Modeling the Effects of Top-of-Rail Friction Modifiers (TOR-FM) on Creep Forces in the Wheel-Rail Interface

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FRA Project "Modeling the Effects of Friction Modifiers on Creep Forces in the Wheel-Rail Interface"

Contents

- Introduction
- Tribological testing
- Modeling
- Model demo
- Summary
- Future work

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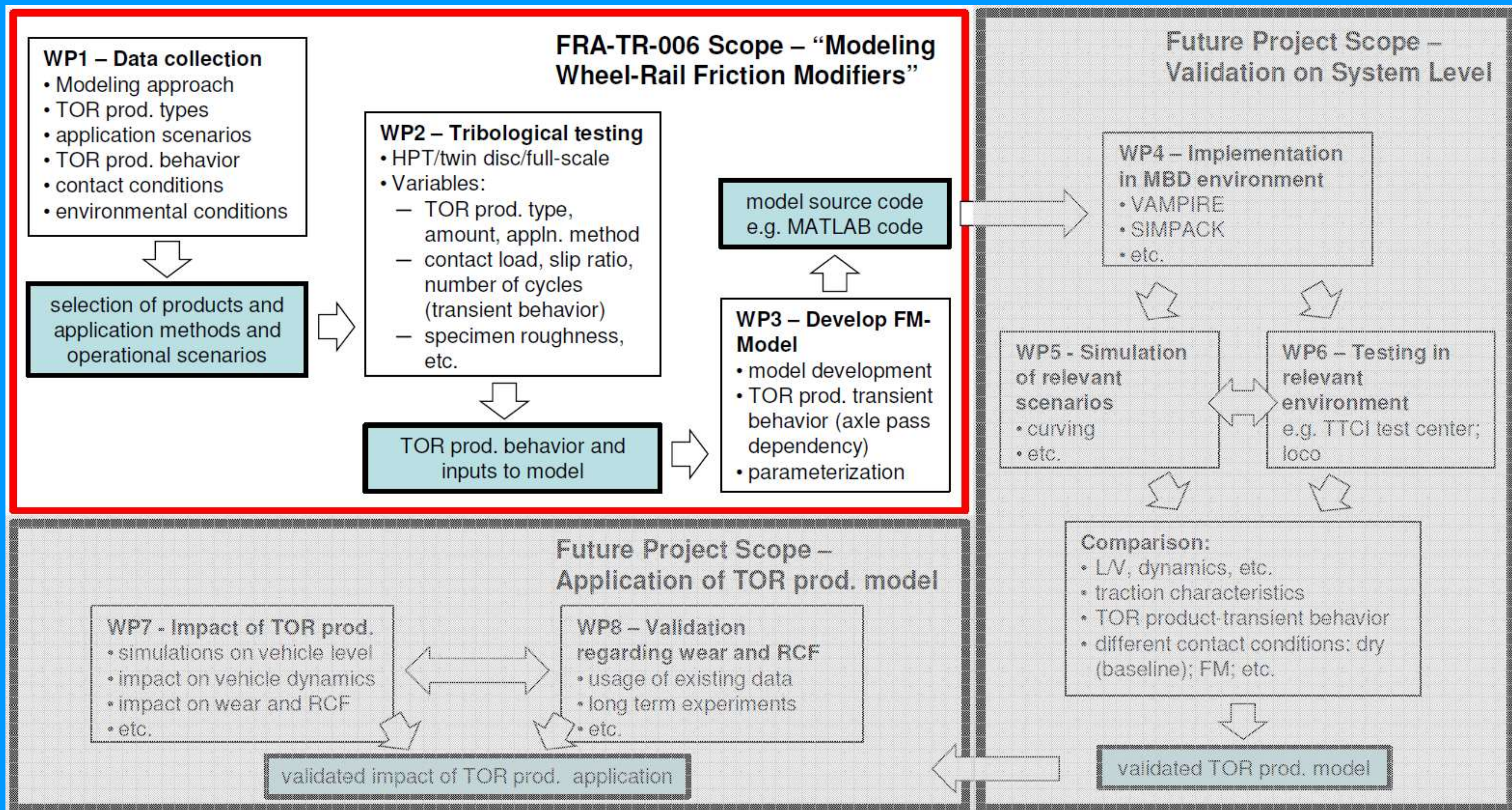
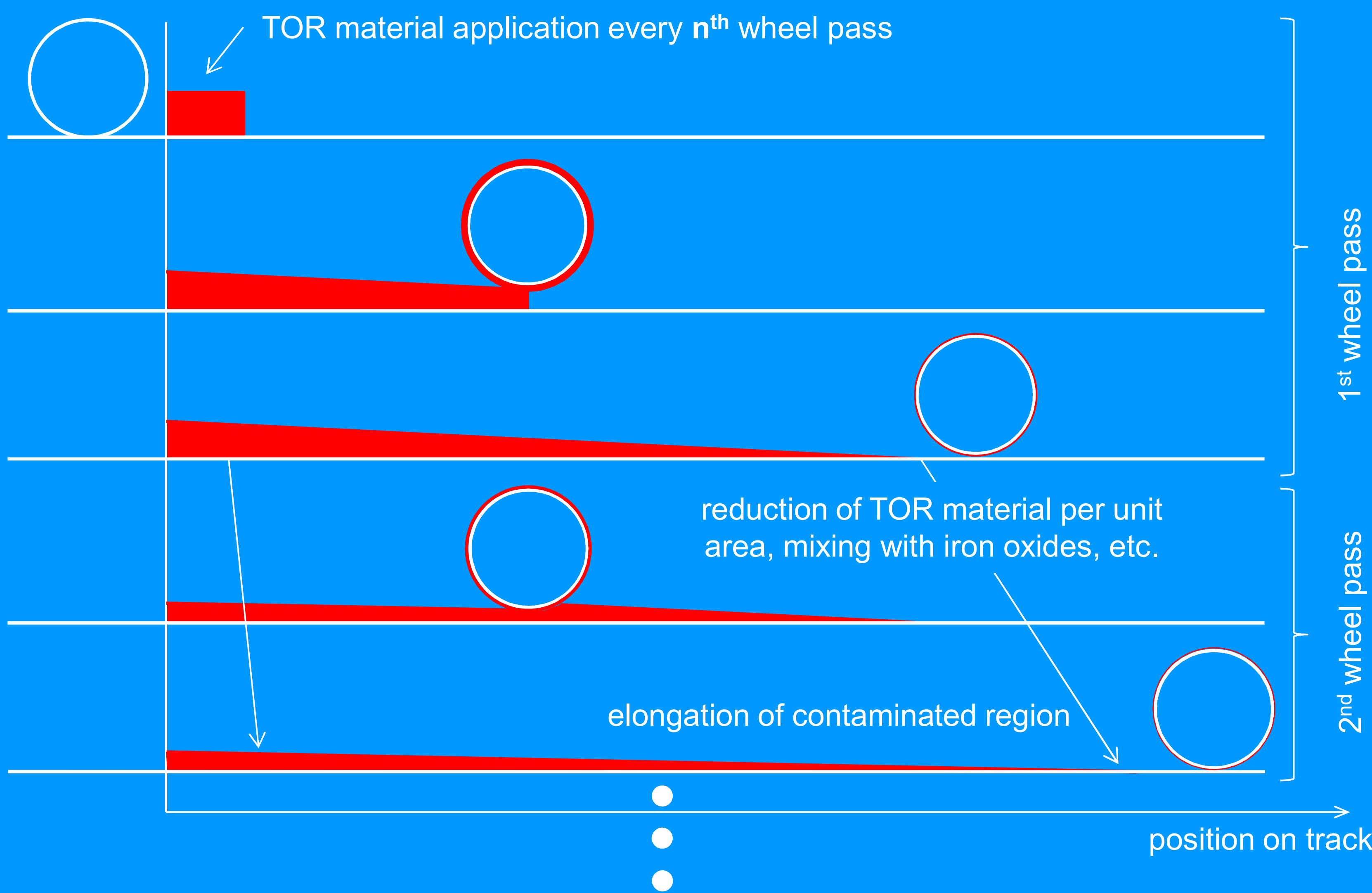
Introduction

