Rail Research UK

Annual Report

2006 | 2007

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2006 | 2007 Annual Report

RRUK Consortium Members

University of Southampton
Principal Investigator: Professor William Powrie
Named Investigators: Professor Mike Griffin, Professor John Preston
Key expertise: infrastructure, geomechanics, transport operations, user needs, logistics, train and infrastructure noise, human responses to train environments

University of Birmingham
Named Investigators: Professor Chris Baker (RRUK Director), Dr Claire Davis, Dr Colin Goodman
Key expertise: aerodynamics, condition monitoring, energy, metallurgy

Imperial College London
Named Investigator: Professor Rod Smith
Key expertise: vehicles, high-speed rail, hybrid trains, wheel/rail interface

University of Leeds
Named Investigator: Professor Chris Nash
Key expertise: rail economics, passenger and freight demand modelling, cost modelling, regulation/competition, infrastructure charging, international benchmarking

University of Loughborough
Named Investigator: Professor Roger Goodall
Key expertise: rolling stock, dynamics, suspension and control, mechatronics, condition monitoring

Manchester Metropolitan University
Named Investigator: Professor Simon Iwnicki
Key expertise: vehicle/track interaction – modelling, validation, laboratory testing

University of Newcastle-upon-Tyne
Named Investigator: Professor Ajay Kapoor
Key expertise: rail steel microstructure, wear and rolling contact fatigue, wheel-rail adhesion, rail joint inspection

University of Nottingham
Named Investigator: Professor John Wilson
Key expertise: human factors including workload assessment and impacts of automation

EPSRC

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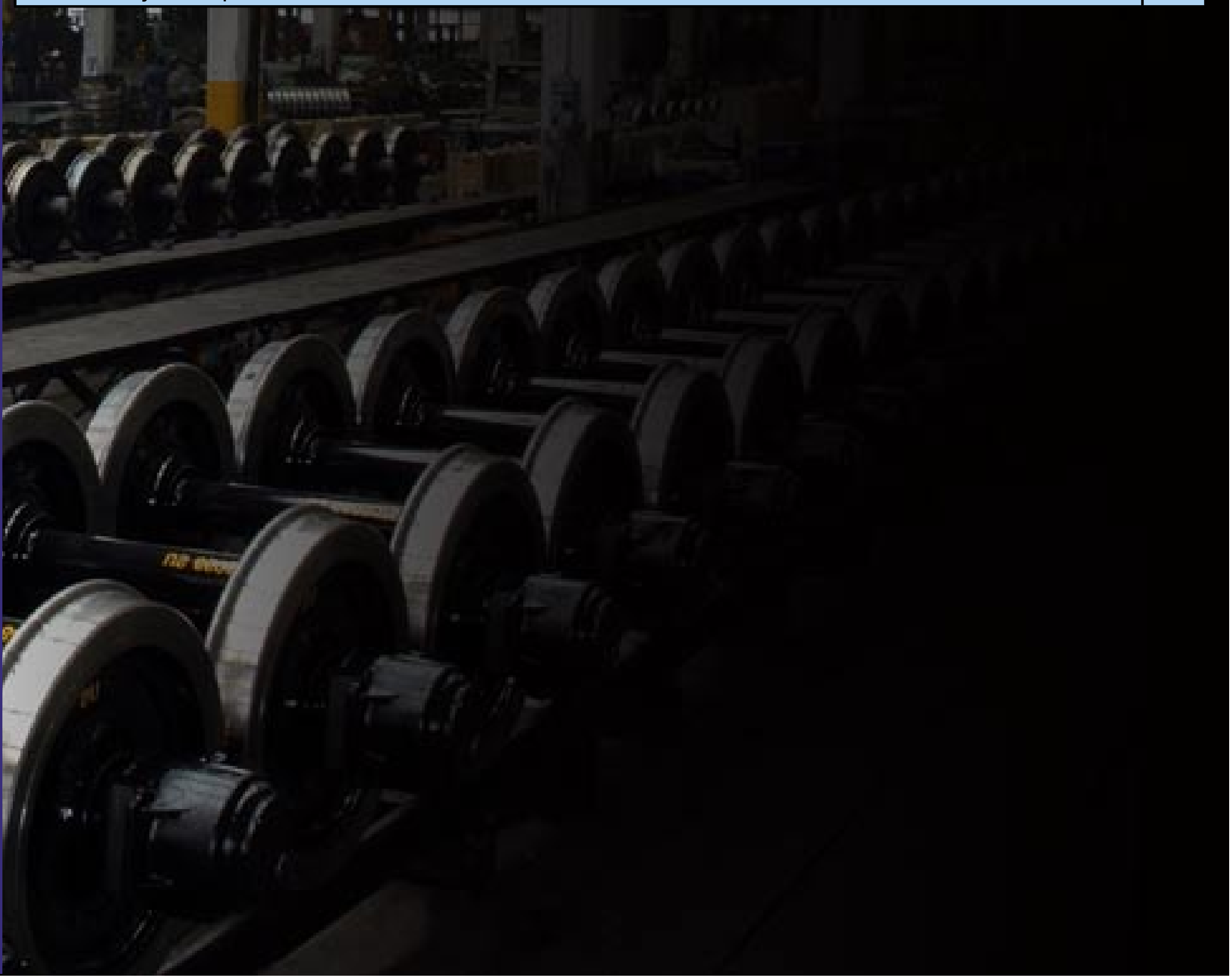

Introduction

We are pleased to introduce this Annual Report, which gives details of Rail Research UK's activity for the period September 2006 - September 2007, covering the first year of operation of the second phase of RRUK.

RRUK1 / RRUK2 Transition

Established by EPSRC in May 2003 with funding of £4.2m, RRUK1 ran for 40 months, ending in September 2006. The Consortium were successful in gaining a second tranche of funding for RRUK2, which runs from September 2006 to March 2010, with funding amounting to £4m (30 months FTE) over 42 months.

2006-07 has been a period of transition, with the completion of the RRUK1 projects and the start of work on RRUK2. In some cases – where the RRUK2 projects are broadly continuous with those undertaken in the first phase – the transition has been very smooth. Other projects are entirely new. For added flexibility, investigators on the RRUK2 grant have been allocated 30 person months, which may be deployed over a 42-month period; one consequence of this has been that the projects have not all started simultaneously and at the same intensity.

RRUK2 has started from a considerably higher base than RRUK1 – with the increased capability and confidence that that implies. Over the past year we have appreciated the benefits of having, in post, a cohort of dedicated railway researchers with skills, knowledge, experience and, importantly, industry awareness and contacts that were simply not available to us three years ago when RRUK started.

That we are in such an advantageous position is, perhaps, testimony to the value and success of RRUK1 – one of the stated aims of which was to fund a cadre of senior research fellows who could provide a stable base for rail research through continuity of research knowledge. But while the research base in university railway research has expanded, so have the expectations, and we are very much aware of the need to continue to deliver high quality science that is relevant to the railway industry, and warrants its support.

RRUK2 Management and Structure

Professor William Powrie has continued as RRUK Principal Investigator; Professor Chris Baker, likewise, continues as Director.

Established at the inception of RRUK1, the internal management structure of Centre Management Team and Council was felt to be working increasingly well during the first phase of funding, and we have not, therefore, had reason to change it for the second stage.

Chaired by Professor Chris Baker, CMT has met every three months; Council, every six months – Professor Roger Goodall continues as Chair.

Following consultation and discussion both within RRUK and with our industry partners, it was decided that the three main research themes - Engineering Interfaces; Whole System Performance; and Users, Community and Environment - adopted in RRUK1 were still relevant and applicable, and should, with their associated Theme Networks, be maintained for the duration of RRUK2.

Industry and External Engagement

It has always been a priority for RRUK to engage and collaborate with the railway industry, and this is an area in which robust progress has been made.

Over the past four years the industry has made extremely valuable contributions to RRUK in a number of ways: helping us to identify and define research problems; advising on the trajectory of current and future RRUK research project; offering support in kind e.g. access to track, vehicles, etc.; participating in RRUK workshops and seminars, and assimilating the results of RRUK research in professional knowledge and practice.

