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Institute of Railway Research

Wheels v Rails

A lecture presented to the IMechE Railway Division
7th November 2016

Dr Paul Allen and Dr Philip Shackleton

Overview

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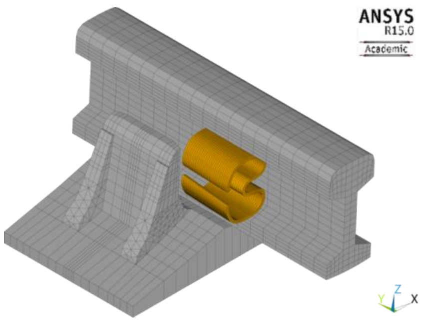
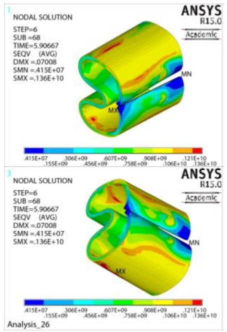
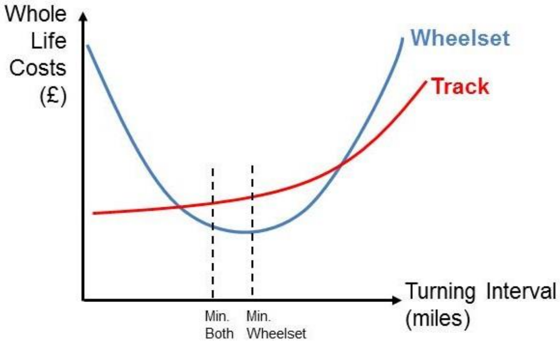
- The Institute of Railway Research
- A <u>bit</u> of wheel-rail interface history
- Some science and maths but not too much!
- Wheel-rail interface maintenance challenges
- Case Study: Crossrail
- A few other related research activities (time permitting!)







The IRR Team

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Management Team

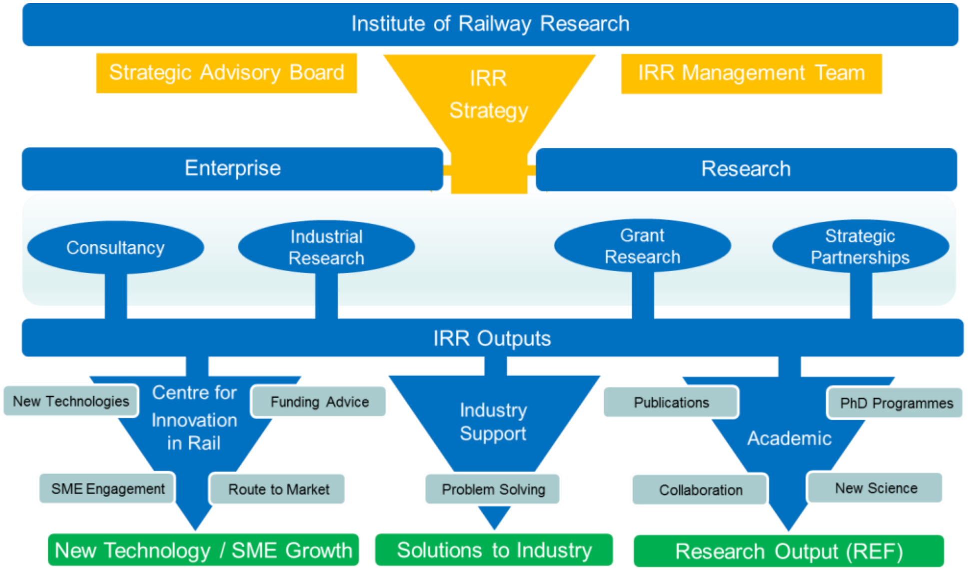
- 6 Senior staff

Research and Enterprise Team

- 25 Multidisciplinary specialists

Administration and Support

- 1 Group Administrator
- 1 Test Applications Engineer



Expertise

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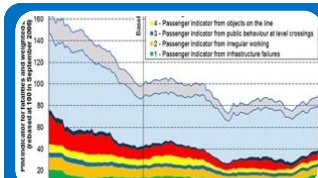
Wheel-Rail Interaction: Modelling and full-scale testing of wheel-rail contact and resulting damage (wear, rolling contact fatigue corrugation etc). Methods of optimising the interface for heavy rail, light rail and metro systems. Wheel-rail adhesion investigations.

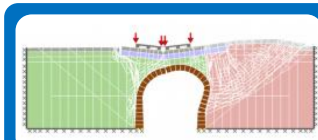
Railway Vehicle Dynamics: Vehicle behaviour and track interaction, performance optimisation for heavy rail, light rail and metro vehicles. Train braking system modelling and full-scale bogie testing facility.

Track-system Dynamics: Modelling and full-scale testing of complete trackforms and vehicle interaction. Predictions of force distributions, track and fixing response and structural resistance. Trackform design and failure mode investigations.

Instrumentation and Condition Monitoring: Vehicle and track mounted measurement systems, condition monitoring systems and asset life optimisation to aid a migration to predictive maintenance.



Railway Safety and Data Analytics: safety/risk modelling, safety system development, societal risk (e.g. modal shift), prognostics and Big data analytics for safety and engineering problems.



Civils and Structures: Masonry arch bridge and tunnel analysis, structural transition zone optimisation, train-structure interaction, noise and vibration.

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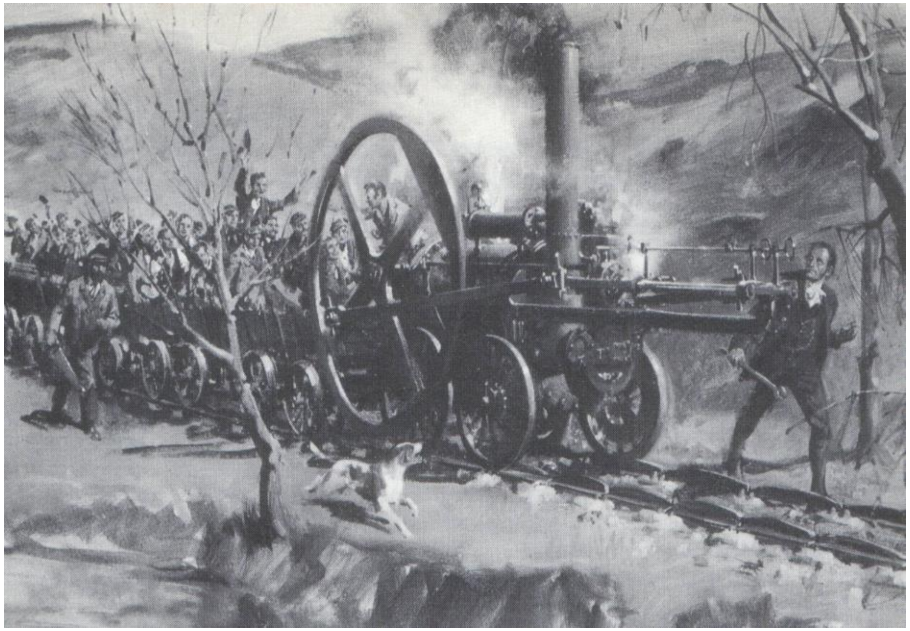
1803, Plateway for cylindrical wheels

Trevithick's 'tram engine' in 1804 running on a Plateway



Wheels v Rails

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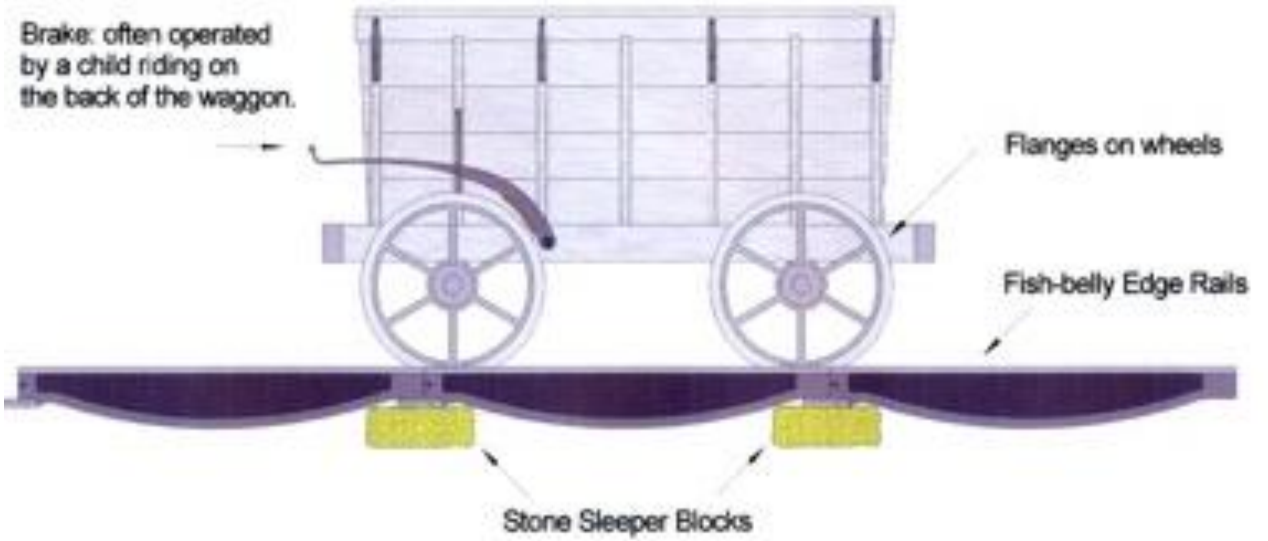
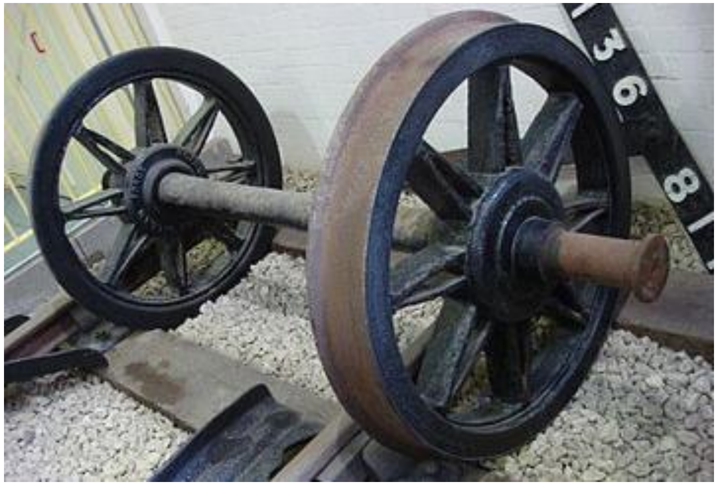


1789, Iron ore cart; William Jessop developed the cast iron Edge Rail and credited with the flanged wheelset.



William Jessop's flanged Wheelset and Fish-belly Edge Rails circa 1806

200 years on – unrecognisable??!!!

