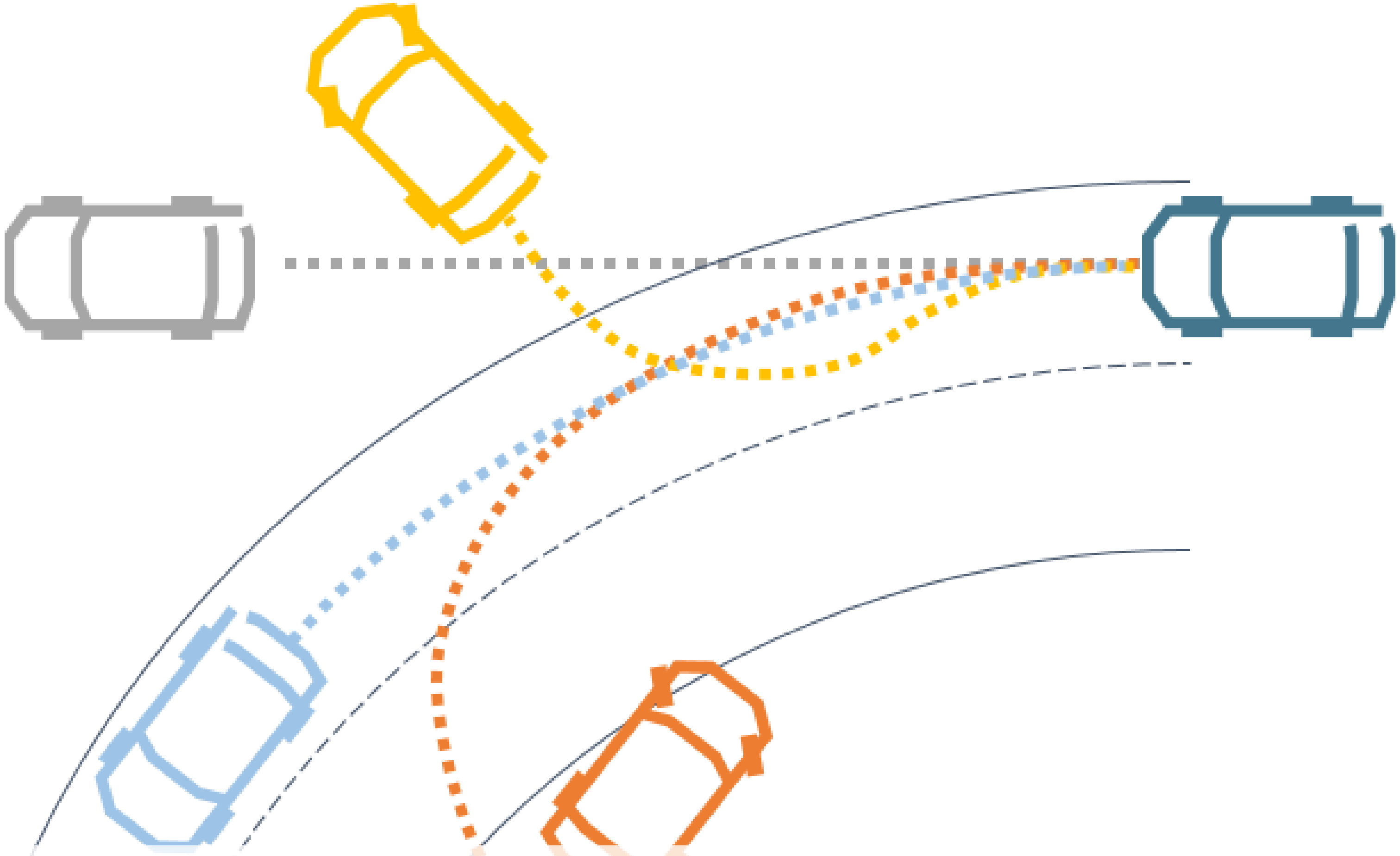

Potential of Vehicle Dynamics Control Systems to laterally control a Vehicle in Case of a Steering System Failure

October 2020, Steven Grall, Peter Lenz

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Agenda

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Outline Bertrandt

1974	Overall performance	About 13.600	More than 50 locations in
Foundation Bertrandt	FY 2018/19: 1 bn Euro	employees	Europe, the USA and China

From the initial idea to production readiness

Design · Vehicle Body · Interior · Electronics · Powertrain · Chassis · Simulation · Testing · Engineering Services

In different Industries

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Range of Services

Trends

- Digitalisation
- Autonomous Driving
- Connectivity
- Electric Mobility
- Vehicle Safety
- IT Services
- Virtualisation

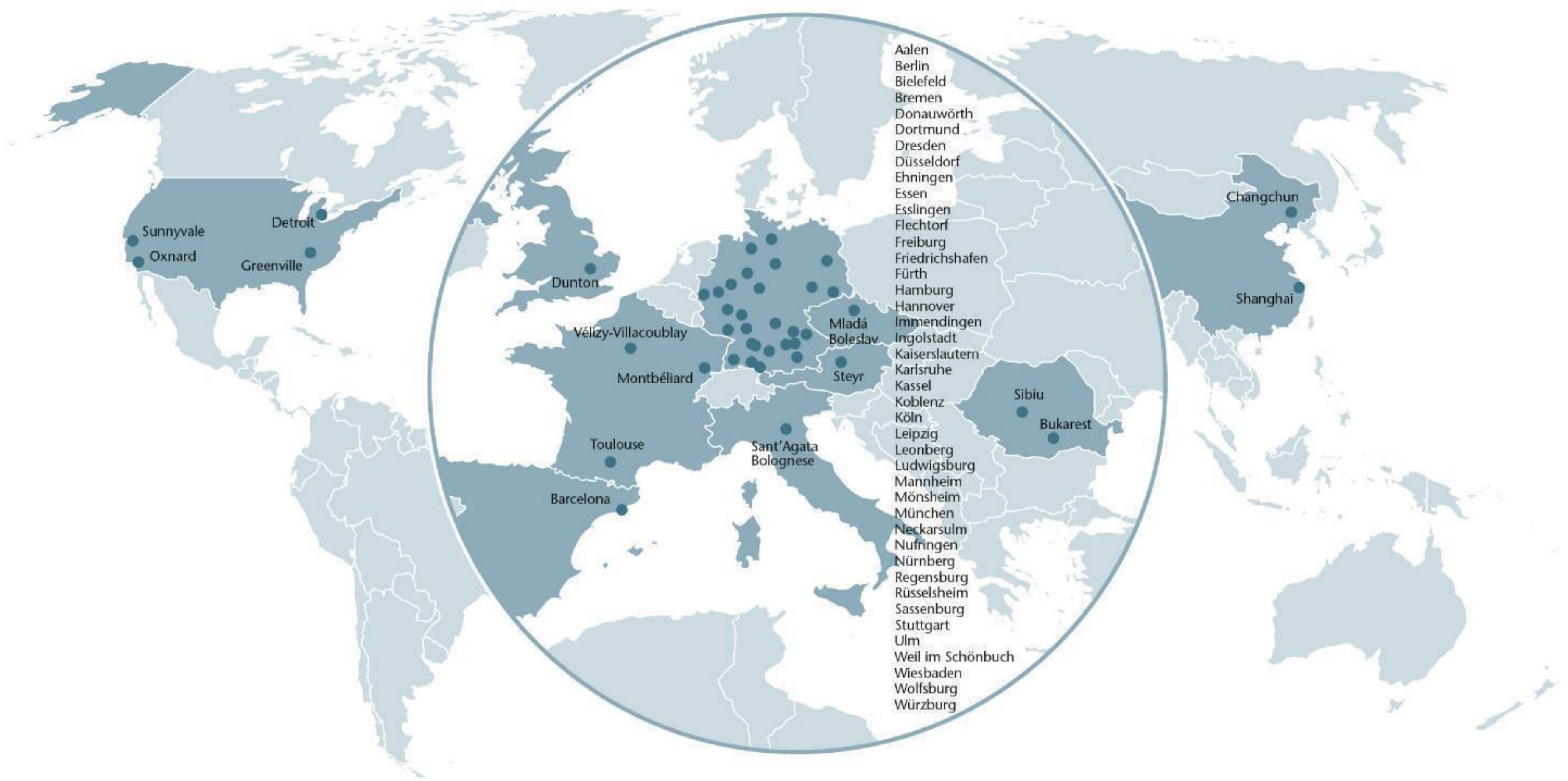
- Design Services
- Interior
- Vehicle Body
- Powertrain
- Chassis
- Simulation
- Electronics
- Modelling-/Rapid Technologies
- Simulation
- Engineering Services

