KTH ROYAL INSTITUTE
OF TECHNOLOGY

Predictive maintenance in railway systems

MBS-based wheel and rail life prediction exemplified for the Swedish Iron Ore line

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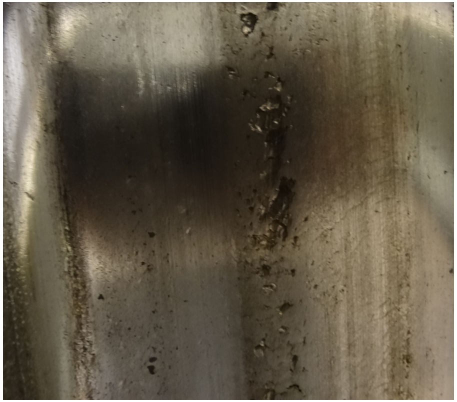
Iron Ore line in Sweden

- In 2020, the Iron ore line carried over 37 million tones of goods corresponding to approximately 20 % of the entire freight transport work in Sweden
- The traffic operated by LKAB typically consists of 67 freight cars hauled by iore-class locomotives. The total train weight is up to 9 400 tones. The maximum permissible axle load is 32.5 tones
- Every day, in average, there are 10 loaded and 10 tare trains traveling on the line.
- The northern loop of the Iron-Ore line has a total of 113 curves with a radius below 750 m
- 170 km single track line located in the Norrbotten county used to transport iron ore from mines in Kiruna, to the ports of Narvik

Wheel-rail life prediction models

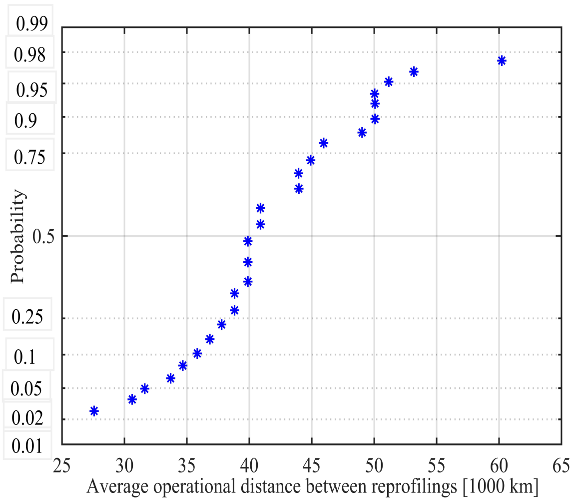
Wheel life (Km):
To predict the onset of wheel **reprofiling** due to Rolling Contact Fatigue (RCF)



Rail life (MGT):
To predict the onset of rail **grinding** due to Rolling Contact Fatigue (RCF)

Wheel life prediction models (locomotive)

- Maximum km running distance before reprofiling due to RCF is 70k km.
- Using simulations, study the effect of the followings on the wheel life
    - W/R friction
    - Flange lubrication
    - Wheel diameter
    - Amount of ED braking



Methodology:

- **Iterative** simulations.
- Evolution of the profiles due to **Wear**: Archard method
- Exceedance of surface shear stresses from the material strength in shear to check the **RCF** risk
- Using Burstow's fatigue life model (Tγ) to consider the effect of wear on RCF

Rail life prediction models

- Grinding of the inner rail after 3.5 months (105 days) for a curve with radius: R508m

- Using simulations, study the effect of the gauge widening on the rail life for distinct track section:

