Institution: The University of Birmingham

Unit of Assessment: B13 – Electrical and Electronic Engineering, Metallurgy and Materials Electronic, Electrical and Computer Engineering submission

Title of case study: Railway Condition Monitoring

1. Summary of the impact

The Railway Systems Group develops state-of-the-art condition monitoring and instrumentation systems that identify system faults before they degrade into failures that cause passenger disruption. The key impacts of the Railway Systems Group lie in the following areas:

- Detection and diagnosis of faults in railway assets (e.g. point machines, track circuits, vehicle components);
- Collection and analysis of track data from in-service railway vehicles (e.g. conductor shoe monitoring, track geometry, non-destructive testing);
- Energy monitoring to quantify loses in the railway power system;
- Assessing the effectiveness of winter weather mitigation solutions.

Examples of direct quantifiable impact are a reduction of over 60,000 minutes in train delays over the last one year period through monitoring of 5,600 railway point machines (the cost to Network Rail of delays is between £20/min to £160/min). Also, the deployment of an award winning conductor shoe monitoring system, which has resulted in an estimated savings of 12,150 minutes. Expert advice and practical prototypes have been through active contracts from railway companies totalling £4.2M. This includes an influence in the £7 billion successful order from the Department for Transport to Hitachi for new trains, energy saving strategies reported by the Office of the Rail Regulator and evidence to the Transport Select Committee on winter operations.
These have been achieved by working extensively with the British and international railway industries in the area of condition monitoring and bespoke instrumentation systems that support an improvement in the dependability of rail travel.

2. Underpinning research

The Railway Systems Group at Birmingham is the only Electrical and Electronic based railway research group in the UK. The group was founded in the 1970's. The group holds a strong international reputation for undertaking industrially focussed research.
The research in railway condition monitoring has been carried out by three academic staff (C Roberts, Professor of Railways System Engineering, 1997-, Dr S Hillmansen, Senior Lecturer, 2006- , Dr E Stewart, Birmingham Research Fellow, 2007-). Since 2008, 20 PhD students have worked (or are currently working) in this area. The active research contracts over this period total over £7M, which includes involvement in 9 European Framework projects, 3 EPSRC projects (including a programme grant), a large ERDF initiative and numerous industrially funded projects. Since 2008, the group has published over 50 papers in international peer reviewed journals.
In addition to funding from the UK, railway condition monitoring research has been supported by funding and collaborations from Hitachi (Japan), Central Railways (Japan), Deutsche Bahn (Germany), Alstom (France), Trafikverket (Sweden) and REFER (Portugal).
Professor Roberts, who leads the group, has excellent research esteem. For example he is founder and chair of the biennial IET International Conference in Railway Condition Monitoring (since 2003). In 2008 Professor Roberts gave a keynote address at the International Federation of Automatic Control (IFAC) SAFEPROCESS conference detailing the significant academic progress and industrial take-up of railway condition monitoring, which was followed in 2013 by a keynote address at the IFAC Workshop on Advances in Control and Automation Theory for Transportation. In 2011 Professor Roberts was asked to give the IMechE Railway Division Annual Research Lecture on his work in the field of railway condition monitoring. In 2013 he developed and co-chaired the 1st IEEE International Conference on Intelligent Rail Transportation in Beijing.
Research at Birmingham has focused on:
(1) The development of sophisticated bespoke instrumentation that is designed to be resilient to the harsh and variable environments of the railway. The instrumentation, based on distributed embedded system design, has been installed on railways throughout the world (UK, Portugal, Germany, Sweden, Japan). Research focuses on solutions that are able to work in-service without human intervention. A current project funded by the EPSRC, as part of the Track 21 Programme Grant, has the objective to advise on appropriate instrumentation systems for the proposed High Speed 2 railway line as well as in other key projects. Other work is developing distributed acoustic