Industries

- Automotive Industry
- Aerospace
- Commercial Vehicles
- Agriculture
- Motorcycle
- Electric Industry
- Mechanical-/Plant Engineering
- Medical Engineering
- Energy Management

We Want to Be Close to Our Customers – Decentralised Organisation

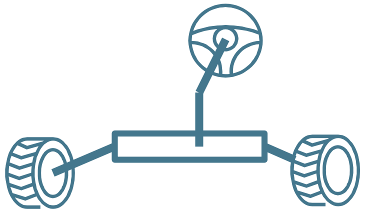
Round **13,000 employees** at more than **50 locations** in Europe, the USA and China.



Motivation

Where we are today

„Mechanical“ steering systems

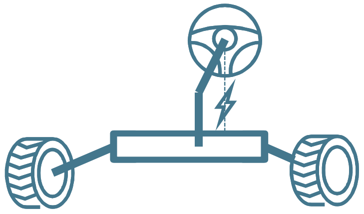


Megatrends:
Electrification
Autonomous driving

Regulations:
ECE-R 79

Where we want to go

Steer-by-Wire



+ Key technology to autonomous driving
+ New functions
+ Package
+ Less complexity

- Synthetic steering feel
- Risk of failure

What is challenging us

Minimization of Risks

Back up: Redundancy

Remaining Risk

Use of existing systems as back up systems to laterally control the vehicle in case of a steering system failure

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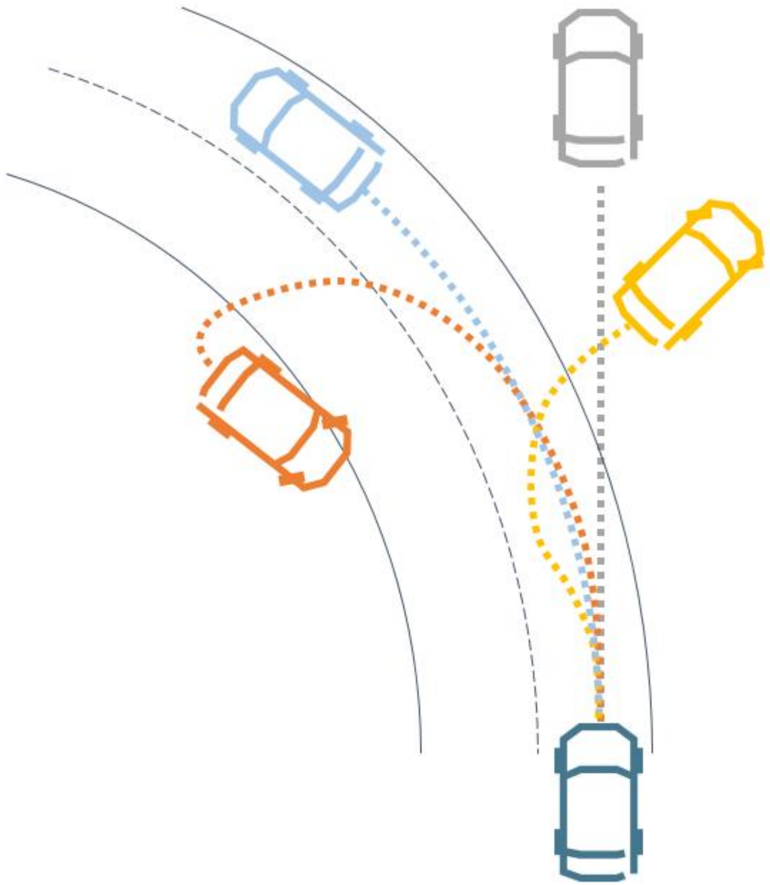
What could go wrong?



Failure Scenarios

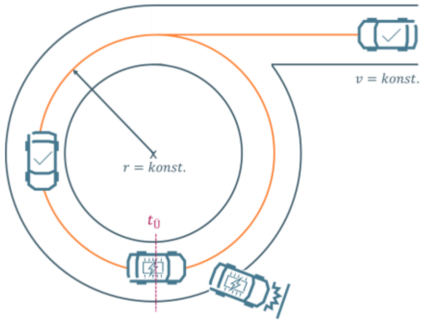
– **Scenario „Loose“**
  > SbW-System without function
  > No torque on the steering rack
  > No lock of current position
  > Front Wheels can turn freely

– **Scenario „Locked“**
  > SbW-System without function
  > Front wheels will be turned into neutral positon with defined steering angle velocity
  > Front wheel angle gets locked at neutral position

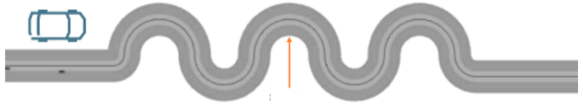
How do we test?

<u>Driving Manoeuvres</u> <u>(excerpt)</u>

– **Steady-State circular test**
  > Driving in a circle with constant radius and constant speed



– **Slalom**
  > Consecutive left and right turns



<u>Test Execution:</u>

– Speed should be kept constant during each test
– Given trajectory should be followed
– Parameters to be varied from test to test:
  > Vehicle Speed
  > Radius
  > (lateral acceleration)

