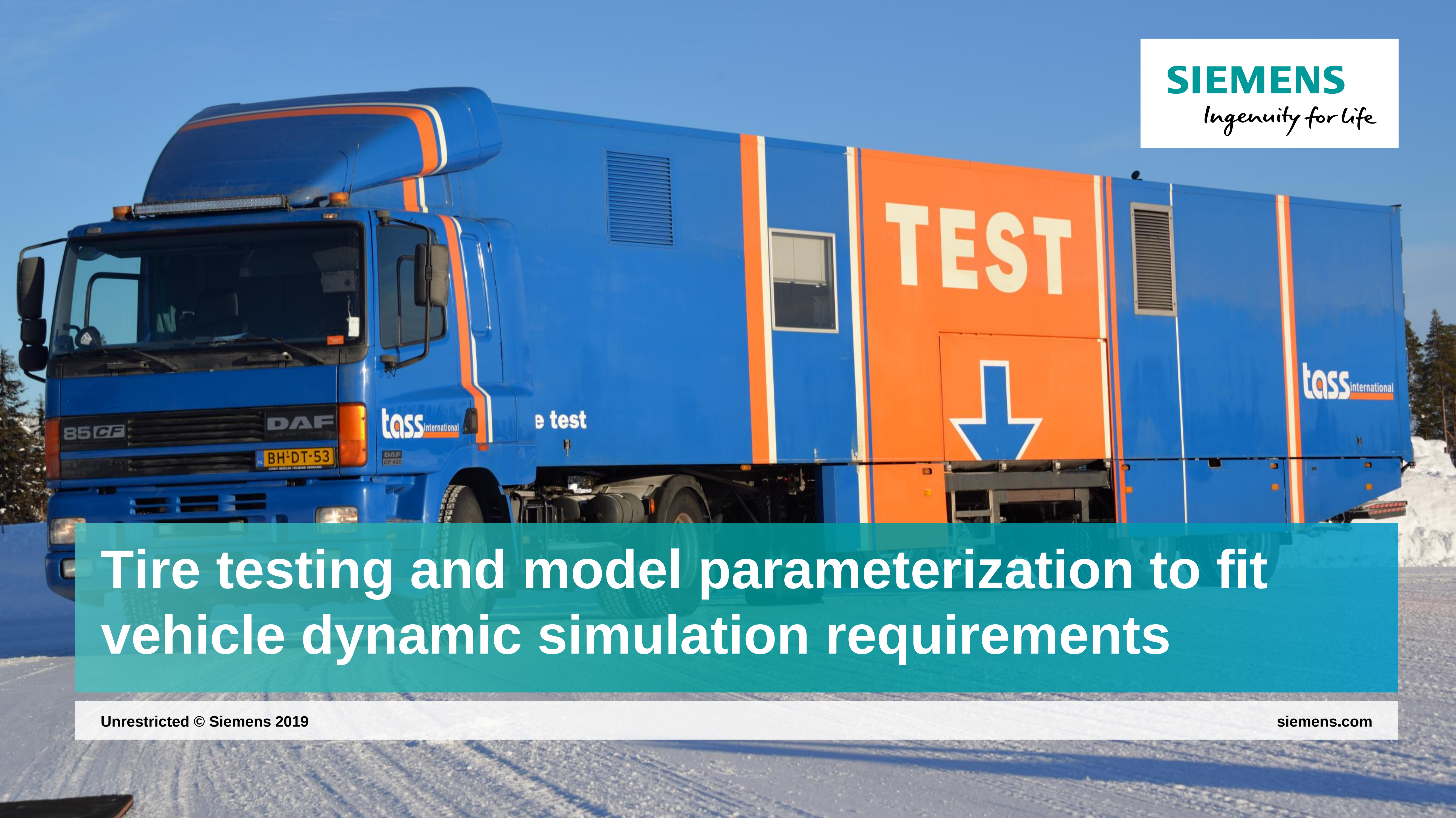
SIEMENS
Ingenuity for life



# Tire testing and model parameterization to fit vehicle dynamic simulation requirements

# The influence of tires on vehicle performance properties

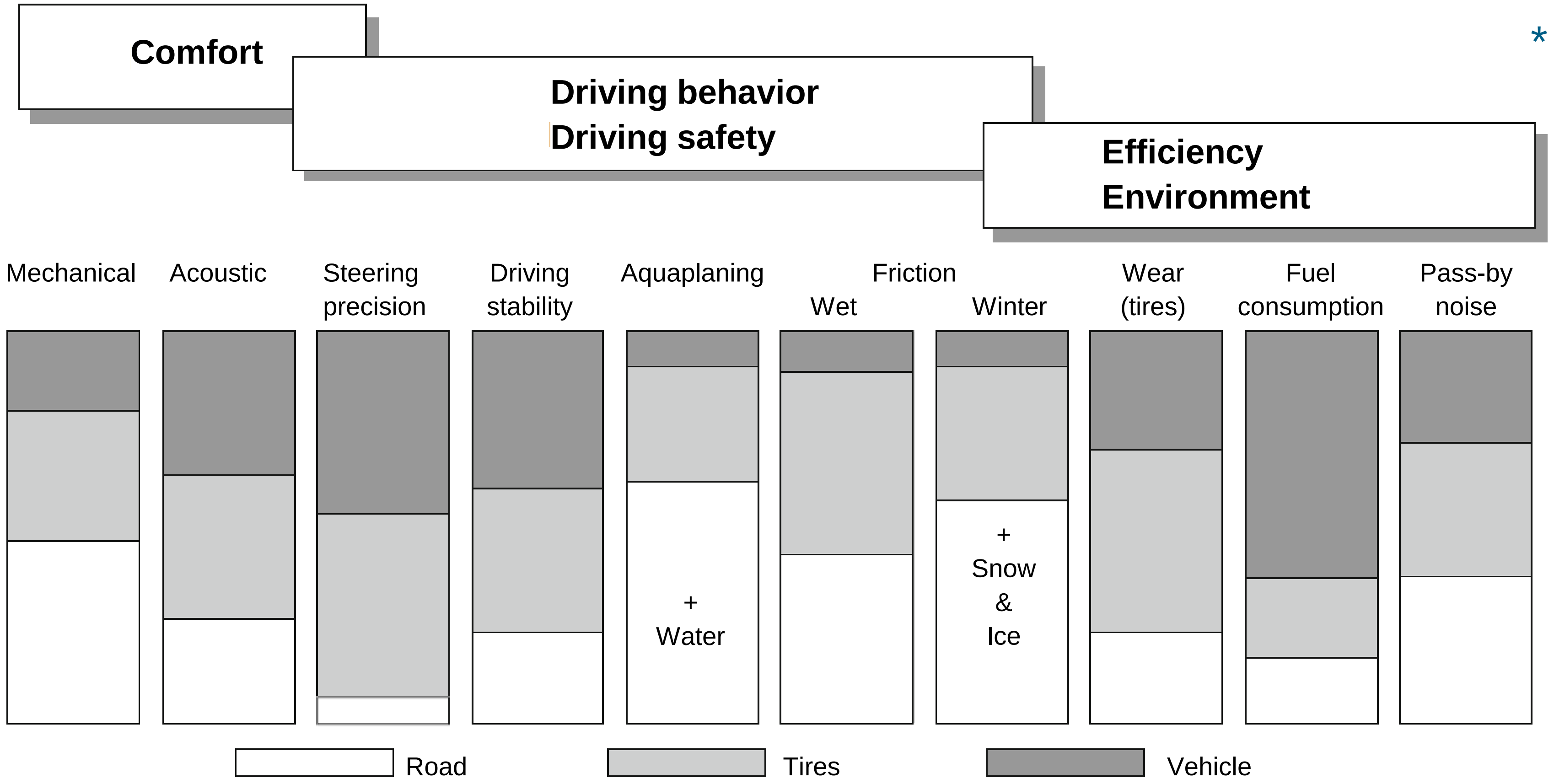


**Abb. 7.73** Influence of Road, Tires and Vehicle on functional properties

*Reference: Vieweg Handbuch Kraftfahrzeugtechnik, 8. Auflage, ISBN 978-3-658-09527-7*

# Tire model parameterization challenge

**Tire models for vehicle dynamics must meet the highest demands regarding model accuracy and predictive analytics**

**Challenge is to manage:**

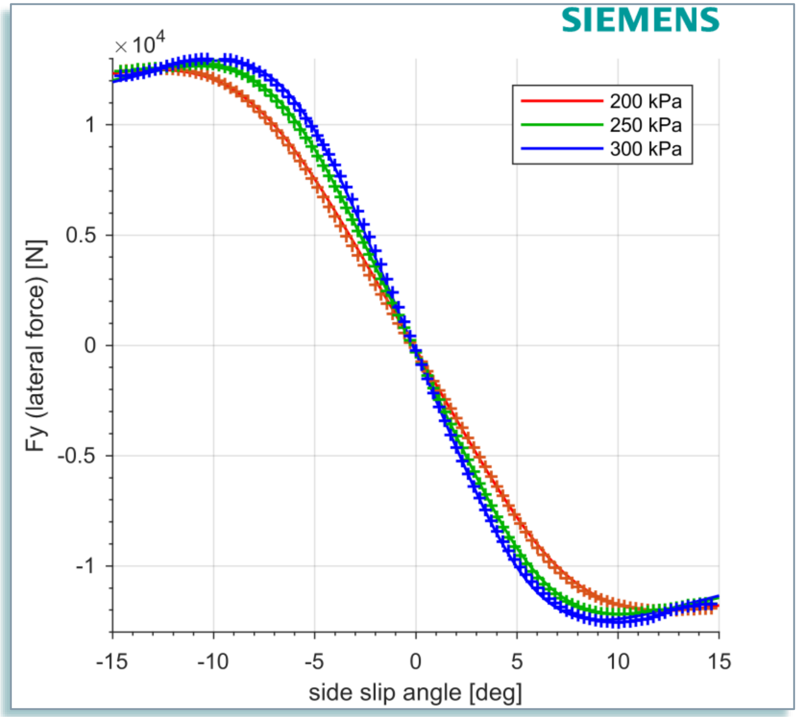
- **All influences on tire performance**
- **Tire modelling across the company**

