Friction Management: an Applications Perspective

Kevin Oldknow, PhD, PEng

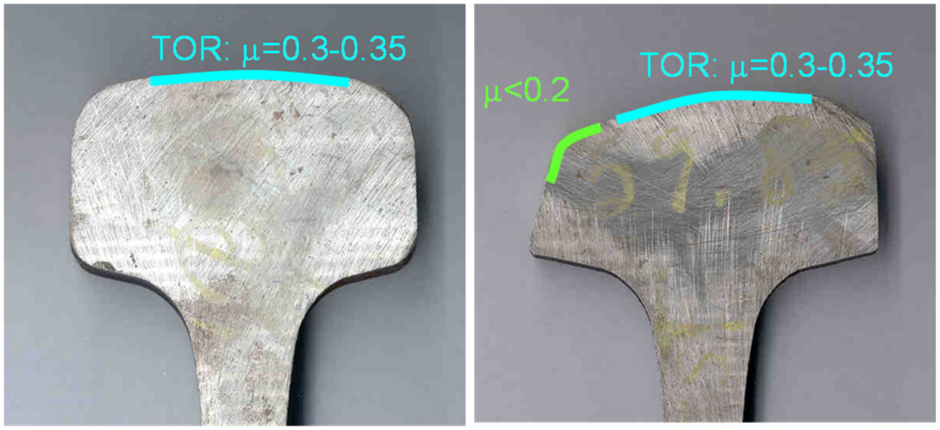
Simon Fraser University

Overview:

Who, what, where, when, why, (and how)?

- **What** do we really mean by friction management?
- **When** have some of the major developments in friction management evolved?
- **Where** is friction management used?
- **Why** is friction management important?
- **How** is effective friction management achieved?
- **Who** is involved in friction management?

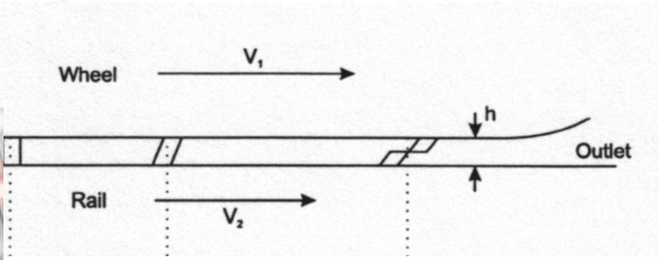
What do we really mean by friction management?

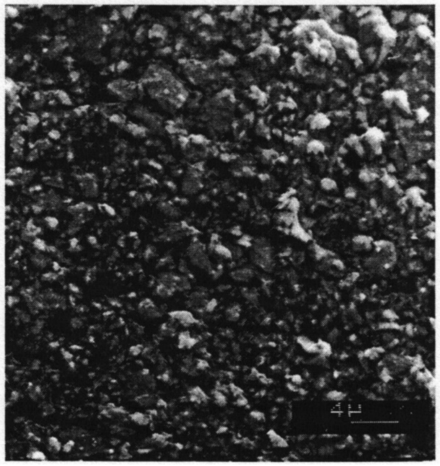


Kalousek, J, K Hou, E Magel, and K Chiddick. "The Benefits of Friction Management: A Third Body Approach," Proceedings of the World Congress on Railway Research (WCRR 1996), Colorado Springs, 1996.

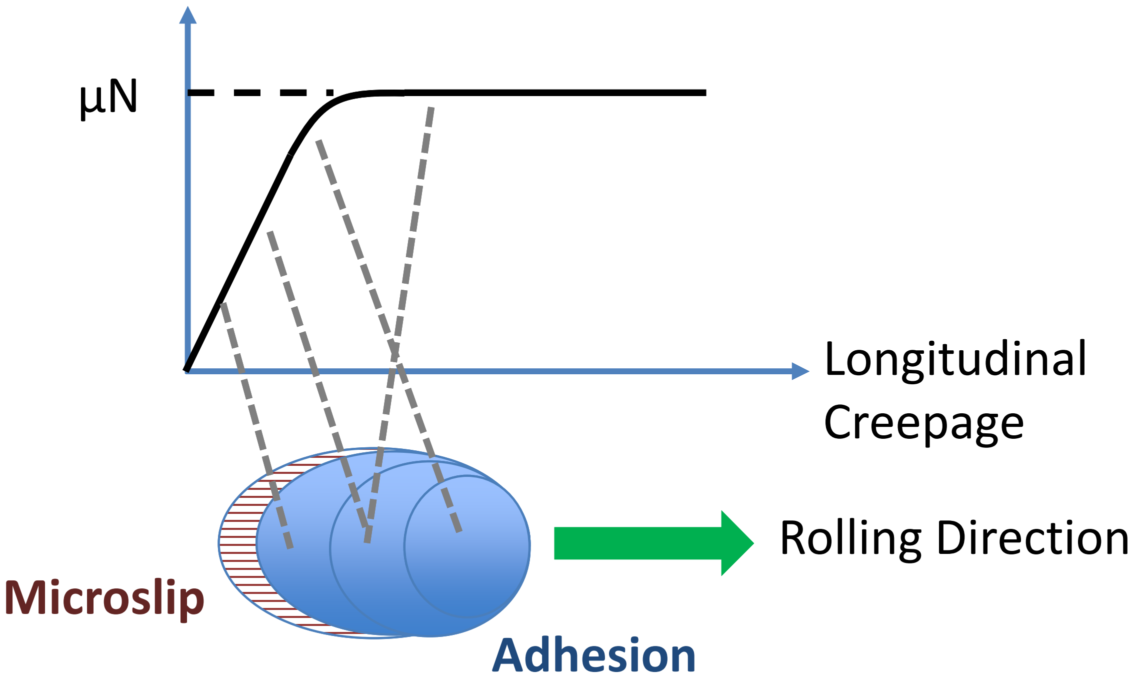
Getting “inside” the wheel-rail interface

J. Kalousek, K Hou, E Magel, and K Chiddick: The Benefits of Friction Management: A Third Body Approach. In Proceedings of the World Congress on Railway Research (WCRR 1996), 8. Colorado Springs, 1996.