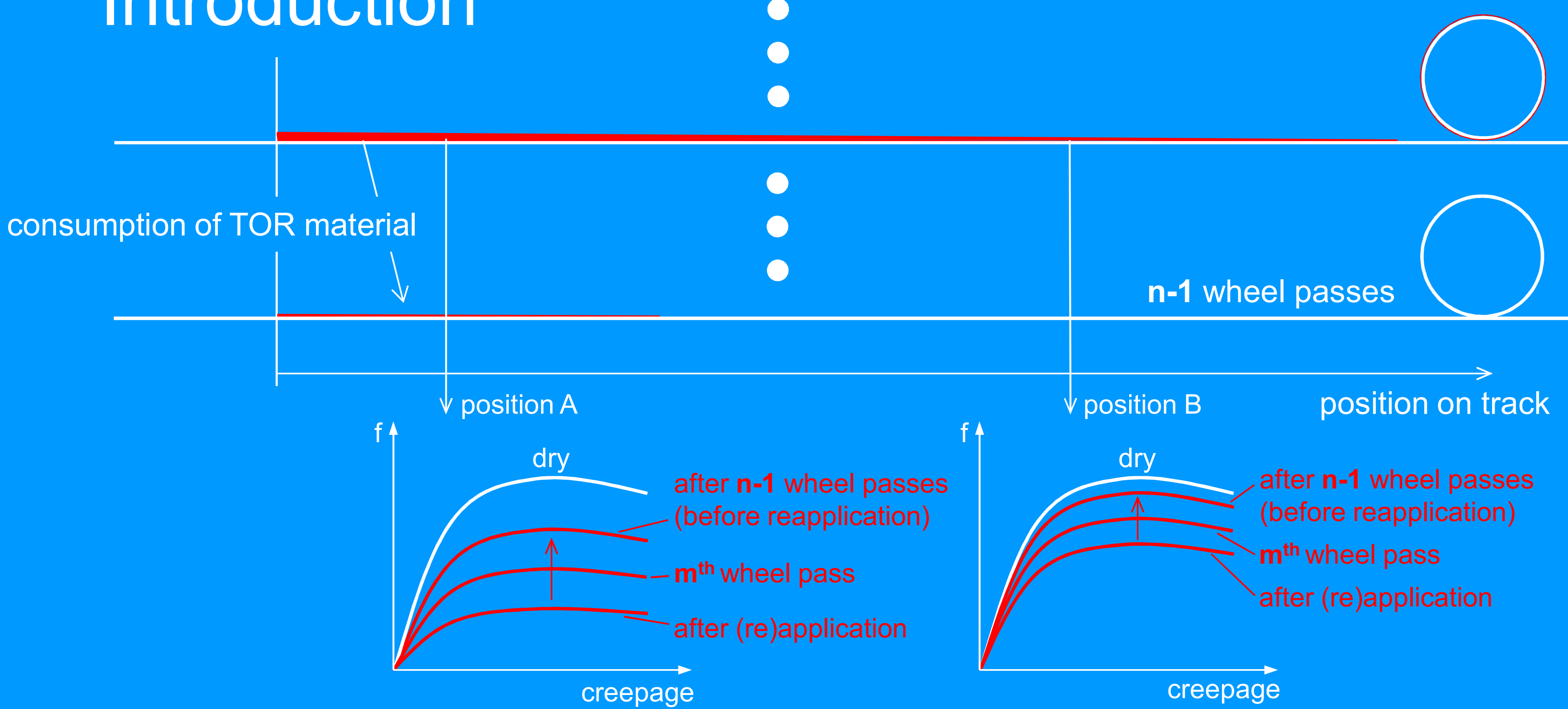


Introduction

Focus on wayside application



Introduction



Goal: Model predicting the development of the adhesion characteristic dependent on:

- TOR material product & amount of application
- Position on track (→ how is it carried along the track?)
- Number of wheel passes **m** (wheel load, speed, creepage → TOR material consumption ?)

Model Uses

Industry Stakeholder	Model Use
TOR material suppliers	• in product development • in developing business case for use of TOR materials • to determine the best approach for product application dependent on operating conditions (load, curve radius, etc.) • tribological test methods developed will also help in product benchmarking
Infrastructure owners/ maintainers	• incorporated into VTI software, the model can help predict the impact of TOR material application on reducing wheel-rail forces and track damage (wear, RCF, corrugation, etc.) dependent on operating conditions (load, curve radius, etc.) • to determine which product to apply where in what amounts (field side application) • it could also be incorporated into a track access charging model to assess track-friendliness of trains applying TOR materials
Train manufacturers/ operators	• incorporated into VTI software, the model can help predict the impact of TOR material application on reducing wheel-rail forces and wheel damage (wear, RCF, polygonization, etc.) dependent on operating conditions (load, curve radius, etc.) • to improve models of train performance taking account of third-body layers • to determine which product to apply where in what amounts (on board systems) • to make the case for reduced track access charging due to improved track friendliness. • to make the case for reduced energy consumption due to reduced curving resistance • to improve traction and braking control strategies
Wheel-rail interface researchers	• to improve models of train performance taking account of third-body layers • to improve development of creep force and damage models

Product Types

TOR Material Type	TOR FM	TOR Oil	TOR Grease	TOR Hybrid
Application Device[1]	Protector® IV	Protector® IV	Protector® IV	Protector® IV
Amount Applied	0.2-0.6 L per 1000 axles	0.2-0.6 L per 1000 axles	0.2-0.8 lb per 1000 axles	0.2-0.6 L per 1000 axles
Frequency of Application (axle nos.)	Every 8 to 24 axles	Every 10 to 48 axles	Every 10 to 48 axles	Every 8 to 24 axles
Pump activation time	0.15-0.25 s	0.15-0.25 s	0.15-0.25 s	0.15-0.25 s
Actual amount per rail per activation	1- 5 mL	1-5 mL	1-5 g	1-5 mL

Note: two TOR-FMs (drying products) were tested, A and B

Contents

Test approaches

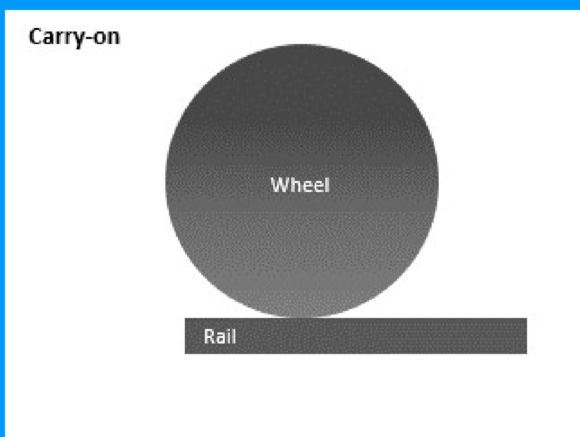
Test Rig	Pick-up behavior	Carry-on behavior	Consumption behavior
Scaled-wheel rig (SWR)	X	X	
Full-scale rig (FSR)	X	X	X
SUROS twin disc rig			X

