3. Predict behavior

How can we predict the deterioration of the railway so that we can plan and optimise maintenance, and ensure actions are taken before safety issues or traffic disruptions occur. Some examples of research leading to improved predictions are presented.
Impact of rail steel grade on rolling contact fatigue

Urs Schönholzer
Swiss Federal Railways SBB CFF FFS
The recommendations for the selection of rail steel grades provided by the International Union of Railways (UIC) have initially been published in 2005 and have been revised in 2015.

A database of all rail defects found in SBB’s entire network by ultrasonic testing has been updated with defect data form 2016 onwards.

An analysis of these ultrasonic defects was conducted with the goal of finding evidence to either confirm or update the currently used criteria that lead to the selection of either normal steel grade R260 or the head-hardened steel grade R350HT.
Results In2Track3

- The results were ambiguous in terms of the currently employed differentiation parameters of curve radius and daily traffic load. Defect initiation is not only influenced by those two parameters.

- A clear result has been achieved that the head-hardened steel grade R350HT performs not as well in tangent track as the normal steel grade R260.
Future work on the topic

- Future work will try to put the dataset of the ultrasonic rail defects in relation to rail used in comparable track conditions but has not developed Rolling Contact Fatigue issues.
- Subsequent work will focus on a statistical Survival Analysis that compares the failure rate of rails under certain circumstances, compare to only looking at the defective rails as done in the present study.
- More information can be found in the respective chapter of the final report.
Anisotropy, thermal loads and crack growth in rails

Johan Ahlström
Chalmers University of Technology
Challenge addressed

- Rolling contact fatigue and thermal loads impact the rails performance in terms of crack initiation and propagation. Predictive rail maintenance must take the material degradation into consideration.
  - The rail surface is work hardened and anisotropic
  - Cracking affected by anisotropy and hardness
  - Grinding depth will influence “surface renewal”
  - Grinding power can cause softening of remaining material, while excessive power will instead cause martensitic transformation, very hard and brittle; thin layers (WEL)
- Estimate limits for different rail treatment techniques regarding depth of material removal that can be applied during treatment without impacting the performance negatively.
Results In2Track3

- Thermo-Mechanical Fatigue experiments to measure residual stress relaxation, spheroidization, softening.
- Experiments on crack initiation in material, imitating the highly deformed surface layer, in axial and torsional loading.
- Modelling of number of cycles to crack initiation in a surface layer based on different types of experiments for improved predictions.

Collab Can @ESRF Yubin @DTU
Future work on the topic

- **Cont’d development of experiments and simulations in Europe’s Rail**

- More info can be found in D2.4, D3.3 and appendices:
  - D3.3, Ch 5.2.2 Influence of thermal loads on rail deterioration:
  - D3.3, Ch 5.2.3 Anisotropy in rails
  - D2.4 Potentials of existing and new materials in S&C rails
Monitoring and prediction of S&C condition

Björn Pålsson
Chalmers University of Technology

Results from Marko Milosevic’s PhD project with supervision from Björn Pålsson, Arne Nissen, Jens C.O. Nielsen and Håkan Johansson
Challenge addressed

Can we identify the crossing geometry irregularity, impact loads and ballast properties from measured sleeper accelerations?

- Yes, quite well

\[ d_{wrt} = d_w - d_r \]

\[ Q \quad k_b \]
Results In2Track3 – Condition monitoring scheme for crossings

- Measuring sleeper accelerations
- Sleeper displacement reconstruction
  \[ A_d[k] = \sum_{\tau=0}^{N-1} d_{\tau}[k] e^{-j2\pi \tau / N} \]
  \[ H[k] = \left( -1/(\omega[k])^2 \right)^2 \]
  \[ D[n,k] = A_d[k] H[k] \]
  \[ d_{out}[n,k] = \sum_{\tau=0}^{N-1} D[n,k] e^{j2\pi \tau / N} \]

- Crossing irregularity reconstruction
- Wheel & rail displacement calculation
  \[ d_{wheel} = \int_{t_0}^{t_1} d_{wheel}(t) dt \]
  \[ d_{axle} = \frac{axle \text{ load}}{d_{axle}} \]
  \[ d_{out} = d_{wheel} - d_{axle} \]