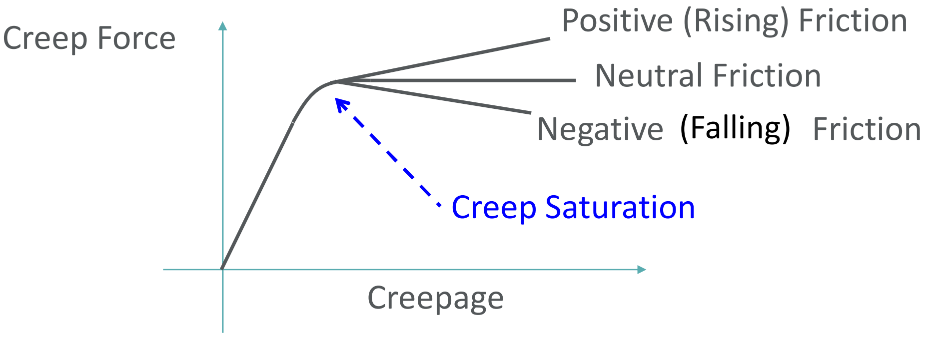




The traction-creepage curve



Manipulating the third-body layer



Creep Force

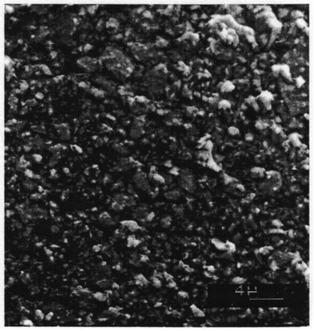
Positive (Rising) Friction

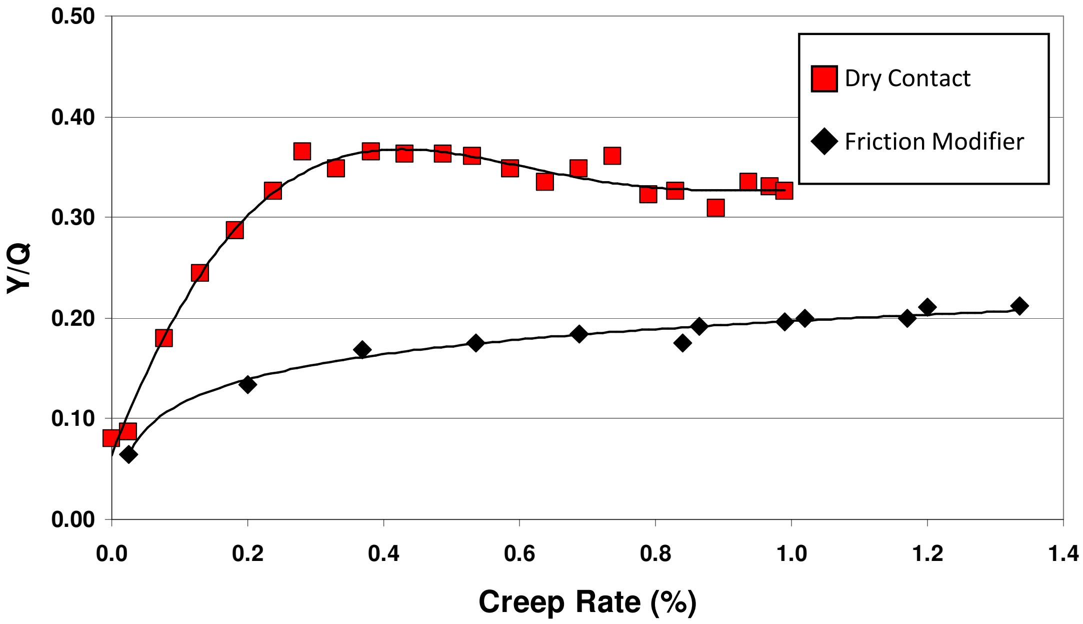
Neutral Friction

Negative (Falling) Friction

Creep Saturation

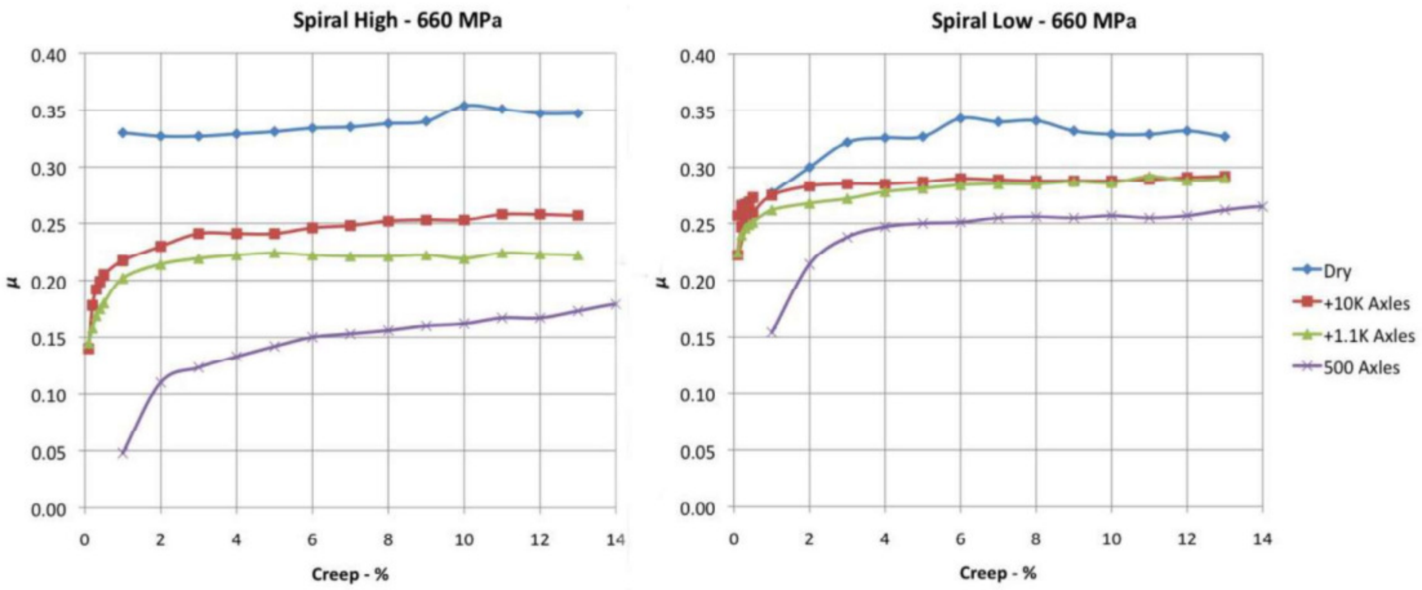
Creepage





* Replotted from: A. Matsumoto, Y. Sato, H. Ono, Y. Wang, Y. Yamamoto, M. Tanimoto and Y. Oka, *Creep force characteristics between rail and wheel on scaled model*, Wear, Vol 253, Issues 1-2, July 2002, pp 199-203

Practicalities of controlling the third body layer



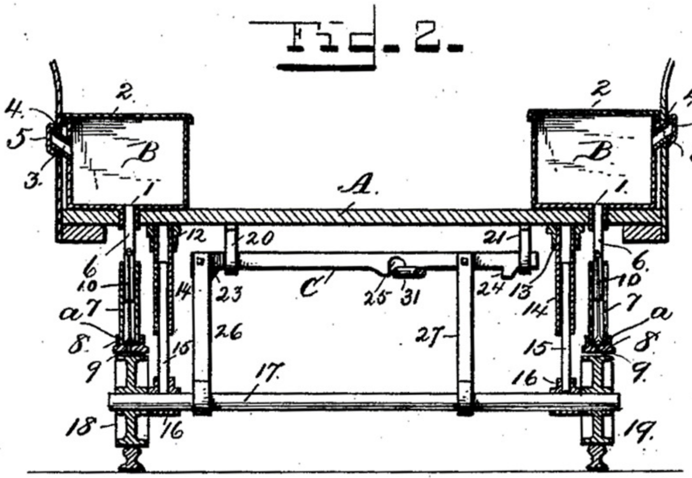
Eadie, D T, H Harrison, R Kempka, R Lewis, A Keylin, and N Wilson. "Field Assessment of Friction and Creepage with a New Tribometer." In Proceedings of the 11th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems, 10. Delft, the Netherlands, 2018.

