Sustainable Maintenance and Analysis of Rail Transport Infrastructure

(SMART rail)

K. Gavin[1], A.J. O'Connor[2], E.J. O'Brien[3], M. Tucker[4]
[1]School of Architecture, Landscape and Civil Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
[2,3,4]Roughan & O'Donovan Innovative Solutions, Arena House, Arena Rd, Sandyford, Dublin 18, Ireland.
email: [1]kenneth.gavin@ucd.ie, [2]alan.oconnor@rod.ie, [3]eugene.obrien@rod.ie, [4]mark.tucker@rod.ie

ABSTRACT: Safe and efficient transport infrastructure is a fundamental requirement to facilitate and encourage the movement of goods throughout the European Union. Currently there are in the region of 215,000km of railway lines in the EU. Many of these were not built to conform to modern design standards and suffer from poor maintenance strategies. The SMART Rail project brings together experts in the field of rail transport infrastructure from across Europe to develop state of the art inspection, monitoring and assessment techniques. This will allow rail operators to manage ageing infrastructure in a cost effective and environmentally friendly manner. RODIS will develop models to greatly improve the ability of the track owners to predict the future condition of their infrastructure. A probability based framework will be developed for optimised whole life management of the infrastructural elements. This will encompass not just bridges but all aspects of rail infrastructure such as track susceptibility to settlement and the stability of slopes and embankments. Sensor information will be incorporated into the structural safety models allowing real time analysis to be performed. This will enable the rate of deterioration of the infrastructure elements to be determined and allow implementation of an optimised and cost effective intervention strategy before any significant damage occurs.

KEY WORDS: Sustainable transport, railways, Structural Health Monitoring (SHM).

1 INTRODUCTION

In its mid-term review of the White Paper on Transport [1] the European Commission proposed concentrating on co-modality, the optimal use of all modes of transport combined or otherwise. Whilst good progress was noted in the area of creating a true internal European market in the aviation and road transport sectors, rail transport had not performed as well. There has been some progress – the TransEuropean Transport Network (TEN-T) program, the deployment of the European Rail Traffic Management System (ERTMS), and technical specifications for the application of Telematics Applications to Freight (TAF), were identified as being positive steps towards achieving the policy of creating an efficient European freight network. *The key obstacle to the development of the rail network was identified as the quality and reliability of the infrastructure.*

Several European countries have highly advanced rail networks where the primary areas of concern in relation to infrastructure performance are related to achieving ever higher network speeds. In new member states such as Slovenia, accession states including Croatia and even in some Western European countries with relatively well developed economies, historic lack of investment in rail infrastructure had led to the situation that some elements of the network are in very poor condition. In these countries, parts of the rail infrastructure would be deemed to have reached the end of its useful life when analysed using conventional assessment methods. When incidents occur such as structural failures or derailments, it is common practice in certain regions to simply close the line. Because of the lack of viable alternative modes of transport, such drastic action cannot be adopted in most countries.

Efforts to improve transport safety within the EU have led to significant reductions in fatalities in the last 20 years. Road fatalities in the EU-27 decreased from approximately 76,000 per year in 1990 to around 39,000 in 2008. When compared with road transport, rail is a historically safe mode of transport. Although the number of journeys by road is significantly higher, in this time period there were over 82,000 million kilometres of train journeys undertaken in the EU as a result of which only 1,814 fatalities occurred. Evans [2] provided detailed consideration of the statistics related to rail accidents and noted that the majority of fatalities were caused by collisions, derailment and accidents at level crossings. Again, sustained efforts at improving safety have resulted in the number of fatalities per billion train kilometres reducing from an average of 4 in 1980, to 1.5 in 2009. Climate change effects are increasing the burden on ageing transport networks with the incidence of infrastructure failure increasing. On the 12th of April 2010 a landslide initiated by heavy rainfall, caused the derailment of a train at Merano, in Italy (see Figure 1). Nine people died in the accident and 28 were injured. Similar recent incidents occurred in Guilin, China, on the 23rd of May 2010 where a landslide on the track caused a crash which resulted in 19 fatalities, and near Wellington, New Zealand, on 30th September 2010, a landslide caused a passenger train to derail and hit an oncoming service.

The construction of the trans-European transport network (TEN-T), which aims to provide interconnection and inter-operability of national transport networks within the EU, is seen as vital for the economic competitiveness of the Union and is central to the objectives of achieving balanced and sustainable development. The Cork-Dublin-Belfast rail line in

Ireland is one of the 30 TEN-T projects. The Irish railways were amongst the first constructed in Europe, and the 180m span Malahide viaduct which carries the Dublin-Belfast line just North of Dublin is one of the oldest railway viaducts in the world.