Friction data available

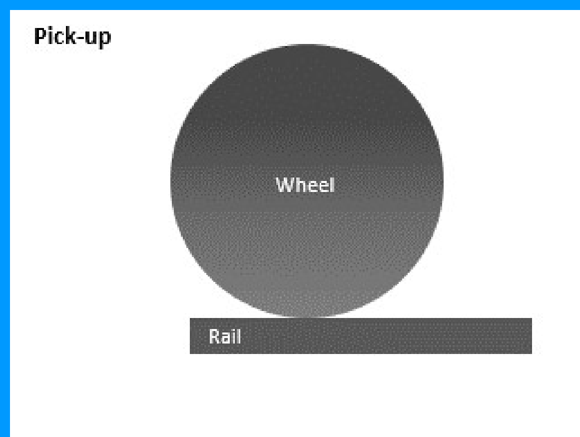
Carry-on, pick-up & consumption

- Examples using FSR

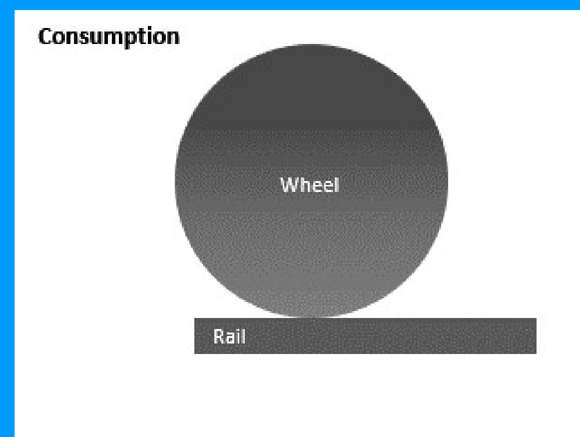
Carry-on



Pick-up



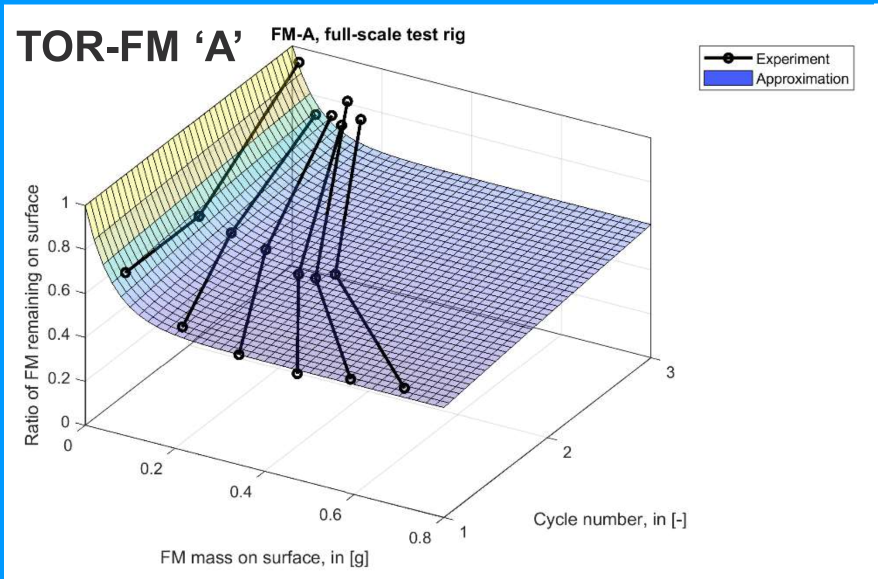
Consumption

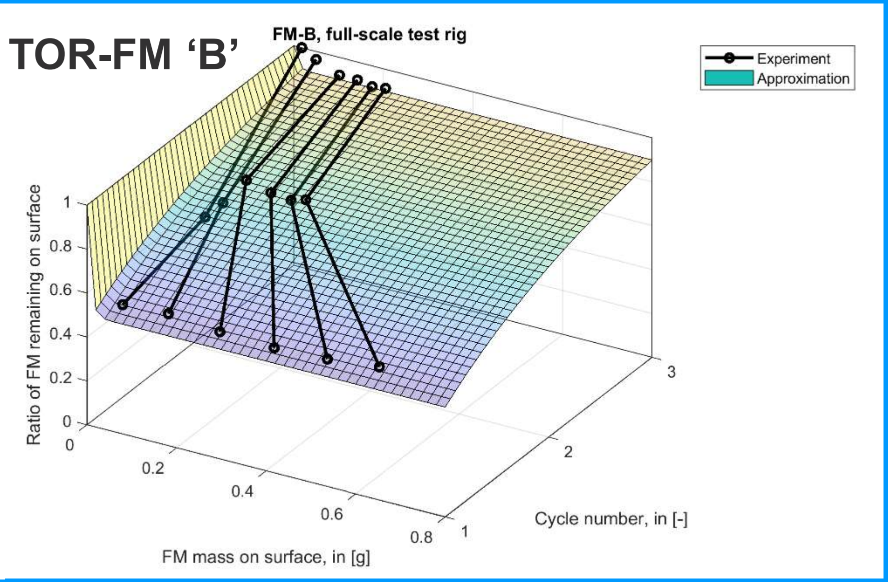


TOR-FM distribution

- Ratio of TOR-FM remaining on surface

Carry-on test results

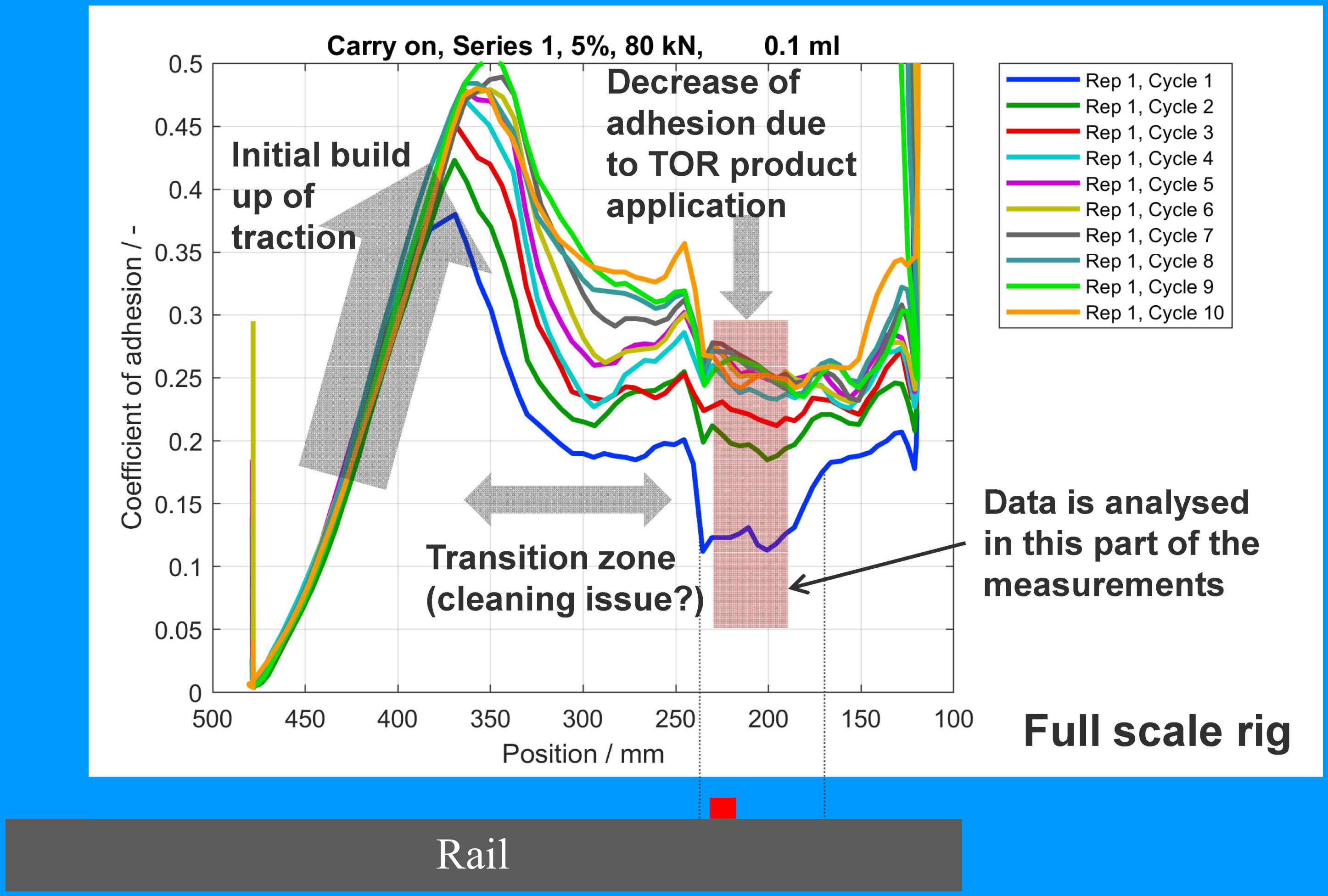




- Ratio of FM that remains on surface increases with decreasing amount of FM
- Both FMs are often evenly distributed in the 1st cycle of wheel-rail interactions
- TOR-FM 'A' is slower than FM 'B' in reaching 1:1 ratio of FM remaining on surface
  - Potentially will have a longer carry distance

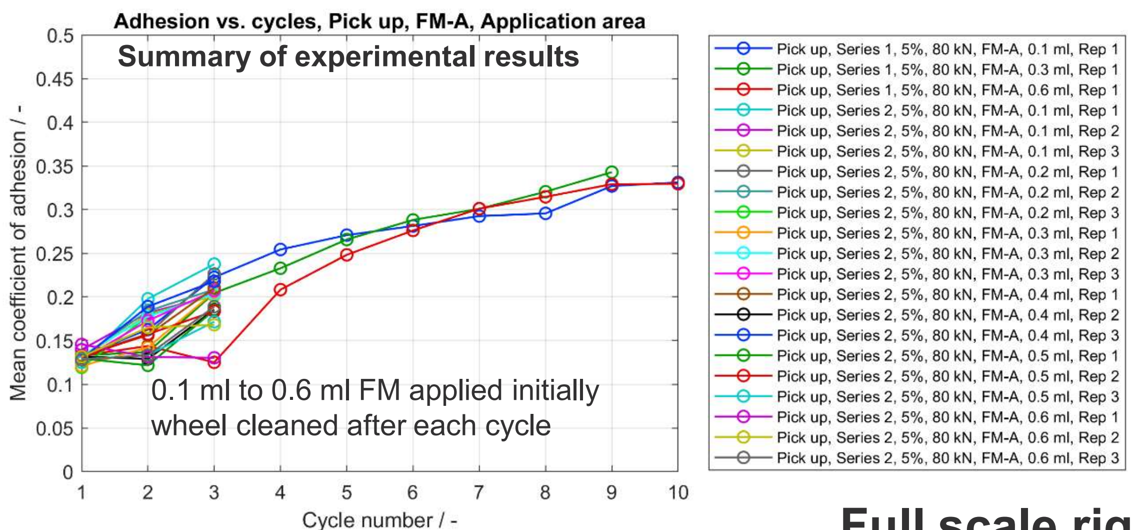
Frictional behaviour of wheel-rail interaction