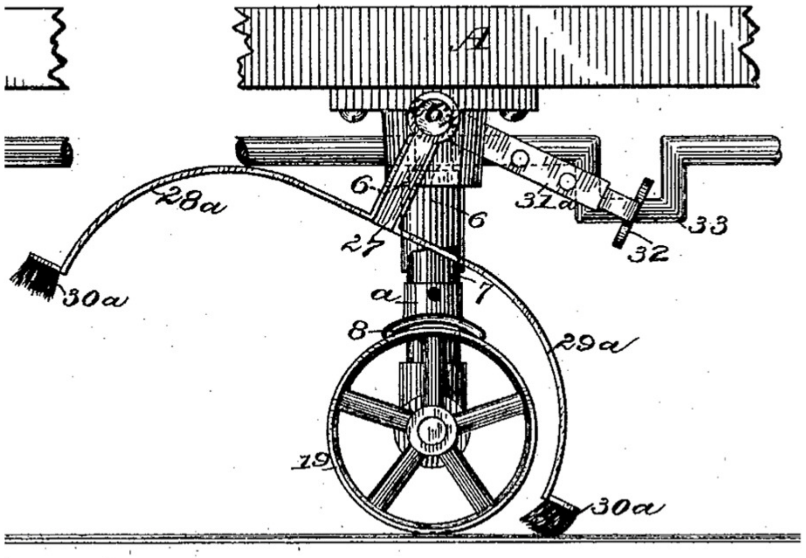
When have some of the major developments in friction management evolved?

APPARATUS FOR OILING RAILWAY TRACKS.

No. 457,045. Patented Aug. 4, 1891.

FIG. 2.





T.L. Ennis: *Apparatus for Oiling Railway Tracks*, USPTO US457045A. El Paso, Texas, issued August 4, 1891.

A (very) broad timeline

- Late 1800's / Early 1900's:
  - Early patents begin to appear in the literature
- Mid-Late 1900's:
  - General adoption of Gauge Face & Wheel Flange lubrication in specific settings
- Late 1900's:
  - Rapid evolution of application system technologies and lubrication consumables
- 1990's - Today
  - First commercial introduction of Top of Rail Friction Management
  - Rapid developments in Friction Modifiers, Traction Enhancers, and Lubricants (esp. retentivity and consistency across wide temperature ranges)
  - Continued developments in application systems and remote monitoring technologies

Where is friction management used?

Broadly defined implementation scenarios

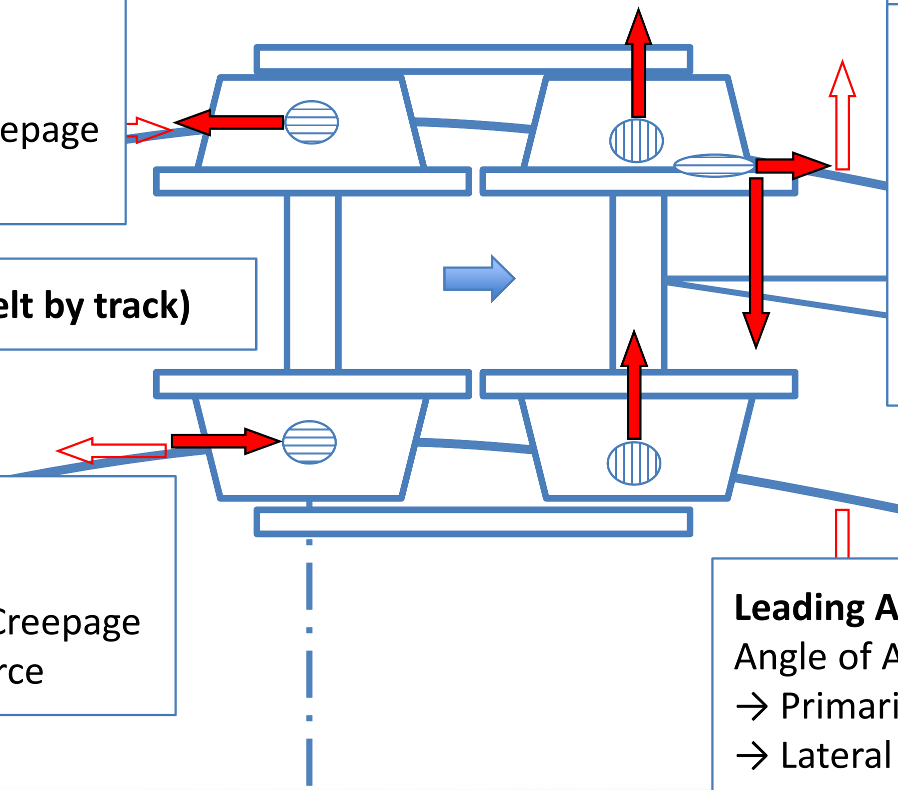
- Freight / Heavy Haul
  - Often (but not always) a territory-wide, trackside system based approach
  - Primary objectives tend to include reductions in wheel and rail wear, RCF, curving forces, track structure degradation, and fuel consumption.

- Passenger Rail
  - In many cases a more "surgical" approach, targeting (e.g.) specific problem areas for curving noise, wear and corrugation development, and track component failure.
  - Also several cases of system-wide and/or fleet-wide programs adopted to maximize (e.g.) wheel and/or rail life.

Why is friction management important?

- Examples: Reductions in…
  - Curving forces and/or derailment risk
  - Rail / wheel wear and RCF
  - Curving noise
  - Corrugations

Curving Forces (Two-Axle Vehicle, Sharp Curve)



Trailing Axle, High Rail:
R < $R_{equilibrium}$
→ Negative Longitudinal Creepage
→ Longitudinal Creep Force

Reaction Forces (felt by track)

Leading Axle, High Rail (Tread):

