

# Performance Evaluation of Products for Rail Head

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**INSTITUTE OF MACHINE  
AND INDUSTRIAL DESIGN**



**BRNO  
UNIVERSITY  
OF TECHNOLOGY**

# Motivation



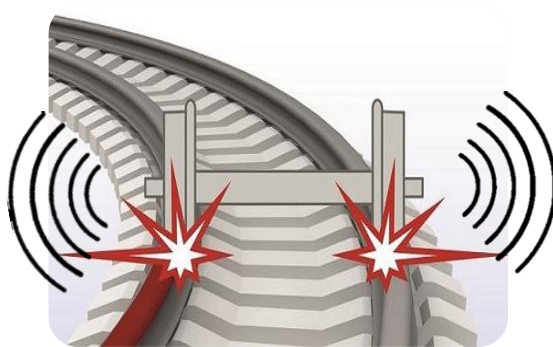
## Railway transit

- + Effective way of transport
- + Low energy consumption
- + Reliability

– Wear



– Noise



Solution

## Friction management

- Reduce curve **squeal noise**
- Reduce / avoid rail **corrugation** growth
- Reduce **wear** and **RCF**
- Reduce the risk of **derailment**
- ...

**THE NEED FOR TESTING**

**LACK OF STANDARDS FOR PERFORMANCE EVALUATION**

# Friction management

## Top Of Rail products

### Top Of Rail Lubricant (TORL)

- liquid
- non-drying
- oil-based

### Friction Modifier (FM)

- liquid
- drying
- water-based

### Solid stick

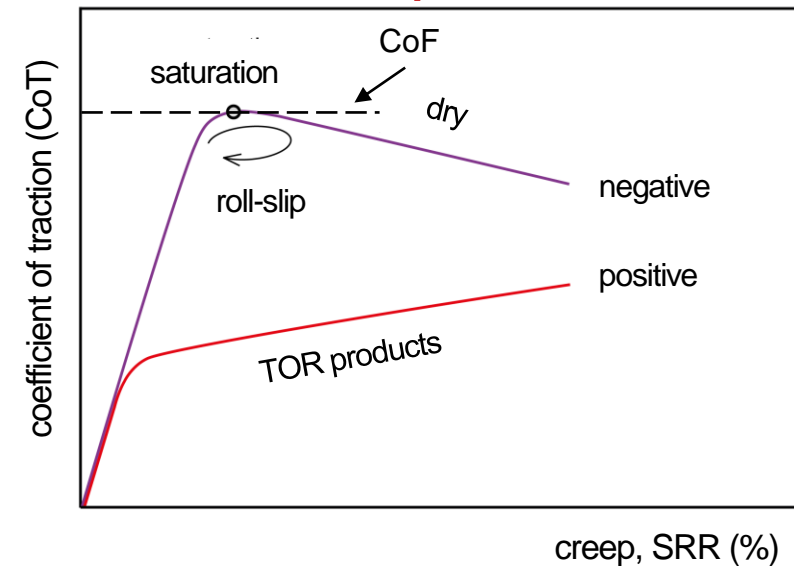
- solid

## Coefficient of traction (CoT)

$$CoT = \frac{T}{Q} \quad \text{from } 0 - CoF$$

Intermediate level of friction (0.2 - 0.4)

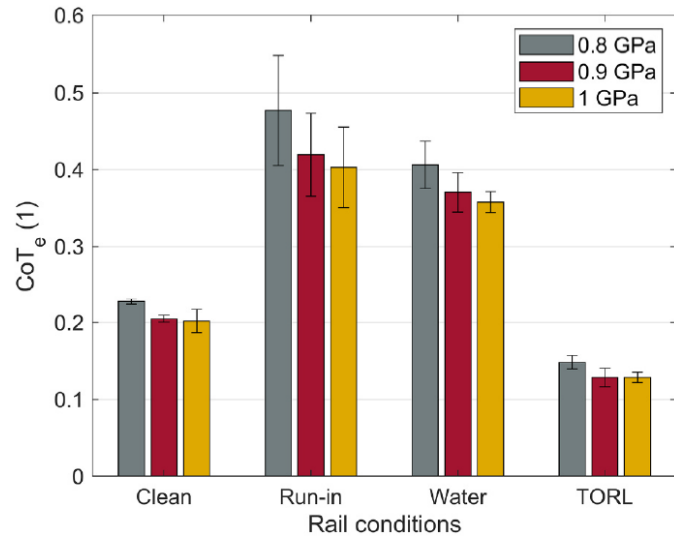
### Creep curve



The positive trend of the creep curve

# State of the Art

## General Knowledge



## Laboratory testing



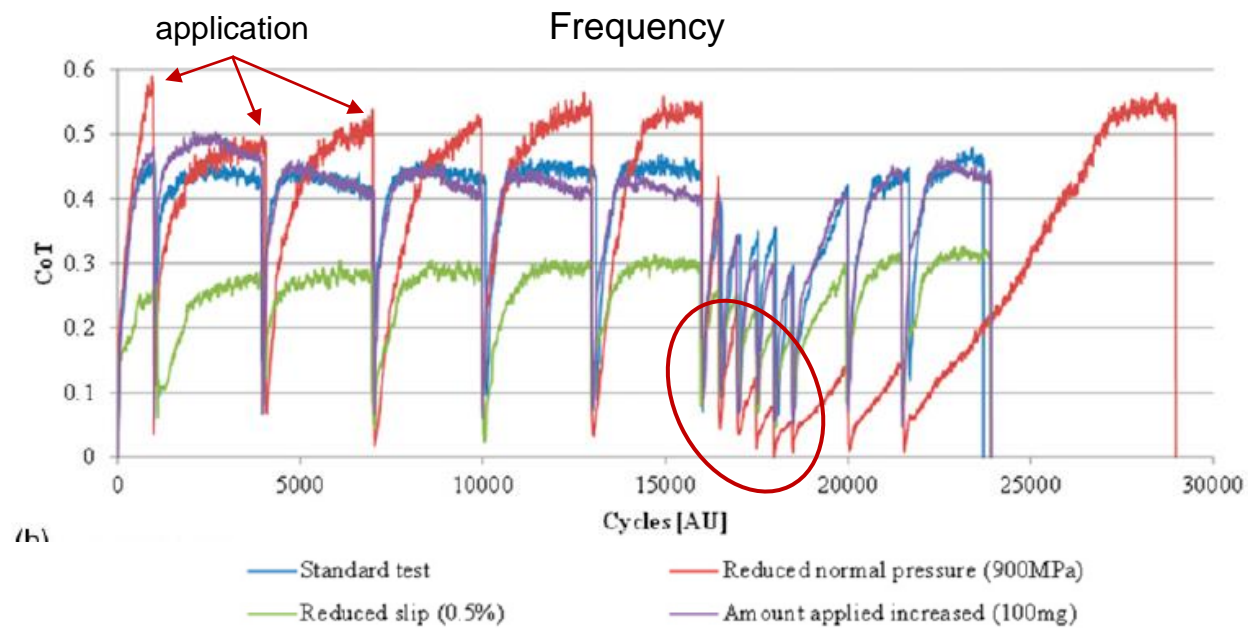
## Field testing



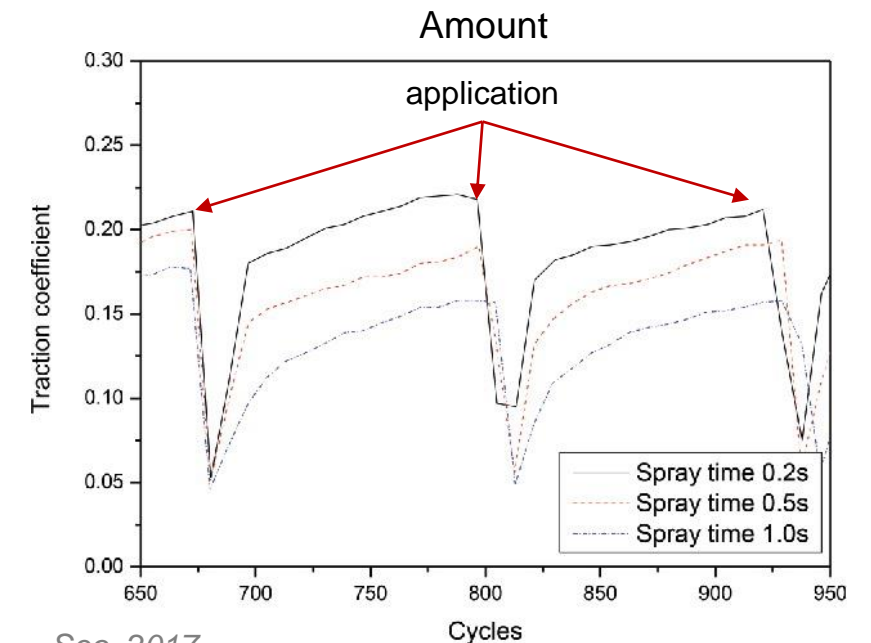
# State of the Art – General Knowledge

## Low friction

- More frequent application may result in lower CoT
- Reduction of contact pressure and slip decreased the consumption rate
- Higher amount provide lower CoT



Lee, 2023

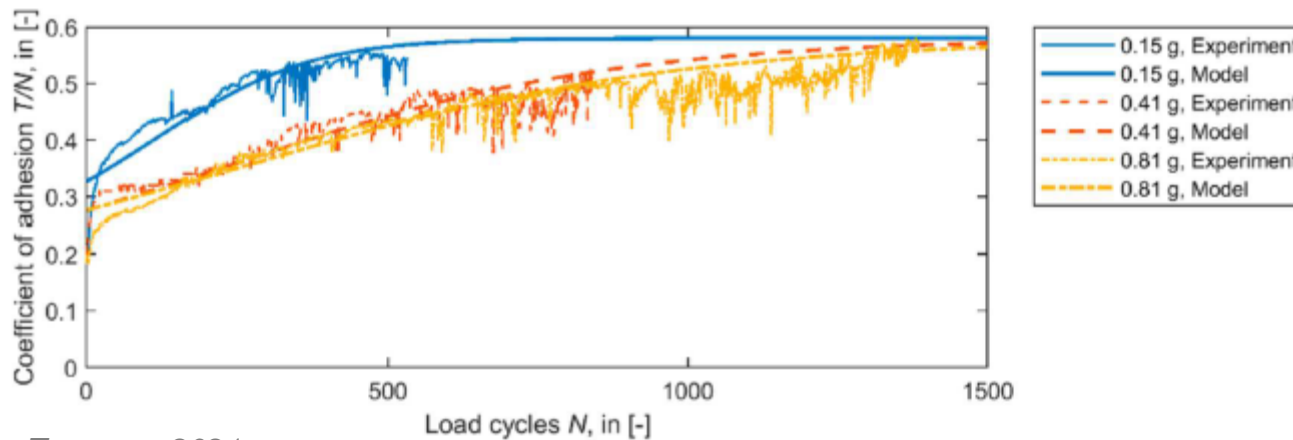


Seo, 2017

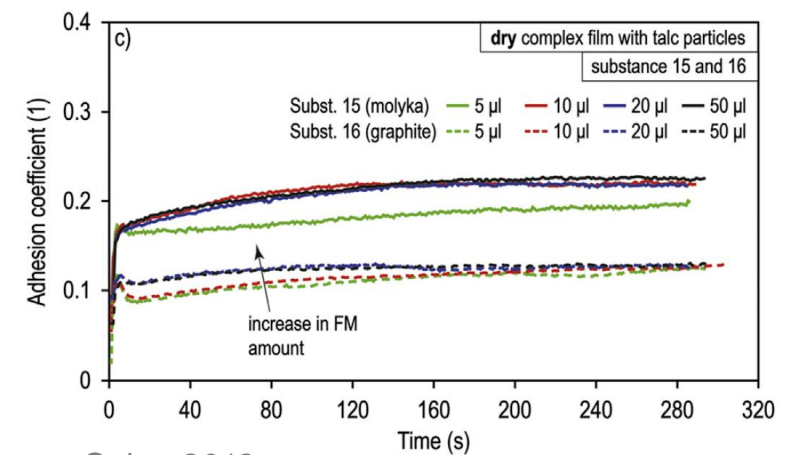
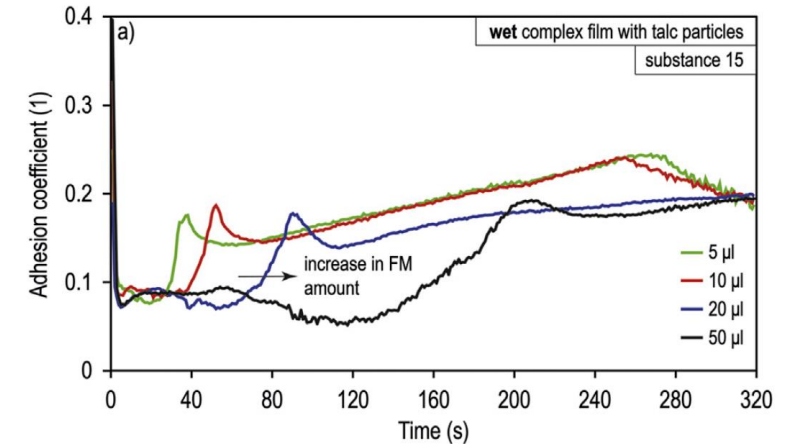
# State of the Art – General Knowledge

## Retentivity

- Higher FM amount leads to longer retentivity but some threshold value exist.
- Higher amount prolongs retentivity and duration of low CoT.
- Dry FM provide more stable CoT and do not cause low friction.