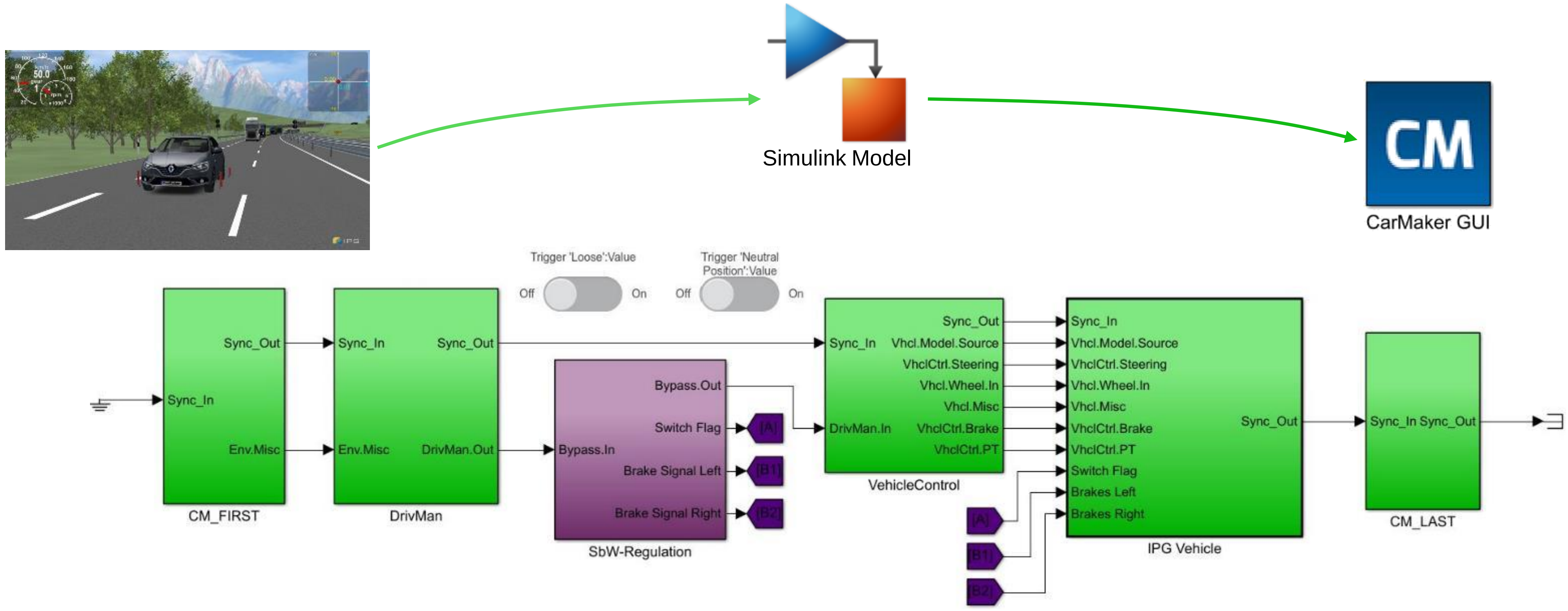
<u>Assumptions:</u>

– Friction coefficient = 1
– Parameters chosen according to Standard highway and rural roads
– Ideal actuator behaviour

Objective: General statement about the ability of backup systems to lateral control of the vehicle

Testing Environment

- Simulation Software: IPG Carmaker
  - > Setup of test cases
  - > Vehicle with electro mechanic steering system
- Development Software: Matlab/Simulink
  - > Control systems
  - > Simulation of steer-by-wire failure



Using longitudinal forces

1) Steer by **brake torque**

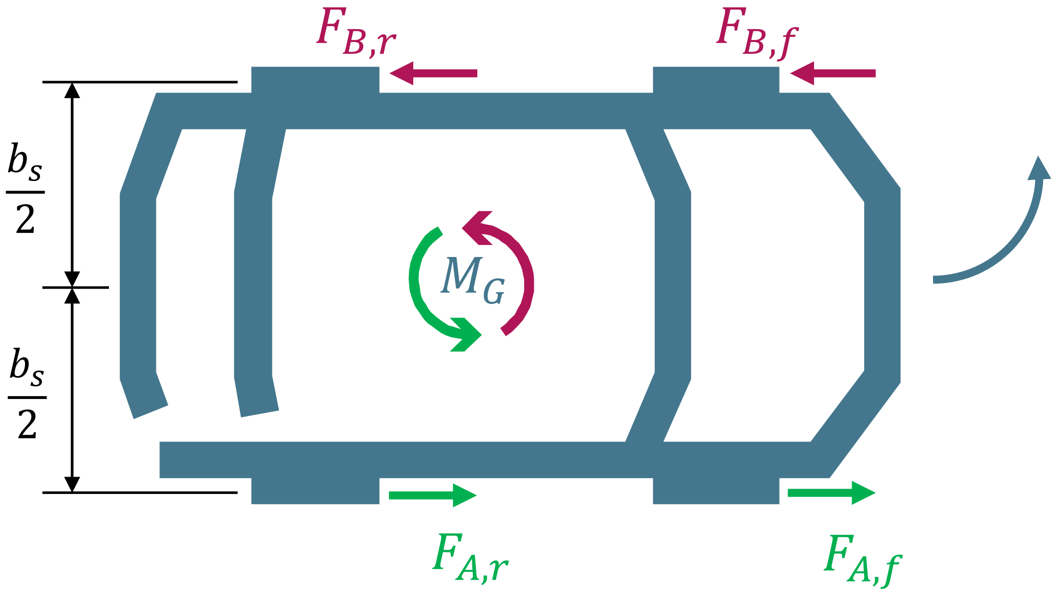
- Using the ESP-System to brake selected wheels individually
- Asymmetric braking creates a torque about the z-axis of the vehicle
- *Vehicle will slow down*

2) Steer by **torque vectoring**

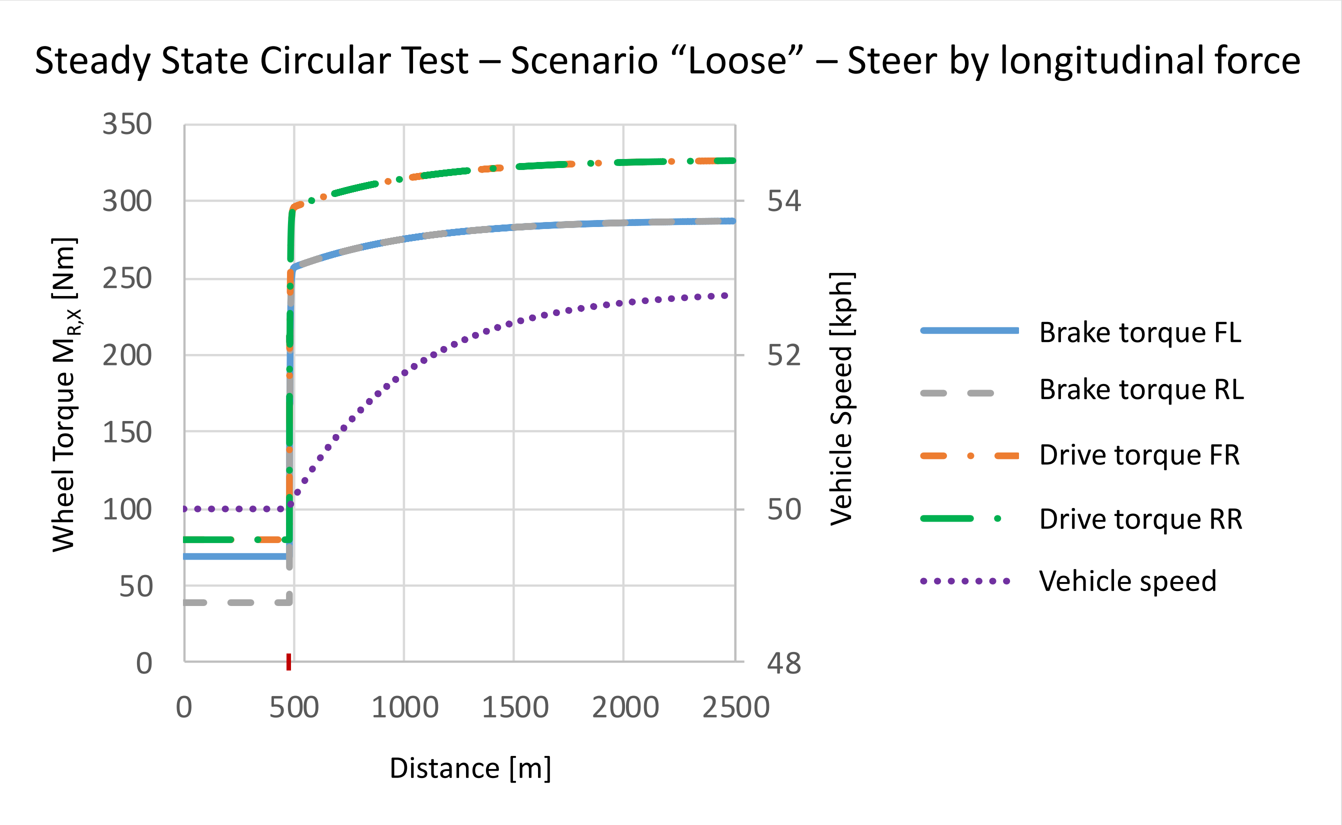
- Transferring engine torque to selected wheels individually
- Asymmetric engine torque creates a torque about the z-axis
- *Vehicle might accelerate*