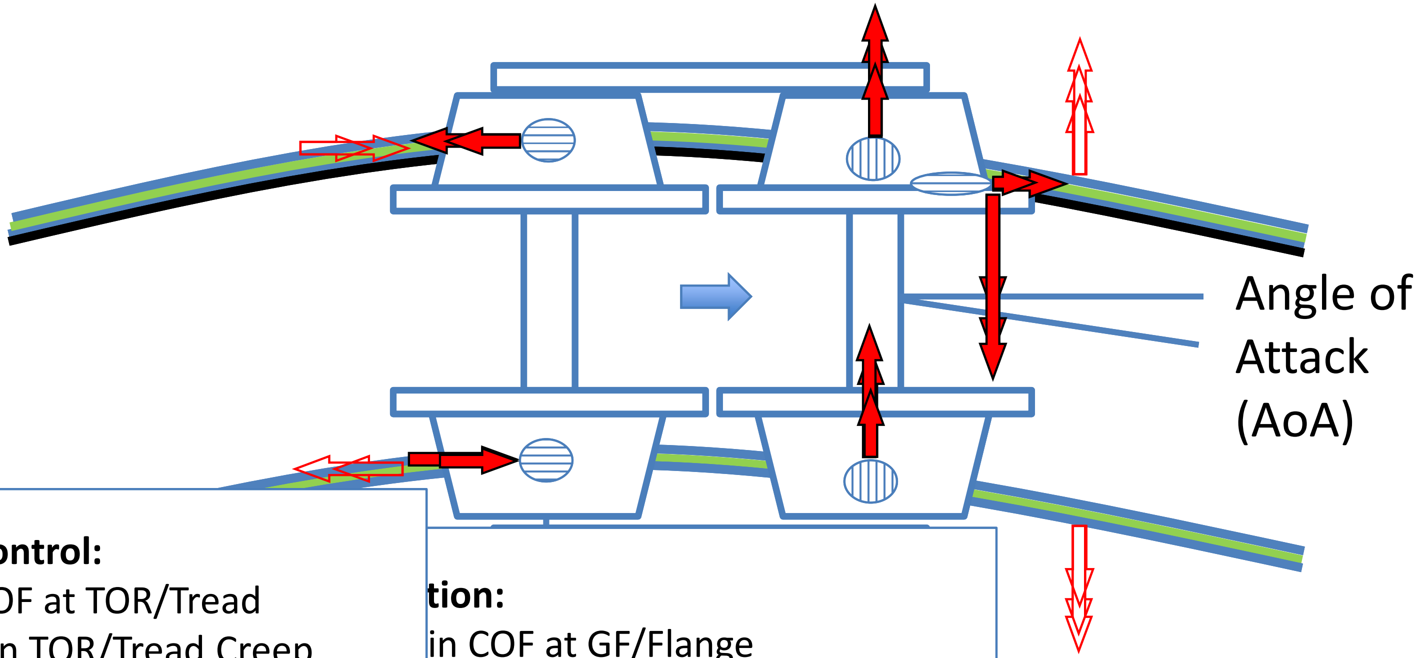
(AOA)

Leading Axle, High Rail (Flange):
R >> $R_{equilibrium}$
→ Positive Longitudinal Creepage
→ Longitudinal Creep Force
Plus:
Normal force (keeps vehicle on track)

Trailing Axle, Low Rail:
R > $R_{equilibrium}$
→ Positive Longitudinal Creepage
→ Longitudinal Creep Force

Leading Axle, Low Rail:
Angle of Attack
→ Primarily Lateral Creepage
→ Lateral Creep Force

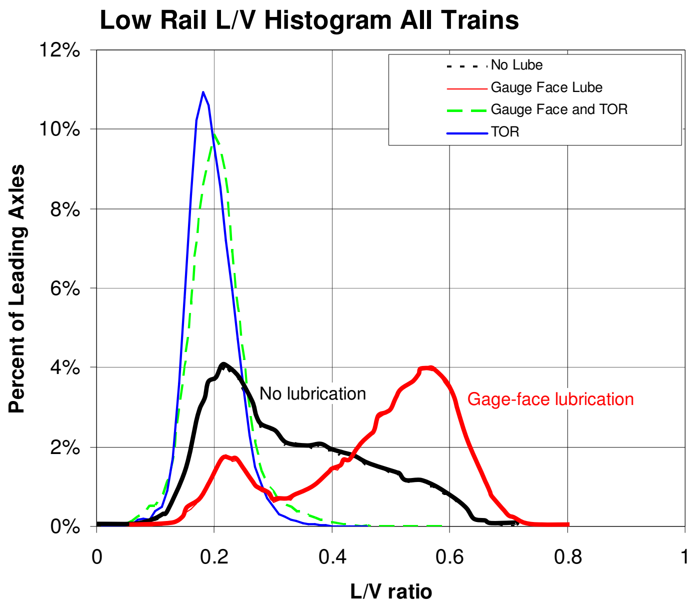
Friction management and vehicle Steering

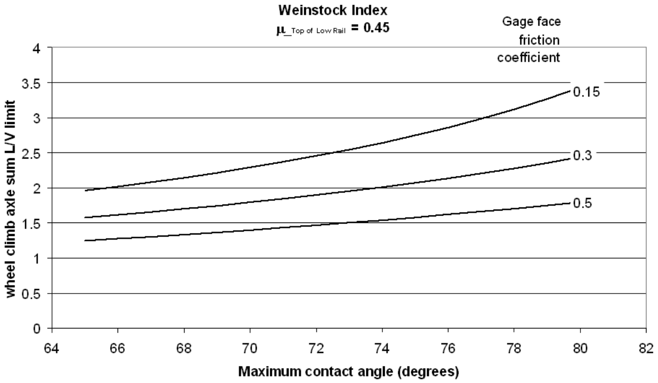


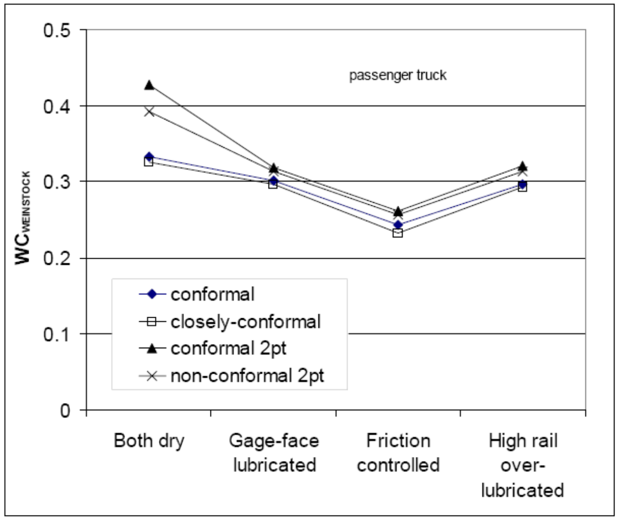
TOR Friction Control:
Reduction in COF at TOR/Tread
→ Reductions in TOR/Tread Creep Forces and *Negative* Steering Moments
→ Reductions in Lateral Forces, Wear, Energy, etc.

tion:
in COF at GF/Flange
ons in wear and energy
tion in Longitudinal Creep Force
e Steering Moment
crease in AoA and Lateral Forces

Curving forces and wheel climb probability





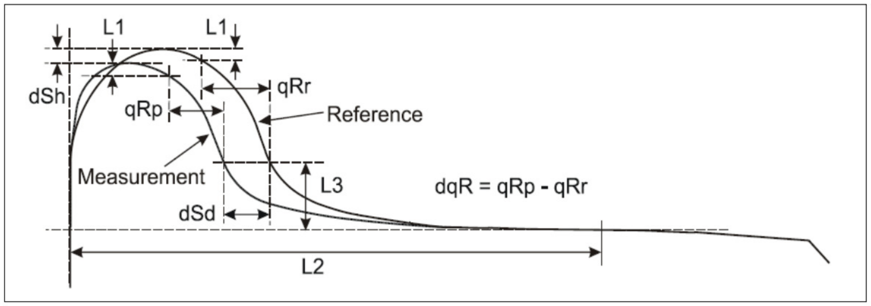


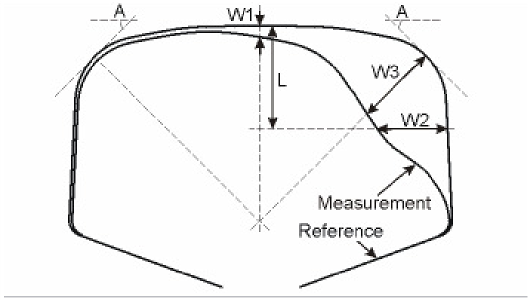
L/V goes up, but Weinstock limit also.

