges installed in the structure are connected to a National Instruments module NI 9236, while the strain gauges installed in the rail are connected to the NI 9237 module. The acquired data is sent, via a 3G connection, to a remote computer. A router manages the communication between the cRIO and the 3G connection. Finally, an Ethernet Switch allows saving a backup of the data in a hard drive installed at the bridge (Figure 17).



Main box - Structure

FIGURE 17 cRIO-9024

The permanent traffic monitoring and subsequent database construction, allowed characterizing the traffic over the bridge. Concerning the train speed histogram, 3 main groups of trains can be identified (Figure 18): 1) Alfa Pendular passenger trains, operating at speeds from 200km/h to 212km/h; 2) Intercity passenger trains, circulating at speeds between 145km/h and 160km/h; 3) Freight trains, at speeds between 75km/h and 95km/h.

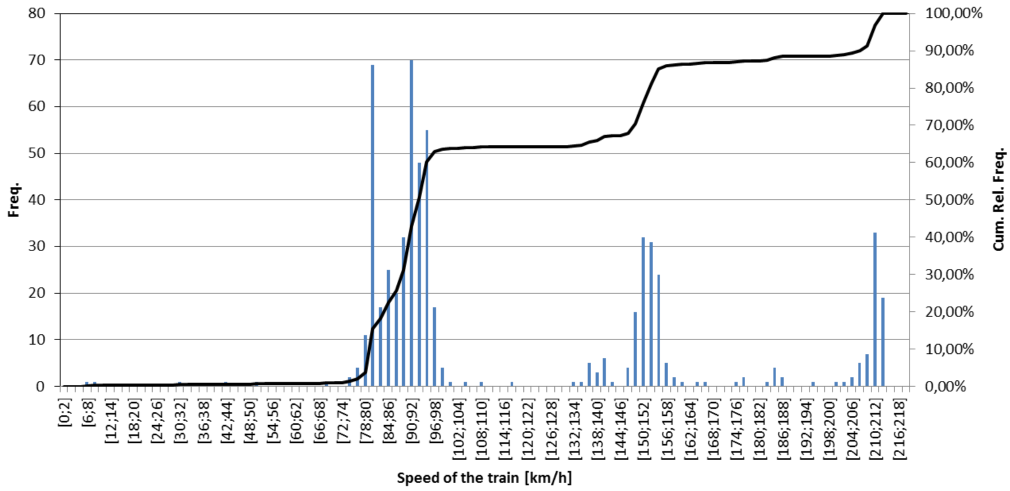


FIGURE 18 HISTOGRAM OF TRAIN SPEEDS

Most axle loads are in the range 180kN to 230kN. Less than 1% of the axles exceed a load of 250kN (Figure 19).

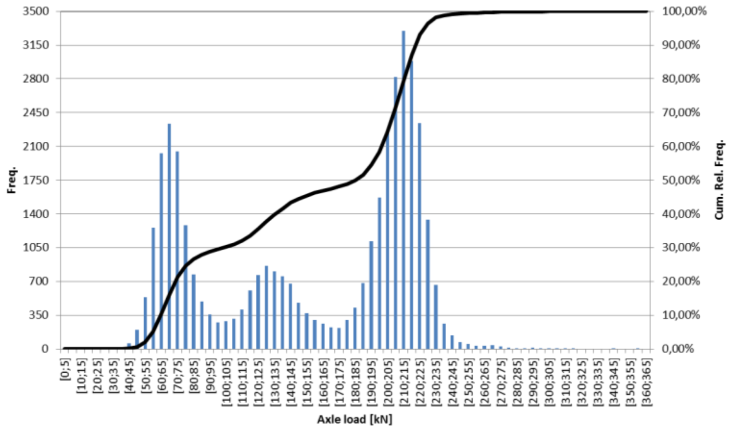


FIGURE 19 HISTOGRAM OF AXLE LOAD

The fatigue damage for details and for all the traffic events is computed using the stress histories. It is observed that most of the fatigue damage at the connection of the diagonals originates from heavy freight trains (>35kN/m) operating at speeds between 70km/h and 100km/h (Figure 20 and Figure 21).