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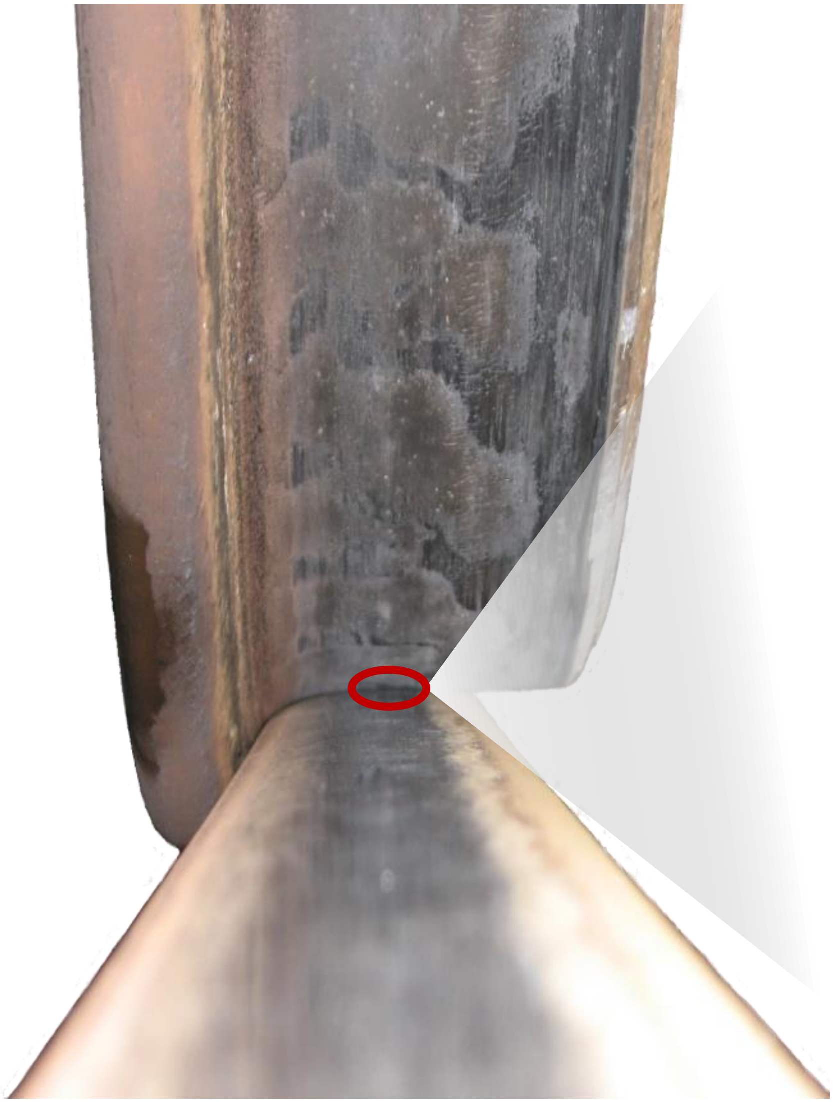
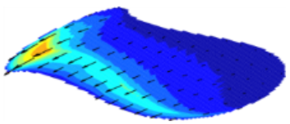


Creep Forces



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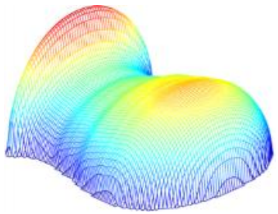
Shear stress

Normal Force



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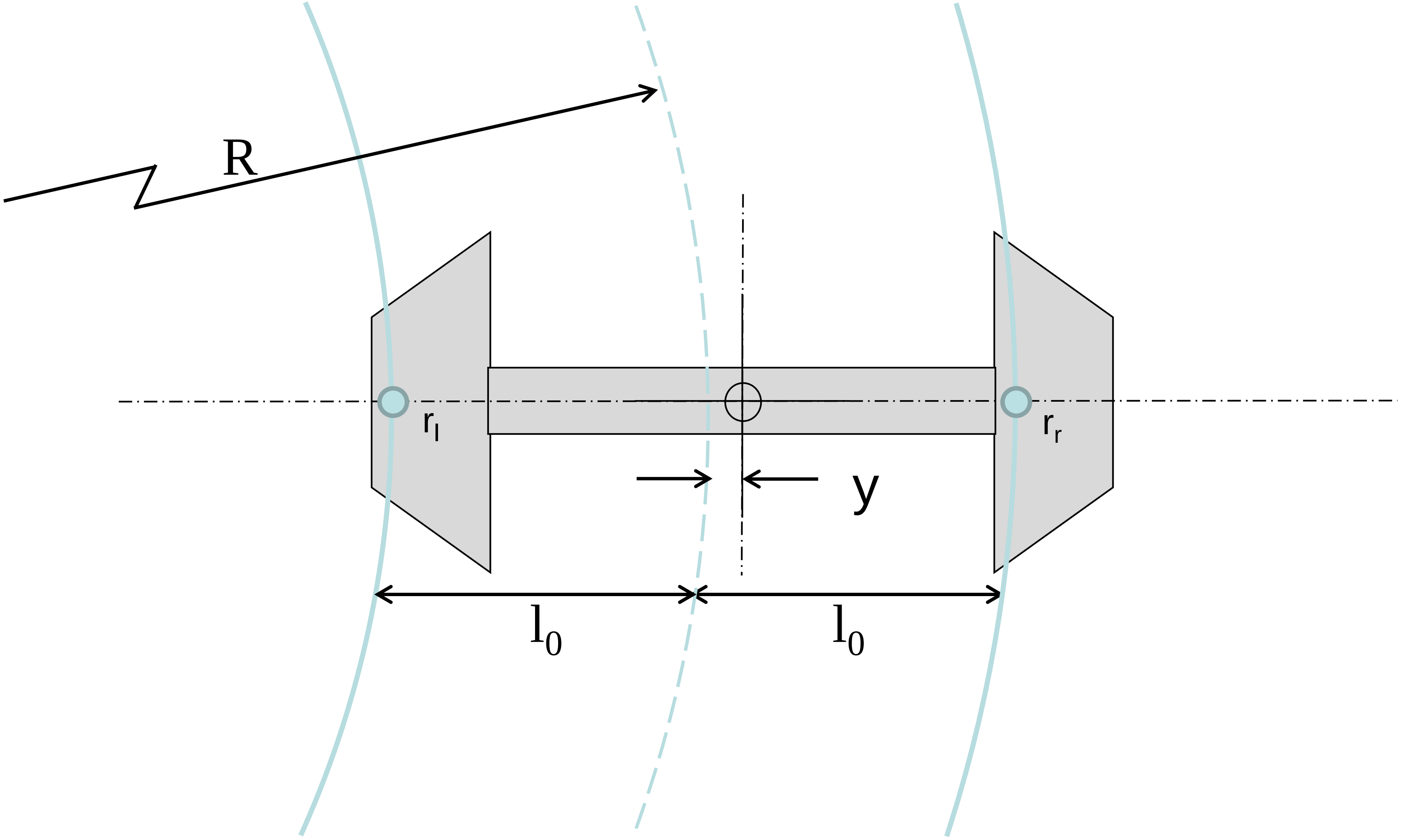
Normal stress
(Contact pressure)

The source of the 'problem'...

An idealised conical wheelset displaced laterally on cylindrical rails:



The source of the 'problem'…

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For perfect curving (pure rolling):

$$\frac{r_0 - \lambda y}{r_0 + \lambda y} = \frac{R - l_o}{R + l_o}$$

so:

$$y = \frac{r_0 l}{R\lambda}$$

Where
r_0 = the radius when the wheelset is central
l = half the gauge
R = the radius of the curve
λ = the conicity

In reality, for a constrained wheelset, pure curving does not exist. The wheel-rail relative slip (creepage) and tangential forces increase as curve radius decreases. This results in *shear stresses* over 2000 MN/m^2 within the interface and energy dissipated as heat and material wear.

The source of the 'problem'…

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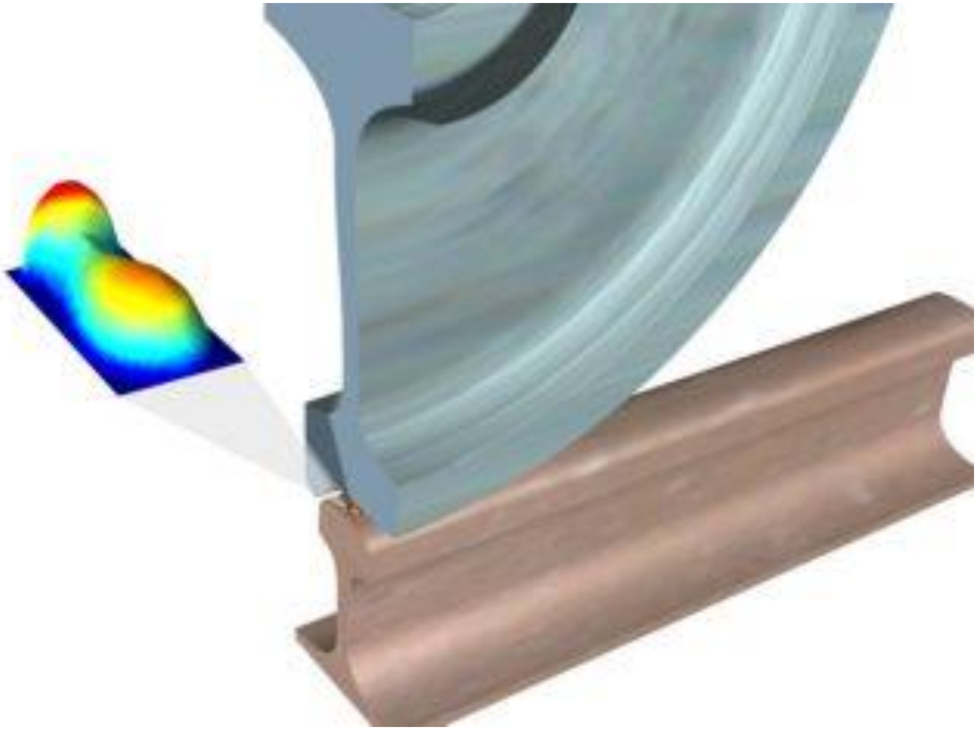
In the UK a single wheel can see a vertical load (Q) of up to 12.5t



The resultant contact patch between wheel and a rail is typically the size of a thumbnail and the *Normal Stress* can exceed 5000 MN/m^2

