Combination of simulation modelling process and experimental material testing program for shakedown analysis in locomotive studies

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Contents

Introduction

- The application of train dynamics and locomotive multibody dynamics simulations is a great help to the predictive maintenance purposes including understanding and characterisation of wheel and track damage considering dynamic and impact loading at the wheel-rail interface.

- The research has been conducted in Victoria, Central Western Australia, and Pilbara regions. The experimental program was run there by the CRE team to obtain the required wheel-rail material samples, track structure design parameters, railway corridor geometry details, tribology related factors to do with the wheel-rail contact interface and wear information for its further application as inputs in detailed analysis using train and vehicle/track interaction simulation technologies.

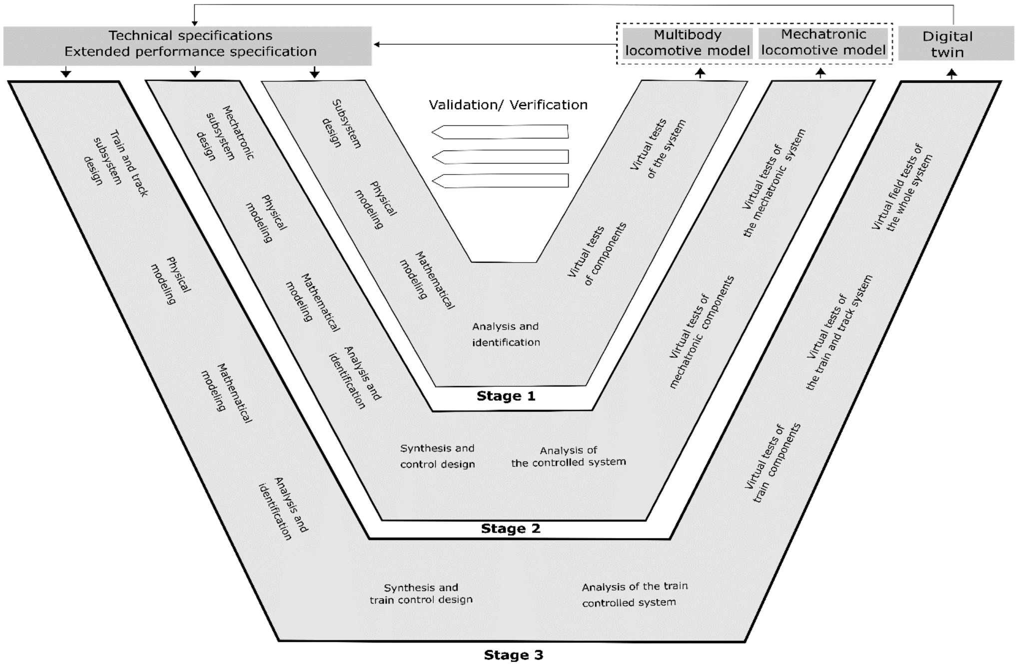
Introduction

- The field-testing and laboratory measurements include two groups of parameters. Firstly, friction versus creep measurements at each contact point of the wheel-rail interface delivered for a specific locomotive design and train operational conditions. Secondly, wheel-rail profiles and measured roughness of their contact surfaces.

- The main goal of this research is to predict the damage mechanisms and service life cycle of Australian rail materials and track components under the specific locomotive and wagon operational conditions in several Australian states.

Design Methodology

V-model with several system integration stages for the design of a locomotive product was presented at ICRT2021:



Outcome

The implementation of this V-model provides the ability to conduct trade-off studies between potential locomotive design variations and ultimately define a design that should suit not only rollingstock owners but also railway owners.

Journal paper was accepted in Railway Engineering Science

Spiryagin M, Wu Q, Polach O, Thorburn J, Chua W, Spiryagin V, Stichel S, Shrestha S, Bernal E, Ahmad S, Cole C, McSweeney T. Problems, assumptions and solutions in locomotive design, traction and operational studies. Railway Engineering Science 2021. Accepted, October 25, 2021.