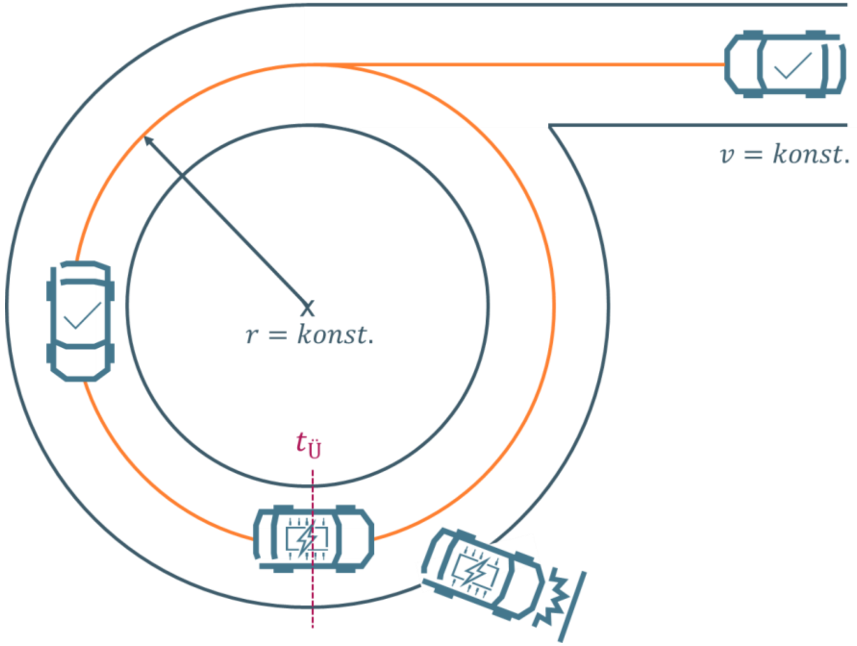
3) **Combination** of brake torque and torque vectoring

- Required torque about the z-axis can be generated
- Vehicle speed can be kept constant



Longitudinal Steering - Test Results

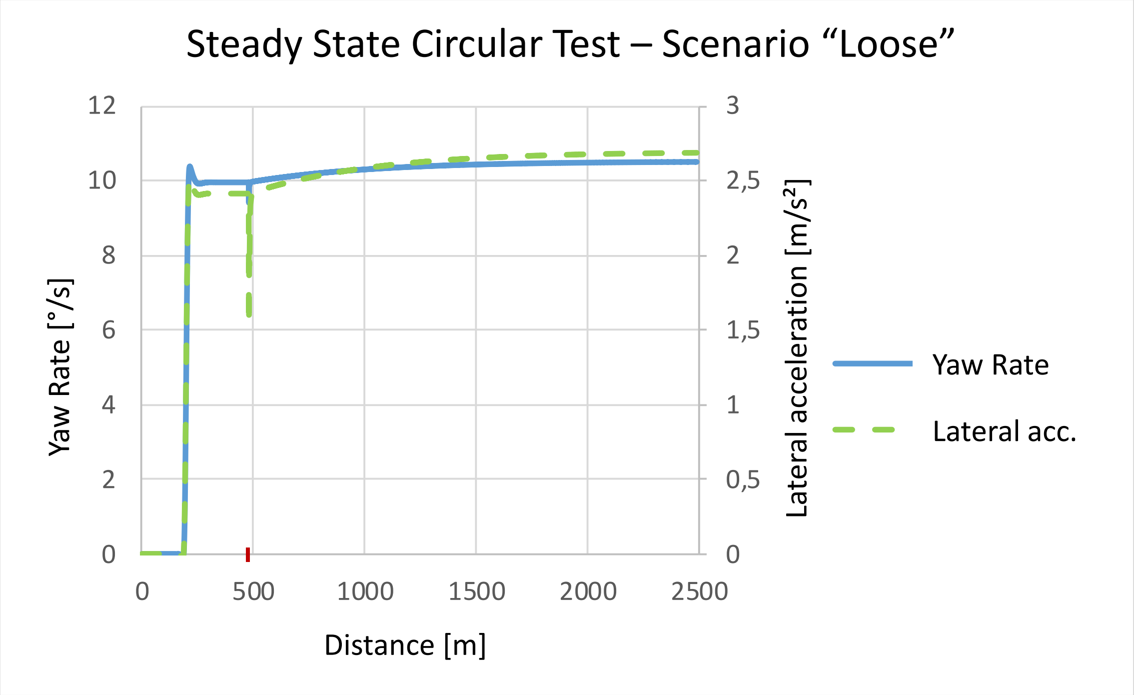


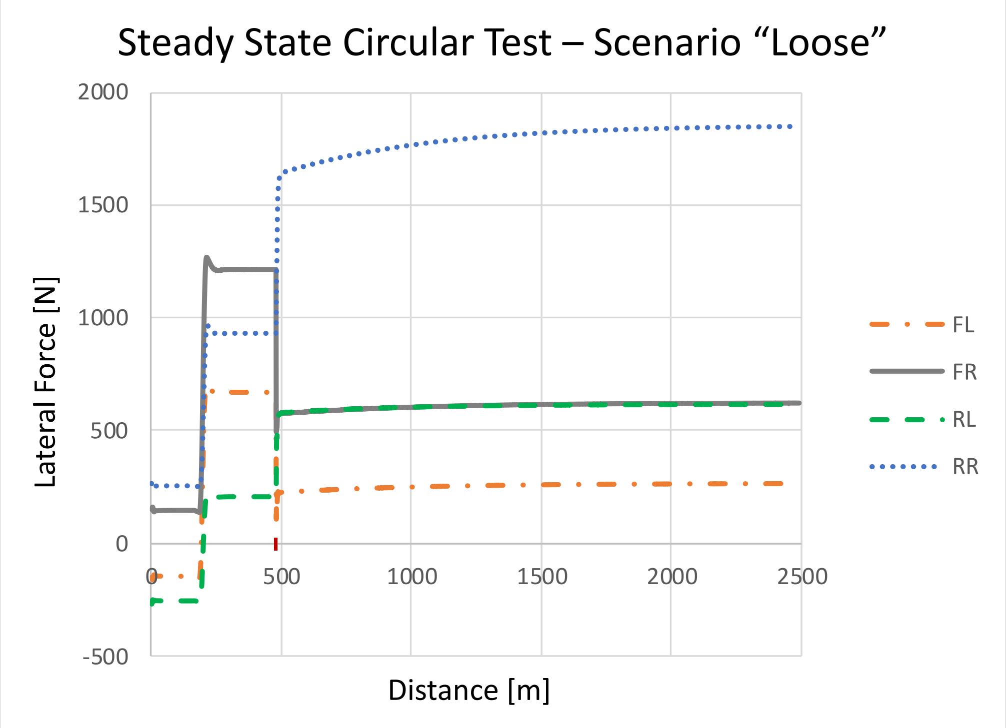


$r = 80\ m$	$a_y = 2{,}4\ m/s^2$
$v = 50\ km/h$	$\dot{\psi} = 9{,}95\ °/s$

- After the switch from conventional steering to steering by longitudinal forces at 500m the brake and drive torque are applied to the related wheels to lateral control the vehicle.
- The vehicle speed is increasing slightly (from 50 kph to ~53 kph)

