Simulation of Friction Management in Railway Operations

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Content

Simulation of Friction Management in Railway Operations

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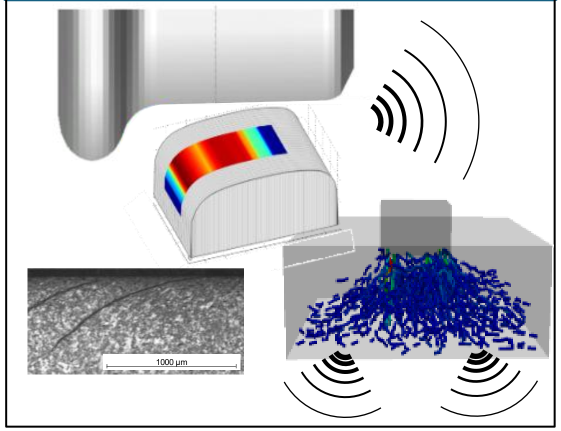
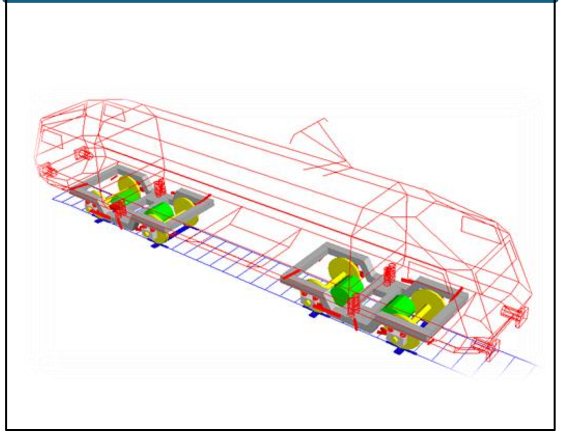
Fields of Activity: Vehicle/Track-Interaction

Wheel-Rail Interaction & Deterioration Phenomena



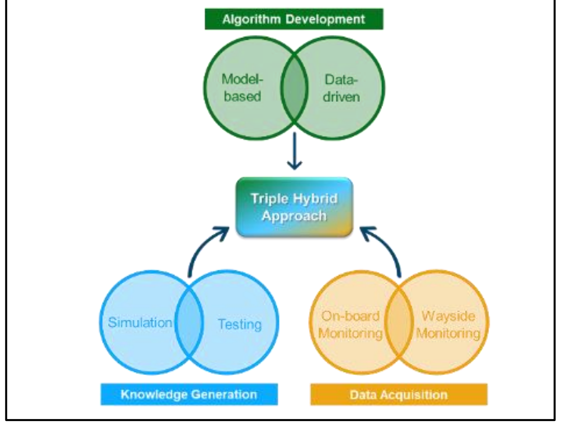
- Profound knowledge of physics
- Modelling of complex interactions and phenomena
- Wheel/Rail profile evolution
- Wheel/Rail surface damage
- Wheel/Rail contact phenomena
- Friction management
- Track degradation
- Noise & Vibrations

Vehicle Dynamics & Operation Analysis



- Profound knowledge of vehicle system dynamics
- Simulation and modelling of vehicle/track interaction
- Vehicle and track parameter identification
- Virtual homologation of running behaviour (EN 14363)
- Probabilistic vehicle and track design

Monitoring & Diagnosis



- Profound context-based knowledge
- Algorithm development based on hybrid approaches
- Model-based and data-driven diagnosis and prognosis methods
- Monitoring, diagnosis and prognosis of vehicle components
- Track monitoring and assessment via on-board and wayside monitoring systems

Digital Twins Network

- Vertical integration: Analysis of interaction between digital twins
- Horizontal integration: System or component behaviour during all life cycle phases
- Single point of truth: Consistent and continuous system data and models

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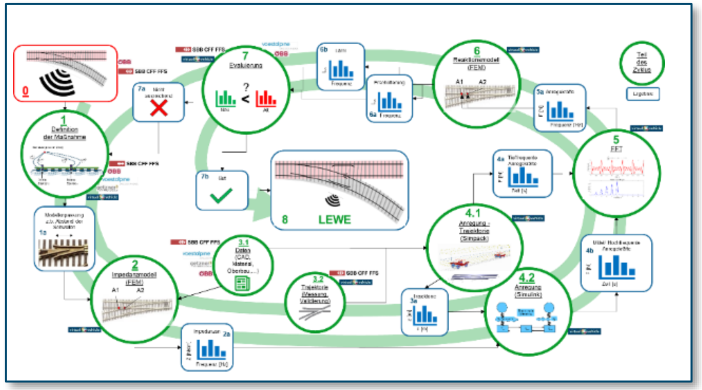
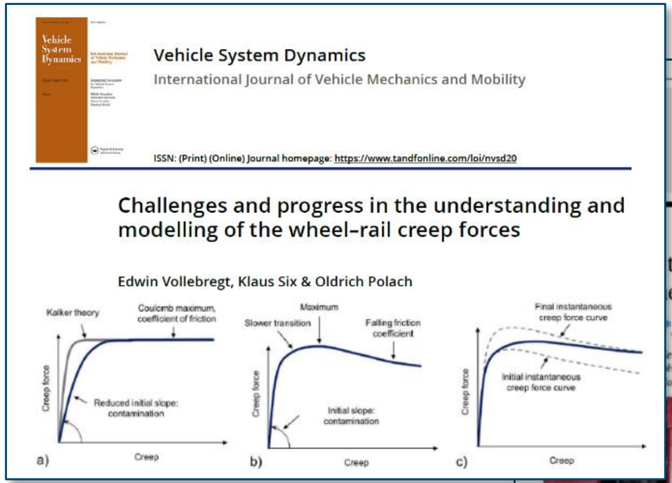
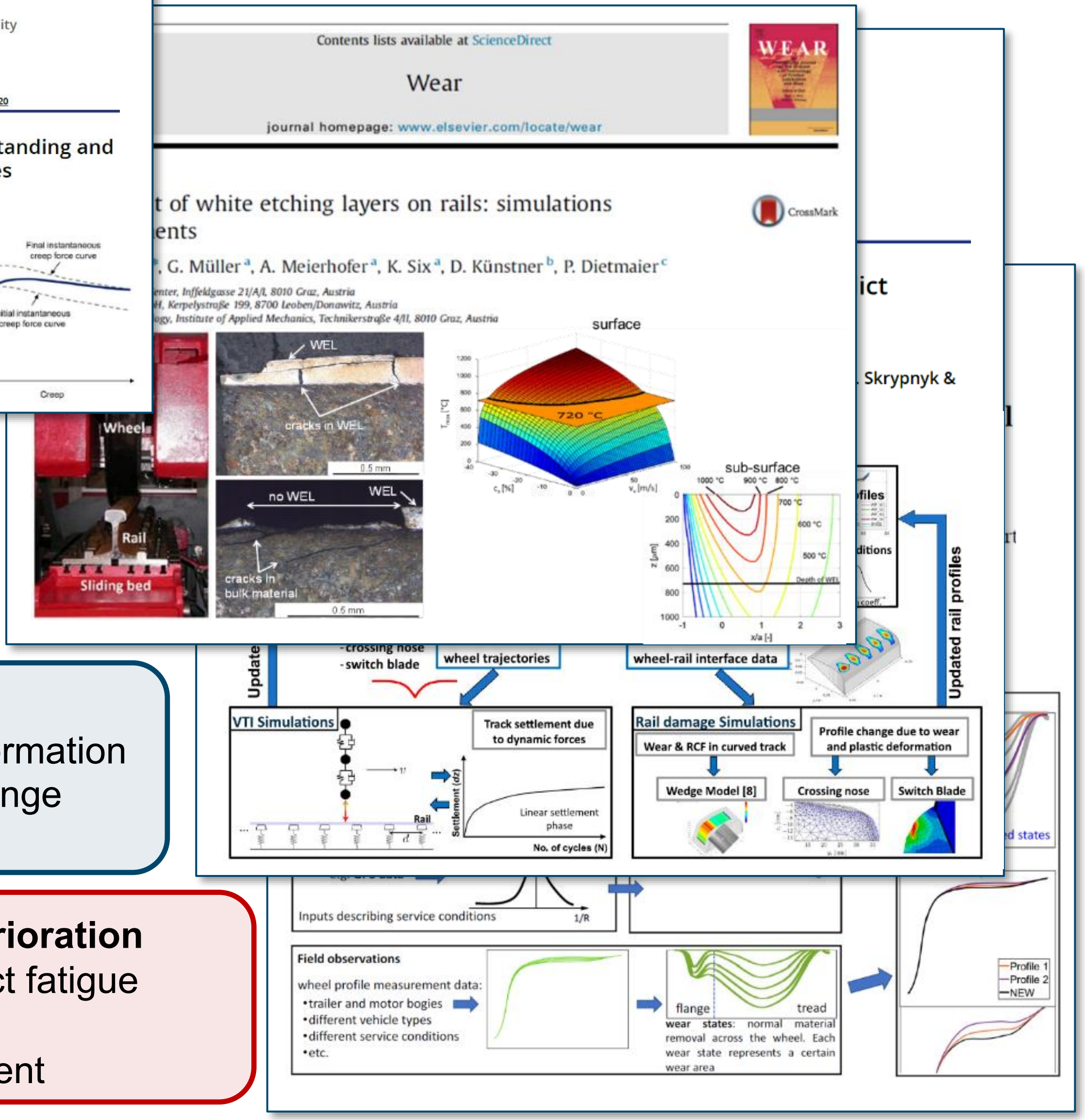
Wheel-Rail Interaction & Deterioration Phenomena