R508m

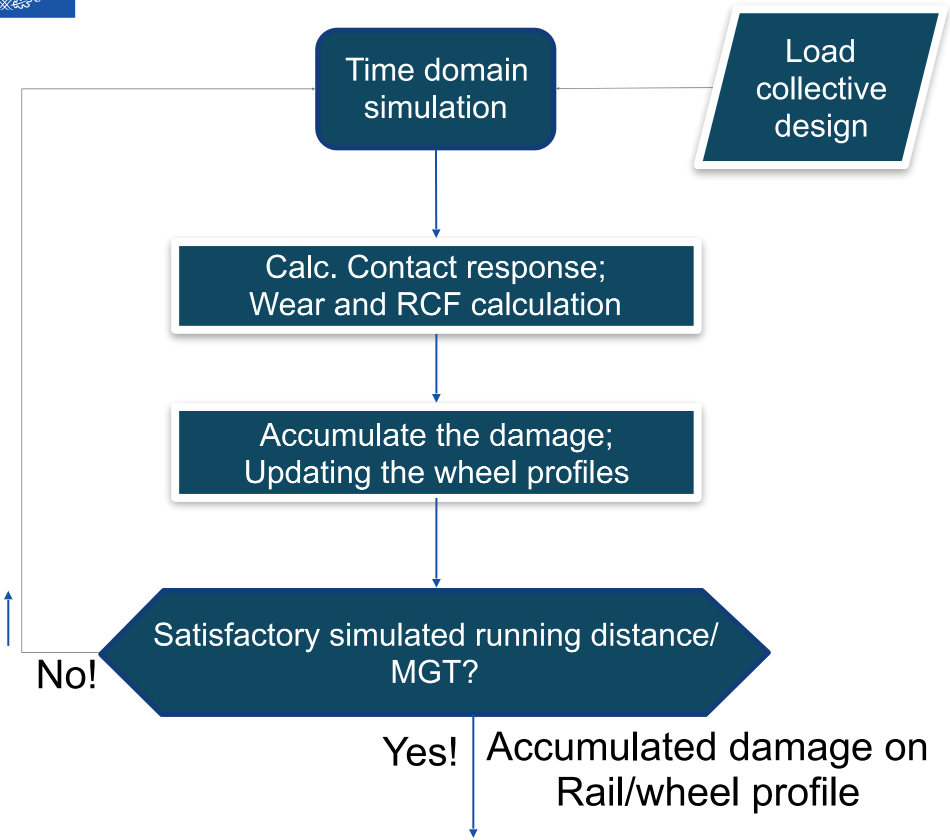
R594m

R621m

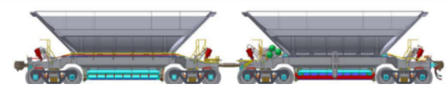
R683m

R724m

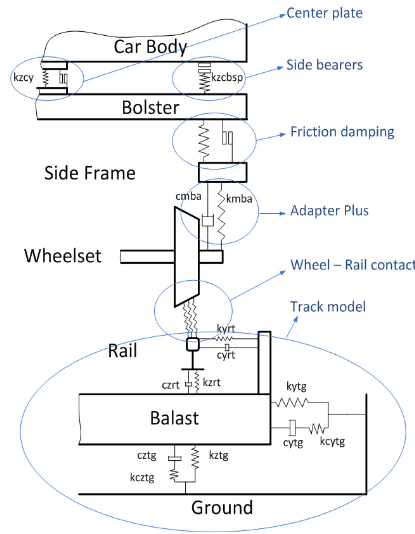
Iterative simulations



Dynamic simulations



- MBS model of wagon running on three-piece bogies is built in GENSYS. The model is validated against measurements and the results are published.
- The locomotive MBS model is made by Bombardier in SIMPACK and translated to GENSYS.

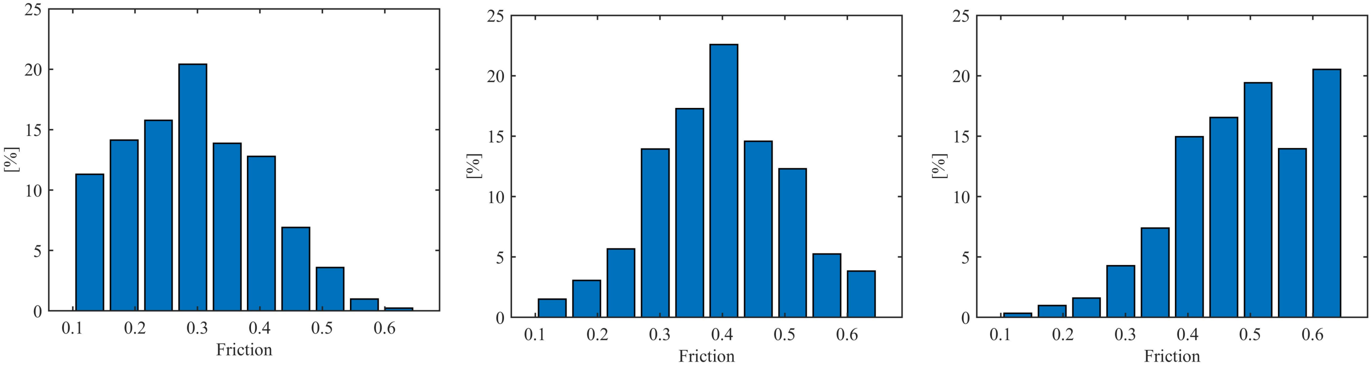


Load collective design (Track sections)

