Innovative Intelligent Management of Railway Bridges, In2Rail - A European Horizon 2020 Project

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Abstract

Innovative Intelligent Railways, In2Rail, is a European Horizon 2020 Project with the objective to enhance capacity, increase reliability and reduce Life Cycle Costs of European Railways. Bridges and Tunnels is the main focus in Work Package 4. The aim is to study, benchmark and further develop new Inspection Technologies in order to create more proactive maintenance procedures. In this paper some preliminary results are presented.

**Keywords:** Railway bridges and tunnels, Measurement technology, Management systems, Monitoring, Maintenance.
1 Introduction

Growth in demand for rail transportation across Europe is predicted to continue. Much of this growth will have to be accommodated on existing lines that contain old infrastructure. This demand will increase both the rate of deterioration of these elderly assets and the need for shorter line closures for maintenance or renewal interventions. The impact of these interventions must be minimized and will also need to take into account the need for lower economic and environmental impacts. New interventions will need to be developed along with additional tools to inform decision makers about the economic and environmental consequences of different intervention options being considered.

With this background the European Commission funds research projects dealing with railway bridges. In this paper some preliminary results will be given from a new project, Innovative Intelligent Railways, In2Rail, which is preparing for a European Joint Undertaking called Shift2Rail [1].

1.1 Preparing for Shift2Rail

Shift2Rail is a European initiative to deliver focused Research & Innovation (R&I) and market-driven solutions meeting key objectives of the EU 2020 Strategy and the EU Transport policy [2].

Shift2Rail is a joint effort of all the stakeholders of the European rail sector to invest together in research and innovation in order to reinforce the attractiveness of rail transport toward passengers and business; and therefore achieve the ambitious objectives set by the European Commission in the 2011 White Paper on Transport [3] including the completion of a Single European Railway Area (SERA) [4]-[6].

For this purpose Shift 2Rail will focus on three major challenges:

- Reliability / Punctuality of Rail services
- Capacity - to cope with increased passenger and freight demand
- Life Cycle Cost Reduction

Figure 2. Bridges are an important part of the vision of European Rail 2050 [6].

The budget of Shift2Rail is jointly funded by the private sector and the European Union and is estimated to be at least €920 million (for the period 2014-2020) – €470 million by the private sector and €450 million from the European Union.

A long-term strategic Master Plan has been built around key research clusters segmented in five Innovation Programs (IPs) for: trains (IP1), traffic management (IP2), infrastructure (IP3), IT (IP4), and freight (IP5).

For each IP, so-called Technology Demonstrators (TD) – each addressing specific topics – have been defined. They will integrate innovative technologies and develop prototypes to generate future competitive sub-systems, and will be assessed with Key Performance Indicators (KPI).

For the preparation of these demonstrators research and benchmarking is necessary, therefore so called Lighthouse projects have started to identify and prepare prototypes to be further developed in Shift2Rail. One of these lighthouse projects is In2Rail.
2. In2Rail

Innovative Intelligent Railways, In2Rail, [7] is a European Horizon 2020 Project with the objective to enhance capacity, increase reliability and reduce Life Cycle Costs of European Railways. It is as mentioned a start-up program to Shift2Rail. The In2Rail project runs from 2015-2018. Bridges and Tunnels is the main focus in work package 4 (WP4). The work package leader is Anders Carolin, Trafikverket. The idea is to study, benchmark and further develop new Inspection Technologies in order to create more proactive maintenance procedures.

The aim is to replace traditional (visual) inspections with methods that are less traffic disturbing giving more accurate data with enhanced quality, more objective, possible to quantify, possible to use for tracking changes over time, possible to be (partly) automated, and at reduced cost. The approach is proactive which gives lower cost and fewer disturbances. The task also includes adoption of methods and technology from other industries.

In an initial survey, the following focus areas were identified for railway infrastructure assets. They are based on the experience of rail bridge managers and earlier results from projects as e.g. Sustainable Bridges and MAINLINE [8]-[10].