Our most structured forum for engagement with the industry has been the RRUK Advisory Board – a group of 18 senior figures mostly from the railway industry who met formally twice a year to advise RRUK on industry needs, review potential projects and comment on scope for collaboration.

The Advisory Board has been important and successful, especially in the early days of RRUK, and has been a useful forum for helping RRUK to become known and gain credibility with the industry. Increasingly, however, the feeling within RRUK and amongst Advisory Board members was that its modus operandi should evolve.

It has been decided that the Advisory Board should remain as a high-level corresponding panel for reviewing reports and project proposals. However, the routine monitoring and review functions of the Advisory Board have been assumed by the Advisory Group for Rail Research and Innovation (AGRRI). RRUK will be a standing item on the agenda for every meeting of AGRRI, and a main item for one meeting annually.

The transfer of monitoring and review functions of the RRUK Advisory Board to AGRRI is a very positive step which is indicative of RRUK's assimilation into the railway industry and the industry's increasing acceptance of and investment in RRUK.

On behalf of all at RRUK, we would like to take this opportunity to record our gratitude to all who have served on the Advisory Board from 2003 – 2006 and remain on the corresponding panel, especially the Advisory Board Chair, Andrew McNaughton. We are also most grateful to AGRRI, in particular its Chair, Richard Gostling, for agreeing to take over the RRUK industry advisory role.

RRUK enjoys a strong relationship with the Rail Safety and Standards Board (RSSB), who are represented on RRUK's Centre Management Team.

Dissemination

A Whole System Cost Modelling workshop was held on the 13th December 2006 at the Institution of Mechanical Engineers in London. It was organised by RRUK's Research Theme B, which focuses on whole system performance, and was chaired by Theme B manager Dr. Colin Goodman of the University of Birmingham.

Nearly thirty representatives from Government, the rail industry and academia attended and heard from seven speakers all of whom are either involved at the forefront of current cost modelling efforts, or are working on research in this field. It was a stimulating day which, as well as providing excellent networking opportunities, presented RRUK in a highly positive light and gave us a valuable opportunity to seek industry advice and opinion regarding current and future research in this area.

Another major dissemination event was the fourth annual RRUK Workshop, held on 22-23 May 2007, at the Burleigh Park Conference Centre, on the Loughborough University site. The highlights this year were some extremely stimulating and informative keynote presentations by John Armitt (Network Rail, EPSRC), Andrew Chivers (One Railway), Anson Jack (RSSB), and Christian Wolmar (columnist, Rail magazine). There were also updates on completed and current RRUK projects and short presentations by all RRUK-funded PhD students, a dedicated poster session and a closing panel discussion with Anson Jack, Ian Walmsley (Porterbrook), and Christian Wolmar.

The railway-themed workshop dinner was held aboard a steam-hauled dining train on the Great Central Railway, providing a memorable and very worthwhile occasion for informal networking and discussion.

The vast majority of RRUK staff and students attended the Workshop, which importantly gives those working on RRUK projects a sense of belonging to the bigger, railway-oriented organisation. It was particularly heartening that over 37 external, mostly railway industry, delegates participated in this year's event and provided a very welcome industry perspective on some of the issues we are dealing with in the research programme. Feedback from the industry delegates was overwhelmingly encouraging. We would like to take this opportunity to thank all those who gave their time to join us, and who made such a valuable contribution.

RRUK Doctoral Training Account

In addition to the main RRUK2 grant, RRUK receives an additional funding alllocation from EPSRC, the purpose of which is to support students carrying out research doctoral research on railway-related subjects. See Table 1 for the full list of current DTA projects.

This year RRUK has awarded three PhD studentships:

- Analysis of information flows as a way to improve the level of resilience of the planning system (Supervised by John Wilson, Sarah Sharples, Brendan Ryan, University of Nottingham; Theresa Clarke, Network Rail)
- Development of models for rail vibration and noise radiation including the effects of rail dampers (Supervised by Professor David Thompson and Dr Chris Jones, ISVR, University of Southampton)
- High speed train driving situation awareness: an account of attention and perception in support of a new cab interface design (Supervised by Dr Mark Young, Brunel University)

RRUK DTA funding is allocated on a competitive basis by the management group of the consortium. The competition for funds is open to all partner institutions and academic members of the Theme Networks.

RRUK is committed to encouraging and collaborating with high quality researchers who may not be members of the core group, and we are therefore pleased to report that Dr Young at Brunel University, whose candidate was successful in this year's competition, is the first Network member to be awarded a DTA studentship. This represents an important step forward in our aim to link up with non-core groups and bring those with appropriate complementary background and skills into the consortium.

Research Project Progress and Outputs

One of the highlights for RRUK this year has been the publication, in March 2007, of a special RRUK issue of Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit.

The articles contained in this volume represent a significant part of the initial research carried out within RRUK and represent an output of which the authors can be justifiably proud. We believe that these papers make a valuable contribution to knowledge and understanding of railway systems. The results presented will not only prove useful in their own right, but will also set the agenda for future research in these areas in the immediate future. It is a testament to the quality and relevance of the research being carried out by RRUK that one of these papers has been nominated for the award of the Thomas Hawksley medal of the Institution of Mechanical Engineers for the best paper published in 2007.

Outputs relating to individual projects and details of progress on each of the current projects are given in the project reports that comprise the remainder of this document. The list of current projects is given in Table 2.

Professor Chris Baker
Director, RRUK
University of Birmingham

Professor William Powrie
Principal Investigator, RRUK
University of Southampton

A Computation Intelligence Approach to Railway Intervention Planning
An Optimised Wheel-Rail Contact Model for Vehicle Dynamics Simulation
Development of models for rail vibration and noise radiation including the effects of rail dampers
Enhanced Information Design for High Speed Train Displays
Forecasting the Use of New Local Railway Stations and Services Using GIS
High Speed Train Driving Situation Awareness: An account of Attention and Perception in support of a new cab interface Design
Optimising Rail Maintenance Techniques
Quantifying the Effects of Climate Change on the Railway Network in the UK
The analysis of information flows as a way to improve the level of resilience of the planning system
Track Stability

Table 1. RRUK2 DTA-Funded PhD Projects

Theme A: Engineering Interfaces Manager: Professor William Powrie; Assisted by Dr Jeffrey Priest
A4 Ground/track/train systems interactions
A5 Aerodynamic/train system interactions
A6 Rail materials
Theme B: Whole System Performance Manager: Dr Colin Goodman; Assisted by Mr Chris Bouch
B6 Human-automation interactions in rail network control
B7 System cost model
B8 Condition monitoring
B9 Optimum use of CCTV
Theme C: Users, Community and Environment Manager: Professor Michael Griffin; Assisted by Dr Chris Jones
C5 Passenger and crew environments
C6 Determining the costs of delays
C7 Minimising energy consumption

Table 2. RRUK2 Themes and Projects

Project A4: Ground / Track / Train Systems Interactions

Named Investigators:
Prof. William Powrie (University of Southampton)
Researchers:
Dr Chris Jones, Dr Jeffrey Priest, Dr Li-Ang Yang (University of Southampton;) Dr Michael Burrow (University of Birmingham)
Current Industry Support: Network Rail, Network Rail CTRL, Deltares (Holland), Pro-rail (Holland)

Background:
Worldwide trends towards increasing train speeds, vehicle weights and intensity of use are placing more and more onerous demands on the track system and its components. Project A4 aims to contribute towards the development of a better understanding of the behaviour of track systems, especially under extremes of intensity and frequency of loading, and models and analytical procedures by which this understanding can be translated into design. In particular, field measurements made during project A1 have provided data on the effective stiffness of track systems, and the variations in stiffness that can occur as a result of differences in the degree of sleeper support. Increased track deflections may lead to increased vehicle dynamic loads and long term damage. Vehicle dynamics studies have not been able to include this information as the computer simulation packages used do not allow accurate representation of variations in track system support conditions, and only very simple track dynamics models are used. Similarly, as both high speed mainline and metro rail networks extend by means of underground construction into densely populated and vibration-sensitive urban areas, there is a need to apply the new insights into the geotechnical response of the track and the ground to dynamic loading from trains to improve the prediction of the generation and propogation of groundborne vibrations.