Wheel-Rail contact modelling for damage prediction

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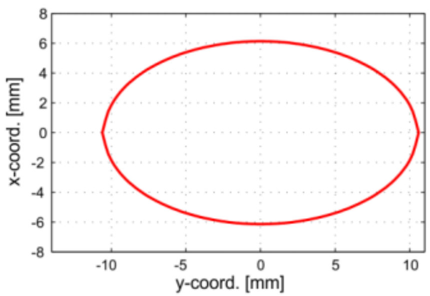
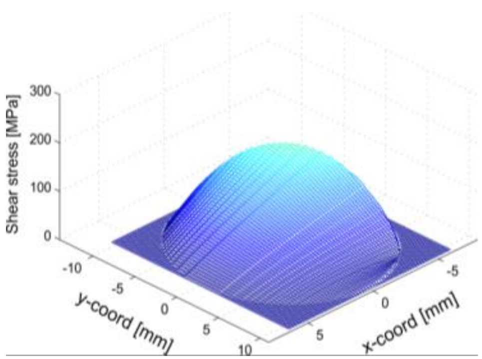
Fast ⟷ **Accurate**

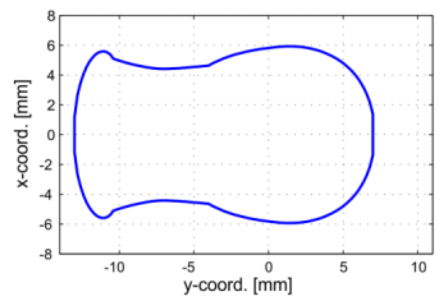
Hertz+FASTSIM

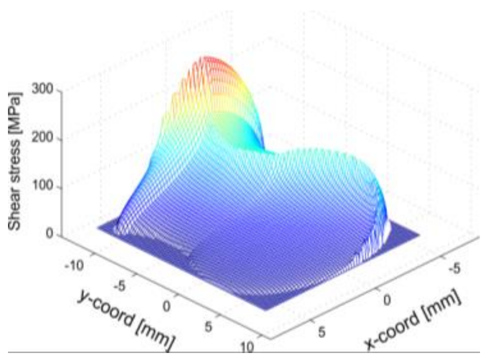




~ 0.02 second

ANALYN+FaStrip





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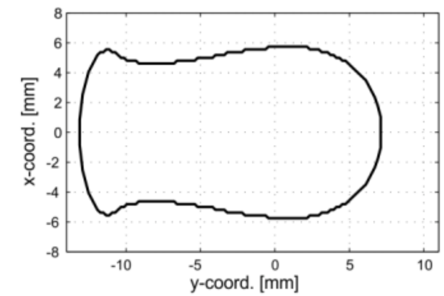
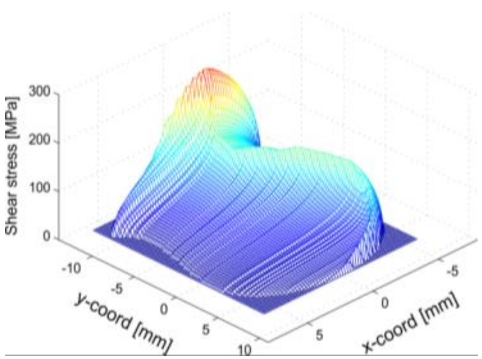
CONTACT code





~ 20 seconds

Resultant maintenance challenges

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Great progress has been made over the last 15 years in managing the wheel-rail interface but Plain line and S&C renewals remain a huge proportion of the railway's asset and maintenance costs.

Wheel-rail forces and contact stresses result in three key degradation mechanisms:

- Wheel-rail wear ($T\gamma$ and contact stress)
- Rolling contact fatigue (RCF)
- Loss of profile shape (Plastic flow)

Costly maintenance measures include:

- Rail re-profiling for loss of shape and RCF crack removal (milling and grinding)
- Wheelset re-profiling for wear/shape loss but also RCF
- Rail renewals
- Wheelset renewals

RCF Prediction

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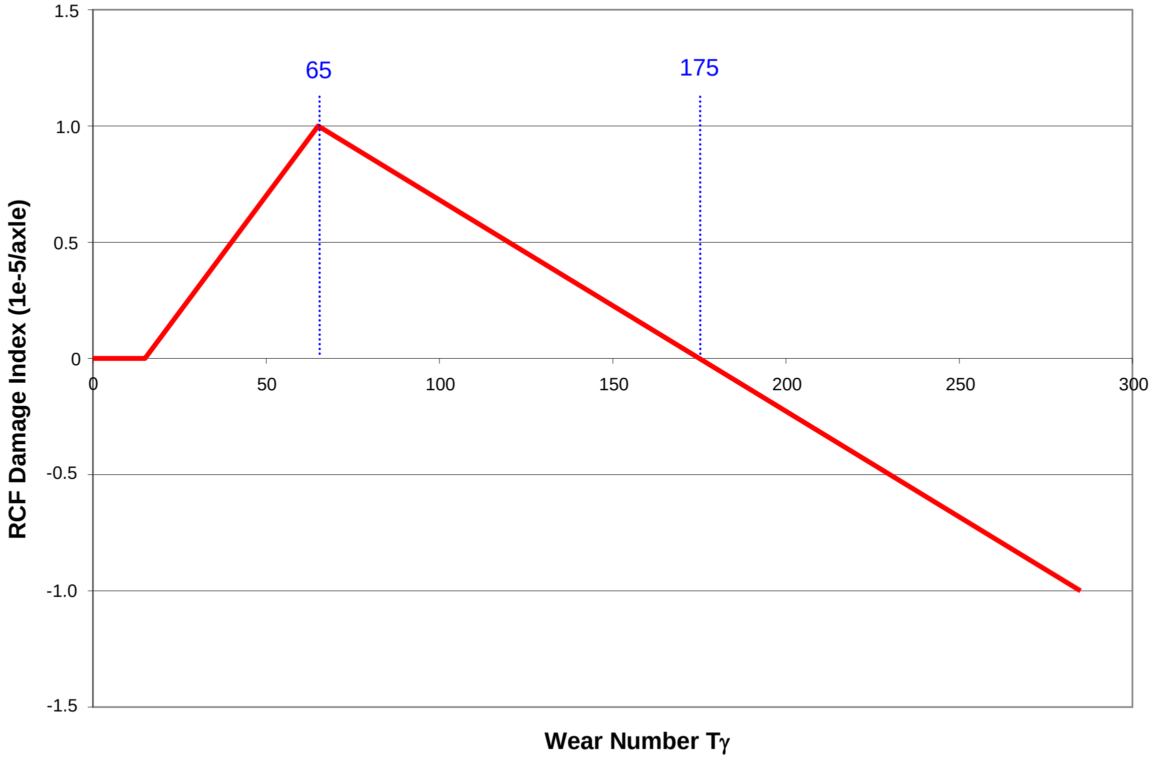
RCF Initiation Model:

(R260 Grade Steel)



- The units of the RCF damage index are 10^{-5} per axle pass, a damage index of 1, would require 100,000 axle passes for RCF initiation.
- In addition to modelling and prediction work, RCF mitigation measures now include:
  - NDT as an inspection measure (Eddy-current and ultrasonic trains)
  - Optimisation of a train’s Primary Yaw Stiffness (PYS)
  - Enhanced visual inspection routines for heavy/severe RCF sites

Wear Prediction

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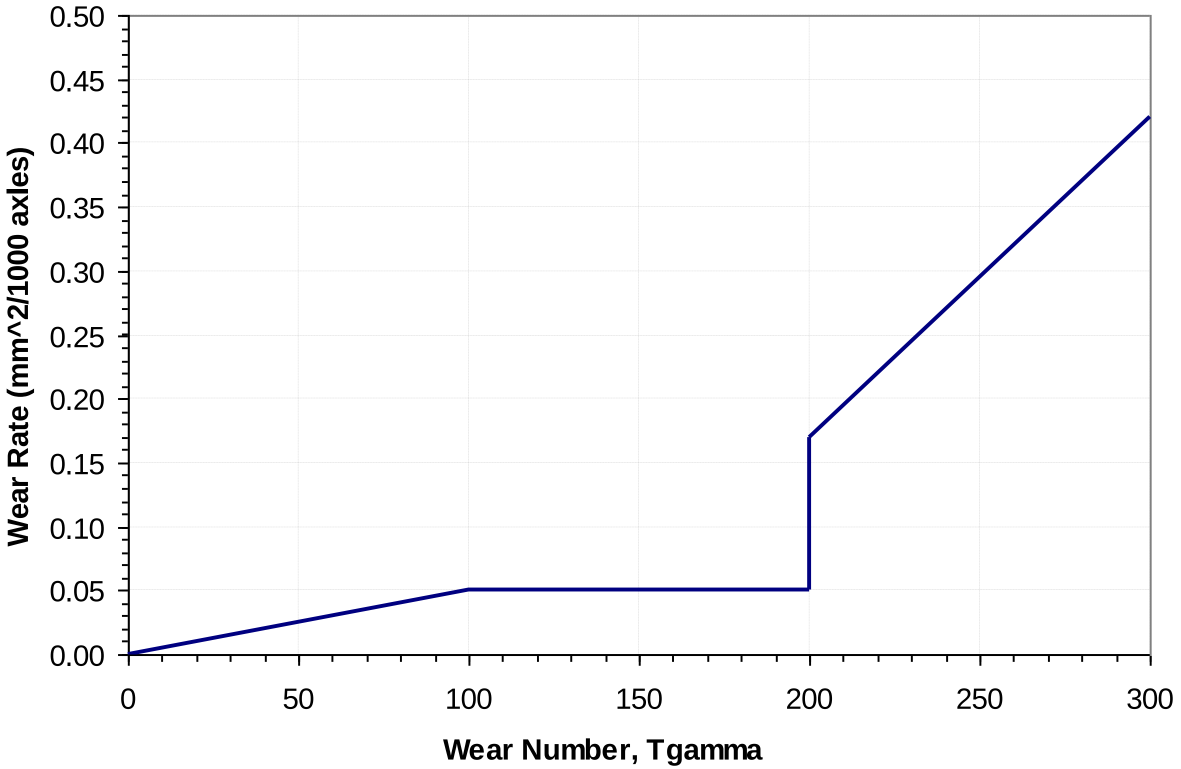
Wear Model:



- Wear model based on BR Research twin-disc tests for a single rail steel grade
- $T\gamma \leq 100N$, mild wear regime
- $100N > T\gamma \leq 200$; Severe region
- $T\gamma > 200N$; Catastrophic wear regime – typical of non-lubricated flange contacts
- Limited data at high $T\gamma$ and under lubricated conditions or Friction Modifcation