Figure 1: Rainfall induced slope failure at Merano, Italy.

In early August 2009 a sailor noticed unusual currents developing around one of the piers of the viaduct and reported this to the network operator. A visual inspection was performed on August 18th and no unusual distress to the structure was noted. On August 21st the pier collapsed as a local passenger train crossed the viaduct and the Belfast-Dublin express service approached. The collapse, which was caused by scour of the foundations (which was not visible to the inspector) caused the line to be closed for seven months and a repair bill in the region of €4 million. The scour problem which caused the failure was accelerated by high flows in the estuary caused by recent flooding.

Figure 2: Collapse of Malahide viaduct

The SMART Rail concept is to provide a whole life cycle tool which will allow infrastructure operators to optimise the existing, ageing European rail network and ensure it remains operable into the future in the context of increased traffic volume and loading, with particular consideration for increased freight capacity. The techniques must consider the effects of changing climate on infrastructure, for example; incidents of flooding causing accelerated scour of bridge foundations, high intensity rainfall events causing slope failures and freeze-thaw action causing damage to bridge and tunnel structures.

The SMART Rail consortium brings together experts in the fields of infrastructure assessment in the road and rail industries, national infrastructure operators and specialist SME’s to achieve these critical aims.

In order to achieve the SMART Rail concept, the following critical and interdependent elements will be developed:

1. A sensor network embedded in key elements of rail infrastructure. These will collect real-time in-situ measurements of key parameters which will be transmitted via an advanced IT network to provide critical input data.
2. State of the art Structural Health Monitoring (SHM) procedures which will provide up to the minute assessments of the safety of the infrastructure elements.
3. A suite of low-cost remediation measures that are region-specific, provide minimal disruption and are environmentally friendly will be investigated. These will be capable of providing short-term remedial solutions for critical sections of the network identified by the SHM models.
4. The sensor networks and SHM techniques will be implemented at demonstration sites (in Slovenia, Hungary and Ireland). After assessments of current safety have been undertaken environmentally friendly forms of remediation will be undertaken and the effect in terms of SHM will be quantified.

2 PROJECT STRUCTURE

There are four main research Work Packages (WPs) in the SMART Rail project, which are highlighted in Figure 3.

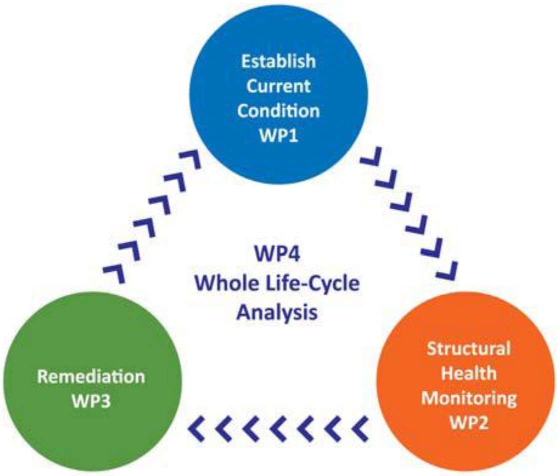

Figure 3: Smartrail Work Packages.

WP 1 examines development of integrated monitoring systems utilising embedded sensor technology to bring about a change in the traditional visually based inspection techniques. WP 2, which is being led by the authors, focuses on the development of models to greatly improve the ability of track owners to predict the future condition of infrastructural elements and to develop efficient maintenance programmes for infrastructure that requires renewal or replacement. WP 3 specifically examines sustainable technologies for the effective rehabilitation and strengthening of older existing rail infrastructure, while WP 4 considers Whole Life Cycle Analysis to assess railway infrastructure rehabilitation techniques both economically and environmentally. This paper subsequently focuses on WP2, highlighting the methodology to be investigated and employed.