Objectives:
The main aim of the project is to study and improve the understanding of the interactions between the ground, the track system and train vehicle behaviour, especially recursive processes giving positive feedback. The specific objectives are:
• To continue the development of instrumentation and carry out further field measurements to understand quantitatively and mechanistically the behaviour of track systems of different types subjected to different loads
• To gather data on the geophysical properties of the ground and vibrations at the same sites
• To carry out further laboratory tests to investigate the susceptibility of different subgrade materials to cyclic principal stress rotation (PSR)
• To assess the ISVR 2.5-dimensional method for modelling ground vibrations from railways by analysing the results from the test sites
• To develop an analytical model for track system response that includes a frequency dependent ground stiffness
• To identify and quantify the parameters needed to model track system behaviour in a vehicle dynamics study
• To develop models that enable the interdependence of vehicle dynamic response, the generation and propagation of groundborne vibrations and the geotechnical characteristics of the track system and the ground to be determined.

Brief Summary of Research Methods:
Field monitoring of dynamic loads and displacements and S- and P- wave velocities, frequency response functions of the ground and track and the vibration response of the track to known train loadings; laboratory cyclic hollow cylinder tests; and 3- and 2.5- dimensional dynamic finite element, boundary element and/or finite difference modelling.

Work Done:
Project A4 combines a number of different, independent tasks in addition to tasks which are interlinked. At present most of the work to date has involved the independent tasks.

Work has continued on the development of instrumentation for site monitoring. This has included the updated remote video monitoring system to include high speed digital picture acquisition for use on high speed train lines. Remote datalogging has been implemented to increase the number of site locations available for monitoring .

The high speed remote video monitoring has been successfully trialled on a section of the Channel Tunnel Rail Link (CTRL) and the West Coast MainLine (WCML) and shown to be effective at quantifying ground deformation at the train speeds encountered. The remote datalogger has been trialled within the lab environment and is currently awaiting NR approval to be validated under working site conditions.

Further field measurements have been carried out on both the WCML and CTRL to understand qualitatively and mechanistically the behaviour of different tracks to different loading conditions. On the WCML work has been conducted to assess the effect of high speed tilting trains (Pendolinos) on track behaviour. Initial studies have shown that Pendolinos increase the magnitude and frequency of loading possibly leading to more rapid degradation of the ballast. On the CTRL, work has been carried out to investigate the mechanism of lifting ballast during train passage. In collaboration with CTRL, UoB and UoS using vibrational and aerodynamic measurement techniques. Initial results suggest that the 'flying ballast' phenomenon cannot be attributed to either geotechnical or aerodynamic effects acting individually, but may be a result of a combination of these in certain site conditions.

Site measurements and analysis have also continued on the Great Central Railway (GCR) near Loughborough through Dr Michael Burrow. A range of geophysical measurements on the Victorian embankment have been made to characterise the geotechnical structure railway embankments.

Advanced 3D modelling and 2D dynamic modelling have been carried out to understand ground behaviour underneath a railway. Stress changes during loading have been investigated, especially in the context of principal stress rotation. Numerical Modelling has considered dynamic stress changes in the track as a function of speed, braking and acceleration and track geometry defects. The numerical code for modelling ground vibrations from railways has been updated with the 2.5 dimensional boundary element code previously developed having been incorporated into a more systematic code that can be more easily maintained. As a result, the boundary elements are now coupled with a much more versatile set of finite elements.

Work Remaining:

Specific tasks remaining include;

- development of an analytical model for track system response that includes a frequency dependent ground stiffness
- identification and quantification of the parameters needed to model track system behaviour in a vehicle dynamics study
- assessment of the ISVR 2.5-dimensional method for modelling ground vibrations from railways by analysing the results from the test sites
- further laboratory tests to investigate the effects of principal stress rotation on sub-base soil behaviour.

Outputs:

- Chambers, J.E. , Gunn, D.A. , Wilkinson, P.B. , Ogilvy, R.D. , Ghataora, G.S., Burrow, M.P.N., and Tilden Smith, R. (Accepted). Non-invasive time-lapse imaging of moisture content changes in earth embankments using electrical resistivity tomography (ERT). *1st ISSMGE International Conference on Transportation Geotechnics.* 25-27 August 2008, Nottingham, UK.
- Gunn, D.A., Chambers, J.E., Reeves, H.J., Ghataora, G.S., Burrow, M.P.N., Weston, P., Ward, D., Lovell, J.M., and Tilden Smith, R. (Accepted). New geophysical and geotechnical approaches to characterise under utilised earthworks. *1st ISSMGE International Conference on Transportation Geotechnics.* 25-27 August 2008, Nottingham, UK.
- Priest, J. A., Powrie, W., Le Pen, L., (accepted). Performance of canted ballasted track during curving of high speed trains. *1st ISSMGE International Conference on Transportation Geotechnics.* 25-27 August 2008, Nottingham, UK.
- Thomas, A.M., Burrow, M.P.N., Rogers, C.D.F., Chapman D.N., Metje, N., Gunn, D., and Nelder, L. (Accepted). Electromagnetic characterisation of a victorian railway embankment fill material. *3rd International Conference on Site Characterization.* 1-4 April, 2008. Taipei, Taiwan.
- Burrow, M.P.N., Bowness D., Ghataora, G.S. (2007). A comparison of railway track foundation design methods. *Proc. IMechE Vol. 221-1 Part F: J. of Rail & Rapid Transit.* pp. 1-12.
- Powrie, W., Yang, L.A., Clayton, C.R.I. (2007). Stress changes in the ground below ballasted railway track during train passage. *Proc. IMechE Vol. 221-2 Part F: J. of Rail & Rapid Transit.* pp. 247-262.
- Powrie, W. (2006). RRUK and Track Systems Research. *Railway foundations, RailFound 06, proceedings of the first international conference on railway foundations.* University of Birmingham, UK. pp 187 -189.
- Clayton, C.R.I., Grabe, H., Powrie, W. (2006). Ground investigations and monitoring for track formation problems. *Railway founations, RailFound 06, proceedings of the first international conference on railway foundations.* University of Birmingham, UK. pp 1 -22.

Project A5: Aerodynamic/Train System Interaction

Named Investigators: Prof Simon Iwnicki (Manchester Metropolitan University); Prof Chris Baker (University of Birmingham)
Researchers: Dr A Bouferrouk (University of Birmingham); Dr Javier Perez (Manchester Metropolitan University)
Current Industry Support: Roger Gawthorpe (Independent Consultant); Interfleet; Porterbrook; RSSB;

Background:
Around the world there is a general trend of increasing train speeds, which brings a number of associated problems. One of these is the increasing significance of aerodynamic forces, because their magnitude increases roughly with the square of train speed. In the past the major aerodynamic concern of train designers has been the aerodynamic drag force, the magnitude of which relates directly to the traction requirements and energy consumption. However in recent years the importance of a number of other aerodynamic forces of an unsteady or transient nature has come to be realised.

A recent RSSB scoping study has identified three types of aerodynamic forces on trains that are of continuing concern:

- The forces and moments on trains due to high cross winds which can, in the extreme, cause vehicles to overturn, and can also cause vehicle and load displacements that potentially, particularly for freight trains, can infringe the kinematic envelope
- The transient forces caused by passing high speed trains, which can result in high transient loadings on train structural members
- The transient forces on train structural members due to the pressure pulses that occur as trains pass through tunnels

These all have major safety implications and are becoming of increasing concern to the railway industry. The RSSB review of current work in this field broadly identified two areas in which fundamental research is required – the specification of the unsteady aerodynamic loads on trains for a variety of situations, and the determination of how these loads interact with the train system.

Brief Summary of Research Methods:

- Determination of aerodynamic forces from analytical methods and previous work.
- Analytical simulation of cross wind characteristics and the resulting forces
- Use of analytical cross wind forces in VAMPIRE model of train, with realistic track simulation (from Project A4)
- FE simulation of transient aerodynamic forces in train frames

Objectives:

- To review current knowledge on the unsteady aerodynamic forces on trains
- To specify appropriate analytical/numerical formulations of the unsteady loading due to cross wind effects, the effects of passing trains, and the pressure transients in tunnels
- To develop a model of train dynamic systems that enables inclusion of the effects of unsteady aerodynamic forces and can be used to predict resulting vehicle displacements
- To develop a model of the internal vehicle forces due to unsteady aerodynamic force input
- To utilise the above formulations of unsteady aerodynamic loads and models to investigate the effects for a variety of different wind speeds, train passing speeds, tunnel sizes etc
- To research and develop methods to link aerodynamic forces on railway vehicles with the dynamic behaviour of the vehicle such that aspects of the behaviour relating to derailment, passenger comfort and structure gauge infringement can be simulated effectively.