Simulation Methodology

Three stages needed for the development of digital twins:

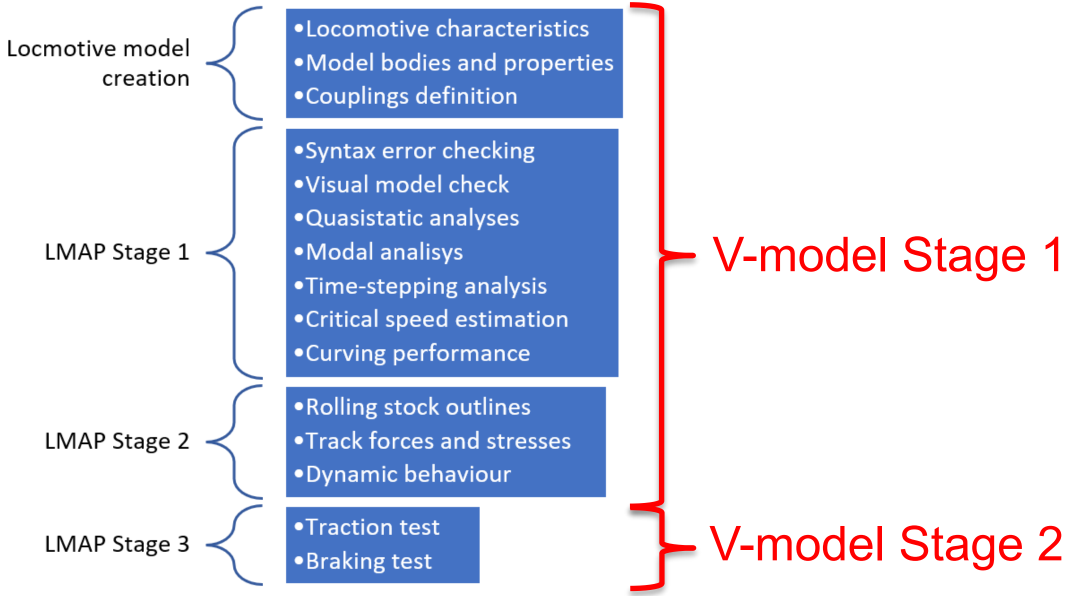
Stage 1: The development of a multibody locomotive model that has a quite established technique and the validation approaches

Stage 2: The design of a mechatronic system of a locomotive that is based on the multidisciplinary engineering knowledge and the application of co-simulation techniques

Stage 3: The design of a great number of models involving the complexities of track design and geometries, the non-linear wheel-rail contact interface characteristics and the numerical characterisation of damage processes considering tribological aspects and train operational scenarios. The latter includes not only a full-mechatronic model of the rail vehicles in the train but also a virtual train driver.

General Concept for the Development of a Realistic Locomotive Multibody Model

As more railway regulatory organisations continue to acknowledge the use of MBS for virtual homologations and the development of complex co-simulation studies, researchers at the Centre for Railway Engineering proposed the Locomotive Model Acceptance Procedure (LMAP) in 2012-2016 to incorporate best practices as used in Australia in the development of locomotive MBS.



Simulation Methodology

V-model Stage 3: Digital twin should include four important parts:

- a model of the object built based on an integrated multiphysics, multiscale, probabilistic simulation approach,
- an evolving set of data relating to the object,
- a means of dynamically updating or adjusting the model in accordance with the data,
- mirror and predict activities/performance over the life of its corresponding physical twin.