# Tire model parameterization

## Challenge: Managing influences on tire performance

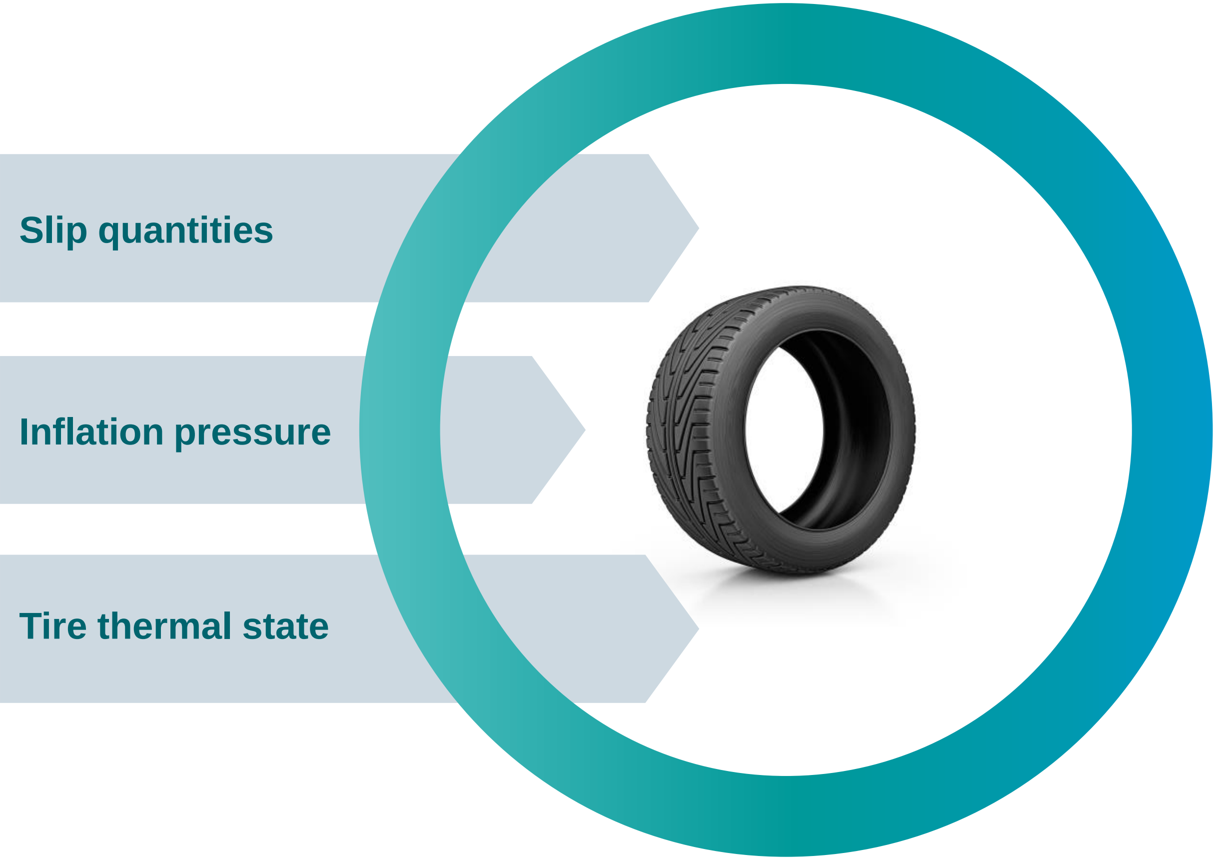
**Slip quantities**

**Inflation pressure**



# Tire model parameterization

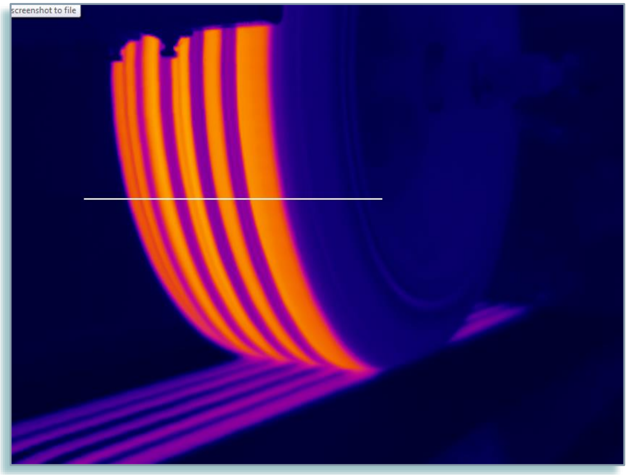
## Challenge: Managing influences on tire performance

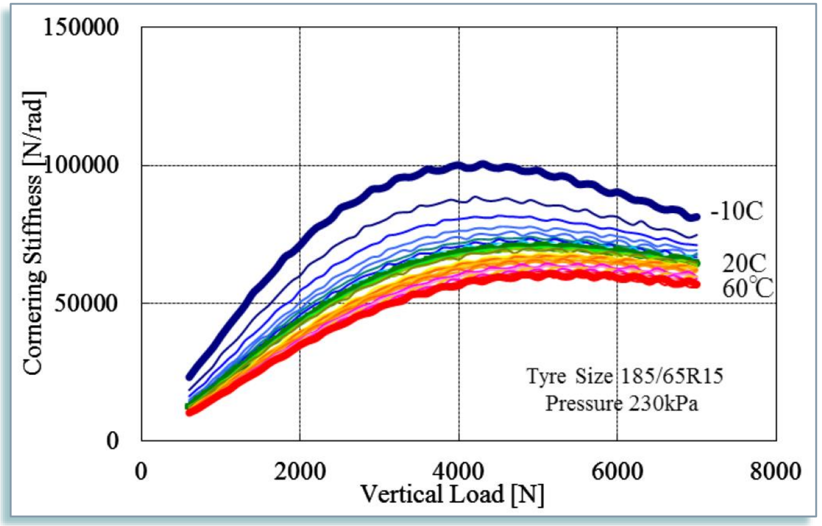


**Slip quantities**

**Inflation pressure**

**Tire thermal state**





*Reference: F2014-IVC-0054, Effects of tyre thermal characteristics on vehicle performance, Okubo*

# Tire model parameterization

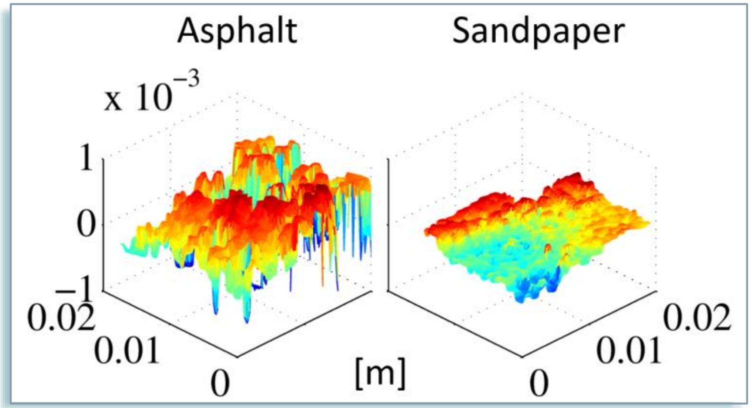
## Challenge: Managing influences on tire performance