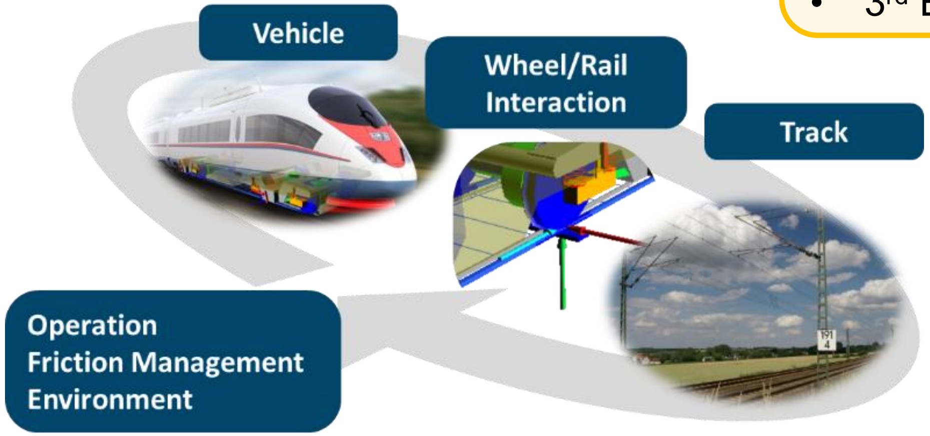


Noise & Vibrations
- Modular approach
- Combination of sub-modules to describe complex situations

Wheel-Rail Contact
- Creep-force curve
- Adhesion
- 3rd Body Layer

Material Modelling
- Severe plastic deformation
- Thermal phase change
- Ballast behaviour

Damage & Deterioration
- Rolling contact fatigue
- Wear
- Track settlement



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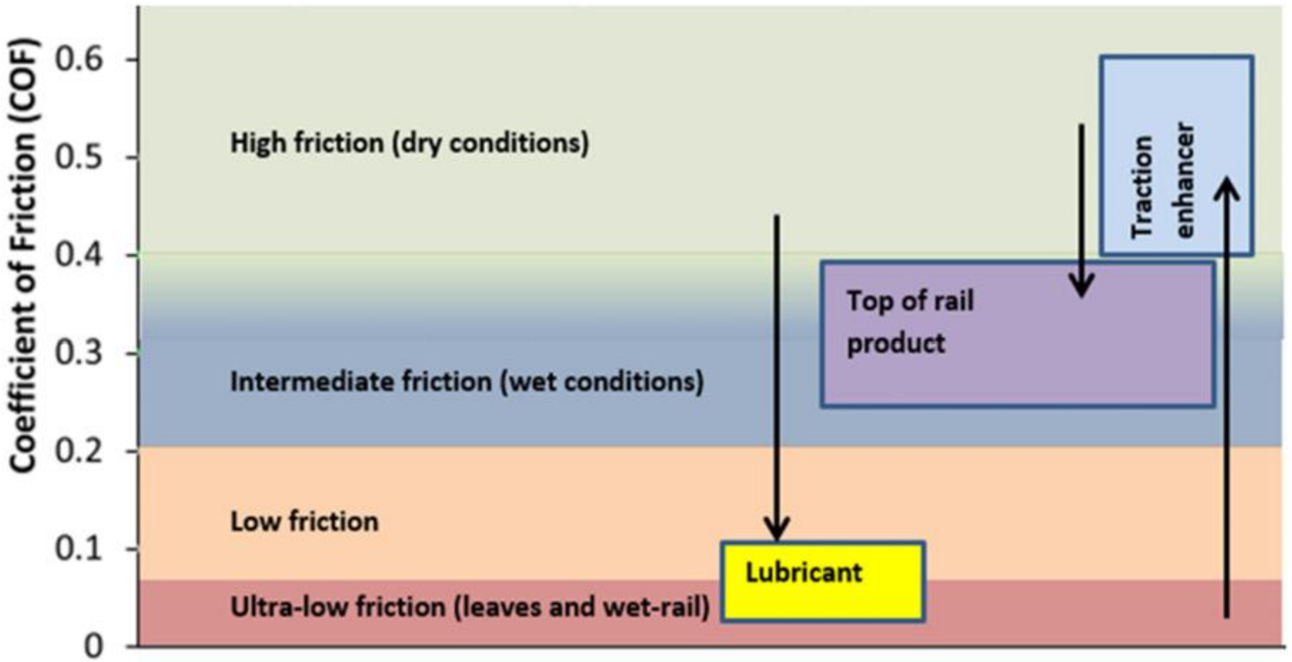
Friction management of the wheel/rail interface

Long history in railway operations:

- Sanding / Traction enhancing products
- Top-of-rail (TOR) friction management products
    - Water-based products
    - Oil- and/or grease-based products
    - Hybrid products (oil/water mixtures)
- Gauge face lubrication



Z.S. Lee, G. Trummer, M. Harmon, B. White, K. Six & R. Lewis, Studying the transfer mechanisms of water based top-of-rail products in a wheel/rail interaction, *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, **2023**, *238*, 164-174.

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Wayside application: Top-of-rail friction management products

Rahmani, H. et al., Carrydown of liquid friction modifier, *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 2022, 0(0)*, 09544097221076258.

- Way-side product application: ToR product is delivered to the rail as a puddle
- In operations: Wayside friction management with ToR product relies on the pick up and carry down of product by the wheels

Z.S. Lee, et al., Studying the transfer mechanisms of water based top-of-rail products in a wheel/rail interaction, *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit,* **2023**, *238*, 164-174

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ToR friction management: Boundary conditions & challenges

Boundary conditions relevant for modelling railway operations:

- Friction management product
- Contact conditions
- Product transfer between surfaces
- Product application
- Local rail head conditions (environment)
- Surface topography
- Contaminations

► **Open tribological system**

► **Varying boundary conditions**

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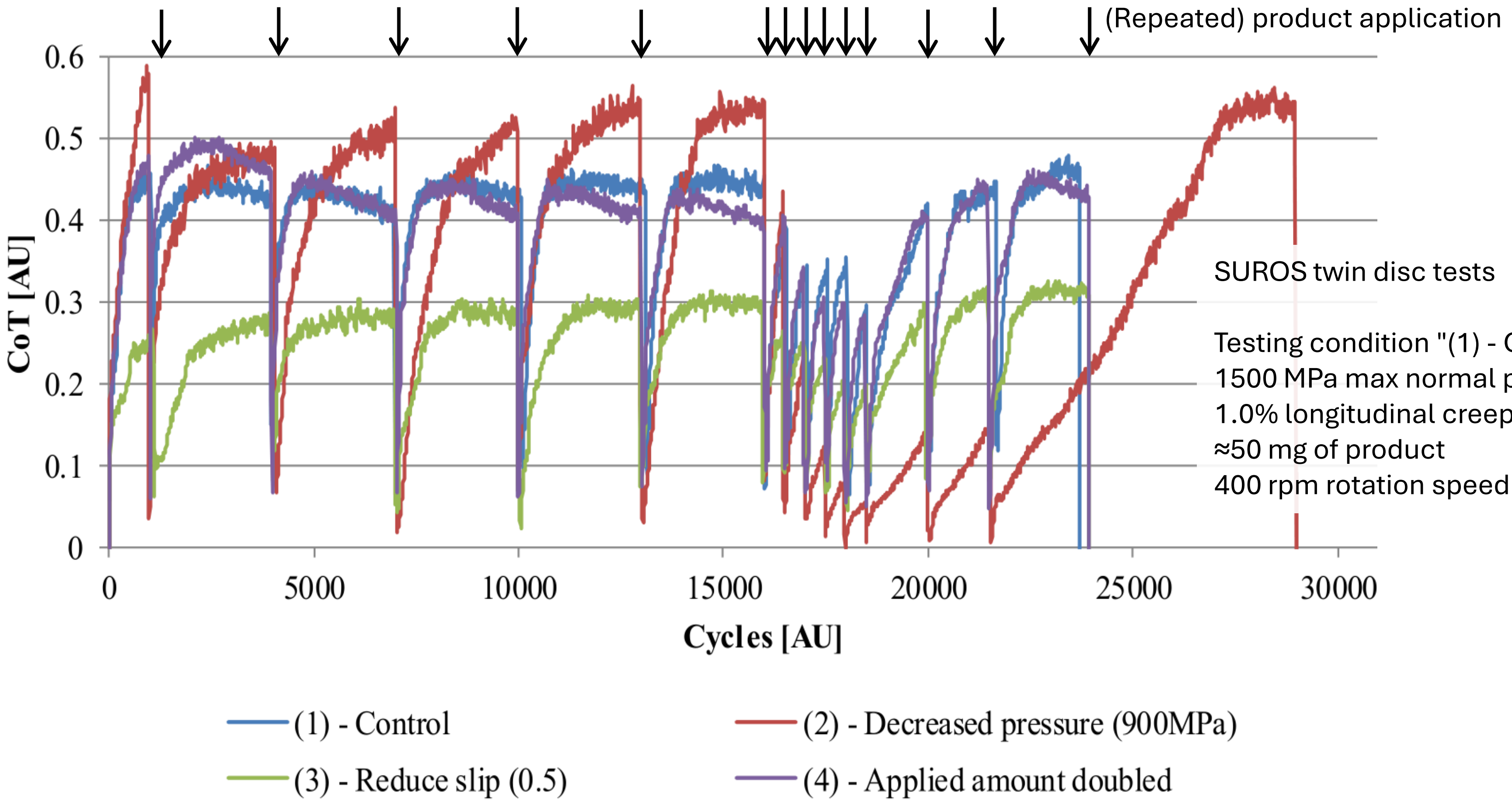
Product degradation testing

Twin disc experiments, water-based ToR product



SUROS twin disc tests

Testing condition "(1) - Control":
1500 MPa max normal pressure
1.0% longitudinal creepage
≈50 mg of product
400 rpm rotation speed

Z.S. Lee, G. Trummer, M. Harmon, B. White, K. Six & R. Lewis, Studying the transfer mechanisms of water based top-of-rail products in a wheel/rail interaction, *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit,* **2023**, *238*, 164-174.