- Typical adhesion vs. rail position recording



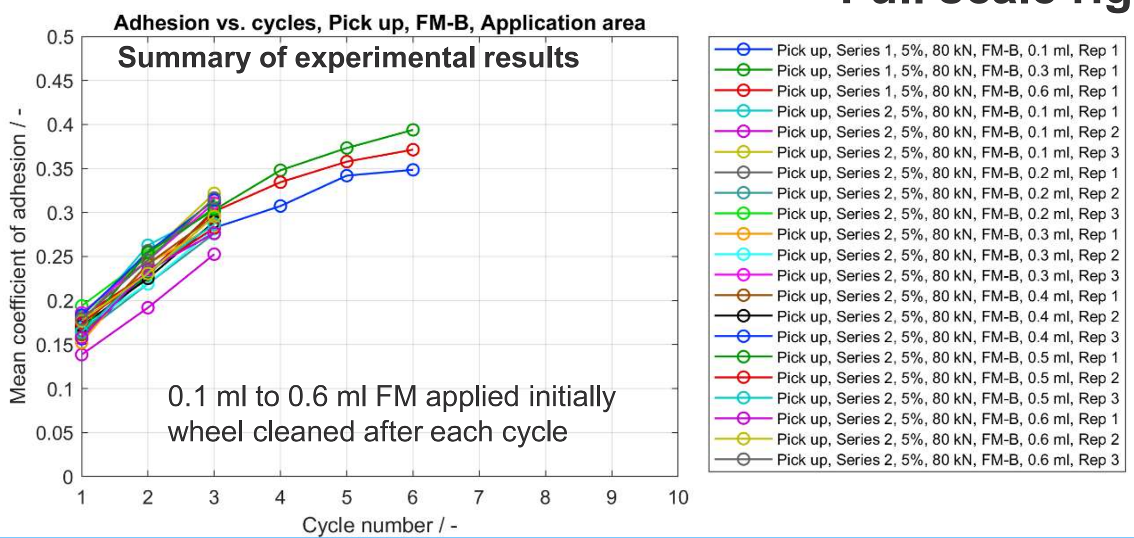
Pick-up tests & friction - FSR

TOR-FM ‘A’



Full scale rig

TOR-FM ‘B’

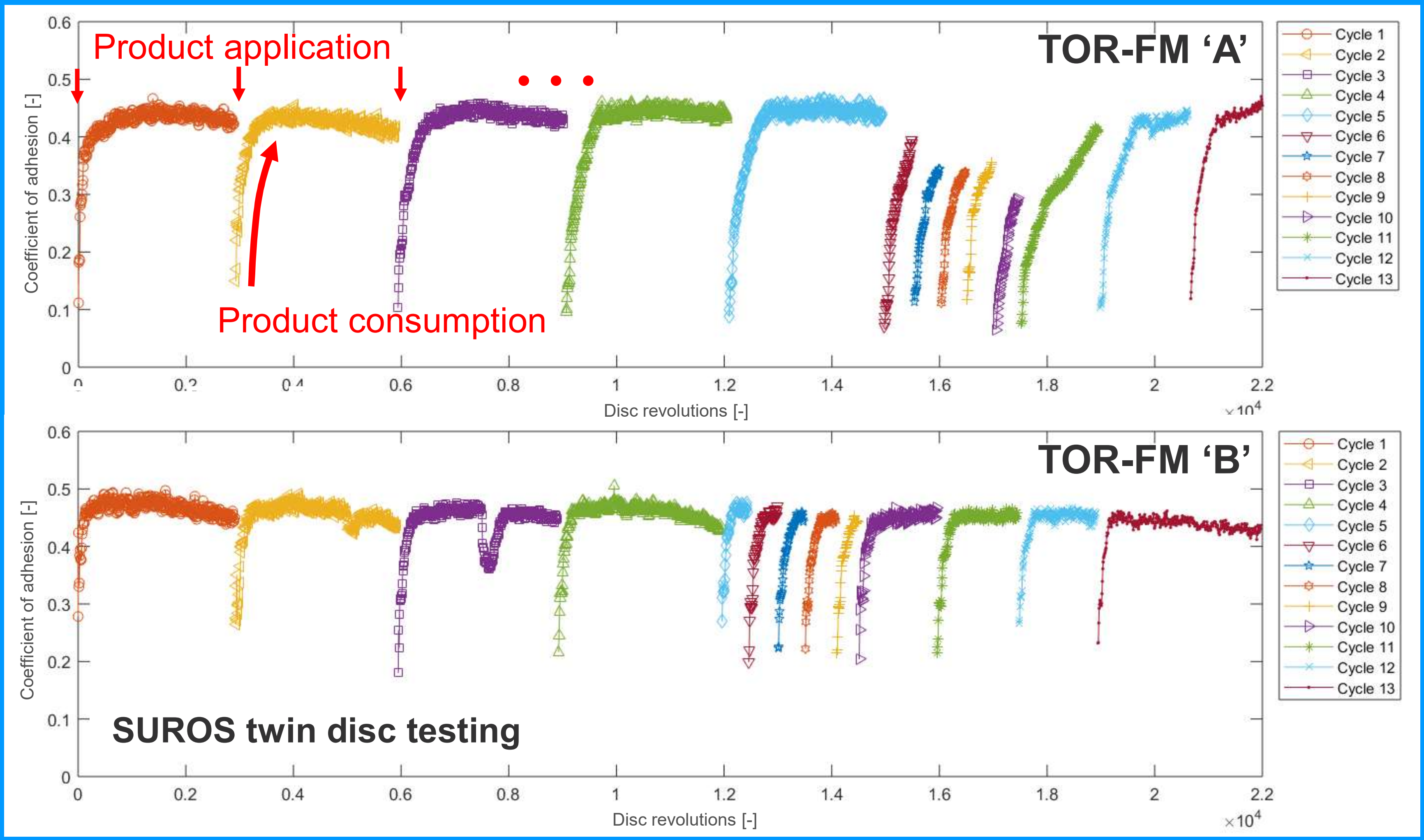


Frictional behaviour of carry-on & pick-up tests

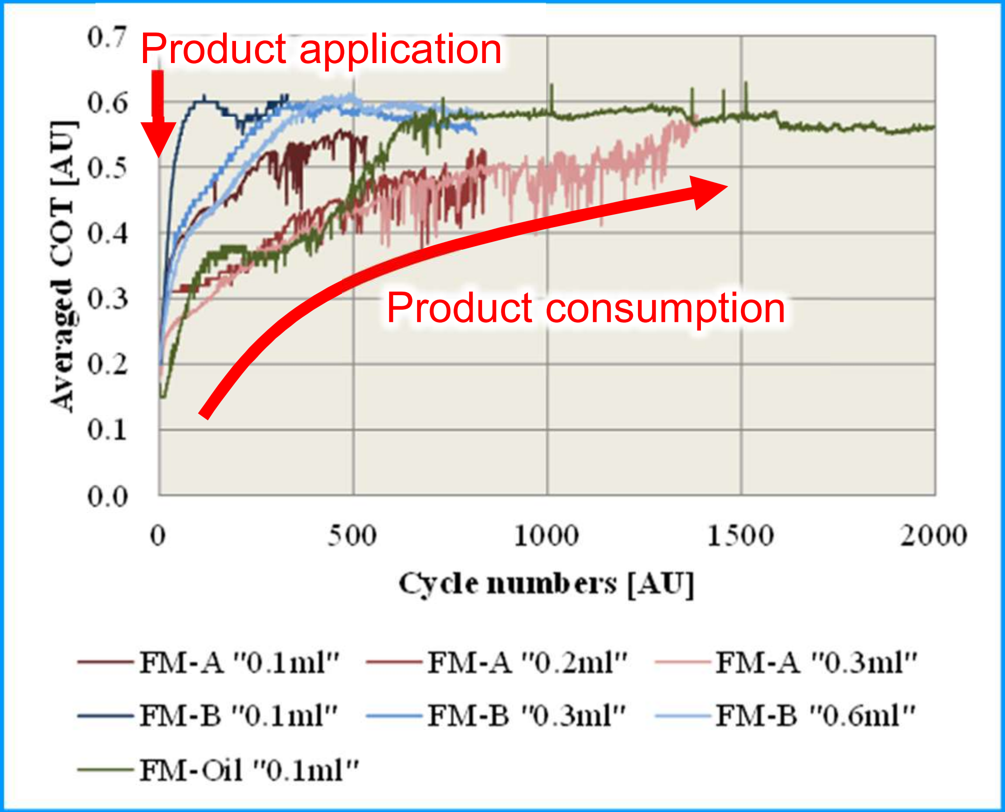
General observation

- Increase in initial TOR-FM 'A' amount applied increased the product retentivity
- Increasing initial TOR-FM 'B' amount applied has minimal effect on friction
- Quick consumption of TOR-FM 'A' in carry-on tests may be due to product transferred outside of the running band