Physical world

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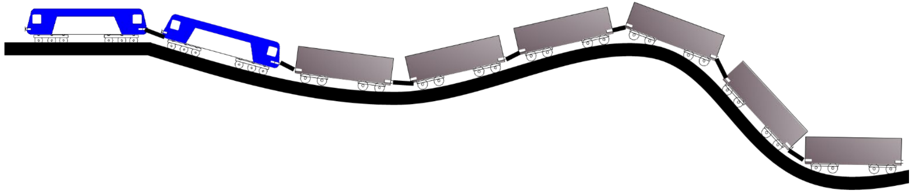
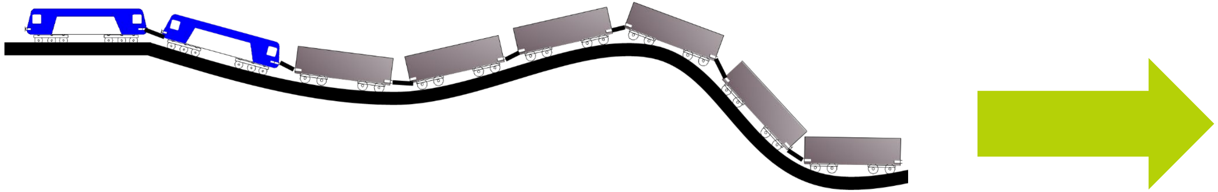


Virtual world

Simulation Methodologies

- The digital twin of a whole locomotive/train/track system should be realised on the virtual simulation platform that is commonly built on a High Performance Computing cluster.



Virtual world

Challenges in the System Modelling and Prediction Approaches

- Friction at the wheel/rail interface
- Wheel/rail contact modelling for traction studies
- Wheel and rail damage prediction in traction studies

Friction at the wheel/rail interface

- There are a great number of complexities associated with the introduction of the changes in friction conditions into the model. These are associated with the existing friction models having no explicit physical interpretation.
- Some limited research activities in this area are in progress.
- There are almost no research activities in terms of numerical modelling on the distribution of lubricants along the track and across the top of the rail under operational conditions.
- Questions exist on how the friction laboratory measurements should be transferred into a real-world prediction study.

Wheel/rail contact modelling for traction studies

- There are a limited number of research activities of research activities on the contact model benchmarking and validation studies.
- There is no comparison of results of wheel-rail couplings with a variable friction coefficient used in the multibody software packages for traction or braking damage studies.
- There are a limited number of research activities on the introduction of conformal contact modelling.
- There is no accurate assessment on how different models will influence the prediction results.

Wheel and rail damage prediction in traction studies

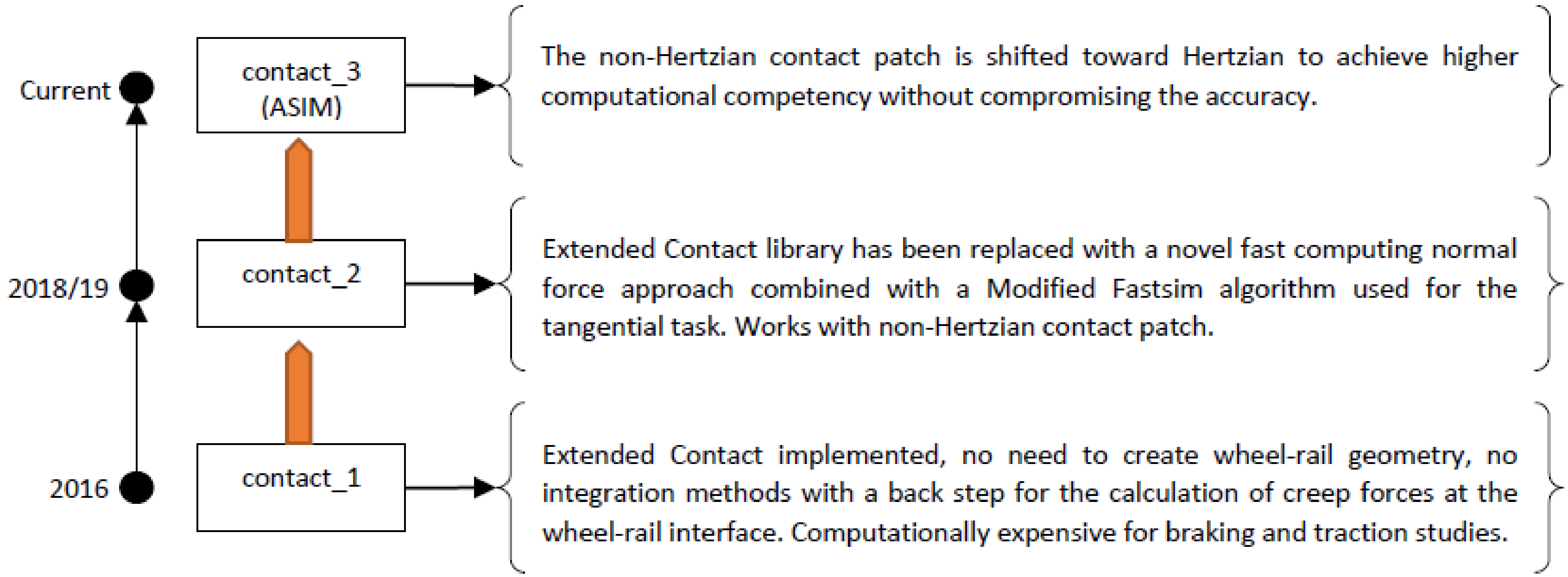
- Most rail wear models are built on the data delivered for specific wheel and rail materials.
- The application of shakedown diagram for the different types of wheel and rail steel materials.
- Questions exist on how the laboratory measurements for rail and wheel steel material combinations should be organised to replicate a real-world application scenario.
- How worn wheel and rail profiles should be introduced in the model for long-term track studies, especially for cases of mixed train operations, still needs development.

