KTH ROYAL INSTITUTE OF TECHNOLOGY

Wheel and Rail Maintenance Planning with Support of Digital Twins

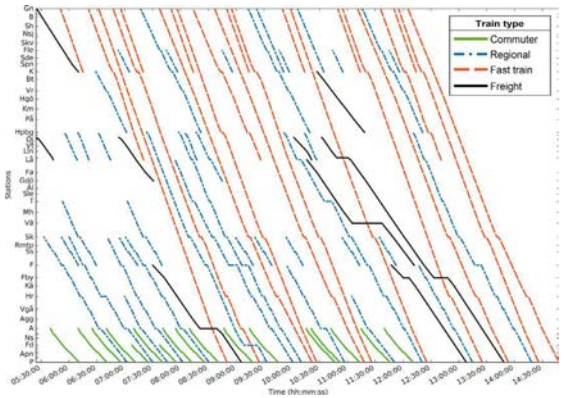
S. Stichel, S. H. Nia, V. Krishna, C. Casanueva
KTH Royal Institute of Technology, Railway Group

Swedens largest technical university

- Around 13,500 full-time students (one-third women).
- Close to 1,700 research students (one-third women).
- More than 3,700 full-time positions (one-third women).
- Five campuses in the Stockholm region.

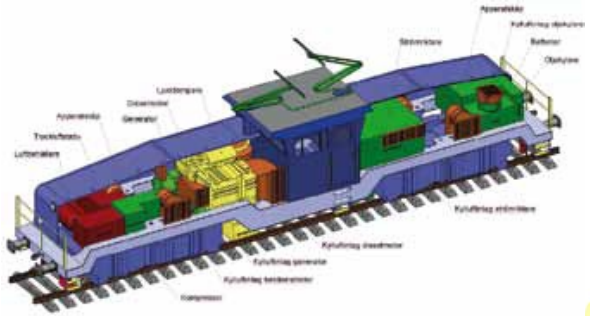
KTH Railway Group – A Multidisciplinary Research Centre

Traffic and Logistics



Signalling

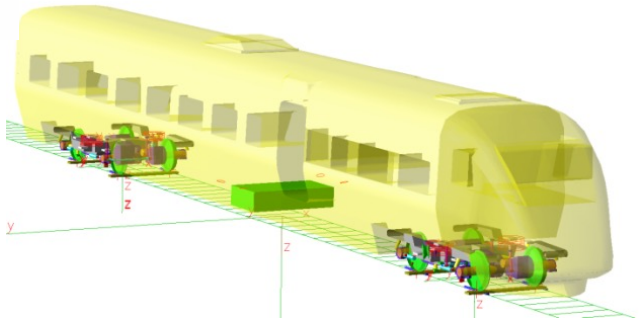
Tribology



Structural Engineering and Bridges

Electric propulsion and energy supply

Rail Vehicles – Vehicle-Track interaction



Division of Rail Vehicles: Research focus

Vehicle-track dynamic interaction

- Vehicle dynamics simulation
- Ride comfort calculation
- Contact mechanics and wear/fatigue prediction
- Active suspension
- Tilting trains
- Crosswind stability
- Condition monitoring

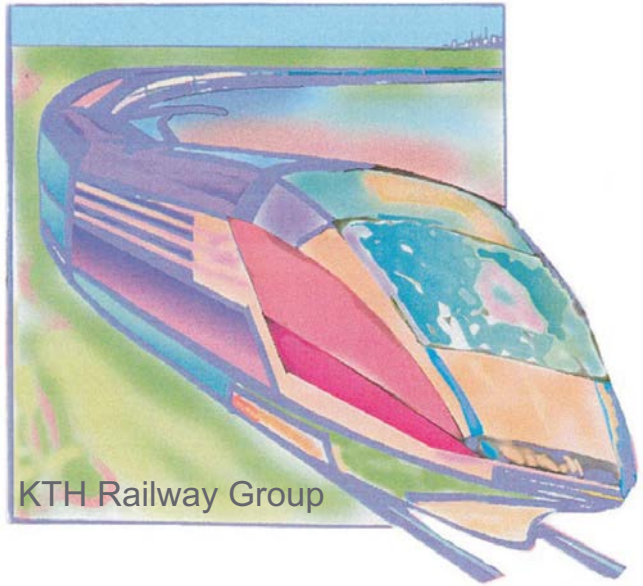
Energy usage and environmental impact

Lightweight structures

Vehicle-catenary interaction

Master in Railway Engineering

Since 2018 we have a Master program together with
RailTec at the University of Illinois Urbana-Champaign

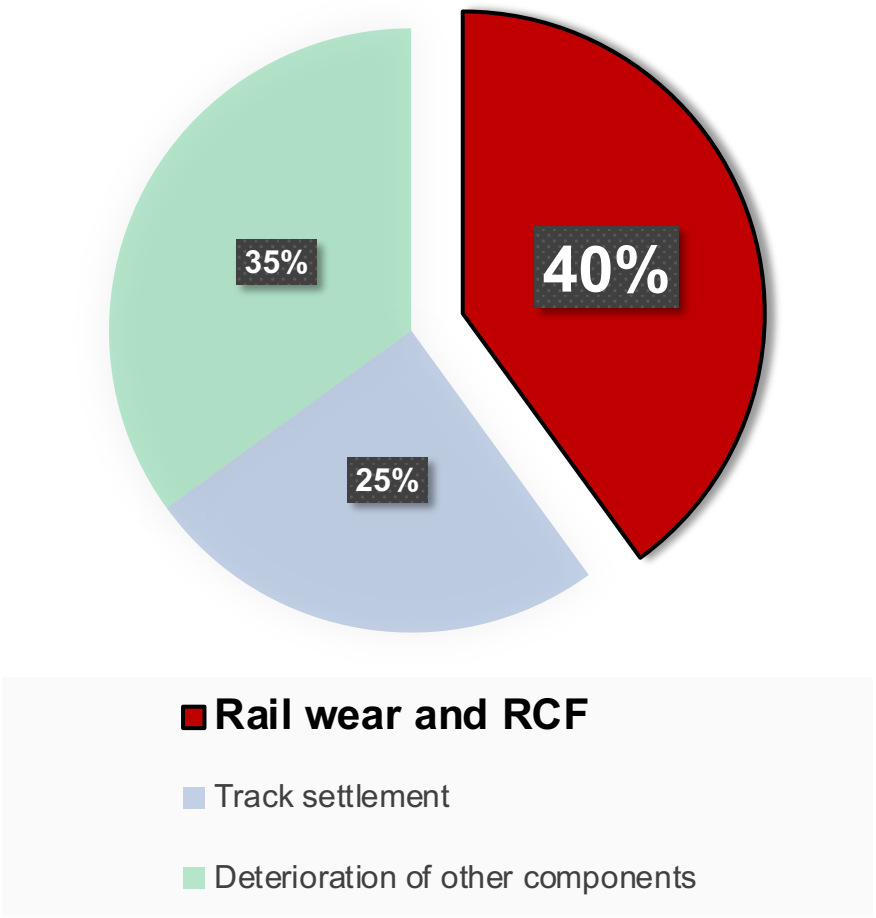


Outline

- Introduction – System Perspective
- Calculation of rail damage – Optimisation of grinding intervals
- Wheel life prediction – Planning of reprofiling intervals
- Machine learning tools to predict component failures
- Summary

Background

- About 40% of track maintenance / renewal costs in Sweden are attributed to rail wear and RCF [1]: **Rail Surface Damage**
- The maintenance activities associated with damage due to **wear and RCF are interlinked**
- The maintenance activities **influence the wheel-rail dynamic interactions** which in turn **influences the damage process**.



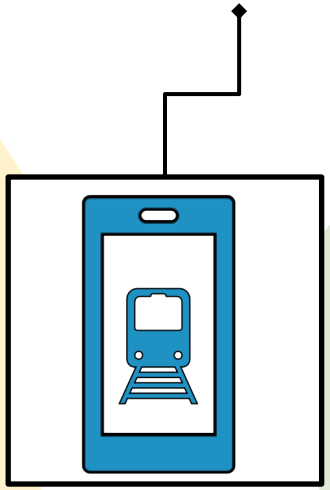
[1] A. Smith, et al., “Estimating the relative cost of track damage mechanisms: combining economic and engineering approaches,” Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit, vol. 231, no. 5, pp. 620–636, 2017.