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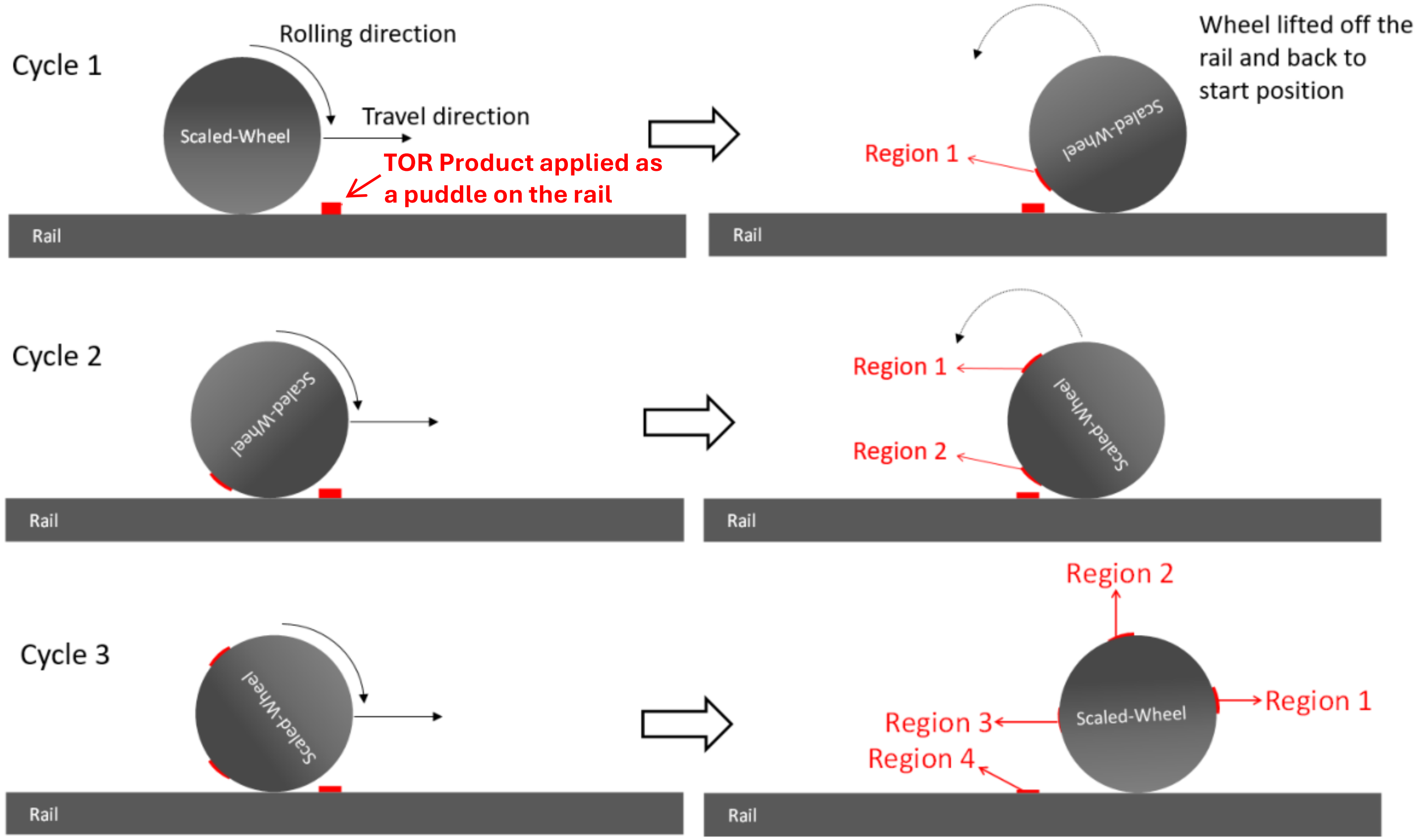
Product pick-up characterization

Scaled wheel test rig experiments



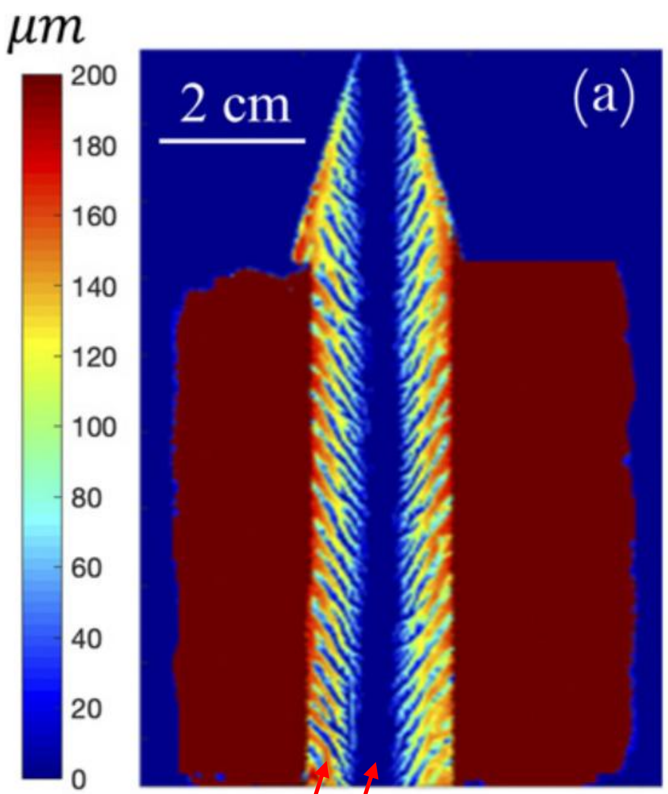
Key observation: Products tend to stay on the surface when product amounts are low (and product is dry)

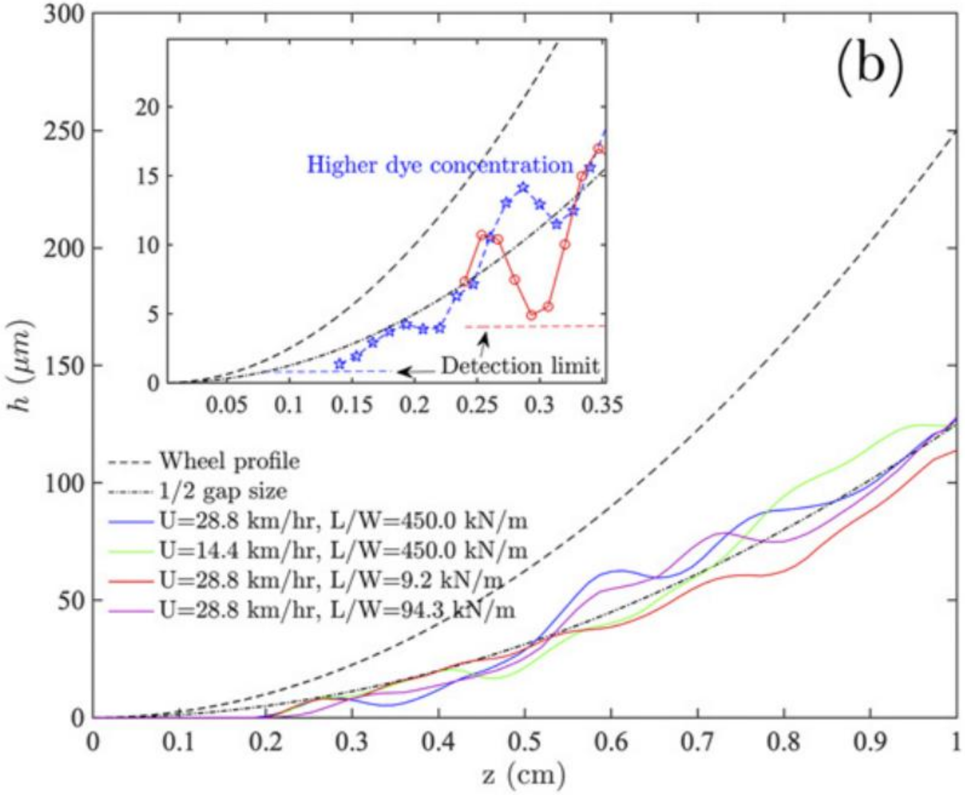
Product amount in different stages of experiment was quantified by weighing the wiped off product

Z. Lee, R. Lewis, G. Trummer & K. Six, Modeling the Effects of Top-of-Rail Products on Creep Forces in the Wheel-Rail Interface, Technical Report DOT/FRA/ORD-24/42, *U.S. Department of Transportation, Federal Railroad Administration, Office of Research, Development and Technology,* **2024**

Wheel rolling through a puddle of product

- <u>Laboratory test</u>: Water-based, liquid product
- Wheel with 200 mm crown radius on flat surface





- Product is squeezed out of the centre of the contact area
- Amount of product in the contact centre is below the detection limit of 1.3 µm
- Product fills the gap between surfaces