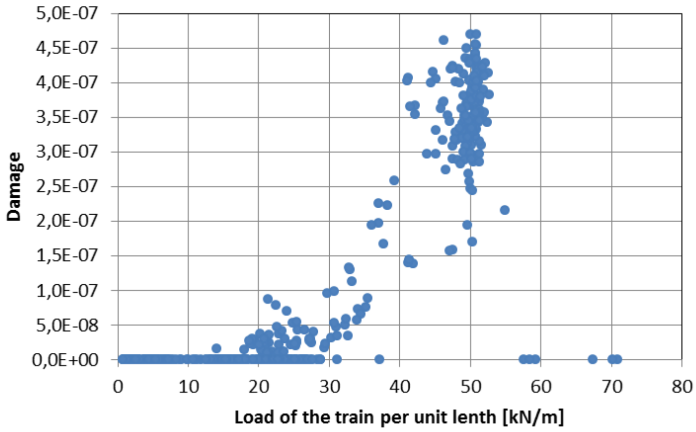


FIGURE 20 DAMAGE VS. TRAIN LOAD

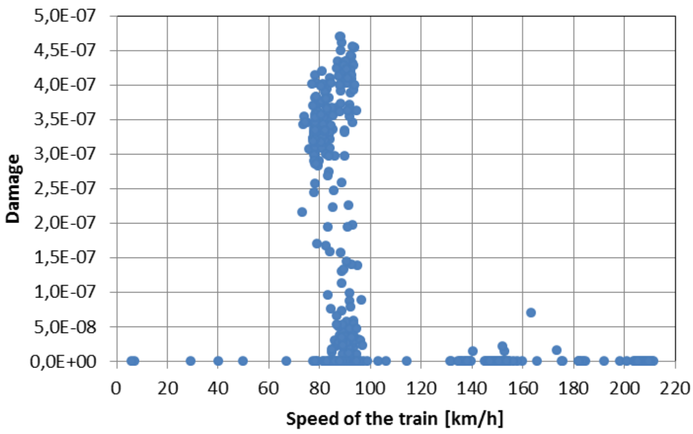


FIGURE 21 DAMAGE VS. TRAIN SPEED

Fracture mechanics analyses were adopted to predict fatigue crack propagation. The local time-history data needed for the fatigue damage assessment is generated using the new concept of modal stress intensity factors and the modal superposition method. This method was employed in connection to a long term monitoring system, allowing real time assessment of fatigue crack propagation.

The crack propagation occurred, as expected, in a direction perpendicular to the largest principal stress. The crack propagation stopped when the maximum computed stress intensity factor reached the adopted material toughness. The entire crack propagation path (crack length of 175mm) is illustrated in Figure 22.

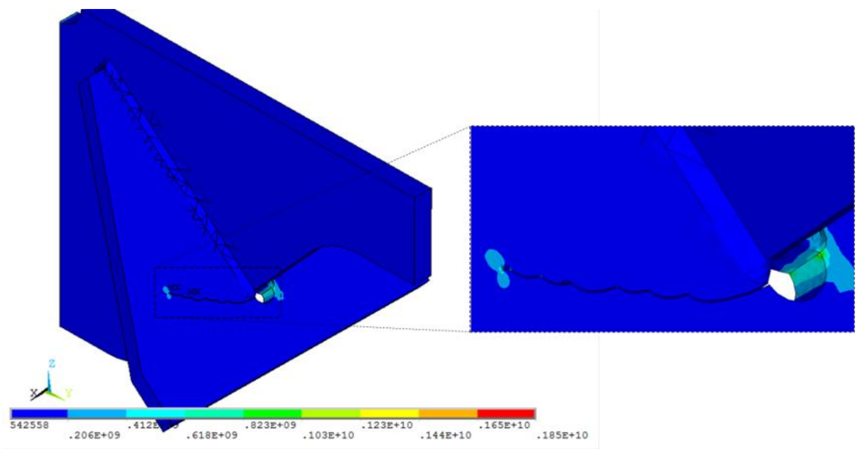


FIGURE 22 FATIGUE CRACK PROPAGATION PATH

The evolution of the total crack length as a function of the accumulated traffic volume is shown in Figure 23. If the current traffic volumes on the bridge were kept stable the remaining life of the bridge (i.e. the hypothetical crack propagation until fracture) would be approximately 95 years.

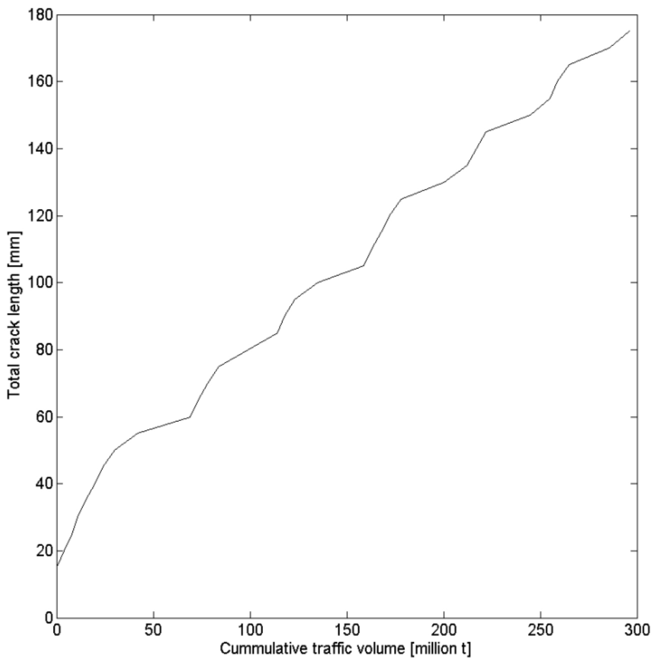


FIGURE 23 CRACK PROPAGATION LENGTH AS A FUNCTION OF CUMULATIVE TRAFFIC

In the EUROCODE, an annual traffic volume of 25×10^6 t / year is considered as a reference. Therefore, a scenario of 25 MM t per year was also included in the analysis. In that case, the simulated crack would need approximately 12 years to propagate to final fracture (Figure 24).