3. Focus areas for bridges and tunnels

3.1 Bridges - Superstructures

Concrete bridges normally require very little preventive maintenance. Damages from vehicles passing under the bridge are common, however not very critical. Settlements of supports are an increasing problem with increased loads also for the superstructure. Secondary parts such as handrails and ballast supports tend to call for most of the attention. Over-amounts of ballast from track adjustments are an increasing problem related to additional dead load. Alkali silica reaction related problems have started to show up, however still relatively rare. Reinforcement corrosion, freeze-and-thaw scaling, and theoretical lack of fatigue capacity exists. Corrosion of reinforcement will, after a period of time, cause concrete cover to spall off, cause splitting of concrete and discolor the concrete. Prestressed concrete are performing well, however, uncertainties on tendon status and prestressing force are raising questions.

Metallic bridges require repainting, which normally shall be done before steel area reduction starts, to avoid capacity loss. Older metallic bridge (prior 1960) tends to have brittle steel with low fracture toughness. Fatigue problems exist in theory and also in reality. Damages related to fatigue normally give cracks close to details such as stiffeners or connections. Fatigue problems can also start from other damages, corrosion or material defects.

Steel-concrete composite are typically part of the newer bridge stock. Uncertainties on composite action and durability of early solutions are arising. Otherwise these bridges perform and have similar problem to pure concrete or metallic bridges.

Masonry structures are actually a combination of brick and soil interaction. Problems relate to transversal or longitudinal cracks, losses of consolidation, block disorganization, opening of voids and infiltrations due to the bad state of the waterproofness layer. With water present, problem with scaling from freeze and thaw action arise.

Metallic soil interaction arches typically have problems with corrosion at water or road surface level.

3.2 Bridges - Substructures

Substructures show a wide range of problems depending on structural type, environment and loading history. Settlements, rotations and displacements are common problems especially in combination with extensive increase of loads. An example is given in Figure 3. It is expected that problems with scour and erosion may increase with more extreme nature of weather.

Older stone masonry substructures may have problems with splitting or separation of stones.
Concrete or metallic substructures also have similar problems.

Figure 3. Torsional cracks in a superstructure from uneven substructure settlement [11]

3.3 Tunnels

The majority of tunnels may be divided into un-lined or lined tunnels. Un-lined tunnels do however typically use some kind of strengthening or drainage system on the rock surface.

Degradation of supportive linings is very dependent on material. Concrete linings may suffer from reinforcement corrosion, freeze and thaw scaling and water leakage. Other linings will have corresponding problems. Protective linings can in addition be damaged by rock fall-outs.

Unlined tunnels can also have rock fall-outs damaging shotcrete strengthening or drainage systems. Block fall-out are also a problem for the function of the tunnel and integrity of rails, i.e. passage for the train. Water infiltration can reduce stability of track bed, cause large icicles and damage electrical installations. Water infiltration also causes separation between shotcrete and rock. Corrosion of bolts for strengthening is another problem. It is important to differ between bolt end corrosion, which can easily be detected, and corrosion of the inserted part of the bolts.

4. Identification of key performance indicators

4.1 General

Having identified all individual infrastructure asset problems the project team tried to identify the most relevant indicators for performance, [11].

Performance of bridges can be divided into bearing capacity, stiffness, aesthetics, clearance, durability and structural safety including robustness. For tunnels the performance can be described by clearance, structural safety, and structural integrity.

Performance indicators, (PI), are here defined as indicators potential of describing either that performance is in perfect condition, or that performance affected. As performance normally reduces over time, it is interesting from a management perspective to describe and predict the rate of deterioration.

In Figure 4 a schematic deterioration profile is given.

Figure 4. Schematic deterioration of performance over time [11]

When deterioration starts it usually doesn’t affect performance directly. Therefore it is considered to be important to define those parameters for each asset type that influence the deterioration process. The aim is to identify different significant parameters to study without prescribing how to monitor and without considering if this data is viable to obtain. The main aim is to describe parameters that can be studied for proactive management: To identify exactly those
parameters relevant for deterioration and a safe railway transport. Not affected by today’s practice, existing doubts, preferences or assumptions on the possibility to record them.

Hereby it might be appropriate to detect deterioration or damages at different levels of severity. In some cases early indicators might be important to monitor (e.g. chloride content to better estimate the rebar corrosion). In other cases depending on the structural behavior of the asset type later stages or only major deterioration can be interesting for precise detection. This is why the project looked closer at each asset type.