Section	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
	m	m	m	m	m	m	m	m	m
Radius interval	300	400	450	600	800	1000	1500	3000	∞
Gauge	1.444	1.443	1.448	1.457	1.445	1.444	1.443	1.440	1.435
Supper-elevation	0.068	0.061	0.066	0.051	0.046	0.037	0.033	0.028	0.00
Length	510	450	340	427	410	400	410	390	500
Contribution to the total line length [%]	1.0	3.5	1.0	1.5	14.0	16.1	7.9	5.0	50.0

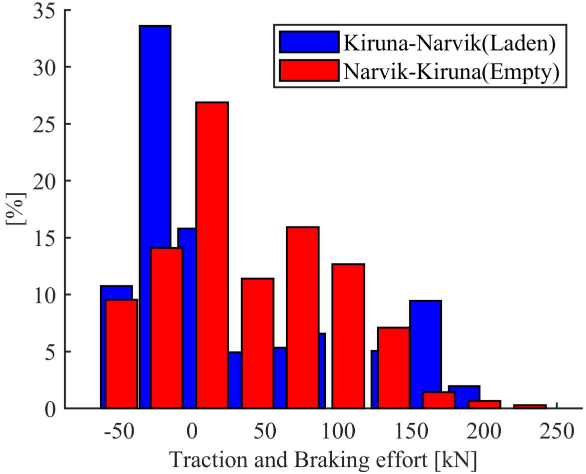
Load collective design (w/r friction)

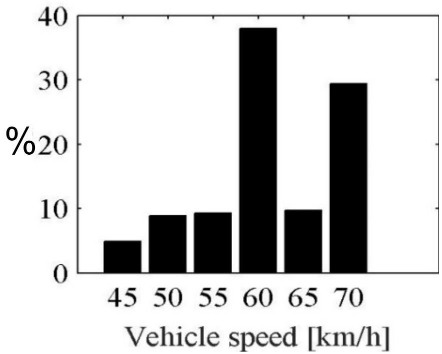
Wheel flange lubrication is applied on outer wheels; friction drops to 0.15 only on the flange.

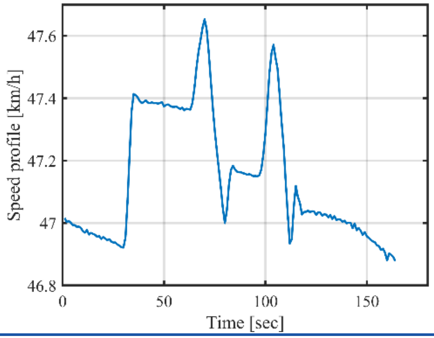


Load collective design (initial speed, traction and braking)

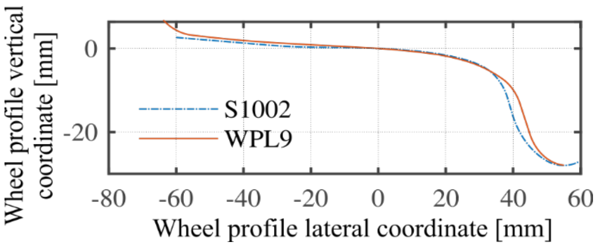
Max. speed for loaded cases 65 km/h; occasionally can rise to 70 km/h

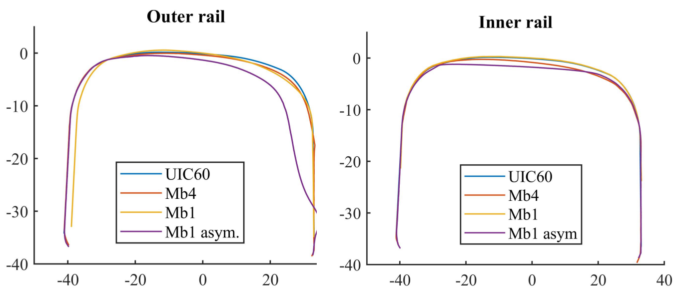






Load collective design (starting wheel/rail profiles)