Trummer, 2021

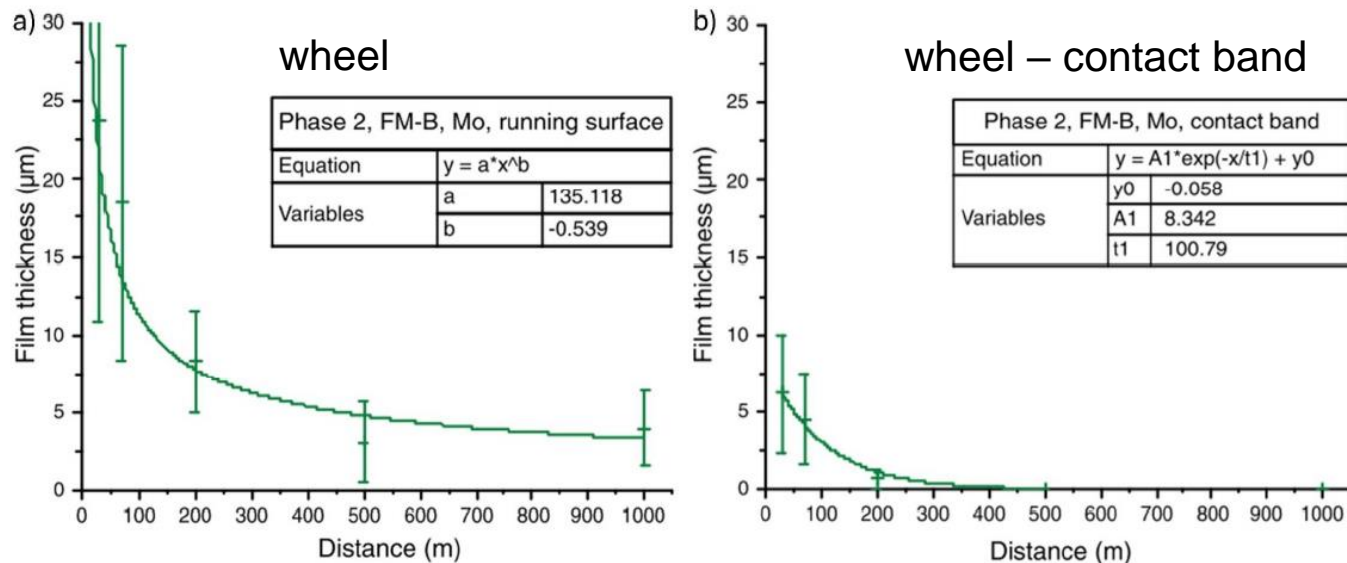


Galas, 2018

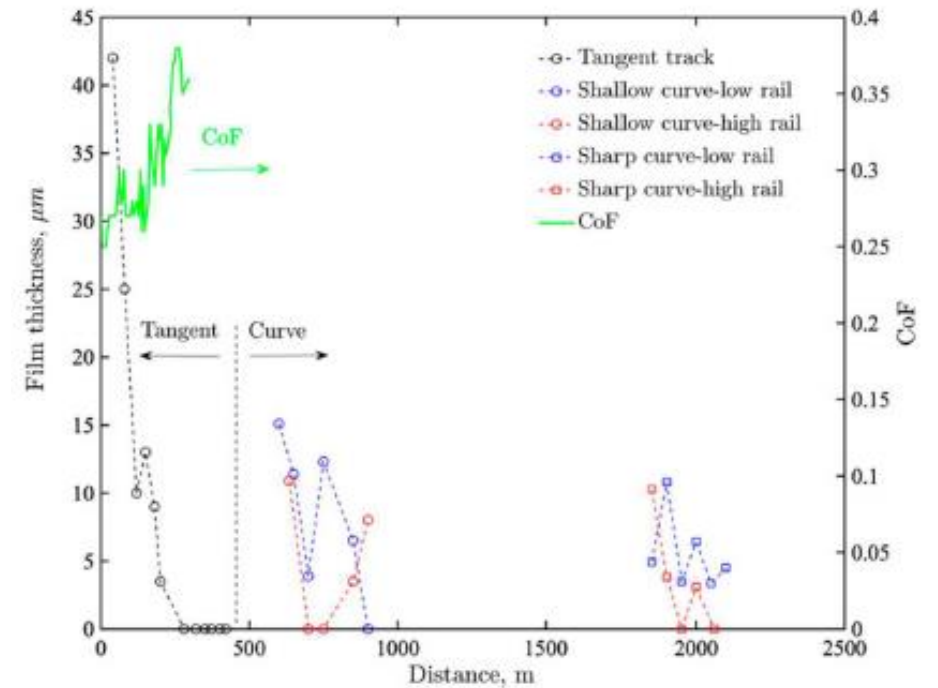
# State of the Art – General Knowledge

## Carry distance

- Significant amount outside of the contact band
- TORP found thousands meters away from application point
- CoF reduced for two hundreded of meter



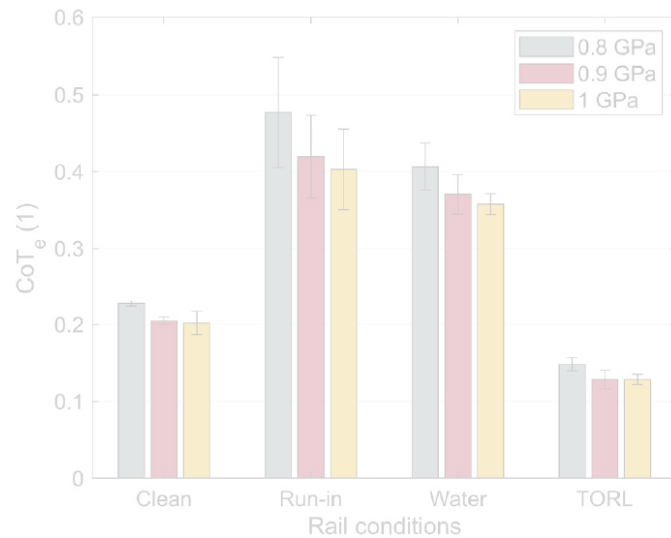
Khan, 2018



Rahmani, 2022

# State of the Art

## General Knowledge



- Benefits strongly dependent on amount
- May results in critical CoT

## Laboratory testing

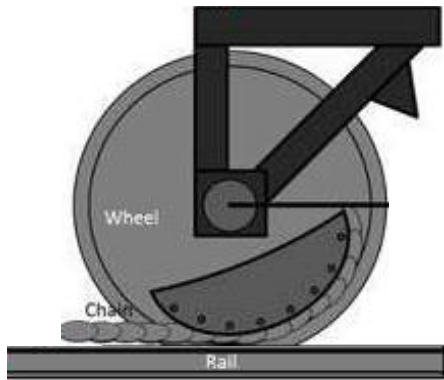


## Field testing



# State of the Art – Laboratory testing

## Full-scale facility



1500 MPa  
40 mm/s  
creep 0-2 %

- + Actual contact bodies
- Low speeds

## Twin-disc machine



400-1500 MPa  
(**1000 MPa**)  
0.3-11.1 m/s  
(**1 m/s**)  
creep 0-25%  
(~1%)

- + Actual materials
- Highly customized

## Ball-on-disc



700-800 MPa  
0.3-1.5 m/s  
(**1 m/s**)  
creep 0-100%  
(~1%)

- + Commercial device
- Bearing steel

## Run-in?

- CoT stabilisation
- Time, No. of cycles
- Dry conditions, lubricant

## Application?

- Brush, spray
- Micropipette
- Syringe

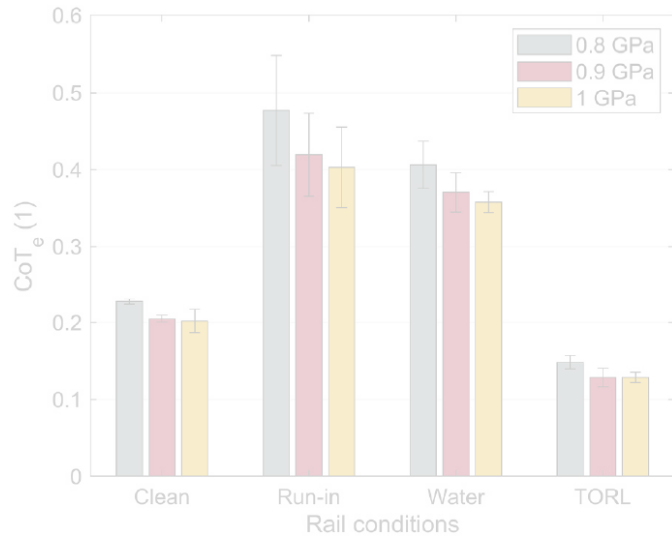
## Amount?

- 1-10  $\mu$ l
- 0.05-0.7 g

## Model scale

# State of the Art

## General Knowledge



- Benefits strongly dependent on amount
- May results in critical CoT

## Laboratory testing



- Wide range of conditions
- Various devices
- Different procedures

## Field testing



# State of the art

Financial and time demands

Instrumented train  
(Lunberg, J., 2015)



Car-pushed tribometer  
(www.semanticscholar.org)



Hand-pushed tribometer  
(www.lbfoster-salientsystems.com)



OnTRAK HO Tribometer



Pendulum tribometer  
(Lewis, S.R., 2011)



Model scale

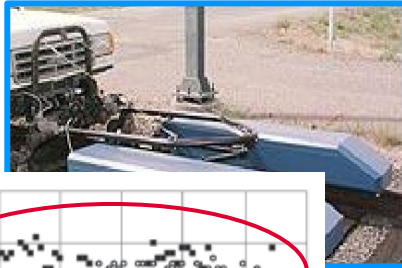
# State of the Art – Field Testing Devices

Financial and time demands

Instrumented train  
(Lunberg, J., 2015)



Car-pushed tribometer  
(www.semanticscholar.org)



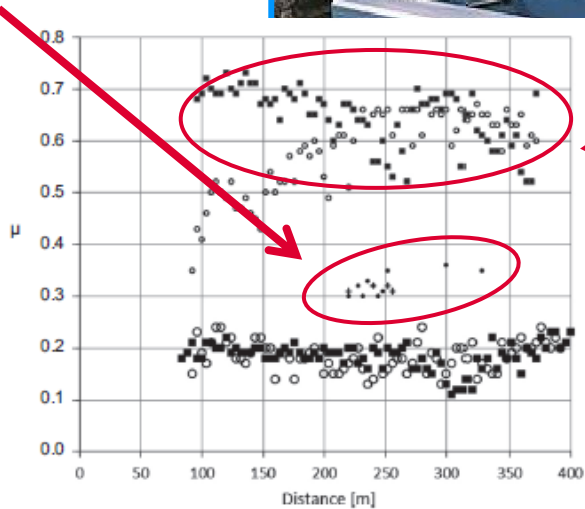
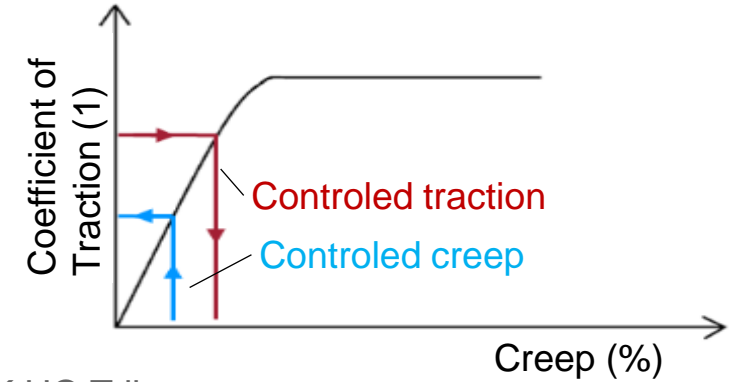
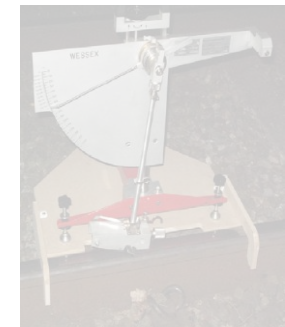
Hand-pushed tribometer  
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Pendulum tribometer  
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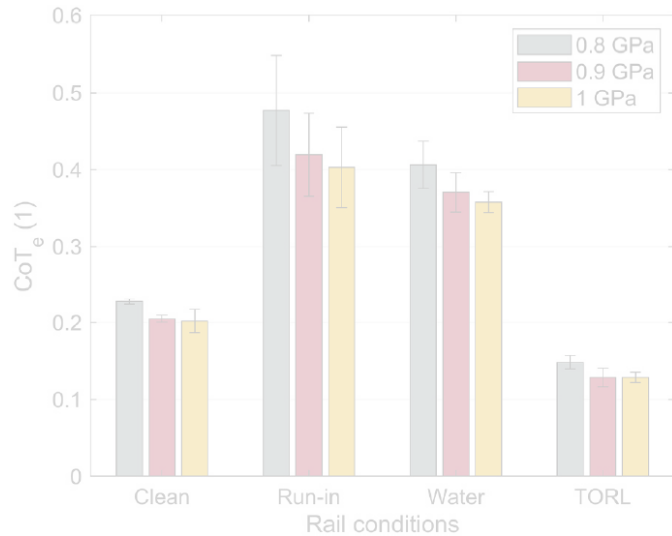


Lunberg, 2015

Model scale

# State of the Art

## General Knowledge



- Benefits strongly dependent on amount
- May results in critical CoT

## Laboratory testing



- Wide range of conditions
- Various devices
- Different procedures

## Field testing



- Challenging task
- Portable tribometer is a suitable method

# Aim of the Study

The thesis aims to develop a multi-phase methodology for evaluating the performance of TOR products.