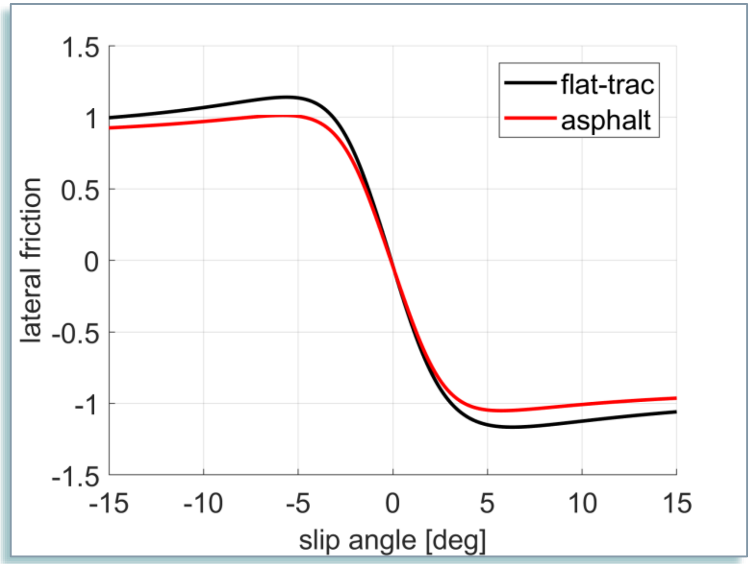
**Slip quantities**

**Inflation pressure**

**Tire thermal state**

**Road texture**





# Tire model parameterization

## Challenge: Managing influences on tire performance

**Slip quantities**

**Inflation pressure**

**Tire thermal state**

**Road texture**

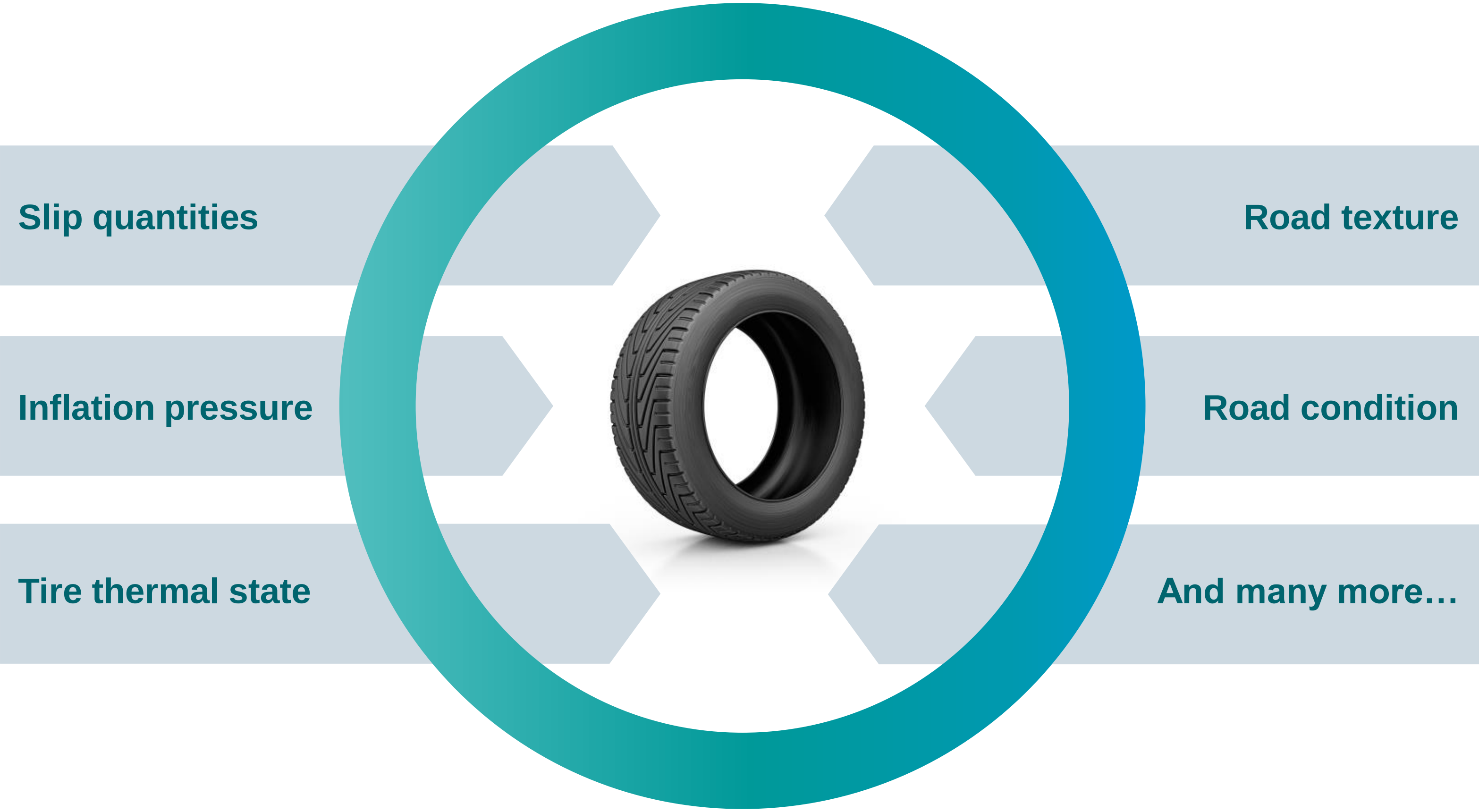
**Road condition**

**Snow**

**Polished Ice**

# Tire model parameterization

## Challenge: Managing influences on tire performance



**Slip quantities**

**Inflation pressure**

**Tire thermal state**

**Road texture**

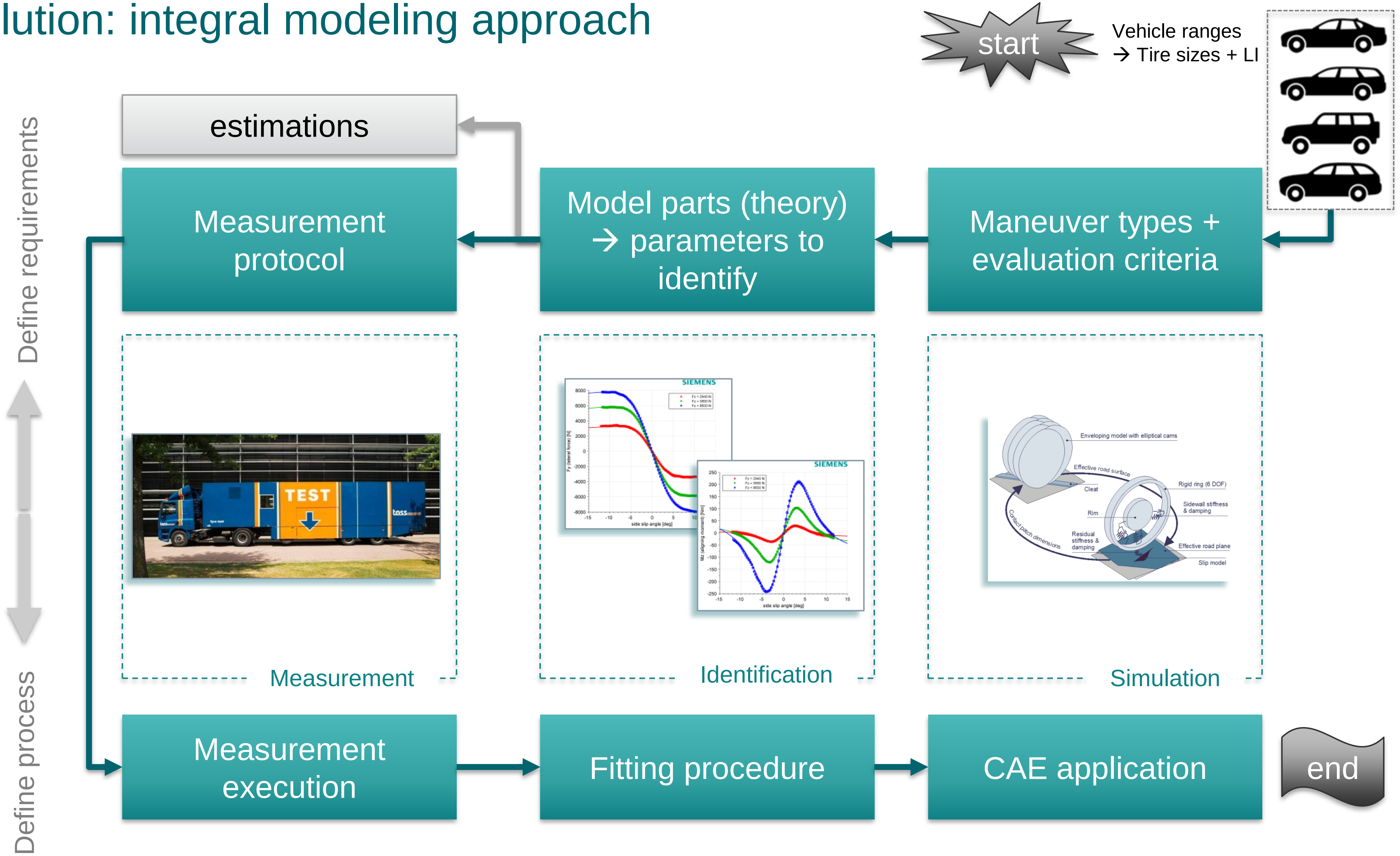
**Road condition**

**And many more…**

**Goal: predict tire performance in context of real-life vehicle performance**

# Tire model parameterization

## Solution: integral modeling approach



start

Vehicle ranges
→ Tire sizes + LI

estimations

Measurement protocol

Model parts (theory) → parameters to identify

Maneuver types + evaluation criteria

Measurement

Identification

Simulation

Measurement execution

Fitting procedure

CAE application

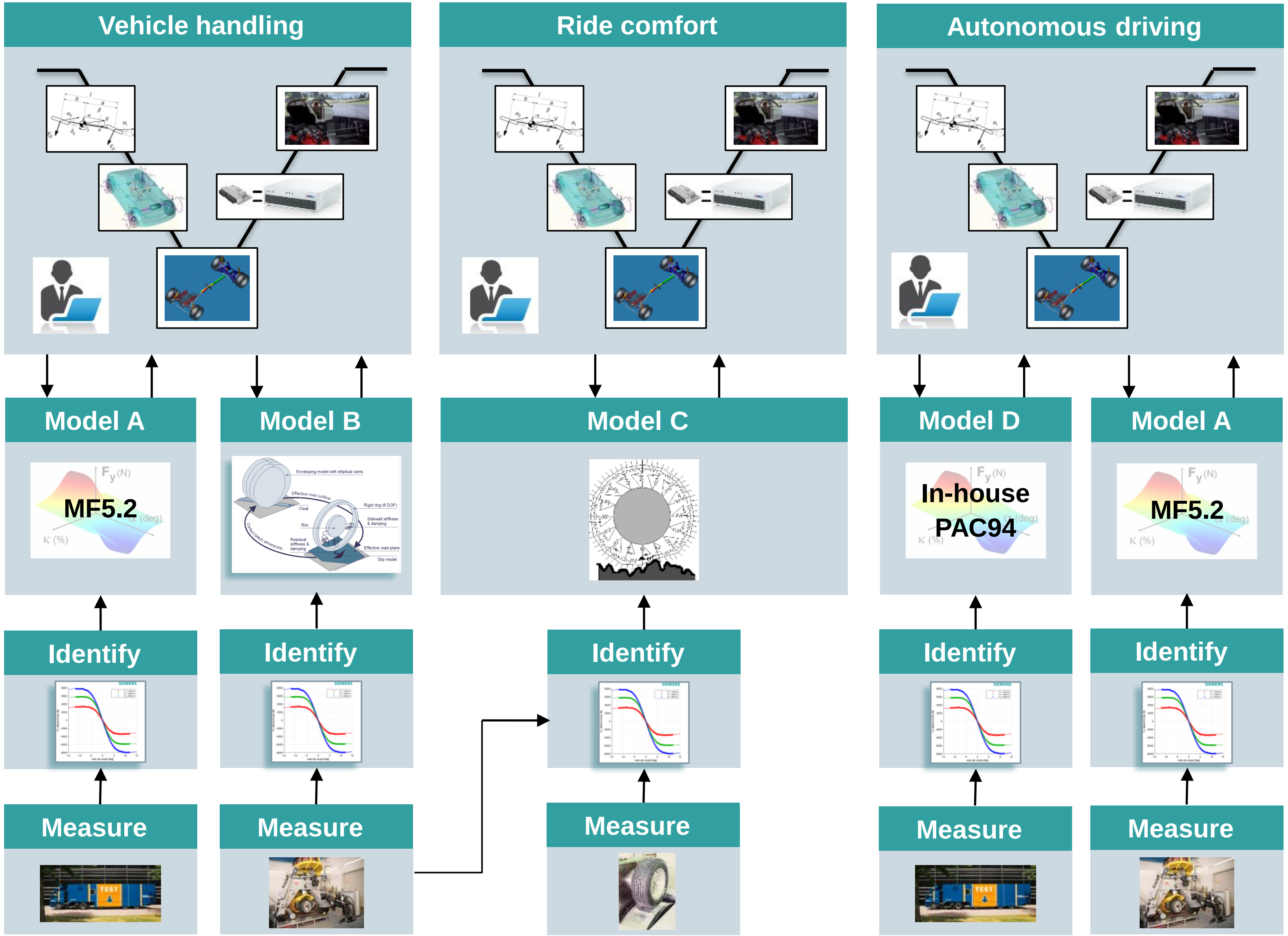
end

Define requirements

Define process

# Tire model parameterization

## Challenge: process complexity



Vehicle handling

Ride comfort

Autonomous driving

Model A

MF5.2

Model B

Model C

Model D

In-house PAC94

Model A

MF5.2

Identify

Identify