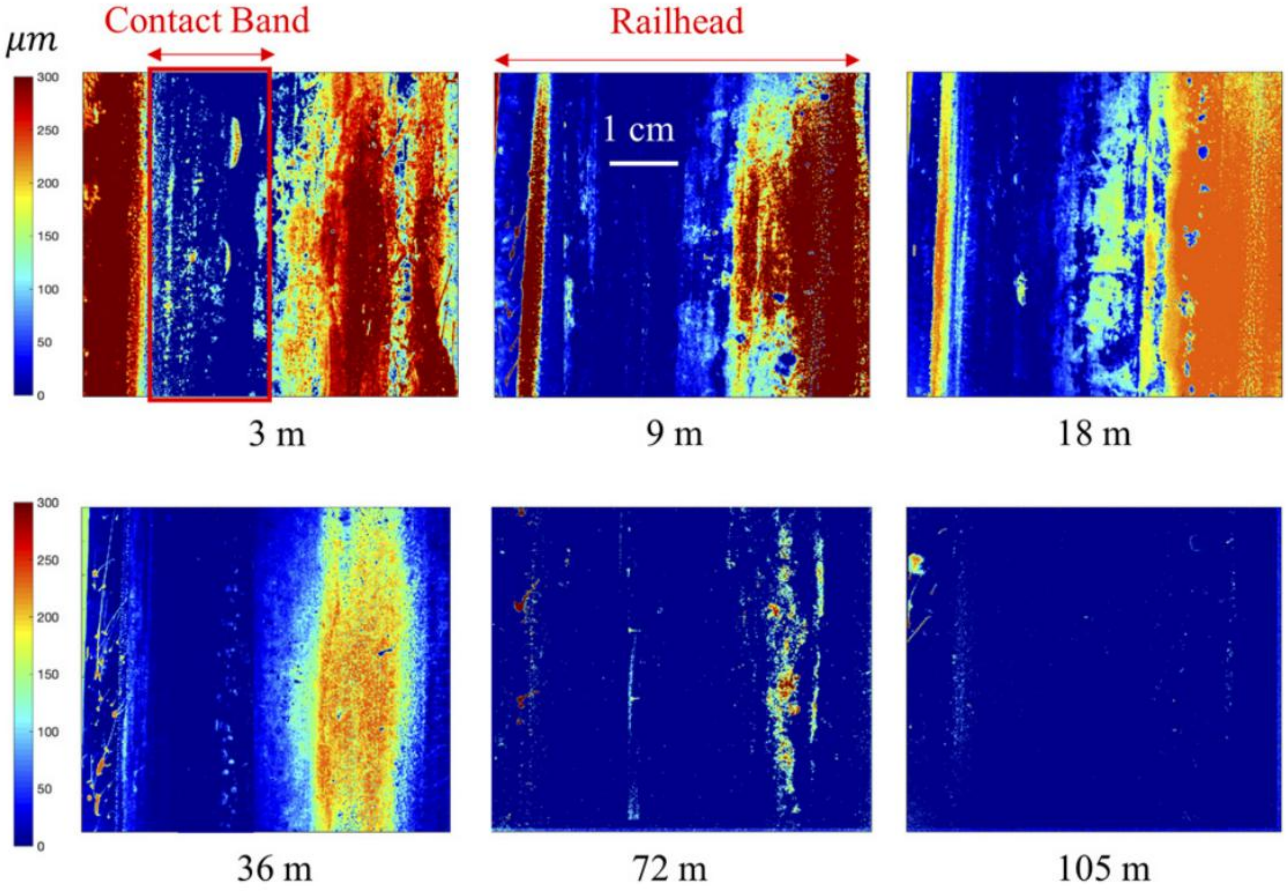
Contact area

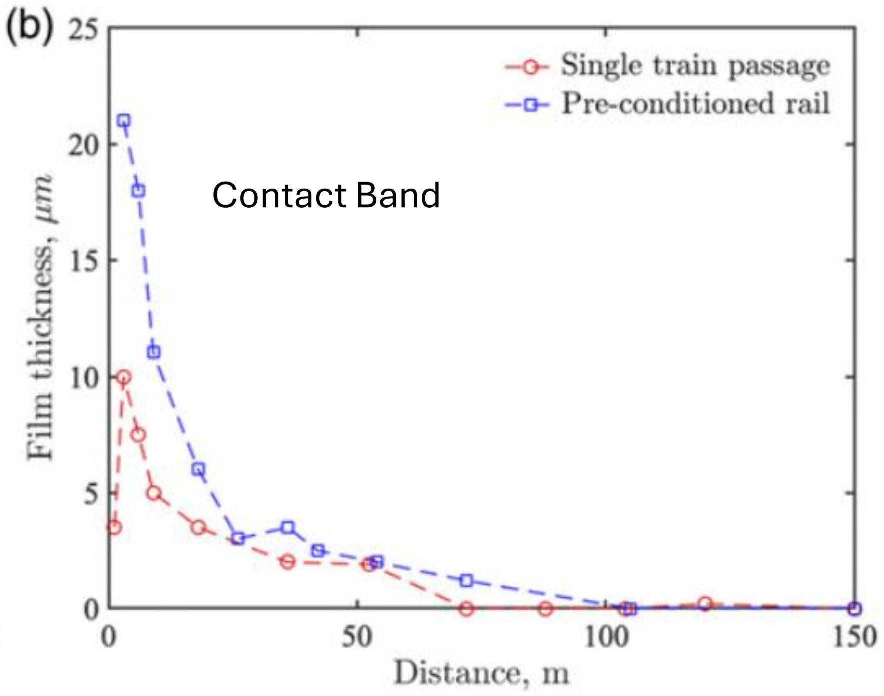
Product height is half height of gap near contact area

Rahmani, H.; Gutsulyak, D.; Stanlake, L.; Stoeber, B. & Green, S., Carrydown of liquid friction modifier, *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 2022, 0(0)*, 09544097221076258.

Product pick up and carry down in operations

Field trials: Product > 3.4 µm (detection limit) up to 100 m from application site found on rail head





Rahmani, H.; Gutsulyak, D.; Stanlake, L.; Stoeber, B. & Green, S., Carrydown of liquid friction modifier, *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 2022, 0(0)*, 09544097221076258.

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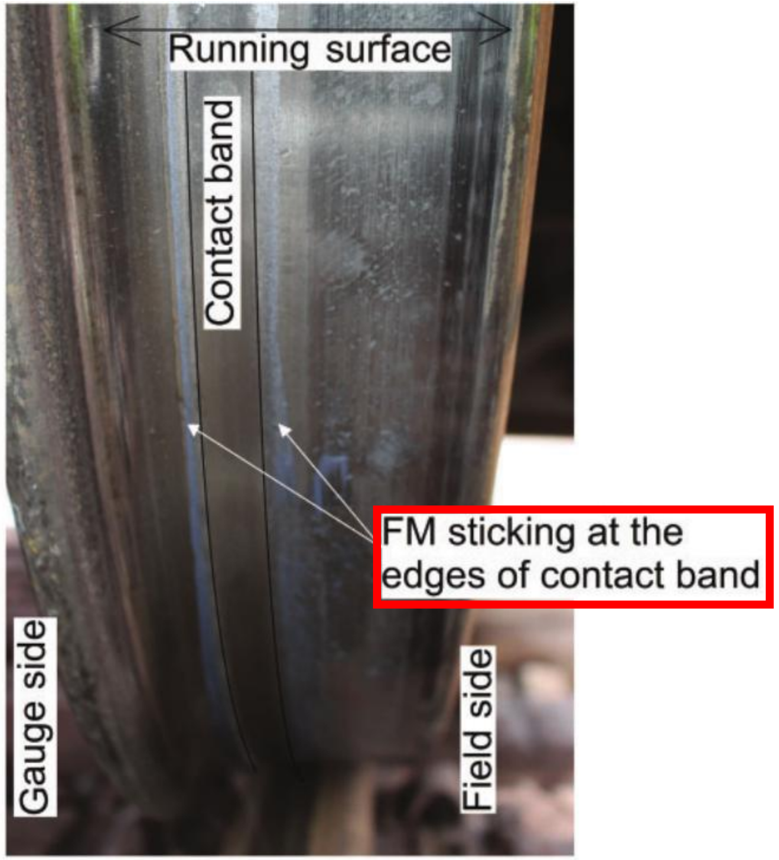
Carry on distance of friction modifier

- Field trial with locomotive
- 15 ml of product applied with a brush on 7.4 m of rail (approximately 2 wheel revolutions)



S.A. Khan, J. Lundberg & C. Stenström, Carry distance of top-of-rail friction modifiers, *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, **2018**, *232*, 2418-2430

▶ Experimentally observed carry down distance in the running band of the rail up to 340 m

▶ Product visible near the contact band on the surface of the wheel

ToR friction management: Boundary conditions & challenges

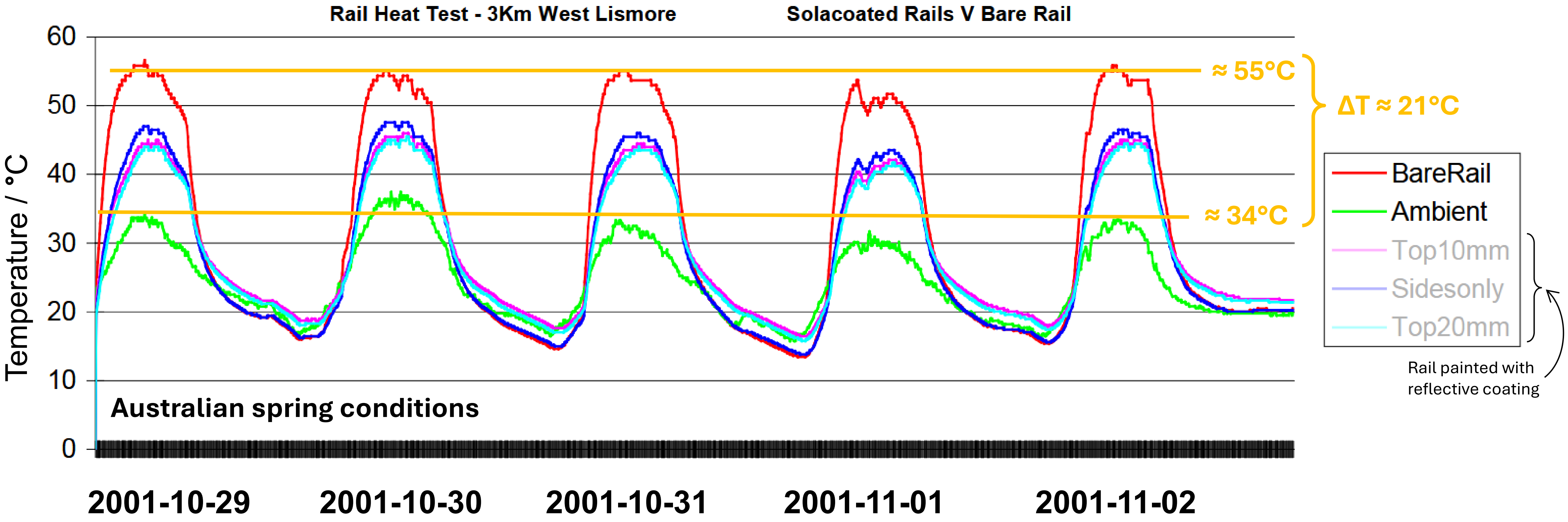
Boundary conditions that need to be considered for modelling railway operations:

- Friction management product
- Contact conditions
- Product transfer between surfaces
- Product application
- Local rail head conditions (environment)
- Surface topography
- Contaminations

► **Open tribological system**

► **Varying boundary conditions**

Ambient conditions & surface temperature of rail



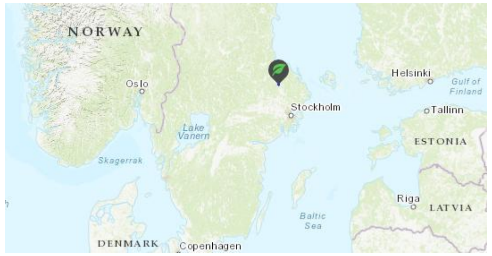
Rail Painting Process, *Pacific Edge Pty Ltd, Pacific Edge Pty Ltd,* **2005**, available at: https://www.solacoat.com.au/wp-content/uploads/2020/07/6-Solacoat-Railway-Painting-Process-Report.pdf

► Surface temperatures on the rail head may be significantly higher than the ambient temperature!

Ambient conditions & surface temperature of rail

Weather station data vs. local conditions on the rail head

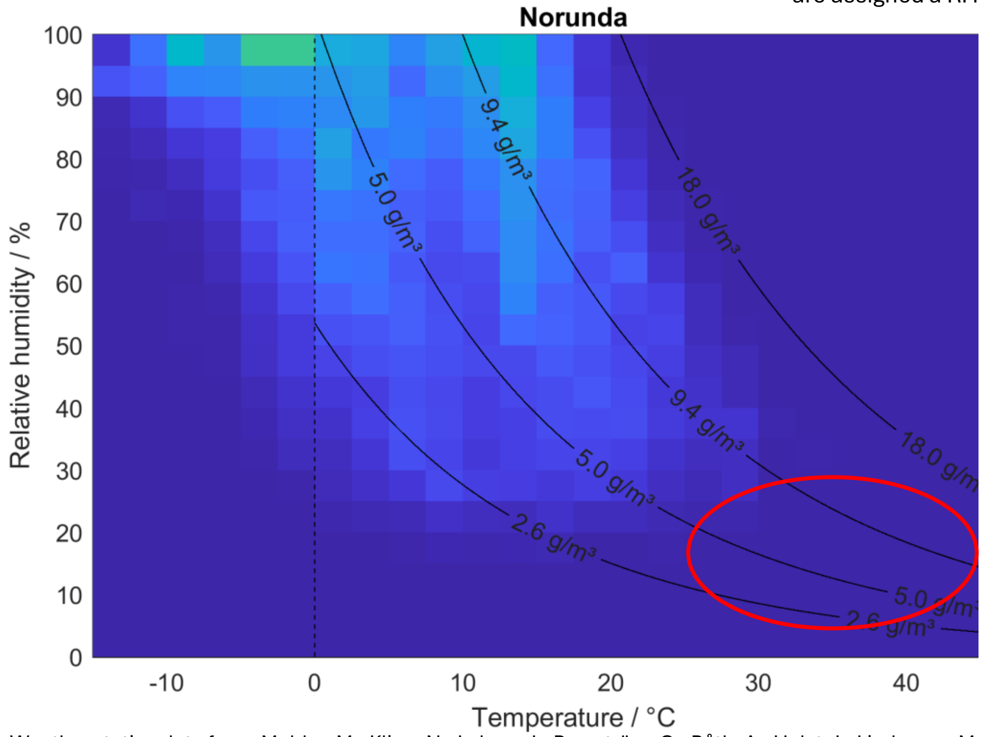
2020-2023

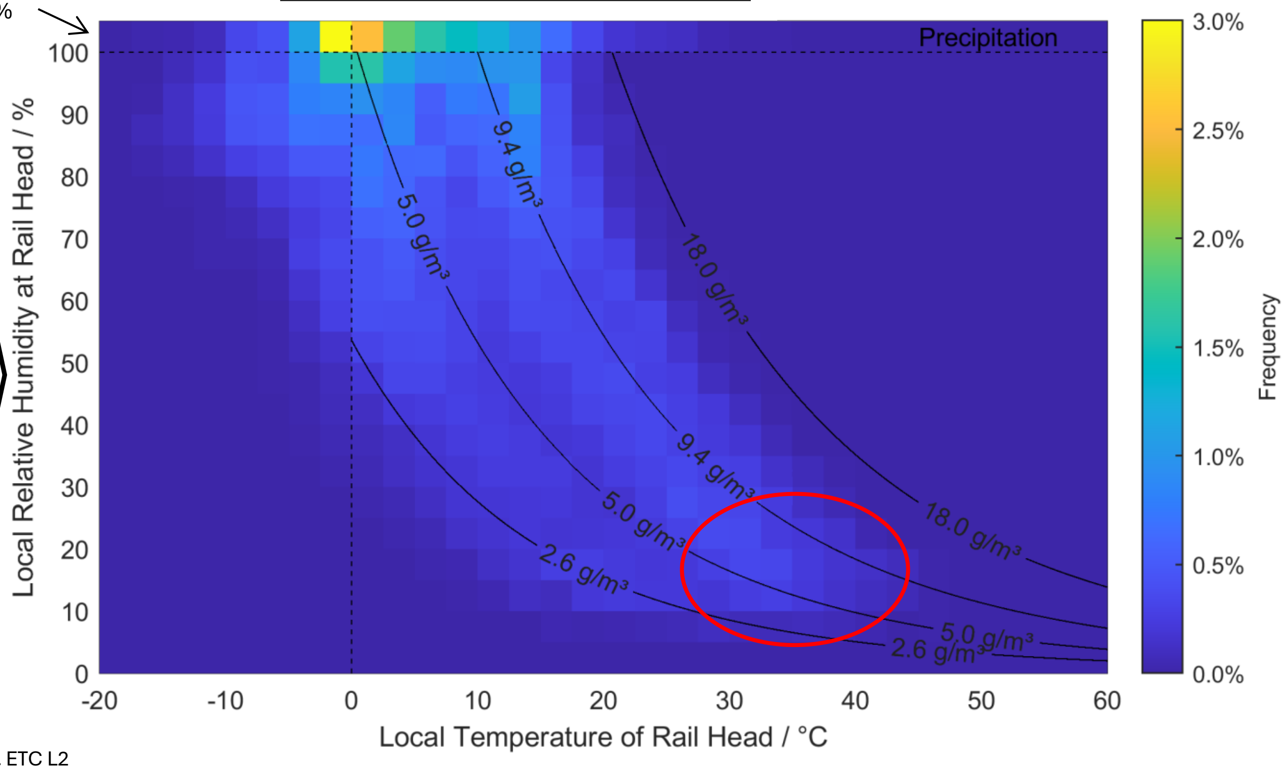


Weather station data

Data points with precipitation are assigned a RH > 100%

Predicted <u>local rail head conditions</u>





Weather station data from: Molder, M., Kljun, N., Lehner, I., Bergström, G., Båth, A., Holst, J., Linderson, M. (2025). ETC L2 Meteo from Norunda, 2017-12-31 – 2024-12-31, ICOS RI, https://hdl.handle.net/11676/oMRU7qFkQcUJPiFnGsykNXP0

G. Trummer, Wheel/Rail Friction Modelling for Top-of-Rail Friction Management Products in Operation, CHARMEC Workshop, 16 June 2025, Gothenburg, Sweden.