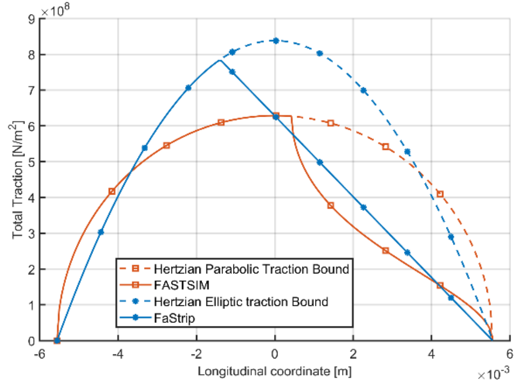
	Equivalent conicity	
	*	**
WPL9-UIC60i30 (Straight)	0.140	0.202
WPL9-Mb4i30 (wide curves)	0.140	0.103
WPL9-Mb1i30 (Straight)	0.053	0.065
S1002-UIC60i30 (EU Standard)	0.101	0.137

*** Lateral wheelset displacement: 3mm**
**** Lateral wheelset displacement: 5mm**

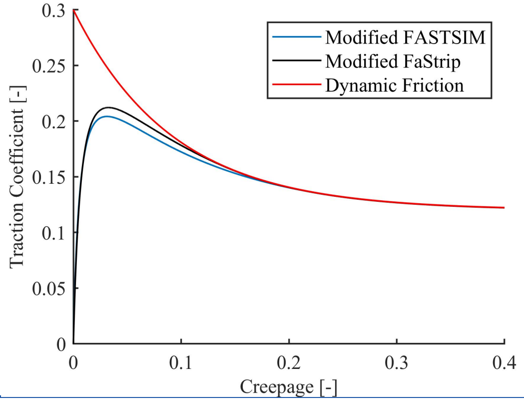
Contact response

- **Wear** depth essentially is a function of normal forces and sliding velocity at th contact patch (Archard).
  - Sliding velocity comprises of creepages (rigid body dynamics) and elastic displacements (shear stresses at the surface).
- **RCF** depth is solely a function of amount of shear stresses above the shear strength of the material (KTH model).

Modified FASTRIP + Hertz

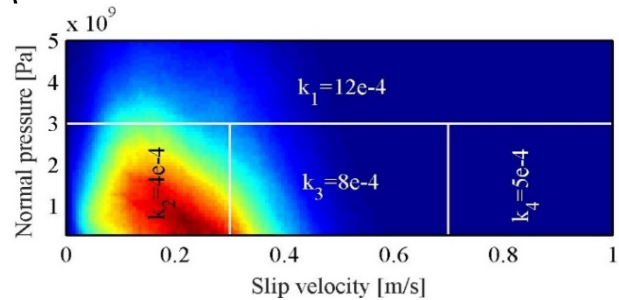


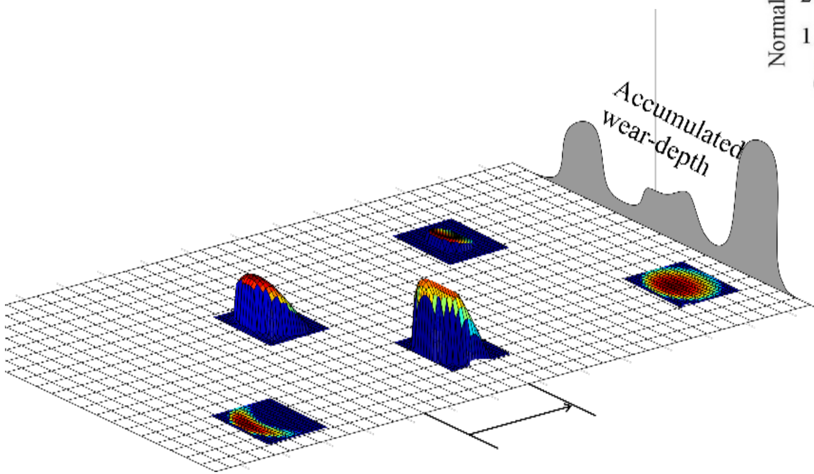
Oldrich Polach



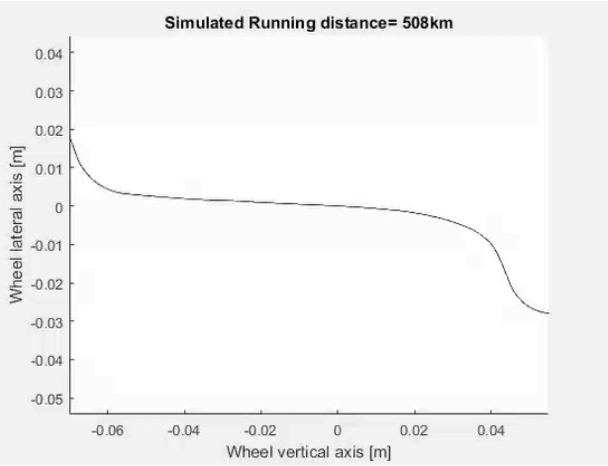
Wear

- Archard formula to calculate wear depth locally:
- $W = k\dfrac{P \bullet S}{H}, \quad S = f(v_x, v_y, \varphi,\ \tau,\ V)$