Case study: Crossrail

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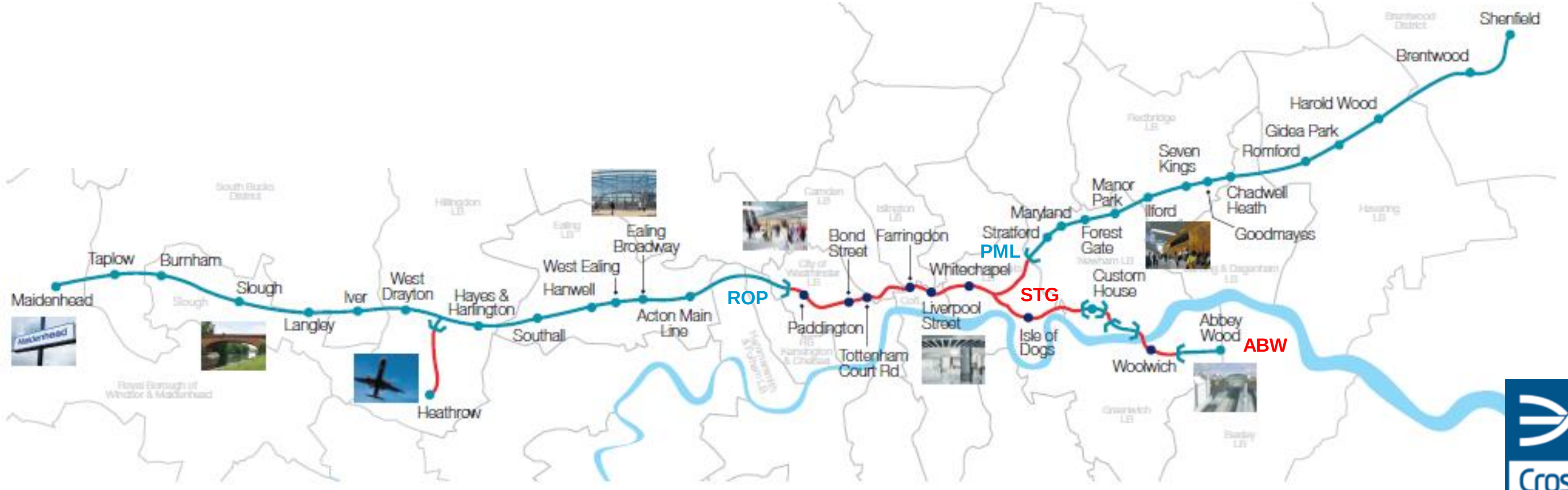
- The Crossrail network consists of 118km of new and existing line
- 53km of tunnelled sections, low radius curves (≈500m) and challenging gradients
- Very high peak service pattern (average 383 trains per day/60MGTPA!)
- Ongoing maintenance overhead and maintaining service levels and reliability is a significant challenge
- Crossrail is adopting an early proactive approach to managing the interface and assisting in developing the science of wheel-rail damage prediction



Crossrail

Case study: Crossrail

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Aims of the study:

- To identify and manage locations which may be prone to early initiation of rolling contact fatigue (RCF) and high levels of wear
- To investigate a range of influencing parameters such as cant deficiency, w/r profile, lubrication and friction modifiers
- To develop a rail life and maintenance visualisation tool to facilitate maintenance planning
- To help further the state-of-the-art in rail damage prediction modelling

- The work includes some developments over previous studies:
    - A revised implementation of the RCF model based on the direction of the creep forces
    - A wide ranging literature review and subsequent inclusion of RCF functions for alternative rail steels
    - A whole route, multi-scenario simulation approach
    - Development of a rail life and maintenance planning visualisation tool

Crossrail

Train mass/traffic levels

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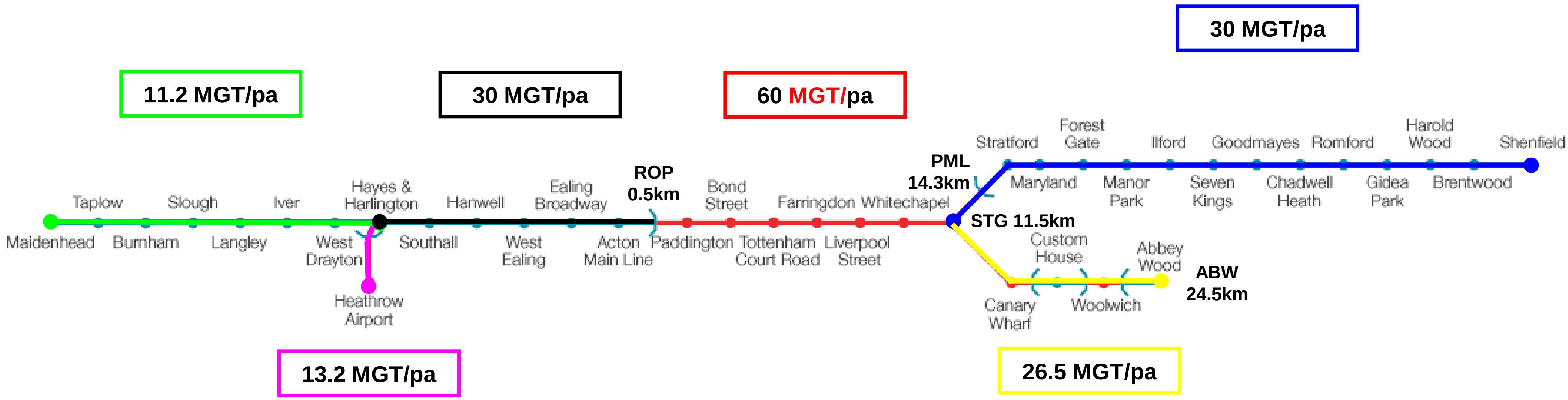
Traffic levels calculated from initial Crossrail service timetable, using following assumptions:

- 9 vehicles per Full Length Unit (FLU)
- Tare FLU tonnage of 320t
- 1500 passengers @80kg (EN 15663)
- Design vehicle gross tonnage of 440t



Above figures indicative

Crossrail

Curvature distribution

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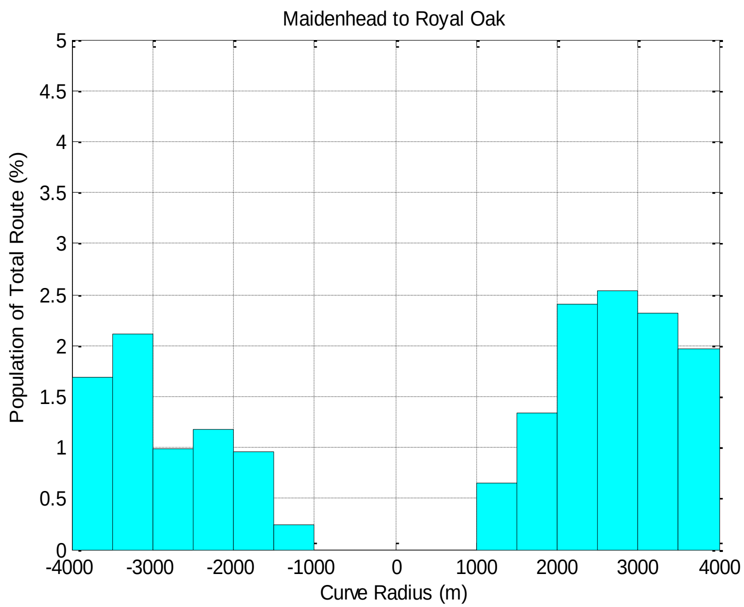
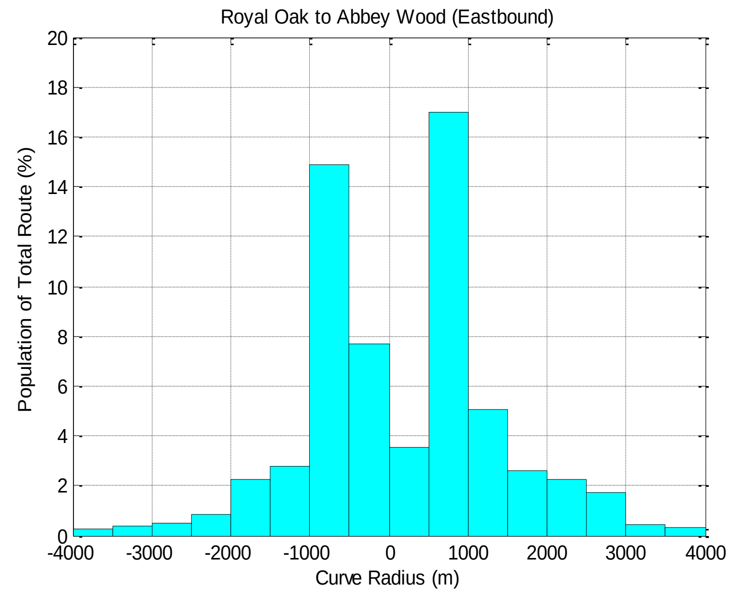
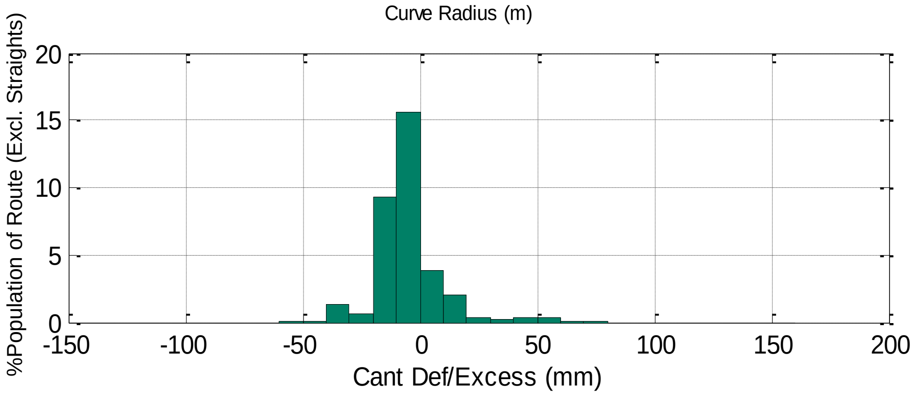
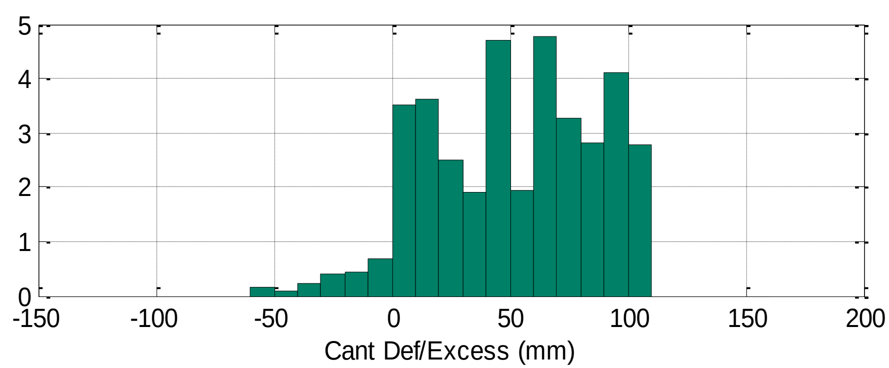
Route Comparisons – On-network v Tunneled









Creep force angle

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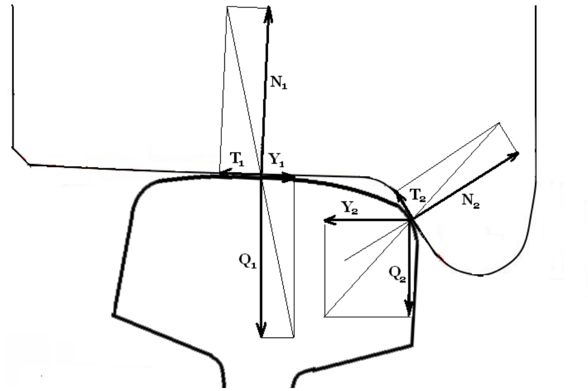
For sites where the w-r conditions differed from the original RCF model validation, it became necessary to consider the varying direction of the creep forces.

$$T\gamma' = T\gamma \times \cos(\alpha)\sqrt{2}$$



- As a general rule, only creepages acting in the tractive direction (crack opening) contribute to the accumulation of RCF damage.
- The modified function ensures the correct resultant of these forces is used in mapping Tγ to RCF damage.