E. Magel: *Vehicle-Track Interaction & Dynamics*, presented at the 24th Annual Wheel Rail Interaction Conference, Chicago, 2018.

Wheel and Rail Wear

- Wear Types:
  - Adhesion
  - Surface Fatigue
  - Abrasion
  - Corrosion
  - Rolling Contact Fatigue
  - Plastic Flow



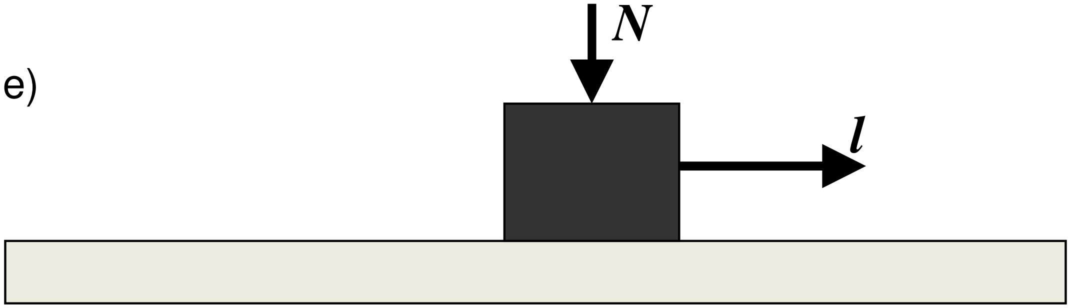


- “Archard” Wear Law:

$$V = \boxed{c}\,\frac{Nl}{H}$$

c **proportional to COF**

- V = volume of wear
- N = normal load
- l = sliding distance (i.e. creepage)
- H = hardness
- c = wear coefficient

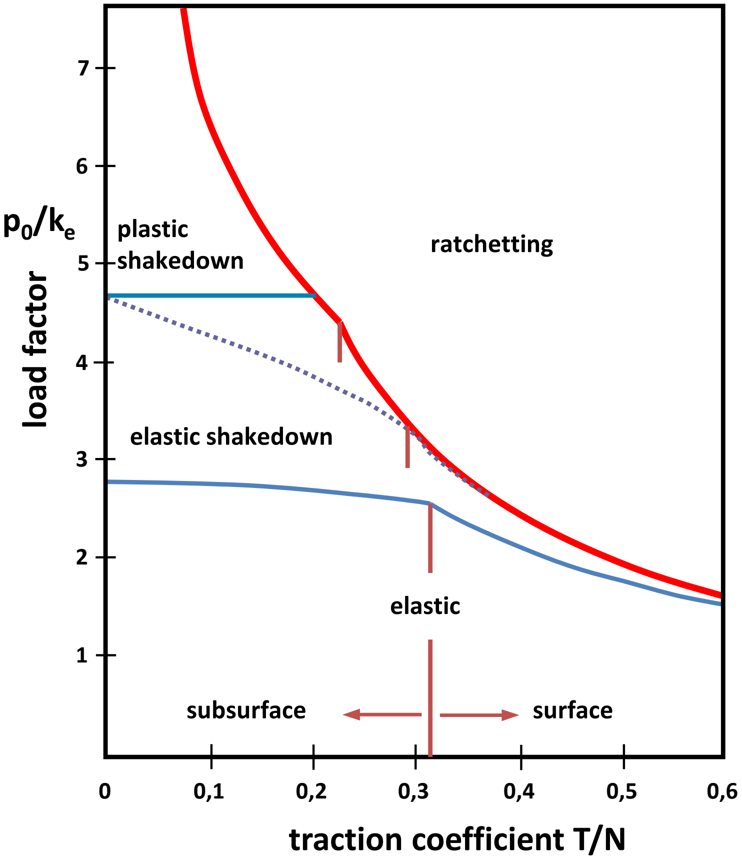


Shakedown and rolling contact fatigue (RCF)

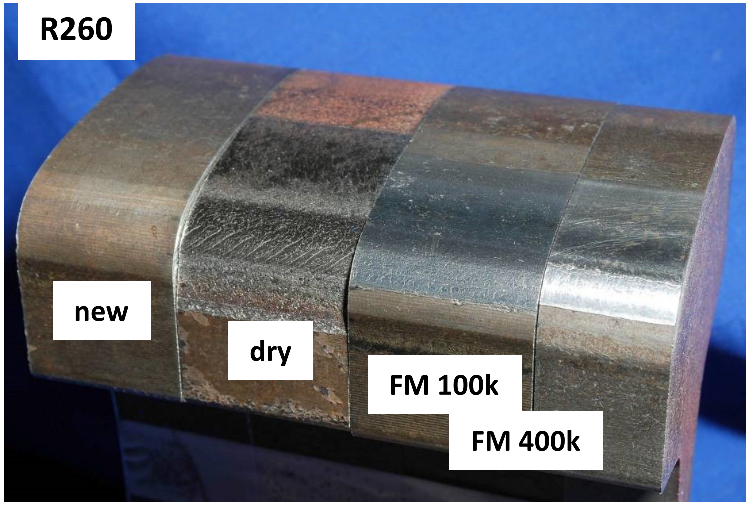
Figure 3: Transverse defect initiated by a deep seated shell from gauge corner collapse.

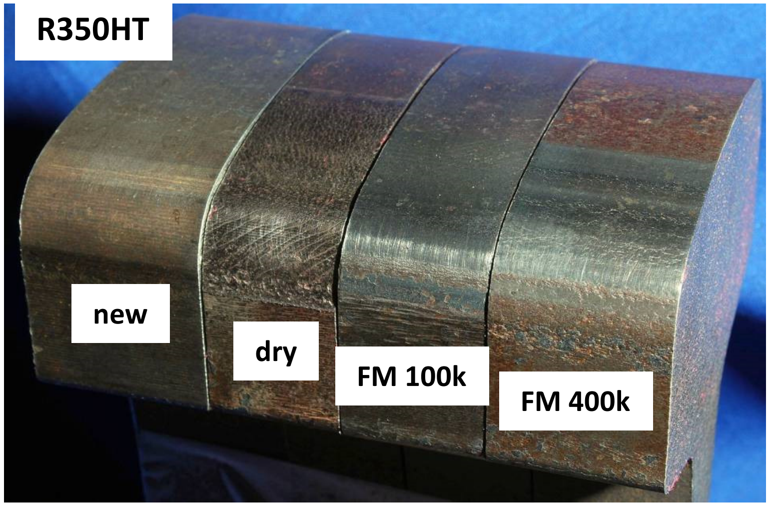
Figure 4: Transverse defect that developed from gauge corner cracking.