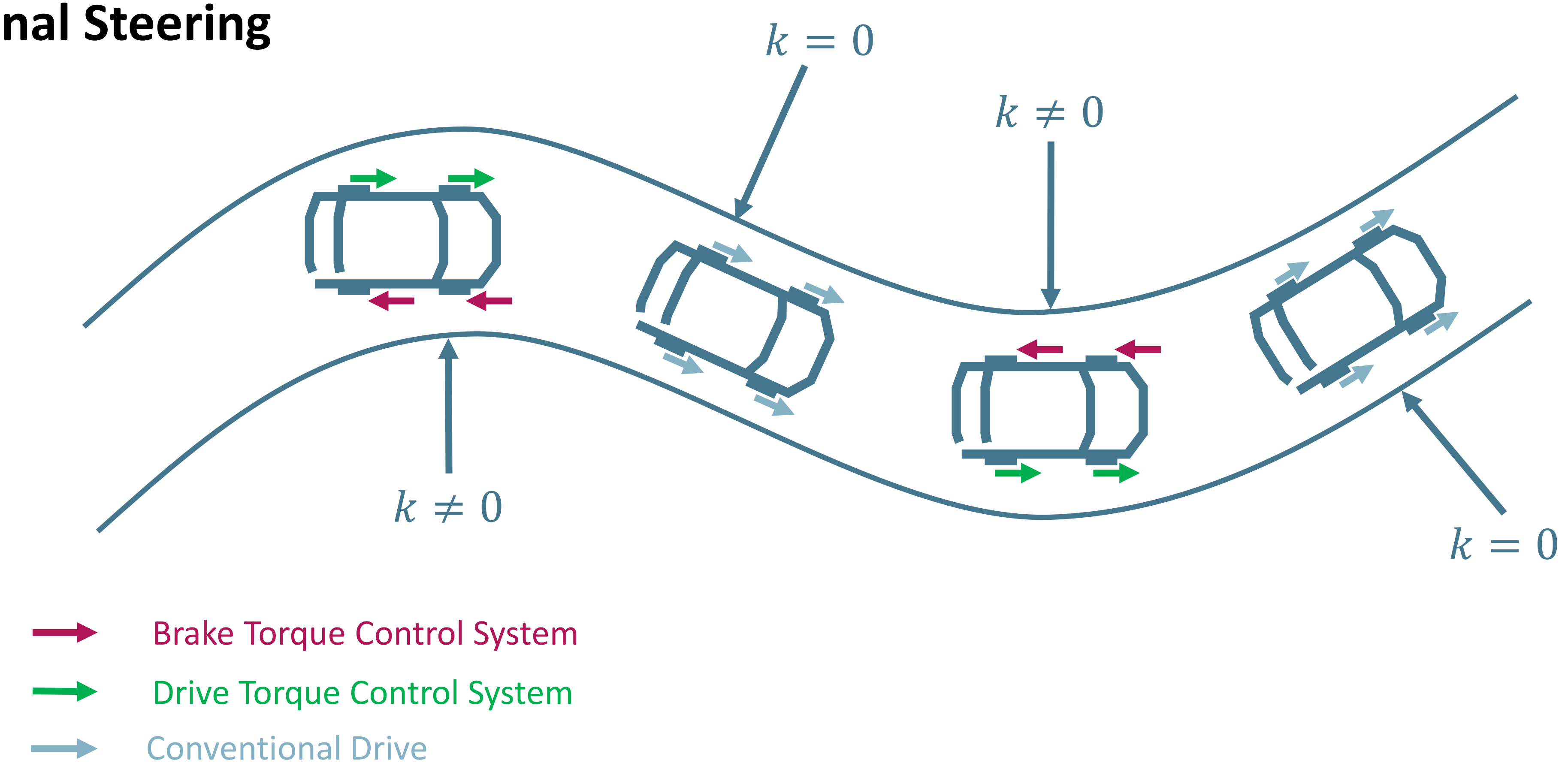
Longitudinal Steering - Test Results





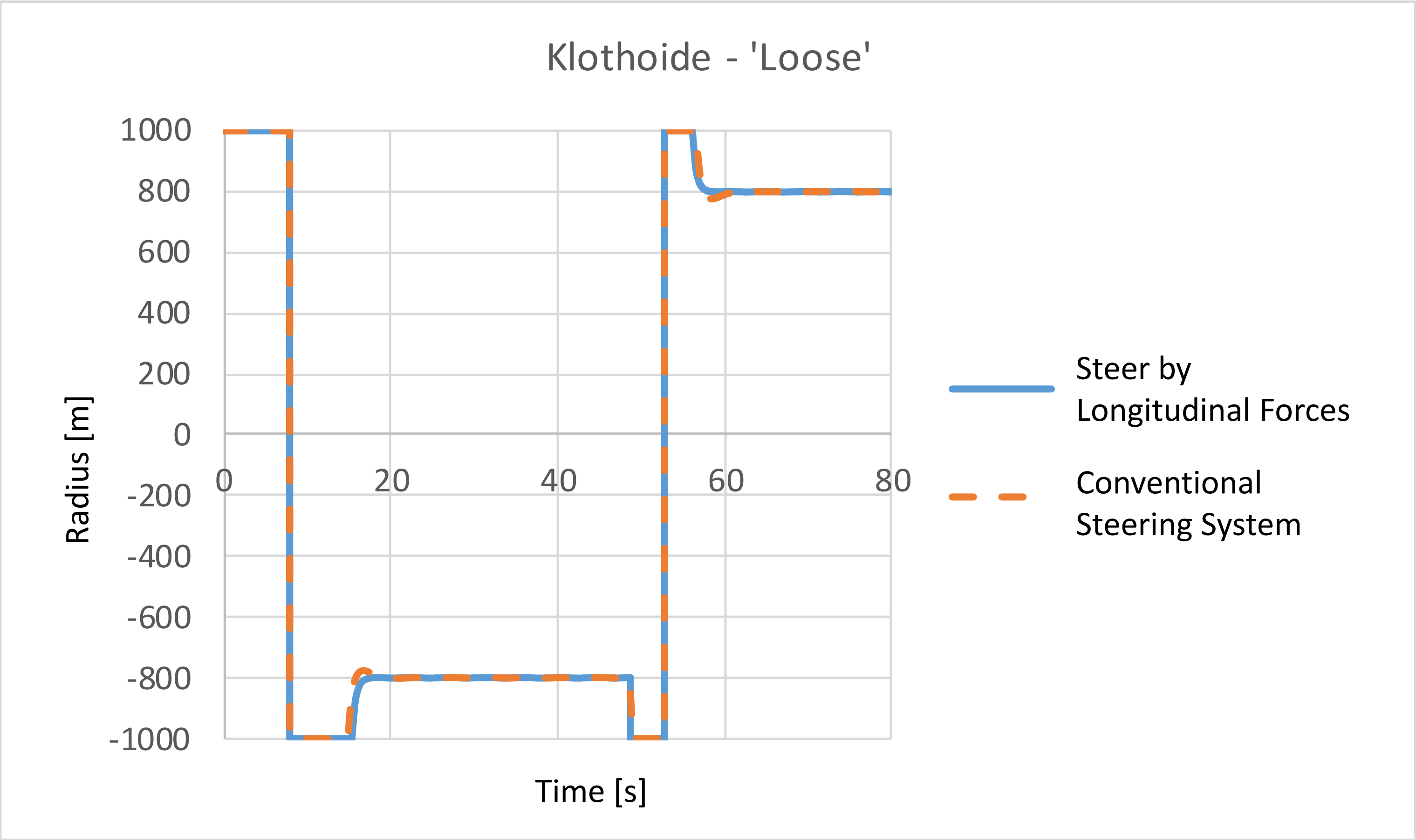
- The **yaw rate stays** constant after the switch from conventional steering to steering by longitudinal forces at 500m
- When the backup-system is working, most of the **lateral force is generated by the rear axle**