3 ASSESSMENT AND MODELLING/STRUCTURAL HEALTH MONITORING

3.1 State of the Art

The current methods of track inspection for the railway networks considered within this project consist largely of visual inspection techniques. The benefits of such an approach are obvious in that trained inspectors and engineers develop intimate knowledge of the visual condition of existing infrastructure and in some cases (e.g. where drainage channels have become blocked) can organise fast remedial works. A further advantage is that it is cost effective as the inspectors are typically employees of the network operator. However, several disadvantages of visual inspections also exist that need to be addressed when new assessments methods are developed:

- safety – visual inspections involve staff walking on usually live railway lines,
- continuity – when experienced staff retire, their knowledge is lost. This was identified as a key factor in the public enquiry of the Malahide Viaduct failure in Ireland (Figure 2), which found that the engineer who performed the critical visual inspection did not in fact have vital information on how the structure maintained stability, and most importantly
- a visual inspection of a slope, tunnel or bridge will not reveal whether some deep-seated mechanism such as a weak soil layer, reinforcement corrosion in concrete or scour beneath a foundation in a river is likely to result in imminent catastrophic failure. For these reasons it is vital that reliable means of providing real-time information on critical sections of infrastructure are deployed.

Assessment of the civil engineering infrastructure of railway networks such as bridges, tunnels and slopes is traditionally performed by defining a model which includes the problem geometry, material properties and loading conditions. Partial safety factors are applied to the loads and material properties (i.e. loads are increased and resistance is decreased) and a snap-shot estimate of the safety of the structure in its current state is obtained. The advantage of the traditional approach is that it is easy and convenient to use. However, the disadvantage of using these techniques for the assessment of existing infrastructure is that, because of adopting unduly conservative safety factors, the capacity and ultimately the remaining safe life of the structure can be underestimated, leading to unnecessary and potentially costly repair works.

In bridge structures, Structural Health Monitoring (SHM) for assessing the performance of a new structure during construction [3] or in its as-built state [4] and the assessment of performance of any rehabilitation [5] or the evolution of safety of a degrading structure [6] are available. The sensor data are analysed to develop SHM markers. The markers typically seek to detect varied events, sudden events and the evolution of the performance of the structure with time. Typically, they include identification of events in the form of some kind of an outlier and the characterisation and calibration of a certain time-span in the form of a defined domain of values. Wavelet based analyses are gaining significant popularity in this regard in the scientific literature [7]. In terms of approach, statistical techniques [8, 9, 10] have also been shown to have great promise. There is some limited existing work based on experiments of full scale bridges. A number of them consider wavelet based techniques [11, 12], while the use of various monitoring devices have also been investigated. Data dependent numerical and statistical algorithms have been observed to be very successful [13, 14] in identifying events. These experiments are extremely important since they not only provide a high degree of confidence regarding the use of a method but also delineate the practical limitations and problems associated with such detection.

To date sensor information has mostly been employed in addressing specific problems in bridge monitoring, maintenance and management. The direct translation of such data is, as yet, not available for a general condition rating. Some research projects have started to link bridge ratings with sensor data [15]. In principle, such a correlation or a ranking has been seen to be of great importance although work carried out in this regard has been limited to visual inspections [16, 17]. It is concluded that the development of algorithms to link continuously observed sensor data with the rating of a bridge would be of significant benefit in monitoring the safety of a structure. The condition rating derived in this process would be significantly more robust than those currently available for non-instrumented bridges due to the reduction in both epistemic and aleatory uncertainties.

3.2 Probability Based Framework

A probability based framework such as that shown in Figure 4 will be developed for the optimized whole life management of railway infrastructural elements/networks. It will encompass, not just rail structures, such as bridges, but all aspects of rail infrastructure such as track susceptibility to settlement and the stability of slopes that may result in landslides onto the track.

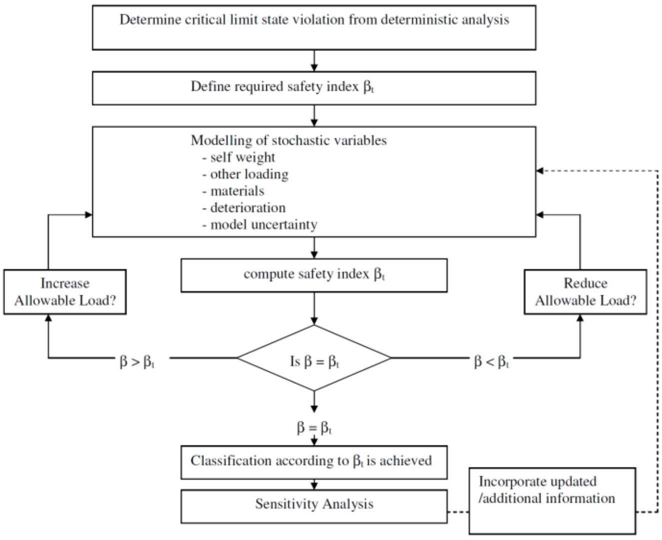

Figure 4: Probability based framework

This cyclic process will involve determination of a safety index, β_t, at the current time t, allowing real time monitoring of the safety of the system. This continuous ‘safety loop’ will allow the model to be updated in real time, using a technique such as Bayesian updating, so any deterioration in the safety index will be detected at an early stage. A key element of this approach is the incorporation of data acquired from in-situ sensors into the structural model allowing a more robust determination of the safety of the infrastructure.