Identify

Identify

Identify

Measure

Measure

Measure

Measure

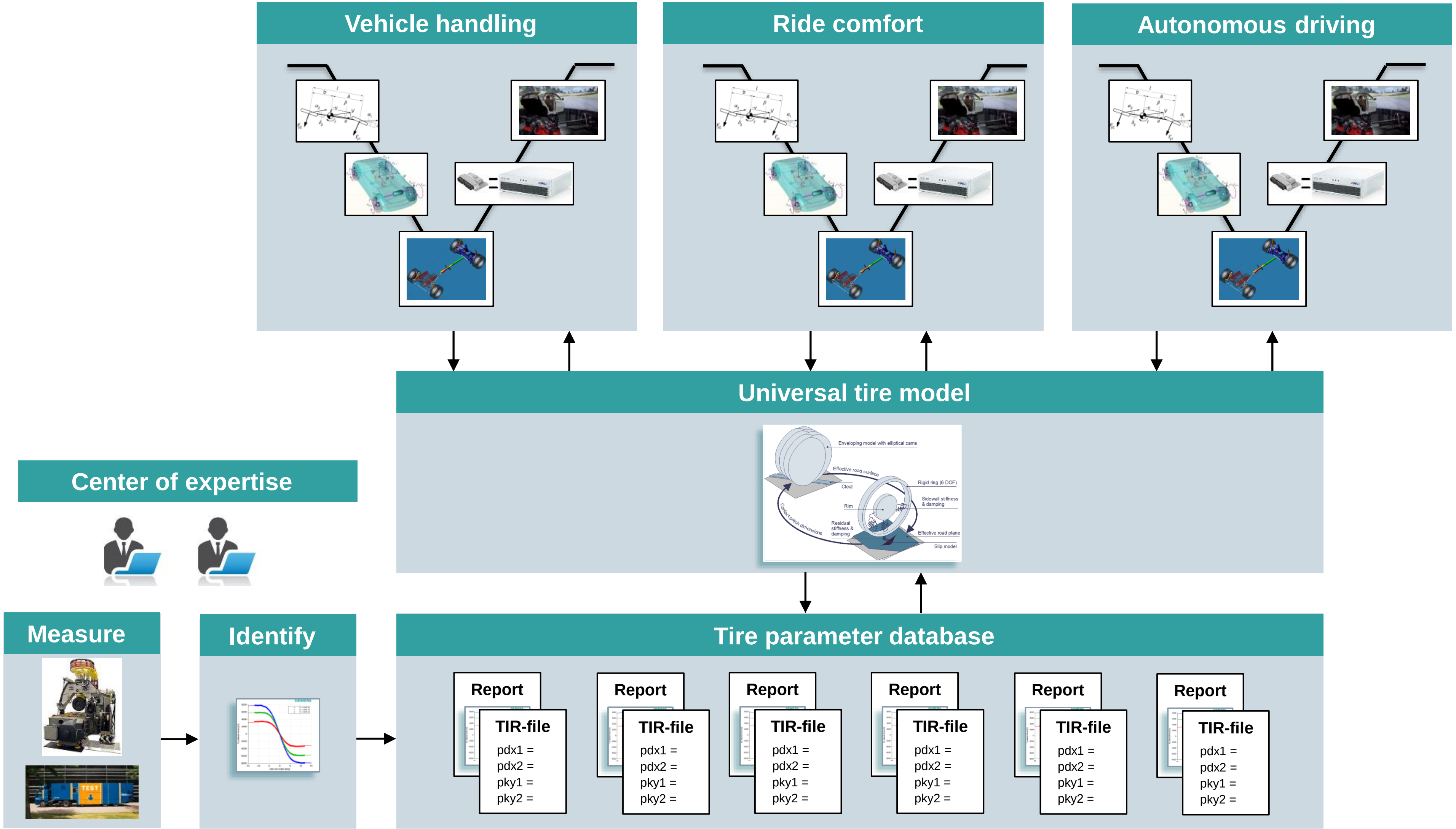
Measure

**Resulting challenges:**

- **Equal tire providing different performance**
- **Cost inefficiency**
- **Unshared local expertise**

# Tire model parameterization

## Solution: process unification



**Vehicle handling**

**Ride comfort**

**Autonomous driving**

**Universal tire model**

**Center of expertise**

**Measure**

**Identify**

**Tire parameter database**

**Report**
**TIR-file**
pdx1 =
pdx2 =
pky1 =
pky2 =

**Report**
**TIR-file**
pdx1 =
pdx2 =
pky1 =
pky2 =

**Report**
**TIR-file**
pdx1 =
pdx2 =
pky1 =
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**TIR-file**
pdx1 =
pdx2 =
pky1 =
pky2 =

**Report**
**TIR-file**
pdx1 =
pdx2 =
pky1 =
pky2 =

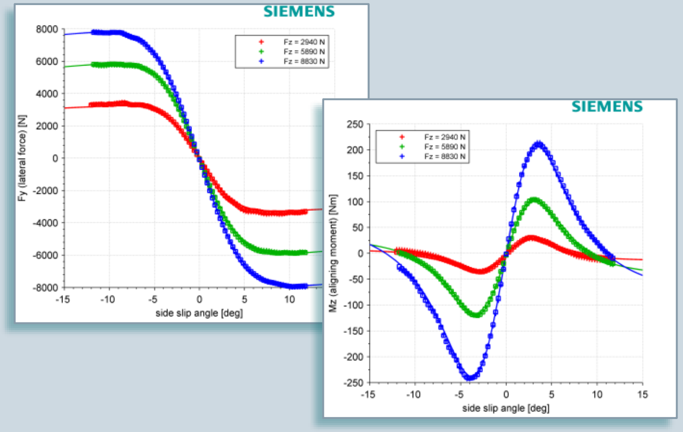
### Resulting advantages:

- Cost efficiency
- Model sharing
- Common ‘language’
- Center of expertise

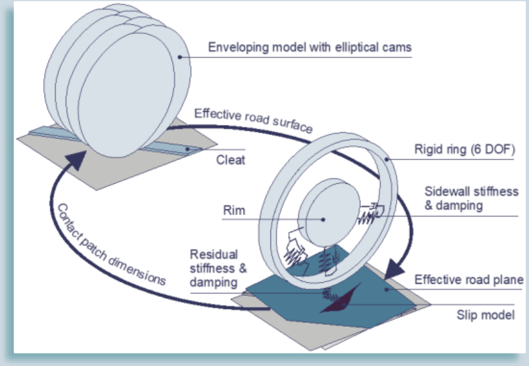
# Tire modeling for vehicle dynamics

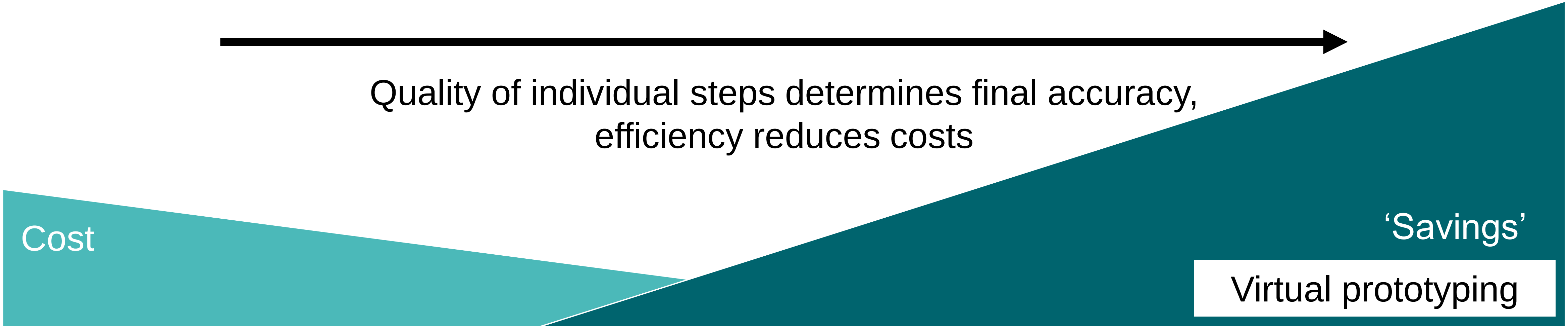
## Tire testing

## Parameter identification



## Simulation





Quality of individual steps determines final accuracy, efficiency reduces costs

Cost

‘Savings’

Virtual prototyping

# Practical use case

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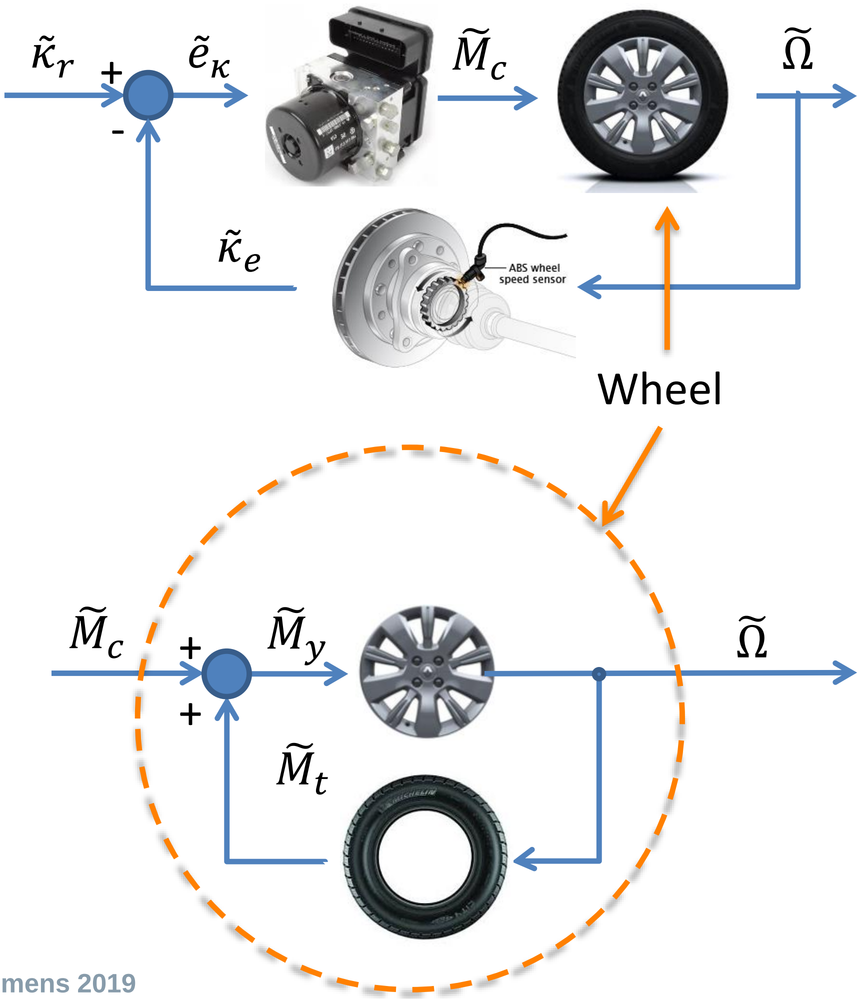
## ABS Braking:

## Cost-efficiently identify the tire transient response

# Use case: ABS braking

## A simplified ABS control loop



- Control loop of a single wheel
- Linearized around an operating point
- Useful to study parameter sensitivity

$$W = \frac{1}{s\,I_y + (-K_{st})H(s)}$$

Wheel inertia moment

Tire steady-state gain

Tire transient response

*Reference: ATZ worldwide, June 2017, Volume 119, Issue 6, pp 16–21*

# Use case: ABS braking

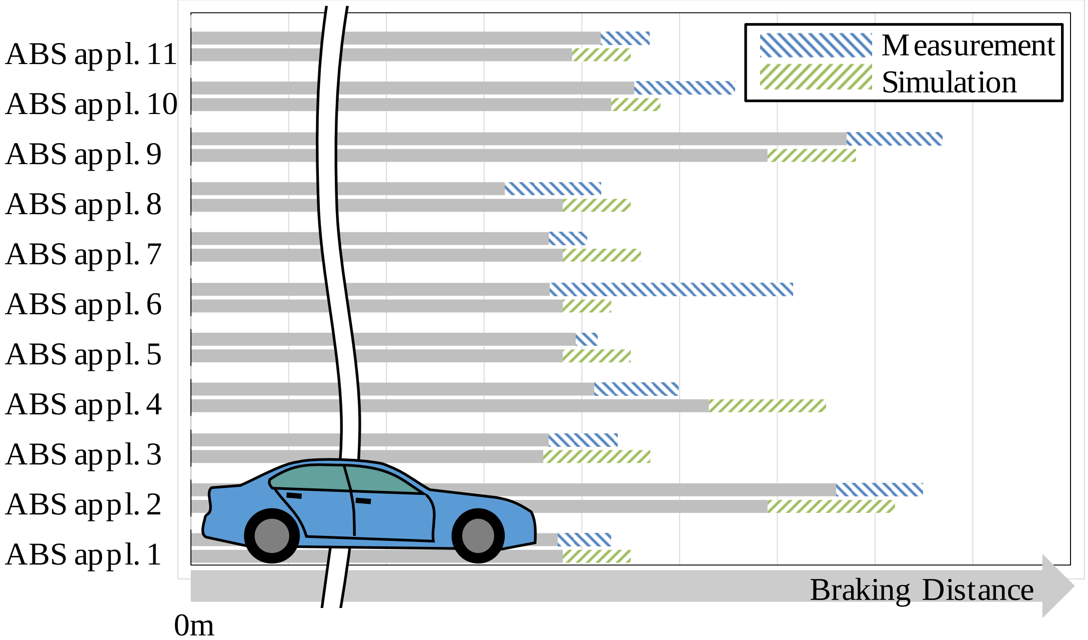
## Challenge in identification of transient tire properties

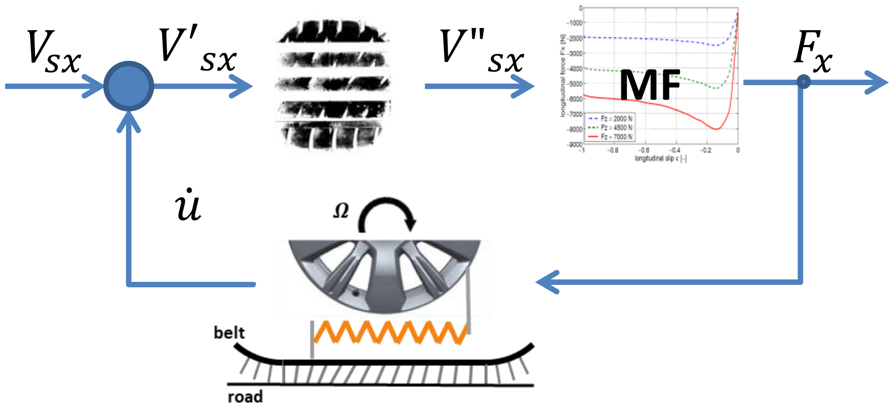
- Accurate prediction of influence of ABS controller setting

- Tire model setup:
  - Non-linear transient model
  - Magic Formula slip characteristics
  - OpenCRG road modelling

- Tire model parameterization:
  - Test Trailer slip characteristics
  - Tire carcass stiffness from cleat measurements

- Challenge: cleat measurements relatively expensive and not always available





*Reference: ATZ worldwide, June 2017, Volume 119, Issue 6, pp 16–21*

# Use case: ABS braking

## Alternative tire transient identification

SIEMENS
Ingenuity for life

- Typical carcass stiffness parameter identification methods:

  Cleat test:
  + accurate (if performed well)
  - complex
  - high costs

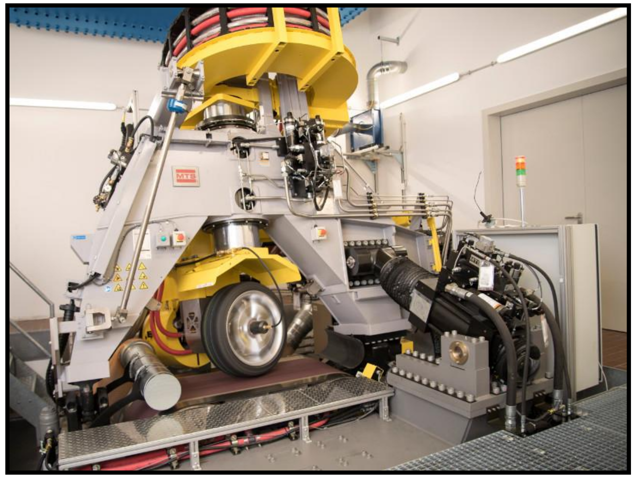
  Static stiffness test:
  + low costs
  - poor accuracy (in representing a rolling tire)

- Alternative: dynamically excite rolling tire to produce a direct measure of the transient response

- MTS Flat-Trac: Harmonically excited longitudinal slip:
  - Amplitude: 2% slip, brake/drive around 0
  - Frequency: [0.1 0.5 1 2 4 6 8 10] Hz


Michelin engineering services

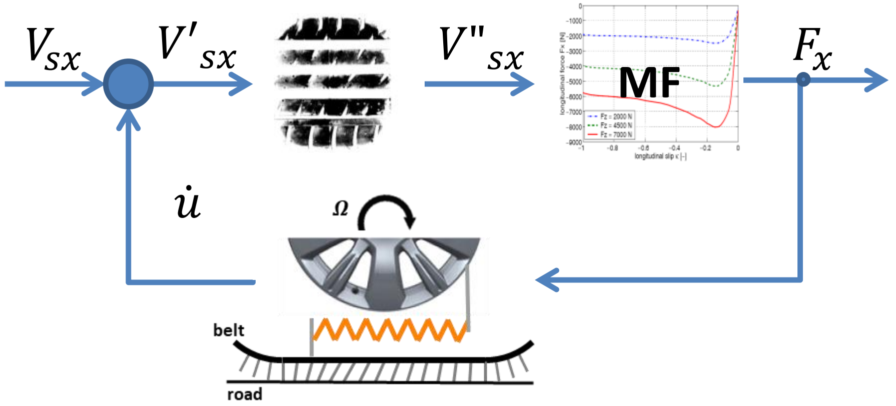

UTTM stiffness tester


FKA MTS Flat-Trac

*Reference: "Improved identification of transient MF-Tyre/MF-Swift parameters", Science Meets Tire, April 2018*

# Use case: ABS braking

## Alternative tire transient identification

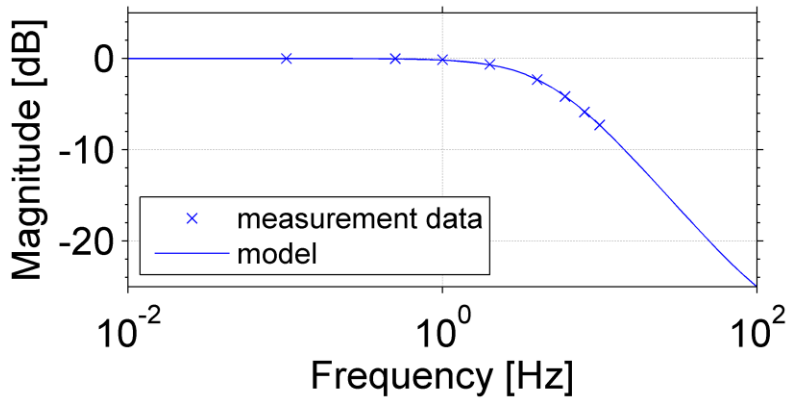


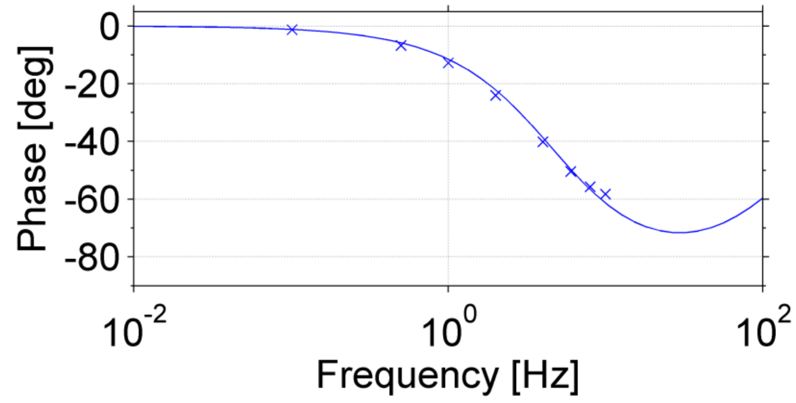
$$H(s) = \frac{F_x}{C_{F\kappa}\kappa} = \frac{|V_x|(k_{cx}s + c_{cx})}{(\sigma_c s + |V_x|)\cdot(k_{cx}s + c_{cx}) + |V_x|C_{F\kappa}s}$$

Known

Default damping

Identified





**Qualitatively similar results at ~50% of the costs, cleat testing provides premium solution**

*Reference: “Improved identification of transient MF-Tyre/MF-Swift parameters”, Science Meets Tire, April 2018*

# Practical use case

## Parking:

## Extend a regular tire model for low-speed maneuvering

# Use case: Low speed maneuvering and parking

## Challenge in modeling low speed tire behavior

- The development of ADAS systems rely on accurate models

- Steering at low speed leads to:

  *Non-uniform velocity* ($\vec{V}_p \neq \vec{V}_c$)

  ↓

  *Non-uniform sliding velocity* ($\vec{V}_{sp} \neq \vec{V}_{sc}$)

  ↓

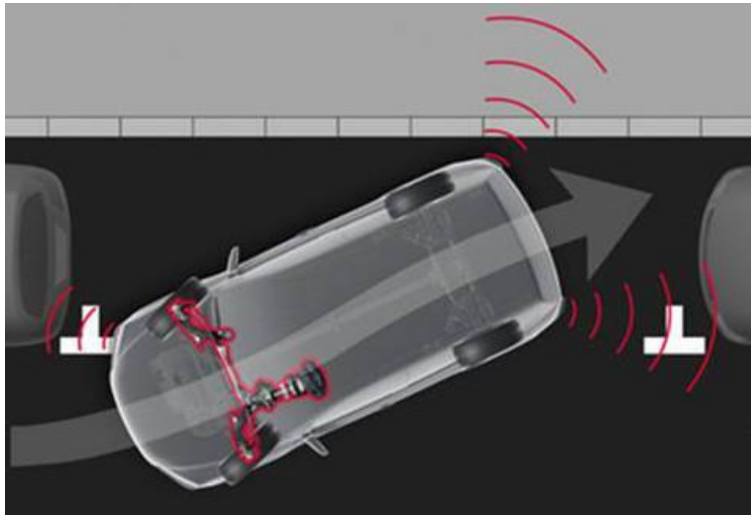
  *Non-uniform horizontal stress* ($\vec{\tau}_p \neq \vec{\tau}_c$)