Longitudinal Steering

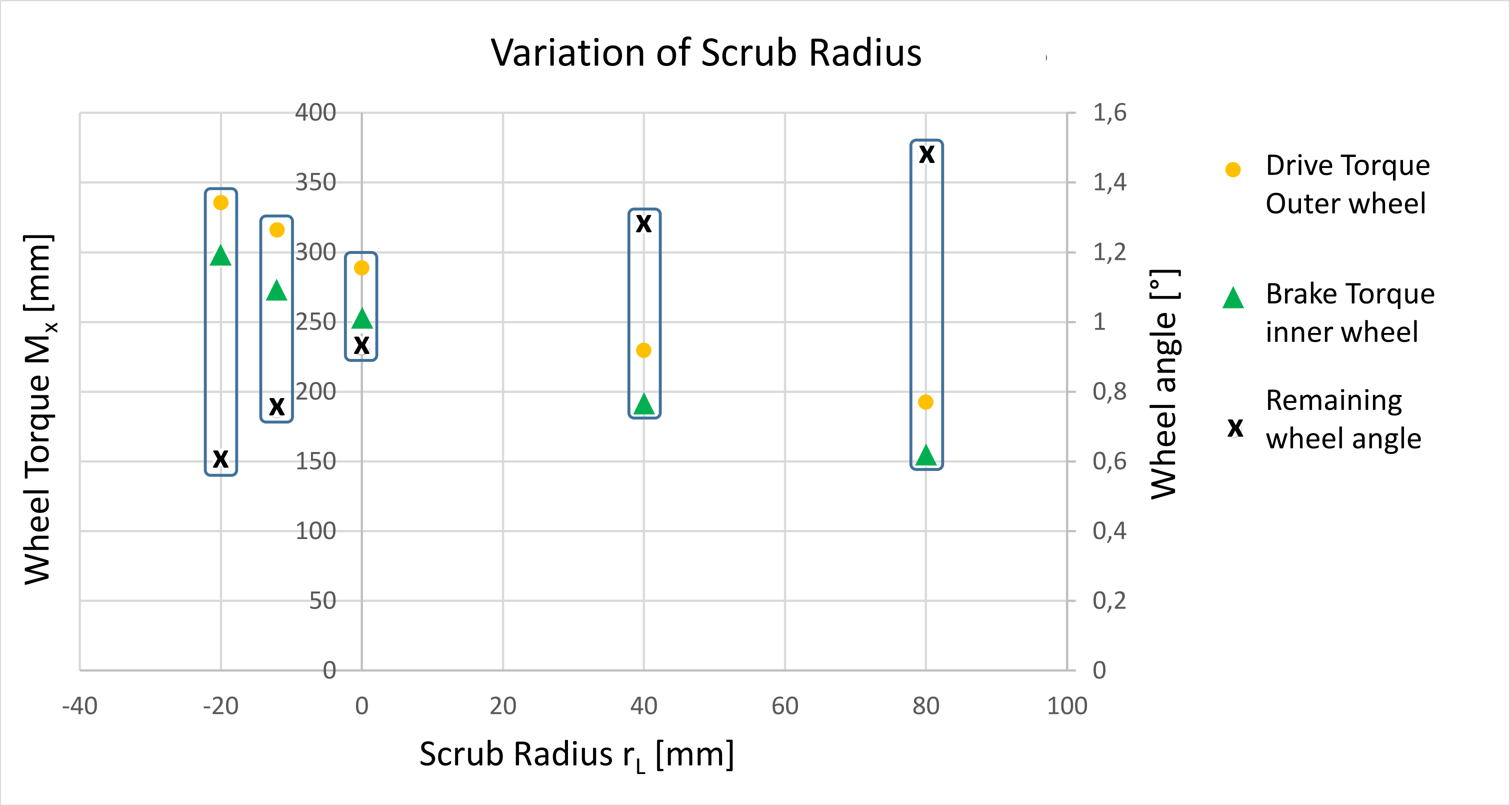


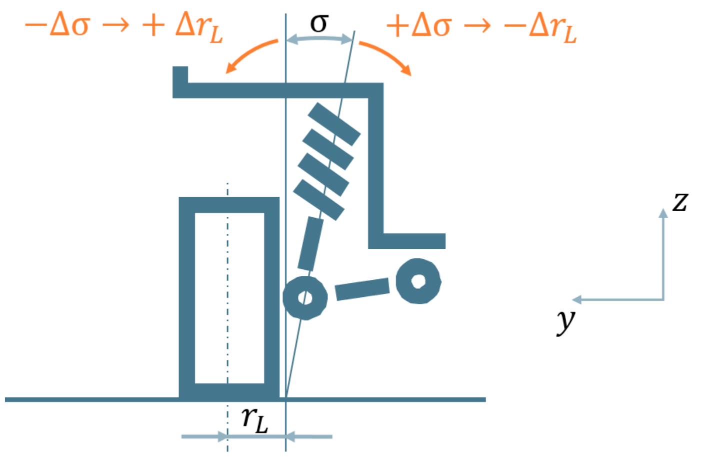
$r = 800 \,\&\, 1000\, m$	$a_y = 0{,}96\, m/s^2$
$v = 100\, km/h$	$\dot{\psi} = 2\, °/s$

Longitudinal Steering - Test Results



Longitudinal Steering - Sensitivity Analysis

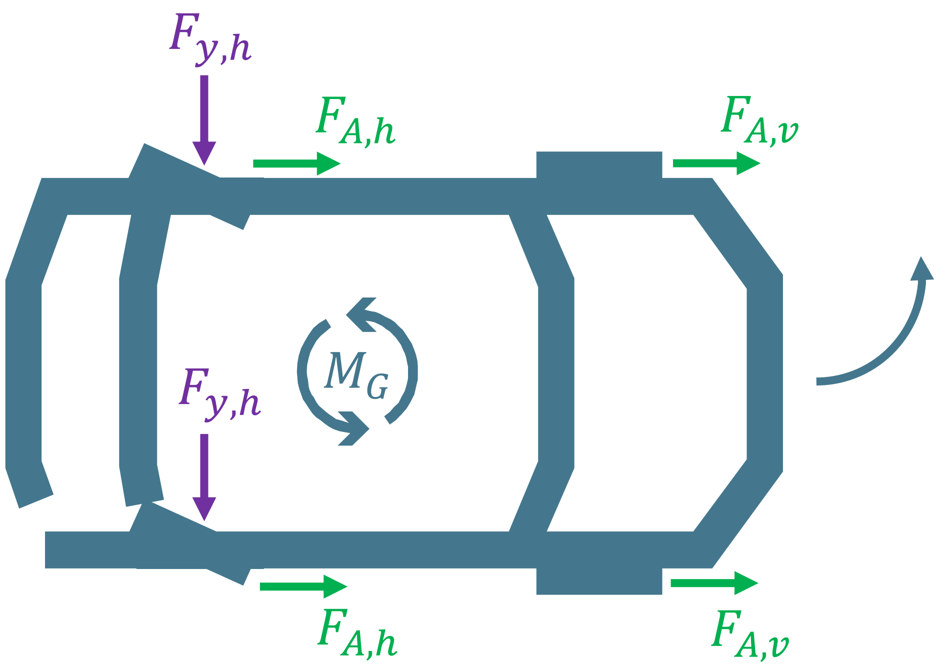




- $\sigma = 0\,°$ results in 45 % less required drive and brake torque in comparison to the base model