Recent developments in the contact modelling

- Friction at the wheel/rail interface
- Wheel/rail contact modelling for traction studies
- Wheel and rail damage prediction in traction studies

Recent developments in the contact modelling

Adaptive simulation and integration method (ASIM) for wheel-rail contact problems in locomotive traction studies



Journal paper was accepted in Vehicle System Dynamics

Spiryagin M, Shrestha S, Persson I, Wu Q, Bernal E, Cole C.
Adaptive simulation and integration method for wheel-rail contact problems in locomotive traction studies. Vehicle System Dynamics 2021; Accepted on October 23, 2021.

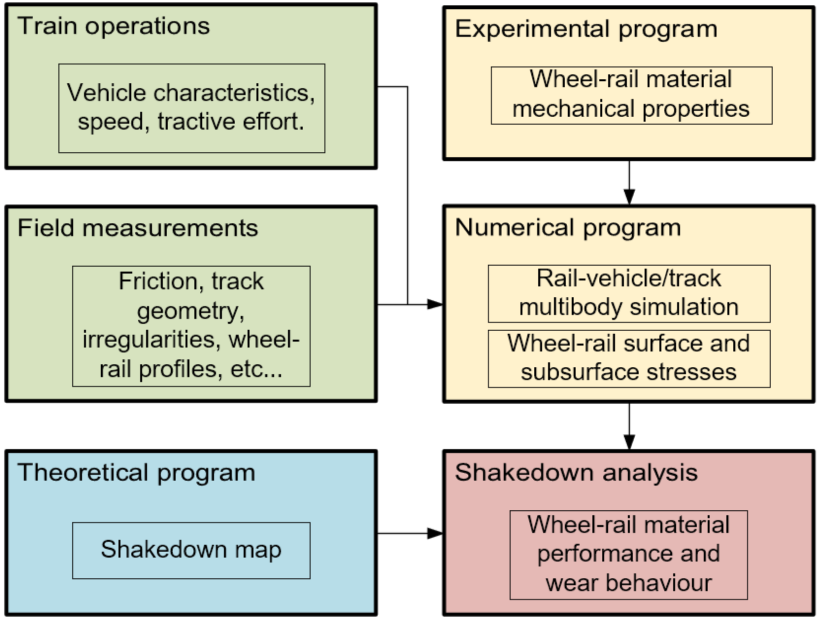
Recent developments in the contact modelling

The ASIM can be used for studies in the V-model Stage 3 but, if the computational capabilities are available, then the best option for performing wheel or track damage studies is to use the Exact theory developed by Kalker directly in the simulation procedure to solve the contact mechanics task at the wheel-rail interface.