E. Magel, P. Mutton, A. Ekberg, and A. Kapoor, "Rolling contact fatigue, wear and broken rail derailments," Wear, vol. 366–367, pp. 249–257, Nov. 2016



Wear and rolling contact fatigue (RCF)





R. Stock, D. T. Eadie, D. Elvidge, and K. Oldknow: Influencing rolling contact fatigue through top of rail friction modifier application – A full scale wheel–rail test rig study, Wear, vol. 271, no. 1–2, pp. 134–142, May 2011

Curving Noise

- Example: wheel squeal

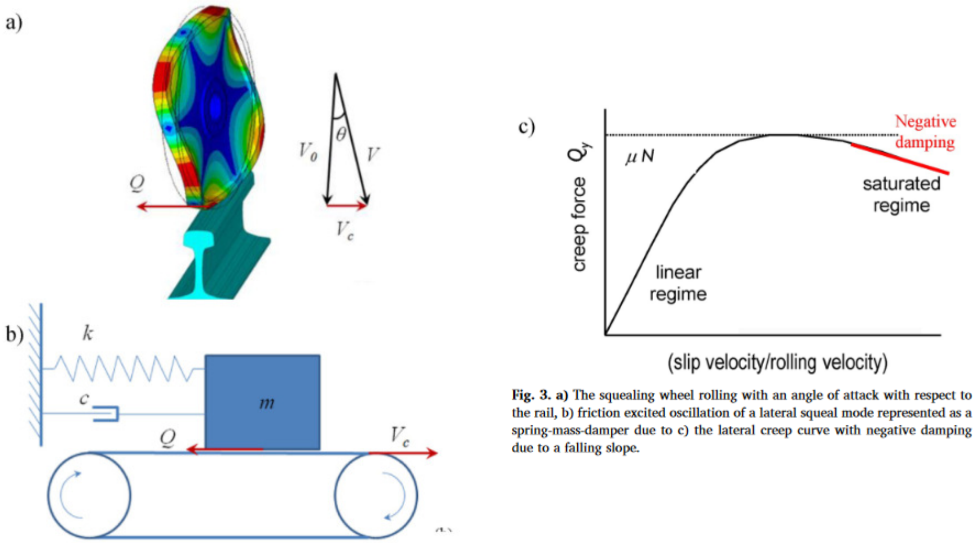
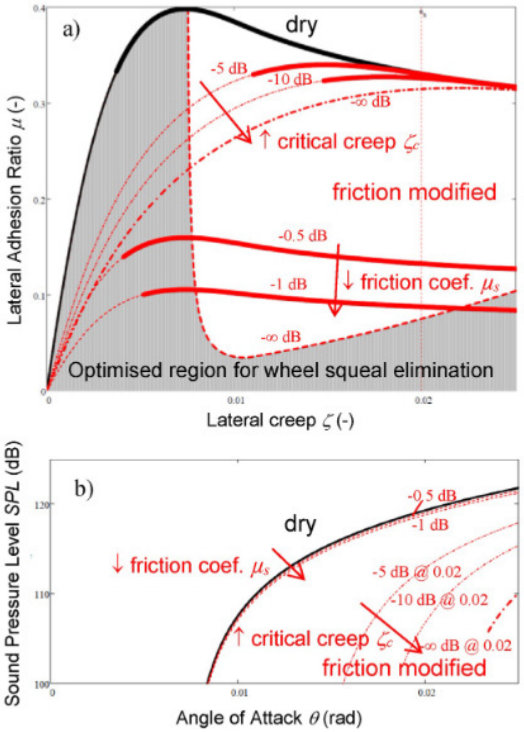
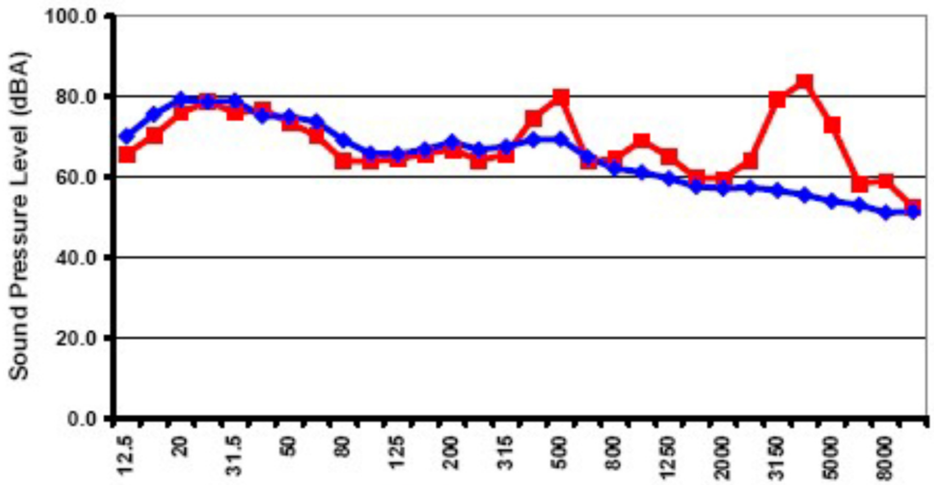


Fig. 3. a) The squealing wheel rolling with an angle of attack with respect to the rail, b) friction excited oscillation of a lateral squeal mode represented as a spring-mass-damper due to c) the lateral creep curve with negative damping due to a falling slope.



Meehan, Paul A., and Xiaogang Liu. "Wheel Squeal Noise Control under Water-Based Friction Modifiers Based on Instantaneous Rolling Contact Mechanics." Wear 440–441 (December 2019): 203052.

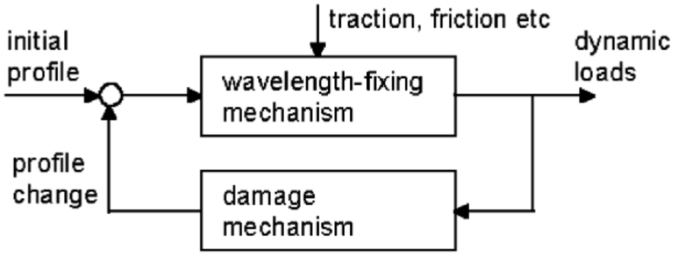
Curving noise



Sound pressure (LLeq) levels measured in a 90m radius curve on a European light rail system under baseline conditions (red line, square markers) and with friction modifier applied (blue line, diamond markers).

M Santoro: *The Effectiveness of Gauge Face, Restraining Rail, and TOR FM in Mitigating Curving Noise*, Presented at the ICRI 2022 Workshop, Ottawa, Canada, 29pp, 2022.

Corrugations


traction, friction etc

initial profile

wavelength-fixing mechanism

dynamic loads

profile change

damage mechanism

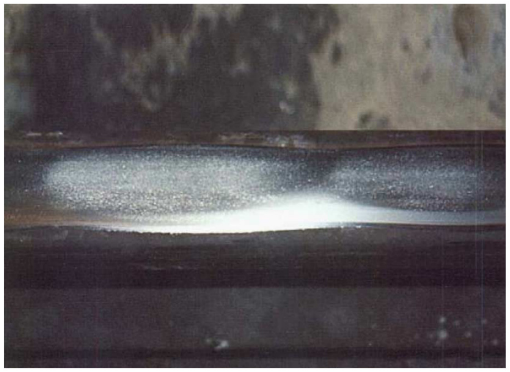


Fig. 7. Severe corrugation on the low rail of curve in a metro system.


Fig. 8. Corrugation at 25–30 mm wavelength arising from excitation of the baseplate on the railpad.