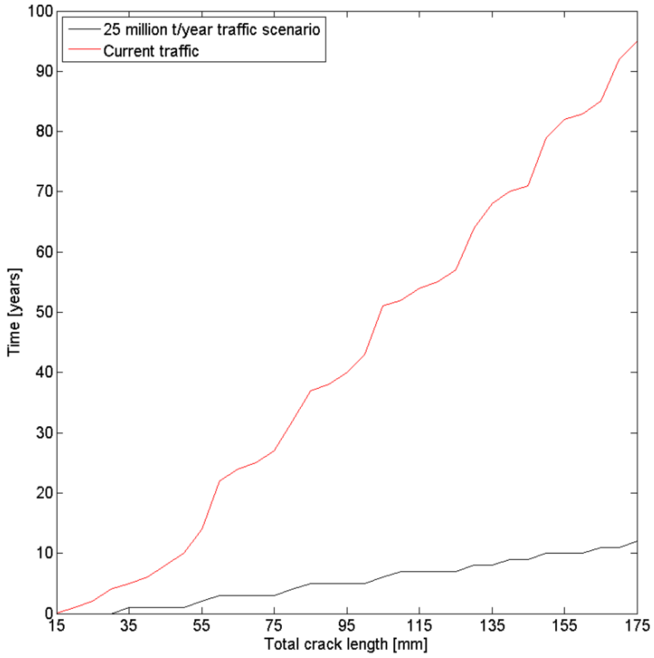


FIGURE 24 CRACK PROPAGATION LENGTH VS TIME

3.5 MONITORING OF TRACK AT TRANSITION ZONES

The railway track at transition zones – from earthworks to bridges or to other structures – frequently is subjected to higher degradation rates. This increases maintenance costs and disturbs railway operations since maintenance actions are required to guarantee safety and passenger comfort at these critical locations. The poor performance of transition zones has been mainly attributed to variations in vertical stiffness of the track and to differential settlements. Both amplify the dynamic loads of the trains and cause further track degradation.

To address these issues, a joint research project started in Portugal in late 2010, between University of Porto – Faculty of Engineering (FEUP) and the Portuguese National Laboratory for Civil Engineering (LNEC), supported by the former Portuguese railway network manager, REFER. The project focused on different aspects of the transitions zones of a recent mixed traffic railway line in Portugal – The Alcácer bypass - that allows maximum speeds of 220 km/h for passenger trains.

In the scope of this project, and among other tasks, periodical field works were carried out to monitor the dynamic behaviour of the track when trains crossed the transition zones. This task involved intensive instrumentation of the track to assess: i) axle loads using strain gauges on the rail web (Figure 25 a); ii) rail displacements using a set of LASER units and PSD transducers on the rail web (Figure 25 b); iii) rail pad vertical deformation using LVDT (Figure 25 c); iv) vertical accelerations on the sleepers using piezoelectric and MEMS accelerometers (Figure 25 d and e); and f) rail seat loads on the rail pads, using fiber optic sensors (Figure 25 f).

The acquisition system comprised a laptop computer, a National Instruments (NI) acquisition unit and various support units for each measurement system (Figure 26). To control, display and collect data from all transducers, an application was developed in LabVIEW environment.