monitoring system to be used by Hitachi to detect bearing faults on its £7 billion Intercity Express Programme trains due to begin operation in the UK between 2016-2018. Some of the technology developed by the group for railways has been applied to wind turbines in Greece [3.1];
(2) The development of robust data processing algorithms that are able to process the data collected from the instrumentation in close to real-time in order to detect incipient faults in systems, or at particular locations on the track. In recent years research has moved on to fault diagnosis and prognosis, and this work has begun to be used in the field, most notably as part of Network Rail's Intelligent Infrastructure programme. For use in railway environments, where system, climate and usage varies, it has been shown that conventional condition monitoring approaches are not suitable. The group has pioneered and demonstrated under real life condition the benefits of combining quantitative and qualitative approaches. Initial work focused on algorithms for the condition monitoring of point machines [3.2]. This work was further enhanced and applied to track circuits [3.3], track geometry measurement using bogie mounted inertial measurements systems [3.4], acoustic emission sensors for crack growth monitoring [3.5] and non-destructive testing evaluation systems for rail and wheelset monitoring [3.6];
(3) In parallel with this work, collaborative research with Network Rail has been undertaken to develop clear, engineering led business cases to support the roll-out of condition monitoring [3.7]. This work has been important to Network Rail proceeding with its Intelligent Infrastructure programme. Additional research has also been undertaken to use instrumentation to help evaluate the effectives of subsystems, particularly to evaluate performance in winter weather. Through this research the University has developed standard test procedure to help Network Rail evaluate the effectiveness of winter mitigation measures.

3. References to the research

The outputs that best indicate the quality of the underpinning research are 3.2, 3.3 and 3.4.

1. M Entezami, S Hillmansen, P Weston, M Papaelias, 2012. Fault detection and diagnosis within a wind turbine mechanical braking system using condition monitoring, Renewable Energy, 47, 175-182. doi:10.1016/j.renene.2012.04.031
2. C Roberts, CJ Goodman, HP Dassanayake, N Lehrasab. 2002. Distributed quantitative and qualitative fault diagnosis: Railway junction case study, Control Eng. Practice, 10(4), 419-429. doi: 10.1016/S0967-0661(01)00159-9
3. J Chen, C Roberts, P Weston, 2008. Fault diagnosis for railway track circuits using neuro-fuzzy systems, Control Engineering Practice, 16(5), 585-596. doi:10.1016/j.conengprac.2007.06.007
4. P Weston, CS Ling, C Roberts, C Goodman, P Li, R Goodall, 2007. Monitoring vertical track irregularity from in-service railway vehicles, Proceedings of the IMechE: Part F – Journal of Rail and Rapid Transit, 221(1), 75-88. doi: 10.1243/0954409JRRT65
5. A Kostryzhev, C Davis, C Roberts, 2012. Detection of crack growth in rail steel using acoustic emission, Iron and Steel Making (available online). doi: 10.1179/1743281212Y.0000000051
6. M Papaelias, C Roberts, C Davis, 2008. A review on non-destructive evaluation of rails: State-of-the-art and future development, Proceedings of the IMechE: Part F – Journal of Rail and Rapid Transit, 222(4), 367-384 (Invited paper). doi: 10.1243/09544097JRRT209
7. F Garcia Marquez, R Lewis, A Tobias, C Roberts, 2008. Life cycle costs for railway condition monitoring, Transportation Research: Part E: Logistics and Transportation Rev., 44(6), 1175-1187. doi:10.1016/j.tre.2007.12.003

4. Details of the impact

The following list demonstrates the impact of the Railways Systems Group, the primary beneficiaries of are the railway network and train operators in the UK, and overseas, with improvements in services benefiting rail users.

<u>Railway Point Condition Monitoring</u>

The key measurable in the rail industry for impact is train delay minutes. The cost associated with delay varies dependent on the type of train service, but lies in the range of £20/minute (non-critical freight trains) to £160 (inter-city trains).

Collaboration on railway point condition monitoring has been ongoing with Network Rail since 2004. Initial work helped to develop a business case for railway condition monitoring [5.1] which resulted in £40M of investment by Network Rail as part of their Intelligent Infrastructure programme. The group has been key to this programme, providing algorithms for fault detection and diagnosis that have now been implemented on 5,600 out of 27,000 point machines. '*The initial implementation was on HW type point machines, has resulted in an estimated reduction of*

29.4% of point machine faults; leading to a substantial reduction in the amount of delay minutes attributed to Network Rail'. In the one year period between 2010-11 there were 646,083 minutes delay on the network due to points failure. Since the rollout of the system in 2012 the number of delay minutes has dropped to 579,063 [5.2].