Grassie, Stuart L. "Rail Corrugation: Advances in Measurement, Understanding and Treatment." Wear 258, no. 7–8 (March 2005): 1224–34

Corrugations

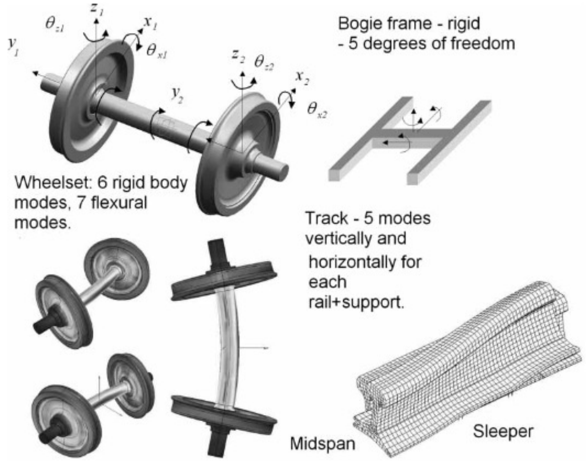


Figure 1. Degrees of freedom of nonlinear bogie model.

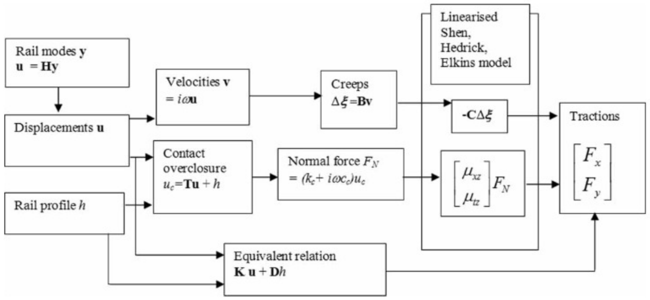
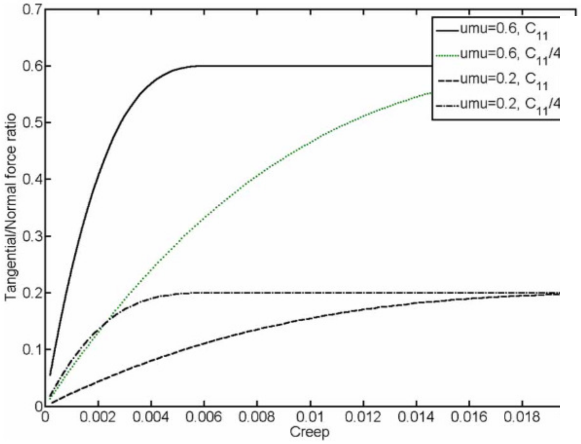


Figure 2. Structure of the linearised wheel–rail contact model.



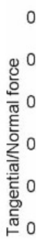


Figure 8. Ch

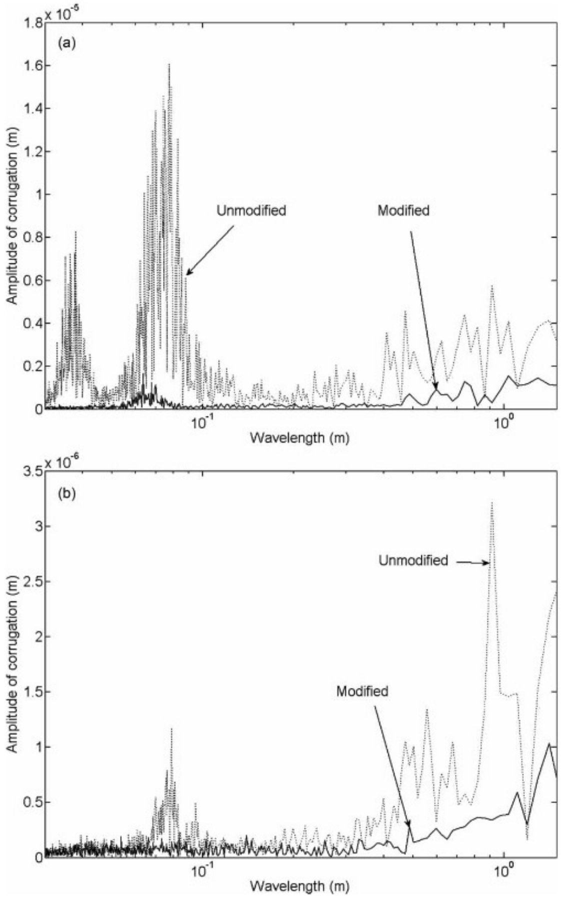


Figure 9. Reduction in wear versus wavelength from the nonlinear model, for the leading axle. (a) Predicted wear on the low rail. (b) Predicted wear on the high rail.

Daniel, W. J.T., C.-Y. Cheng, and P.A. Meehan. "Modelling the Effects of Friction Modifiers on Rail Corrugation in Cornering." Vehicle System Dynamics 46, 9, 845–66.

Corrugations

Corrugation development in curved track on a European metro system under dry conditions, 65 days after grinding

The same location, with friction modifier applied, 155 days after grinding

D.T. Eadie, M. Santoro, K. Oldknow and Y. Oka: *Field Studies of the Effect of Friction Modifiers on Short Pitch Corrugation Generation*, in Proceedings of the 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006), Brisbane, Australia, 9pp, 2006.