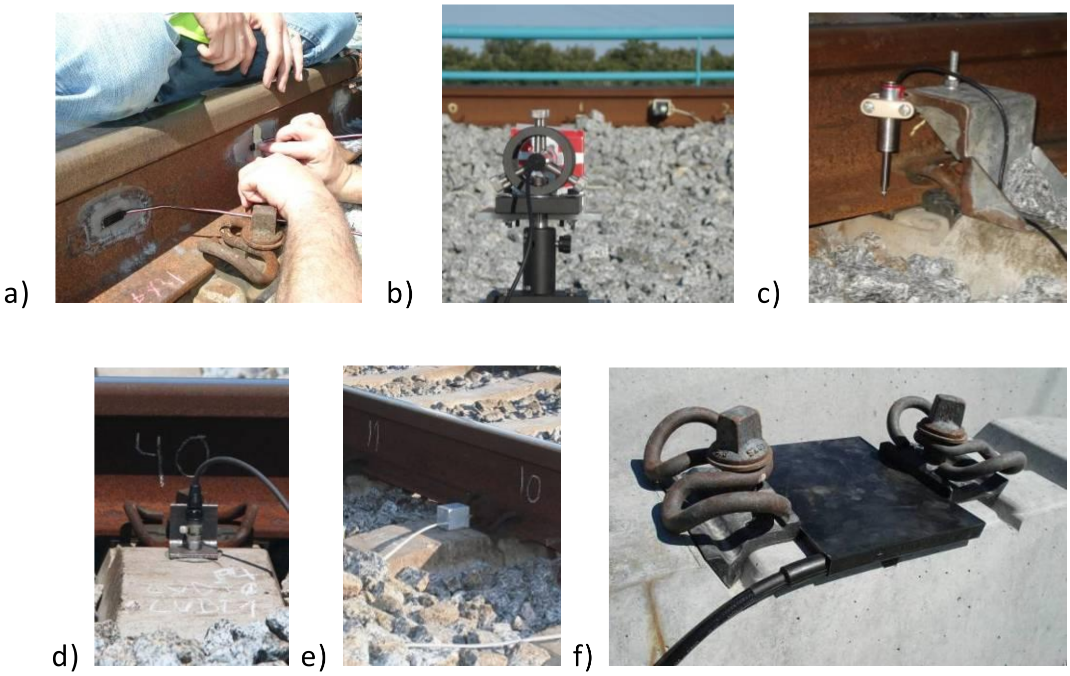


FIGURE 25 TRACK INSTRUMENTATION WITH DIFFERENT MEASUREMENT SYSTEMS

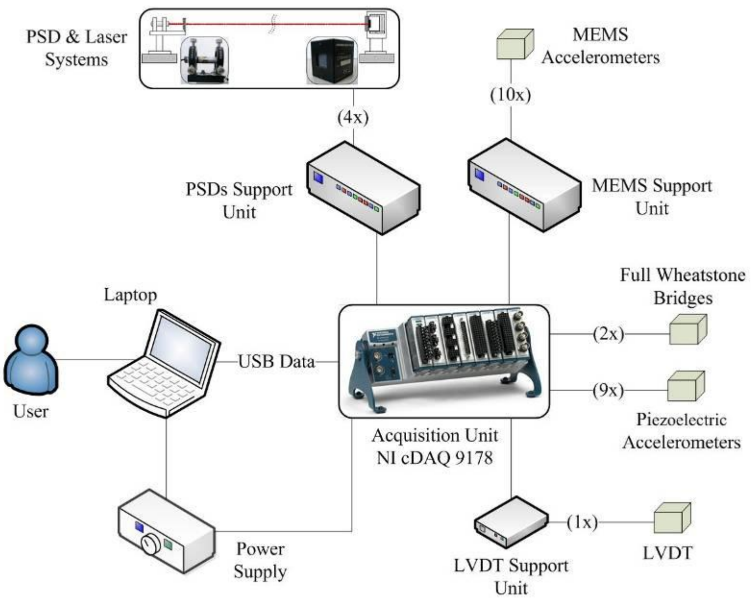


FIGURE 26 SCHEMATIC REPRESENTATION OF THE DATA ACQUISITION SYSTEM

The following figures show examples of dynamic axle loads, rail vertical displacements and sleeper vertical accelerations (after using a type II Chebyshev filter with cut-off frequency of 80 Hz) when passenger trains (with axle load of about 132 kN) crossed the southern transition zone to the bridge over Sado river, at about 220 km/h.