► Surface of the rail is warmer and "drier" than surrounding air on sunny days

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ToR friction management: Boundary conditions & challenges

Boundary conditions relevant for modelling railway operations:

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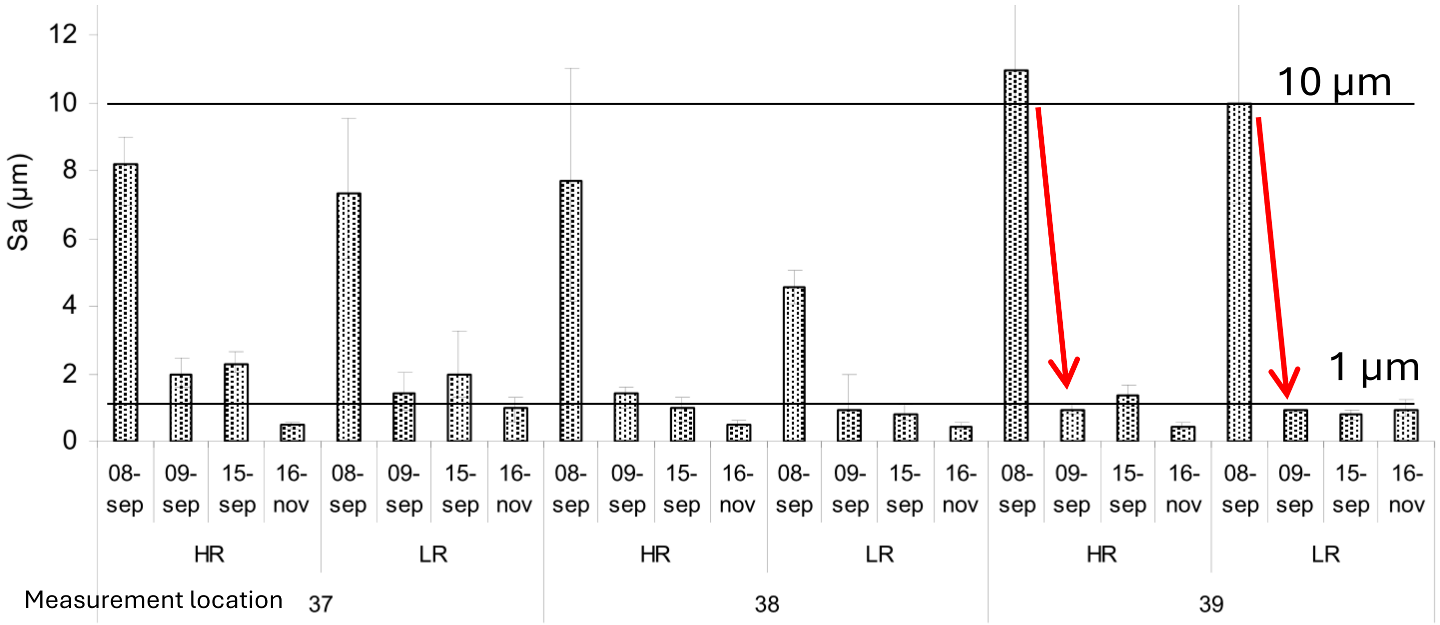
Surface roughness in railway operations

- Test site: 655 m radius curve on the Malmbanan (Sweden)
- Three different locations, called 37, 38 and 39 with 50 m spacing in between them
- Measurements on same grinding facet in the running band



Measurement schedule on the Malmbanan:

1. 8 September, newly ground rail
2. 9 September, approximately 26 800 ton of traffic
3. 15 September, approximately 259 000 ton of traffic
4. 16 November, approximately 2 070 000 ton of traffic

J. Lundmark, E. Höglund, B. Prakash, Running-in behaviour of rail and wheel contacting surfaces, AITC-AIT 2006, International Conference on Tribology, 20-22 September **2006**, Parma, Italy

► Reduction of rail roughness from Sa ~ 10 µm to Sa ~ 1 µm within 26 800 tons of traffic (35 h)!

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Wheel/rail interface friction prediction model

Objective: Build a simulation model to predict the **wheel/rail interface friction** for **operational scenarios** for different **top-of-rail friction management** products

Key model features:

- (Realistic) operational contact loading
  - Contact patch data from multi-body dynamic simulations of railway vehicles
    - Each individual axle of the railway vehicle (e.g. leading / trailing) with its varying contact conditions along the track is considered
- Arbitrary track layout
  - Track may consist of tangent track, transition curves, and curves specified by track curvature
- Detailed modelling of how the product degrades and spreads on the surfaces of wheels and rail in operations
- Computationally efficient simulation model
- Considering the influence of (ambient) temperature and humidity (work in progress)

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Wheel/rail interface friction prediction model

Two simulation approaches for operational simulations with arbitrary track layout:

"Offline" calculation:

Friction prediction model in MATLAB to post-process contact patch data

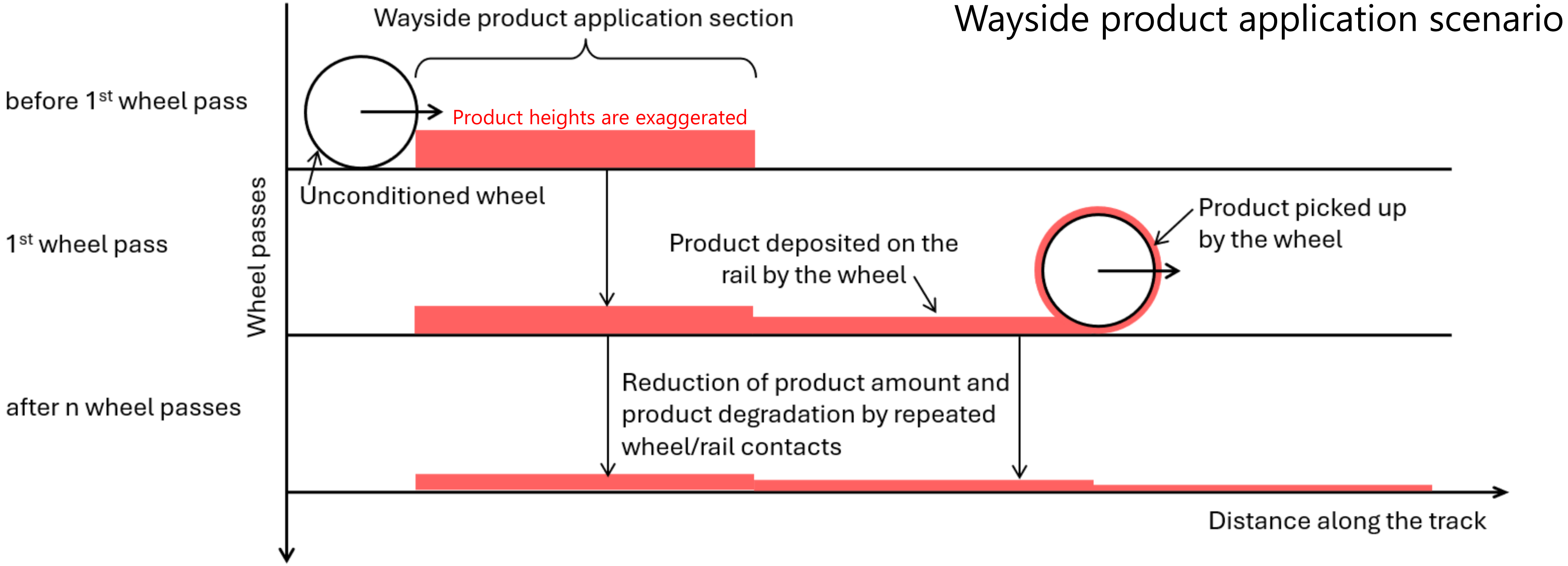
- Contact patch data (e.g. from MBD simulations) needs to be provided as an input to the model
- Limited influence of vehicle dynamics
- Computationally very efficient, calculation on 10k+ wheel passes (on a laptop computer)
- Investigation of steady-state friction conditions, product application strategies

"Online" calculation:

Friction prediction model integrated as a user function in the multibody dynamics simulation software SIMPACK

- Friction condition of the wheel/rail interface influences vehicle dynamics (full coupling)
- Computationally more expensive, Lower number of wheel passes
- Detailed studies of product pick-up and carry down behaviour

Carry down of product along the rail



Key mechanisms:

- Pick-up of product by wheels (at the application site and thereafter)
- Product (re-)deposition to the rail by wheels

} Product transfer between surfaces

- Product degradation
- Loss of product from the contact area

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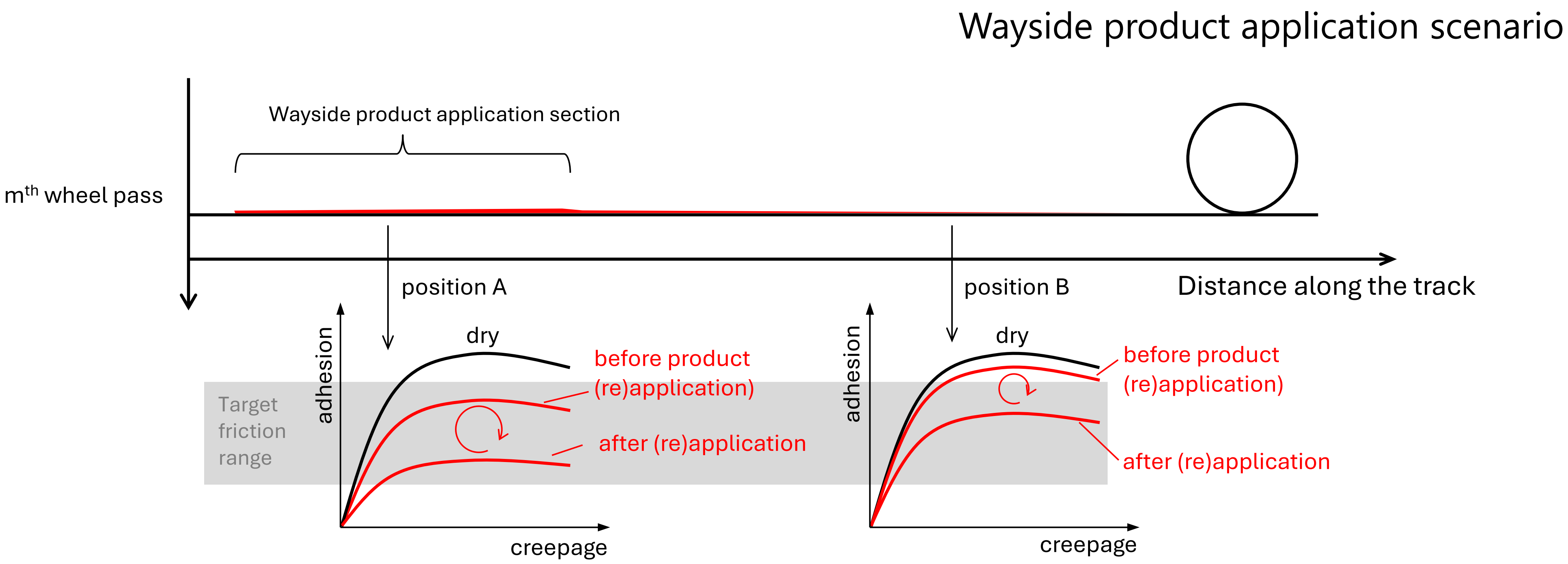
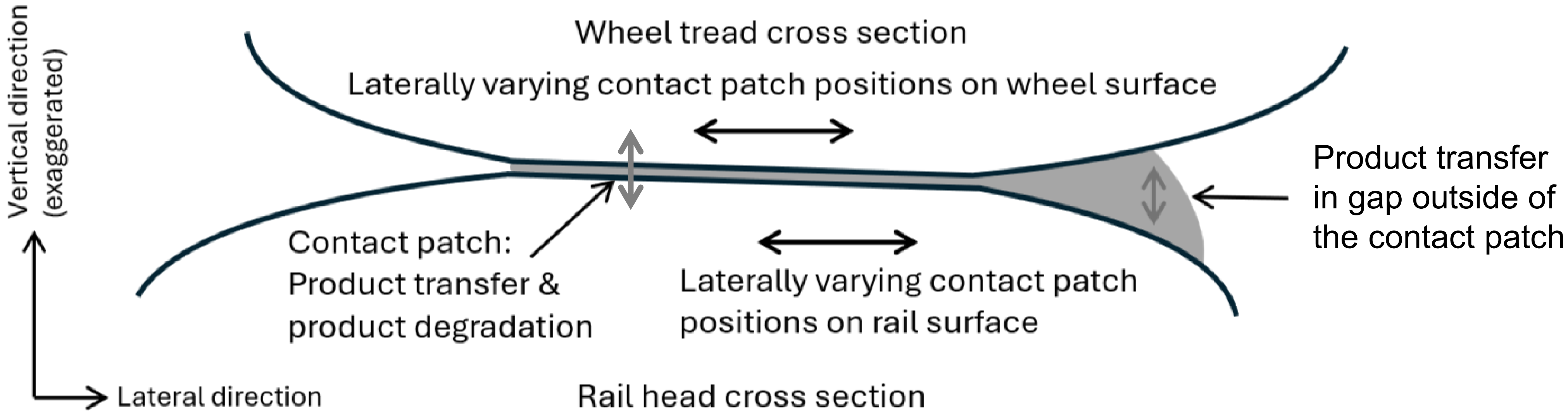
Carry down of product along the rail