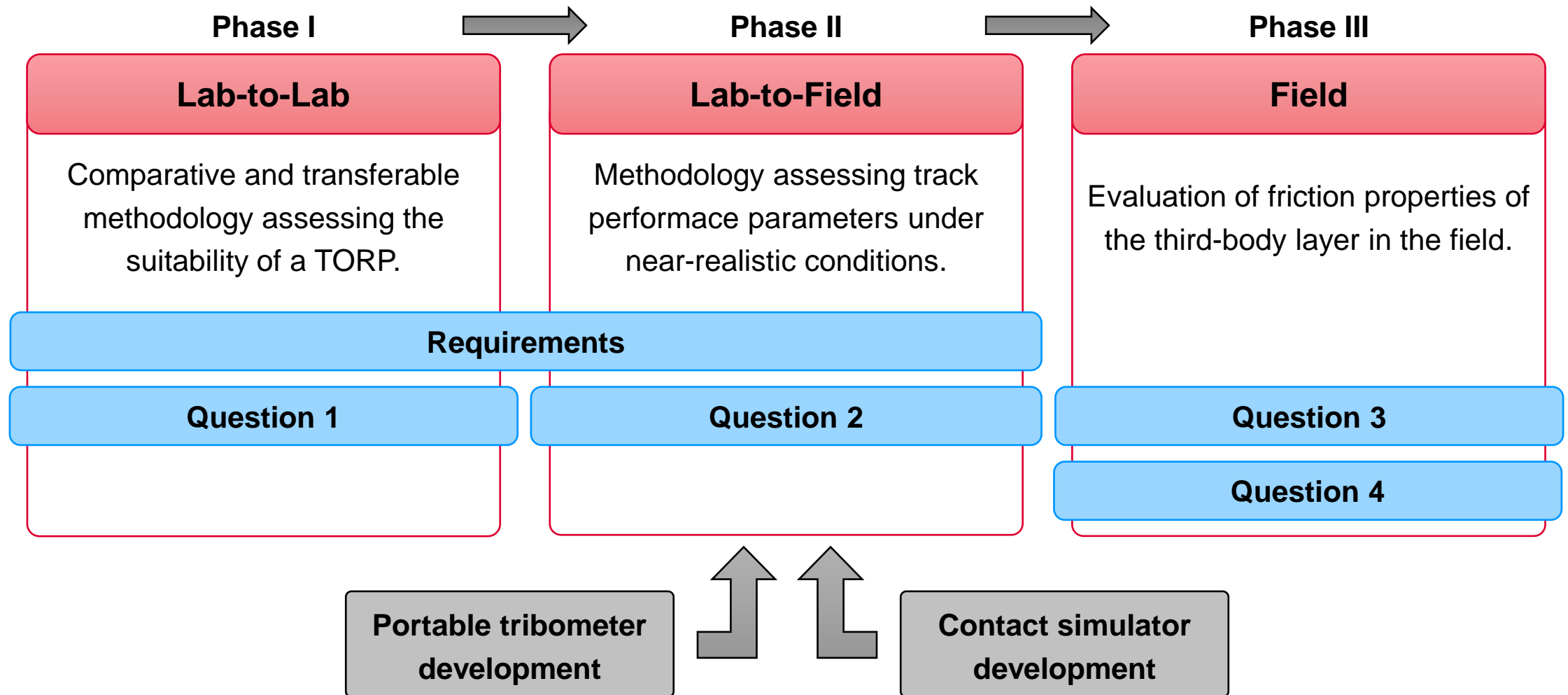
Phase I

Phase II

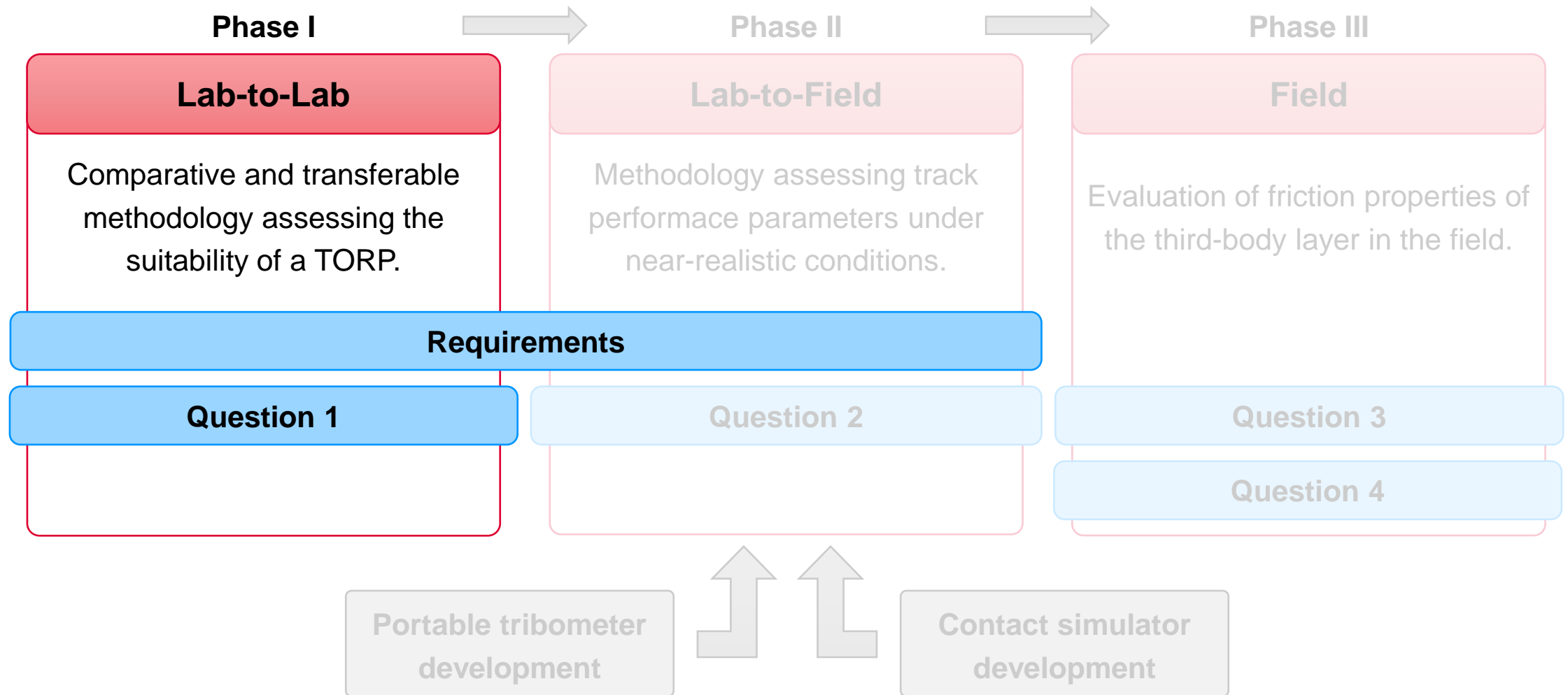
Phase III



# Thesis Layout



# Thesis Layout



# Thesis Layout

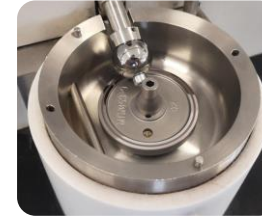
## Lab-to-Lab

Comparative and transferable methodology assessing the suitability of a TORP.

## Requirements

- Transferable
- Comparative results
- Representative results
- Good repeatability
- Multi-parameter evaluation
- Determine sensitivity on applied amount

## Material

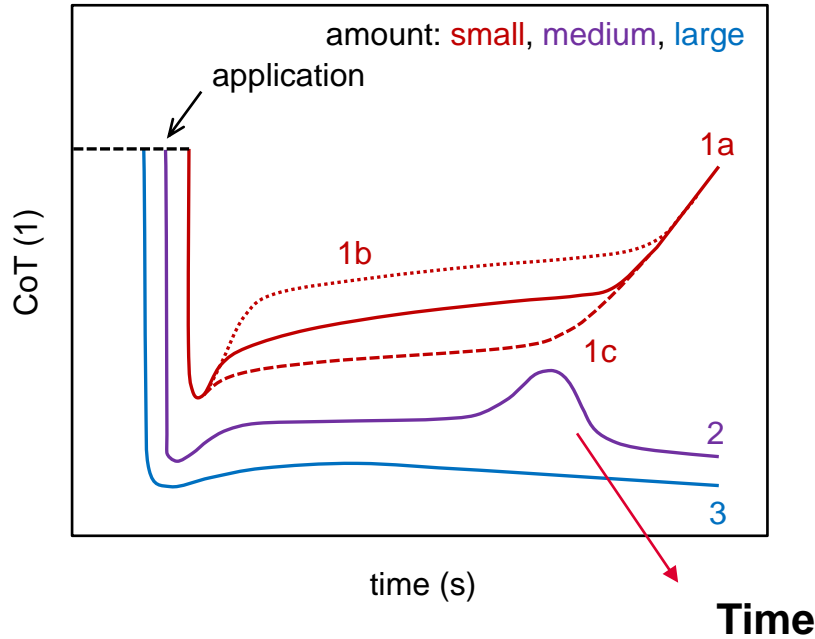


Mini Traction Machine

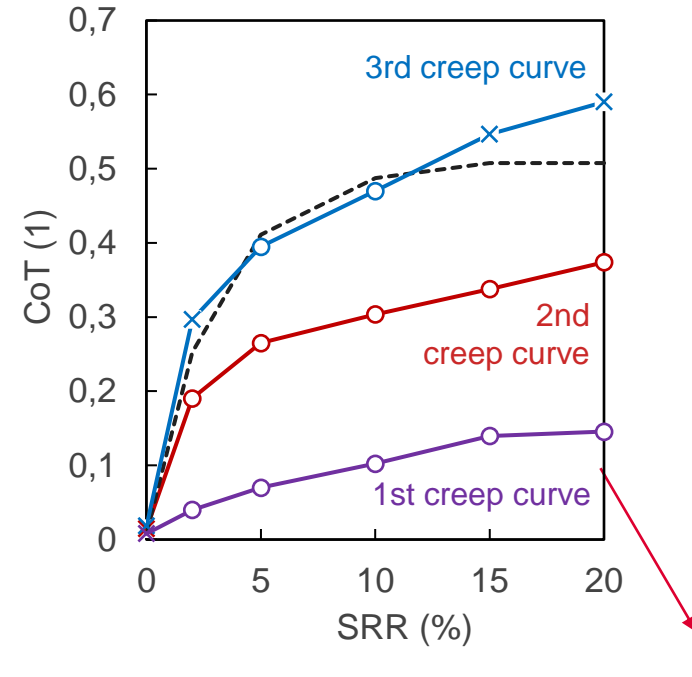
- Commercial tribometer
- Rolling-sliding contact
- Standard specimens
- Common contact conditions

# Results: Lab-to-Lab Methodology

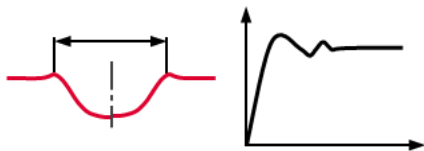
## Time tests



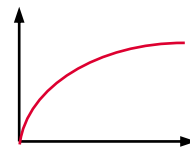
## Traction test



Wear-in, run-in?



Baseline/threshold curve?



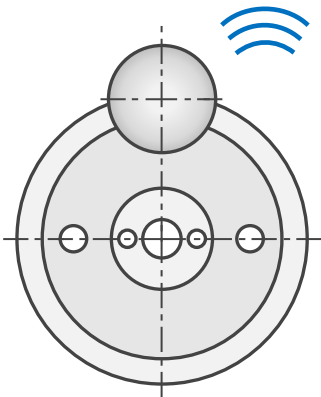
Application?



# Results: Lab-to-Lab Methodology

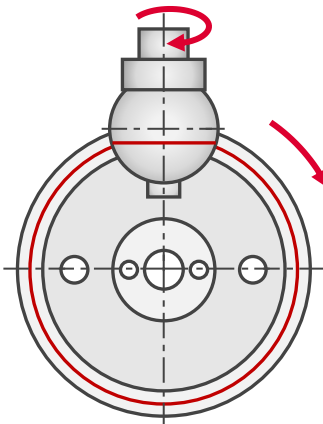
Performance test = Preparation phase + Measurement phase (5x)

**S1** new<sup>1</sup> / worn<sup>2</sup> pair



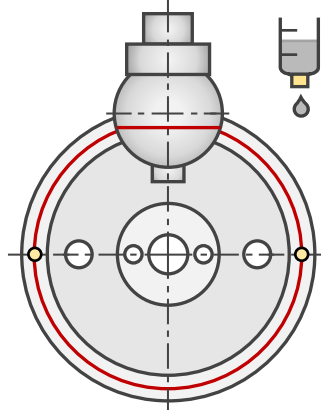
20-min acetone cleaning  
in an ultrasonic bath

**S2** wear-in<sup>1</sup> / run-in<sup>2</sup>



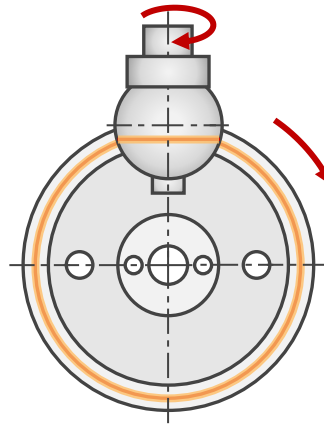
60-min wear-in /  
30-min run-in

**S3** product application

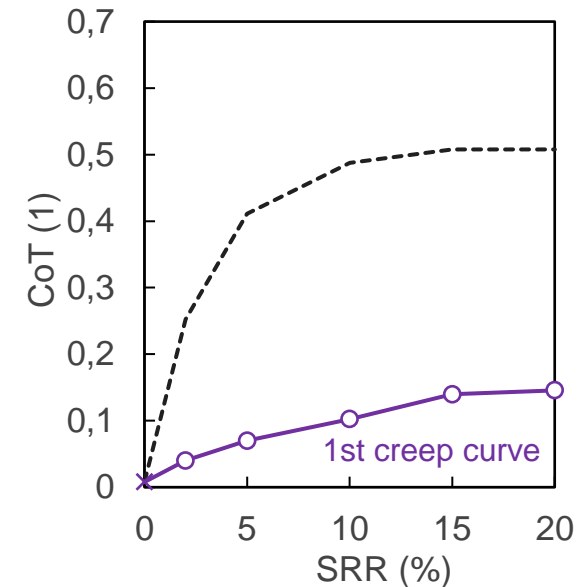


• each drop = 1  $\mu$ l  
(micropipette)

**S4** traction test



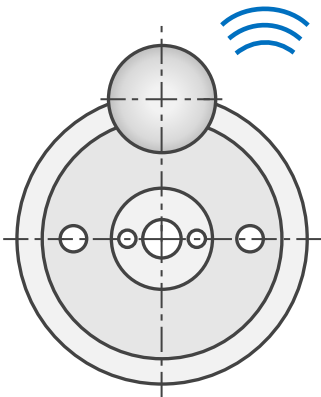
traction test at  
6 *SRR* values  
1 m/s 0.8 GPa



# Results: Lab-to-Lab Methodology

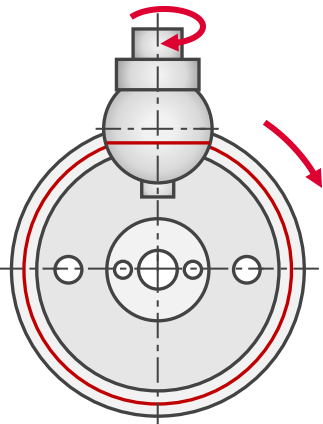
Performance test = Preparation phase + Measurement phase (5x)

**S1** new<sup>1</sup> / worn<sup>2</sup> pair



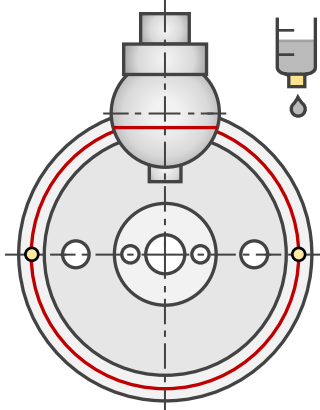
20-min acetone cleaning  
in an ultrasonic bath

**S2** wear-in<sup>1</sup> / run-in<sup>2</sup>



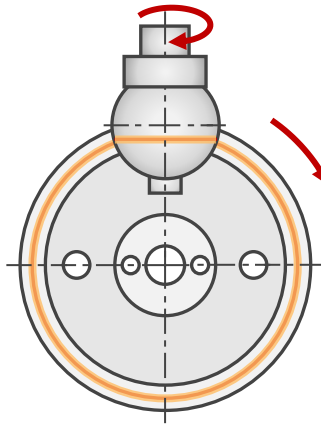
60-min wear-in /  
30-min run-in

**S3** product application

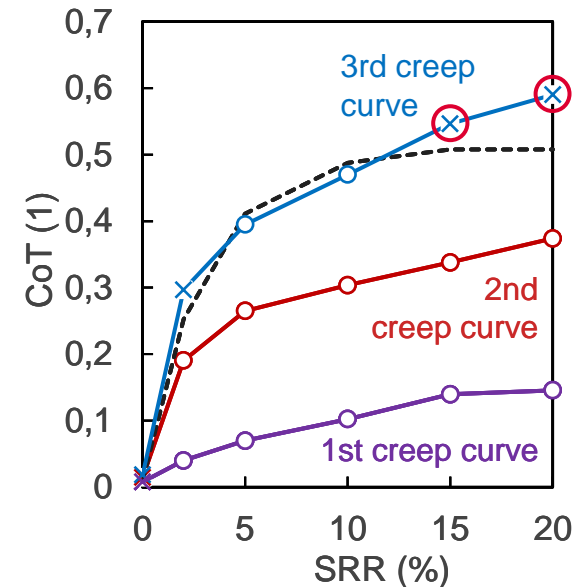


○ each drop = 1 μl  
(micropipette)

**S4** traction test



traction test at  
6 SRR values  
1 m/s 0.8 GPa



Another traction test



**S5** checkpoint

Two consecutive  
points above  
threshold curve?