Alternative steels for RCF resistance

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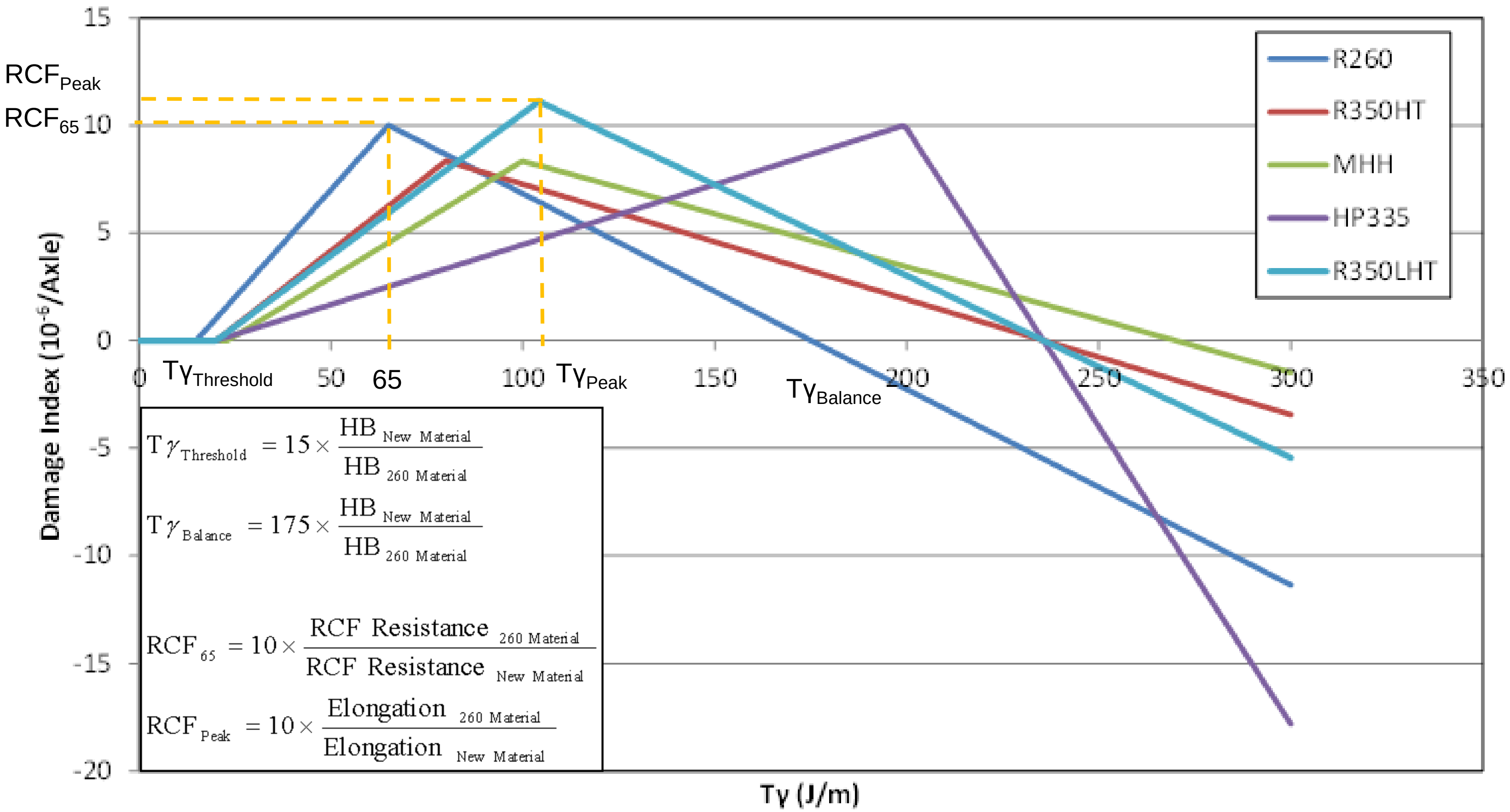
The original Crossrail work was extended and the following RCF functions were included in the study (RSSB T775, M. Burstow, NR):



A maintenance planning tool

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Crossrail's rail maintenance strategy is based on milling operations to manage RCF/Wear and restore profile shape:

- Three maintenance triggers identified
  - Periodic preventive milling
  - Reactive milling to manage RCF
  - Reactive milling to restore loss of profile (due to wear or material flow)
- A maintenance planning and visualisation tool is being developed which will:
  - Help facilitate a scenario based approach to optimising rail asset management
  - Aid the review of predicted damage against in-track observations
  - Continuously monitor and update milling and renewals planning activities
  - The tool is based around just under 20,000 pre-calculated and tabulated whole-route based vehicle dynamics simulations

A maintenance planning tool

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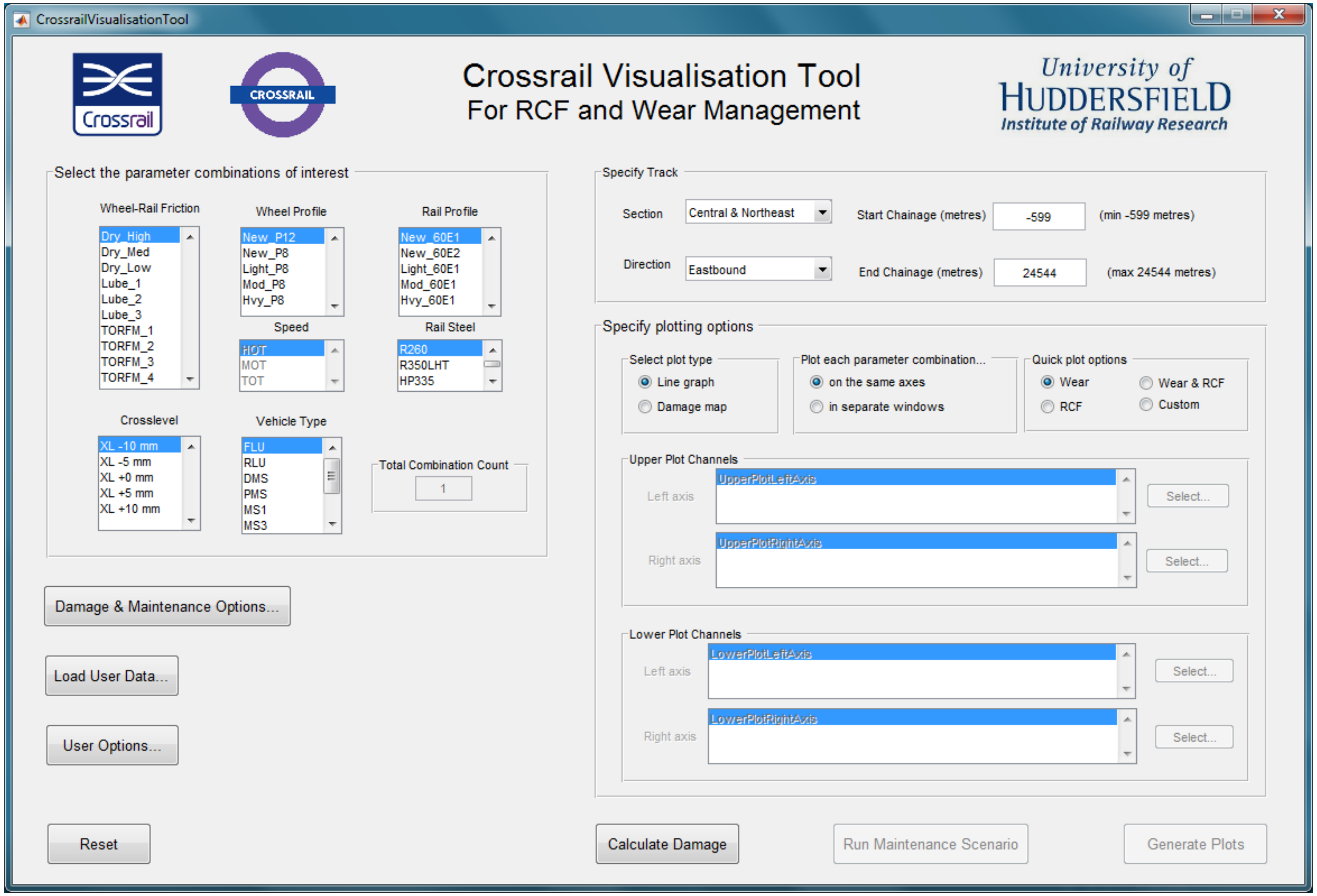