Following the success of this work on point machine monitoring with Network Rail, the group were approached in 2010 to carry out a monitoring trial on the Japan Central Shinkansen High Speed 'Bullet Train' line South of Tokyo. Following the initial data collection exercise Japan Central Railways seconded an employee to the University of Birmingham for 2 years to work with the team to develop a system for application in Japan [5.4]. Following this work, Japan Central Railways has begun an implementation programme on all of their Shinkansen lines. In addition to Japan, initial trials have been undertaken with Deutsche Bahn in Berlin [5.3] and Hefei Metro in China.

Based on the success of the Birmingham condition monitoring algorithm research for the Intelligent Infrastructure programme, in February 2012 Network Rail formed a £1.65M investment Strategic Partnership with the group in the area of Data Integration and Management to further develop the existing algorithm work as well as developing new applications.

<u>Conductor shoe monitoring</u>

A collaborative industry research project has resulted in the University of Birmingham together with Southern Railway and Network Rail being awarded the Stephenson Award for Innovation at the National Rail Awards in 2012. The work, which developed an in-service condition monitoring system to assess the state-of-the-health of the power conductor rail, automatically identifies sections of track that put excessive force into a train's conductor shoe. In 2012, the system identified more than 30 locations that required remedial action in the Southern region; previously these locations were unidentifable. In 2012, 25,000 minutes of train delay were caused by conductor rail problems of this kind [5.6], with an average of delay of 405 minutes per incident. This initial deployment of the system has therefore an estimated savings of 12,105 minutes.

<u>Track circuit monitoring</u>

Previous research work [3.1], funded directly by London Underground, is now being used in this REF period to provide expert advice through consultancy work that is specifying and designing an innovative track circuit condition monitoring system (hardware, algorithms and architecture) for London Underground. This system will revolutionise how London Underground maintain one of their key assets, allowing them to move from a scheduled to reactive maintenance regime. London Underground will invest '*several million pounds over the next 5 to 10 years*' in this technology [5.5].

<u>Bearing Monitoring</u>

In 2012 Hitachi received a £7 billion order from the Department for Transport to build a new fleet of trains for the UK. One of the key criteria for selection of Hitachi was due to the proposed method for the safe rollout and the ongoing life cycle cost benefits of the new train. This, in part, is based on a series of monitoring systems to ensure the health of key components. In the area of wheel bearing safety, these assertions have been based on expert advice from research undertaken by the University in collaboration with Hitachi to develop a prototype acoustic monitoring system that was able to detect and diagnose bearing and gearbox faults on the new train. During Phase 1 of the project field trials took place to verify the work. Phase 2, which is currently underway, is developing a full prototype system that will be sited on the High Speed 1 line in early 2014.

<u>Inertial Measurement Unit</u>

In 2011 and 2012 in-service inertial measurement units have been developed and deployed on two in-service trains for MerseyRail and Southern that are able to identify track locations that require maintenance. These systems are the first of their kind in the UK, and are currently operating on the UK network. As part of the EPSRC Track 21 Programme Grant, the system monitoring the track in the south of England has been used by Network Rail to help steer and monitoring a track renewal at Black Boy Lane Level Crossing in the Southern Region.