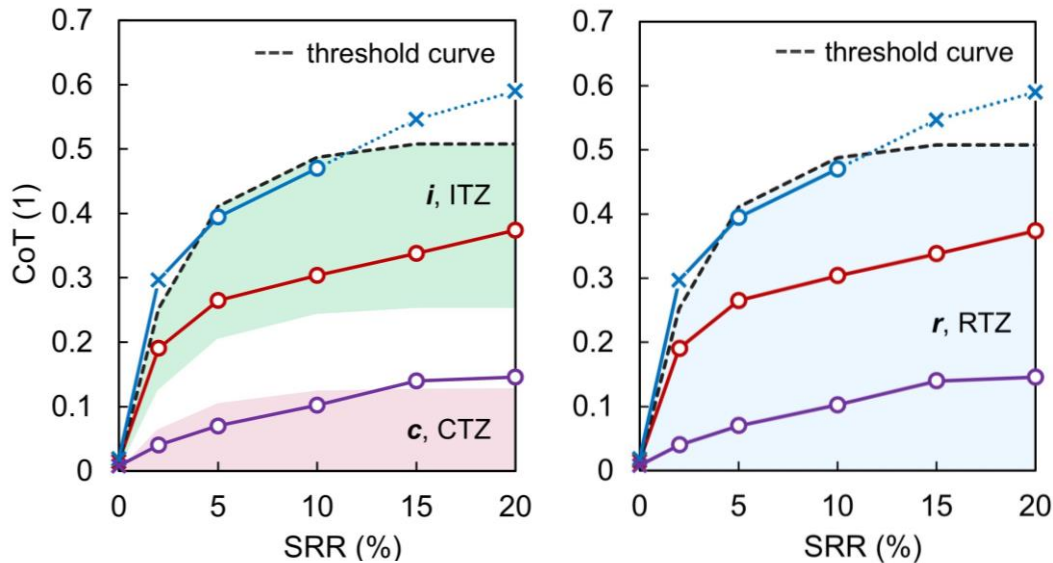


New performance test

# Results: Lab-to-Lab Methodology

## Evaluation phase

**S7** performance parameters

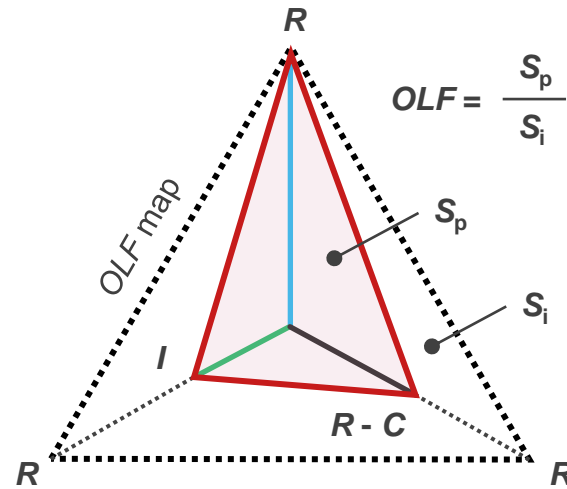


■ CTZ → 5x *c* → *C*    ■ RTZ → 5x *r* → *R*

■ ITZ → 5x *i* → *I*

„Effective retentivity“

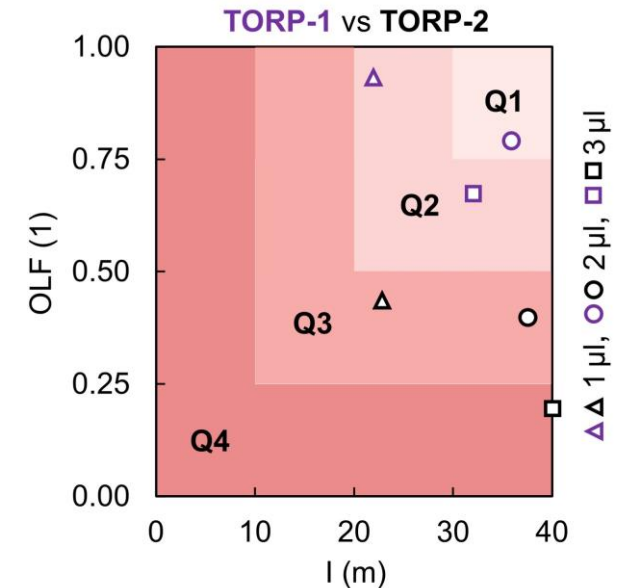
**S8** OLF: Over-lubrication factor



OLF: from 0 to 1

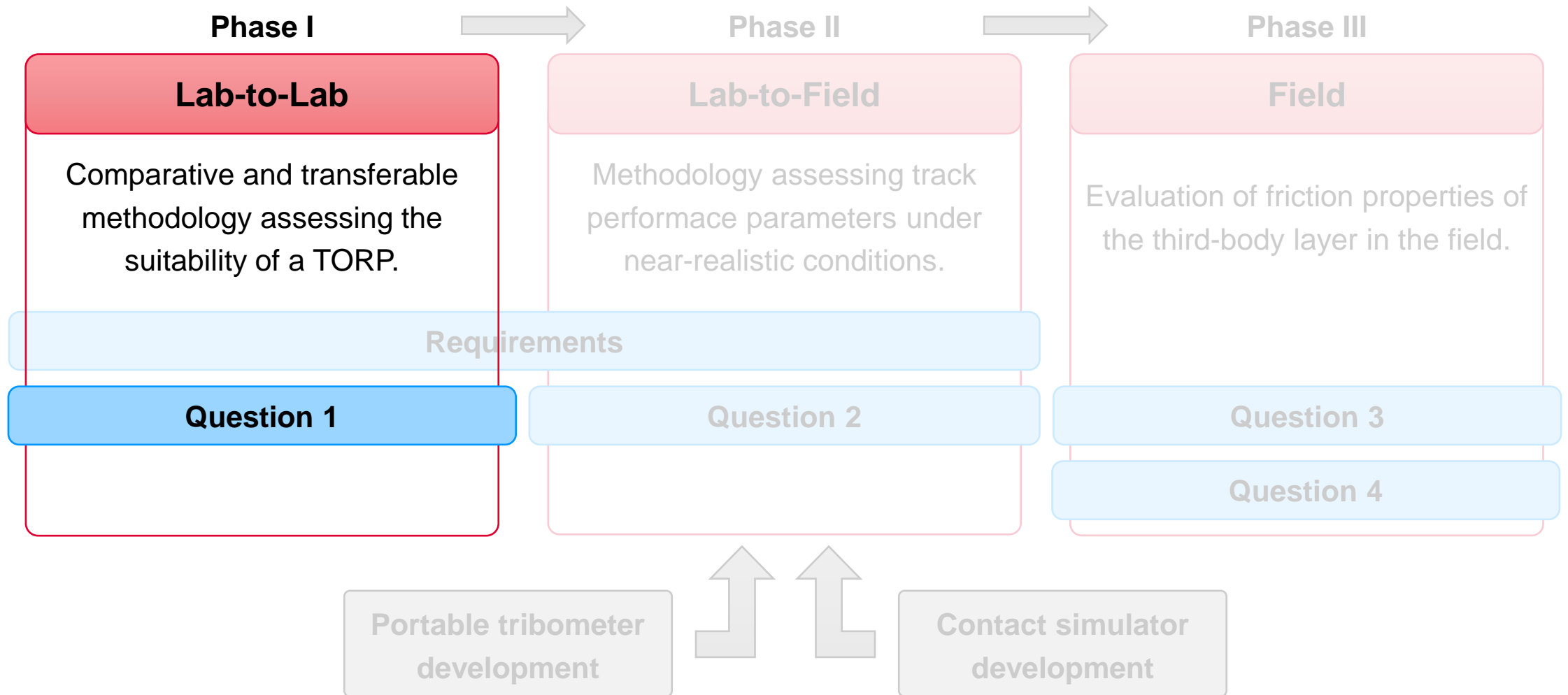
← low adhesion risk

**S9** overall assessment: performance map

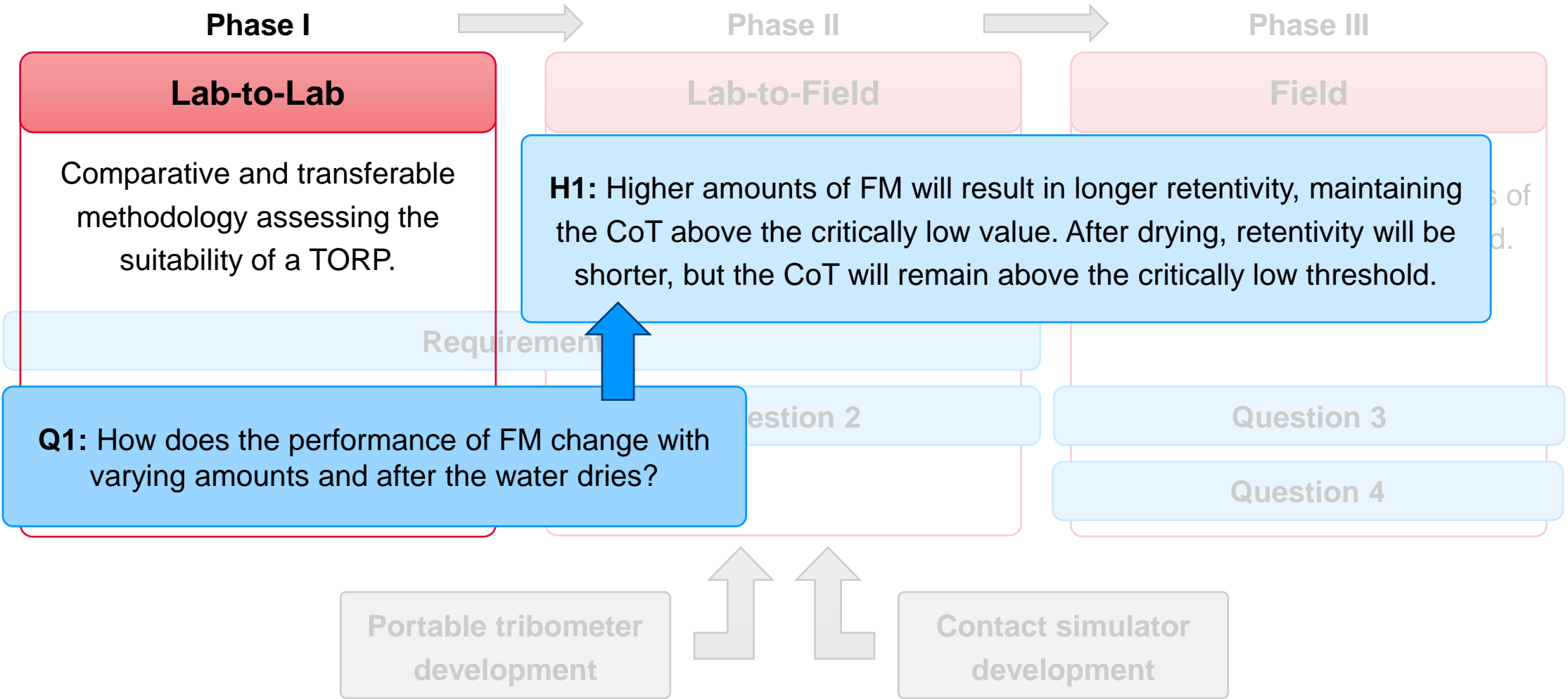


Q1 – Q4: performance classes

# Scientific question



# Scientific question



# Results: Case Study

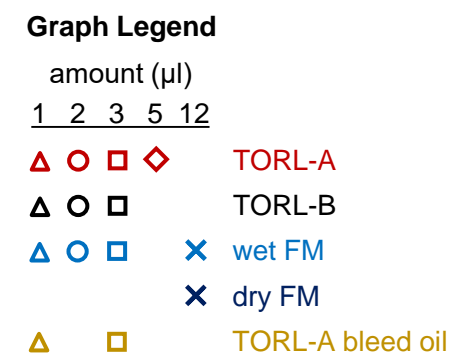
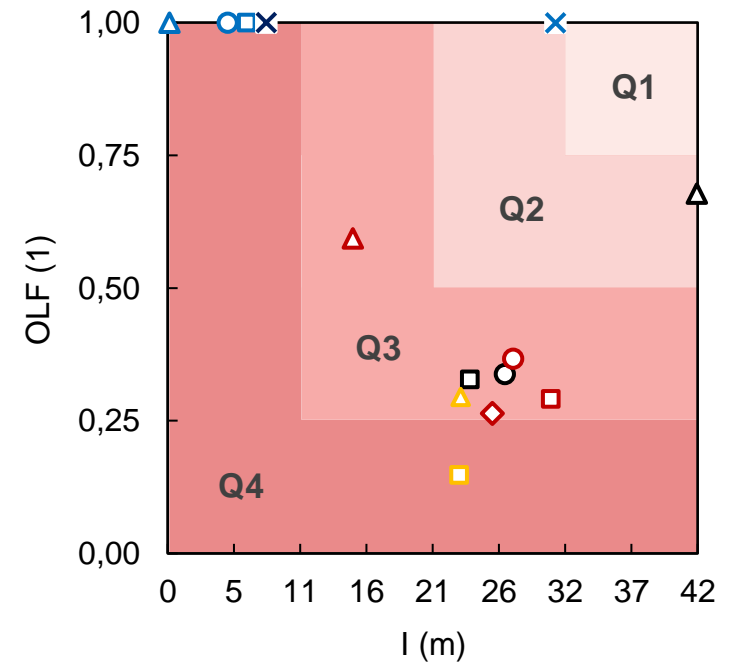
TORL-A TORL-B FM Bleed oil