A maintenance planning tool

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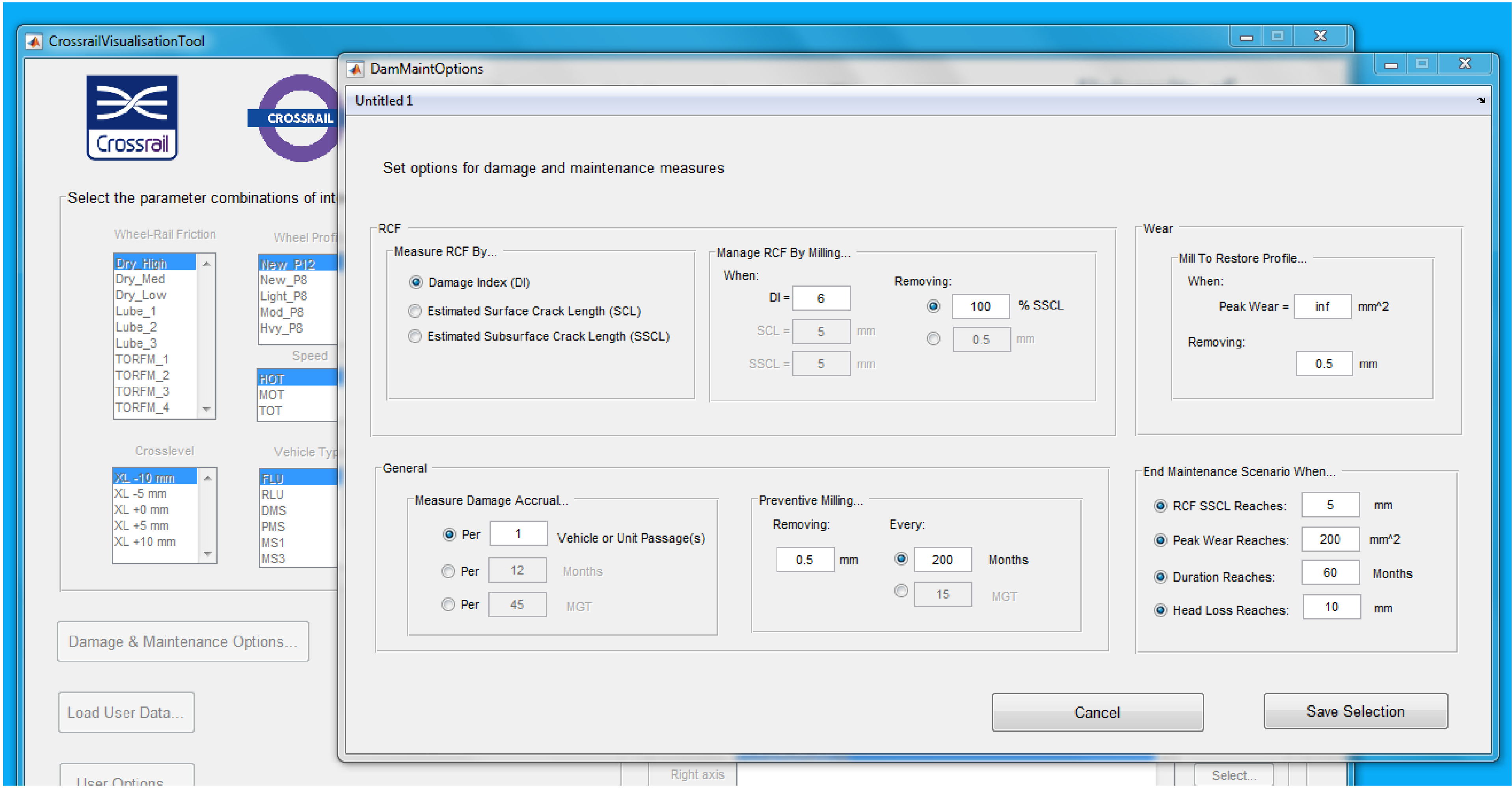
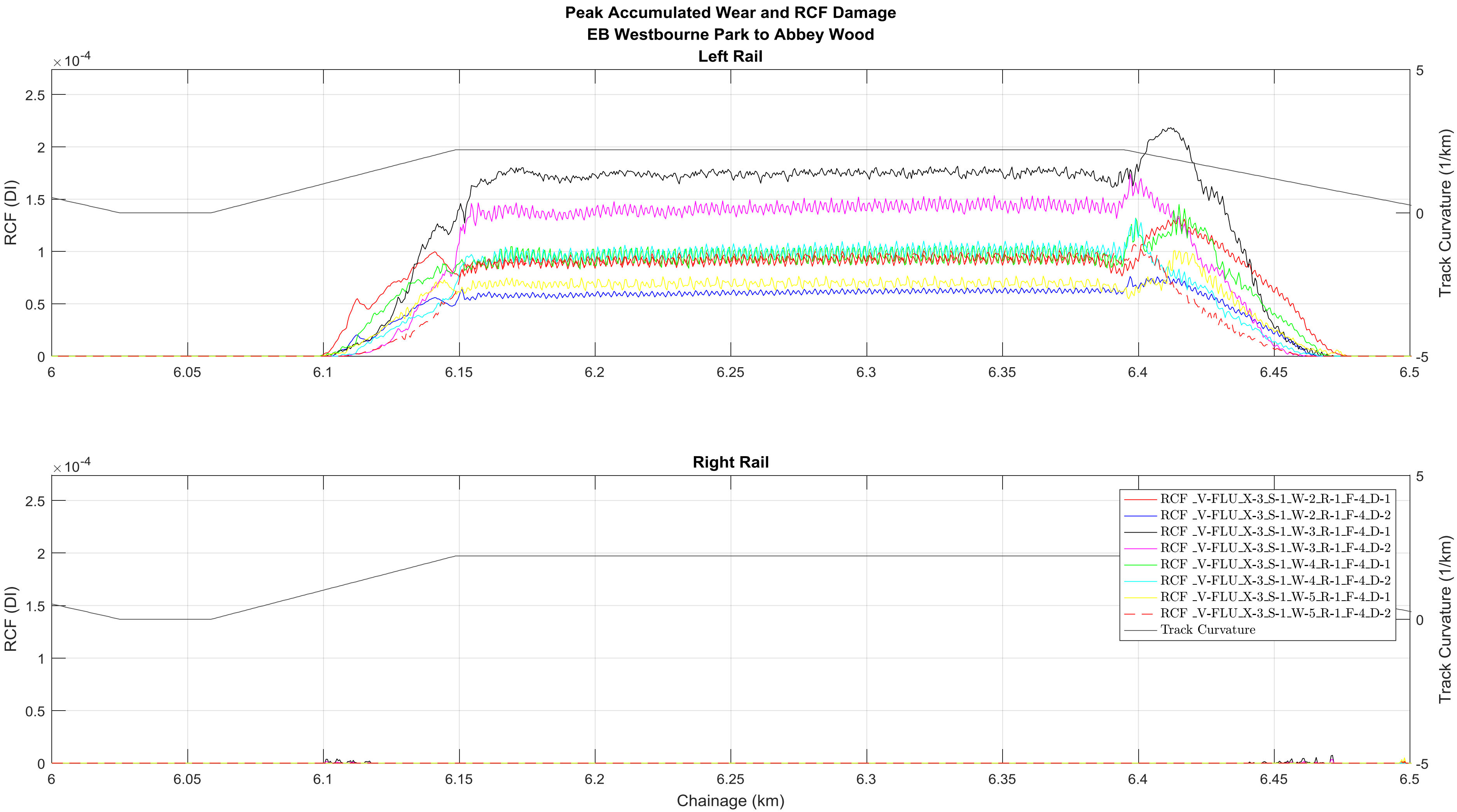


RCF prediction example



Wear and RCF prediction (R260)

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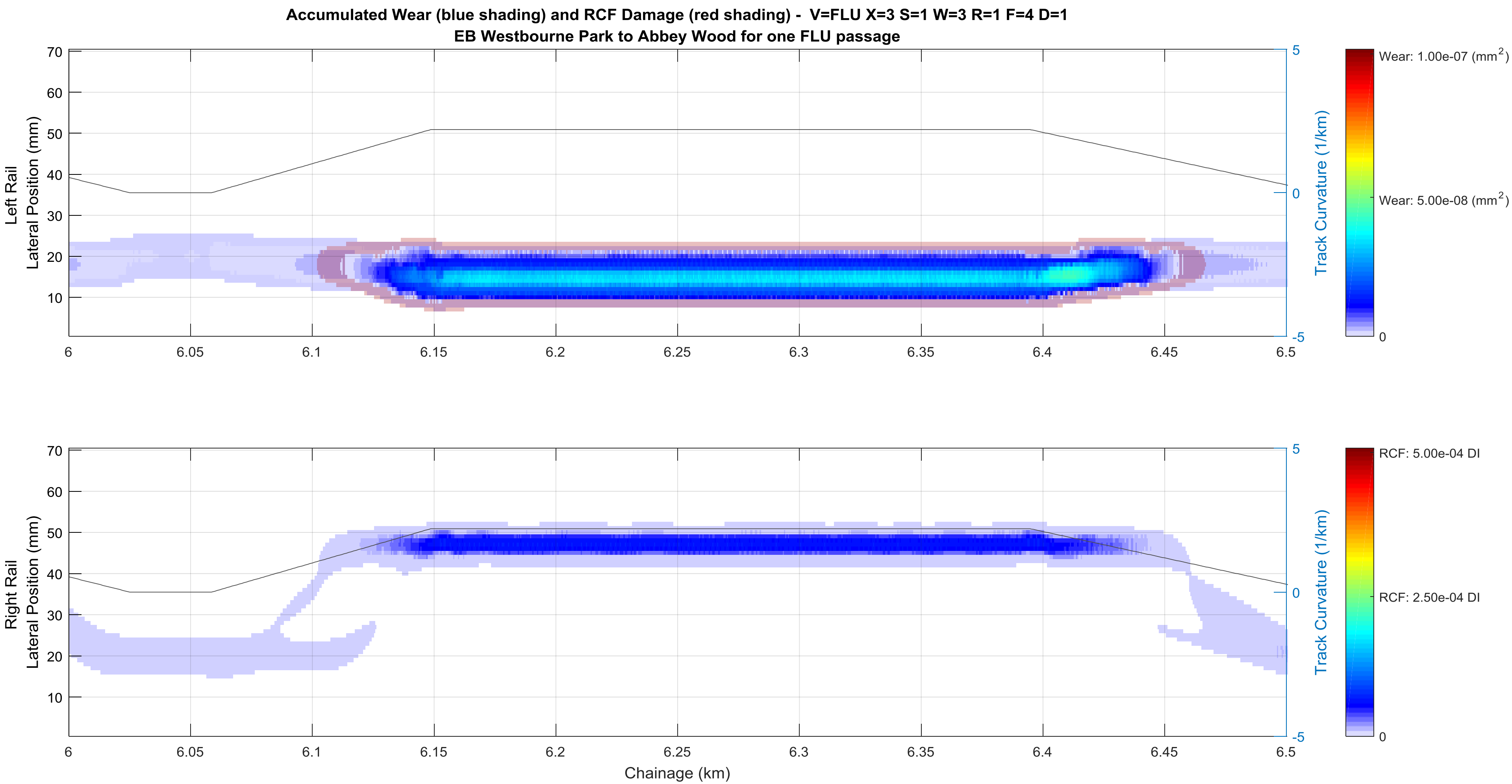