Model shall predict the evolution of the coefficient of friction as a function of:

- Amount and position of applied product
- Position along track (→ How is it carried along the track)
- Number of wheel passes (with given wheel load, speed, creepage → Product degradation

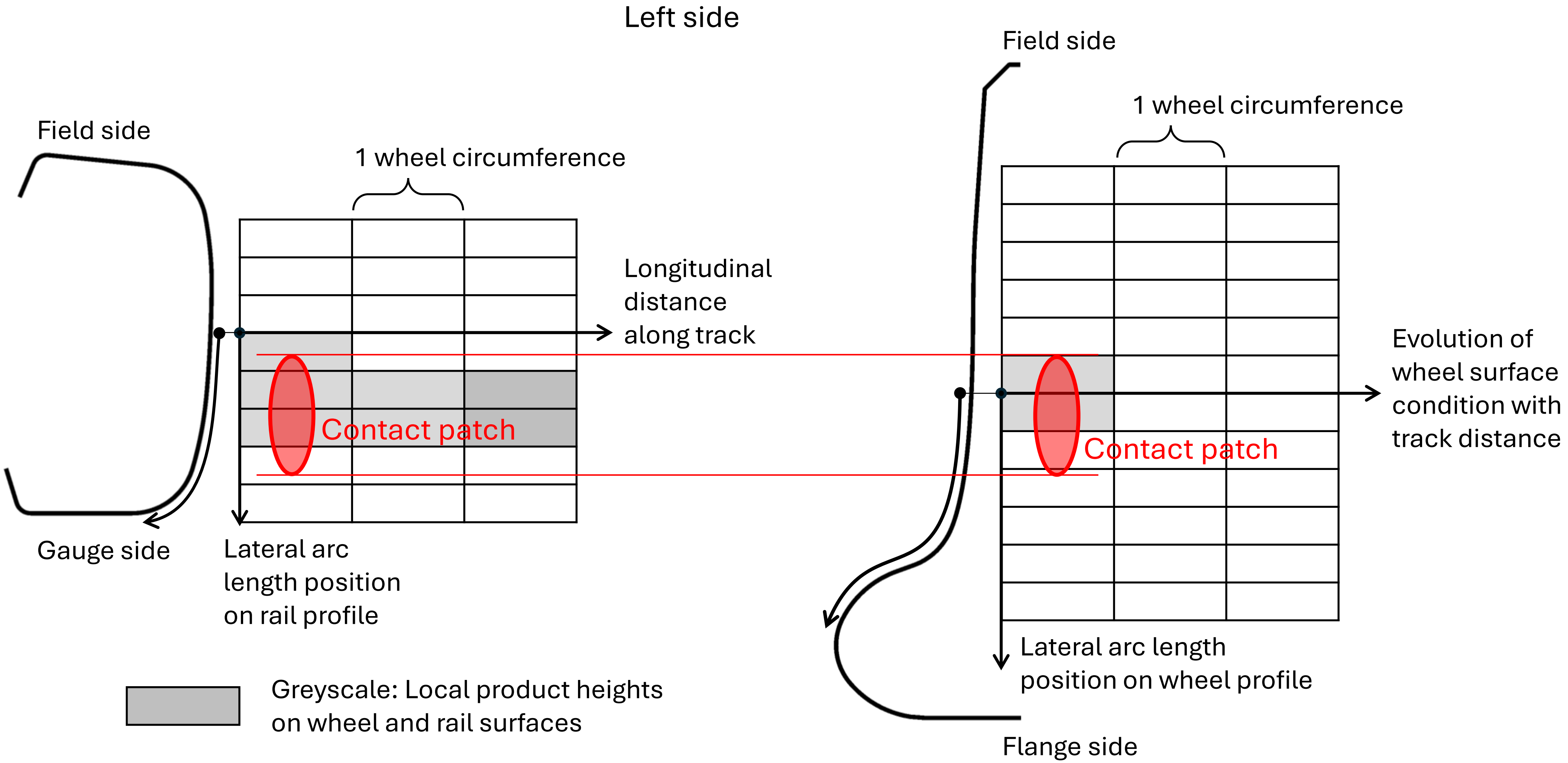
Product transfer between surfaces



Key mechanisms:

- Product transfer inside the contact patch
- Product transfer in the gap outside of the contact patch
- Laterally varying contact positions on the surfaces of wheel and rail
- Product degradation

Model discretization



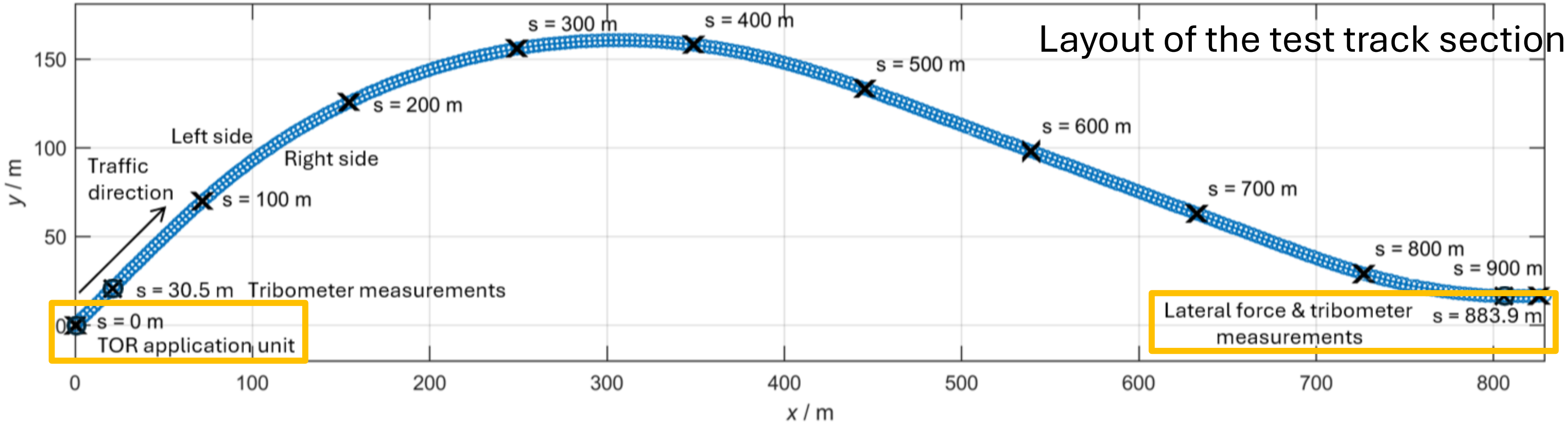
G. Trummer, Prediction of Wheel/Rail Interface Friction in Case of Top-of-Rail Friction Management for Operational Scenarios, 13th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems, 22-26 September, Tokyo, Japan, 2025.

