A Qualitative Comparison of Advantages and Disadvantages of Structural Health Monitoring of Railway Infrastructure over Conventional Inspection Methods

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Passenger and freight rolling stock traffic density has increased considerably in recent years in the majority of rail networks across the world. At the same time travelling speeds and axle loads have also increased putting considerable pressure to maintenance engineers who are tasked with ensuring reliability and safety of railway network operations. Inspection of rail infrastructure using various types of methods and equipment has traditionally been the cornerstone of evaluating the structural integrity of critical structural components such as rails, crossings, tunnels and bridges. However, as traffic density increases further and the likelihood of round the clock railway operations nears closer to realisation, the opportunities for inspection based on conventional approaches are reduced by a significant margin. It is therefore, important to develop alternatives for the evaluation of the structural integrity of critical railway infrastructure assets before the technical challenges currently faced manifest themselves more imperatively. In this paper, a qualitative comparison of the key advantages and disadvantages of structural health monitoring techniques over conventional inspection methods are presented and analysed from an infrastructure manager perspective. The discussion focuses on how realistic is the replacement of conventional inspection methods with structural health monitoring techniques currently and what steps need to be taken before a change in the status quo can occur.

Keywords: rail infrastructure, structural health monitoring, inspection

Introduction

The structural integrity of critical railway infrastructure components, particularly rails, crossings, tunnels and bridges deteriorates with time due to the application of complex dynamic loading and adverse environmental conditions [1-3]. Maintenance and repair requirements of railway tracks are normally determined by the infrastructure manager based on the total tonnage accumulation data, i.e. annual rolling stock traffic, and inspection reports. Therefore, the applied maintenance strategies are largely based on corrective and preventive approaches rather than predictive. Predictive maintenance allows track renewals and repairs to be planned ahead, hence minimising impact on network operations.

Nonetheless, as traffic density increases, it becomes progressively more difficult to deploy inspection teams and test trains operating at much lower speeds than passenger and freight rolling stock during normal rail network operation times. Thus, most inspection activities need to take place at night, when rail traffic is reduced or stopped completely.
As the requirements for rail transport increase further, round the clock railway operations will become more likely. As a result reliable inspection will be rendered more challenging and complicated, whilst any unplanned corrective maintenance activities will lead to at least some level of disruption. The application of wireless digital Remote Condition Monitoring (RCM) technology based on the Internet of Things can minimise the need of conventional inspection techniques currently in use.

Digital railway RCM based on high-frequency acoustic emission and vibration analysis can be used to continuously evaluate the structural health of rails, crossings, bridges and tunnels during normal operation without the need for costly disruption to normal rail operations which result in reduced availability and traffic capacity of the rail network. The data generated can be analysed to assess damage evolution with time, allowing the rail network infrastructure manager to implement effective predictive maintenance strategies with adequate notice given to rolling stock operators in order to minimise disruption on the rail line concerned.

Recent feasibility studies performed at the University of Birmingham have shown that the low cost Remote Condition Monitoring (RCM) technology can be used to effectively assess the structural integrity of rails, crossings and other assets in real time with minimal disruption [1, 4-21]. With hundreds of thousands of miles of rail tracks worldwide, the total addressable rail-based RCM market is noteworthy.

**Challenges**

Major railway networks around the world, including the British railway network managed by Network Rail Infrastructure Limited (NR) which is one of the most densely operating rail network worldwide, have experienced an unprecedented increase in passenger and freight traffic. To cope with current growth in passenger and freight numbers significant improvements in operational efficiency are required. Although railway infrastructure enhancements are undeniably beneficial, experience has shown that as soon as they are in place, they tend to be used up rapidly to their full capacity. This means that additional measures are required to support these enhancements.

Several major rail infrastructure managers around the world have invested extensively in the implementation of new technologies and supported research and development activities that contribute to the realisation of the high Reliability, Availability, Maintainability and Safety (RAMS) levels required for the optimisation of railway operations with minimal probability of operational disruption. As traffic density and operational speeds increase, the occurrence of any unexpected faults in critical railway infrastructure or rolling stock can result in severe delays and disruption of normal rail services. Moreover, severe defects that are not detected in time can potentially lead to catastrophic failures, involving dangerous and costly derailments with adverse consequences for the rail industry as a whole.