Amount:  
1 – 12  $\mu$ l

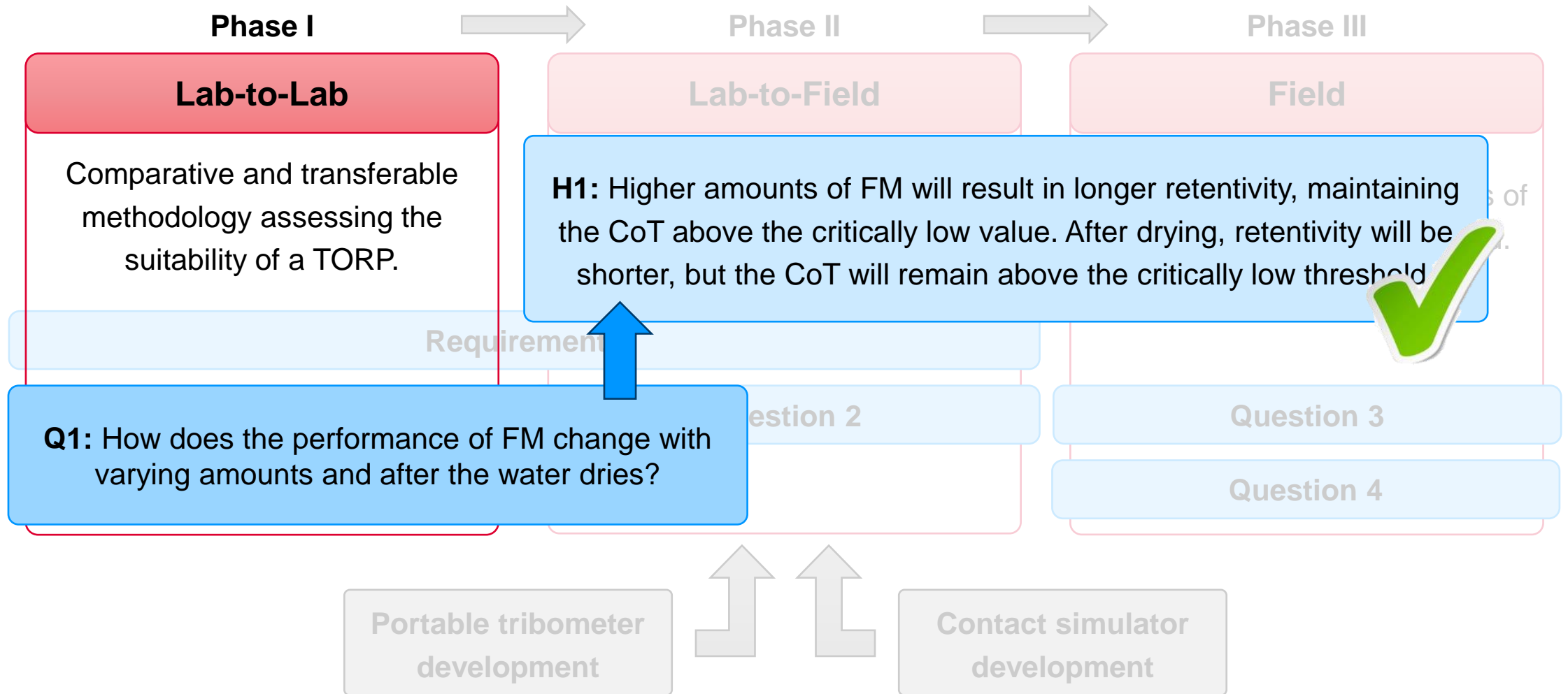
- The performance of **TORLs** is strongly dependent on the amount and may provide critical CoT.
- The **FM** product is not risky in terms of low adhesion and larger amounts are required.

$p$	$v$	$SRR$
0.8 GPa	1 m/s	0-20%

$t = 24^{\circ}\text{C}$  RH = 50% AISI 52100



# Scientific question



# Discussion

## Lab-to-Lab

MTM, bearing steel AISI 52100

1 m/s, 2% SRR, 60 min (run-in 30 min)

traction test (0 – 20% SRR)

5 (same contact pairs)

~5 – 7 hours

performance parameters base on traction zones

performance map (Q1 – Q4)

## Device and specimens

### Wear-in / run-in

### Type of test

### Required no. of tests

### Test time

### Evaluation

### Overall assessment

## CEN/TS standard

MTM, bearing steel AISI 52100

0.1 m/s, 50% SRR, 30 min

traction test (0.25 – 10% SRR)