<u>Gauge corner cracking instrumentation</u>

In 2012, the University demonstrated the first high speed gauge corner cracking test system in collaboration with REFER, the Portuguese railway infrastructure manager. The system is designed to detect and quantify rolling contact fatigue cracks on the rail gauge corner. The system integrates ultrasonic, vision and ACFM (alternating current field measurement) technology. The integration of these systems allows high speed inspection to be carried out. The system operates at up to 120 kph, whereas conventional systems typically operated at 30-40 kph

<u>Energy monitoring</u>

Environmental impact is evident throughout the groups work; however it is particularly predominant in this study. In 2012 a monitoring and simulation study was undertaken to drive a system-wide energy saving on the MerseyRail network. The study has been developed for long-term monitoring of the MerseyRail network looking at DC railway power systems to understand the losses, and hence set the price of the energy paid by the train operating companies throughout Britain. The work is led by the University of Birmingham and is supported by Network Rail and the Department for Transport with in kind contributions from MerseyRail, Association of Train Operating Companies, the Rail Safety and Standards Board, London Underground and Angel Trains. The work has highlighted key energy saving strategies and will inform future train procurement for the MerseyRail, and other networks. The results of the study have been issued to the Office of the Rail Regulator in Network Rail's report TPD-NST-021 LOSS-REP-0012 which is being used to set the price of the energy paid by the train operating companies throughout the UK [5.7]. This is a key step in helping the rail industry meet its target of achieving a 20% reduction in energy usage by 2020 (which equates to an annual saving of 580 GWh of electricity and 91 million litres of diesel). Following the success of this work, a project is now underway with Guangzhou Metro in China.

Winter mitigation

Since winter 2009 the group has developed specific instrumentation and a number of national test rig to help Network Rail manage the effect of snow and ice. The research undertaken has helped Network Rail in understanding the cause of winter problems, and hence write requirements and standards for the rail industry for winter mitigation measures and assess the develop benchmarking tests evaluate manufacturers solutions. So far the University has helped specify and evaluate over 30 different products, on which Network Rail now spends approximately spent around £200k to £500k per year. The work undertaken by the University was identified as a successful collaboration case study in the Department for Transport's Railway Industry Research Strategy document [5.8]. Furthermore, in 2010 the Rail Industry's National Task Force, to which the University provides advice, referred to the importance of the work being undertaken by the University when giving evidence to the Transport Select Committee [5.9].

5. Sources to corroborate the impact

1. To corroborate work with Network Rail on condition monitoring business case generation (paper co-authored with J Amoore, Research and Development Manager at Network Rail): C Roberts, R Lewis, J Amoore, 2006. Making the case for railway condition monitoring, Proc. of the 7th World Congress of Railway Research, Montreal, (http://www.uic.org/cdrom/2006/wcrr2006/pdf/652.pdf).
2. To corroborate algorithm usage as part of the Intelligent Infrastructure programme: Evidence in a letter from the Intelligent Infrastructure Technical Manager, Network Rail.
3. To corroborate development of algorithms for Network Rail, Deutsche Bahn and Japan Central Railway. University partnerships for a better railway, Science in Parliament, Journal of the Parliamentary and Scientific Committee, Spring, 7-9 (by John Amoore, Research and Development Manager at Network Rail): (http://www.vmine.net/scienceinparliament/sip68-1.pdf).
4. To corroborate collaboration with Japanese Central Railways (paper co-authored with Tomo Asada, Japan Central Railways): T Asada, C Roberts, T Koseki, 2013. An algorithm for improved performance of railway condition monitoring equipment: alternating current point machine case study, *Transportation Research Part C: Emerging Technologies*, 30, 81-92.
5. To corroborate saving to London Underground: Evidence in a letter from the Signals Maintenance Sponsor, London Underground.
6. To corroborate the impact of the conductor shoe monitoring research: Prevention is better than cure - Southern's TRIME project, *Rail Strategies*, September 2011, 92-93.
7. To corroborate Network Rail engaged the University of Birmingham to undertake train simulation and transformer rectifier modelling: Network Rail report - Estimate of DC losses: Electricity Supply Tariff Area Analysis TPD-NST-021 LOSS-REP-0012:
8. To corroborate the range and importance of work undertaken on winter mitigation (Department for Transport Rail Industry Research Strategy): http://assets.dft.gov.uk/publications/rail-industry-research-strategy/railresearch.pdf
9. To corroborate statements relating to the importance of the work undertaken to Network Rail's winter programme (reference to the work of the University by the Rail Industry's National Task Force when giving evidence to the Transport Select Committee): http://www.publications.parliament.uk/pa/cm201011/cmselect/cmtran/writev/weather/m13.htm