The immediate key challenges faced by the rail industry are: a) the improvement in the safety of the railway systems, b) the development of new railways to accommodate the continued growth in demand, and c) the operation of sustainable railway through the delivery of further efficiencies and exploiting sufficiently technological innovation.

The growth prospect of global economy is closely linked with the level of mobility and transport efficiency. The more efficient the transport system is, the more important its
contribution to the economy becomes. A smoothly operating transport system increases productivity and helps safeguard societal integrity. It allows strong links to be formed with key economic hubs within the country as well as overseas ensuring goods and citizens can move around safely, reliably and on time. Maintaining existing business and attracting new investments require by default a well-coordinated and reliable transport system. Improving the efficiency of rail services has profound positive technical, economical and societal impacts. There is a strong need to increase rail transport capacity, improve efficiency and reduce operational cost. Therefore, technologies that support the implementation of digital railway in order to improve long-term efficiency and operational performance are of significant interest. NR’s maintenance budget for the ongoing Control Period (CP) 5 (2013-2019) is estimated at approximately £4.5bn. Investment in supporting new inspection and digital RCM infrastructure capability throughout the UK network has been placed at £100mn [22].

Digital RCM systems currently in use are not designed to monitor rail infrastructure. Thus, it is necessary to deploy inspection engineers and test trains on the network using specialised manual and automated non-destructive testing equipment. Despite the high capital cost of modern rail inspection equipment, performance is not satisfactory. Inspection needs to be scheduled when normal rail operations have ceased. This reduces the maximum availability and capacity possible for the rail network and complicates further the implementation of a 24-hour railway in the future. There are also limitations in the defect resolution with increasing inspection speed. This means that certain severe defects can be occasionally missed or their severity underestimated. Digital RCM methods can be used to detect and evaluate damage in rails and crossings in real-time, reducing inspection costs and enabling the optimisation of maintenance planning. In addition, acoustic emission and vibration analysis are able to detect faults in rolling stock wheelsets and suspensions. When severe defects are detected, immediate replacement of the rail section or crossing affected is required.

Corrective maintenance can result in noticeable abortive costs associated with other planned works including track renewals, track patrolling, prep works, etc. per night. Train delay attribution minutes associated with corrective maintenance activities also constitute a significant expense [23]. The delay of passengers and goods, although not officially considered, is a significant unnecessary cost to the global economy.

The availability of the rail network needs to be optimised and its capacity maximised, ensuring efficient and uninterrupted rail services for passengers and goods alike at an acceptable cost. Supporting the growth of rail transport has also significant environmental benefits since it increases the number of passengers and tonnage of goods being moved by train. Advanced high-speed inspection and digital RCM technologies which are able to continuously and reliably evaluate critical railway assets are yet to be used to their full potential.

**RCM for detection of structural defects in rails and crossings**

Various tests have been carried out to assess the applicability of AE in detecting damage propagation in rails and crossings by the University of Birmingham. Figure 1 shows the overall system architecture of the customised RCM system for monitoring rails and crossings. The same approach can be used for monitoring tunnels and bridges.
Figure 1: Customised AE system used for monitoring cast manganese crossings and conventional rail sections [7].

RCM equipment can be integrated to maximise the information obtained from the various sensors. Figure 2 shows the crack growth propagation in rail steel and the corresponding cumulative AE signal energy captured with damage evolution.

![AE System Diagram](image)

Conclusions
Conventional inspection methods are not optimised to support dense traffic densities. Therefore, the gradual shift to digital RCM will gradually occur to enable uninhibited rail operations in an effort to optimise availability and capacity factors of major rail networks around the world. Work carried out to date has shown that RCM techniques can offer distinct advantages over traditional inspection approaches currently in use. Moreover, high-speed inspection methods which can be deployed using trains from normal traffic can result in
significant benefits in the overall operational efficiency as well as help push operational and maintenance costs of rail transport by a significant margin. This will have a profound effect not only to the overall expenditure of rail infrastructure managers but will also help reduce operational costs of rolling stock operators, resulting in cheaper and more competitive rail transport in comparison with other modes of travel such as air and road transport.

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