Consumption behaviour & friction – SUROS



Consumption behaviour and friction – FSR



General observations:

- TOR-FM ‘A’ has lower consumption than FM ‘B’
  - Low consumption = high retentivity
- TOR-FMs generally have the highest consumption rate among the TOR products

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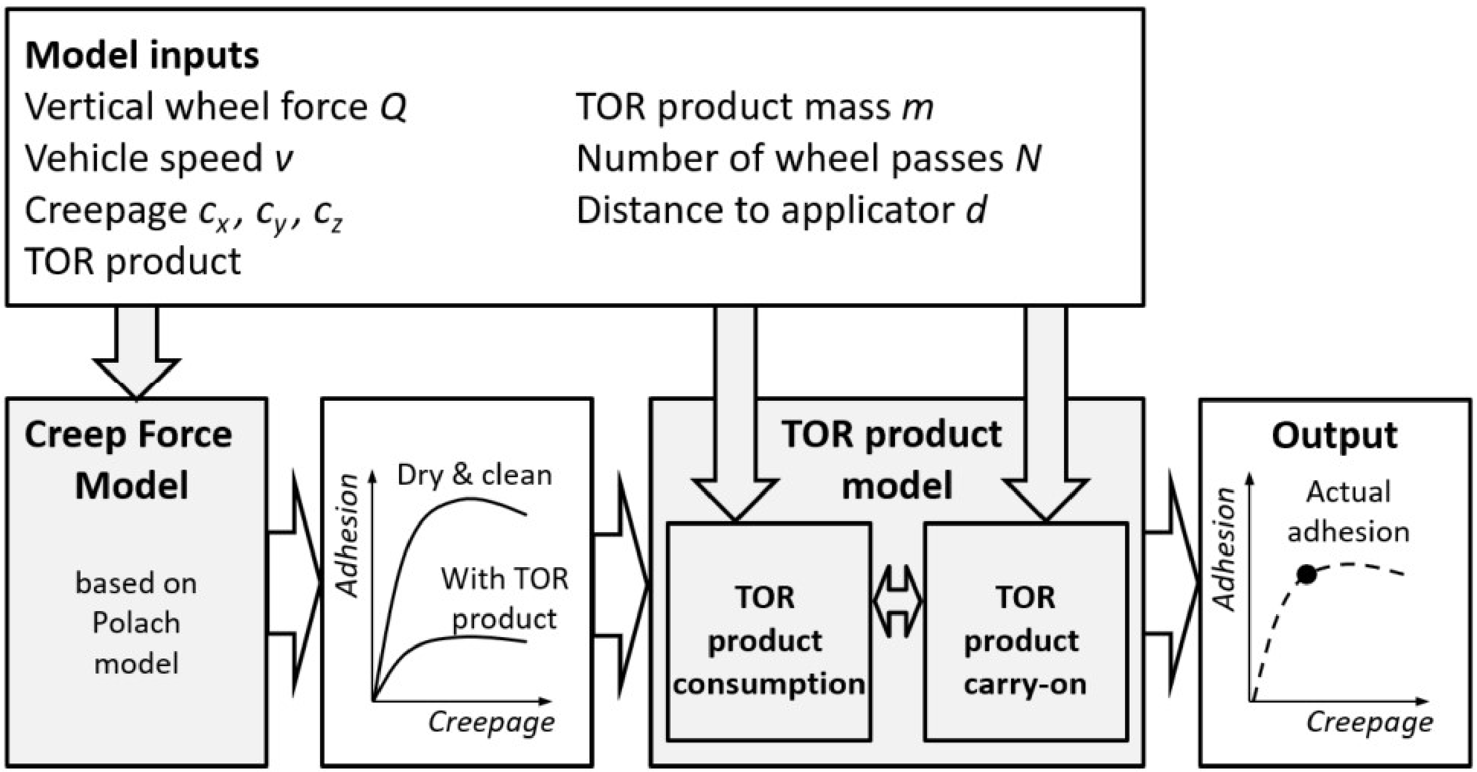
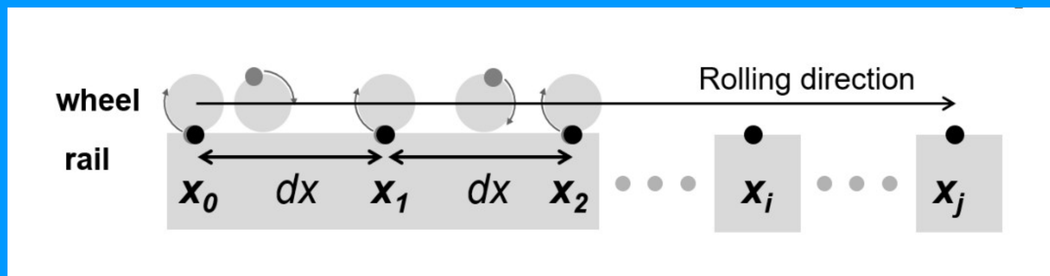
Modeling approach

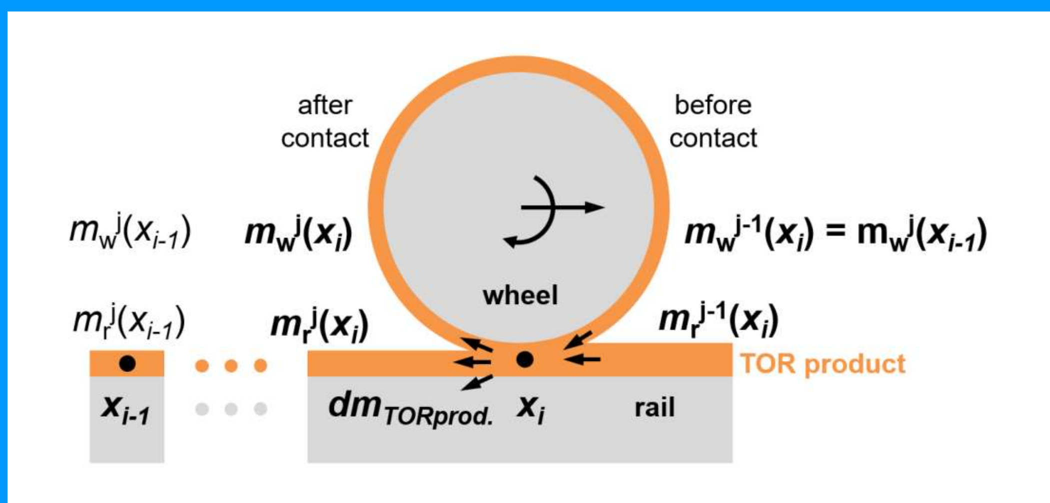


Model details

- Discretization along track



- Flow of TOR product through contact patch



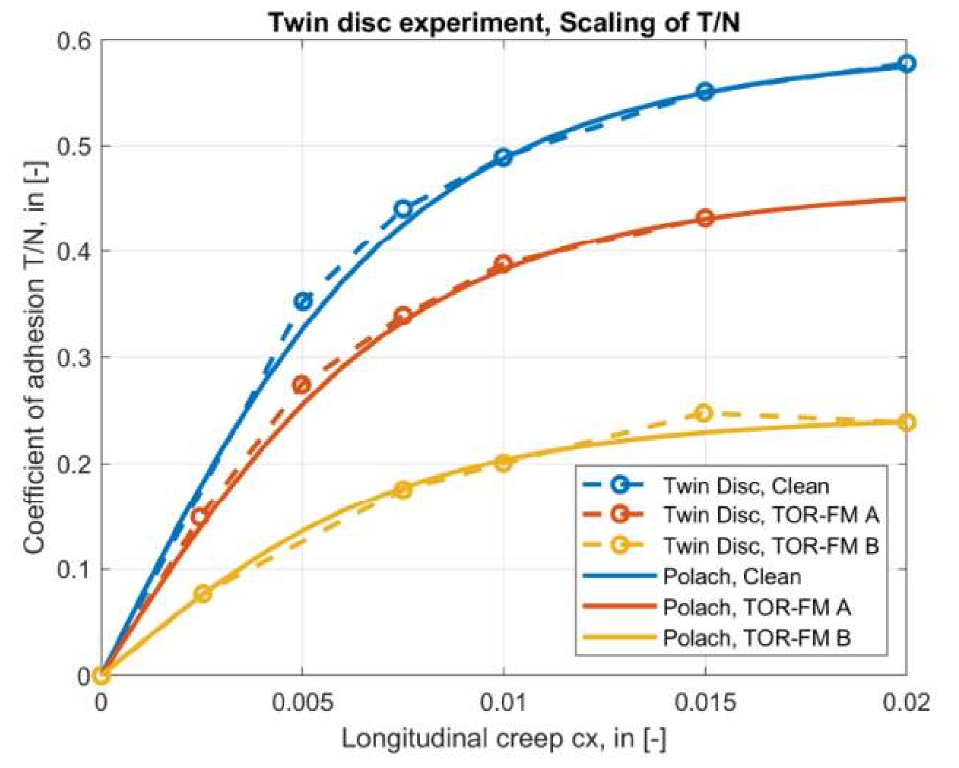
i	Index track position
j	Index wheel/rail interaction
x	Track position
m	Mass of TOR product
r	Rail
w	Wheel

Model details

- Creep force model: Polach‘s approach

$$(T/N)_{TORprod.} = (T/N)_{clean} \cdot \frac{\mu_{TORprod.}}{\mu_{clean}}$$

TOR-FM application reduces friction value and initial gradient of creep-force curve



Experimental Twin Disc results from:

Gutsulyak, D., Stanlake, L., & Qi, H. (2018). Twin Disc Evaluation of Third Body Materials in the Wheel/Rail Interface. Proceedings of the 11th International Conference on Contact, Mechanics and Wear of Rail/Wheel Systems (CM2018), Delft, The Netherlands, September 24-27, 2018.