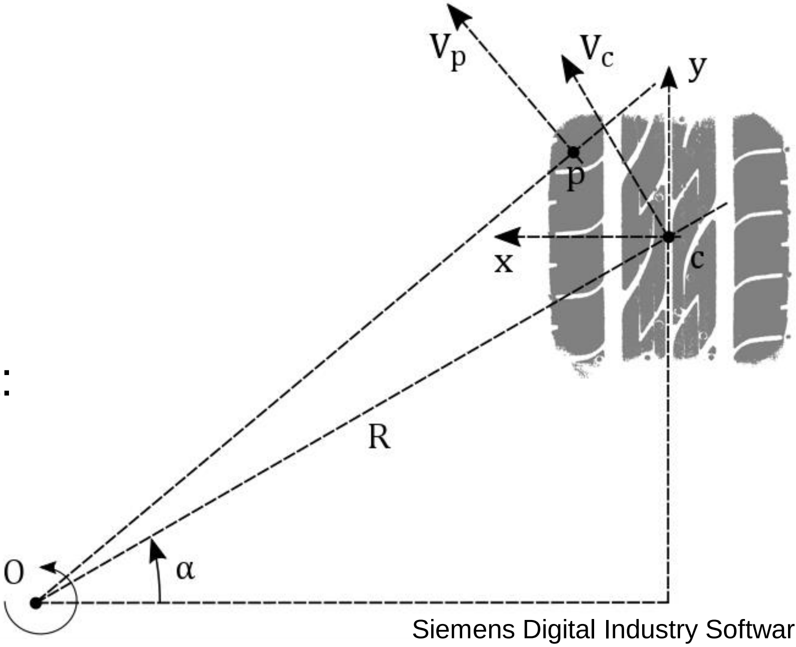
  ↓

  *Generation of extra aligning moment*

- Challenge: effect not taken into account by traditional Magic Formula:

$$M_z = f(F_z, \alpha, \gamma, \kappa, p_i)$$





*Reference: SAE Paper 2016-01-1645*

# Use case: Low speed maneuvering and parking

## Modeling tire spin phenomena

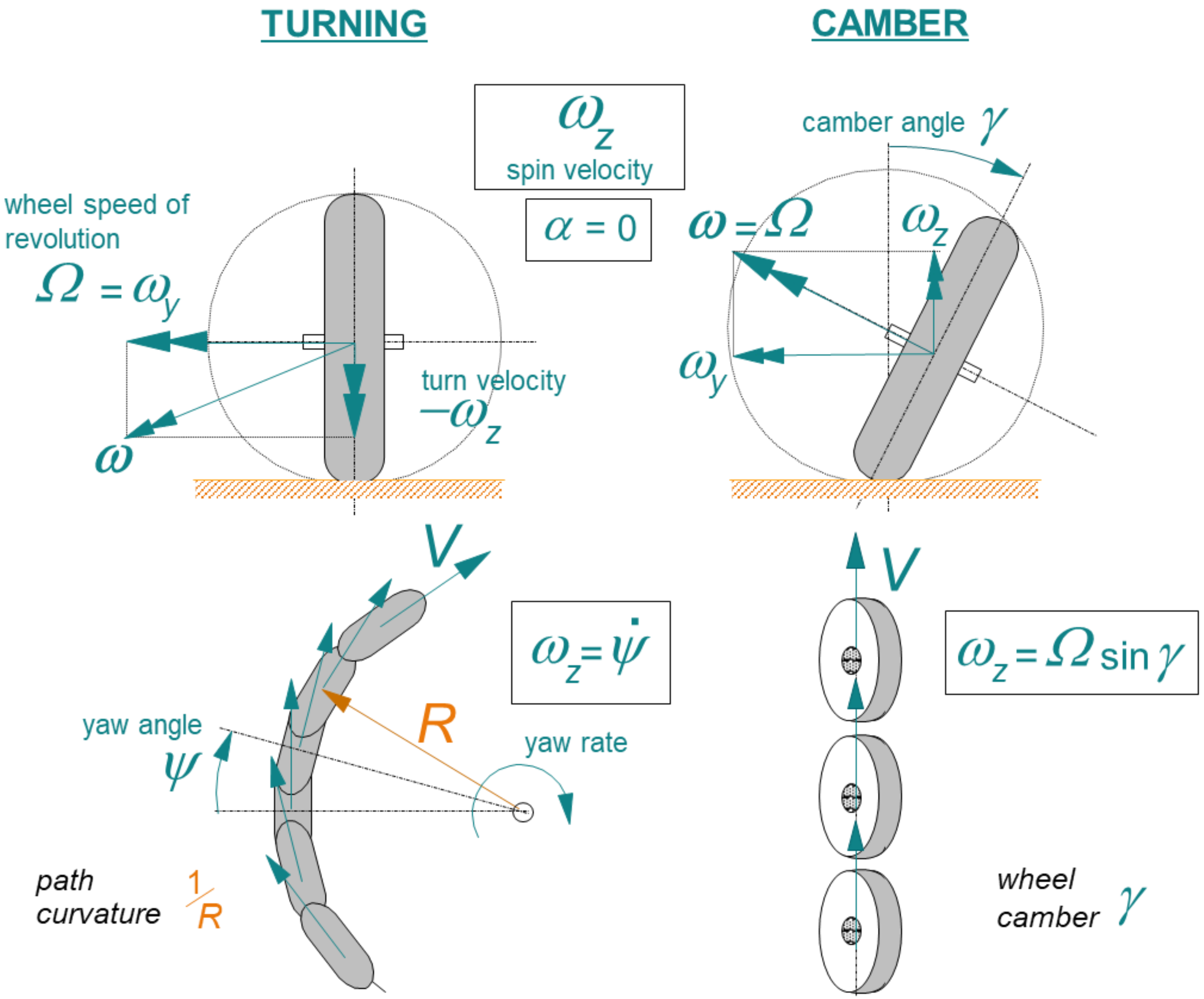
- Spin (or rotational slip) is described by two components:
  - Spin due to path curvature (referred to as turn slip)
  - Spin due to wheel camber (referred to as camber slip)

- Spin defined as:

$$\varphi = -\frac{1}{V}\omega_z$$

- Tire model extended with spin:
  - Dedicated model for standstill
  - Magic Formula extension

$$M_z = f(F_z, \alpha, \gamma, \kappa, \underline{\varphi}, p_i)$$

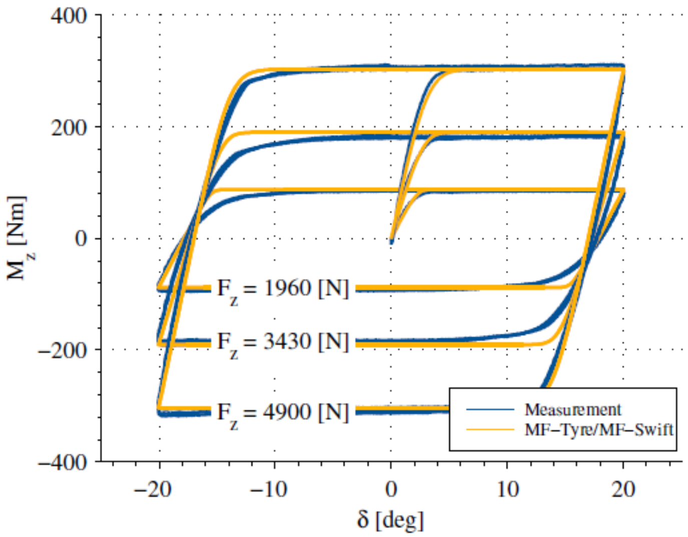


*Reference: SAE Paper 2016-01-1645*

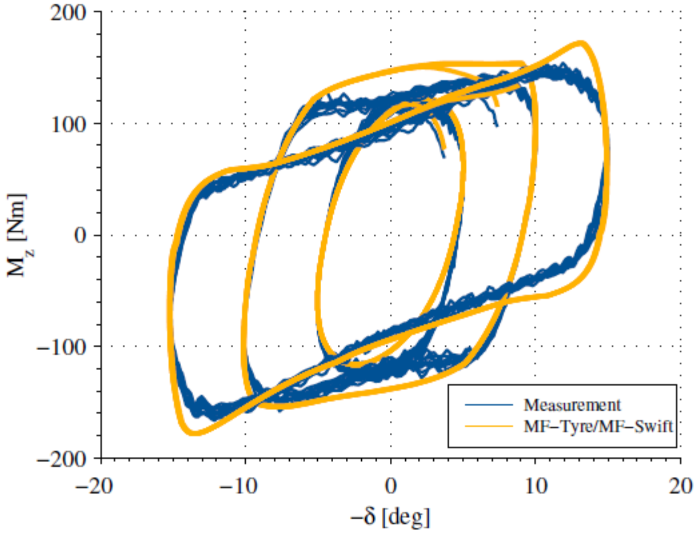
# Use case: Low speed maneuvering and parking

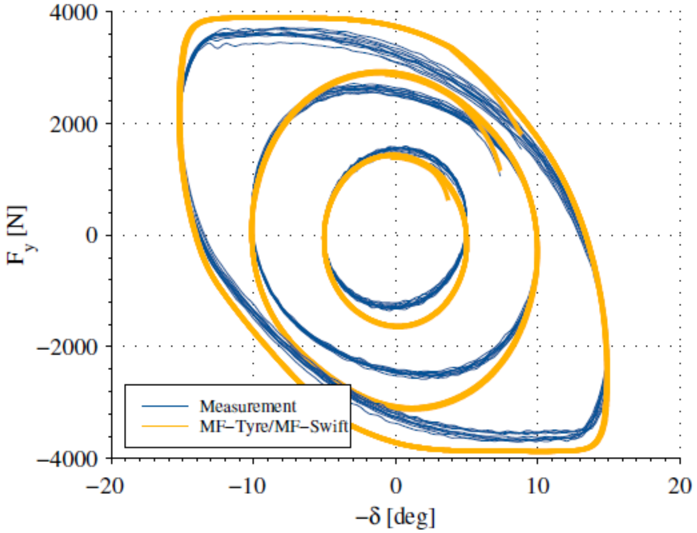
## Tire testing and model parameterization

- Standstill testing protocol
  - V = 0 km/h (standstill)
  - 3 vertical loads
  - Camber angle 0°
  - Steering sweep:
    - Amplitude: 20 deg
    - Frequency: 0.125 Hz



- Low speed testing protocol
  - V = 2 km/h
  - 3 vertical loads
  - Camber angle 0°
  - Steering sweep:
    - Amplitude: 20 deg
    - Frequency: 1 Hz (or highest possible)