Work Done:

- Development of analytical models for cross wind forces on trains, and simulation of cross wind force time histories
- Inclusion of these forces within VAMPIRE model and determination of running conditions that involve risk in terms of vehicle roll over and flange climb derailment. Work to date has concentrated on cross wind effects, and these aspects of the first three objectives have been achieved.

Work Remaining:

Future work will begin to investigate sudden pressure transients, and then move onto objectives 4 and 5 which will involve FE modelling of aero forces in train frames. These models will be applied to assess the vehicle behaviour in various running conditions. This work will more than consume the remaining staff resources and it is likely that the original project scope will have to be trimmed somewhat.

Outputs:

- Baker C J, Bouferrouk A, Perez J, Iwnicki S D (accepted). The integration of cross wind forces into train dynamic calculations. *World Congress on Rail Research*, Seoul, S Korea.
- Dobney K, Baker C J, Quinn A D, Chapman L (accepted). Quantifying the Effects of High Summer Temperatures due to Climate Change on Buckling and Rail Related Delays in the UK. *World Congress on Rail Research*, Seoul, S Korea.
- O'Neil H, Baker C J, Bouferouk A (forthcoming 2008), T689 Project; Pantograph sway and wire displacements under wind loading. *Interfleet report to RSSB* ITLR-T18615-003.

Project A6: Three-Dimensional Microstructural Modelling of Crack Initiation in Rail Steel

Named Investigators: Prof Ajay Kapoor (University of Newcastle); Dr Claire Davis (University of Birmingham)
Researchers: Dr David Fletcher, Dr Francis Franklin (University of Newcastle); Dr John Garnham (University of Birmingham)
Current Industry Support: Corus Rail Technology

Background:
Rolling-sliding, cyclic contact of wheel and rail progressively alters the microstructure of the contacting steels, eventually leading to micro-scale crack initiation, wear and macro-scale crack growth in the railhead. Relating the microstructural changes to subsequent wear and cracking is being accomplished through modelling at three spatial scales: (i) bulk material (ii) multi-grain and (iii) sub-grain. The models incorporate detailed information from metallurgical examinations of used rails and tested rail material. The initial 2-dimensional models representing the rail material are being developed into 3-dimensional models, which will have capacity to take account of thermal effects and the traffic patterns to which the rails are exposed.

Brief Summary of Research Methods:
The research carried out within this project is based on a combination of very detailed microstructural observations and characterisation, novel methods for three-dimensional crack analysis and advanced computer modelling. Specifically the experimental work has involved: metallurgical analysis (optical and scanning electron metallography; macro-, micro- and nano-hardness testing; chemical analysis); heat treatment; twin-disc rolling-sliding contact testing; X-ray computed tomography; focussed ion beam microscopy. The modelling work is using Dyna3d explicit finite element code, and in-house developed C/C++ code for materials modelling and summation of damage under variable rail traffic.

Objectives:
The main aim of the project is to predict rail life based on knowledge of particular rail steel microstructures. This will enable rail grades to be selected appropriately for specific routes, according to traffic / track geometry, in order to minimise maintenance costs. The objectives are:

- To understand and model the three-dimensional nature of the rail steel microstructure and the implications for crack initiation and growth.
- To identify critical factors limiting rail life and suggest rail management strategies to minimise their impact.
- To provide guidance to infrastructure owners and rail manufacturers on desirable rail microstructures for minimising crack initiation and wear.

Work Done:
Following the work done within project A2, further series of twin disc rolling-sliding tests have been carried out on rail material (as received and heat treated to generate a range of microstructures with different pro-eutectoid (PE) ferrite fractions) at varying fractions of rail life. These tests have generated samples with rolling contact fatigue cracks at different lengths corresponding to initiation events within one prior austenite grain to cracks of length equivalent to several grains.

These samples are enabling the complex interaction between the initiating and propagating small cracks and the 3D microstructure to be investigated, for example using X-ray tomography, FIB / SEM analysis (shown below) and serial sectioning. The materials modelling work is concentrating on developing the 'dynarat' computer simulation tool. In the simulation, the material properties of each element can be selected to construct a representation of rail steel microstructure, initially as a hexagonal pattern requiring input from the microstructural characterisation work described above. This is a reasonable approximation of rail steel microstructure for the wear model and for indicating the probable depth of initiating cracks.

However, to understand how cracks initiate and begin to grow in real steel microstructures, the regular and 2D nature of the hexagonal microstructure is not appropriate since barriers to crack growth are not represented. Hence 3D microstructures are being generated using 3D cellular automaton (which uses random processes to 'grow' grains) or Voronoi polyhedra. The Voronoi method has the advantage that grains can be represented by their surfaces, making manipulation and graphical representation easier and reducing computation time.

Of course, representation of pearlitic rail steel as 'pearlite' grains with (prior-austenite) grain boundaries is overly simplistic. At the sub-grain level, standard pearlitic rail steel is a 3D composite of ferrite and cementite phases, plus non-metallic inclusions. Failure is dependent on how stress and strain are accommodated by these phases, inclusions and the bonds between them. This is being investigated using an elastic-plastic large strain deformation explicit finite element study of the microstructure, which will provide property information at the micron level, with a detail impractical to measure experimentally. For suggesting rail management strategies to minimise the impact of crack initiation the focus is on rail grinding. Software written in C is being developed to rapidly sum and quantify the interacting processes of crack initiation, propagation and wear damage over periods of years from multiple types of rail traffic. Through this model the effect of rail grinding interventions can be examined to find optimum strategies for removal of damage.

Work Remaining:
At Birmingham further experimental work is proposed to examine the small cracks in relation to their 3D interaction with the microstructure using the techniques mentioned above. At Newcastle, work will focus on modelling of crack initiation and early growth focusing on predicting the rail management required to minimise impact of this damage. Software will be developed for modelling grains as Voronoi polyhedra.

Outputs:

- Fletcher, D.I., Franklin, F.J., Garnham, J.E., Muyupa, E., Papaelias, M., Davis,C.L., Kapoor, A., Widiyarta, M., and Vasić, G., (accepted). Three-dimensional microstructural modelling of wear, crack initiation and growth in rail steel. *World Congress on Rail Research, WCRR 2008*, Seoul, Korea.
- Franklin, F.J., Garnham, J.E., Fletcher, D.I., Davis, C.L. and Kapoor, A., (accepted). Modelling rail steel microstructure and its effect on crack initiation. *Wear.*
- Garnham, J.E. and Davis, C.L., (accepted). The role of deformed rail microstructure on rolling contact fatigue initiation. *Wear*.
- Hyde, P., Fletcher, D.I., Kapoor, A., and Richardson, S. (accepted). Full-scale testing to investigate the effect of rail head treatments of differing pH on railway leaf films. *World Congress on Rail Research, WCRR 2008*, Seoul, Korea.
- Fletcher, D.I., Franklin, F.J. and Kapoor, A., (forthcoming, 2008). Chapter on Rail wear and fatigue in *Wheel/Rail Interface Handbook* edited by R. Lewis and U. Olofsson. Woodhead Publishing.
- Franklin, F.J., Garnham, J.E., Fletcher, D.I., Davis, C.L. and Kapoor. A., (forthcoming 2008). Chapter on Modelling damage in rails' in *Wheel/Rail Interface Handbook* edited by R. Lewis and U. Olofsson. Woodhead Publishing.
- Garnham J.E., and Davis, C.L.., (forthcoming 2008). Chapter on Rail Materials in *Wheel/Rail Interface Handbook* edited by R. Lewis and U. Olofsson. Woodhead Publishing.
- Franklin, F.J., and Kapoor, A. (2007). Modelling wear and crack initiation in rails. *Proc. IMechE Vol. 221-1 Part F: J. of Rail & Rapid Transit*, pp. 23-33.
- Garnham, J.E., Franklin, F.J., Fletcher, D.I., Kapoor, A., and Davis, C.L. . (2007). Predicting the life of steel rails *Proc. IMechE Vol. 221-1 Part F: J. of Rail & Rapid Transit*, pp. 45-58.