Reason: ASIM works on the assumption regarding the relationship between the contour (surface waviness irregularities) area of contact and the real (surface roughness irregularities) area of contact. The relationship was delivered through a numerical experiment, and it does not represent a physical explanation on the processes at the wheel-rail contact.

The work is ongoing in this direction!!!

Shakedown analysis and its application



- The digital twin technique involves field data, experiments and numerical components

Experimental/theoretical program

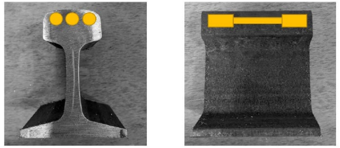
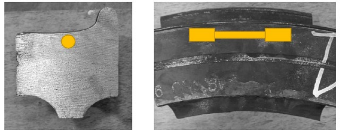
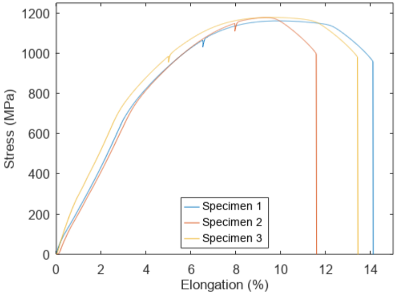
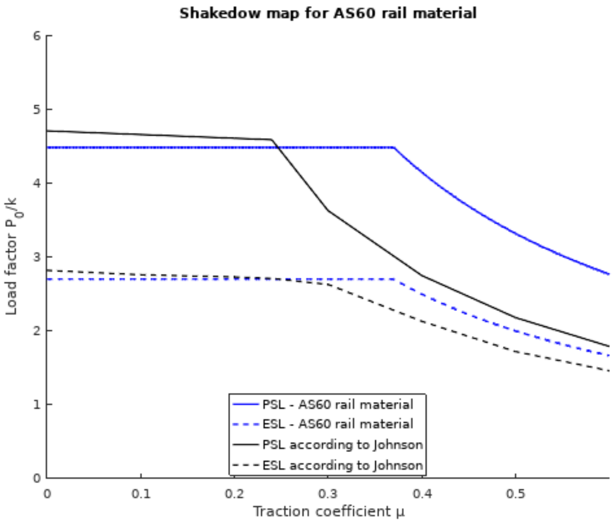


Figure 1. Tensile sample position in rail.