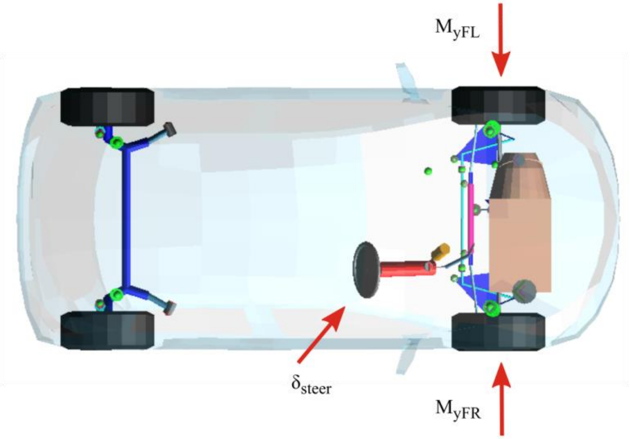


*Reference: SAE Paper 2016-01-1645*

# Use case: Low speed maneuvering and parking

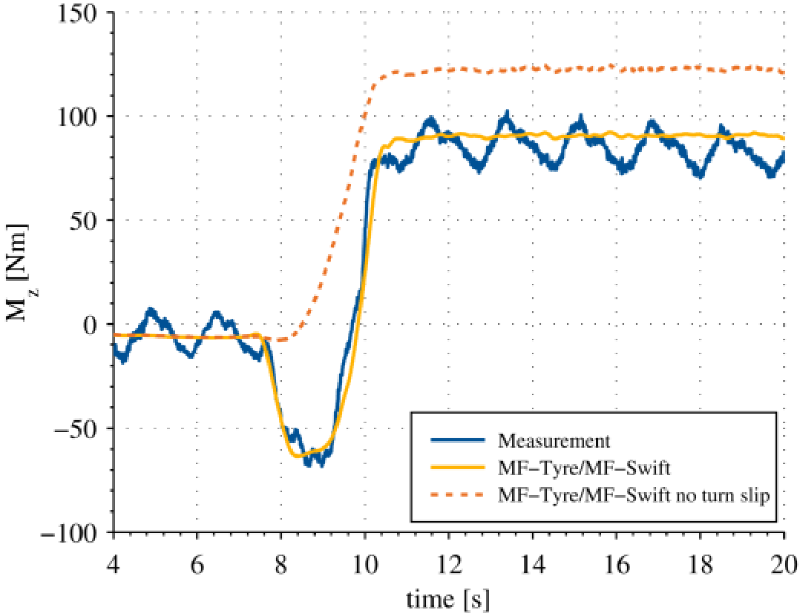
## Validation

- Comparison of forces and moments between test vehicle and simulation model



- Inputs from the test vehicle are given to the simulation model: $M_{yFL}, M_{yFR}, \delta_{steer}$

**The turn slip model is essential for accurately simulating a parking manoeuvre**



*Reference: SAE Paper 2016-01-1645*

# Practical use case

**Extreme handling:**

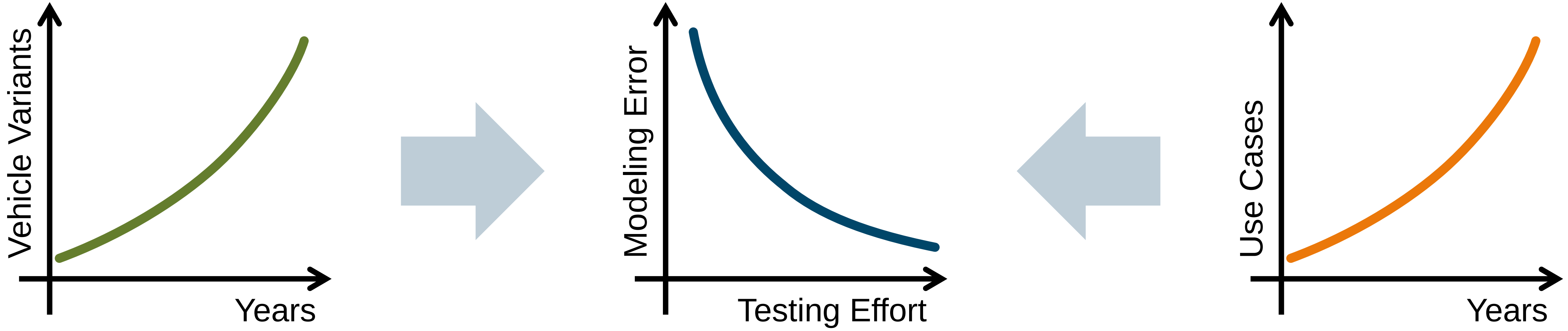
**Define optimal balance between model accuracy level and number of tire tests**

# Use case: Combined Slip tire modelling
## Finding effort vs accuracy balance

Significant increase of vehicle and tire variants

Tradeoff model accuracy and testing effort

Significant increase of use cases



**Challenge: find optimal balance between model accuracy and testing effort for combined slip**

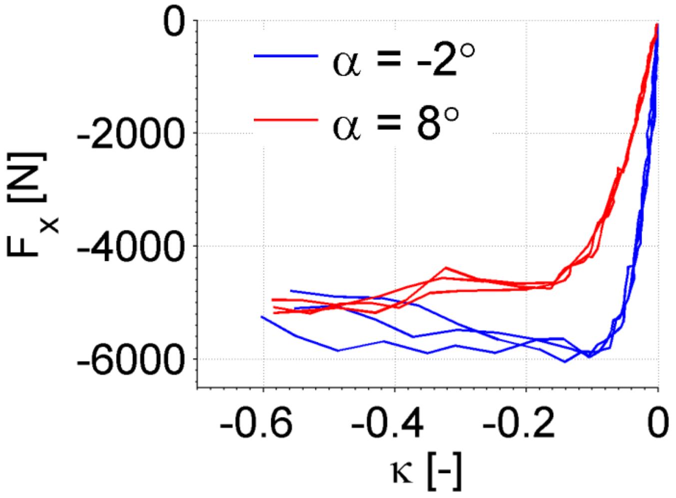
*Reference: optimization of measurement procedures and methodology for combined slip tire behavior*
*Aachener Colloquium Automobile and Engine Technology 2018*

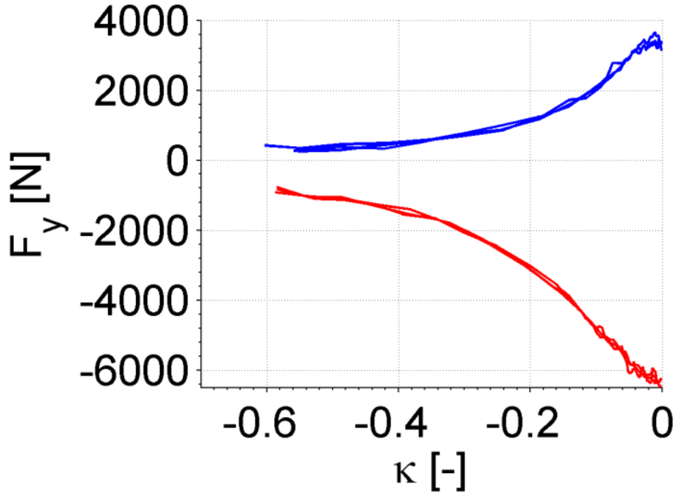
# Use case: Combined Slip tire modelling

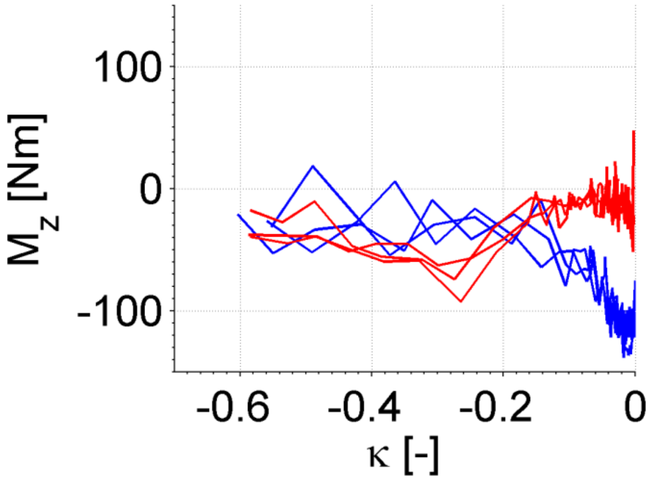
## Research tire testing

- Six tire specifications in 15”-20” size range tested
- Three repetitions for testing condition to evaluate the measurement spread
- Standard deviation of the measurement spread averaged across the testing conditions and the tire specifications.

| $\sigma_{Fx}$ | $\sigma_{Fy}$ | $\sigma_{Mz}$ |
|---|---|---|
| 2.5% | 1.0% | 13.0% |







*Reference: optimization of measurement procedures and methodology for combined slip tire behavior*
*Aachener Colloquium Automobile and Engine Technology 2018*

# Use case: Combined Slip tire modelling

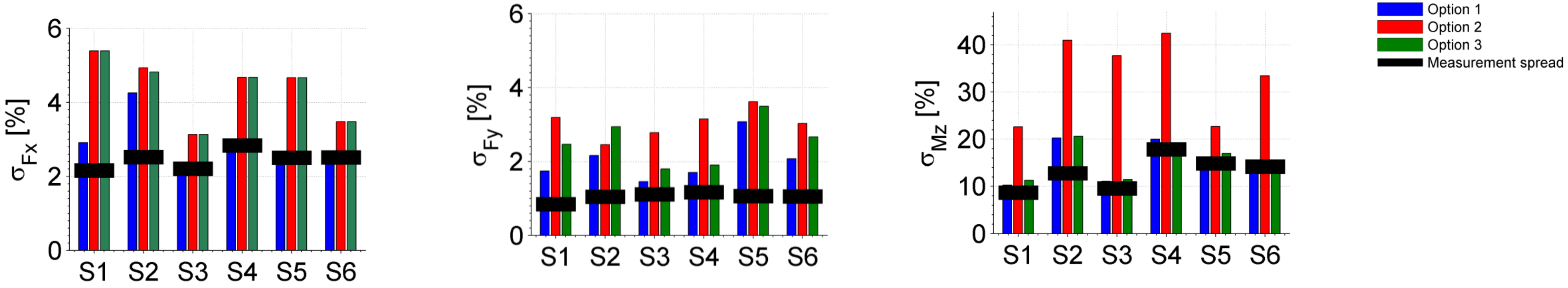
## Balanced tire testing and parameterization methodology

SIEMENS

*Ingenuity for life*

| | # testing conditions | | | |
|---|---|---|---|---|
| Parameterization option | Pure brake/drive | Pure cornering | Combined Slip | Total |
| 1. Full CS | 6 (3 Fz x 2 $\gamma$) | 6 (3 Fz x 2 $\gamma$) | 24 (3 Fz x 2 $\gamma$ x 4 $\alpha$) | 36 |
| 2. Estimated CS | 6 (3 Fz x 2 $\gamma$) | 6 (3 Fz x 2 $\gamma$) | 0 | 12 |
| 3. Partial CS | 6 (3 Fz x 2 $\gamma$) | 6 (3 Fz x 2 $\gamma$) | 3 (3 Fz x 1 $\gamma$ x 1 $\alpha$) | 15 |