Project B6: Human-Automation Interactions in Rail Network Control

Named Investigators: Dr Sarah Sharples (University of Nottingham); Prof John Preston (University of Southampton)
Researchers: Sarah Harris, Nora Balfe [PhD student sponsored by Network Rail and EPSRC] (University of Nottingham); John Armstrong (University of Southampton)
Current Industry Support: Network Rail; Arup

Background:
Signallers and controllers are crucial for the efficient, reliable and safe running of railways. Understanding the skills and expertise of these key workers is particularly important in the case of modern technical support systems, such as ARS, ERTMS and the prototype tools developed by Project B1, which may also require new organisational systems.

The Human Factors approach addresses issues arising from a belief that automation will solve operational problems and that better technical systems will improve performance. 'Ironies of automation' have been found in many industries. Automation often fails to provide the expected benefits in functionality and reliability compared to human-centred systems. Automation can fail and then recovers less well than do people. The people designers believe to be unreliable in fact keep the total system running, despite technical failures. The very skills that people can bring to a hybrid (automation plus people) system are difficult to develop and maintain if the design philosophy is for them to be monitors only. Failure of automatic systems can then be catastrophic for performance continuity. There is therefore an ongoing need for the involvement of people in complex operating systems such as rail network control.

Objectives:
1. To explore and define the technical and organisational systems which best allow a hybrid control option whereby safe, efficient and reliable network control is achieved through well-designed collaborative partnership between human operators and various types and level of automated system.
2. To identify decision and communications support that make best use of staff skills to interpret, prioritise, intervene and optimise.

Brief Summary of Research Methods:
The project will draw from and expand on current work with Network Rail to identify the skills, experience and needs of signalling and control (see, for example, Pickup et al., 2005) and examine these in the light of requirements of ERTMS and other systems, such as the prototypes developed by Project B1. A variety of methods will be used. Ethnographic field analysis and cognitive work analysis will be used in the early stages. They will be followed by expert panels and cognitive walkthrough to examine the roles of key workers with various levels of automation, and particularly to generate functional analyses, scenarios and roles for a hybrid system using human skills and high quality technical support. Identification and development of existing and possible future forms of technical support will be based on the work on train control carried out in B1. The cognitive work analyses, operation sequence diagrams and human reliability predictions produced will then be used to assess the effectiveness of the different hybrid system options in terms of total system reliability and performance.

Anticipated Impacts and Benefits:
The need for improved train control has been identified by Network Rail, DfT Rail and TOCs. This project will bring together the relevant human factors and train control issues, to reduce delays to trains and their users and improve the efficiency with which the railway network is used.

Work Done:
UNott: This work has primarily been focussed on development of methodology and understanding of the impact of automation within rail control. The ironies of automation (Bainbridge, 1983) have been revisited and the key issues that are relevant for the modern railway control environment identified. These will be used as the basis for the analysis of ethnographic data collected in rail control environments during 2008-2009. A study has been done to assess the reliability of the observation methods and signaller work description categories to be applied in the data collection phase and this has shown an acceptable level of inter-rater reliability and validated the categories of work description to be applied.

In addition, work done in the NR sponsored project has examined the relationship between different signaller activities within ARS IECC environments.

Work is now underway to apply the observation techniques to a set of signal environments and compare the data obtained with the operational demand evaluation checklist (ODEC) and Integrated Workload scale (IWS) to gain a further understanding of the relationship between different types of automation use, signalling environment and perceived levels of workload.

UoS: Work has focussed on synthesising the results of the preceding project B1 (Preston et al., 2007) to determine the possible benefits of automation. Professor Preston contributed to a workshop on Network Management Research held in Stockholm in May 2007 and convened by Banverket and Network Rail. Related work has examined automating the import of rail timetable data (Armstrong et al., 2007), whilst more general work has examined possible railway futures (Armstrong and Preston, 2007). Future work will examine how a hybrid system might be developed to assist in network train control.

Outputs:

- Balfe, N., Wilson, J.R., Sharples, S. and Clarke, T. (accepted). Understanding rail signalling automaton. *World Congress on Rail Research*. Seoul, South Korea, May 2008.
- Balfe, N., Wilson, J.R., Sharples, S. and Clarke, T. (accepted). Structured observations of automation use. *Ergonomics Society Conference*. Nottingham, UK, April 2008.
- Armstrong, J., Preston, J. and Carlsson, M. (2007). Automating the import of electronic timetable data to EMME/2-based public transport models. *International Association of Railway Operations Research Conference*. Hannover, Germany.
- Armstrong, J. and Preston, J. (2007) Possible railway futures. Presented at *Transport – the Next 50 Years*. Christchurch, New Zealand.
- Balfe, N., Wilson, J.R., Sharples, S. & Clarke, T. (2007). Analysis of current UK rail signalling systems. *Human Factors and Ergonomics Society European Chapter conference on Human Factors for Assistance and Automation.* Braunschweig, Germany, October 2007.
- Preston, J., Armstong, J., Bouch, C., Goodman, C., Weston, P. and Takagi, R. (2007). Decision support system for dynamic re-scheduling of trains under disturbance. *11th World Conference on Transport Research*. Berkeley, California.

Project B7: Rail Industry System Cost Model

Named Investigators: Prof Chris Nash, Leeds; Prof Rod Smith, ICL; Dr Clive Roberts (B'ham)
Researchers: Kat Lovell, ICL; Dr Andrew Smith, Leeds; Phill Wheat, Leeds; Chris Bouch (B'ham)
Current Industry Support: ATOC; DfT

Background:
In the light of recent very sharp rises in rail industry costs, it is crucial for the rail industry and policy makers to maintain pressure to improve the efficiency of the system. The introduction of new technologies has an important role to play in this respect. However, there are concerns that the fragmented structure may be inhibiting the industry's ability to take a system-wide view in making investment decisions. In addition, it is important that the evidence from other countries is brought to bear in assessing the relative efficiency of Britain's rail industry and, in turn, that the industry learns from and implements best practice from overseas where appropriate.

Objectives:
This project builds on the outputs from project B4 (which include a detailed analysis of rail industry cost trends; and the development of a methodology for testing techno-economic trade-offs in the rail industry) and B5 (international benchmarking).

The project has three key objectives, which are:

1. System cost model - to build on the methodology developed in project B4 to develop a methodology to test the whole system cost impact of selected proposed technological developments in the industry;
2. Institutional arrangement - to investigate the institutional arrangements in the fragmented rail industry, assess the extent to which these arrangements provide appropriate incentives for whole system cost minimisation, and develop alternative options for improving the current arrangements;
3. Benchmarking - to compare the efficiency of Britain's rail industry and constituent parts using national and/ or international benchmarks

Brief Summary of Research Methods:
Data sources/collection methods; workshops, interviews/work with industry bodies; information contained in company annual reports and other published information; overseas railway specific data from our academic and railway company contacts overseas. Interviews will also be used to investigate the impact of the current, fragmented structure of incentives on investment decisions. Econometric methods (including frontier techniques) will be used to compare productivity/efficiency measures across countries and overtime, combined with discussions (meetings/workshops) with overseas railways/academic partners with regard to both the econometric work and engineering-based approaches to benchmarking.

Work Done:

1. System cost model:

The model/methodology produced by this project is intended to support the process of understanding the impact of a technology change in technology selection/decision making.

So far, work has focused on:

- Agreement on a statement of the operational concept of the model;
- Modelling of the high-level rail operations architecture using entity-relationship methods;
- Obtaining an understanding of the rail technological innovation process as the basis for identifying those technologies ready to migrate into the railway, and;
- Identification of cost categories and unit costs for inputs.

A decision has been made to use a system modelling tool called CORE to provide a framework for the model, and to act as a repository for systems information. As a result Chris Bouch has attended a CORE training session to gain experience in the use of the tool. Birmingham has also obtained a free academic licence and has begun work on developing the model in this environment. Work to date has concentrated on modelling standards (requirements), stakeholders and process flows through the use of constrained examples.