Use case: Simulation of experiments at FAST

- Simulations based on literature data published in:
  D. Szablewski, J.L. Presti & T. Sultana, Testing of latest top-of-rail friction modification materials at FAST, *Railway Track & Structures*, **2015**, 13-16.
- Way-side product application testing of TOR friction modification products at FAST test ring at TTC in Pueblo, Colorado, U.S.
- Data published: Coefficient of friction measured by **tribometer** & **Lateral force measurements** for varying product application rates
- Data of **two oil-based products** used for this work

Google maps view of the FAST ring

Layout of the test track section



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Use case: Product distribution on wheel and rail surfaces

Track layout

Product height distribution on the **wheel** surface at respective track position

Product height distribution on the **rail** surface

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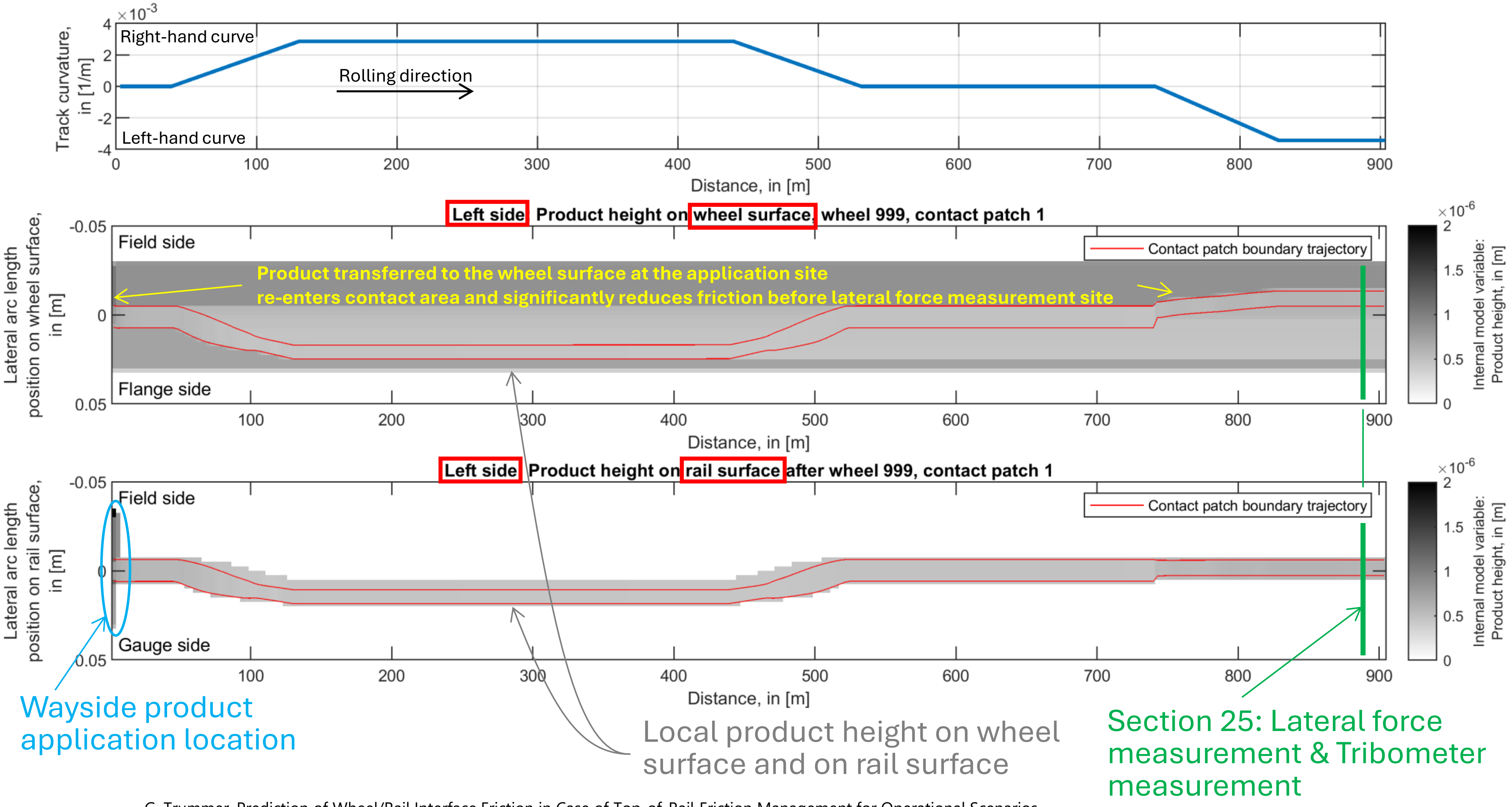

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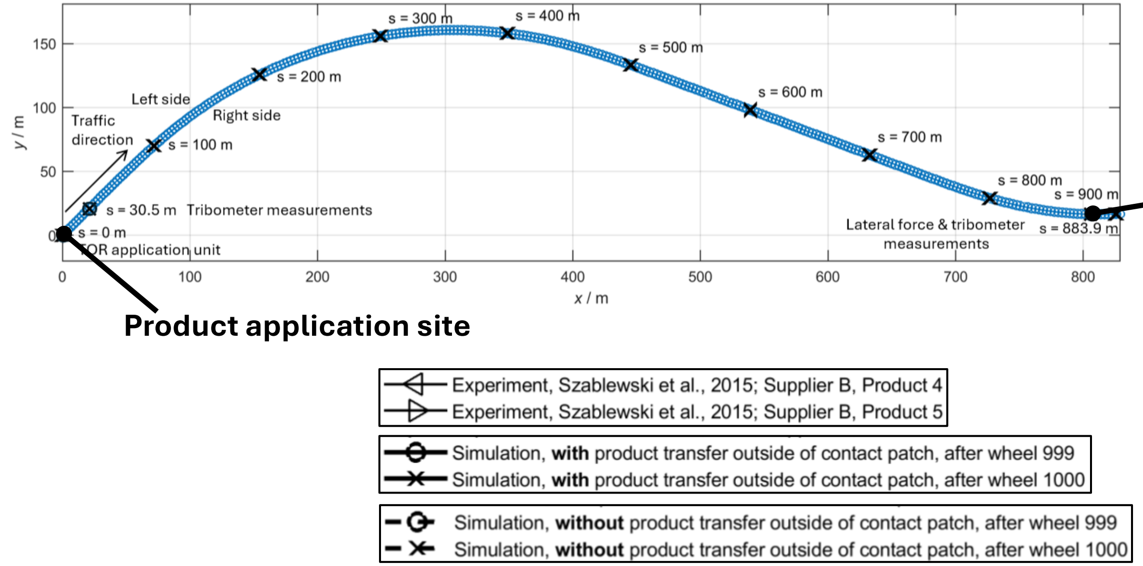
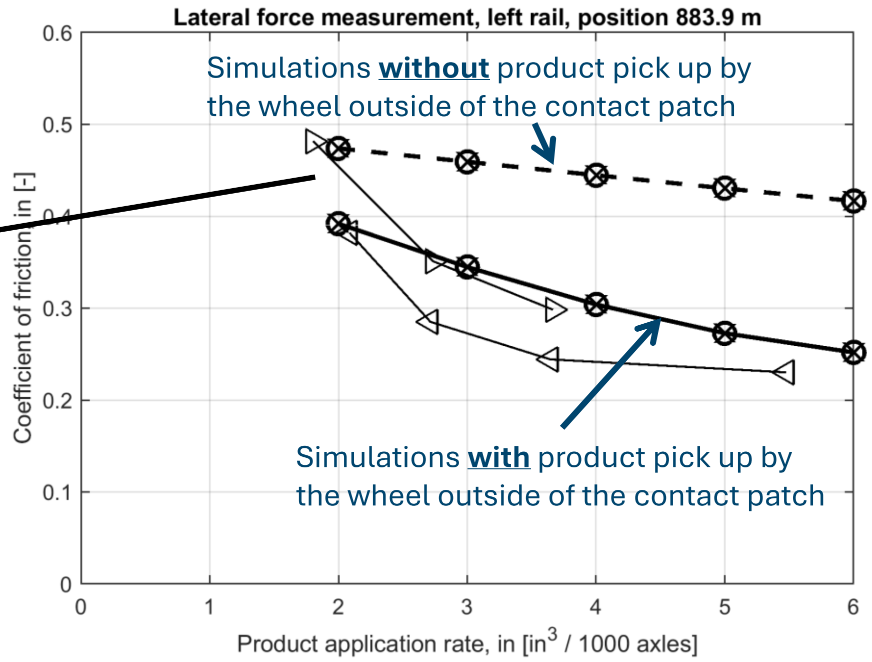
Use case: Comparison of wheel/rail interface friction

Simulations with (———) and without (- - - -) product pick up by the wheel outside of the contact patch





Thin lines: Experimental data
Tick lines: Simulation data

- ▶ Predicted wheel/rail interface friction agrees with lateral force measurement data
- ▶ Results highlight the importance of product pick up and carry on (outside of the contact patch)

G. Trummer, Prediction of Wheel/Rail Interface Friction in Case of Top-of-Rail Friction Management for Operational Scenarios, 13th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems, 22-26 September, Tokyo, Japan, 2025.

Summary & conclusions

- **Simulation models** have been developed to predict the evolution of **wheel/rail interface friction** for **operational scenarios** when **top-of-rail wayside friction management** products are applied
- Models cover important aspects & mechanisms, such as:
  - **Arbitrary track layout**: Sequences of tangent track, transition curve and curve sections can be specified
  - **Realistic contact loading** conditions used (contact patch data from MBD simulations)
  - **Laterally changing contact patch positions** along the track considered
  - **Product spreading** on surfaces of wheel and rail:
    - **Pick up of product** from the rail surface by the wheel in the contact area and in the gap adjacent to the contact patch
    - **Re-deposition of product** to the rail surface by the wheel

    } **Carry on of product**

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Summary, conclusions & outlook

- Capabilities of the simulation model demonstrated for a **literature use case**
- Simulation model is a **powerful tool** to investigate the effect of **top-of-rail friction management** on wheel/rail interface friction with respect to:
  - Application strategies (wayside/on-board)
  - Application frequency
  - Application amounts
  - Track layout
  - Vehicles / Railway traffic
- Work in progress & future work
  - Consideration of the **influence of ambient conditions** (temperature & humidity)
  - **Model validation** through track testing

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THANK YOU FOR YOUR ATTENTION!

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