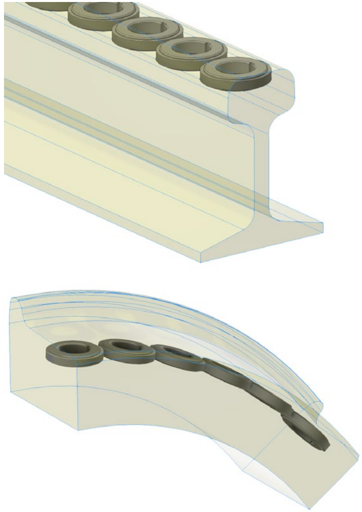


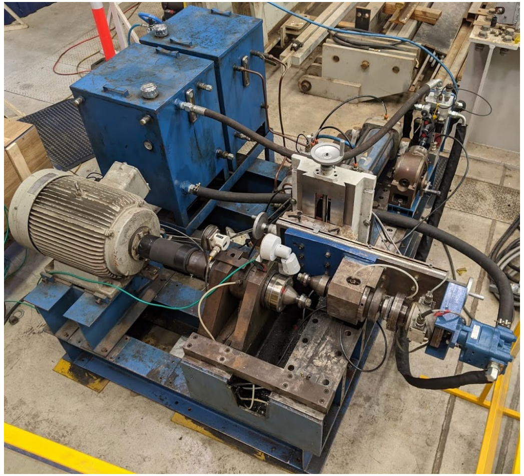
Tensile test



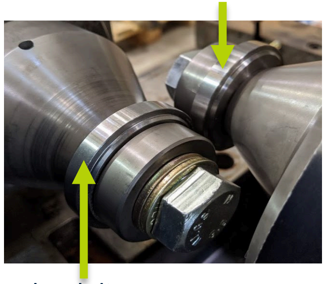
Calibrated shakedown map

Experimental material testing requirements and program





Rail disc



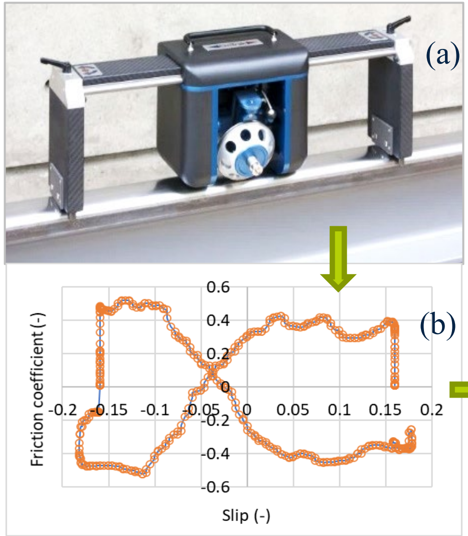
Wheel disc

- Wheel-rail samples extraction
- Twin-disc RCF life test
- Worn samples

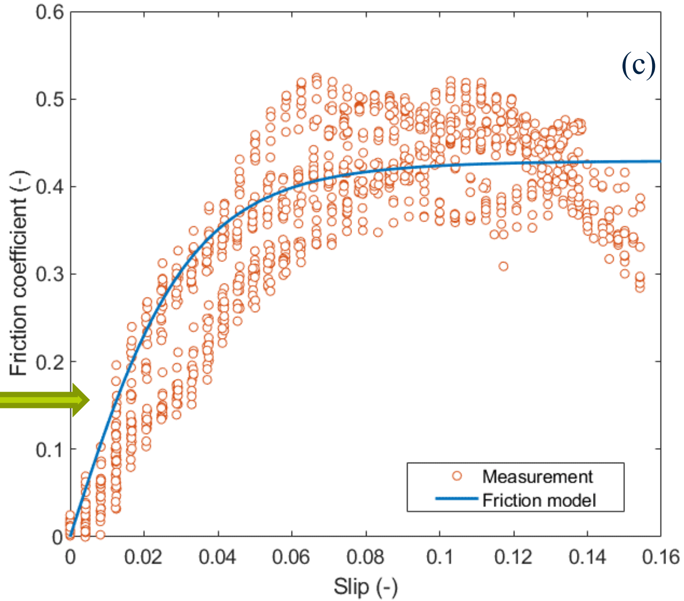
Applications in the 'virtual world'

- Field measurements
- Data analysis
- Numerical experiment
- Shakedown analysis example

Applications in the 'virtual world': Input parameters from field measurements



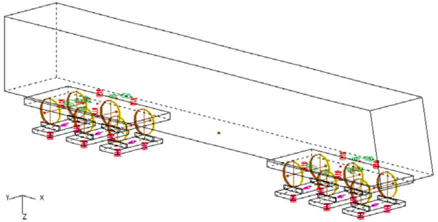
HO tribometer



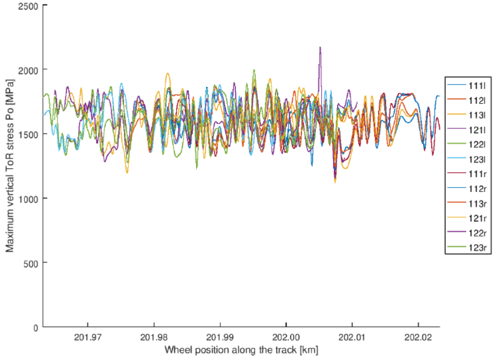
Friction data post postprocessing

Friction characteristics are delivered for several track locations

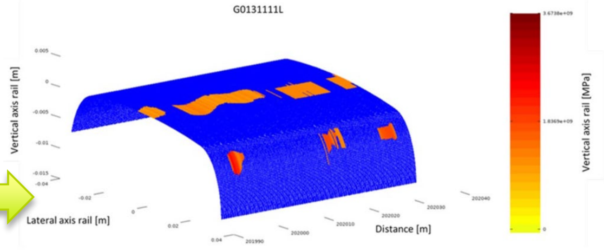
Applications in the ‘virtual world: Numerical experimental program