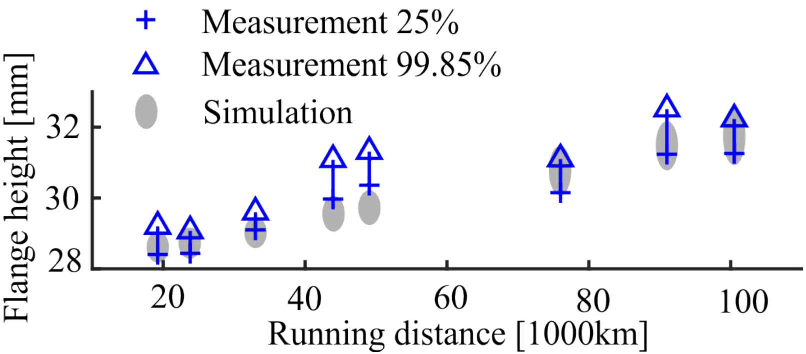




Wear



Simulated Running distance= 508km
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
Wheel lateral axis [m]
-0.06
-0.04
-0.02
0
0.02
0.04
Wheel vertical axis [m]



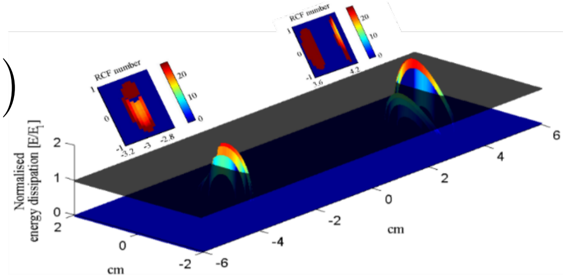
Measurement 25%
Measurement 99.85%
Simulation
Flange height [mm]
32
30
28
20
40
60
80
100
Running distance [1000km]

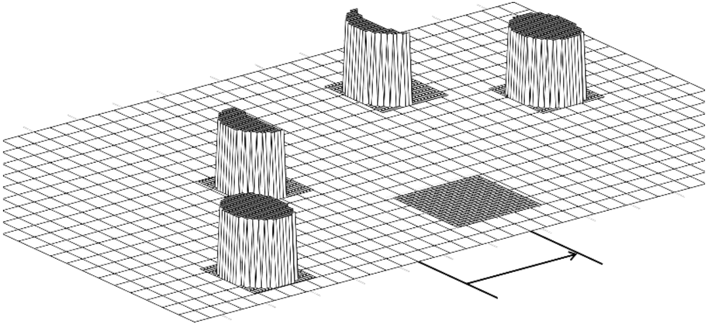
RCF

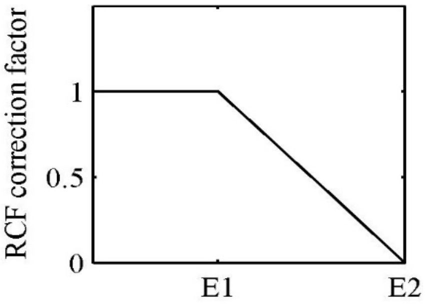
1. Exceedance of shear-stress in each mesh from the yield-limit in shear: RCF-number (N_r)

2. Correct the RCF-number (N_r) values by *E*

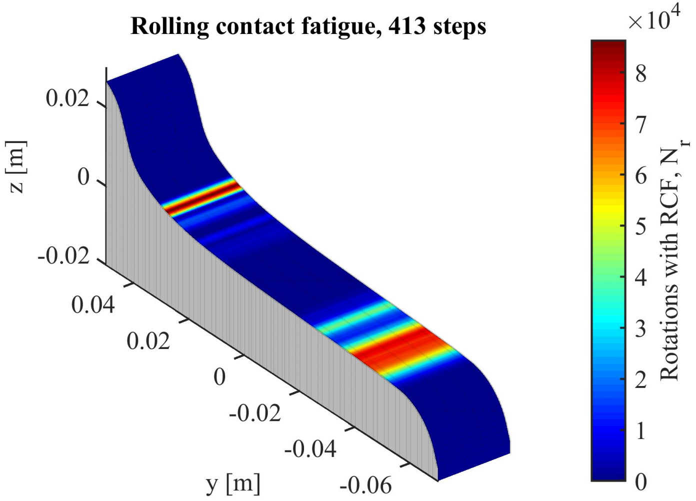
- $E(x,y) = \tau_{zx}(x,y) \bullet (v_x - \phi \bullet y) + \tau_{zy}(x,y) \bullet \left(v_y + \phi \bullet x\right)$
- $\bar{E}_i = \dfrac{v_i \bullet A}{2\sqrt{3}}\left(\sigma_y + \sigma_U\right),\ \text{for } i = 1, 2$
- v_i are 0.1%, 0.3%