To verify and demonstrate the model a series of technology case studies will be used. To aid the selection of appropriate technology case studies Imperial is investigating the current innovation activities of the rail industry. This research uses interviews with industry members, which also provide an opportunity to discuss technology projects underway that might be appropriate cases for the model development.

2. *Institutional arrangements:*

The work at Imperial work will later contribute to a study on industry incentives to use technology introduction to reduce whole system costs. In investigating innovation in this industry, which is constrained by national boundaries and which has had innovation practices and technology trajectories disrupted by an externally imposed restructuring, this work can make a contribution to innovation studies in addition to that made to railway industry research.

3. *Benchmarking:*

Most of the work done to-date by Leeds has been in the area of benchmarking. Since Leeds is now undertaking an international benchmarking exercise for rail infrastructure for ORR, the RRUK funded work has instead focused on train operating costs. In this area, international data is inadequate for the purpose, so we have concentrated on analysis of the 25 or so British TOCs over the period since privatisation (1996-2006), using top down econometric techniques. This work is the first of its kind to study passenger train operating costs over the critical period since around 2000 when costs in the industry have started to rise considerably. Key findings include:

- between 2000 and 2006, passenger train operating costs (per train km) in Britain increased by 35%. Whilst some of the increases in cost can be explained (for example, by higher wages, the introduction of the 35 hour week, and changes in the characteristics of rolling stock), a large part of the increase (around 19%) remains unexplained in the model;
- those TOCs that ended up with re-negotiated franchise agreements or on management contracts saw much faster cost growth than other TOCs, possibly indicating that these arrangements weakened incentives for cost control at a critical time for the industry;
- the model also produces new results on the elasticities of cost with respect to variables such as passenger km, train km, and train length.

The TOC econometric work feeds into area 3 in the objectives, but also provides important information on efficiency performance and on some of the elasticities required to feed into the overall system cost modeling.

Work Remaining:

Leeds will focus the remainder of its resources on supporting Birmingham and Imperial on the technology cost modeling element of work, and also on investigating further the institutional arrangements and their impact on cost. The latter work will be taken forward via an interview programme, which will shed light on issues such as the way in which new technologies are introduced into the industry and the incentives for doing so. It will build on the work already completed by Imperial in this area.

Birmingham will continue work the development of the system modeling activity. A meeting has been arranged with the Department for Transport in mid-March. It is intended that after this meeting the scope and remit of the modeling work can be set.

Imperial will work with Birmingham on the development of the model through the investigation of a series of technologies, how they might be implemented and the anticipated effects of their introduction into the UK rail system.

Outputs:

- Nash, C.A. and Smith, A.S.J. (2007). Passenger Rail Franchising - British Experience. *Competitive Tendering for Rail Services,* OECD / ECMT, Paris.
- Smith, A.S.J. and Wheat, P.E. (2007). A Quantitative Study of Train Operating Companies Cost and Efficiency Trends 1996 to 2006: Lessons for Future Franchising Policy. *European Transport Conference,* AET.

Project B8: Advanced Concepts for Condition Monitoring around the Wheel-Rail Interface

Investigators: Prof Roger Goodall, Dr Roger Dixon (Loughborough University); Dr Clive Roberts (University of Birmingham); Prof William Powrie (University of Southampton)
Researchers: Dr Guy Charles (Loughborough University); Dr Paul Weston, Mr Edward Stewart (University of Birmingham); Dr Jeffrey Priest (University of Southampton)
Current Industry Support: Alstom, Arup, Bombardier, DeltaRail, HSBC Rail, LUL, Metronet, Network Rail, PCMS Eng, South Eastern Trains

Background:
A feasibility assessment of innovative ideas in relation to condition monitoring of the wheel-rail interface was started at Loughborough within the first phase of RRUK, in particular the problem of real-time estimation of the wheel-rail profile. RRUK2 Project B8 has both continued this work and broadened the scope to include Birmingham and Southampton, firstly to investigate condition monitoring of switches and crossings, and secondly to link in some of the track monitoring concepts achieved in project A1.

The research on the condition monitoring of switches and crossings, which remains a significant proportion of the total cost of infrastructure, is aimed towards facilitating a move from calendar-based to condition-based maintenance will provide large benefits to operating costs. The estimation of wheel-rail profile is a more speculative deliverable, but if real time profiles can be achieved then short-term variations will provide information of the condition of the rail head, long-term variations indicate wear of the wheel itself. The exact way in which the information would be utilised is to be determined as part of the research, but potential impact is large because this information is currently not available.

For railway track and the train, wheel irregularities, such as wheel flats, bad axles, are a major contributor to the performance of each. Current monitoring systems employed by NR are expensive and so only a small number exist at key sites. Therefore both freight and commuter trains on regional lines may never be assessed. This part of the project is therefore concerned with developing a monitoring technique for assessing irregularities in the wheel profiles of passing trains, which is both inexpensive and portable such that it can be utilised on any part of the rail network.

Objectives:
The overall aim is to employ advanced monitoring and processing concepts in order to provide the basis for a new generation of condition monitoring systems for railways principally focussed on vehicle-track interaction (VTI). Specific objectives are as follows:

1. To establish methods and benefits of fusing the data obtained from vehicle and track instrumentation, with a view to providing more effective and robust indications of the condition of vehicles and track.
2. To develop concepts and techniques for providing meaningful monitoring of switches and crossings.
3. To research estimation techniques by which wheel-rail profile can be estimated while the vehicle is travelling along the track.
4. To develop inexpensive, portable track-based monitoring that can both broaden the applicability of monitoring around the railway network and provide the information related to objective 1.
5. To provide experimental validation of new techniques with respect to available track data.

Brief Summary of Research Methods:
A range of model-based and knowledge-based techniques are being used to process data gained from both vehicle and track measurements. A key feature is to understand in a general case the benefits gained by bringing together the data from the track and vehicle sensors, and this will be applied to both specific condition monitoring objectives (2 and 3).

The work on switches and crossings is extending some of the concepts developed as part of a previous DTp-funded project, as well as studying the incorporation of track-based sensors in a manner still to be determined. The wheel-rail profile estimation is a scientifically-challenging problem that will start from a dynamic model as the main element to process the sensor data, but it is likely that prior knowledge of typical profiles will be built in to facilitate the non-linear estimation problem. Model-based condition monitoring approaches are central to the approach being followed, mainly concentrated on Extended Kalman Filters, but including work on Least Squares estimation methods.

The track monitoring aspects are focussed upon appraisal of wheel profile irregularities and their effect on track performance, in particular to assess the potential for ground based instrumentation, such as geophones, to quantify the degree of wheel irregularity It involves the development and implementation of track bed-based instrumentation to measure wheel irregularities, building on the work undertaken in project A1 and continuing in A4 with regard to use of ground based instrumentation. Analysis of data from site investigation is incorporated as part of the work, and correlation of such data with train mounted instrumentation will help differentiate the influence of train behaviour or track behaviour on sleeper velocities.

Work Done:
The following paragraphs describe achievements related to objectives 2, 3 and 4. A variety of opportunities are being followed with respect to experimental validation (objective 5).
Initial work used data collected from the Tyne and Wear metro to identify fey features of switches and crossing observable from in-service monitoring equipment. An improved six degree of freedom data acquisition system has been designed and constructed. This will be used during field tests with South Eastern trains scheduled for March 2008.

Initial feasibility studies have been completed aimed at estimating a nonlinear conicity function (in simulation results). These have applied Extended Kalman Filter and Least Squares Method approaches to the simulated vehicle response data and have highlighted key areas of difficulty in applying the Kalman Filter in higher complexity models.

Work done to date has focused on developing wireless data logging capabilities for the geophone system. The existing geophone measurement technique required hard wired connection between the various geophones. Due to NR policy this limited where the instrumentation could be used on the network. Lab trials have been completed using a wireless data logger provided by Microstrain Corporation, USA. So far there has been limited progress in terms of understanding how integrating the vehicle and track measurement data (objective 1).

Work Remaining:
To date the work at Birmingham has mainly focussed on data collection. Further planned work includes analysis of data collected during tests, detailed measurement of test switches and crossings and development of an in-service test.