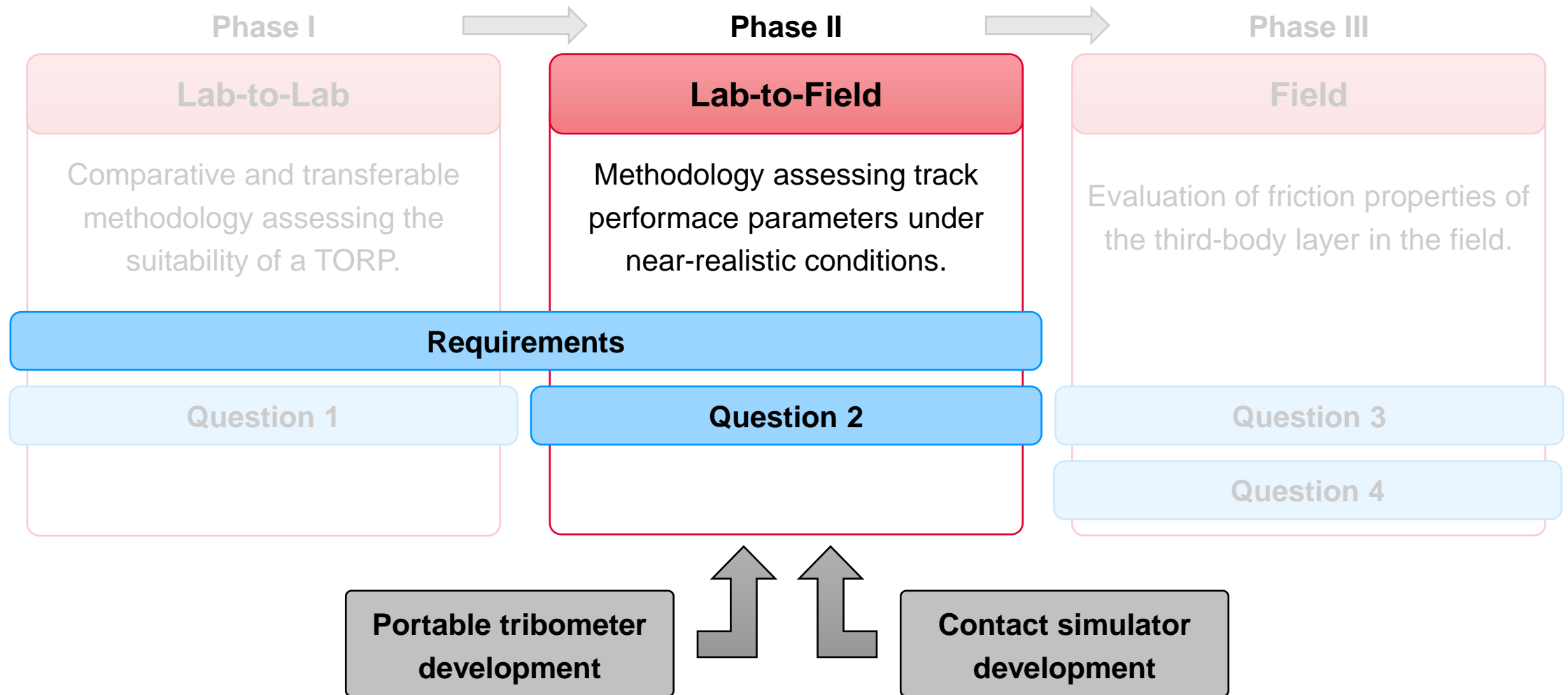
1

~1 hour

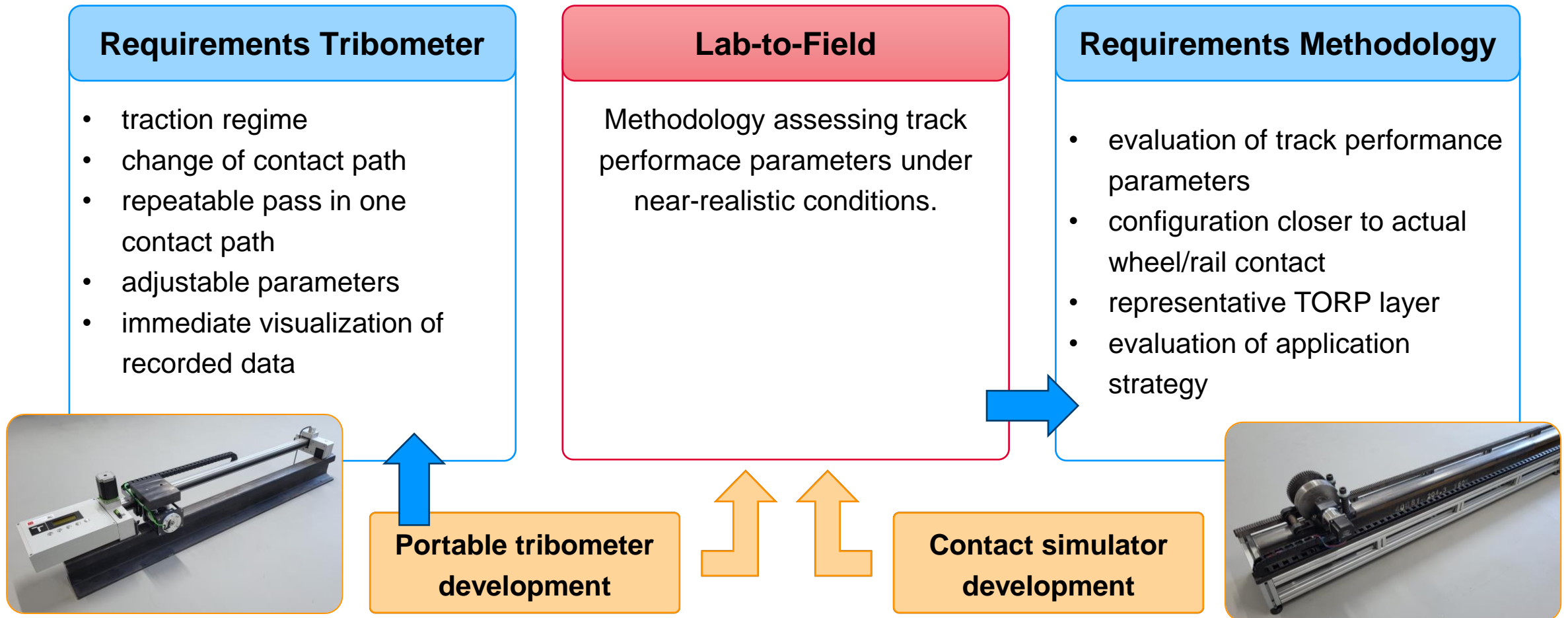
CoT at 10% SRR

good / bad

# Thesis Layout



# Thesis Layout

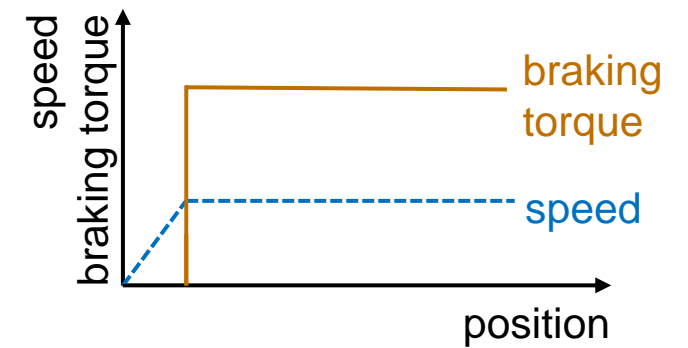


# Results: BUT Rail Tribometer

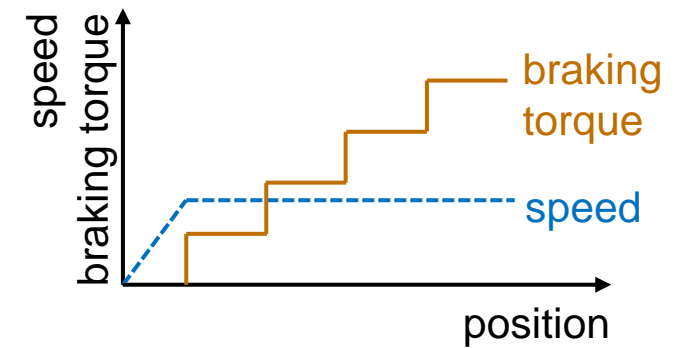


## Measuring modes

Constant

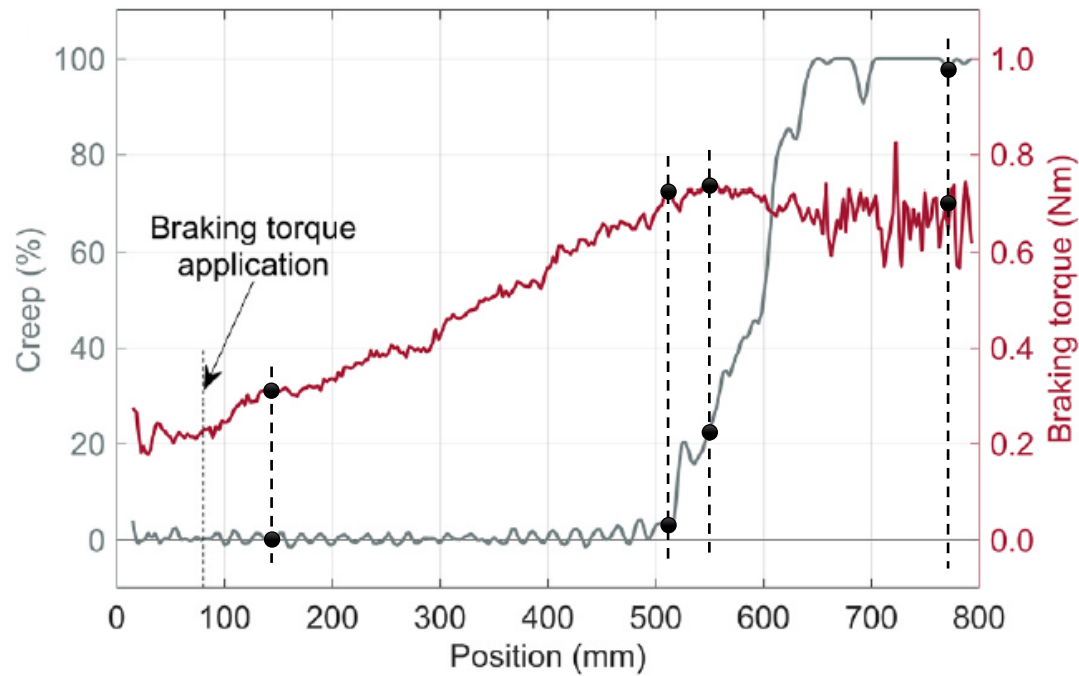


Ramp



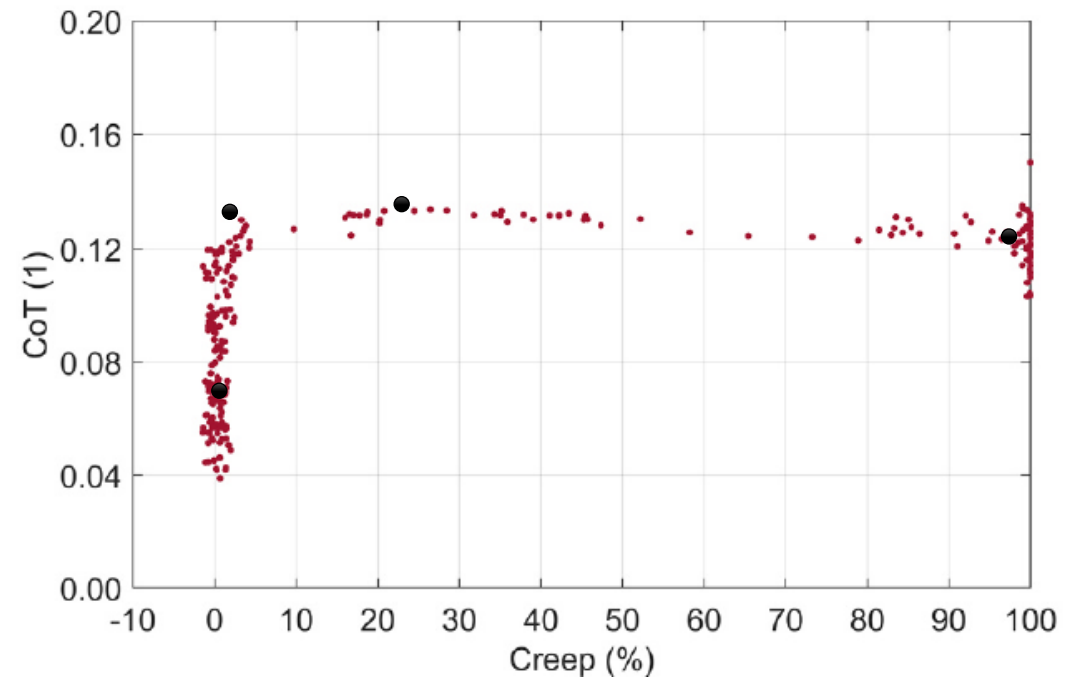
# Results: BUT Rail Tribometer

### Development of creep and braking torque



mode: ramp

### Creep curve

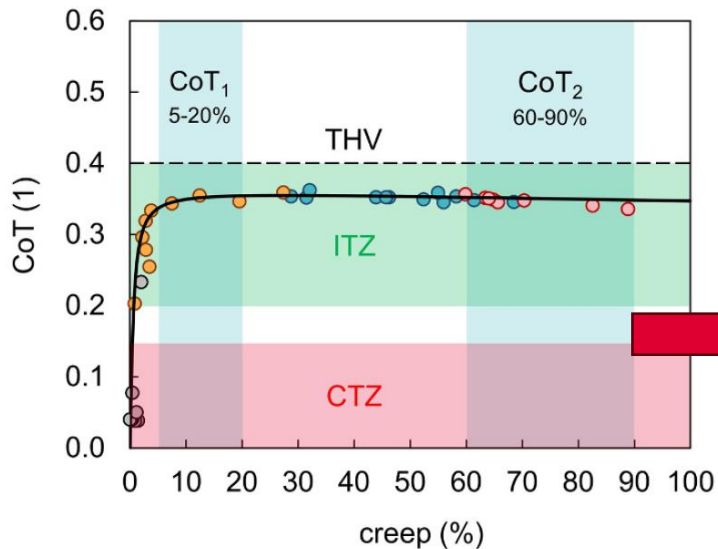


# Results: Lab-to-Field Methodology

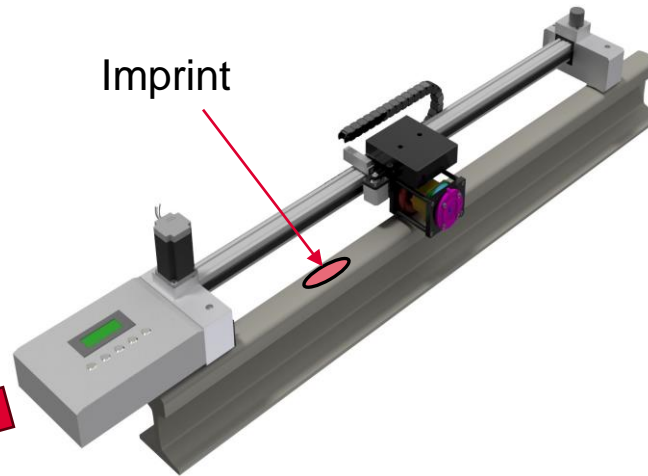
## Initial tests

Contact conditions      dry, TORL-B  
Applied amount        4, 10, 20, 80  $\mu$ l

Run-in process  
Traction zones  
Optimal amount of substance



CoT<sub>1</sub>, CoT<sub>2</sub>  
C,I,R → OLF

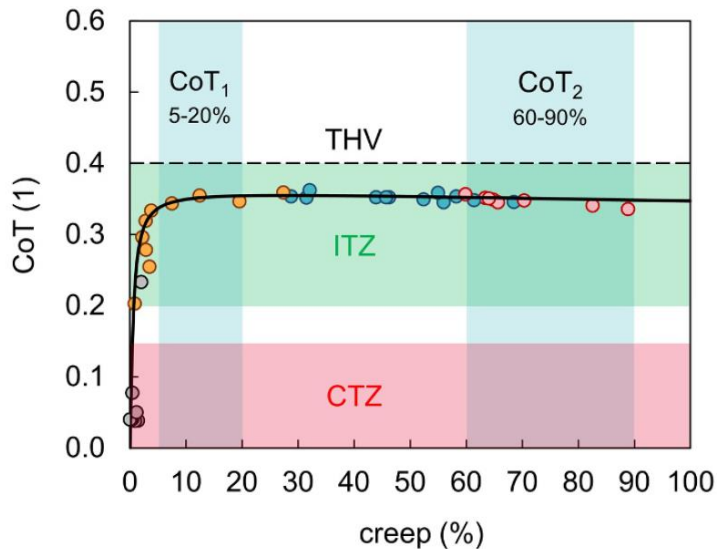


# Results: Lab-to-Field Methodology

## Initial tests

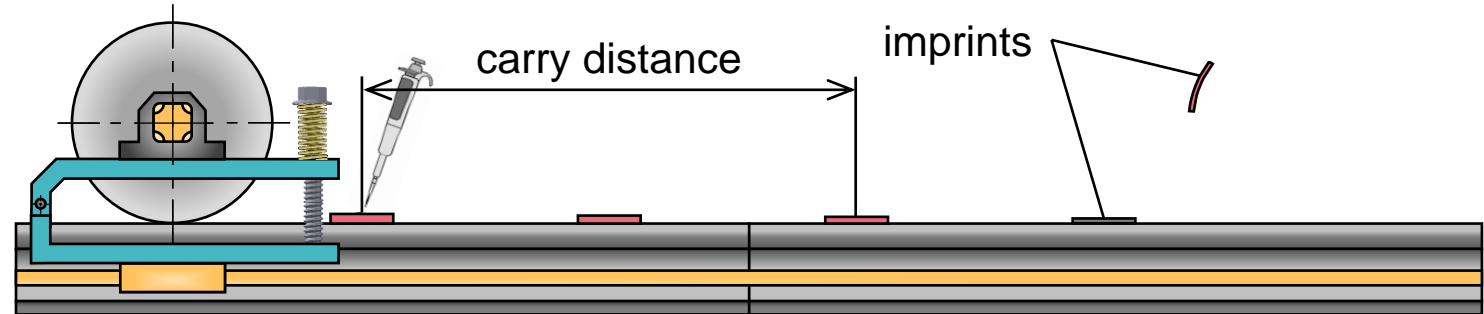
Contact conditions      dry, TORL-B  
 Applied amount        4, 10, 20, 80  $\mu$ l