- Deviation between model and measurement in comparison to measurement spread



**Methodology allows to define optimal balance between modelling error and testing effort**

*Reference: optimization of measurement procedures and methodology for combined slip tire behavior*
*Aachener Colloquium Automobile and Engine Technology 2018*

# Practical use case

## Low-friction ESC controller tuning:

## Perform accurate tire model parameterization for low-friction

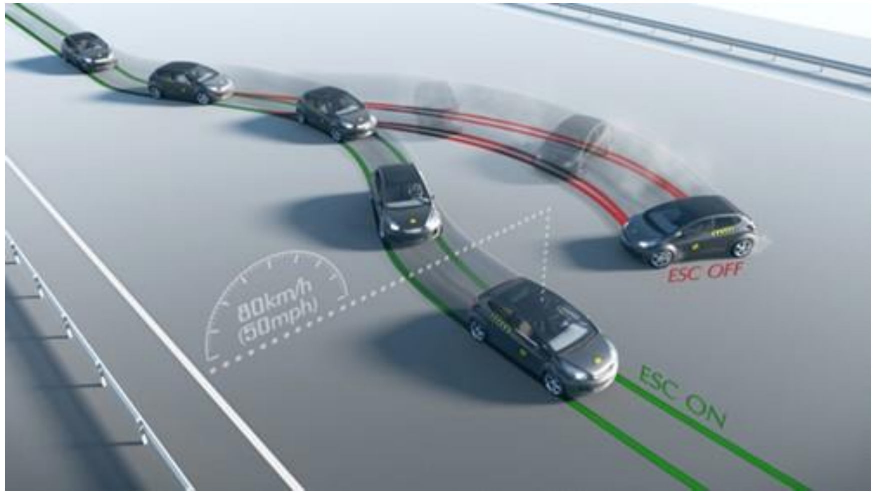
# Use case: Electronic Stability Control at low mu

## Development challenge

- Electronic Stability Control
  - Mandatory since 2014
  - Sine With Dwell

- Challenges of full vehicle ESC testing under winter conditions:
  - Cost intensive
  - Only possible in limited time window
  - Large variation of operating conditions

- Digitalization requires tire model parameterization on different roads surface, e.g.:



https://www.euroncap.com/en/vehicle-safety/the-ratings-explained/safety-assist/esc/

**Polished Ice**

**Snow**

**Scraped Ice**

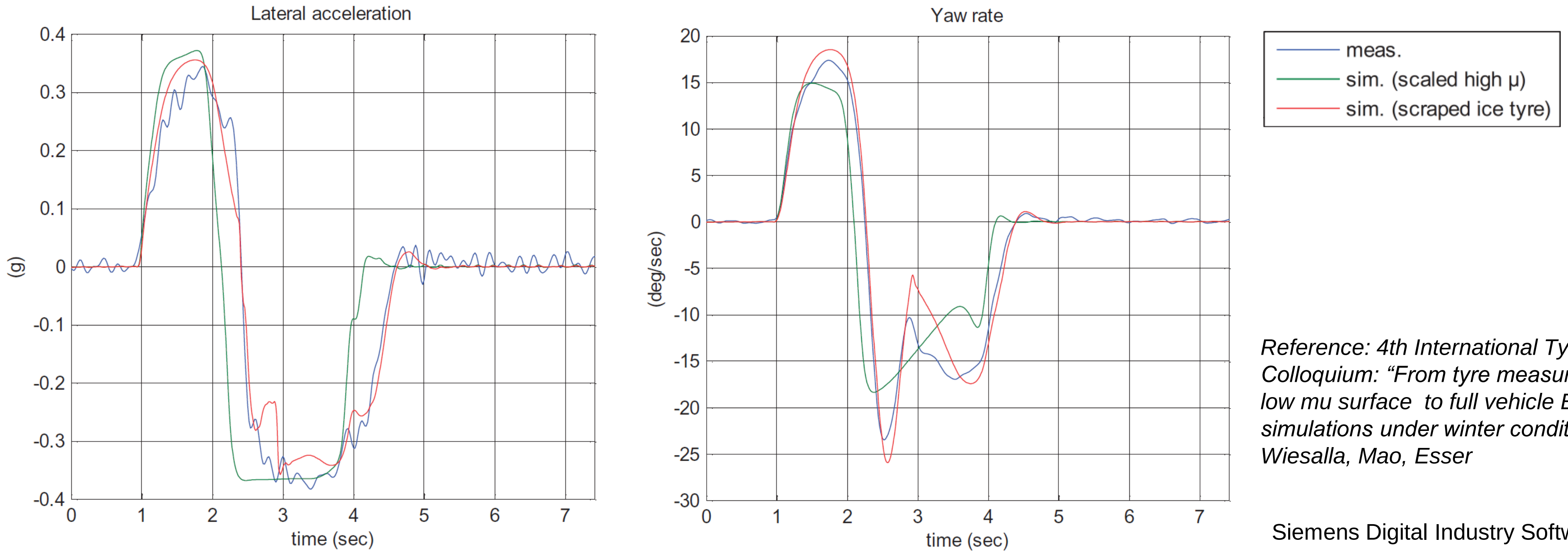
# Use case: Electronic Stability Control at low mu

## Tire testing and validation

- Low mu tire modelling methodologies:
    - Traditional friction scaling of a high mu tire model
    - Low mu tire testing and model parameterization

- Validation study: vehicle and tire testing at same day, location and road surface

- Sine With Dwell maneuver results:

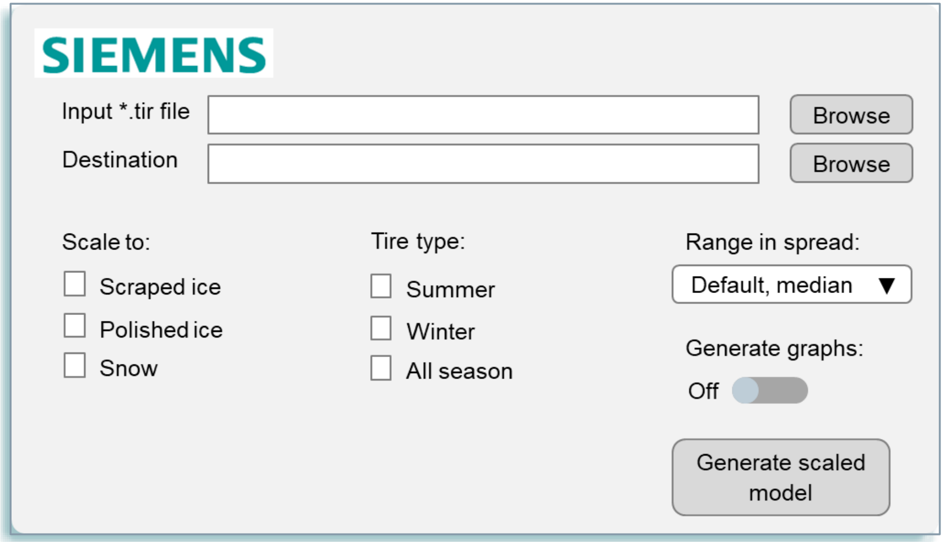


*Reference: 4th International Tyre Colloquium: "From tyre measurements on low mu surface to full vehicle ESC simulations under winter conditions", Wiesalla, Mao, Esser*

# Use case: Electronic Stability Control at low mu
## Tire model scaling

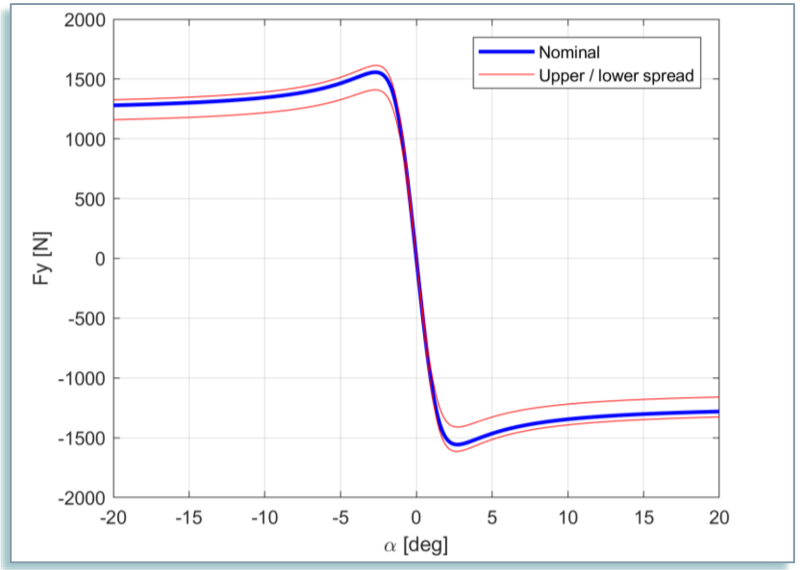
- Environmental conditions have large influence on road conditions and hence on tire performance

- Customized tire model scaling tools:
  - Based on physical relationships
  - Including spreading



Range in spread: Default, median ▼

Generate graphs: Off



**Modeling low mu tire behavior for of ESC provides:**

- **Year-round virtual testing possibilities**
- **Proof of robustness under all conditions**
- **Reduction of costs**

# Alternative solution

Tire Model Marketplace

# Tire Model Marketplace

- 77 directly available tire model parameter sets
- Slip characteristics based on on-road testing, divided in 3 categories

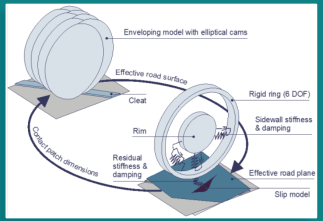
**Alternative to tire testing services with unmatched price/quality ratio**

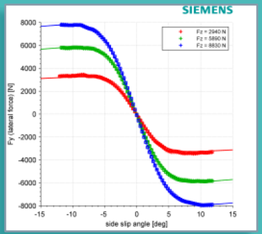
| | Surface | Magic Formula | Turnslip | Rigid Ring | Enveloping |
|---|---|---|---|---|---|
| MF-Tyre + turnslip | Dry asphalt | Measured | Measured | Estimated | Estimated |
| MF-Tyre low mu | Snow/ice | Measured | - | - | - |
| MF-Swift estimated | Dry asphalt | Estimated | Estimated | Estimated | Estimated |

# Summarizing

Tire testing

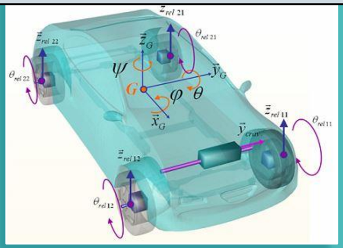
Tire model theory





Tire model parameterization

**Integral tire modeling approach to reach the highest accuracy and efficiency**



Tire model application