Moreover some performance indicators are more important than others and they will be called Key Performance indicators, KPIs. To understand and study PIs it is important to understand the overall structural behaviour of the complete structure and to differentiate between cause and indication.

4.1 Causes and consequences

In addition to deterioration profiles, proactive maintenance is possible if one understands and studies chains of cause and consequences.

Looking closer at a tunnel these causes and consequences should be explained here. One can define causes and they are mainly divided into, see Figure 5:

- “outside actions” are all parameters which come from the in situ rock and groundwater condition;
- “inside actions” are conditions which could be present during the operation of the tunnel;
- “within actions” are the result from processes within the construction.

Based on these causes the project developed so called causes and consequences chains for each asset type which end up with performance indicators (PI). Figure 6 shows the influence of different causes on tunnel parameters.

Figure 5. Causes on tunnel structures. From outside: rock and water pressure. From inside: impact, explosion, climate, fire and flooding. From within: chemical influence and corrosion. [11].

Figure 6: Causes and consequences for tunnel structures from outside, inside and within [11].
From these chains one can identify the consequence of a cause for different areas of performance of the structure

The consequences can be divided into those that affect the “structure”: the structural integrity, sealing and lining. Provoking “equipment” which means that signals, water supply, emergency supply, catenary are affected. And those that change the “clearance” which is the minimum profile needed for safe train service.

In addition such chains can have several links where one consequence from a cause will be the next cause for another consequence. At the end one can isolate the relevant performance indicators.

Deliverable D4.1 [11] quantifies inspection parameters for these performances indicators required by Infrastructure Managers for inspection of Railway Bridges and Tunnels. They are represented as the numerical value for each asset type: threshold and precision can vary and should be allowed to be discussed separately. An example of preliminary performance indicators for concrete bridges are given in Table 1

Table 1. Preliminary Performance Indicators (PI) for concrete bridges [11].

<table>
<thead>
<tr>
<th>Parametric type</th>
<th>Measurable object</th>
<th>Threshold</th>
<th>Precision</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early indicator</td>
<td>Water presence in wrong place</td>
<td>Damp areas</td>
<td></td>
<td>Especially if freeze-thaw cycles</td>
</tr>
<tr>
<td>Early indicator</td>
<td>Carbonation</td>
<td>10 mm depth</td>
<td>5 mm</td>
<td></td>
</tr>
<tr>
<td>Early indicator</td>
<td>Fatigue loading</td>
<td>More than design</td>
<td>No. of cycles</td>
<td>Per component</td>
</tr>
<tr>
<td>Early indicator</td>
<td>Chlorides</td>
<td>Elevated presence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early indicator</td>
<td>Stiffness change</td>
<td>Onset</td>
<td></td>
<td>Will be visual if continues</td>
</tr>
<tr>
<td>Early indicator</td>
<td>Reinforcement corrosion</td>
<td>Onset</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early indicator</td>
<td>Poor track foundation</td>
<td>Stiffness change</td>
<td></td>
<td>Jump and bump will increase the Dynamic Amplification Factor (DAF)</td>
</tr>
<tr>
<td>Early indicator</td>
<td>Clearance under bridge</td>
<td>Any below normal</td>
<td>0.1 m</td>
<td>Will cause damage from trucks</td>
</tr>
<tr>
<td>Visual deviation</td>
<td>Shear cracks</td>
<td>Presence</td>
<td>20 mm of length</td>
<td>Especially for fatigue critical components</td>
</tr>
<tr>
<td>Visual deviation</td>
<td>Flexural cracks</td>
<td>0.4 mm</td>
<td>0.1 mm length</td>
<td></td>
</tr>
<tr>
<td>Visual deviation</td>
<td>Surface scaling</td>
<td>Any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual damage</td>
<td>Deformation</td>
<td>Delta/Span: 1/600</td>
<td>1/100</td>
<td></td>
</tr>
<tr>
<td>Visual damage</td>
<td>Irregular crack pattern</td>
<td>1 m²</td>
<td>0.1 m²</td>
<td>To detect Alkali Silica Reaction (ASR)</td>
</tr>
<tr>
<td>Visual damage</td>
<td>Water leakage</td>
<td>Leakage of portlandite</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These parameters are to be developed as Key Performance Indicators, KPI, to:
- Meet current and future safety and performance requirements
- Identify early environmental factors affecting deterioration
- Monitor visual damage

