Institution: Manchester Metropolitan University

Unit of Assessment: B15 General Engineering

Title of case study: The Impact of MMU Research on the Optimisation of Railway Vehicle-Track interaction

1. Summary of the impact The School of Engineering at MMU has longstanding research into many aspects of railway engineering. This commenced in 1998 under the leadership of Professor Simon Iwnicki, who carried out research into the interaction between railway vehicles and the track. The understanding of the dynamics of the wheel rail contact that has resulted from this work has been developed into a number of tools and techniques that are being used on a daily basis by the rail industry both to design new railway systems and to predict the deterioration of railway wheels and rails. This allows railway engineers to predict and control roughness growth on rails and to optimise wheel profiles and maintenance intervals on wheel and track.

This work is now helping the railway industry internationally to realise both economic and environmental impacts as track maintenance costs are reduced, safety levels are enhanced and passengers continue to switch from road to rail in increasing numbers. This is evidenced by the award of new research contracts and industry funding and by direct input into industry standards.

2. Underpinning research One of the most important and most complicated factors influencing the dynamic behaviour of a railway vehicle is the nature of the interface between the wheel and the rail. There is a highly non-linear relationship between the motion of the vehicle and the forces on the wheels. The very high stresses present cause elastic and plastic deformation of the steel and high levels of wear and fatigue are common, which ultimately could lead to track failure. Analytical methods, together with mathematical computer models that can accurately predict and model this deformation have been developed by a team of dedicated rail researchers at MMU (listed below) and are being used widely by industry to improve the design of vehicle suspension and track construction to increase safety and reliability levels, reduce cost and improve performance of the railway system **[3, 5 and 6].** This modelling and analytical work made step-change improvements to computer tools which, prior to this work, were not able to include some of the many variations which actually exist in track such as local changes in the support stiffness or the sleeper type or spacing or the shape or flexibility of the rail. The team supported this work with expertise in laboratory testing, on-vehicle instrumentation, data collection and advanced computing techniques.

In several EPSRC funded projects (detailed in section 3), together with partners at Birmingham and Southampton Universities, research has been carried out by the Rail Research Team to allow prediction of damage to railway wheels and rails **[1, 2 and 4]** and to allow railway engineers to optimise vehicle and track design. Through involvement in the European Research Framework 6 and 7 projects INNOTRACK, CATRIN and DYNOTRAIN, improved modelling techniques have been developed to predict the non-linear and non-steady wheel-rail forces. Novel techniques and tools have been developed to allow optimisation of vehicle suspensions and track structures. This work is continuing in the Framework 7 projects SUSTRAIL, SPECTRUM and D-Rail.

More recently, Rail Research within the School of Engineering has also focussed on the preventative maintenance and condition monitoring of rail and tramway using machine vision techniques (e.g. via EU Framework 7 project PMnIDEA).

Key Researchers:
Simon Iwnicki (1998 – 2012), Professor of Railway Engineering, Julian Stow (1998-2012), Research Fellow, Yann Bezin (2000-2012), Research Fellow, Nick Bowring (2004 – present) , Professor of Electronic Engineering.

3. References to the research

[1] Iwnicki S.D., Bjoklund S. And Enblom R. 'Wheel-rail contact mechanics' chapter in 'Wheel-rail interface handbook', Woodhead Publishing, 2009 (ISBN 978-1-84569-412-8)

[2] Bezin Y, Iwnicki S.D. and Cavalletti M. 'The effect of dynamic rail roll on the wheel-rail contact conditions' Vehicle System Dynamics, Supplement to Vol 46 (2008), pp 107-117 (ISBN 90-265-1972-9)

[3] Xie X., Iwnicki S.D. 'Calculation of wear on a corrugated rail using a three-dimensional contact model' Wear 265 (2008) 1238-1248 *This work was subsequently used to assist the operators of*

Copenhagen Metro to deal with noise problems on their system.
[4] Iwnicki S.D. 'The effect of profiles on wheel and rail damage' International Journal of Vehicle Structures and Systems, Volume 1, Number 4 (2009) *As a result of this work further development of the novel modular steel track support system was undertaken by partners Tata Steel and an improved product is now being marketed.*
[5] Bezin Y., Iwnicki S.D., Cavalletti M., de Vries E., Shahzad F. and Evans G. 'An investigation of sleeper voids using a flexible track model integrated with railway multi-body dynamics' Proc. Instn. Mech. Engrs,. Vol 223 (2009), Part F, pp597-608 (ISSN 0954-4097) DOI: 10.1243/09544097JRRT276
[6] Persson I., Nilsson R., Bik U., Lundgren M. and Iwnicki S. 'Use of a genetic algorithm to improve the rail profile on Stockholm Underground' Vehicle System Dynamics, Volume 48, Supplement 1 (2010), pages 89 – 10 *This presentation of the application of a novel technique for designing an optimised rail profile has since been applied to several railway systems.*