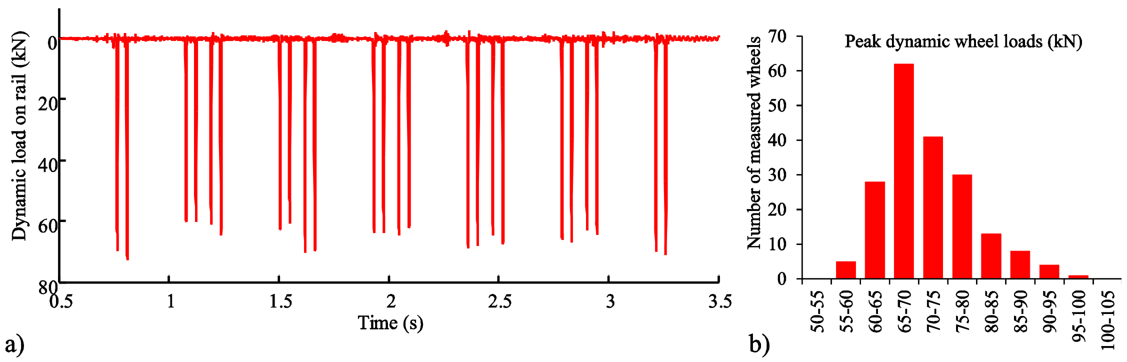


FIGURE 27 DYNAMIC WHEEL LOADS: A) EXAMPLE OF A TIME HISTORY; B) DISTRIBUTION OF PEAK LOADS

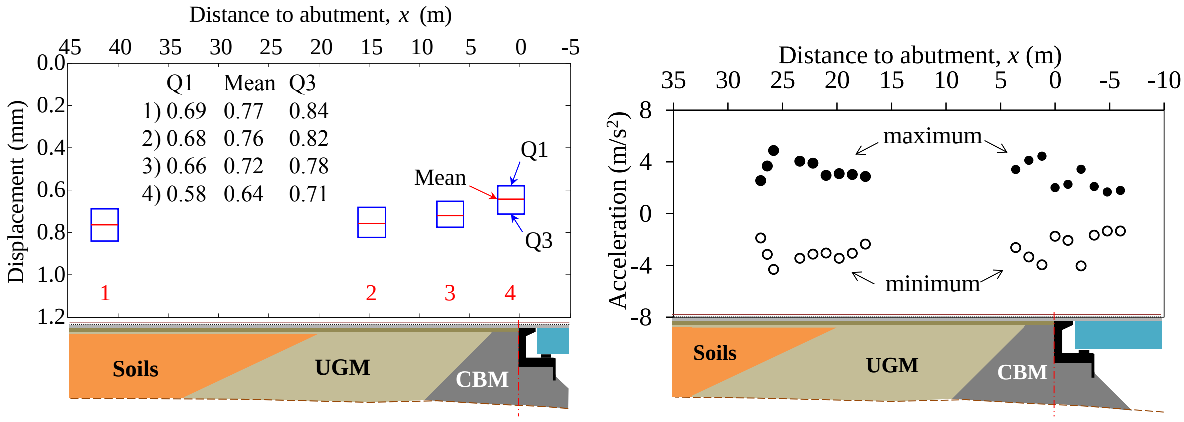


FIGURE 28 PEAK VERTICAL DISPLACEMENTS OF THE RAIL ON THE LEFT: MEAN VALUES, 25TH AND 75TH PERCENTILES (Q1 AND Q3, RESPECTIVELY); MEDIAN VALUES OF THE PEAK VERTICAL ACCELERATIONS OF THE SLEEPERS (F<80HZ) ON THE RIGHT

The analysis of the recordings indicates different levels of vertical elastic deformation of the track, denoting a gradual stiffness increase when approaching the bridge. This result was expected for this type of structure and is due to the variations of the track support conditions along the transition zone.

In the scope of this project it was also possible to compare the structural behaviour of a transition zone with USP against another transition zone with standard track at the approach towards similar box culverts. Identical monitoring setups were considered in both transition zones. Rail vertical displacements and sleeper vertical accelerations were measured at different sections and some results are presented in Figure 28 (with cut-off frequency of 80 Hz).

Results showed that USP strongly influenced the dynamic behaviour of the track, increasing its vertical flexibility and amplifying both rail displacements and sleeper accelerations. This suggests the need for a careful selection of the USP stiffness.

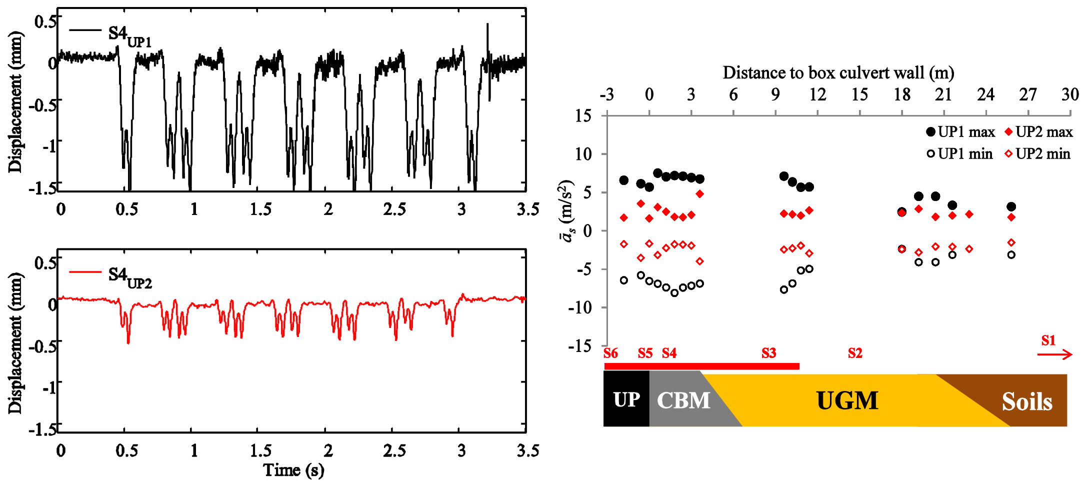


FIGURE 29 TIME HISTORIES OF RAIL DISPLACEMENTS MEASURED IN SECTION S4 (LEFT) AND AVERAGE BOGIE PEAK ACCELERATION VALUES AT UP1 AND UP2 (RIGHT)

To assess the long-term behaviour of transition zones, in terms of differential settlements that develop at the backfill, complementary approaches were used: sub-horizontal inclinometer tubes installed inside the backfill; topographic surveys of the longitudinal profile of the track; and data obtained with track inspection vehicles. Figure 30 shows an example of the longitudinal settlement profile of the backfill layers obtained with inclinometers after construction, regarding the first 16 months after opening the line to traffic. The results suggest an uneven, but gradual, settlement profile on the backfill which contributes to smooth out the differential settlements between the bridge and the embankment.