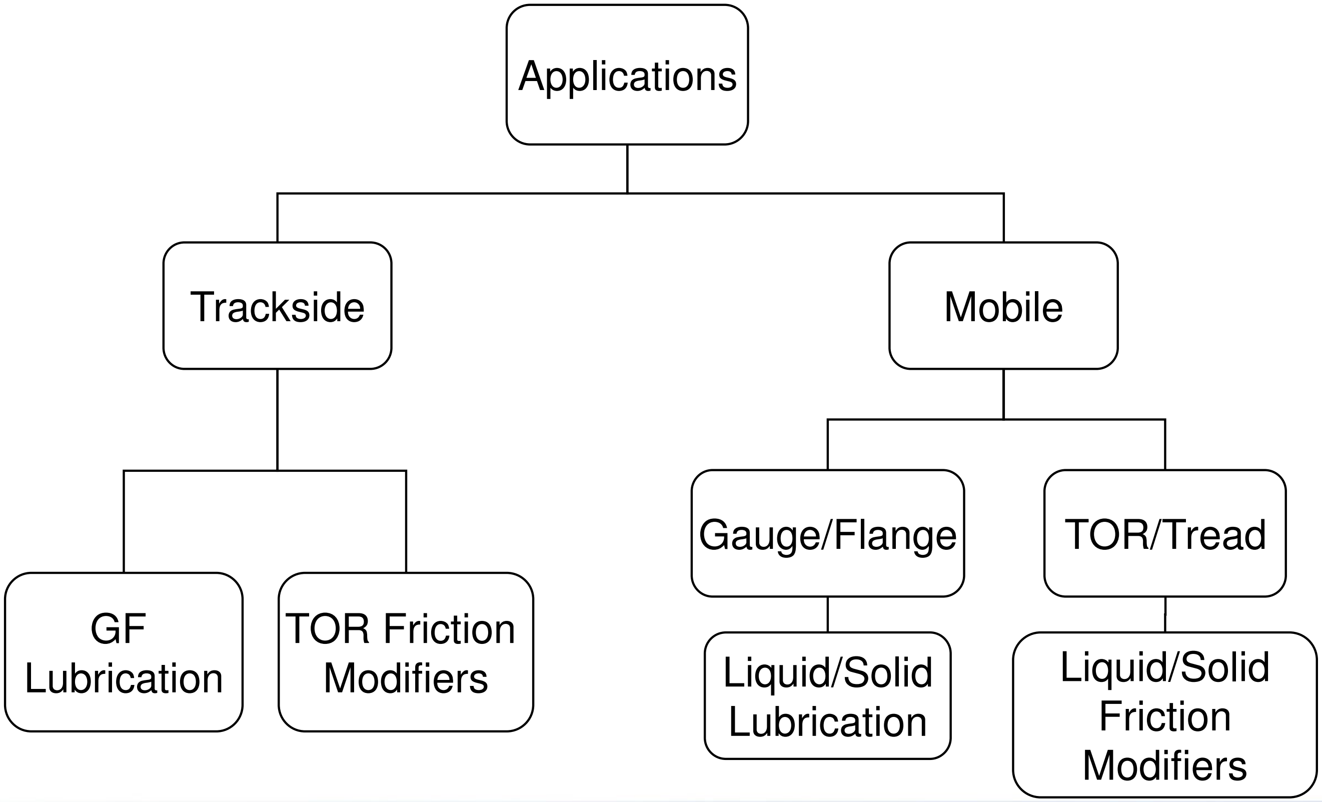
Pausing to consider…

- The relationship between desired benefit(s), effective coverage distances, and wheel-rail friction characteristics in TOR friction management applications…

Benefit type	**Effective coverage distances**	**Frictional properties needed (Hypothesis)**
L/V reductions	++++	"Bulk" reductions in COF
Wear & RCF	++++	"Bulk" reductions in COF
Curving Noise (esp. Squeal)	+	Controlled traction-creepage relationship
Corrugations	++	Mix of bulk reductions and traction-creepage

How is effective friction management achieved?

Friction Management Approaches



Applications

Trackside

Mobile

GF Lubrication

TOR Friction Modifiers

Gauge/Flange

TOR/Tread

Liquid/Solid Lubrication

Liquid/Solid Friction Modifiers

As I was thinking about this presentation on May the 4th, I paused to reflect…

Could Chewbacca really exist?

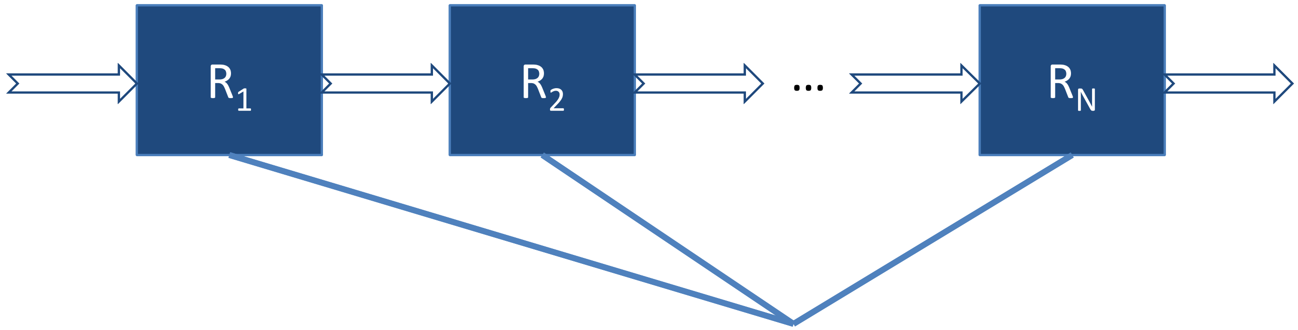
The Drake Equation*

- “The Drake equation is a probabilistic argument used to estimate the number of active, communicative extraterrestrial civilizations in the Milky Way Galaxy”
- “The equation was formulated in 1961 by Frank Drake, not for purposes of quantifying the number of civilizations, but as a way to stimulate scientific dialogue at the first scientific meeting on the search for extraterrestrial intelligence (SETI).”
- $N = R_* \circ f_p \circ n_e \circ f_1 \circ f_i \circ F_c \circ L$
  - N = the number of civilizations in the Milky Way galaxy with which communication might be possible
  - R_* = the average rate of star formation in our Galaxy
  - f_p = the fraction of those stars that have planets
  - n_e = the average number of planets that can potentially support life per star that has planets
  - f_l = the fraction of planets that could support life that actually develop life at some point
  - f_i = the fraction of planets with life that actually go on to develop intelligent life (civilizations)
  - f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space
  - L = the length of time for which such civilizations release detectable signals into space

Dr. Frank Drake

**https://en.wikipedia.org/wiki/Drake_equation*

Coming back to Earth: Conceptualizing the reliability "success path" for a friction management system


Input

R_1

R_2

…

R_N

Output
("Success" or "Failure)

Reliability Blocks

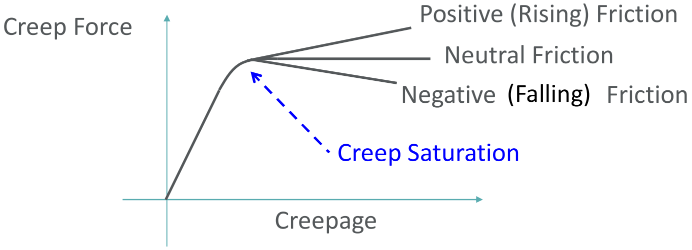
Probability of Success: $R_1 \circ R_2 \circ \ldots \circ R_N$

Question: how should we define "success"?

Defining success(?)

- Friction has been controlled to the desired level*, at the intended wheel-rail interface location(s), at the intended times.

******and in some cases with a specific traction-creepage relationship*



What are the reliability factors?

- Working in reverse (a rough sketch)…
  - **R_7:** FM material has not been consumed/depleted from the intended wheel-rail interface location by passing traffic
  - **R_6:** FM material was deposited at, or carried to, the intended location at the wheel-rail interface in sufficient quantity to achieve the specific intended benefit(s)
  - **R_5:** Applicator applied the intended amount of FM material, at the intended location, at the intended time
  - **R_4:** FM material was supplied to applicator in the intended/expected physical state (e.g. viscosity, pressure)
  - **R_3:** Application system controls functioned as intended
  - **R_2:** Sensing components functioned as intended
  - **R_1:** FM material was available in reservoirs (e.g. tanks)

How can we improve the R values?

Examples…

- Material selection
- Application rates
- Applicator type and configuration
- Applicator placement
- Applicator spacing
- Proactive and well-resourced equipment maintenance
- Proactive and well-resourced consumable refilling
- Remote monitoring (and control?...)
- Performance verification

Measurement & Verification

Example: COF measurement using "tribometer" systems

(esp. GF lubrication)

Example: Lateral / Vertical force measurement using instrumented cribs or wheelsets

(esp. TOR friction control)

Who is involved in friction management?

Involvement, education, buy-in, commitment, and resourcing are critical

- Track and/or vehicle maintenance personnel
- Area supervisors
- Engineering and purchasing resources
- Senior management
- Others…

Conclusions:

Who, what, where, when, why, (and how)?

- **What** do we really mean by friction management?
- **When** have some of the major developments in friction management evolved?
- **Where** is friction management used?
- **Why** is friction management important?
- **How** is effective friction management achieved?
- **Who** is involved in friction management?

Thank You