Wheel-rail damage prediction: A system tool

Principles & processes

- Advanced MBS models
- Contact mechanics
- Damage models
- Fast calculation methods
- Mathematical Optimization
- Optimized vehicle suspension design
- Wheel-rail interface management
- Modelling maintenance activities
- Validation of tools
- Differentiated track access charges

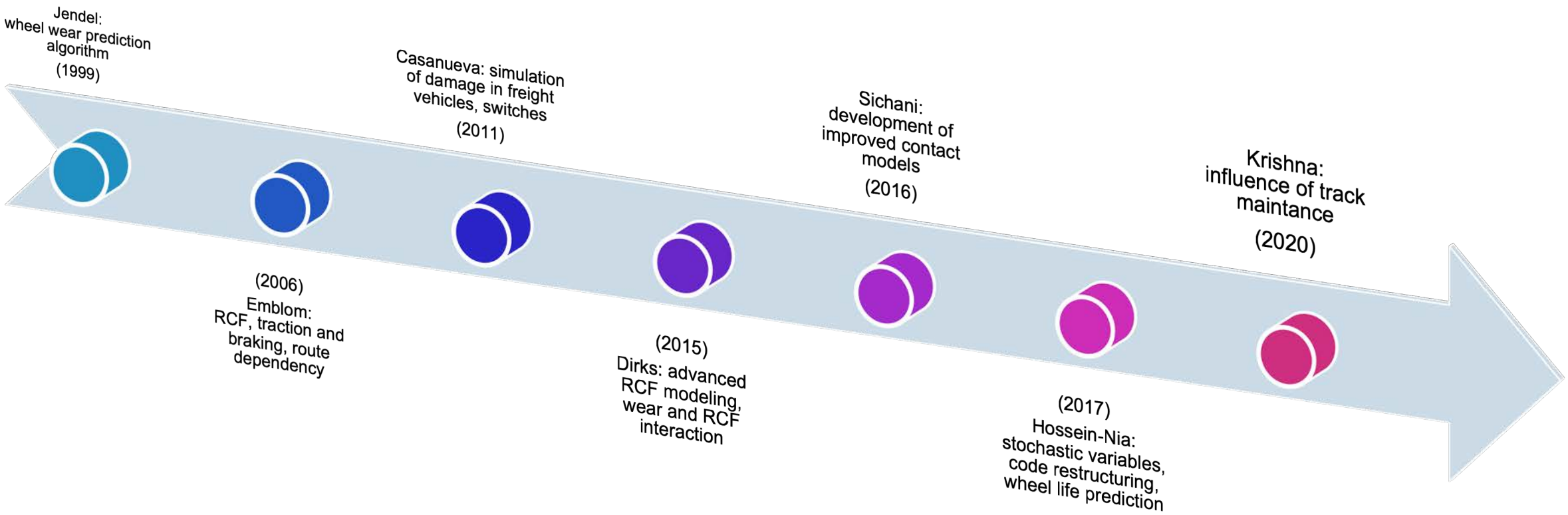
A Digital Twin to predict & achieve outcomes



Outcomes

- **Higher infrastructure availability**
- **Reduced track maintenance**
- **Reduced costs due to delays**
- **Lower operating costs**
- **Reduced vehicle maintenance**
- **Higher vehicle availability**
- **Better ride comfort**
- **Less running instability**

Wheel-Rail contact damage models



Evolution of the KTH Damage Model

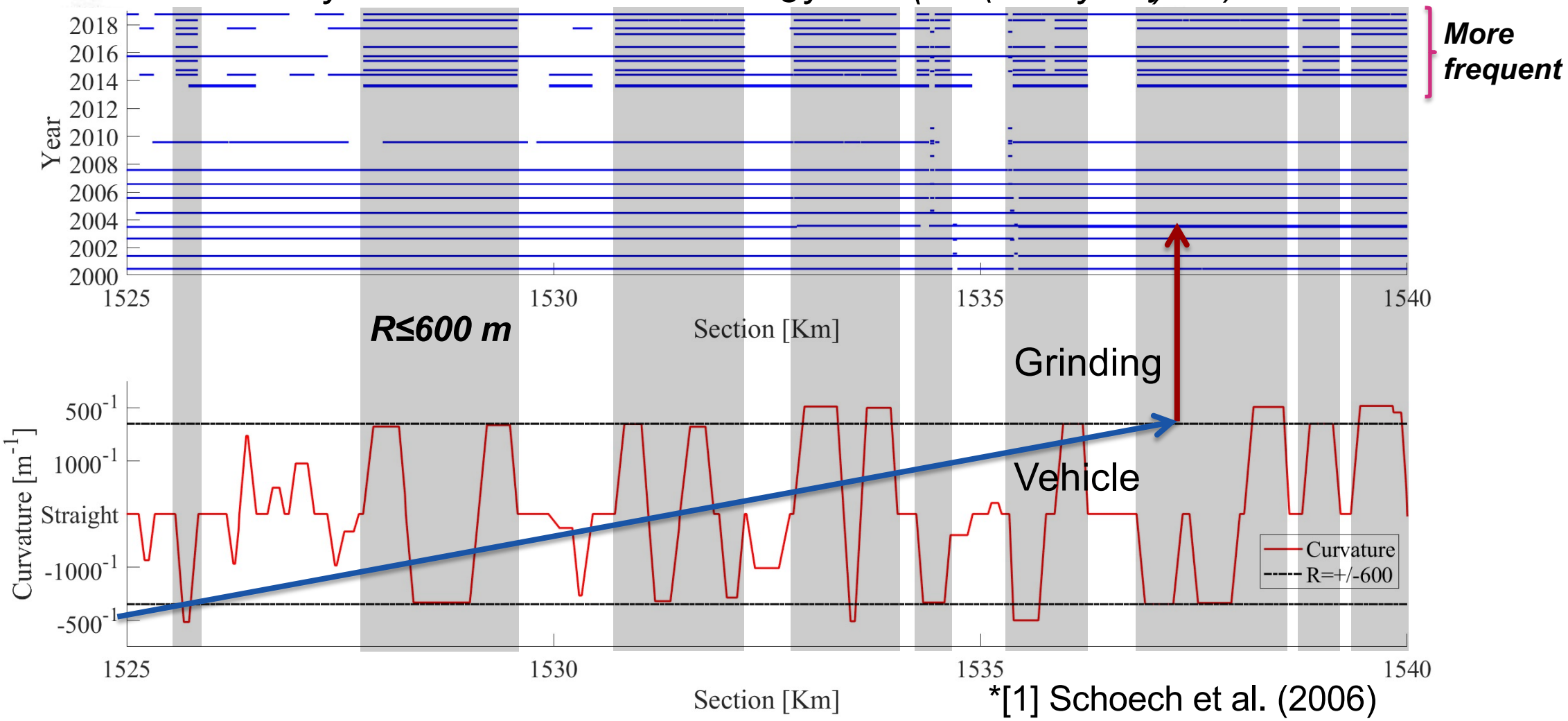
Examples discussed in the presentation

- Calculation of rail damage – Optimisation of grinding intervals (ongoing PhD work)
- Calculation of wheel damage – Wheel life prediction (finished PhD thesis)
- Calculation of rail damage – Influence of track gauge (recent master thesis)
- Using Machine Learning tools to detect vehicle hunting or to monitor track irregularities (ogoing PhD work)
- Identification of local rail defects with help of Machine Learning (recent master thesis)

Calculation of rail damage – Optimisation of grinding intervals

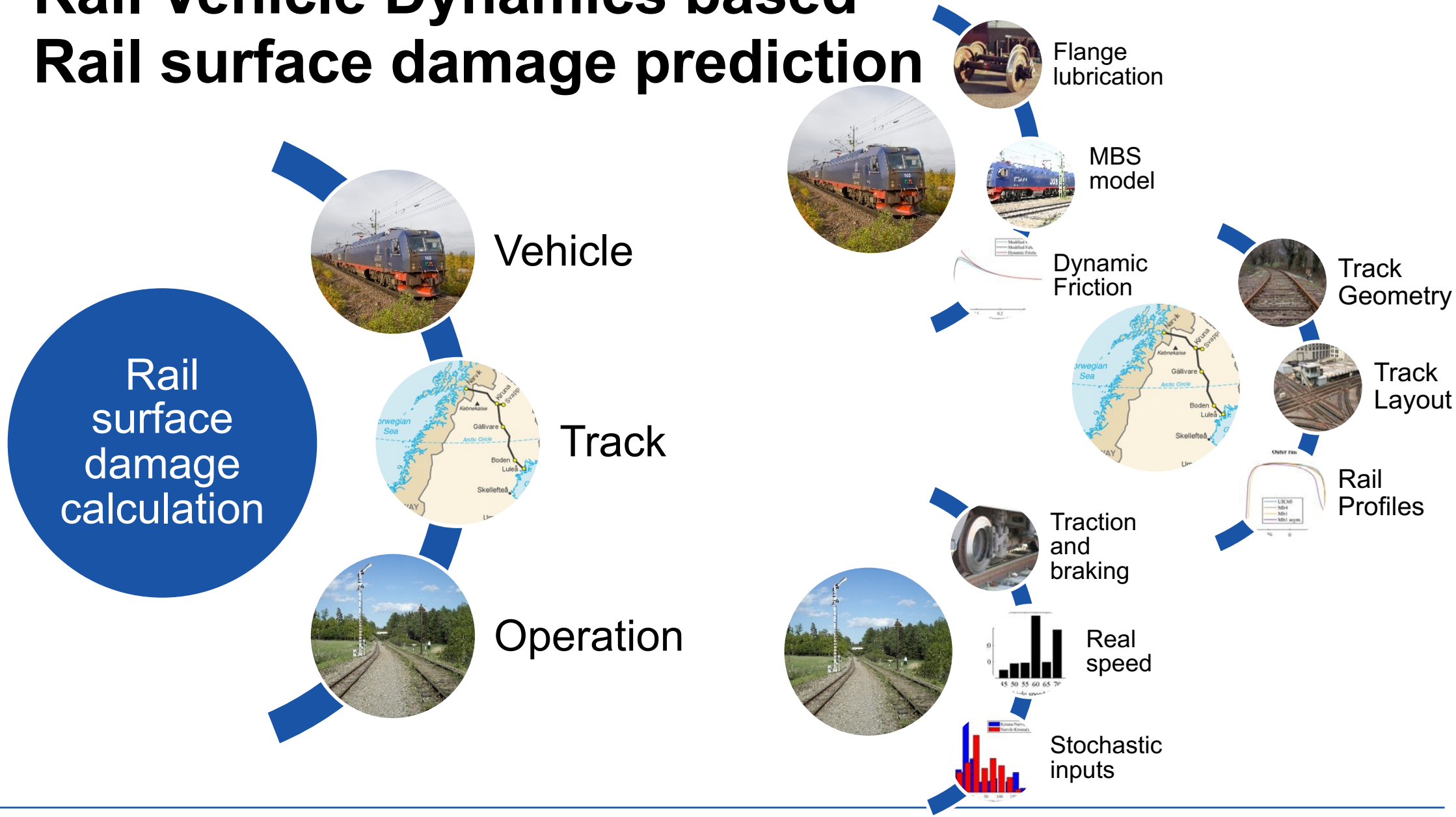
Significance of maintenance interventions