Model details

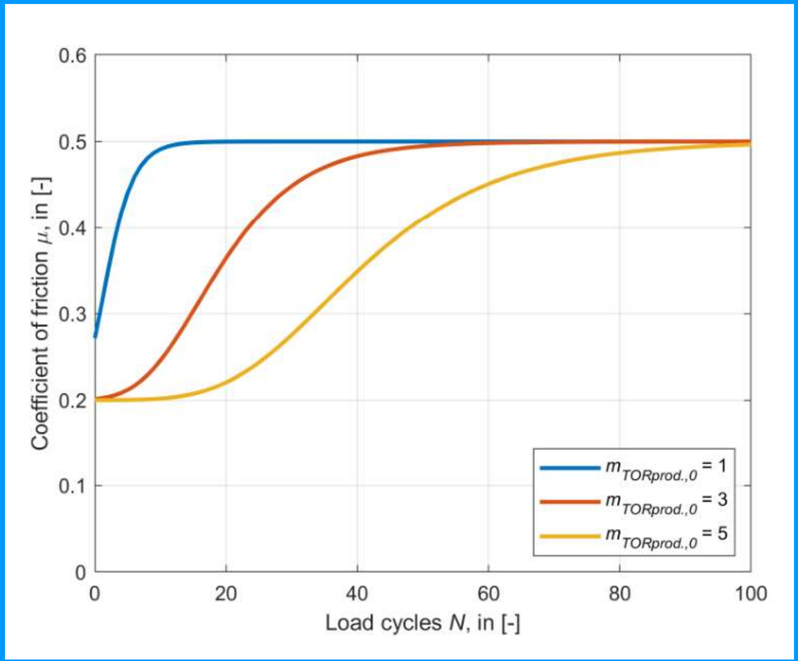
- Evolution of COF as a function of load cycles

TOR product consumption (per cycle)

$$\frac{dm_{TORprod.}}{dN} = k_0 + k_{m1} \cdot \left(1 - exp\left(-\frac{m_{TORprod.}}{m_0 \cdot k_{m2}}\right)\right) \cdot f_p(p_m) \cdot f_c(c_x) \cdot f_i$$

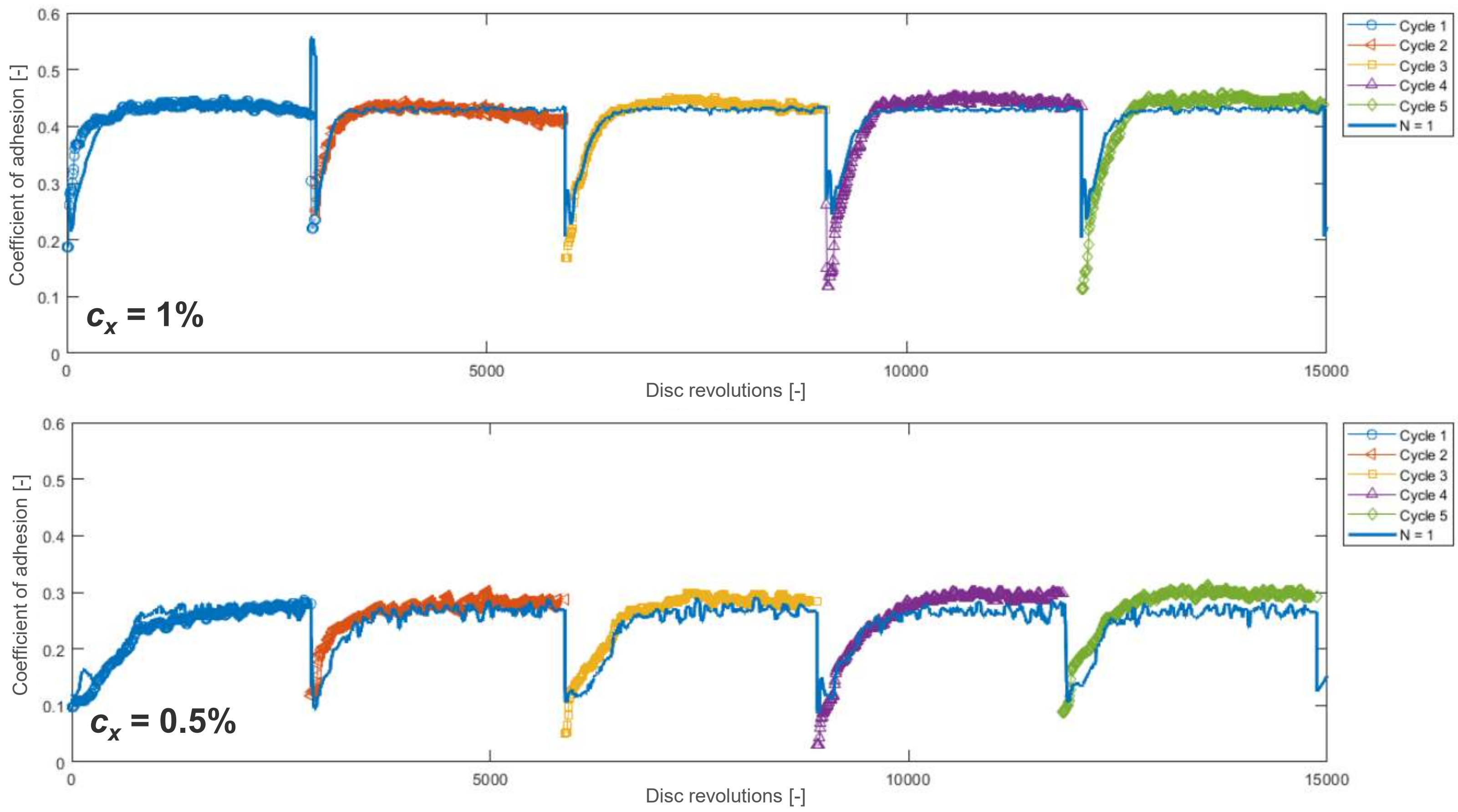
TOR product mass – friction relation

$$\mu = \mu_{TORprod.} + (\mu_{clean} - \mu_{TORprod.}) \cdot \exp\left(-\frac{m_{TORprod.}}{k_m}\right)$$



Model parameterization - Friction / consumption

Twin Disc Experiment, TOR-FM „A“, p_0 = 1500 MPa



Model parameterization - Friction / consumption

Full-scale Rig Experiment, Friction

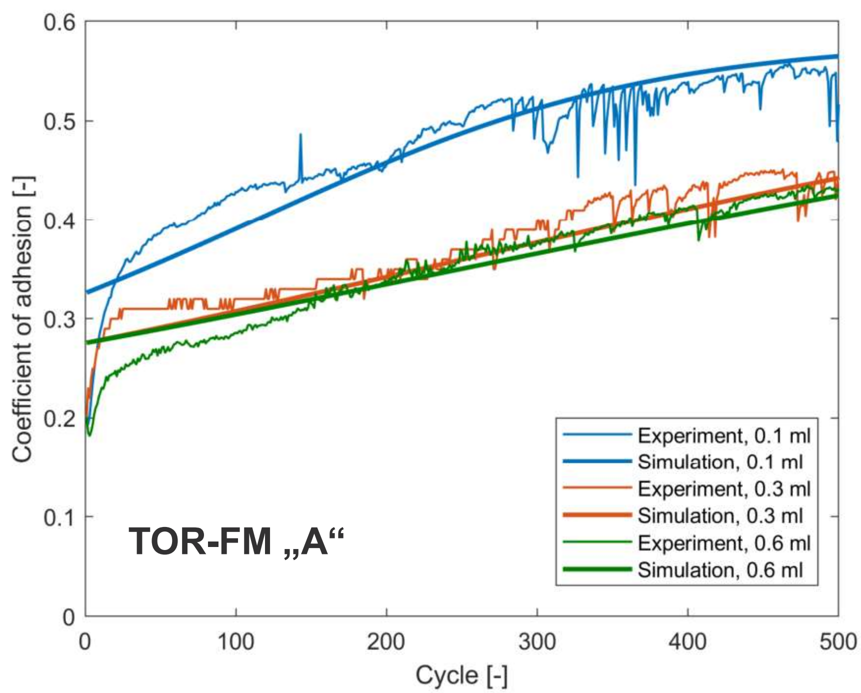


Figure 44: Experimental FSR data (thin lines) for three different amounts of applied TOR product at 80 kN wheel load and creepage $c_x = 5\%$ compared to results of the TOR product model (thick line) to check the model parameterization.