**Run-in process**  
**Traction zones**  
**Optimal amount of substance**



## 1. Carry distance test

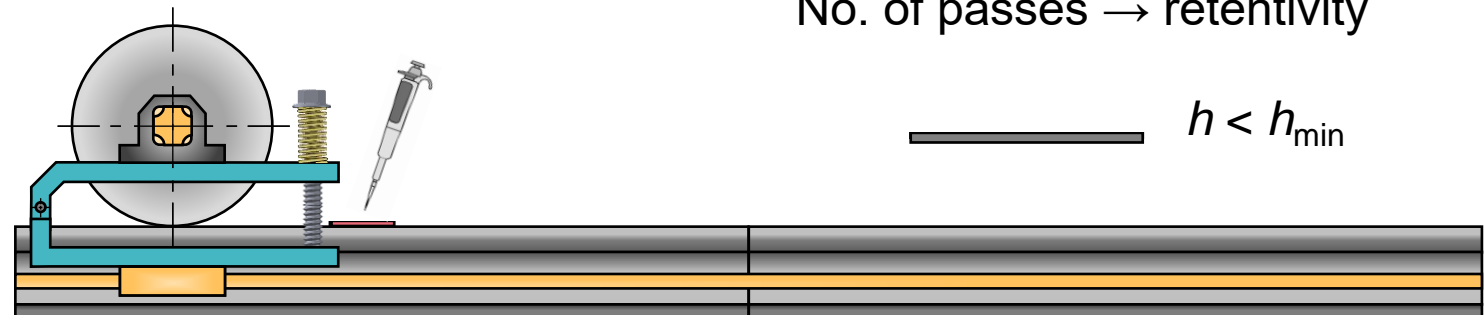
Test end: CoT above threshold



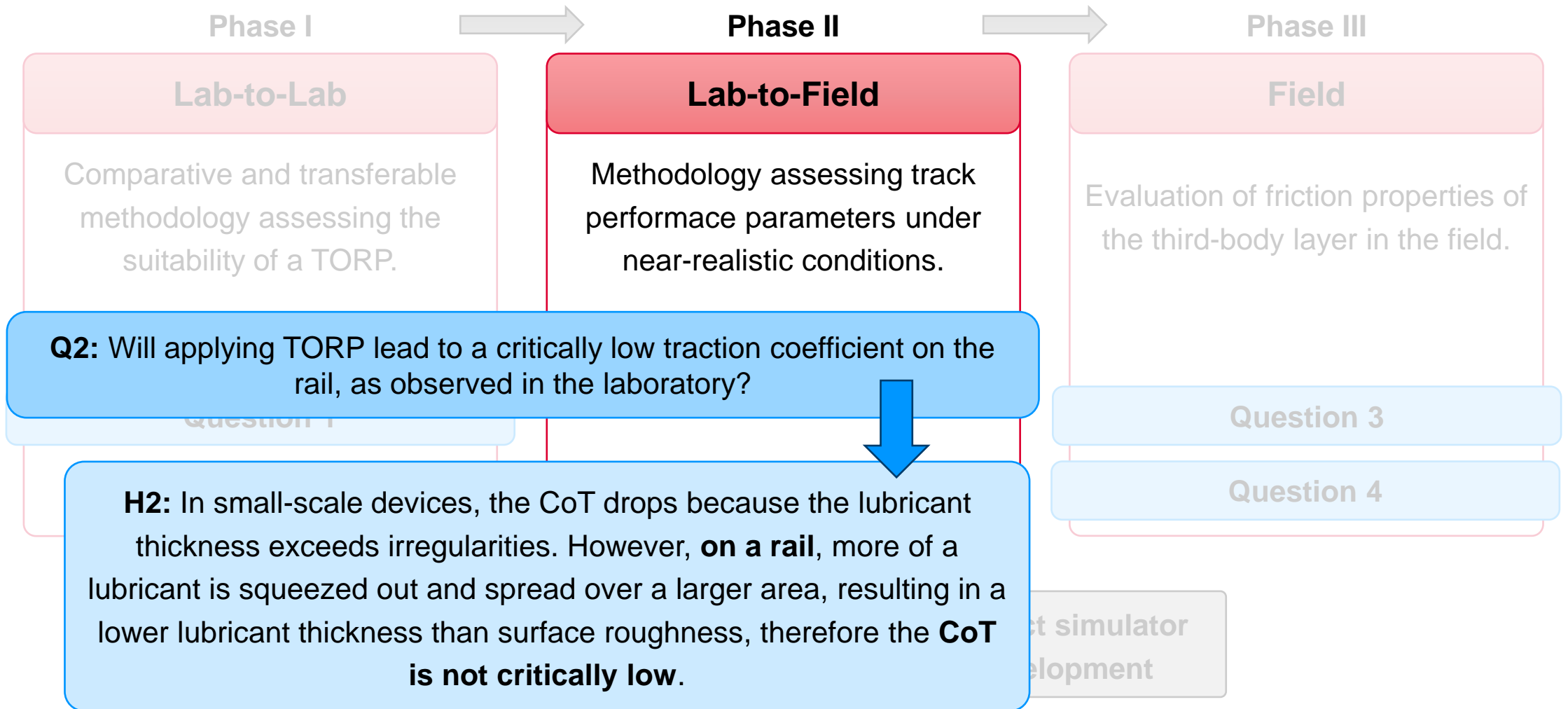
## 2. Retentivity test

Test end: CoT above threshold

No. of passes → retentivity



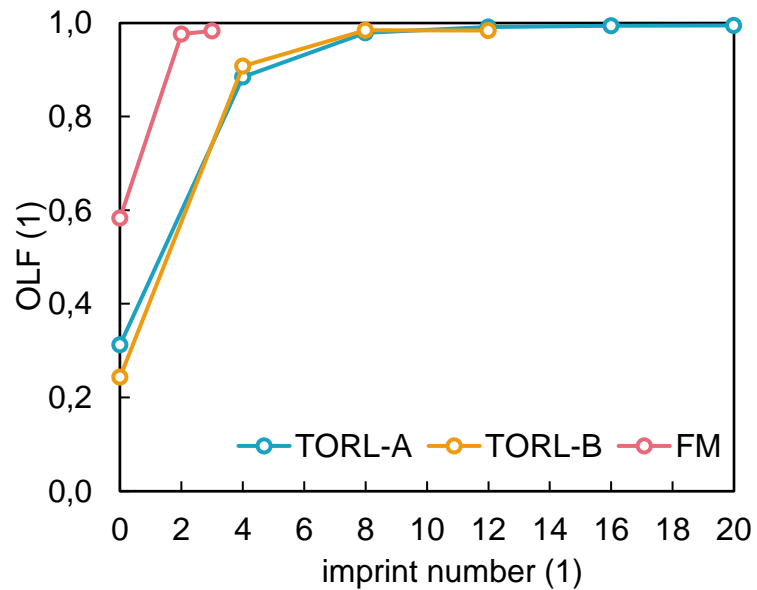
# Thesis Layout



# Results: Case Study

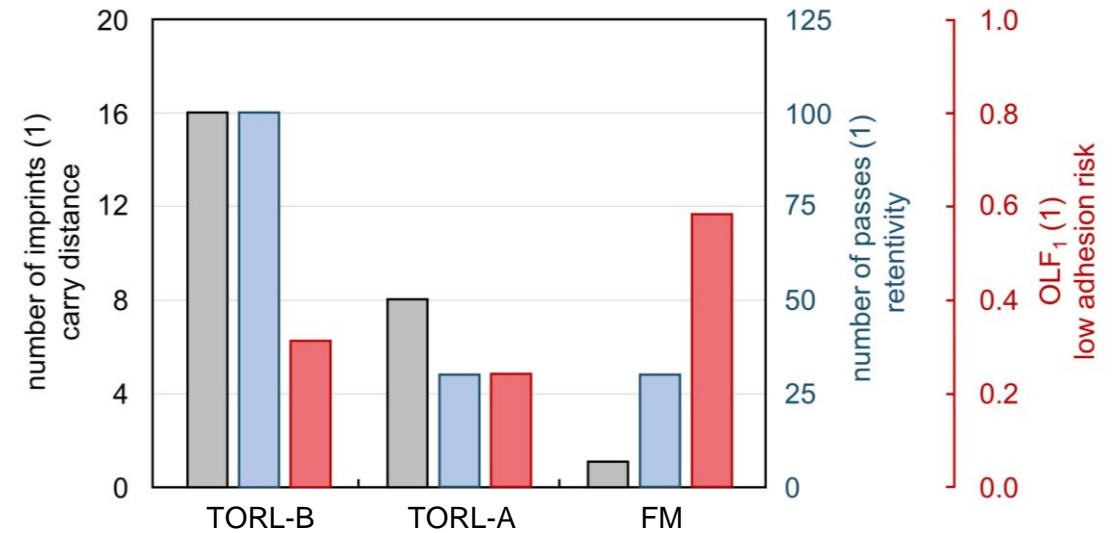
Amount:  
80  $\mu$ l

TORL-A TORL-B FM

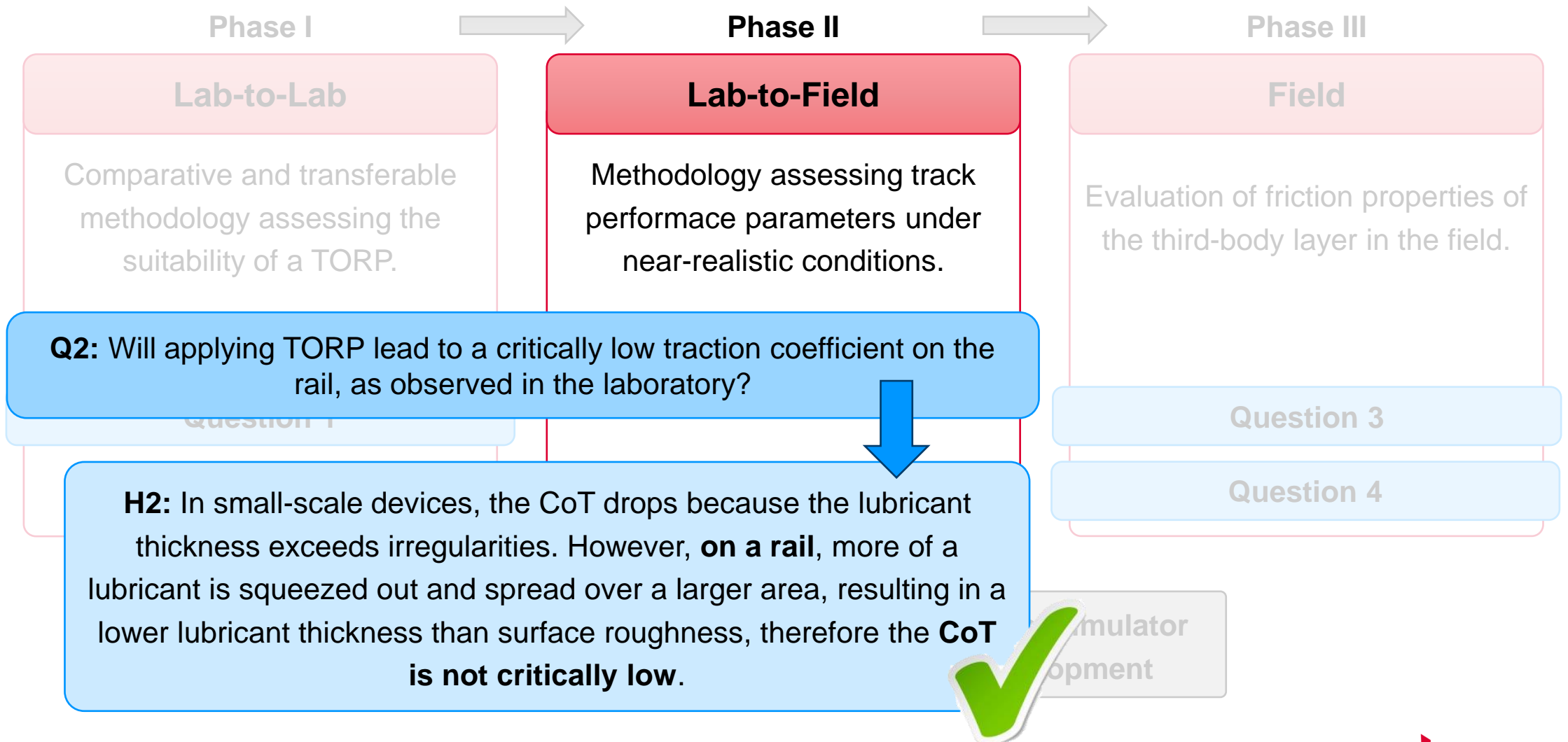


- How far is the product effective?
- For how long is the product effective?
- How risky is the product in terms of low adhesion?

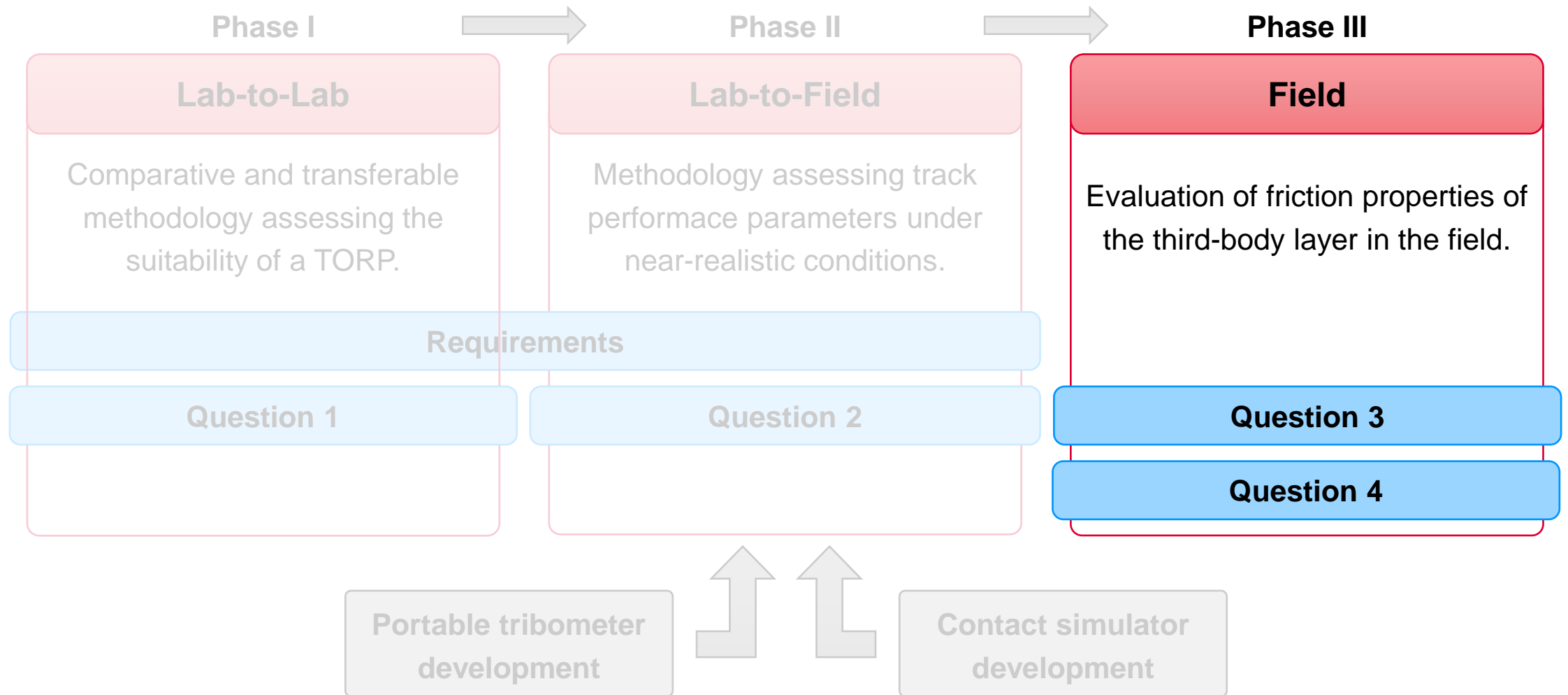
## Final assessment



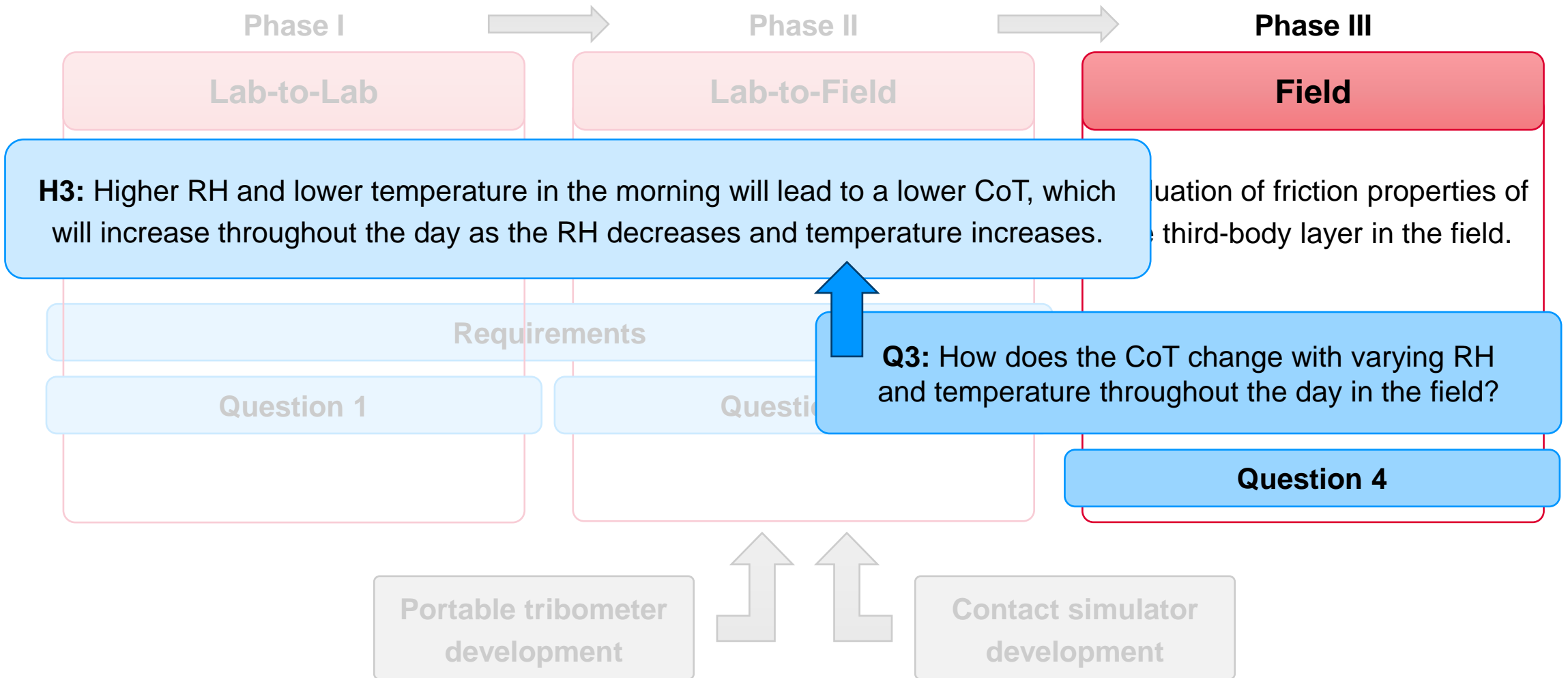
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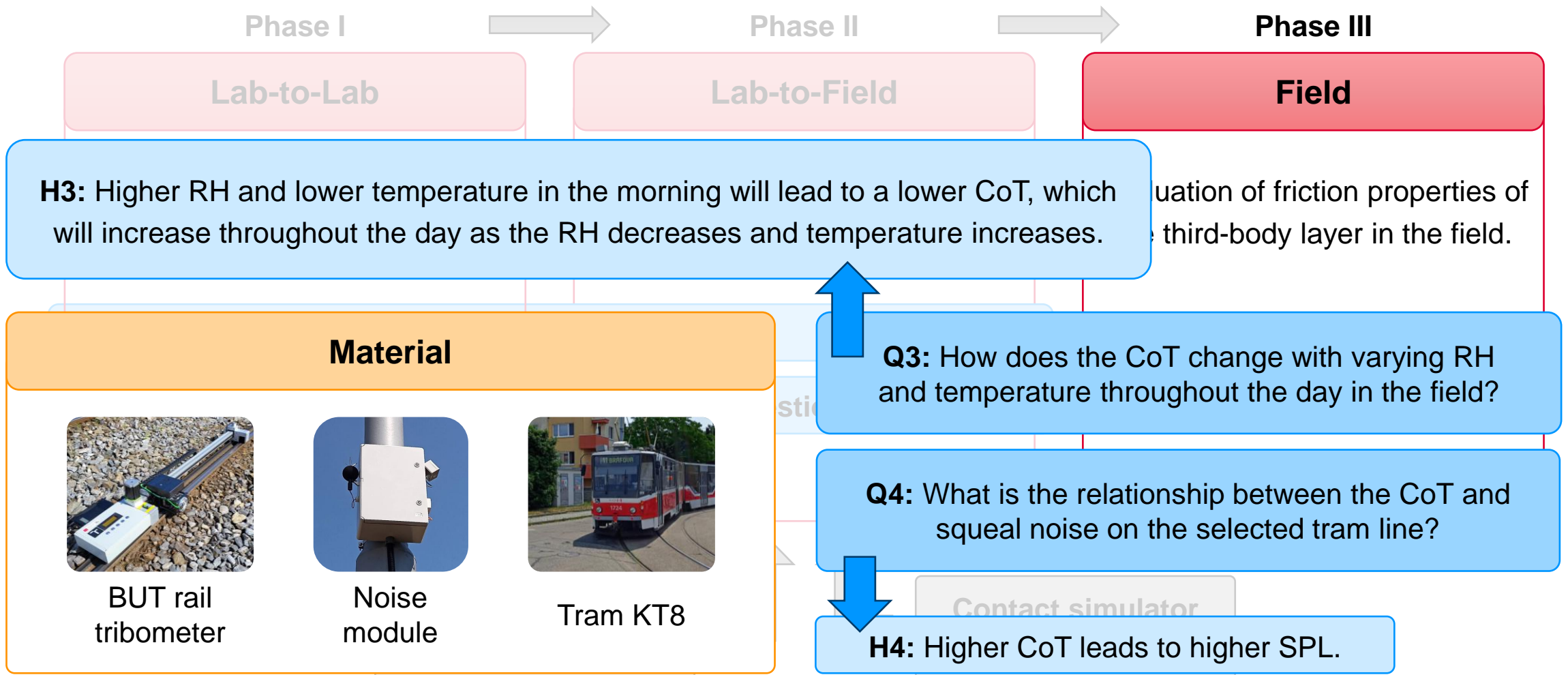
# Thesis Layout