Continuation of the application of various condition monitoring methods, to include Particle Filters, multiple model Kalman Filter, Sliding Mode approaches. Identify the feasibility of a practical solution to estimation wheel-rail profile in real time, and establish a practical measurement set to perform this.

Work remaining includes field trial of the wireless data logger to ensure that electrical interference from the overhead lines, or third rail, does not occur. Once field trials are complete the instrumentation will be used to monitor sleeper velocities for a number train passages to obtain data. Subsequent analyses of the data will be conducted to assess the effectiveness of geophones in quantifying the magnitude of wheel irregularities. The monitoring will be conducted at various sites through out the UK.

A key outstanding item is to meet objective 1, i.e. to understand the value of bringing together track and vehicle measurement data. The effort in this respect is currently being applied to identifying testing opportunities when it will be feasible to gather coordinated data from the two measurement systems under development.

Outputs:

- Bruni, S., Goodall, R.M., Mei, T.X. and Tsunashima, H., (2007) Control and Monitoring for Railway Vehicle Dynamics, *Vehicle System Dynamics*, 45(7-8), pp. 743-779, ISSN 0042 3114
- Charles G. A., Goodall, R. M., and Dixon, R., (2006) Wheel-Rail Profile Estimation, *Proc IET International Conference on Railway Condition Monitoring*, pp 32-37. ISBN 0 86341 732 9

Project B9: Optimum Use of CCTV on Railway Systems

Named Investigators: Dr Alex Stedmon (University of Nottingham)
Researchers: Sarah Harris (University of Nottingham)
Current Industry Support: Network Rail (project co-funders)

Background:
The use of CCTV on Europe's railways is becoming more widespread with increasingly diverse applications:
- at stations it can be used to alert staff to potential suicides and potential/actual criminal behaviour/ vandalism, the presence of suspicious packages, and to get early warning of and help manage problems of overcrowding and passenger flow
- on board trains, it is used to help drivers scan the behaviour of passengers boarding and alighting
- at level crossings it may be used to help signal staff ensure that the crossings are clear and safe for barrier lowering
- in maintenance and inspection tasks it can be used to help examine track for potential defects.

In the UK, CCTV is a pervasive technology however there is very little general guidance on its design and use. Research in the fundamental human factors issues is very limited and any guidance that exists appears to be very much application specific. At a basic level the successful use of CCTV relies on the skill and competence of operators performing complex visual tasks, supported by the technical capabilities of image quality, complexity and temporal aspects such as speed of change in the visual scene.

Brief Summary of Research Methods:
The focus of investigation within this work package has been drawn Network Rail's interest in station security and the associated issues of identifying suspicious activities. A variety of methods are being used in this work:
- literature reviews to provide a context and basis for work conducted in this work package
- field observation at signal boxes, using expert users (signallers) to gain an understanding of CCTV use for crossing safety
- expert consultation with Network Rail to clarify focus of investigation
- experimental approach using laboratory studies to investigate specific issues in CCTV use
- field observation at stations, using station security personnel to develop wider understanding of issues at station level

Objectives:
The main aim of the project is to examine and make recommendations for the optimum use of CCTV on the railway network. Specific objectives are:
- to identify salient characteristics of objects, people and their behaviours in railway settings on which to base a human factors experimental programme, construction of algorithms for automated analysis of security video
- to prioritise the critical human factors and develop an experimental programme to investigate the key human factors issues to do with monitoring of CCTV
- to develop a hybrid (in technical and organisational terms) human and automated monitoring system for security related CCTV in a railway context
- to make proposals for implementation and management of security CCTV monitoring for railway use and generalised more widely, which best integrates human and automated inspection capabilities now and in the future.

Work Done:
Two literature reviews have been completed (one general review and another specifically focussed on CCTV for railway applications). Two field visits have been conducted at signal boxes and three experiments have been conducted to investigate the use of CCTV and aspects of suspicious behaviour.

Work is now being focussed on field observation of CCTV use at stations (possibly with London Underground) to underpin the experimental work already conducted and develop the framework for classifying suspicious behaviour at stations in more detail.

Project C5: Passenger and Crew Environments

Named Investigators: Prof Michael Griffin (University of Southampton); Prof Kenneth C Parsons (Loughborough University)
Researchers: Dr Henrietta Howarth, Mr Martin Toward (University of Southampton); Miss Lisa Kelly (Loughborough University)

Background:
Current methods of evaluating the physical environment of passengers and crew are of variable quality. While some methods used in the rail industry reflect up-to-date knowledge others do not. In some cases alternative conflicting standards are in use with differences between the alternative methods and conclusions. In other areas, there is no clear guidance. Even when guidance exists, those needing the knowledge can find it difficult to locate and interpret.

Project C1 defined a facility for reproducing the internal environment of railway carriages, including noise, vibration and thermal environment. This simulator is available for use in project C5. Project C1 also developed draft 'design guides' to convey information to industry. During Project C5, the design guides will be further developed.

Brief Summary of Research Methods:
Systematic laboratory studies of passenger and crew responses to individual physical stressors (noise, motion, thermal, seating, etc.) relevant to the rail environment, laboratory studies of the combined effects of more than one physical stressor, the development of design guides, and the conduct of selected field trials.

Objectives:
The main aim of the project is to improve understanding of human response to the physical environment of passengers and crew in trains and to make this information available to the industry.

The project involves the use of the simulator to test and improve existing methods so as to provide guidance for the measurement, assessment and evaluation of the physical environment with respect to seating, vibration, motion sickness, noise, thermal and visual environments. The research includes the study of the relative importance of motion, noise, and the thermal environment in trains and the interactions between these environmental factors.

Some individual laboratory studies are being designed in the areas of thermal stress and vibration where the rail environment presents specific challenges (e.g. unilateral heat loads, and use of computers). The design guides are being continually developed and extended, partly to reflect growing knowledge and partly in response to industry needs.

During the project, the simulation facility will be available for the study of specific questions raised by the rail industry. Field studies will be conducted where they are considered the best means of obtaining information on passenger or crew responses to the train environment.

Work Done:
- Simulator design finalised September 2006
- Simulator cabin completed December 2006
- New building completed April 2007
- Simulator installation 2007
- Acceptance of the simulator under principal specification completed December 2007
- Draft design guides circulated for comment September 2006
- Studies of effects of vibration on passenger operation of keyboard devices completed 2007
- Laboratory studies in a solar simulation chamber and practical evaluations in trains for the provision of a practical model for the prediction and assessment of thermal comfort.

Work Remaining:
Optimisation of the new simulation facility will be conducted during early 2008 leading to a demonstration of its capability of reproduce ranges of noise, vibration, and thermal conditions relevant to railways. The final commissioning and acceptance under the full specification is expected to be completed in March 2008. Future work using the simulator will seek to provide methods of measuring, evaluating, and assessing the measured or predicted environment in current and future railway carriages so as to identify passenger and crew reaction (discomfort, interference with activities, motion sickness, and safety) and means of minimising such adverse reactions.

Specific investigations to be conducted during the coming months are laboratory experimental studies of the equivalence between noise, vibration, and thermal conditions, and field measurements of motion in rail vehicles. The laboratory studies will involve reproduction of rail vehicle vibration on the simulation facility. The findings will be employed to determine the relative importance of the different environmental factors on passenger comfort. The expertise and facilities will also be applied to railway-induced noise and vibration in buildings. In addition, the design guides are being developed to reflect growing knowledge and in response to industry needs.

Outputs:

- Griffin, M. J. (2007). Discomfort from feeling vehicle vibration. *Vehicle System Dynamics*, 45:7, pp. 679 – 698.
- Joseph, J.A. and Griffin M.J. (2007). Motion sickness from combined lateral and roll oscillation: effect of varying phase relationships. *Aviation, Space and Environmental Medicine*. 78:9 pp. 44–50.
- Qiu Y (2007) A seat-occupant model for the prediction of backrest transmissibility in the fore-and-aft direction. *42nd UK Conference on human responses to vibration*. Southampton, 10th – 12th September 2007.
- Toward M.G.R. (2007). Effect of subject characteristics on apparent mass. *42nd UK Conference on human responses to vibration*. Southampton, 10th – 12th September 2007.
- Morioka M. and Griffin M.J. (2006) Magnitude-dependence of equivalent comfort contours for fore-and-aft, lateral and vertical whole-body vibration. *Journal of Sound and Vibration*. 298, pp. 755–772.