Swedish Rail cross section Grinding schedule (17 MGT/year)



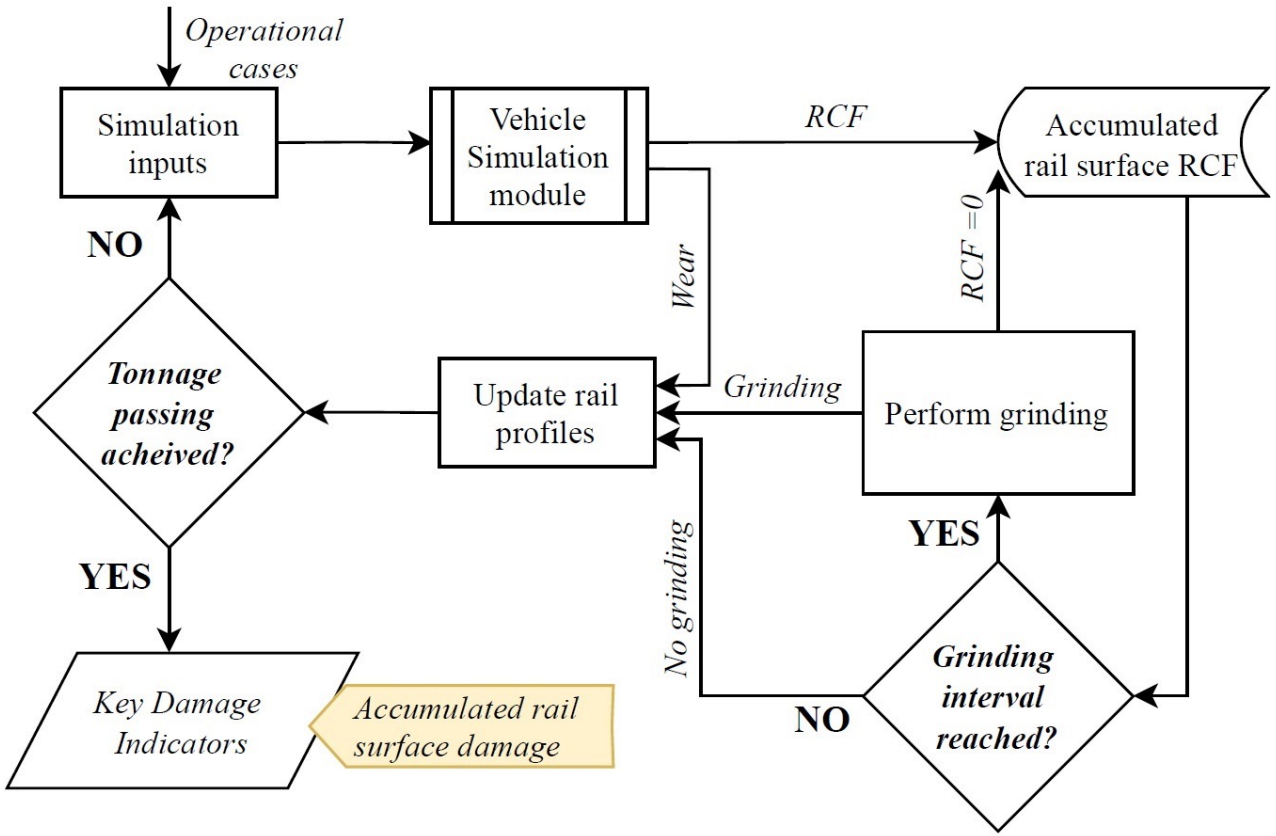
*[1] Schoech et al. (2006)

Rail Vehicle Dynamics based Rail surface damage prediction



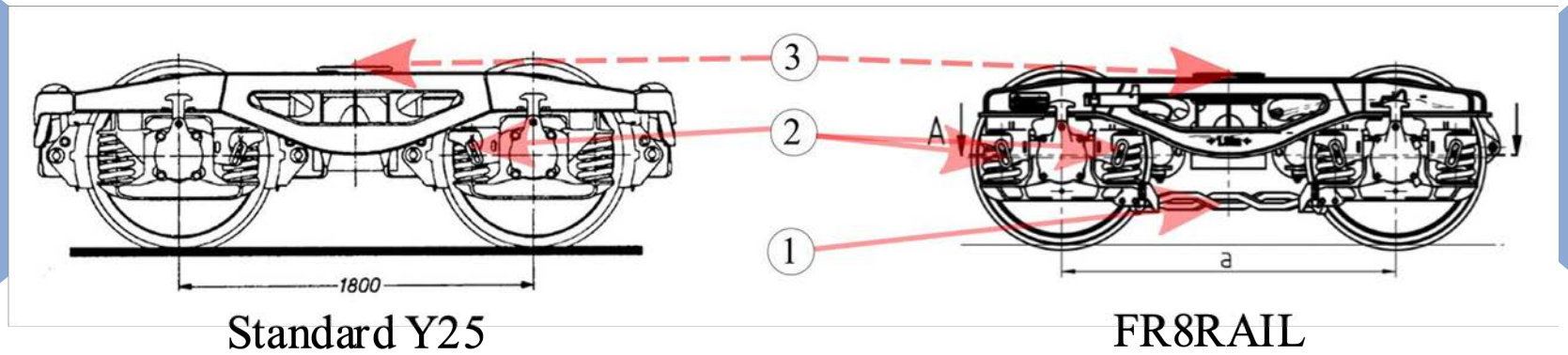
Calculating long term rail surface damage

- A MBS simulations-based method to assess long term accumulated rail surface damage due to
  - Vehicle passing
  - Intermediate maintenance actions



Comparing bogie designs

1. Cross bracing linkages
2. Double Lenoir links
3. Sidebearer longitudinal clearnance



Elements of simulation modelling

Vehicle Designs

- Suspension elements
- Axle loads
- Wheel profiles

Track operation

- Track design geometries
- Friction levels
- Operating speeds
- Rail profiles

Maintenance

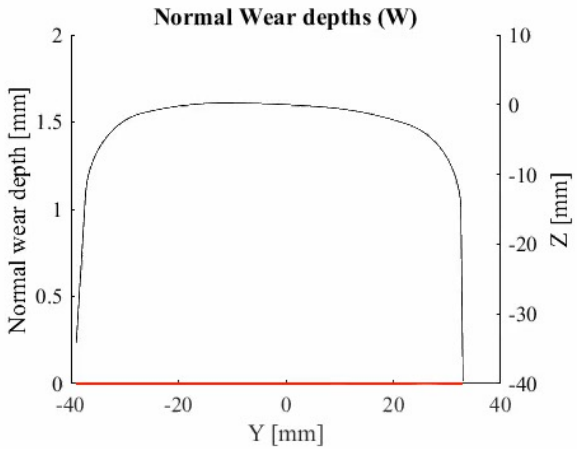
- Type (Grinding/milling)
- Intervals
- Depths