# Thesis Layout



# Thesis Layout

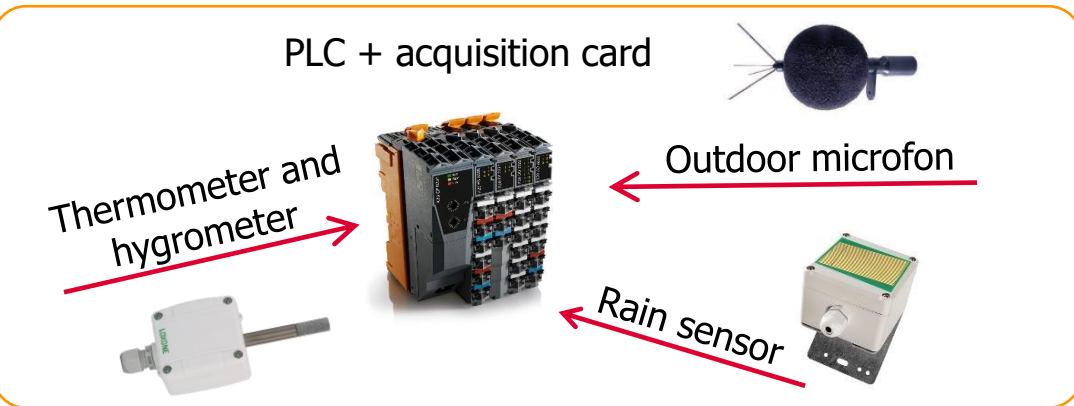


# Material and Methods

## Noise module

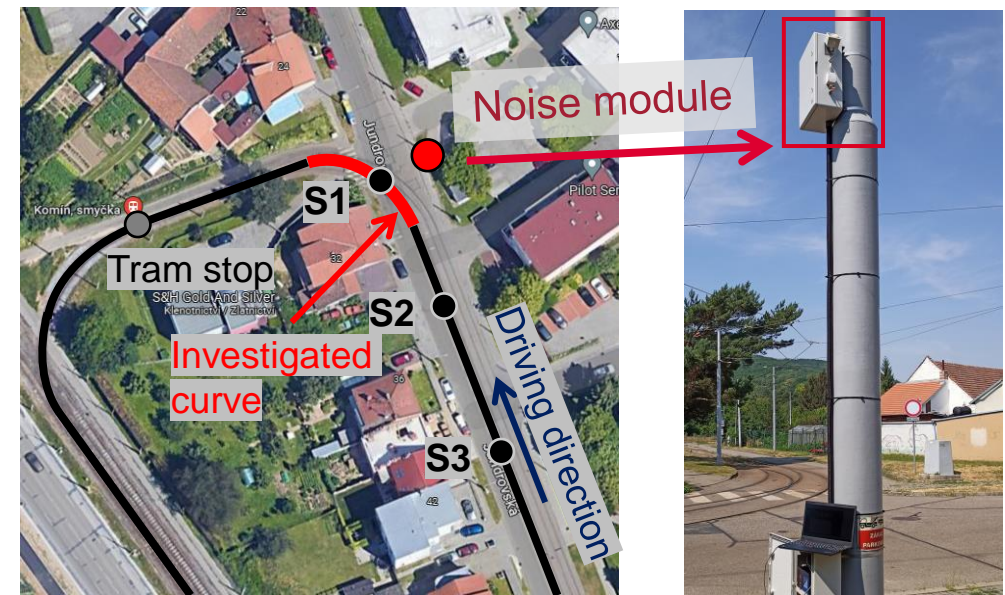


- Squeal and flange noise
- Recording is created when threshold is exceeded.
- SPL rms, Max SPL, noise duration.

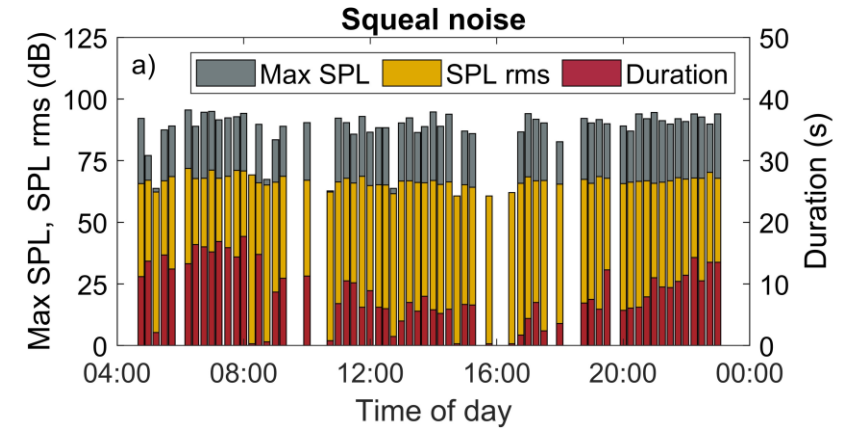
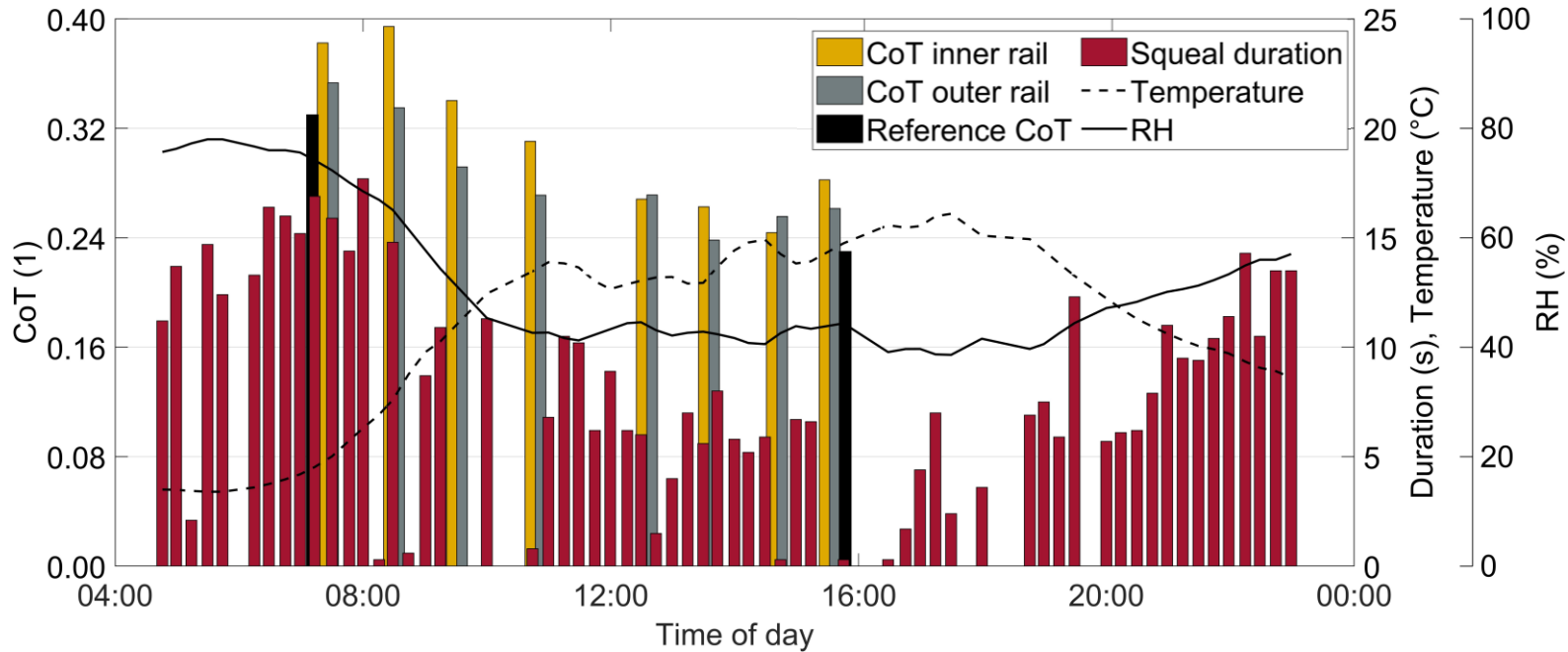


	Frequency band	Threshold
Squeal noise	500 – 650 Hz	60 dB
Flange noise	3800 – 5800 Hz	50 dB

- Regular tram operation
- CoT measurement on both rail at three spots.
- A day study with 9 mounts of noise measurement.



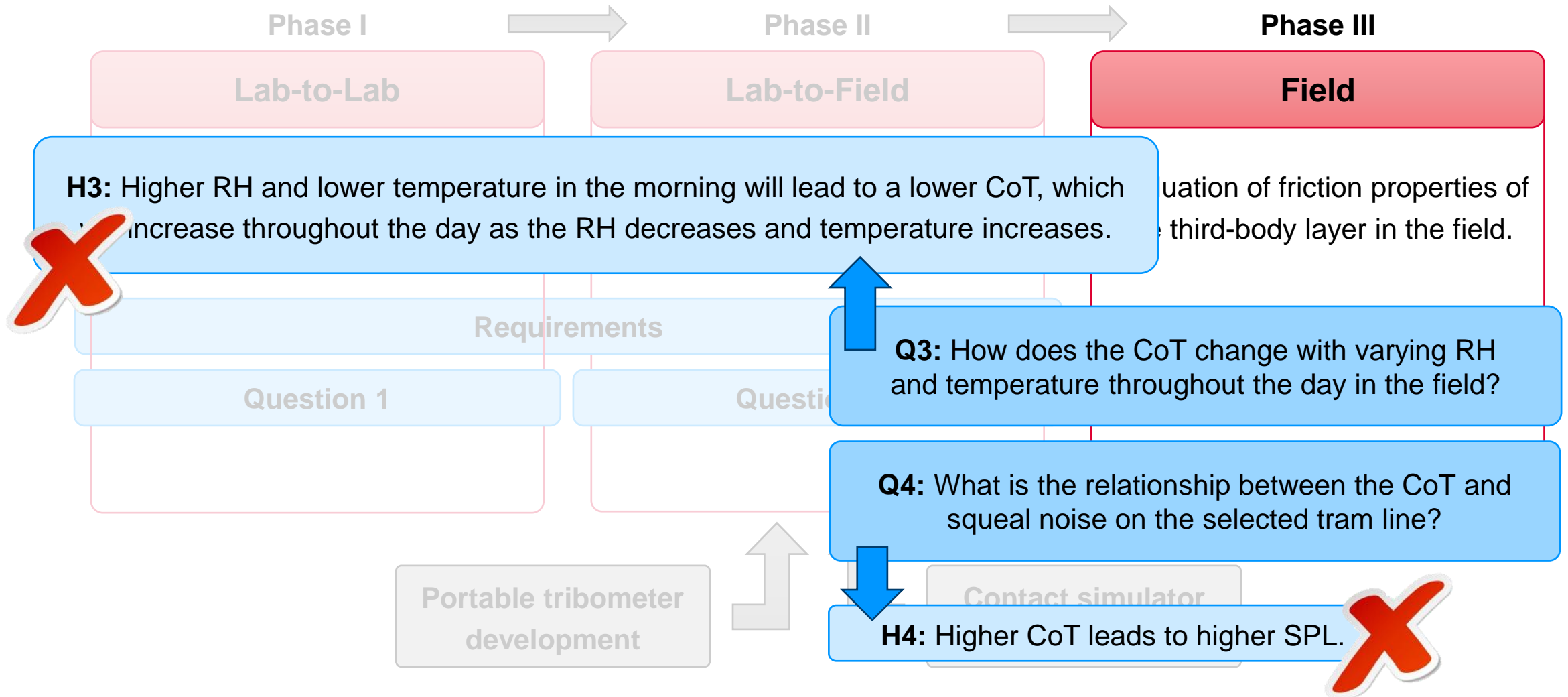
# Results and Discussion



- Squeal noise duration varies and SPLs remain more or less constant.
- CoT decreases during a day together with Relative Humidity.
- CoT vs duration provide significant correlation.
- CoT vs SPLs non-significant correlation.

	Pearson correlation coefficient	p-value
Temperature vs. CoT	-0.805	<0.001
RH vs. CoT	0.811	<0.001

# Thesis Layout



# Conclusion

1st

## Lab-to-Lab

Comparative test, Q1-Q4  
Result transferability  
Effect of amount  
Suitable TOR product

Mini-traction machine

Faster development of the new  
top of rail product

2nd

## Lab-to-Field

Test close to track conditions  
Track performance parameters  
Suitable amount  
Suitable application strategy

Contact simulator + BUT tribometer

Future step

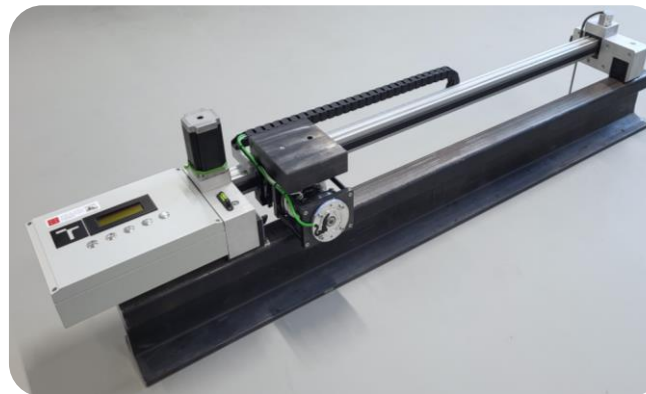
## Field

Interaction of naturally formed  
third body layer and TOR product

Railway track + BUT tribometer

Identification of the most  
silent tram.

Cooperation in accident  
investigations.



# Thank you for your attention

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