Locomotive MBS

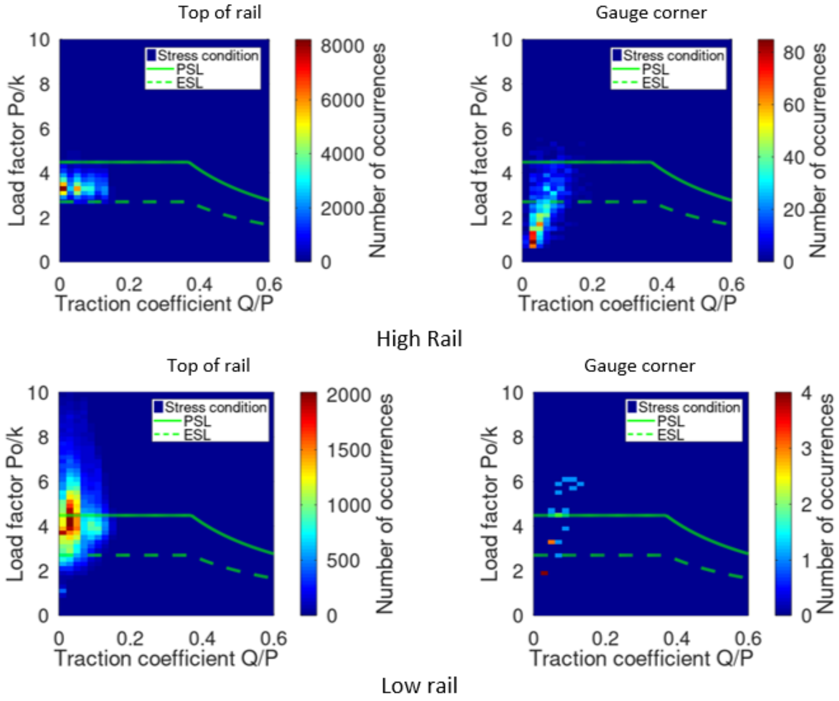


Surface and subsurface rail stresses



Contact patch position

Applications in the ‘virtual world: shakedown analysis example



- Results distinguish between high/low rail and top of rail gauge face and gauge corner contact
- Shakedown heatmap of occurrences facilitate the identification of operating conditions that promote rail health in traction studies

Challenges in the characterisation of shakedown diagram for different rail steel materials

- Influence of wear on RCF for modern rail materials
- Measurement/estimation of rail material **shear stress**
- Validation of elastic and plastic shakedown limits for hardened rail materials
- Contact stress calculation approach: planar, non-planar; top of rail contact vs. gauge corner gauge face contact

Conclusions

- The presented simulation modelling method allows unprecedented studies that allow identification of operational conditions that promote or prevent RCF, considering specific wheel-rail material mechanical properties, variable friction characteristics and traction/braking scenarios
- Implementation of locomotive digital twin and high performance computing enables studying thousands of cases resulting from combinations of wheel/rail profiles, track layouts and irregularities, vehicle speeds, rail materials, etc.
- The RCF prediction is presented as a stress occurrence shakedown heatmap, as a tool that facilitates the comparison of different scenarios and making operational decisions.
- RCF predictions are validated through twin-disc tests performed on actual samples of wheel/rail materials.
- Future research should focus on better estimation of shear stress, the influence of wear on RCF for modern wheel-rail materials and the influence of different surface and subsurface stress calculation approaches.

Thanks

Comments, questions & discussions

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