The experimental works presented here comprise relevant case studies for studying the track behaviour and were used in the calibration and validation of advanced structural numerical models of transition zones.

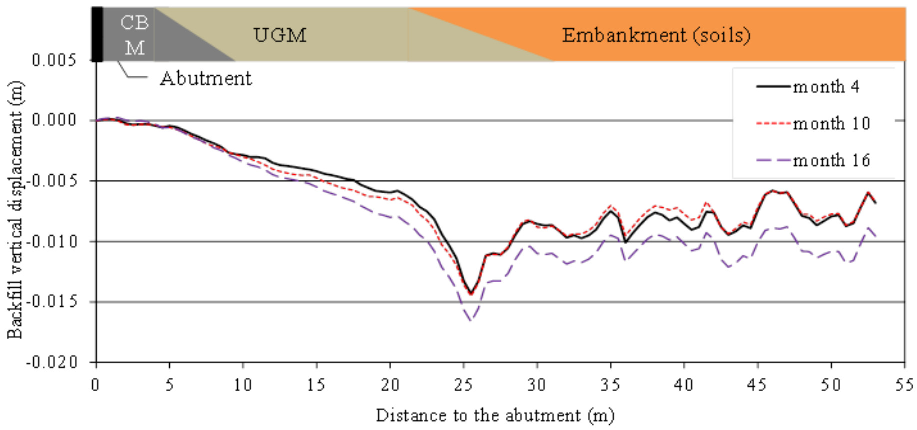


FIGURE 30 LONGITUDINAL SETTLEMENT PROFILE OF THE BACKFILL LAYERS AFTER CONSTRUCTION, OBTAINED WITH SUB HORIZONTAL INCLINOMETERS INSTALLED INSIDE THE EMBANKMENT

4. Monitoring gaps to be filled

Due to technical innovations in sensoring, nearly all monitoring needs can be fulfilled, considering some exceptions like contact patch size and pressure distribution, small surface cracks, anisotropy of the rail surface material etc. Apart from providing relevant and reliable data the main questions for the introduction in the railway are as follow:

- Costs for devices. The huge number of track side devices (due to the length of tracks) shows the urgent need of low-cost-devices. Each monitoring spot has to be economically justified.
- Energy supply: nowadays high-tech batteries have a lifetime up to 15 years. After that period, a change is necessary and that increases the maintenance costs. If, and that is the goal of SP4, a huge number of monitoring devices will placed within the network to give a seamless overview of traffic and asset conditions these costs are quite high.

New monitoring systems may be able to deliver important information that is needed for the optimisation of maintenance and prevention of breakdowns. But the implementation of monitoring systems on the whole network needs also an analysis of the financial return of investments. Given that, Capacity4Rail is not only looking for the technical performance and advantages, but also for the economic performance of monitoring systems.

Important in this regard are two additional work packages of SP4, i. e. WP 4.3 “Implementation in new structures” and WP 4.4 “Migration of innovative technologies to existing structures”.

4.1 Low cost monitoring

Traditionally the cost of monitoring systems used in railways is in most cases quite high. This is consequence of several factors such as:

- Small market. Reduced number of suppliers; Proprietary solutions;
- Non-existence of standards with a wide range of applications;
- The need of monitoring systems to comply with the severe constraints due to the railway environment (with quite strong differences over Europe);
- The heavy need of human intervention for installing and maintaining;

In the last years, especially since the end of last century, there has been a huge development in electronics, telecommunications, energy sources that has resulted in a new generation of sensor. These are, more precise, reliable, with pre-processing capabilities, integrating wireless communications, a strongly reduced of energy consumption and with the great advantage that the prices are quite more affordable than before.

The cost of a monitoring system is mainly dependent of:

- Acquisition and installation costs. In this we can highlight the technology price and the number of sensors/system needed;
- Maintenance costs and life expectancy of the system.

Having in consideration these factors among others, it is possible to identify that in a cost-benefit analysis the cost related with the sensors is the major key. The benefits of monitoring systems although they are recognized by all stakeholders, often come up against the budgetary constraints of railway managers who have to decide between the various investments that are proposed.