Using Rear Wheel Steering

- rear wheels turn opposite to the front wheels
- Steering torque will be mainly generated at rear axle
- Assumptions:
  - > Rear axle steering angle up to **15°** (comparable to front axle)
  - > This system will only be used if the front wheels are **locked in neutral positon**



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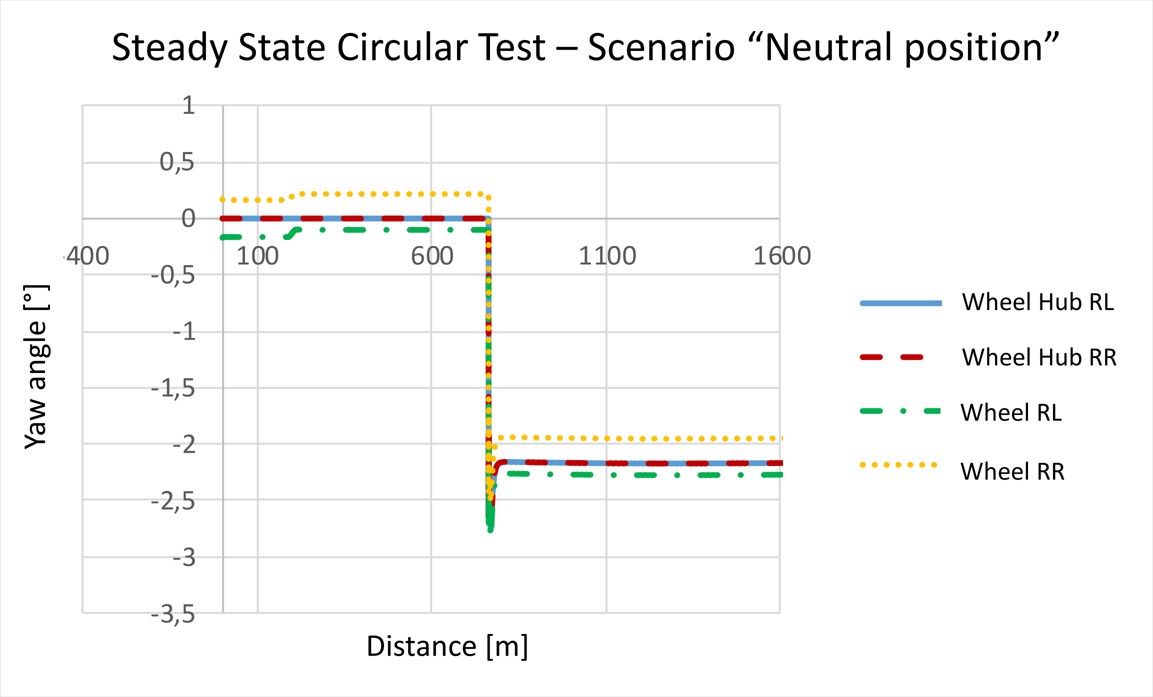
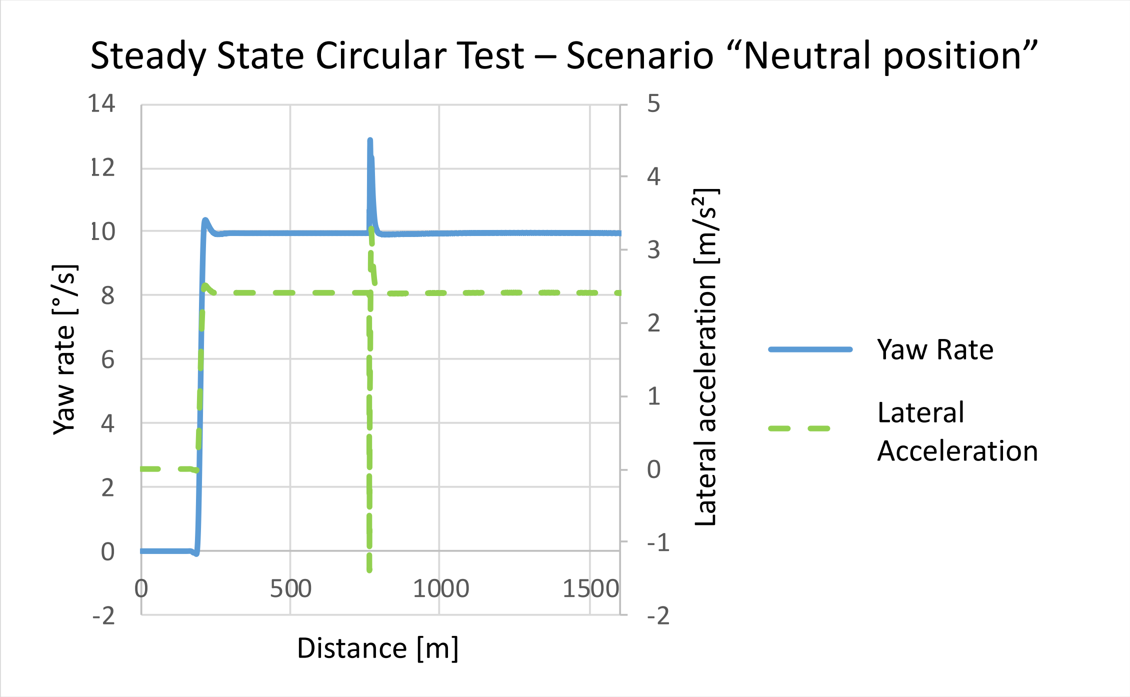
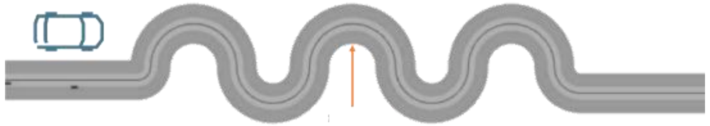
Rear Wheel Steering - Results