5. Identify, benchmark and develop existing technologies

The Key Performance Indicators, KPIs, will be used to identify, compare, evaluate and further develop the technologies for new inspection methods and possible remote monitoring systems. For the key parameters identified some promising assessment methods have been identified for further studies:
- **Image analysis** (Digital Image Correlation, DIC). Figure 7 shows an example of Digital Image correlation, where photos are taken at time intervals and analysed for changes in strains. The method can be used for assessment of a variety of performance indicators, see e.g. [12] - [14].

![Image](image1.png)

**Figure 7. Principle strain obtained by Digital Image correlation, DIC, in a trough bridge web for a load of 6 MN (top), 8 MN (middle) and 10.8 MN (bottom). From Sas et al [17], [18].**

- **Ground penetrating radar**, GPR. The technique is based on the emission and reception of electromagnetic waves and the behaviour of these waves in the inspected heterogeneous element. It is a multipurpose device for concrete, masonry, and rock inspection which may allow identification of geological irregularities, voids and cracks, rebar mapping, concrete cover and depth measuring at high speeds, see e.g. [15].

- **Motion magnification** or muon tomography is a technique that can amplify very small motions in videos, which can be used to qualitatively and quantitatively analyse the mechanical behaviour of a structure, see e.g. [16].

- **Terrestrial microwave interferometry** is a relatively young technique from the field of geodesy to measure relative displacements to an existing position from a distance of up to 1000 m, see e.g. [17].

- **Fatigue recording by measurements and models** Fatigue consumption is highly dependent on stress amplitude and detailing. Stress on individual parts depends mainly on global load configuration and structural action. By monitoring loads and corresponding stress amplitude in selected elements, fatigue consumption of all details can be found by tailored models, see e.g. [18], [19].

**Other interesting methods** may be:

- Conductivity
- Drones used for inspection
- Laser scan
- Accelerometers
- Induced dynamic excitation
- On board measurement of reactions
- MEMS (MicroElectroMechanical Systems)
- Wireless sensors and energy harvesting
- Intelligent Self-Monitoring System
- Thermography
- Half-cell potential corrosion mapping
- Potential measurements
- Fiber optic sensors
- Electrical resistivity
- Classic electrical resistance sensors

The project aims to finally present note cards in a report to enable a closer look at new and innovative techniques to assess infrastructure. Therefore different methods also from other industries are evaluated and examples for application studied. The scope is to find good, reliable and repeatable methods that can be used in short time at best without any traffic interruptions. Future monitoring systems are...
They also acknowledge the contributions from all the other partners in the project: Network Rail Infrastructure Ltd, United Kingdom, Deutsche Bahn AG, Germany, Acciona Infraestructuras S.A., Spain, FCC Construccions SA, Spain, Société National des Chemins des Fer, France, and ÖBB Infrastruktur SA, Austria.

The LTU group also want to thank their colleagues in the Swedish Universities of the Built Environment (Chalmers in Göteborg, KTH in Stockholm and LTH in Lund) for fruitful cooperation during many years.

8. References


[4] SERA – Single European Railway Area. The European Union (EU) has adopted a law addressing the lack of competition, poor regulatory oversight and low levels of investment that have long hampered the development of an efficient and coherent rail transport system across Europe, see http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV%3Atr0041


6. Conclusions

Based on defined requirements and value adding parameters, existing technology has been identified, and will now be further studied and benchmarked so that is suitable for inspection for different types of railway assets.

Developing new inspection and monitoring technologies is best done by an iterative process where requirements should be allowed to evolve during the process. By introducing strict requirements from the beginning, promising technologies risk being excluded. If possible, requirements should at this stage instead be flexible and tackled by a combination of method, frequency, accuracy and precision. This way an evaluation of experimental techniques most prone to give the best results is ensured.

In collaboration with other on board technology will be developed to perform structural health monitoring when passing structures in ordinary traffic.

7. Acknowledgements

The authors gratefully acknowledge financial support from the European Union, Trafikverket, and Luleå University of Technology (LTU).


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