RCF



RCF-number (N_r) after 75000 km simulated running distance; Leading inner wheel.

Wheel life

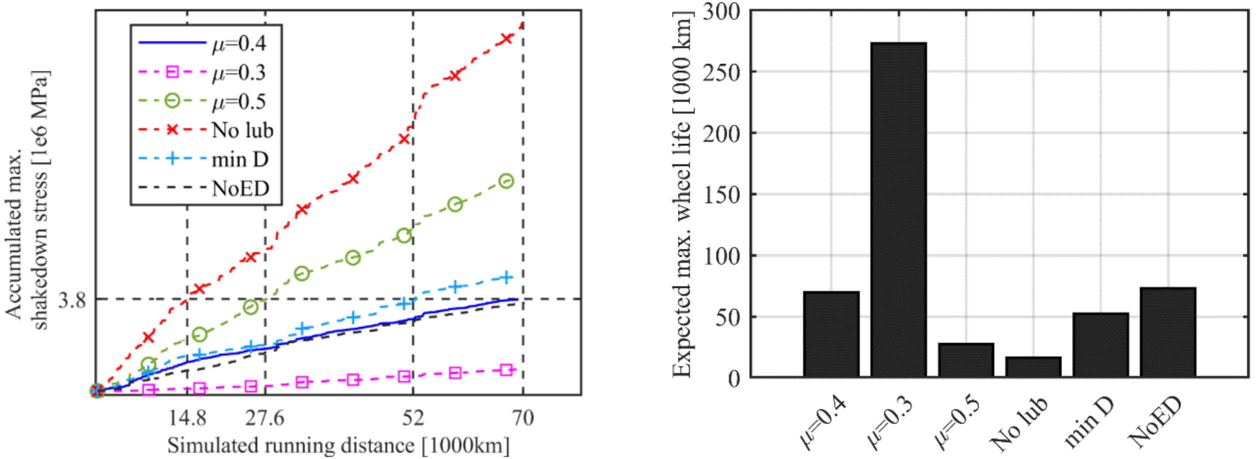


Figure 7, Cumulative shakedown-stresses (left) and the corresponding expected wheel life (right)

Rail life: Track sections & scenarios

The northern loop of the Iron-Ore line has a total of 113 curves with a radius below 750 m, so a selection of five curves is made, one in each 50 m interval from 500-750 m, as a representative for the interval

Radius [m]	Start km	End km	Cant deficiency [mm]
508	122.216	122.689	-11.2
594	78.086	78.446	-1.3
621	61.930	62.105	-21.3
683	13.735	14.155	1.3
724	47.153	47.313	7.4

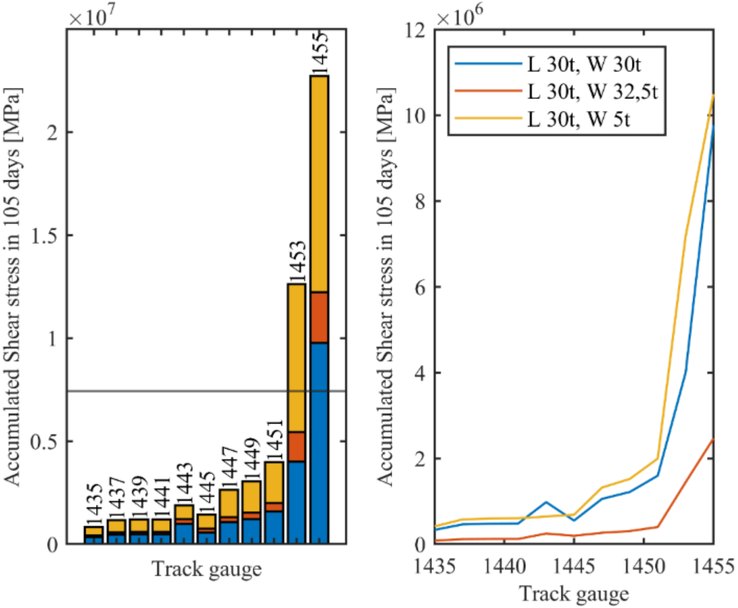
In the current work the time which it takes until the cracks appear on the low rails is considered for the simulations, i.e. 3.5 months.