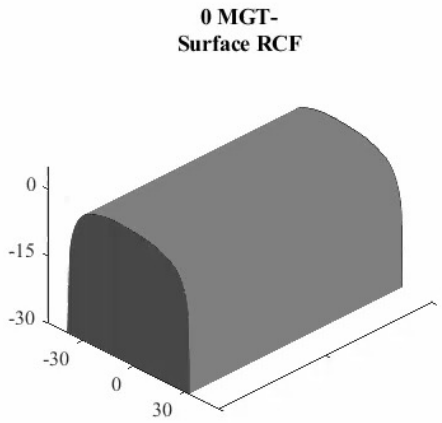
Rail surface damage evolution

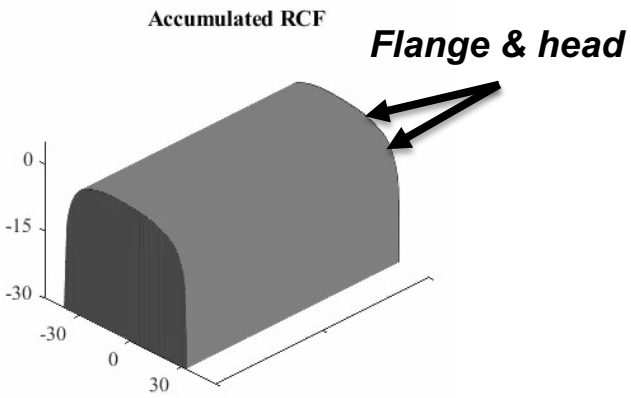
Standard Y25 bogie

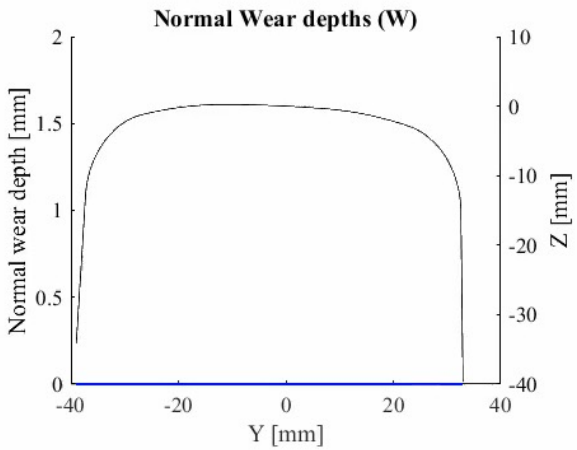
R = 450 m
Outer rail
100 MGT
~4 years

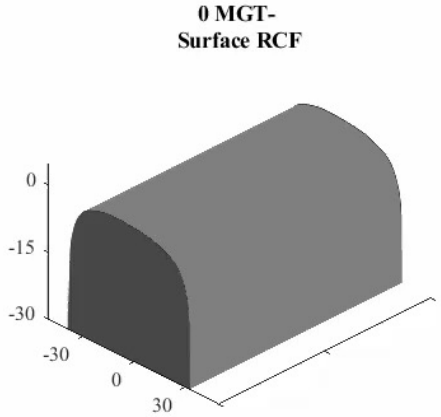
FR8RAIL bogie

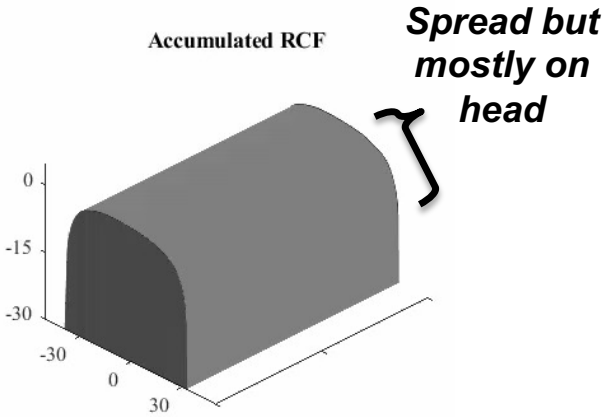












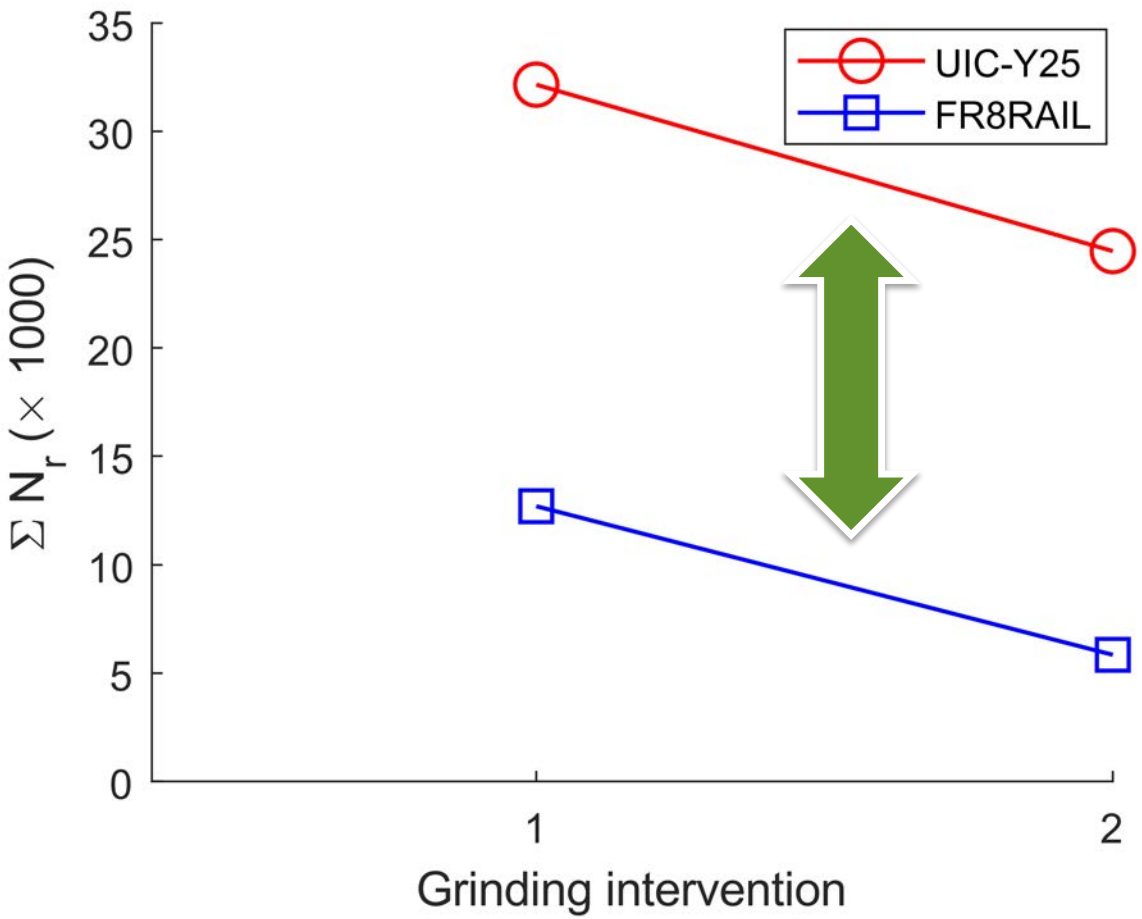
Wear depth | Surface RCF | Accumulated RCF

Optimization of grinding intervals

- The RCF accumulation (**ΣN_r**) on the rail surface just before each grinding pass are plotted for

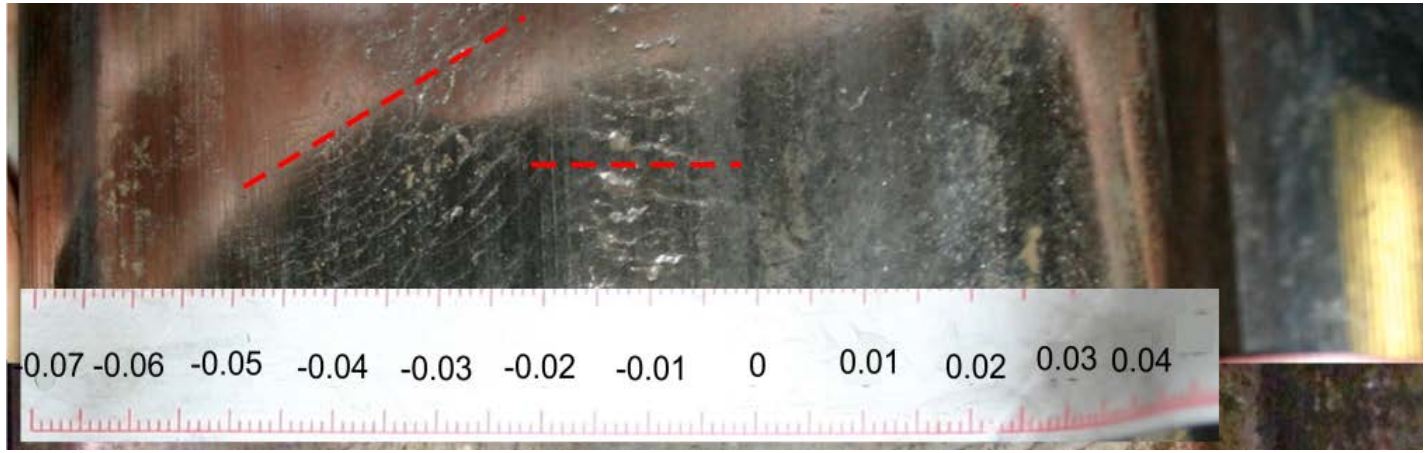
➢ R450
➢ R600
➢ R1500

- Presents **opportunity to modify grinding intervals w.r.t running gear behaviour** for different curve radii.