If we can create more economic monitoring systems the possibility of implementing them rises, because we can achieve more benefits for the same amount or at least we get the same benefits at a lower cost.

For this reason the Capacity4Rail project intents to study and develop monitoring systems using a new generation of sensors that fulfill the future technical and cost requirements. The sensors must also have a fairly long life expectancy and be simple and cheap to maintain or replace.

The overall goal of this new generation of monitoring systems is that with a small fraction of the current budget it will be possible to monitor and get more reliable and precise information about the infrastructure, the rolling stock and their interaction.

4.2 Energy independent devices

In the railway environment having access to an electrical power supply is not guaranteed. This is due to the long extensions of track far from human habitats.

The use of electrical feeders along the track is not a rule for most of the infrastructure managers, due to the costs of installing such a system. For this reason Capacity4Rail will develop a new set of methodologies.

- Use of new generation of batteries;
- Energy harvesting at a very low power;
- Wayside “traditional” energy harvesting and power transmission.

A new generation of batteries is under development, taking the advantages of a new era of mobile devices that demands more power with smaller sizes. This is exactly what is needed in the railways; also batteries that are functioning in harsh environments, like quite extreme temperatures (under -20ºC in the Scandinavian countries to above 40ºC in the south of Europe).

Taking the advantage of the use of very low power sensors and electronics mentioned in the previous chapter, a quite small pack of batteries can supply power for highly efficiency sensors for a period that can approach the mark of 10 to 15 years. Wireless charging is another technology with enormous advantage in railways as we can build quite hermetic systems that are better adapted to be placed and survive in all kind of weather conditions.

For monitoring systems with very low consumption the development of embedded energy harvesting can be a perfect solution since it permits the creation of autonomous and independent systems that can function with the logic of deploy and forget. The technologies behind this kind of energy harvesting are piezo, peltier, induction, wind and solar. The actual problem with these is that the energy produced is quite low (order of micro-watts)

The third option that will be studied is the use of more powerful and well developed power sources like solar panels and vertical wind turbines to collect and store energy outside the track and then using the technology of power transmission to supply the monitoring systems placed in the track. This solution has quite important advantages like the production of a high power (several watts). The wireless power transmission systems can achieve more than 50% efficiency in the energy transmission (for distances in the order of 1 to 2 meters between the transmitter and receiver it is possible to obtain in the receiver more than 50% of the energy emitted by the transmitter). With one emitter it is possible to feed more than one system without the need of cables.

One of the concerns with this technology is the study that must be made to ensure that the radiation produced does not affect the wayside and onboard systems, especially safety related systems. These kind of studies are also in the requirements of the project.

4.3 Wireless data transmission

The current trend in monitoring systems leans towards wireless systems. Although initially wireless systems used to be mainly applied in the domestic applications, currently, its use in industrial environments has increased considerably

Standardization and openness of protocols result in more and more products and also that major manufacturers want to claim to be the universal standard for such applications.

Today we already have many wireless systems based on the concept of sensor network, using low cost and low power consumption wireless communication protocols.

A sensor network is a network of distributed devices using sensors to monitor at different locations. These devices must be small and cheap so that they can be produced and used on a large scale. These features make their energy consumption, memory, communication speed and capacity limited.

Each device is equipped with a sensor, a transmitter, a small microcontroller and a power source (typically a battery). The devices communicate wirelessly with each other using an ad-hoc architecture (no predetermined infrastructure).

The flow of information terminates in special nodes (collectors or "sink" nodes) that have superior capabilities to the sensor nodes and allow to send information to other networks for further processing. (GPRS, Ethernet, etc ...). Apart from its ability to communicate wirelessly, the WSNs also are able to self-organize and self-configure in order to avoid network failures

Generally the sensor networks use a network topology that resembles a mesh, a sensor can discover their neighbours and routing software opens multiple connections so that they always can find a way to the final destination.

The most widely used standards for implementing wireless sensor networks are mainly based on the IEEE 802.15.4 (for physical layers and media access) although other technologies are used as, Bluetooth, RFID or WiFi. Also new IP-based standards are appearing, like 6LoWPAN.

In regard to the sensor systems, they uses transducers that convert the magnitude to be measured (temperature, pressure, etc.) in a useful signal that can be analysed and processed. Sensors based on MEMS technology are being highly developed nowadays and are typically used in wireless sensor networks because of their very low power consumption. In fact, the main features of MEMS sensors are microscopic scale (about 1 mm), and ultra-low power consumption

As already mentioned, each sensor node consists of four basic components, the sensor unit, the transceiver, the power supply unit and the processing unit:

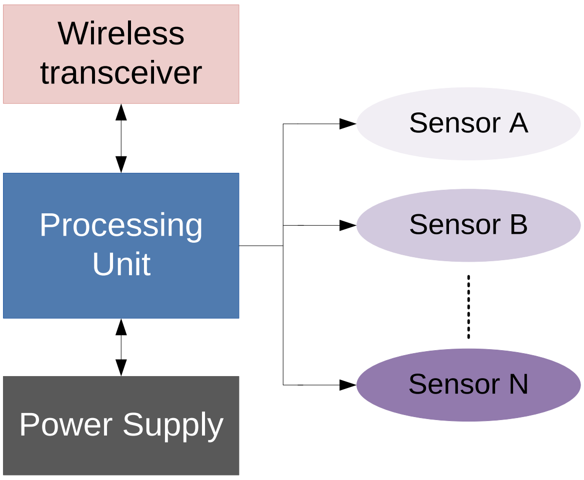


FIGURE 31 WIRELESS NODE-ARCHITECTURE

Processing Unit handles the procedures for the node to collaborate with others, it is responsible for processing the sensor data and all other tasks carried out in the wireless node. There are devices that combine wireless stage (communications) with a processor (more or less commonly used) in a single integrated circuit.

The keys to the success of such networks are the low power consumption (and therefore long battery life), a cheaper unit cost of each node and its ease of installation and maintenance.

Talking about power consumption, each of the components forming the system should be optimized. They are currently supported by batteries but the trends point to energy harvesting or energy scavenging. The same MEMS technology is being used in this field. Especially in the rail sector, the traditional solution for maintenance and monitoring of track status requires a very expensive infrastructure, with highly complex installation and maintenance processes. With wireless sensor networks it could be possible to obtain unattended devices able to work for years with minimum (or none) maintenance.

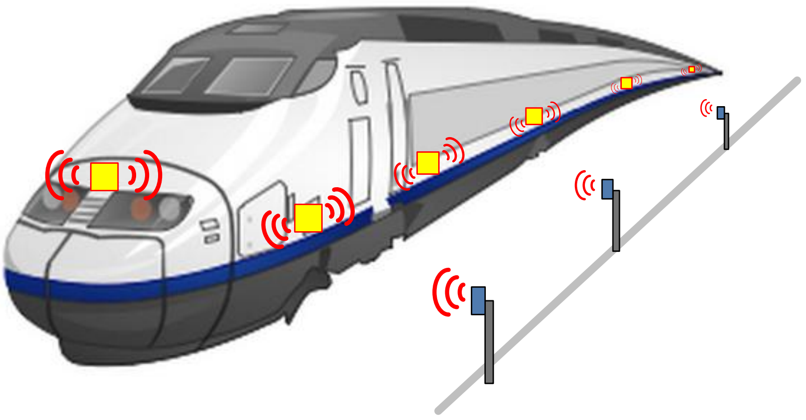


FIGURE 32 EXAMPLE OF WIRELESS MONITORING SYSTEMS

In this sense, remote wireless systems mean that you no longer have to send people out into the field to take measurements or into dangerous trackside locations to maintain static systems.

Sensor networks are one of the technologies or concepts that are associated with other terms and concepts such as environmental intelligence and especially the Internet of things (IoT).

In fact they constitute one of its pillars. With the keys of the low consumption, reduced size and price and consolidation of wireless personal communications area will be one of the concepts that will expand. The join of different sensors with communication architectures generates innovative applications and complex services, especially when its integration with Internet (Internet of things, IoT) cause the monitoring and tracking of any kind of item is possible regardless of location; besides allowing at the same time to interact with all kinds of applications such as payment systems, access control, information panels or even rail infrastructure.

Another advantage of the use of wireless sensor networks for these applications is the ability to install sensors or control elements in places where it previously was not worth to use them, or where they could not be installed due to required electrical interconnections.

5. Conclusions

The report gives an overview of possibilities to avoid failures and defects in the infrastructure by using available technologies able to monitor the “health” of components and systems. The high safety standard in railways today is based on an inspection strategy – in some countries in fixed time intervals, in other countries (semi)-condition-based. The common understanding of the infrastructure managers (IM) is that the economics of maintenance must be improved to be competitive to road/water/air.

The identification of the top components which are most expensive in maintenance or traffic interruptions/delays is a suitable starting point for the development of monitoring systems. The report gives an overview, which technologies are today available and can be introduced within a short time into the network. It also highlights difficulties of a migration strategy, since all solutions need their own infrastructure for energy supply and data transmission. Based on the latest innovation programs funded by the EC, the first products have come to the market that are smaller, cheaper, less energy consuming and WiFi/GSM compatible.

Another, often underestimated, problem is the diagnosis platform and the assessment of measured monitor data. Because this topic is very often strong coupled with company IT policies, it was not in the focus of the report.

Reflecting on the needs of IM, the targets for the developments in the C4R-Project are described. The additional requirements are: Low cost, simple use, maintenance free. The data should be able to be processed into diagnostic information so that failure prevention and a reliable maintenance forecast can be done. In this context it should be noted that the whole monitoring strategy must be a part of the business case “infrastructure management”.

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