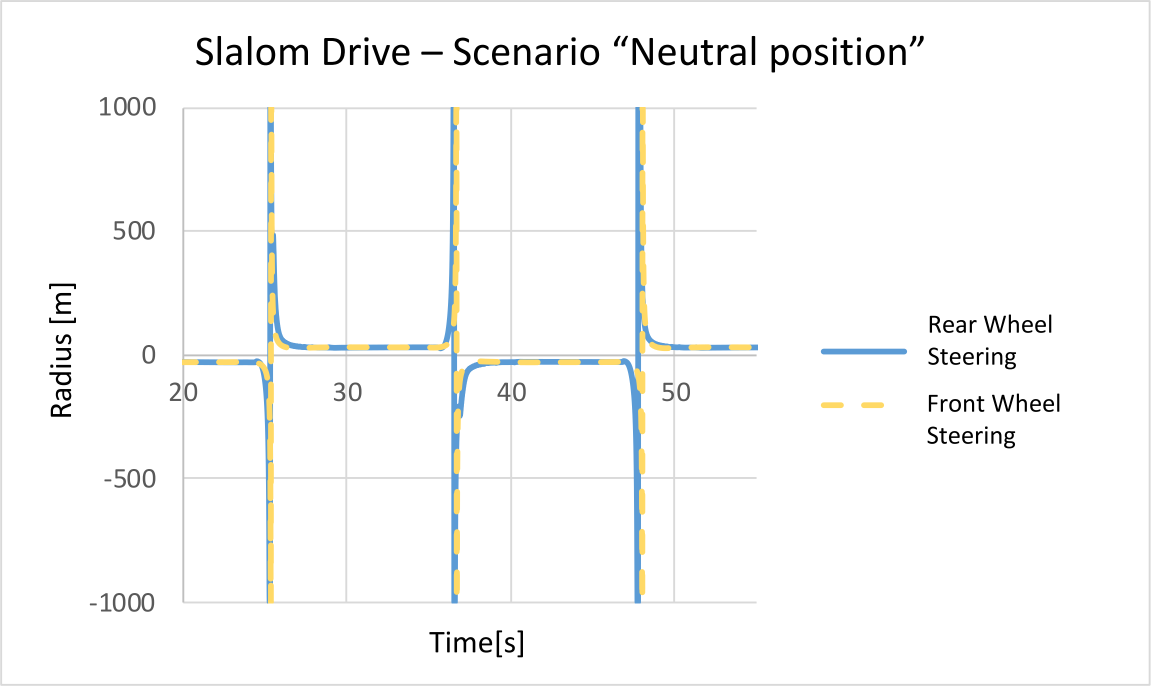


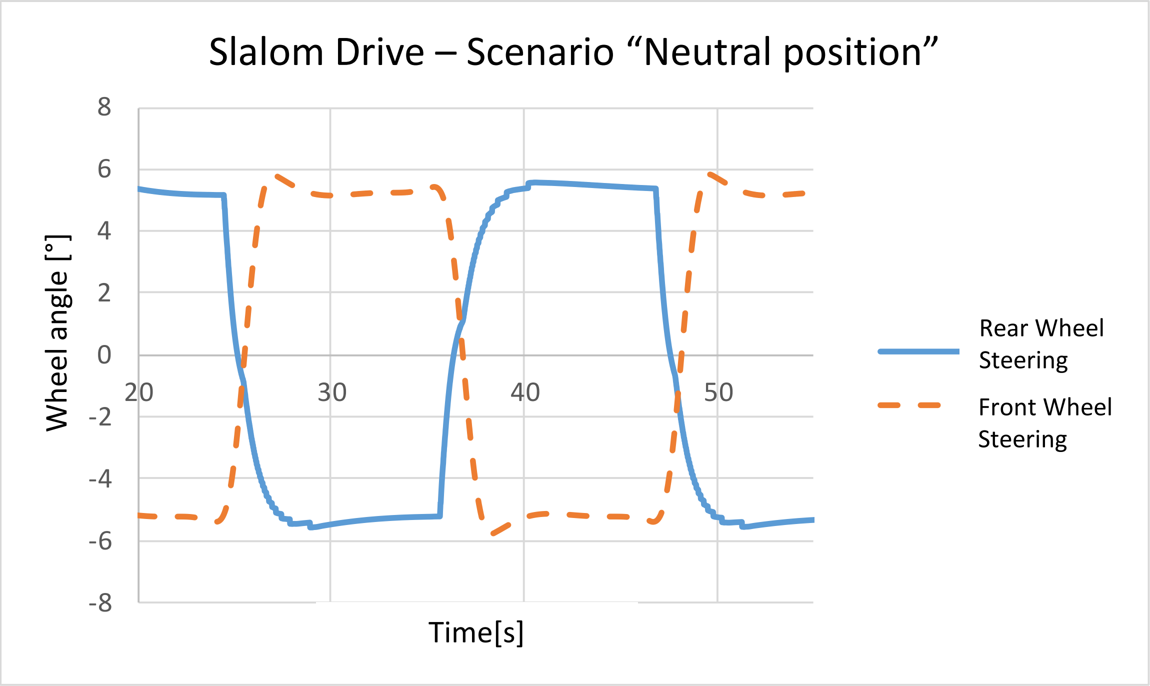


- Rear wheel steering is taking over the lateral control at ~750m
- Difference between wheel and wheel hub angle is based on toe angle depending on the suspension position
- The peak of yaw rate and lateral acceleration are caused by the delay of 0,15s between the failure of the steering system and the takeover of the backup system at ~750m

Rear Wheel Steering - Slalom







$r = 30\ m$	$a_y = 1{,}54\ m/s^2$
$v = 30\ km/h$	$\dot{\psi} = 15{,}9\ °/s$

Comparison of standard front wheel steering and Rear wheel steering

– Same radius and so following the same path

– Very similar steering angles of the affected wheels

> Just the sign is the opposite

Summary

- Both tested backup systems (Steer by brake & drive torque and rear wheel steering) have **a potential to laterally control** a vehicle with a non-functional steering system
  - Working in almost any situation we tested, when the **lateral acceleration is $< 4\ m/s^2$**
  - The appropriate backup systems is **depending on the error case**

- Steering by brake an drive torque is **more complex** than steering with rear axle

- Steering by brake and drive torque has a **higher system demands**

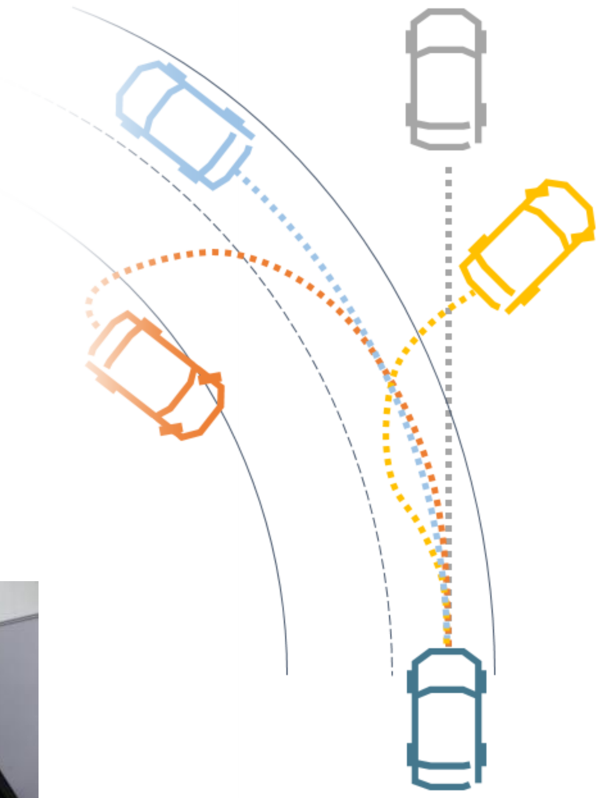
- Torque vectoring and rear wheel steering are **not available** in most of the vehicles

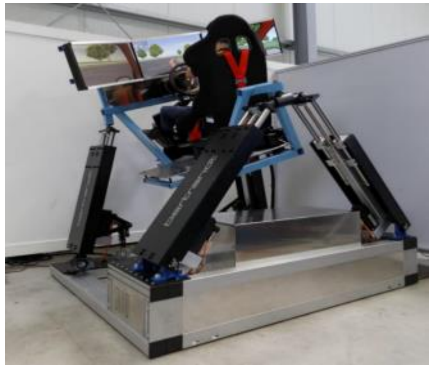
What is next?

– **Get closer to Reality**
  > More detailed models for the actors
  > More detailed suspension models
  > More Scenarios (e.g. “random position locked”)

– **More Simulation & Testing**
  > New driving manoeuvres
  > Wider range of curvature and speed to be looked at
  > More parameters to vary (friction coefficient)
  > Sensitivity analysis of more suspension parameters

– **Human-in-the-Loop Testing**
  > Implementing the backup systems an our dynamic driving simulator
  > Subjective evaluation of the steering feel of backup systems





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