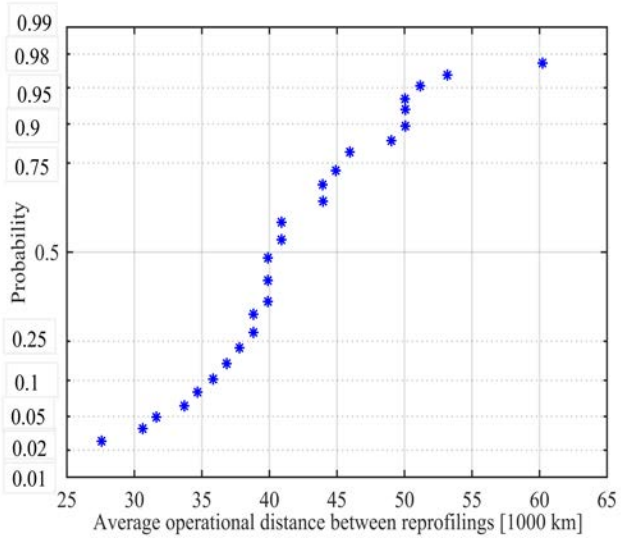


Calculation of wheel damage – Wheel life prediction

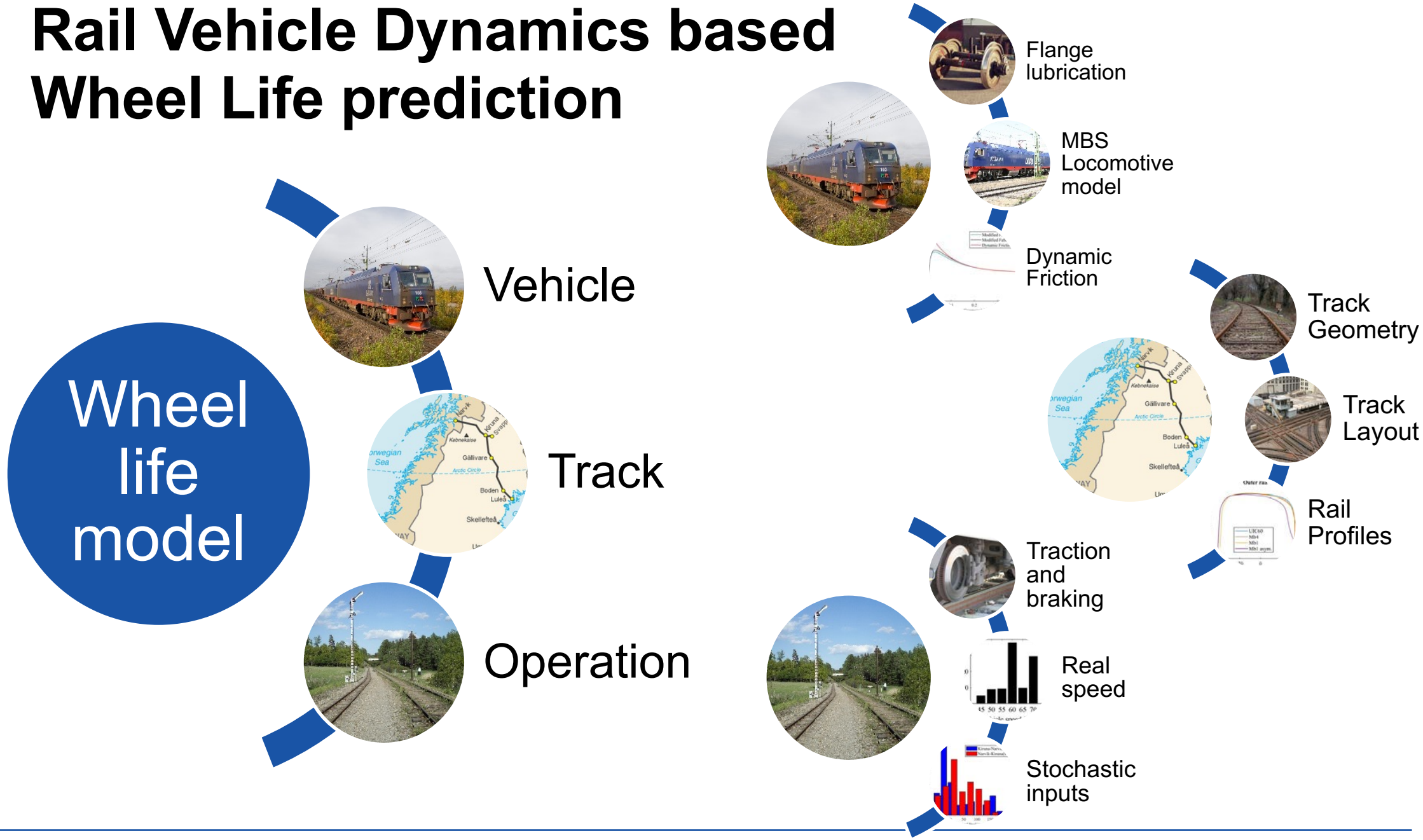
Wheel life prediction



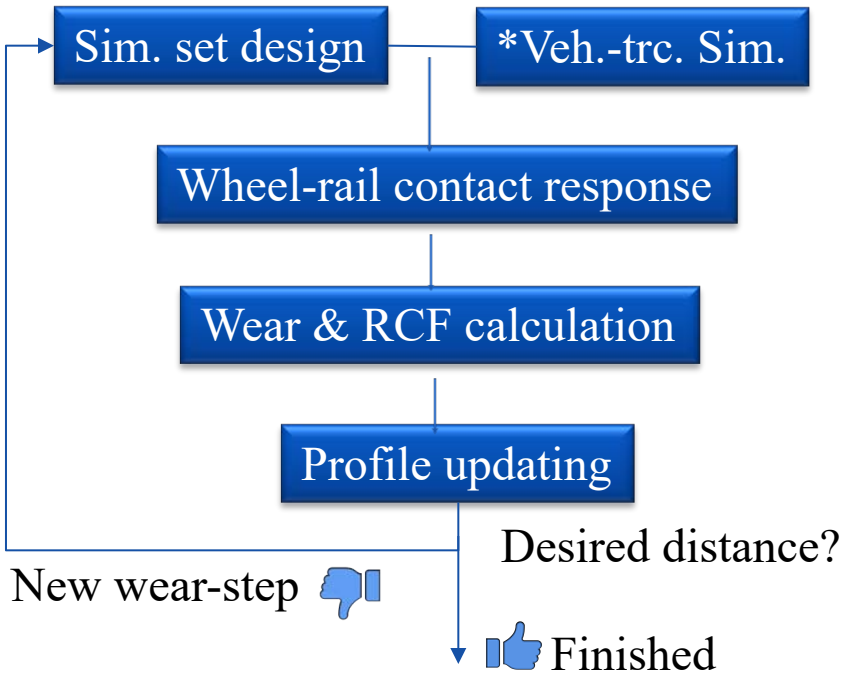
Anders Ekberg, Chalmers



Rail Vehicle Dynamics based Wheel Life prediction

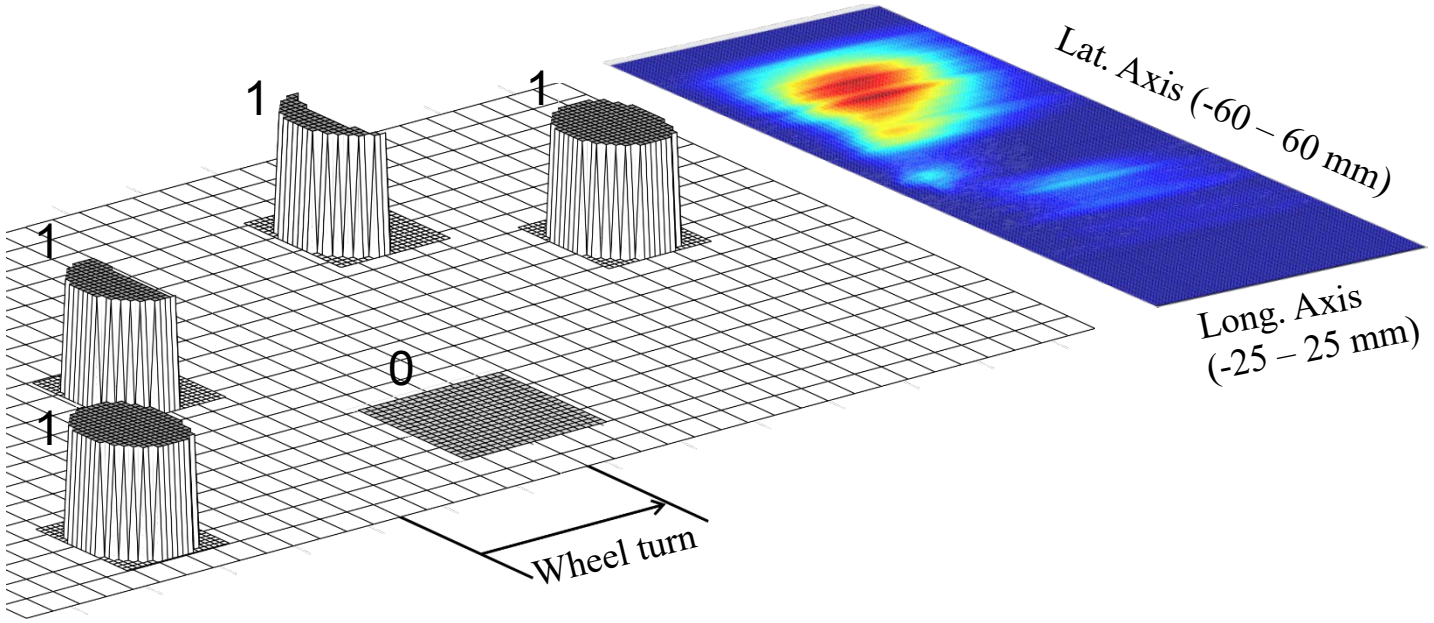


RCF Calculation



RCF calculation

1. Check the exceedance of the yield limit in shear in each element of the contact mesh
2. Count the amount of incidents where #1 occurs



RCF calculation

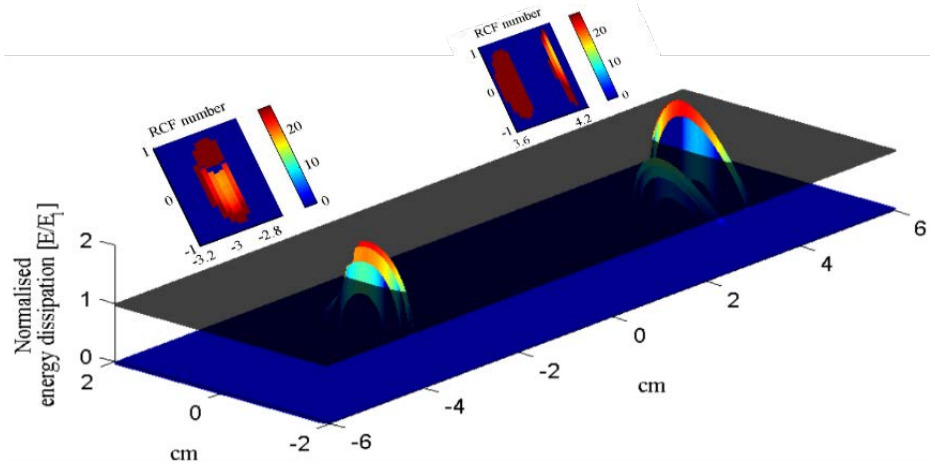
1. Check the exceedance of the yield limit in shear in each element of the contact mesh
2. Count the amount of incidents where #1 occurs
3. Correct the RCF-number (Nr) values by energy dissipation method (Burstow)

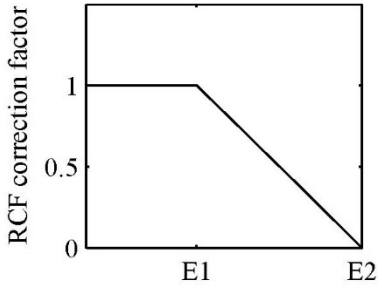
$$\bar{E}_i = \frac{\nu_i \cdot A}{2\sqrt{3}}\left(\sigma_y + \sigma_U\right), \text{for } i = 1, 2$$