- Frequency domain integration
- Ballast stiffness
- MBS model calibration
- Inverse load identification

Crossing irregularity
(40-250 Hz content for typical train speed)

Impact load
(Up to 250 Hz)
Industry actors have shown interest in the results

Results will provide the starting point for coming PhD project “Digital Twin for improved maintenance of S&C”
  – How to use the condition monitoring scheme to optimise maintenance for reduced LCC-costs

More information can be found in
  – D1.2 & D1.3
  – Journal publications
    • https://doi.org/10.3390/s22031012
    • https://doi.org/10.1016/j.ymssp.2023.110225
    • Coming paper “Inverse wheel–rail contact force and crossing irregularity identification from measured sleeper accelerations – A model-based Green’s function approach”
Whole system modelling and hybrid testing

Gerald Trummer
Virtual Vehicle Research GmbH
Challenge addressed

Modelling of rolling contact fatigue (RCF) (& wear) considering the influence of microstructure and plastic deformation
Results In2Track3

- **Mesoscale crack growth model**
  - DEM-based model representing the material microstructure (pearlite colonies, cementite orientation)
  - Key result: Prediction of crack growth rates as a function of microstructure and plastic shear deformation

\[ \Delta K (\text{MPa} \cdot \text{m}^{0.5}) \]

- Simulated fatigue crack growth curves;
- Simulated crack path in undeformed and deformed material.

- Undeformed microstructure
- Initial crack
- Propagated crack
- Colony Boundary

- Deformed microstructure
- Initial crack
- Propagated crack
Results In2Track3

- **Macroscale RCF model**
  - Model is one element of the whole system modelling toolchain
  - Input:
    - MBS contact patch data
  - 2D discrete spring network (bonds)
  - Local fatigue model (based on bond strains)
  - Key result:
    Crack growth (rate) under rolling contact loading

Reference cracks for validation from full-scale rig (above) and modelling results (below).
Future work on the topic

- Further refinement of the modelling toolchain and the sub-models approach together with industrial partners
- Further detail about the mesoscale crack growth model and the macroscale rolling contact fatigue model can be found in the IN2TRACK3 final report, deliverable D3.4

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Links
- Virtual Vehicle Research GmbH: https://www.v2c2.at/
Transition zone design and integration

Moncef Toumi\textsuperscript{a}, Samuel Hawksbee\textsuperscript{b}, Michel Sebès\textsuperscript{c}, Pedro Jorge\textsuperscript{b}, Yann Bezin\textsuperscript{b}

\textsuperscript{a}RAILENIUM

\textsuperscript{b}University of Huddersfield

\textsuperscript{c}Université Gustave Eiffel
Challenge addressed

- Transition zones are subject to substantial differential settlement due to abrupt changes in track construction leading to:
  - Support stiffness variation,
  - Increased dynamic loading,
  - Stress variation in support layers.

- Switches & Crossings (S&Cs) are a special case of transition zones with significant changes in the superstructure properties.

- Differential settlements introduce voiding under sleepers and accelerate fatigue and damage of S&C component.

  Need of a deep understanding of the impact of superstructure stiffness on the short and long-term behaviour of the S&C.

  Need of an accurate prediction of differential settlements to estimate remaining asset life, whole lifecycle costs and plan maintenance.

[H. Wang et al. 2017]
Results In2Track3

- Numerical modelling solutions have been developed and are able to:
  - Model accurately the dynamic behaviour and the Vehicle/Track Interaction in S&C and the transition zone to Plain Line
  - Capture the variable track characteristics in S&C (varying superstructure & substructure characteristics)
  - Estimate the settlement in S&C taking into account the dynamic loading and the asymmetrical loading and voiding

- The dynamic model was calibrated and validated using measurements from the S2R S&C demonstrator (in the switch panel)
Future work on the topic

- The methodology and tool developed to estimate settlement will require further validation from an instrumented site or dedicated laboratory experiments.
- Further improvements should consider flexible sleepers in the Vehicle/Track Interaction model.
- The level of discretization along a sleeper should be investigated, and specifically its effect on the distribution of differential settlement and voids.
- More information can be found in D2.4_S5.4.