Figure 5: Incorporation of sensor data into computer model

This enables scheduling of preventative action before significant damage occurs to the infrastructure element being monitored, allowing optimization of the rehabilitation efforts to ensure the service life of the infrastructure is maximized in a cost effective manner (Figure 6).

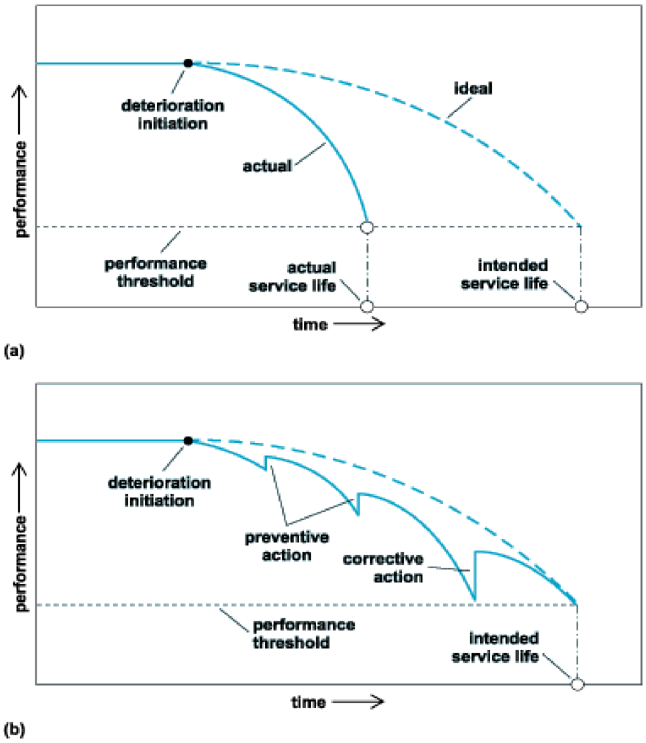

Figure 6: Optimization of service life of infrastructure

Incorporation of sensor data will not only allow real time updating of the structural model but will also enable deterioration under the surface to be detected that would be missed by conventional visual inspection techniques (e.g. such as that seen in the Malahide Viaduct collapse – Figure 2).

3.3 Slope Stability

Reliability theory and probabilistic approaches are traditionally focused on structural applications such as bridges, however, the frequency and importance of infrastructural elements such as slopes and embankments and the resulting disruption that would occur as a result of failure of these elements, makes them a central consideration in the SMART Rail project. Figure 7 shows the failure of a slope near Castlebar, Co. Mayo.

Figure 7: Slope failure near Castlebar, Co. Mayo

For slope stability, both below and above the track, models will be developed of rain infiltration, taking account of expected changes in climate and the resulting reliability of slopes. There will be a particular focus on ‘legacy rail track’ which are much steeper than those built for modern infrastructure networks. Input will be taken from a so-called ‘smart slope’ with sensors measuring stress, water content and slope deformation. Data from on-site weather stations will also be incorporated. Other inspection techniques such as Ground Penetrating Radar (GPR), used to obtain geophysical measurements, will be investigated for use in the reliability models.

For all the analysis techniques and models developed, direct links will be established with existing approaches allowing probabilistic techniques to be incorporated without completely overhauling current methods. A simplified approach to infrastructure assessment will also be developed, benchmarked against the advanced probabilistic techniques described above. This will ensure the new assessment methods will be adopted widespread across the railway industry down to a local level.

4 CONCLUSIONS

This paper outlines the Marie Curie FP7 SMART Rail research project. The goal of the project is to provide a framework for infrastructure operators to ensure the safe, reliable and efficient operation of ageing European railway networks. This will be achieved through a holistic approach developing whole life cycle cost models which will consider input from state of the art inspection, assessment and remediation techniques. WP 2, being led by the authors, focuses on developing degradation models for real time monitoring of the health of rail infrastructure elements. This will include not just structures, such as bridges, but also the stability of geotechnical elements such as embankments and slopes. The outputs from the project will result in enhanced safety, reliability and capacity of the rail infrastructure network and will address European policy in the areas of transport safety, security, and inter-modality.

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