ν_i are 0.3% and 1%

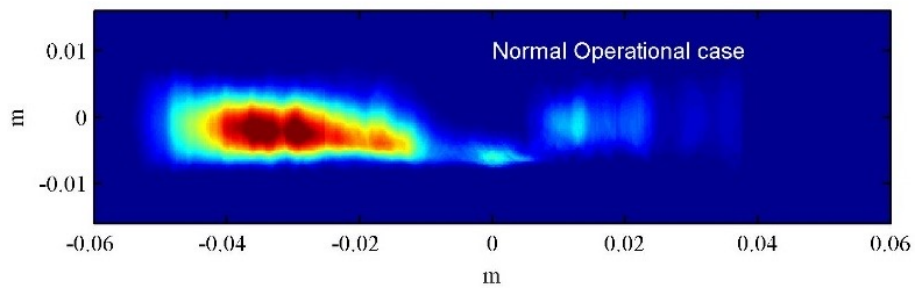
σ_y and σ_U are material yield limit and its ultimate tensile strength

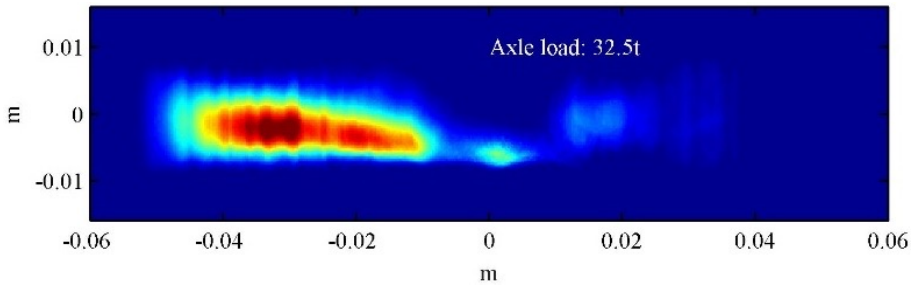
$$E(x, y) = \tau_{zx}(x, y) \cdot (\nu_x - \phi \cdot y) + \tau_{zy}(x, y) \cdot \left(\nu_y + \phi \cdot x\right)$$

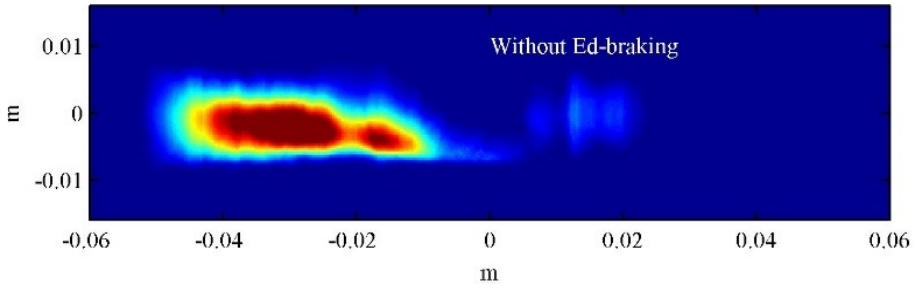


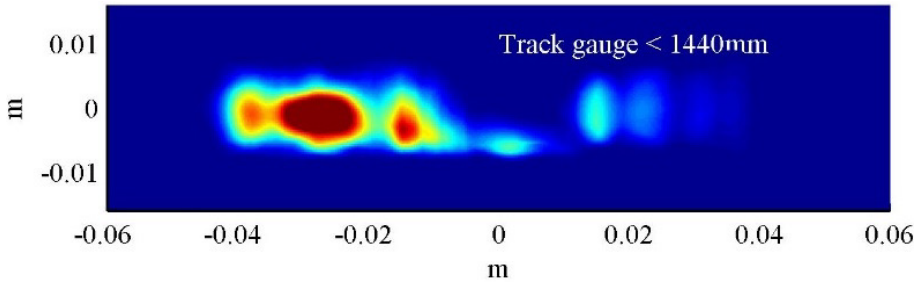


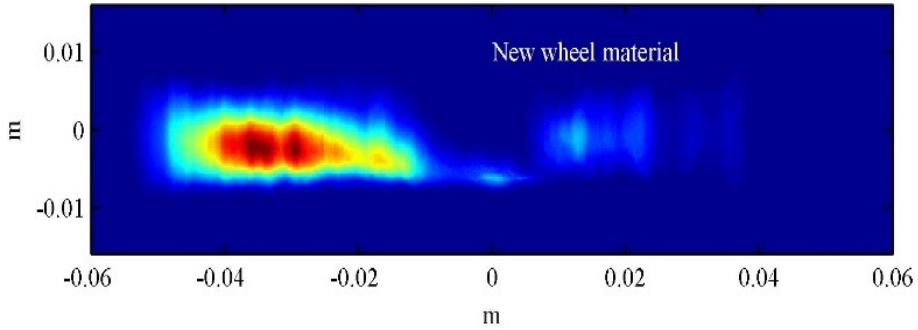
RCF results (N_r)





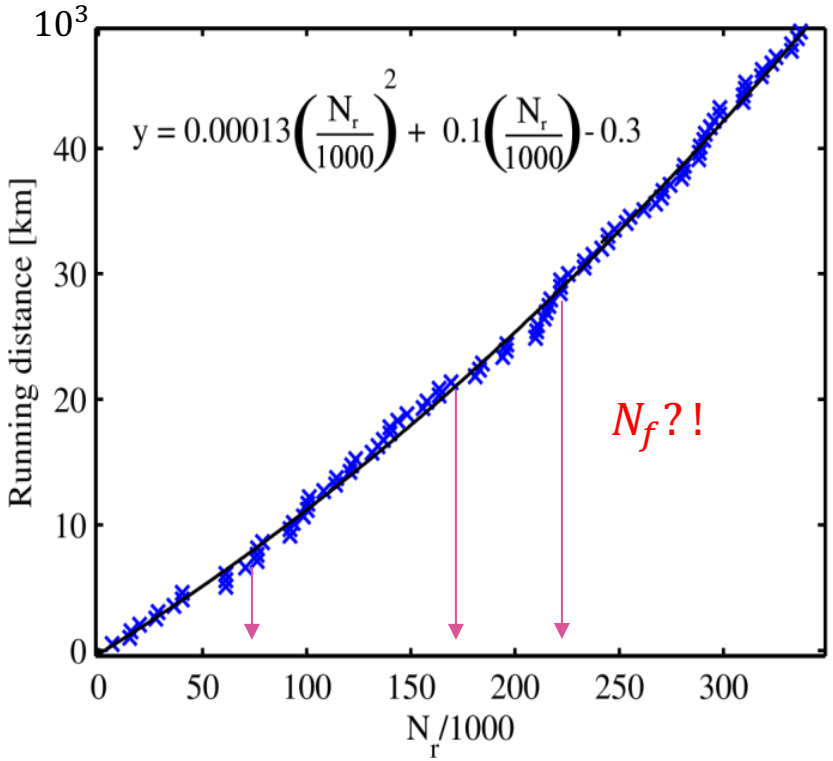






Simulated RCF results for various operational cases after 50 000km; maximum value for the colour-bar is set to 300 000 RCF number.