Field simulation

Evolution of friction along rail determined by:

I) Product pick-up & repeated redistribution between wheel and rail surface

II) TOR product consumption

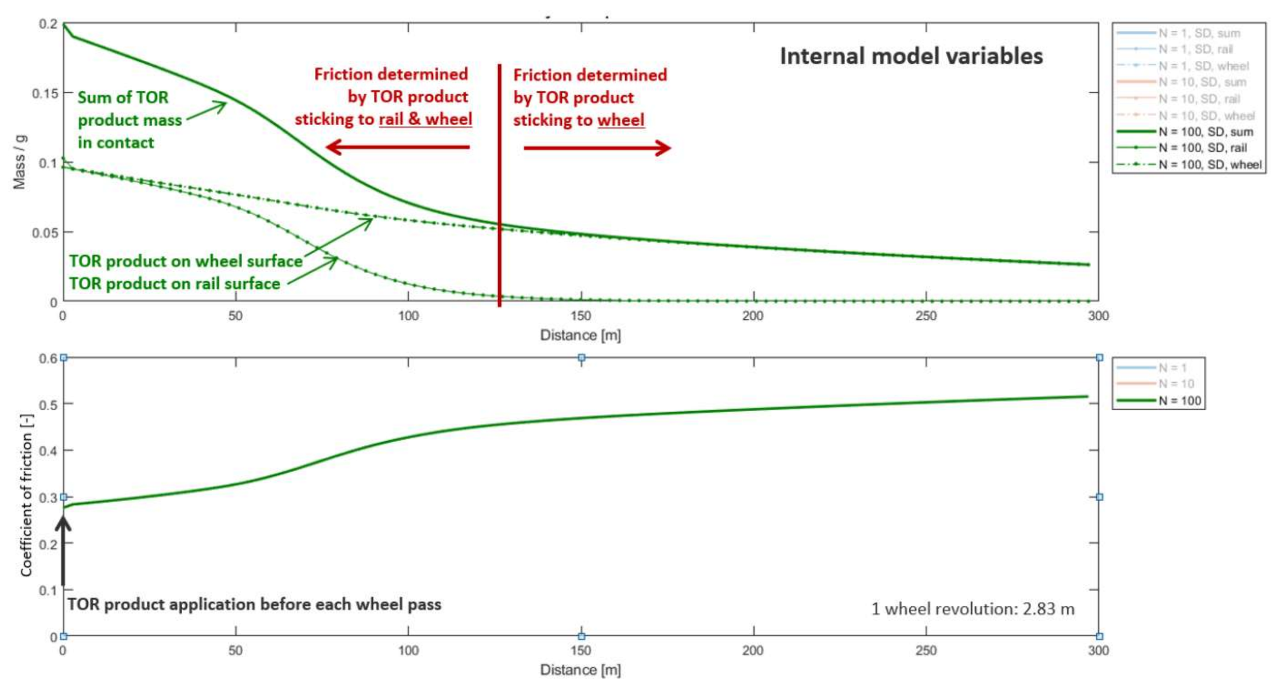


Figure 48. a) Evolution of internal model variable "TOR product mass" on the surfaces of wheel and rail after 100 wheel passes with TOR product application before each wheel, b) Corresponding coefficient of friction for wheel pass N = 100 with 5% creepage.

Field simulation

- Comparison of TOR products

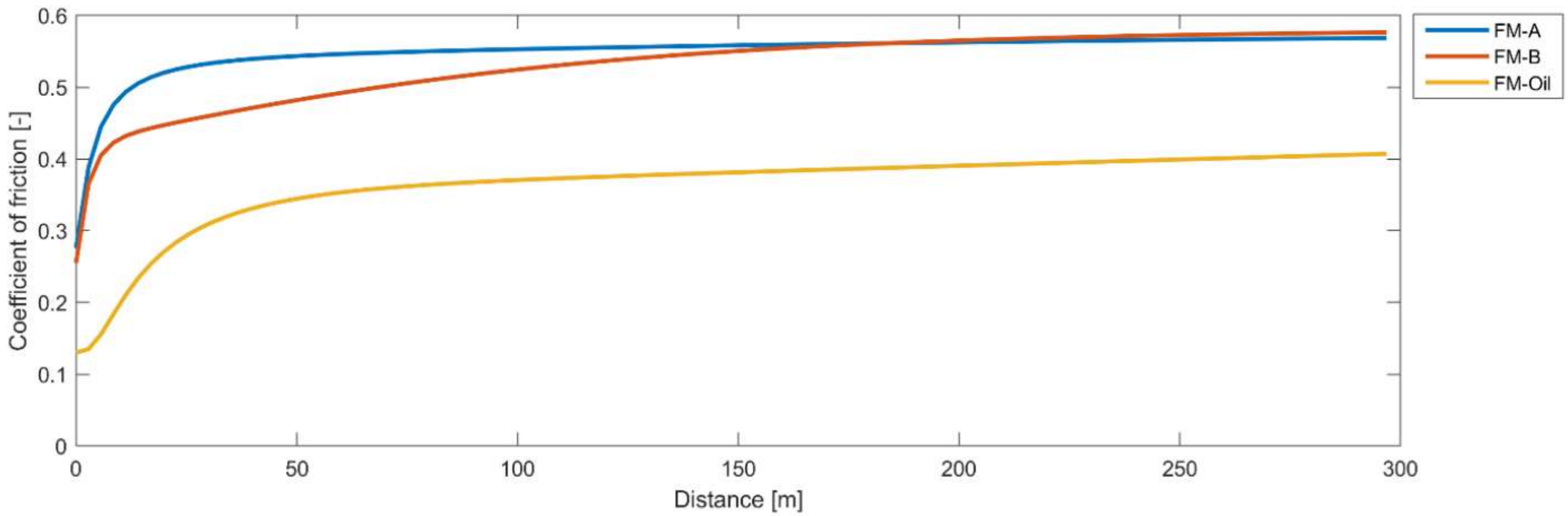


Figure 52. Comparison of friction as a function of distance from the application site for TOR-FM A, TOR-FM B and TOR-Oil for wheel pass N = 1 after application of 0.20 g TOR product.