Project C6: Determining the Costs of Delay to Different Types of Train

Named Investigators: Prof John Preston (University of Southampton); Prof Chris Nash (University of Leeds)
Researchers: Dr Graham Wall (University of Southampton); Daniel Johnson, Dr Richard Batley (University of Leeds)
Current Industry Support: ATOC; DfT

Background:
Network Rail's train regulation objective is to achieve a "fair and reasonable balance" between the minimisation of overall delay to train movements, the minimisation of overall delay to passengers and time-sensitive goods, the maintenance of connections between passenger trains, the avoidance of undue discrimination, the protection of commercial interests and the maintenance of safety and security. However, it is also difficult to make trade-offs between delays to passengers on different types of journey (e.g. through and connecting) and time-sensitive goods without knowing the respective values (costs) of those delays. The train classification system in use by Network Rail is too limited and coarse to be of much use for detailed timetabling and train regulation.

Objectives:
1. To develop a better understanding of the social costs of delays to passengers and freight trains.
2. To establish delay cost values for different train types.

Brief Summary of Research Methods:
The values of time, and thus the costs of known delay, to different types of traveller (business, commuter, leisure) and different types of freight, are already known and established. There is also a body of research on the value of reliability/punctuality, which concludes that in general the value of time for an unplanned delay is greater than the value of time for known journey time. For freight services, we will use the results of recent surveys undertaken by the University of Leeds using the LASP (Leeds Adaptive Stated Preference) software tool which have sought to quantify the value of reliability. For passenger services, we are planning additional Stated Preference research to consider variations in values by passenger type and time of day/week of travel, as well as the impact of information provision on the valuation of delay. Particular attention will be paid to valuing the trade-offs in terms of passenger delays of holding trains to ensure connections.

Using these values in conjunction with data on typical or actual train loading will enable the estimation of the aggregate costs of planned and unplanned delays to different types of train. While these total train delay costs will reflect the numbers and constituencies of their users, consideration will be given to whether delays to longer-distance services may have more extensive and serious effects than those to local services, through the loss of paths at later stages in the journey. A further consideration is the social cost resulting from delays if they impact on levels of rail traffic and hence mode split. Knowledge of relevant own and cross elasticities will be reviewed and existing values of external costs for road and air transport adapted to measure these further costs of delay, which will depend heavily on not just how much traffic is lost to other modes, but also on the location and time of day of that traffic. The costs will be greatest for peak hour trains paralleling heavily congested roads.

This topic has becoming particularly relevant given debates concerning the performance targets set in the 2007 White Paper Delivering a Sustainable Railway. In its 2007 Strategic Business Plan (SBP), Network Rail suggests a reliability target of 91.6% in England and Wales by the end of Control Period 4 (2014) is more realistic than the White Paper's 92.6%. Network Rail indicate that a 92.6% target could be achieved by expenditure of £400 million – but '(i)t remains unclear how highly passengers value continuous improvements in punctuality beyond around 90 per cent' (SBP, page 12). We will investigate whether such a threshold effect exists.

Work Done:
Work at Southampton has included synthesizing relevant work from projects C2 and C3 (Preston and Wall, 2007, Wardman et al., 2007) and developing a detailed literature review with respect to costs of delays for passenger services (Wall and Preston, 2007). A similar review for freight services is being undertaken by Leeds and is nearing completion.

The proposed Stated Preference work will complement substantial work using Revealed Preference data undertaken by Leeds for the Department for Transport (Batley et al, 2007) building on theoretical developments in the marginal valuation of travel time and scheduling (Batley, 2007).

Work Remaining:
Work at Southampton will focus on the design and implementation of the Stated Preference surveys.

Outputs:

- Batley, R. (2007). Marginal valuations of travel time and scheduling and the reliability premium. *Transportation Research.* E, 387 – 408.
- Batley, R., Nicolás Ibáñez, J., Wardman, M., Shires, J. and Whelan, G. (2007). A discrete choice study to assess the impact of reliability on passenger rail demand. *European Transport Conference.* Strasbourg, France.

Project C7: Strategies for Minimising Railway Energy Consumption

Named Investigators: Prof Rod Smith (Imperial College London)
Researchers: Matthew Read (Imperial College London)

Background:
There is an increasing awareness within the railway sector that it faces real economic and environmental challenges, coupled with new technology opportunities. Rising energy/fuel costs (particularly oil) and increasingly stringent environmental regulations are already beginning to take effect and this process will continue. This has particular significance in the UK where there is a heavy reliance upon diesel (fossil fuelled) traction (some 50% of total train miles in comparison with 10-15% on other major European railways). In addition the long lifecycle of rolling stock (from procurement to retirement) and infrastructure means that the rail sector is often unable to capitalise on immature technology which could well reach full market maturity during the life cycle of the assets. Rail therefore may lose competitiveness relative to other modes over time. The key to future sustainability therefore lies in the development of technological solutions and energy stewardship options that deliver improved environmental performance at reduced cost.

Brief Summary of Research Methods:
The project has focused primarily on traction energy use and technologies to reduce this. Therefore computer simulation of rail vehicles in order to calculate traction energy consumption using detailed power-train component models is the major basis of this research. This will be used to assess current performance and the potential for energy reduction of new technologies. In parallel analysis of available operational data will be conducted, allowing validation of computational methods. Small-scale experimental testing of power-train configurations is also proposed to provide further validation. The context of this in the overall well to wheel performance will be studied through research of the literature.

Objectives:
To understand and model the energy flow within the railway industry from well to wheel, and to develop cost effective strategies to optimise the use of energy within the rail industry.

Work Done:
A computer simulation tool has been developed in order to facilitate this research, this tool will continue to be developed and refined. At this point the tool has been used to conduct fundamental analysis of train driving styles and techniques, and of the power-train design and control strategy. Significant energy effects were predicted by varying driving technique, and also relatively simple design changes such as selective use of distributed traction motors and diesel engines have been studied. Evaluation of new traction technologies such as on-board storage hybrids has been commenced.

The design of a laboratory rig to investigate new technologies and provide model validation has been started. Substantial background research of the literature into the well to wheel context of the project has been completed.

Work Remaining:
The development of the computer simulation tool will include a train driver model based on current operating practice. This will be achieved through analysis of recorded journey data, and will focus on identifying the conditions under which powering, braking and coasting are initiated. This will be used to define a base level of performance for current rail vehicles, and to assess what energy savings may be achieved through improved driver training.

The evaluation of potential new traction technologies will focus on kinetic energy storage systems consisting of flywheels and continuously variable transmissions; these being identified as potentially efficient and cost effective options for enabling regenerative braking on diesel powered rail vehicles (particularly those with hydrodynamic transmissions). Comparison of a range of power-train components and configurations will be investigated using detailed computational modelling, and experimental testing will be carried out to prove some power-train concepts and validate simulation work. Performance of the full scale simulated vehicles will be compared with current diesel-electric and diesel-hydrodynamic vehicles.

RRUK Project Reports 2003-2007

• Bye, R., Hockey, G.R.J. (2006). Cognitive work analyses to investigate macroergonomic issues in train driver performance.

• Cox, G., Farrington-Darby, T., Wilson, J.R. (2006). Expertise in Railway Signalling: An analysis of the work of signallers and the skills, characteristics, knowledge and strategies that contribute to expert performance. IOE/RAIL/06/04DR.

• Farrington-Darby, T., Wilson, J.R. (2006). Expertise in Railway Control: A work analysis of the skills, characteristics, knowledge and strategies that contribute to expert performance in railway control. IOE/RAIL/06/01DR.

• Fowkes, A.S., Johnson, D.H., Whiteing, A.E., Nash, C.A. (2006). Freight Modelling Report. RRUK Report C3/5.

• Hatano, L. (2006). Comparing the Kyushu and UK transport and rail markets. RRUK/B5/2.

• Hatano, L. (2006). International Railway Comparisons & Benchmarking. RRUK/B5/Final.

• Preston, J., Wall, G., Whiteing, A. (2006). Rail User Needs and Delivery Mechanisms: Final Report. Report RRUK/C2/06.

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