Wheel life prediction model

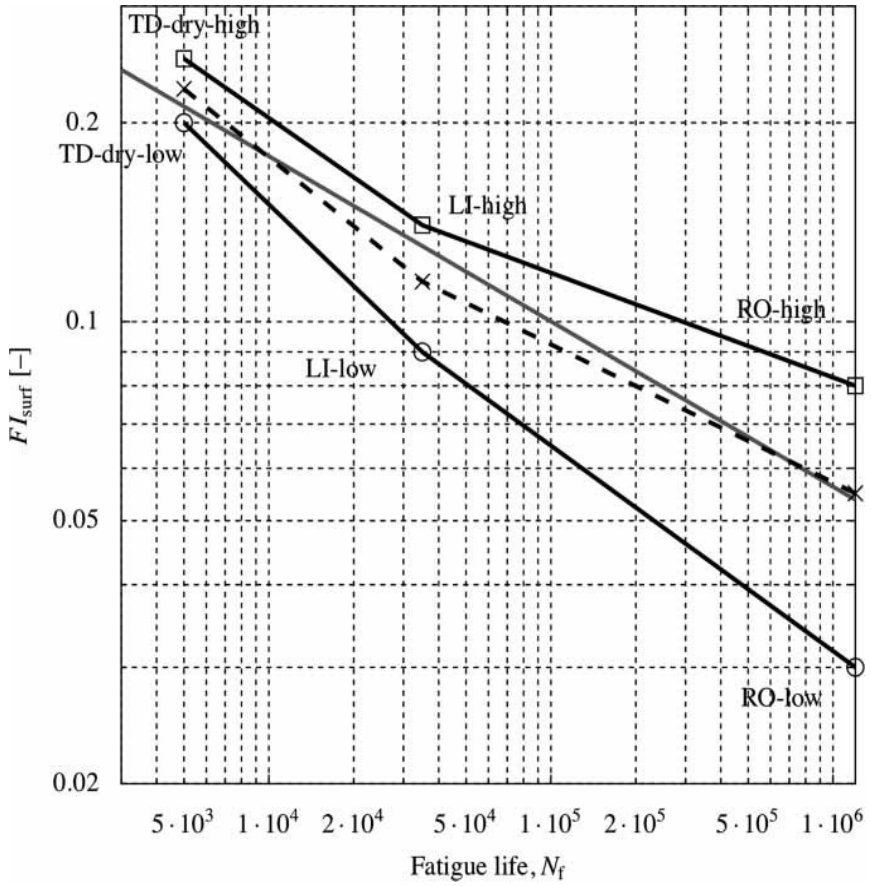


N_f Fatigue life

Wheel life prediction model

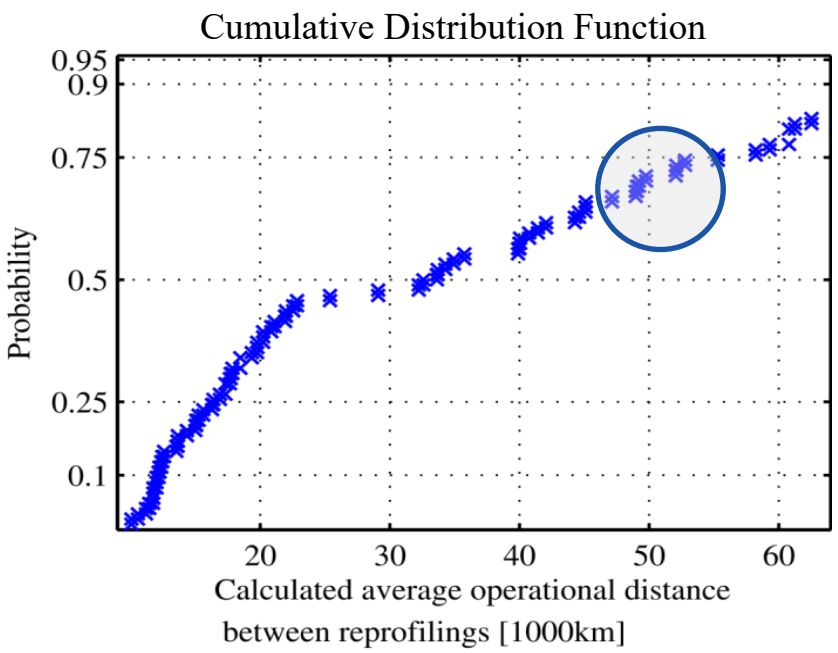
$$N_f = \frac{10}{FI_{surf}^4}$$

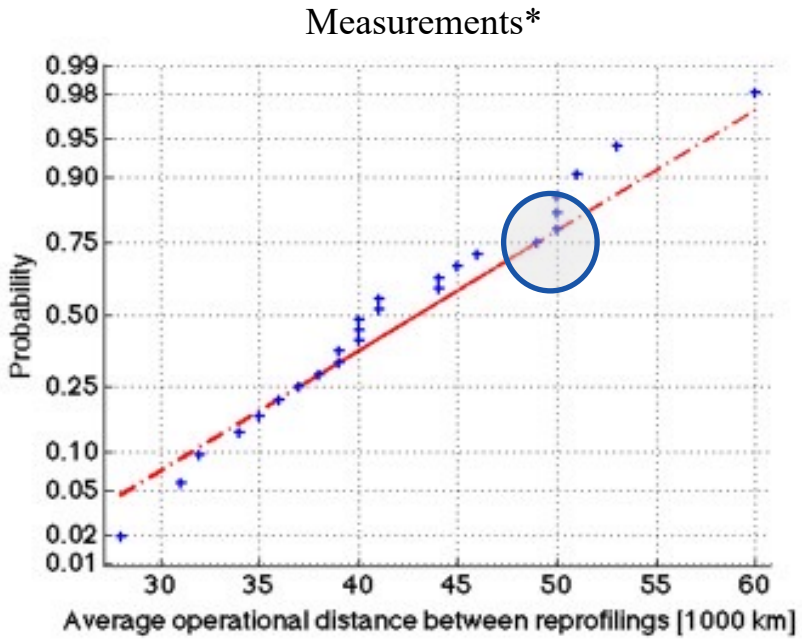
*Fatigue life: N_f



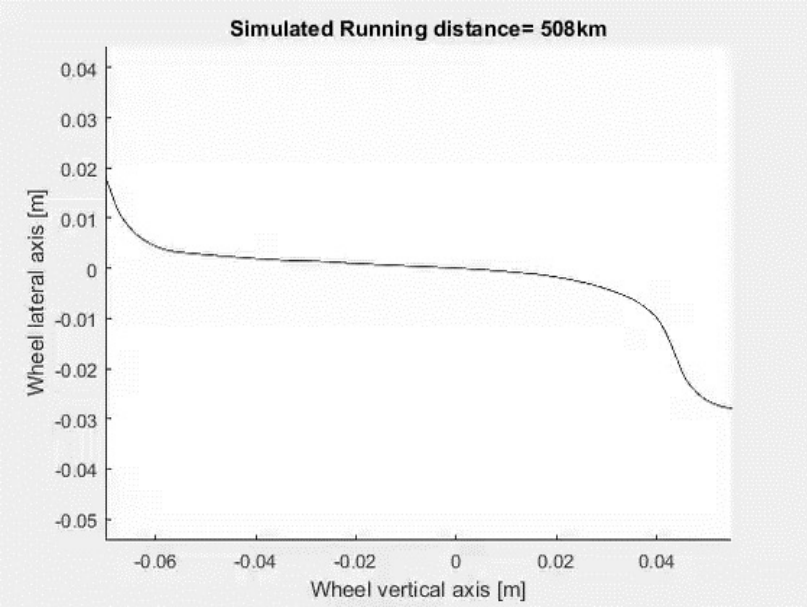
***Kabo E., Ekberg A., Torstensson PT. and Vernersson T. Rolling contact fatigue prediction for rails and comparisons with test rig results. Proceedings of the Institution of Mechanical Engineers Part F-Journal of Rail and Rapid Transit. 2010; 224: 303-317.**