Guidance on maintenance actions

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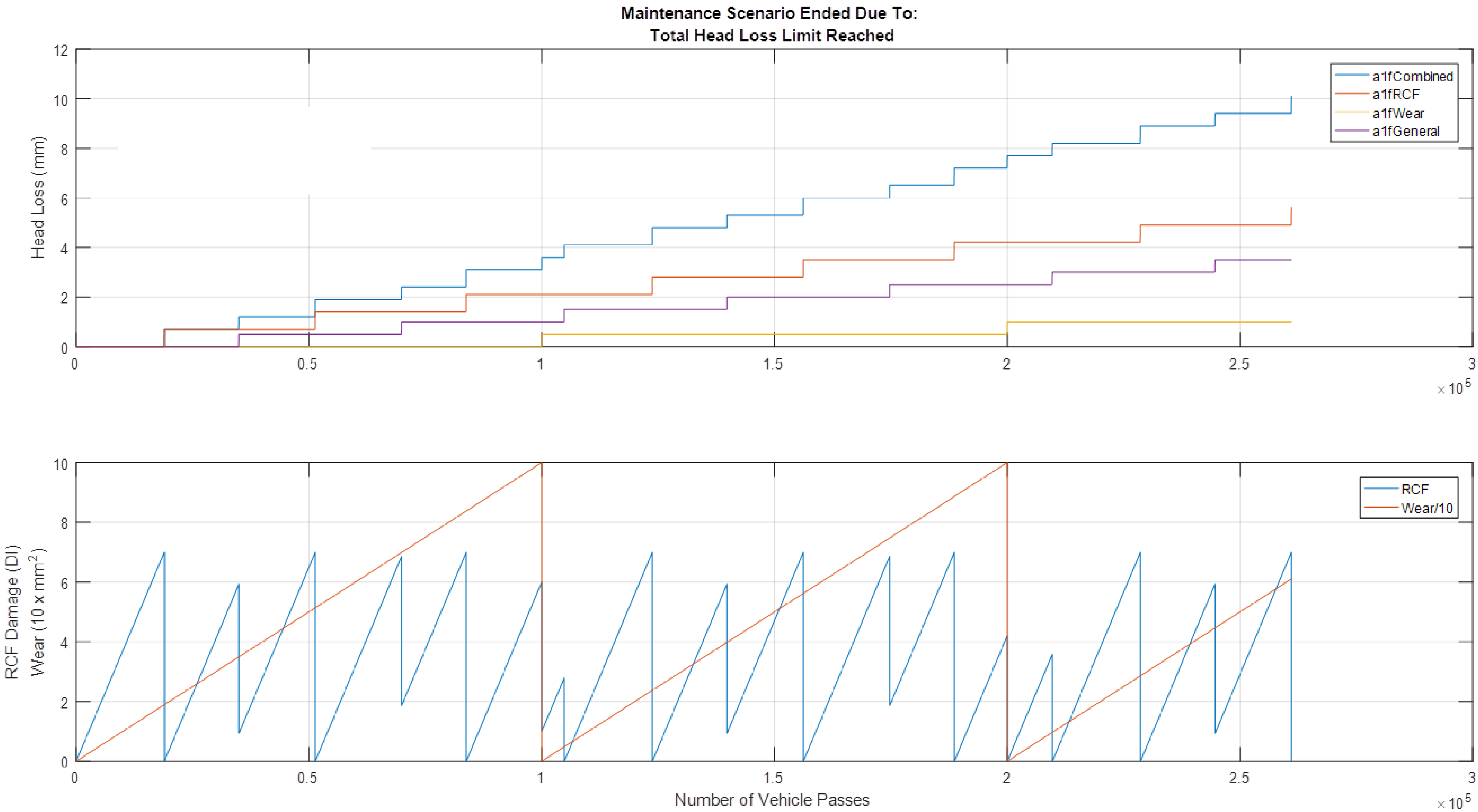
- Rail life calculation must terminate at some point
  - Rail ‘failures’
    - RCF damage
    - Wear (loss of profile)
    - Head loss (from milling)
  - Duration of interest is exceeded
    - E.g. 10 years
- Rail life with respect to milling (head loss)
  - Sum of material removed for the three maintenance triggers
  - Rail life determined in relation to
    - Number of vehicle or unit passages
    - MGT
    - Time

Guidance on maintenance actions



Summary

The final tool will be delivered at the end of 2016

- Will be used to inform planning and aid optimisation of maintenance activities
  - Lubrication and friction modifiers
  - Resource allocation (Milling activities)
  - Expected asset life (Renewals schedules)

- Data from the live network will feed back to support further development of the modelling tools
  - Improve damage prediction accuracy
  - Particularly premium rail grades
  - A significant opportunity to further the state-of-the-art

Acknowledgements

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University of Huddersfield's IRR:

- Dr Philip Shackleton
- Dr Adam Bevan

The Crossrail Project Team:

- Phil Hinde
- Maria Seco
- Martyn Chymera
- Mike Allen
- Susan Simmonds

Network Rail:

- Dr Mark Burstow; collaborating author of the original and on-going developments in rail degradation modelling and RCF predictions

Before we finish….

Wheels v Rails

A few other related research activities……

Track to the Future (T2F)

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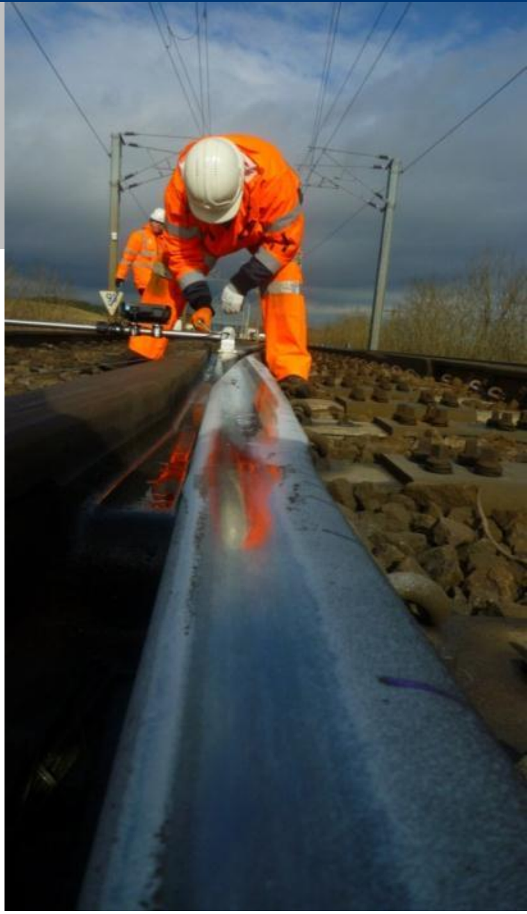
TRACK to the FUTURE



- £6.2M, 5 year EPSRC Programme Grant
  - TRack4Life (RC1)
    - to develop low-maintenance, long-life track systems with optimised material use
  - Designer crossings and transitions (RC2)
    - Design crossings and transitions so as to optimise vehicle behaviour through them, hence maximising resistance to damage
  - Noise-Less track (RC3)
    - develop and demonstrate an integrated approach to designing a low-noise, low-vibration track consistent with reduced whole life costs and maintenance needs

EPSRC
Engineering and Physical Sciences Research Council

Rail Steel Composition

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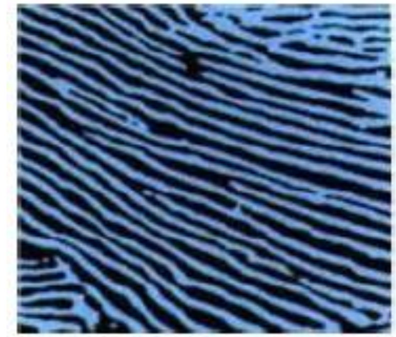
- 2-year EPSRC/RSSB/DfT research programme

Objectives:

- Improve the understanding of steel microstructures to imposed loading conditions
- Establish features of microstructures that provide maximum resistance to key degradation mechanisms
- Development of standardised material tests and guidance for rail steel grade selection



RSSB

Department for Transport

EPSRC
Pioneering research and skills

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UNIVERSITY OF CAMBRIDGE

UNIVERSITY OF LEEDS

Cranfield UNIVERSITY

Research Project: H2020 In2Rail

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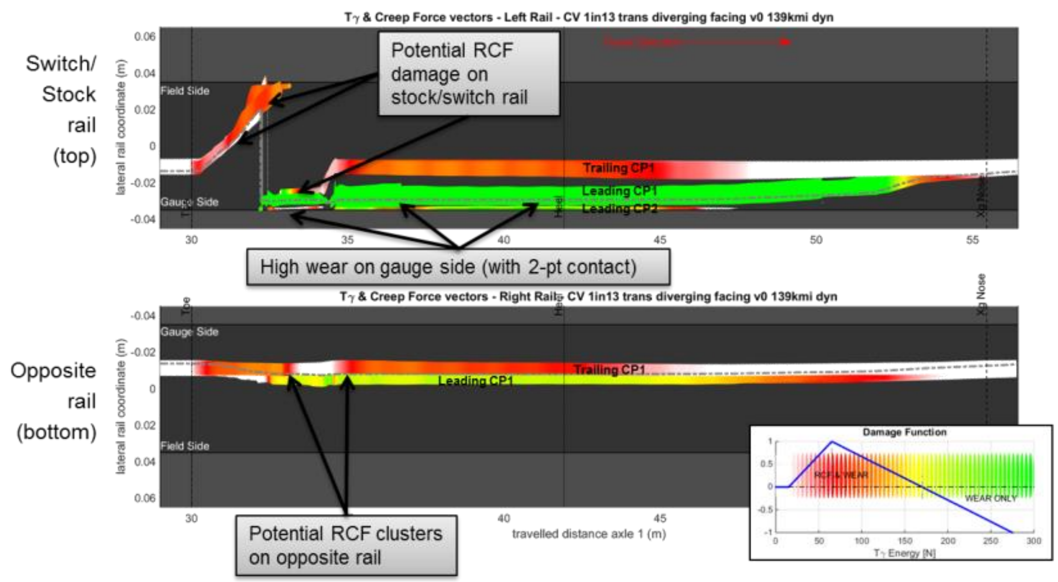
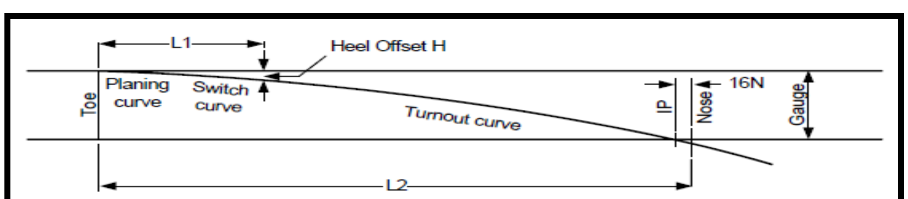
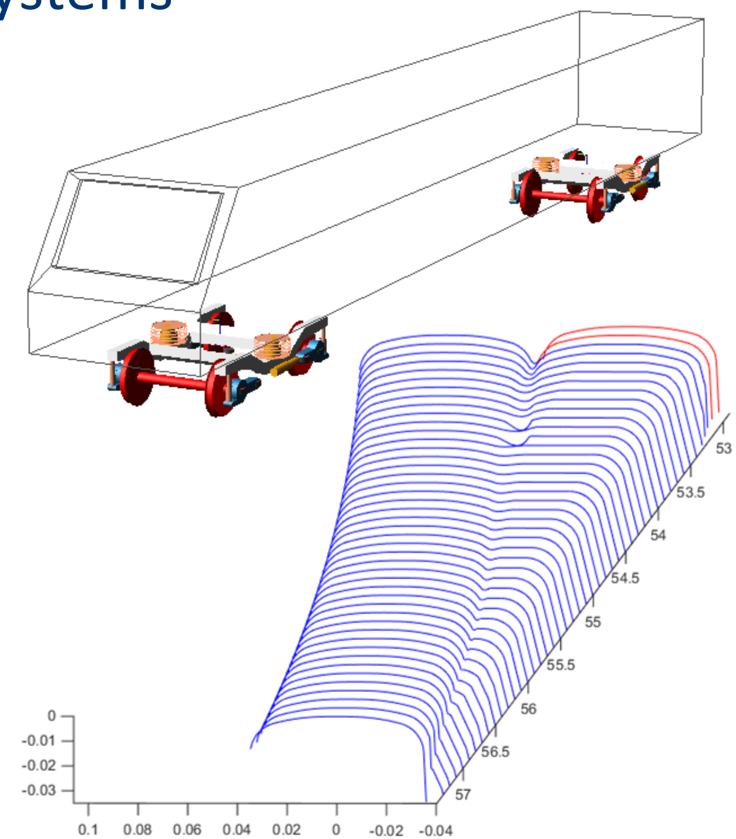
In2Rail