Rail life: Track sections & scenarios

Vehicle specific		Common parameters				
Wheel profile	Load	Gauge [mm]	Radius [m]	Wheel-rail friction	Rail profile	Wheel dia-meter [mm]
Loco 1: nominal wheel	Loco 1: 30t/Axle	1435	508	0.2	Low: UIC60 High: MB1 Both nominal	Reprofiling 1 Loco: 1250 Wagon: 915
Wagon 1: Nominal wheel	Wagon 1: 5t/Axle	1437	594	0.3	Low: UIC60 High: MB1 Both worn	Reprofiling 2 Loco: 1222 Wagon: 898
Wagon 2: Worn wheel (168,000 km)	Wagon 2: 30t/Axle	1439	621	0.4		Reprofiling 3 Loco: 1200 Wagon: 882
	Wagon 3: 32.5t/Axle	1441	683	0.5		Reprofiling 4 Loco: 1176 Wagon: 864
		1443	724	0.6		
		1445				
		1447				
		1449				
		1451				
		1453				
		1455				

Rail life: reference case

The limit values for the low rail using the MGT of axle passes is 0.357 and accumulated maximum shear stress above the shear strength of the rail is 7,430,000 MPa. The validation case then, provides a reference damage accumulation value for the other simulations.



Rail life: other cases

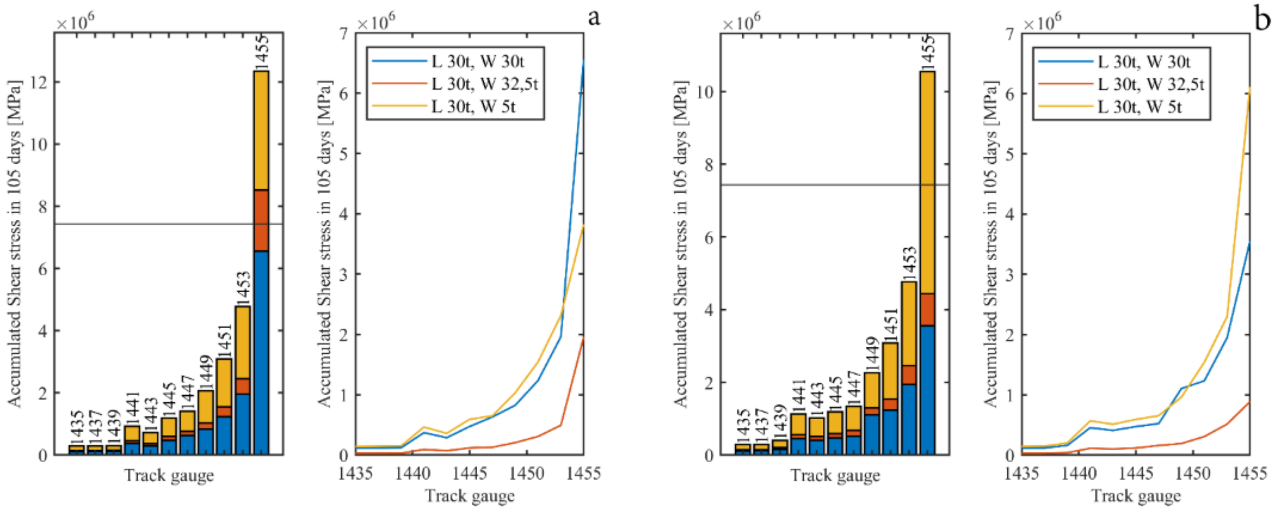
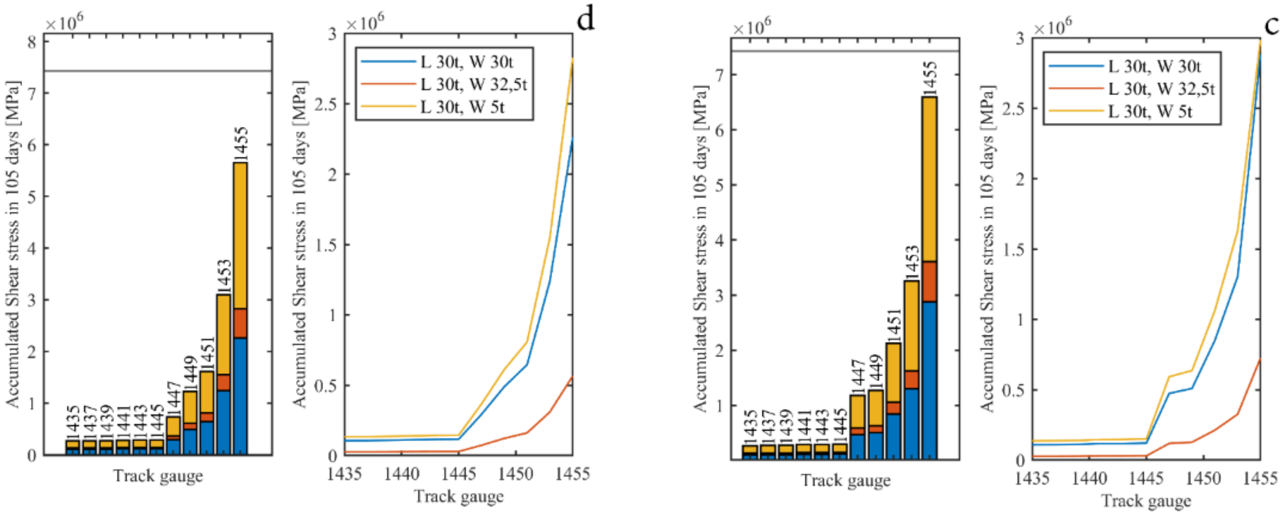