Major Grants awarded to MMU in connection with the work described here:
EPSRC: GR/R31447/01 'Railway Vehicle and Track System Integration', October 2001 to January 2005 (with University of Birmingham) £255k to MMU, Iwnicki as PI
EP/D080207 'Aerodynamic/Train System Interactions' September 2006 to August 2009 (with University of Southampton) £468K to MMU, Iwnicki as Co-I
EP/D033918/1 'Prediction of defect development with a track system model' November 2005 to October 2008 £220K to MMU, Iwnicki as PI
EP/H024743/1 'Factor 20: reducing CO2 emissions from inland transport by a major modal shift to rail', January 2010 to October 2011 (with Universities of Southampton, Salford, Leeds, Sheffield and Newcastle) £201K to MMU, Iwnicki as Co-I

European Commission: MMU has secured £1.6M Euros for FP6 and FP7 projects relating to this case study including: EURNEX (to create a European rail research network of excellence) (2005-2007), INNOTRACK (to undertake research on track support structure, switches and crossings, rails, and logistics for track maintenance and renewal) (2004-2007), CATRIN (to undertake research into the cost allocation of transport infrastructure) (2007-2009), DYNOTRAIN (promoting interoperable rail traffic in Europe by reducing certification costs) (2006-2010)

Industry funding: A total of over £1.5M including research projects for Network Rail, Corus/Tata, Docklands Light Railway, Hitachi

4. Details of the impact Research findings have resulted in major impacts across the international rail sector. Impacts have been achieved in relation to passenger safety through the introduction of industrial standards and "best practice" guidelines as well as improvements to vehicle track interaction that minimise rail degradation. Commercial and environmental impacts have been realised through changes to vehicle acceptance costing and procurement processes and through policy development on freight charging standards.

Impacts on Passenger Safety and Track Maintenance As a direct result of the research described above, MMU are recognised as leading authorities in the field of modelling rail-wheel interactions and having advanced computational models capable of accurately predicting rail and wheel wear. In September 2010, the UK Rail Safety and Standards Board (RSSB) produced a research brief on Project T613 *"Trials of wheel and rail rolling contract fatigue control measures"* undertaken by MMU researchers using computational modelling of new trains. The work was designed to support a business case for the adoption of sustainable operation limits (SOL's) by Network Rail. In 2012 MMU were invited to lead Project T963 which involved studies into the production of cost-effective, track-based "sustainable operation limits" for rolling contact fatigue. All of this work was monitored and tested over time and the successful results are now underpinning Network Rail efforts to roll-out sustainable operation limits across the UK rail sector **[A].** This leads to improved vehicle track interaction and therefore enhanced levels of passenger safety. Team members took part in the roll out of the new tool in a series of workshops for industry during 2012 and 2013 organised by RSSB and carried out by MMU and SERCO. Training has subsequently been delivered to over 200 industry colleagues who are now using the tools in planning the day-to-day maintenance of the UK railway network.

Research has contributed to the production of several guidelines related to rail safety. For example, in response to the Office of the Rail Regulator commissioning a study of optimising wheel and rail profile designs to reduce the risk of derailments, Julian Stow produced "A Good Practice Guide for Managing the Wheel-Rail Interface of Light Rail and Tramway Systems', Feb 2008] **[B].** This guide and the accompanying "Determination of Tramway Wheel and Rail Profiles to Minimise Derailment" **[C]** have been presented to the Light Railway Engineers Group which includes all of the major UK light rail operators. Both guides are publically available on the Office of the Rail Regulator's Rail Safety Research web pages http://www.rail-reg.gov.uk/server/show/nav.1184

Research has also supported improvements to the safety of new railway vehicles leading to partnerships with manufacturers such as Siemens and Hitachi. In 2007, Hitachi called in MMU expertise to assist in ensuring the safety and efficiency of their *Olympic Javelin* bullet trains which were rolled out into operational use in 2009. The successful roll-out of the vehicles, designed to improve passenger experiences for the London 2012 Games and which travel at 140mph, relied on MMU techniques to predict wheel wear **[D].**

Researchers have delivered workshops for the Rail Accident Investigation Branch (in 2008) and for the Light Rail Engineers group (annually from 2009-2011). MMU established an bi-annual European Rolling-Stock Summer School (with Politecnico di Milano and Sileasian Technical University) in 2010 attended by 40 delegates from industry.

Impacts on Rail Policy Development including Crossrail, Freight Charging and Industry Standards During 2010 and 2011 MMU worked in partnership with Mott MacDonald to support the Crossrail project partners in a study to investigate the consequences of challenging gradients on the proposed cross London rail link. A wheel-rail force assessment and mitigation study was carried out to consider the potential performance and maintenance requirements of the current state of the art resilient track systems. As a direct result of this work, an effective wheel-rail management policy has been instigated by the Crossrail management team that will allow the high density of service required for the planned Crossrail operation.