- Novel S&C concept generation and validation
- New rail repair techniques development
- Enhanced ballast and hybrid track systems







Siemens "Tracksure" Void Detection System

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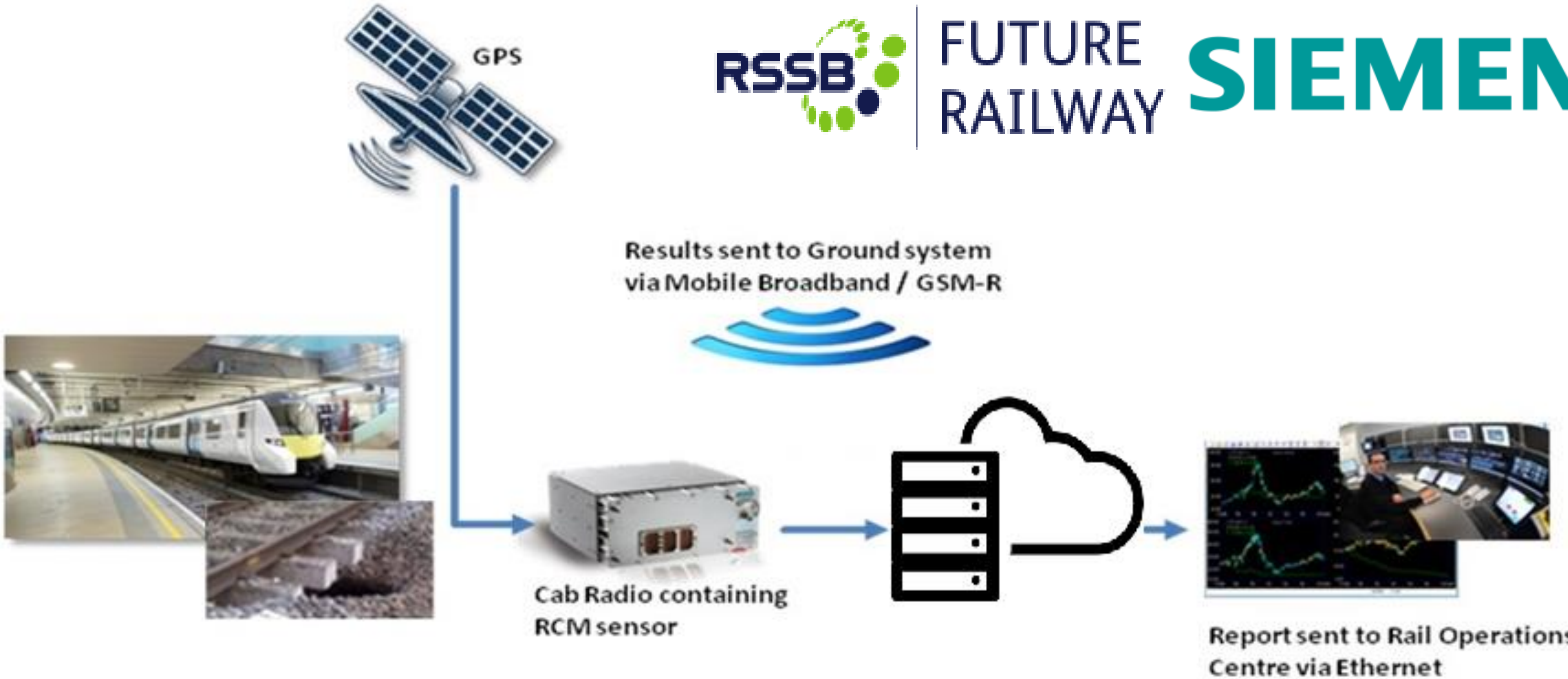
RSSB | FUTURE RAILWAY | SIEMENS



- Detailed vehicle-track modelling to investigate feasibility of using in-vehicle acceleration data for the detection of track defects
- Assisted in sensor selection and development of a highly efficiently algorithm to process large quantities of acceleration data to detect and categorise severity of under-track voids using in-vehicle sensors

Wheelset Maintenance

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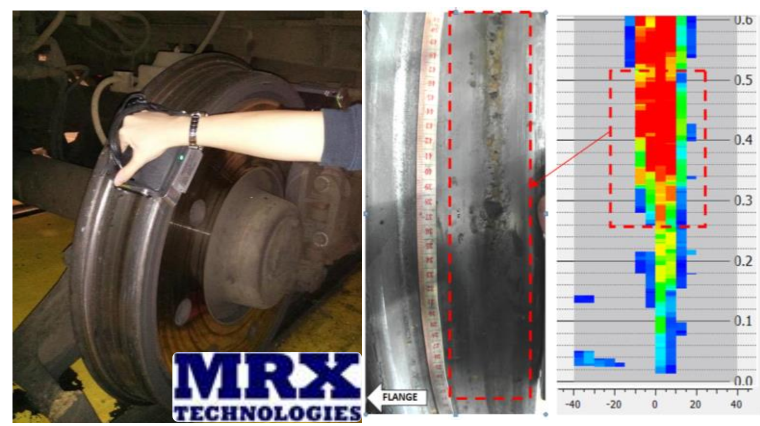
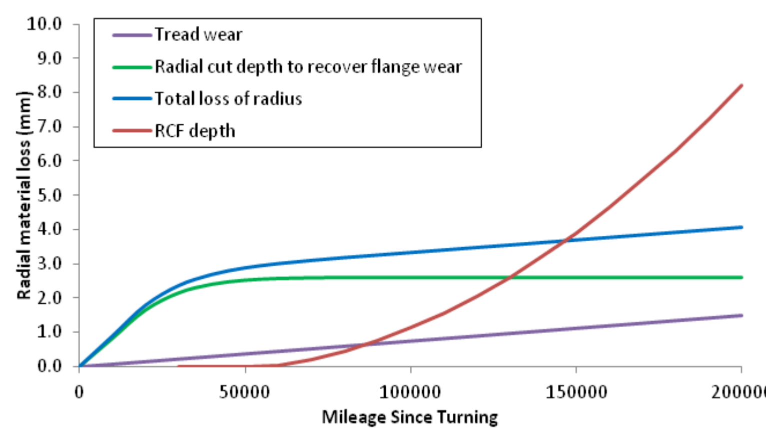
- Wheelset account for a large proportion of a fleets whole-life costs (40%)
  - Strong demand to reduce costs through extended reprofiling intervals and better wheelset life
- Research areas include:
  - Improved understanding of damage mechanisms
    - *Wheel Tread Damage Guide (RSSB T963)*
  - Quantifying surface damage
    - *MRX Surface Crack Measurement (Future Railway)*
  - Optimisation of maintenance routines to prolong life
    - *Siemens TPE Class 185*
    - *Economic tyre turning (RSSB)*





Full-scale bogie test rig

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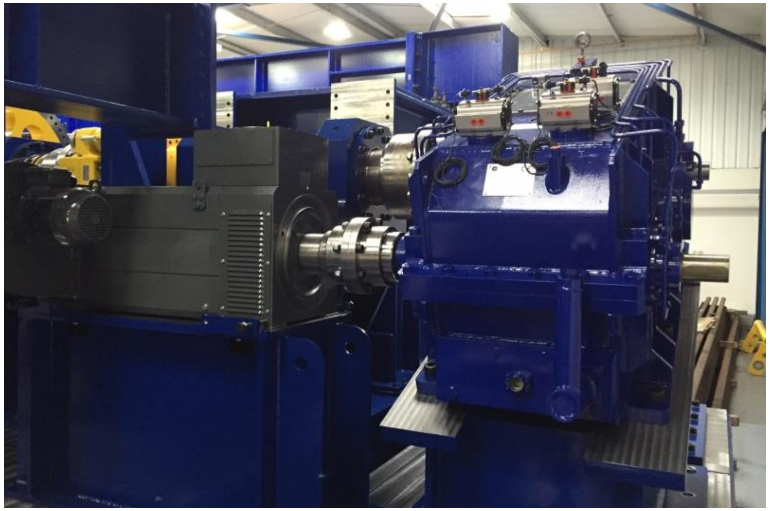

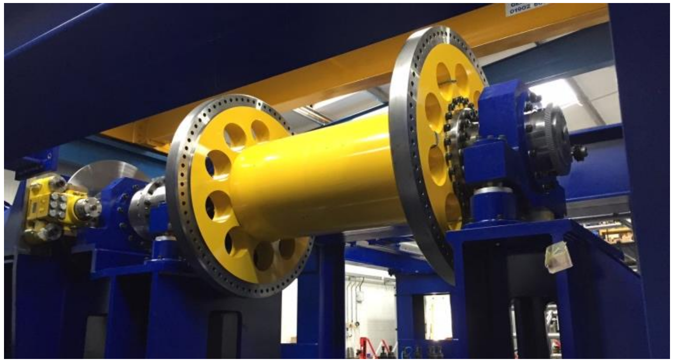

Potential research applications

University of Huddersfield
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Example applications:

- Bogie/wheelset dynamics
  - Wheelset longitudinal suspension (yaw) optimisation for minimisation of steering forces
  - Vertical bogie dynamics; optimisation of primary and secondary suspension
  - Analysis of novel wheelset and bogie technologies
  - Noise and vibration analysis (wheel squeal)
- Adhesion and braking research
  - Effect of wheel-rail contaminants on interface performance
  - Wheel-rail friction modifier evaluation
  - Traction and braking/WSP performance optimisation
  - Brake pad material development and change-out studies (duty cycles)
- Wheel and rail profile design evaluation
  - Assessment of existing (measured) wheel and rail profiles
  - Identification of profile development areas (e.g. flange root/tread geometry) and trial of new profile shapes
  - Assessment of ground/milled rail profile proposals
  - Wheelset life estimation and extension
  - Minimisation of contact forces – reductions in wear and RCF
- Materials research
  - Novel wheel and rail material evaluation
  - Composite and conventional wheelset testing
  - Accelerated fatigue testing