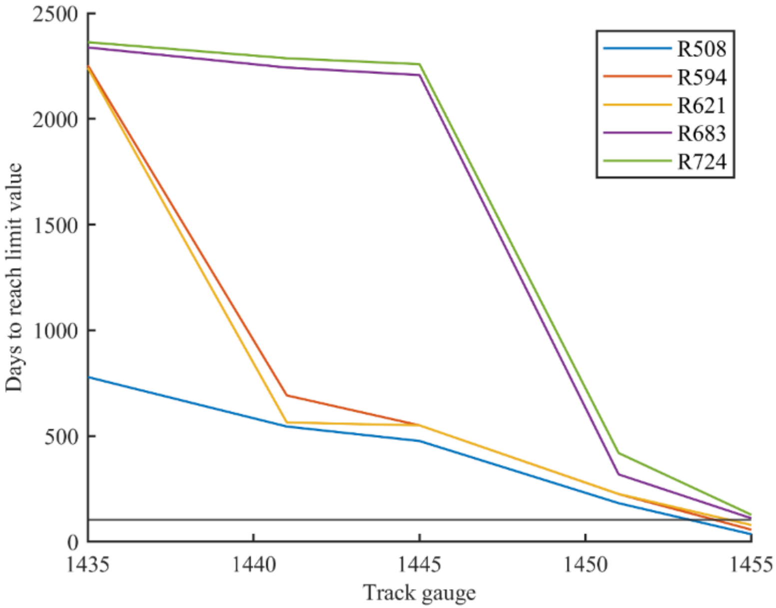
Figure 11, Accumulated shear stress above the shear yield limit in 3.5 months traffic on the low rail [MPa] vs Track gauge [mm] at Curve 3, L = locomotive, W = wagon; **a) R594 m, b) R621 m**

Rail life: other cases



Accumulated shear stress above the shear yield limit in 3.5 months traffic on the low rail [MPa] vs Track gauge [mm] at Curve 3, L = locomotive, W = wagon; **C) R683 m and D) R724 m**.

Rail life: results



Conclusions

- This methodology allows to analyse the influence of different parameters in the asset life in an automated way, enabling a fast and resource-light analysis of system-level changes.
- The methodology has been applied to the Iron-Ore line in northern Sweden.
    - First, life of **locomotive wheels** has been determined and its variation with different operational and environmental variables has been studied, such as ***stochastic friction*** values in the wheel-rail contact or the influence of ***wheel diameter*** on RCF generation, but also deterministic variables such as the use of ***electrodynamic braking***.
    - The second case study calculates **rail damage**, specifically the effect of ***gauge widening*** on the expected rail life. The analysis also covers the experimental validation of the damages with respect to contact bands for different curve radii.

Thank you very much!

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