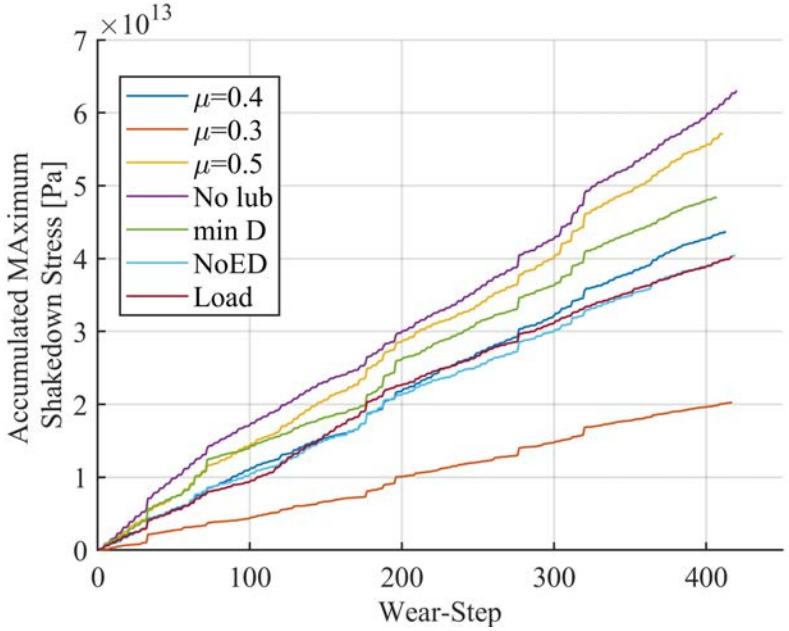
Wheel life prediction model: results

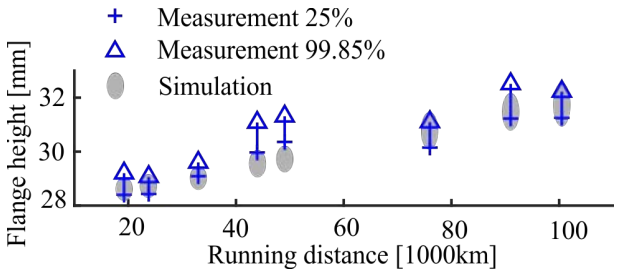


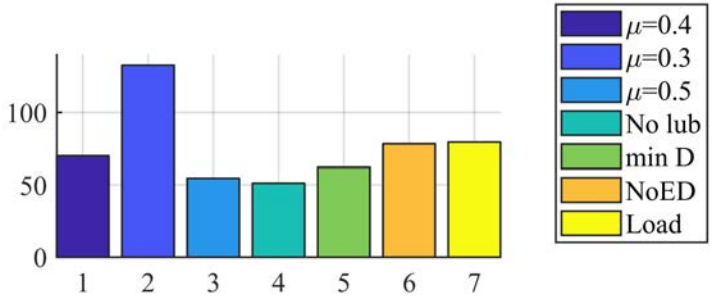


Wheel Life prediction: wear and RCF





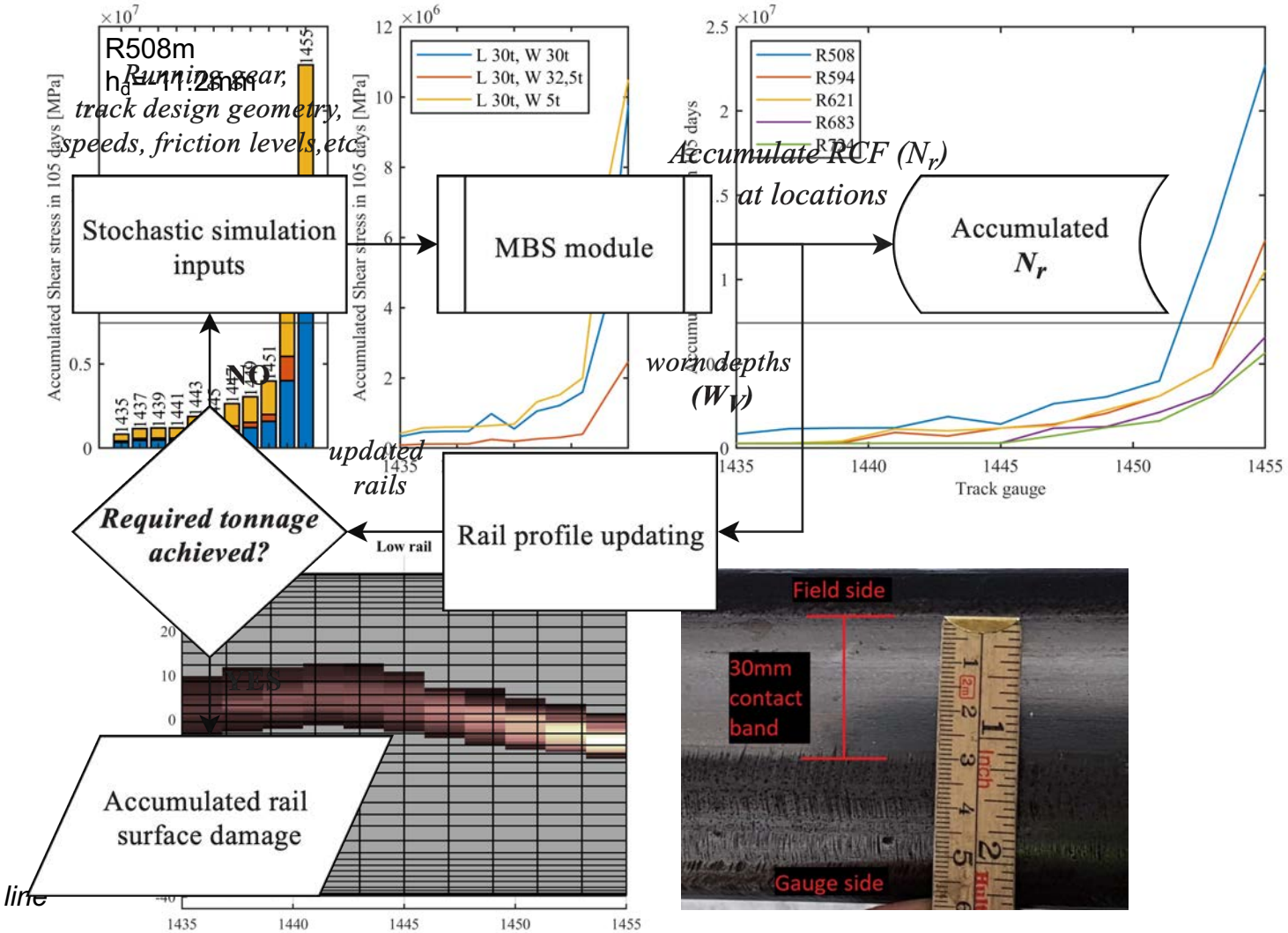




S Hossein-Nia, S Stichel, 2019, *Multibody simulation as virtual twin to predict the wheel life for Iron-ore locomotive wheels* International Heavy Haul Association Conference, IHHA 2019, Narvik

Calculation of rail damage – Influence of track gauge

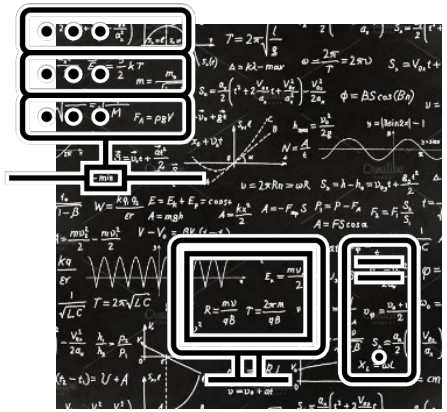
Rail Life prediction



J. Flodin, 2020, *Investigate the track gauge widening on the Iron-ore line and suggest maintenance limits*, KTH Master thesis

Machine Learning

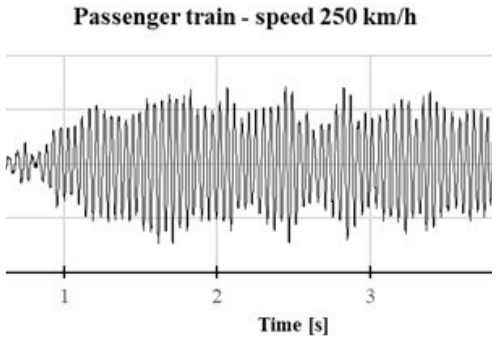
- Computer algorithms that improve automatically through experience
  - Use a dataset in order to build a mathematical model that can make further predictions
  - Used where it is not feasible to develop conventional algorithms to perform the tasks



Machine Learning Algorithms for condition monitoring and fault diagnostics

Track geometry

Local track defects

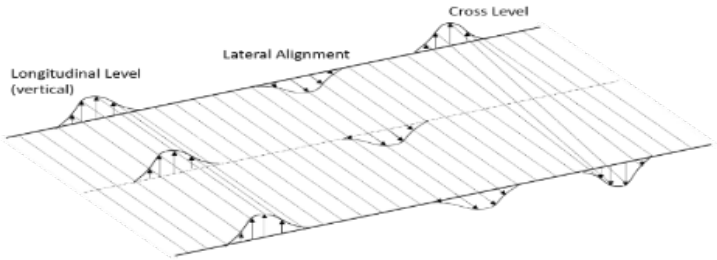


Running instability

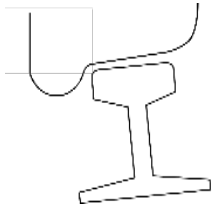
Component failure

Rail Vehicle Dynamics Informed Machine Learning Algorithms for **onboard** condition monitoring and fault diagnostics

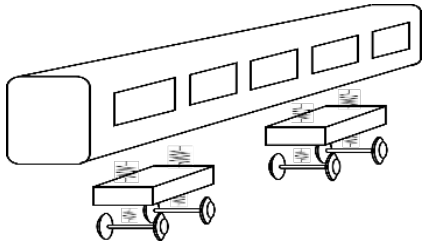
Monitoring of track geometry irregularities



Track irregularities

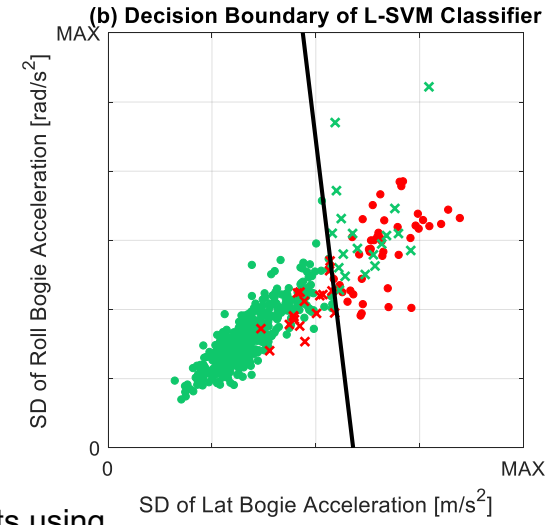


Wheel–rail contact



Vehicle dynamic response

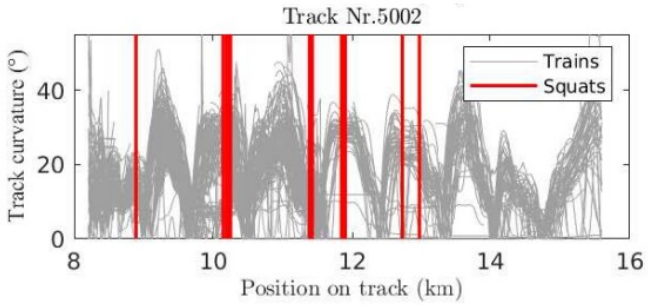
Onboard Vehicle Dynamic Measurement → Feature Extraction → Data Driven Fault Classifier → Monitoring of Track Geometry Irregularities

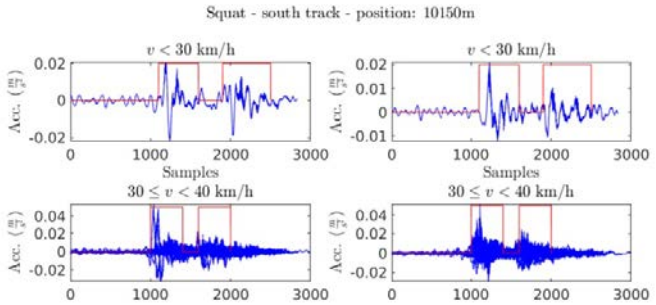


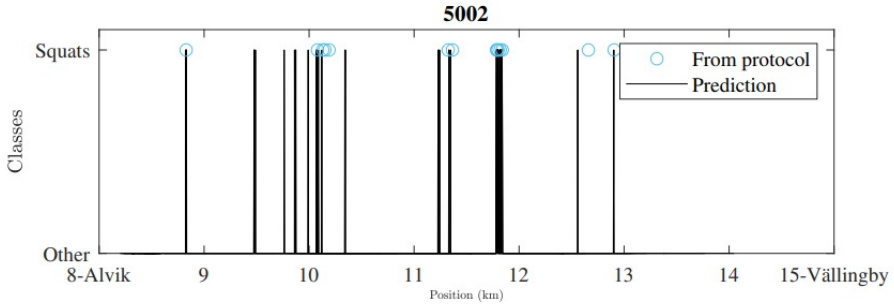
A. D. Rosa et al., 'Monitoring of lateral and cross level track geometry irregularities through onboard vehicle dynamics measurements using machine learning classification algorithms', Proceedings of the Institution of mechanical engineers. Part F, journal of rail and rapid transit, 2020.

Identification of local defects

Identification of rail squats from axle box acceleration measurements using machine learning algorithms







T. Niewalda, ‘Deep Learning Based Classification of Rail Defects Using On-board Monitoring in the Stockholm Underground’, KTH Master thesis, 2020.

Summary

The presented tools

- Show good agreement with field observations

and could be used to

- Optimise rail grinding or wheel turning intervals with respect to
  - Track section
  - Operational changes
  - Vehicle type
  - Changes of wheel or rail profile type
  - …
- Detect faults in vehicle and/or track with help of **Rail Vehicle Dynamics** Informed Machine Learning Algorithms