In 2011, Network Rail commissioned the MMU Team to review the methods used to allocate charges to freight vehicles. The report issued in 2011 proposes a new approach for allocating freight vehicles to suspension bands. Network Rail carried out a wide scale industry consultation on these proposals before adopting them fully and implementing them in Charging period 5 which begins in 2016 **[E and F].**

In 2011, MMU helped to establish the Rail Research Association (RRUK-A), http://rruka.org.uk/ a network of over 20 universities and the rail industry who are working together to improve the safety and efficiency of Britain's railways. The network, funded by the Rail Safety and Standards Board and Network Rail, and launched by transport Minister Theresa Villiers, has led to the development of significant new research that directly addresses the challenges of the rail industry. It provides a forum for targeted knowledge exchange between universities and the industry, including the organisation of workshops and wider networking opportunities and also maintains a 'map' of expertise to prevent duplication of research activities. **[G]**

Researchers have also underpinned on-going contributions to industry standards through membership on various committees and working groups including Vehicle Track System Interface Committee Technical Advisory Group, BSI Gauging Standards Committee, CEN European Working Group on gauging. Simon Iwnicki is the Editor in Chief of Part F of the Proceedings of the Institution of Mechanical Engineers (the Journal of Rail and Rapid Transit regarded as a key journal for disseminating results of rail research to industry and MMU researchers edited and contributed to "The Handbook of Railway Vehicle Dynamics" (2006) now regarded as the key text for researchers in Higher Education and Industry.

Commercial and Economic Impacts in the Rail and Light-Rail (Tram) Industry
Research findings led to the creation of a sophisticated 'Virtual Test Track' computational toolbox, developed between 2008 and 2010. The 'Virtual Test Track' allows users to produce a short

section of track data for use in computer simulations that fully represents all the features found in real track. This work has been instrumental in the development of a new version of the European standard EN14363 (confirmed in Sept 2011), which will allow computer simulation in place of physical testing allowing reductions in the costs of vehicle acceptance **[H].**

In 2008, MMU researchers were commissioned by the Victorian Government Department of Transport to carry out a study of vehicle-track interface on the Melbourne Tram system. Researchers benchmarked vehicle-track interface conditions and specified maximum wheel-rail forces for various types of vehicle-track interaction. This data was used to inform procurement decisions for tram fleets, ensuring that new vehicles do not increase the prevailing rate of track degradation experienced at the time of the study. Research has also informed improvements to the Stockholm Metro (2008, **[6]**) where a method for optimising railway wheel profiles using genetic algorithims to solve problems of high wheel wear was developed and Copenhagen Metro **[3],** where MMU's input reduced the environmental impact of noise problems caused by corrugation on the rail in curves. The INNOTRACK project has also developed significant impacts **[I]**.

5. Sources to corroborate the impact

[A] Example of Research report from UK Rail and Safety Standards Board. MMU leading role referenced under Deliverables on p 4.
http://www.rssb.co.uk/sitecollectiondocuments/pdf/reports/research/T613_rb_stage4.pdf

[B] Link to "A Good Practice Guide for Managing the Wheel-Rail Interface of Light Rail and Tramway Systems", Feb 2008 http://www.rail-reg.gov.uk/upload/pdf/sres-RTU-rep_90_3B_iss1.pdf (available on the Office of the Rail Regulator's rail safety research website (http://www.rail-reg.gov.uk/server/show/nav.1184) corroborating impacts on rail safety research.

[C] Link to "Determination of Tramway Wheel and Rail Profiles to Minimise Derailment" Feb 2008 http://www.rail-reg.gov.uk/upload/pdf/sres-RTU-rep_90_3A_iss1.pdf (available on the Office of the Rail Regulator's rail safety research website (http://www.rail-reg.gov.uk/server/show/nav.1184) corroborating impacts on rail safety research.

[D] Web links to press release on MMU partnership with Hitachi corroborating research impacts on the safety and efficiency of railway vehicles:
http://portal.railresearch.org.uk/RRUK/Shared%20Documents/MMU%20Hitachi%20Press.pdf and
http://www.theengineer.co.uk/news/mmu-helps-put-bullet-trains-on-track/301805.article and
http://www.mmu.ac.uk/staff//news/articles/693/

[E] 2011 report on Quantifying Freight Vehicle Suspension Bandings for Network Rail
http://www.networkrail.co.uk/browse%20documents/regulatory%20documents/access%20charges%20reviews/cp4%20charges/i.%20suspension%20banding%20review%20-%20final%20mmu%20report.pdf

[F] Network Rail letter in relation to the Quantification of Freight Vehicle Suspension Bandings
http://www.networkrail.co.uk/browse%20documents/regulatory%20documents/access%20charges%20reviews/cp4%20charges/h%20-%20suspension%20banding%20review%20-%20nr%20consultation%20letter.pdf

[G] Web Link to story on the launch of Rail Research Association (RRUK-A)
http://www.staff.mmu.ac.uk/manmetlife/news/view/research-to-help-britain-s-railways-run-smoothly
And link to RRUK-A website: http://rruka.org.uk/

[H] Network Rail article corroborating the economic and environmental impacts of improved vehicle procurement using the "Virtual Test Track" software and accompanying testimonial from Network Rail Research Manager (MMU p 9) http://www.les-bi.org/documents/Spring2011SiPwhole.pdf

[I] Press release from UNIFE 2010 (the Association of the European Rail Industry) corroborating economic and commercial impacts on track maintenance and renewal costs of INNOTRACK.
http://www.unife.org/uploads/100429_NR_Innotrack_Webco_final.pdf