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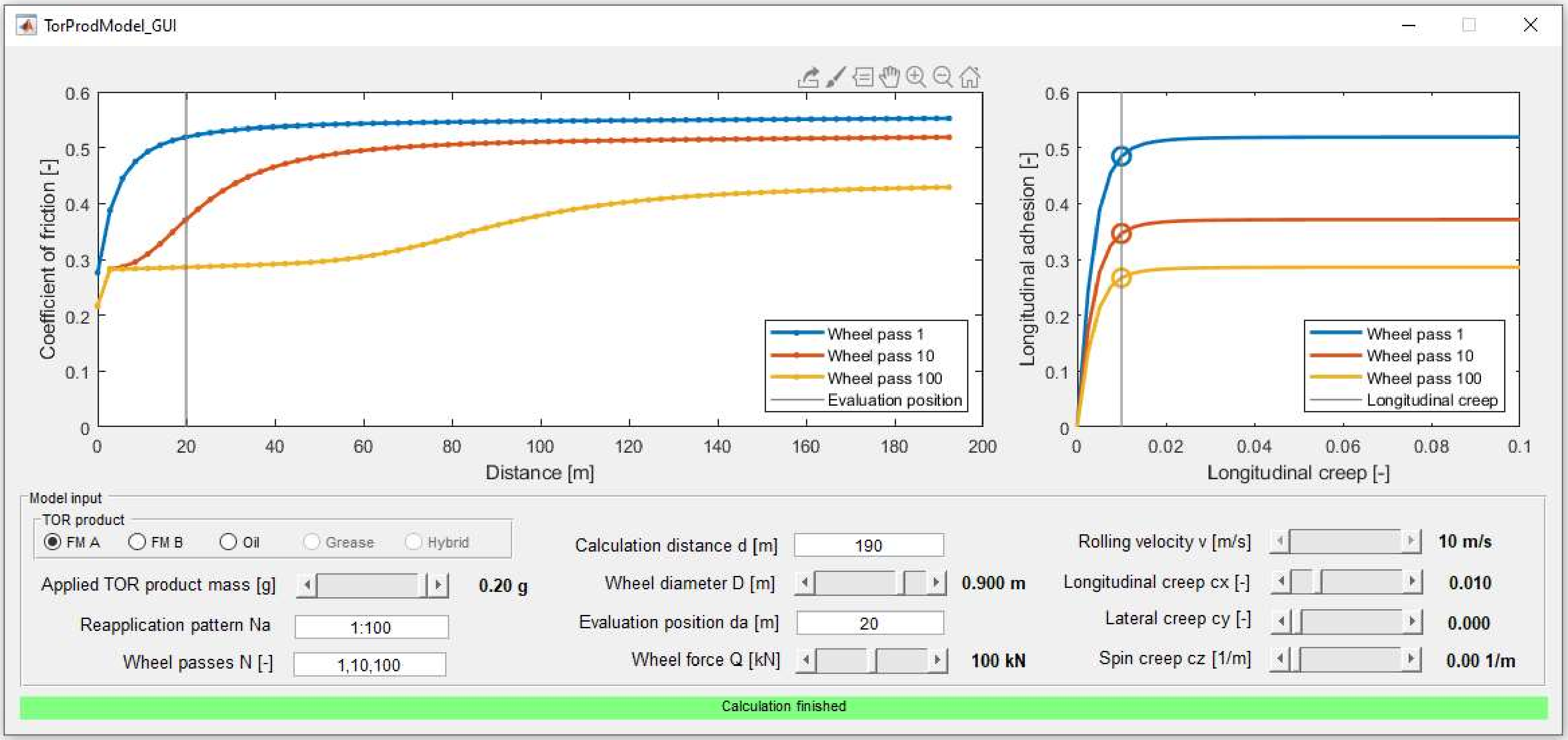
Model demo



TorProdModel_GUI
Coefficient of friction [-]
Distance [m]
Wheel pass 1
Wheel pass 10
Wheel pass 100
Evaluation position
Longitudinal adhesion [-]
Longitudinal creep [-]
Wheel pass 1
Wheel pass 10
Wheel pass 100
Longitudinal creep
Model input
TOR product
FM A
FM B
Oil
Grease
Hybrid
Applied TOR product mass [g]
0.20 g
Reapplication pattern Na
1:100
Wheel passes N [-]
1,10,100
Calculation distance d [m]
190
Wheel diameter D [m]
0.900 m
Evaluation position da [m]
20
Wheel force Q [kN]
100 kN
Rolling velocity v [m/s]
10 m/s
Longitudinal creep cx [-]
0.010
Lateral creep cy [-]
0.000
Spin creep cz [1/m]
0.00 1/m
Calculation finished

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Summary

- Experiments carried out for different TOR products
  - Information about carry-on, pick-up, consumption and friction
- Model developed and parameterized
  - for wayside application
  - describing carry-on, pick-up, consumption and friction phenomena
- Possible applications
  - choosing the right location for application devices
  - choosing the right type / amount of material dependent on the scenario of interest, …

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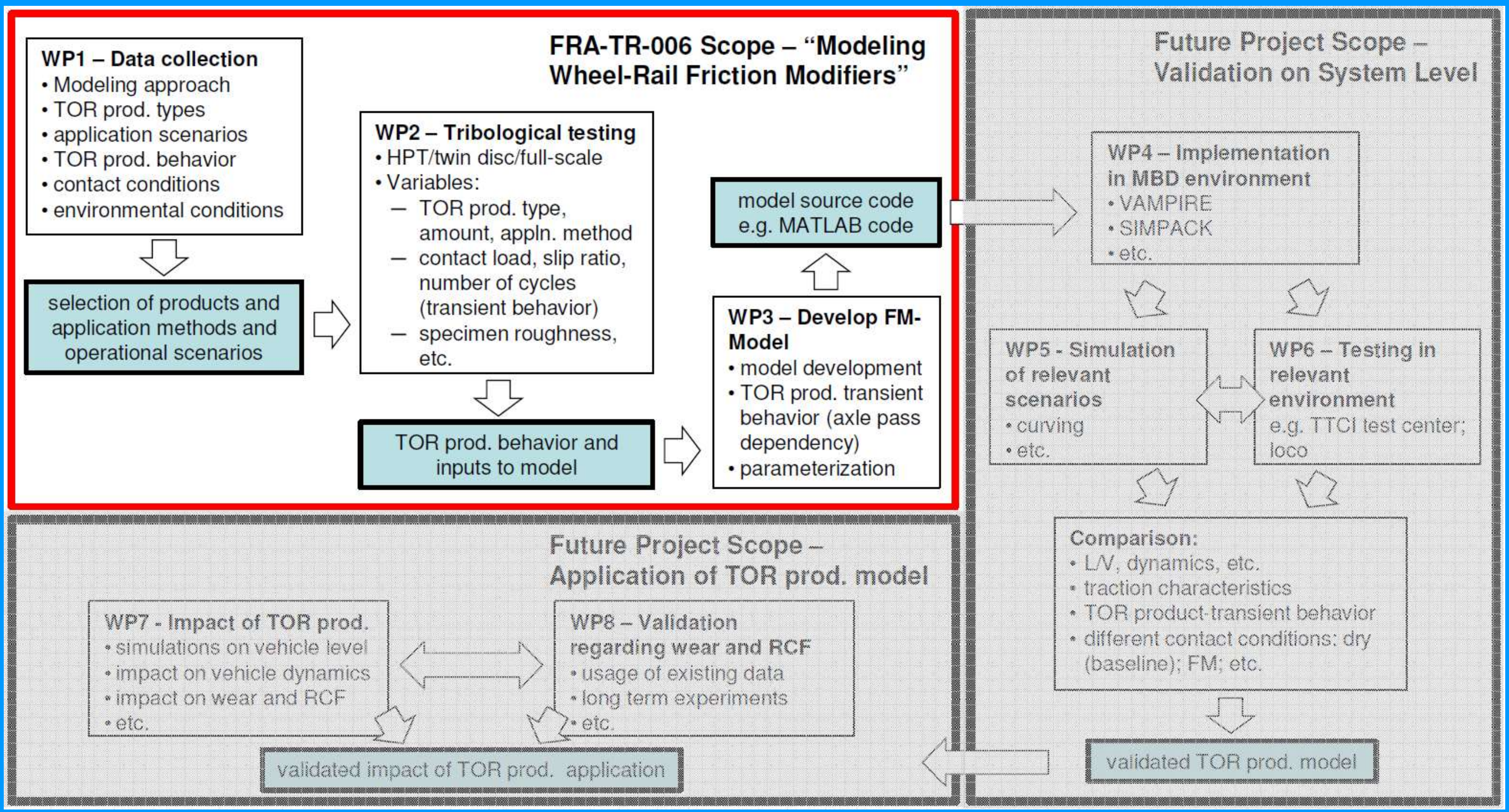
Future work



FRA-TR-006 Scope – "Modeling Wheel-Rail Friction Modifiers"
WP1 – Data collection
• Modeling approach
• TOR prod. types
• application scenarios
• TOR prod. behavior
• contact conditions
• environmental conditions
selection of products and application methods and operational scenarios
WP2 – Tribological testing
• HPT/twin disc/full-scale
• Variables:
– TOR prod. type, amount, appln. method
– contact load, slip ratio, number of cycles (transient behavior)
– specimen roughness, etc.
TOR prod. behavior and inputs to model
model source code e.g. MATLAB code
WP3 – Develop FM-Model
• model development
• TOR prod. transient behavior (axle pass dependency)
• parameterization
Future Project Scope – Validation on System Level
WP4 – Implementation in MBD environment
• VAMPIRE
• SIMPACK
• etc.
WP5 - Simulation of relevant scenarios
• curving
• etc.
WP6 – Testing in relevant environment
e.g. TTCI test center; loco
Comparison:
• L/V, dynamics, etc.
• traction characteristics
• TOR product-transient behavior
• different contact conditions: dry (baseline); FM; etc.
validated TOR prod. model
Future Project Scope – Application of TOR prod. model
WP7 - Impact of TOR prod.
• simulations on vehicle level
• impact on vehicle dynamics
• impact on wear and RCF
• etc.
WP8 – Validation regarding wear and RCF
• usage of existing data
• long term experiments
• etc.
validated impact of TOR prod. application

Future work

- Expanding the model to take lateral position into account
- Integration of the model into a multi-body dynamics simulation to assess various operating scenarios
  - Curving
  - High rail and low rail
- Improving the model with validation using field data
- Assess the impact of TOR product use on vehicle dynamic performance
- Influence of TOR product use on wear/RCF