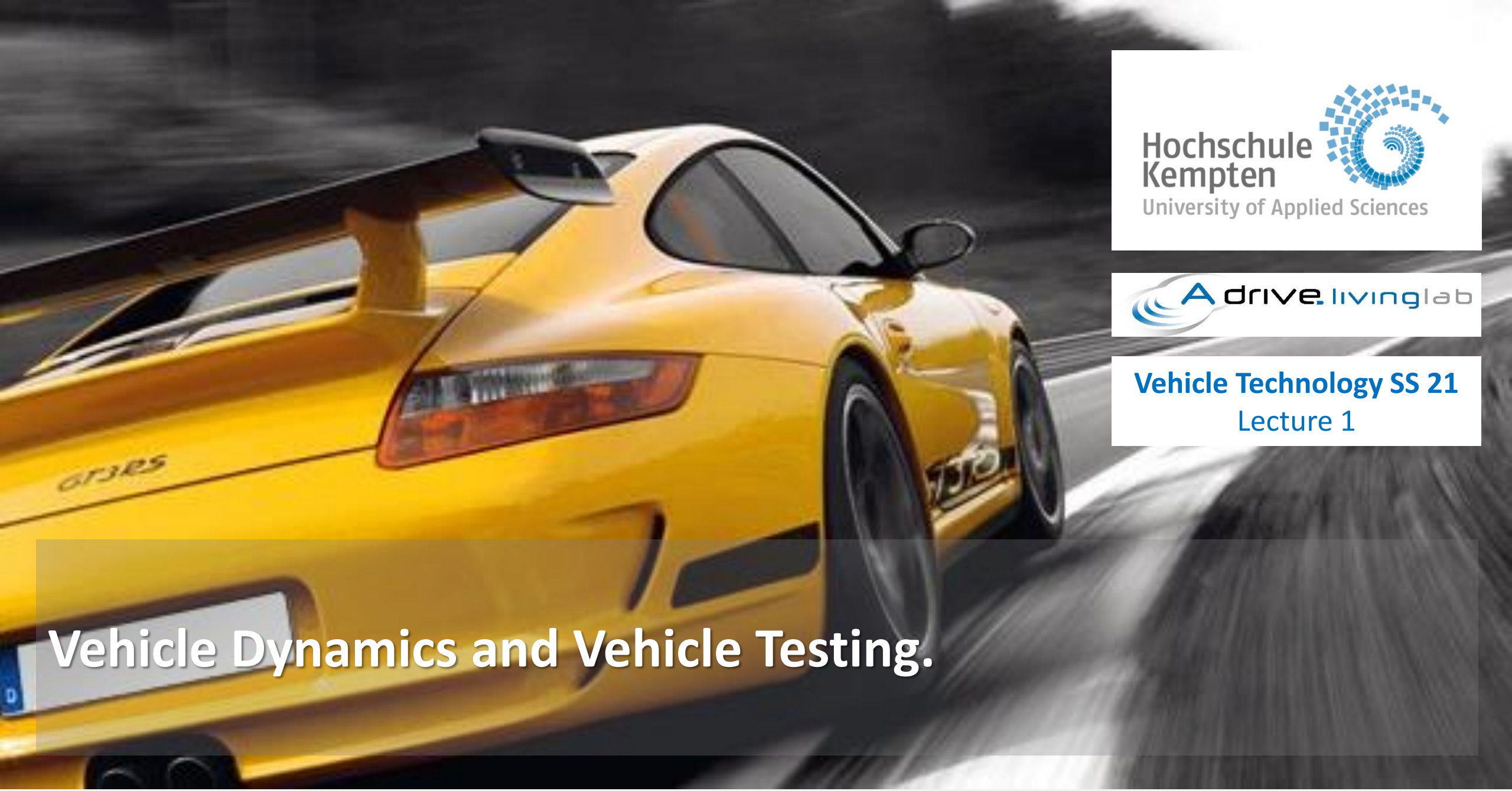

Hochschule Kempten
University of Applied Sciences

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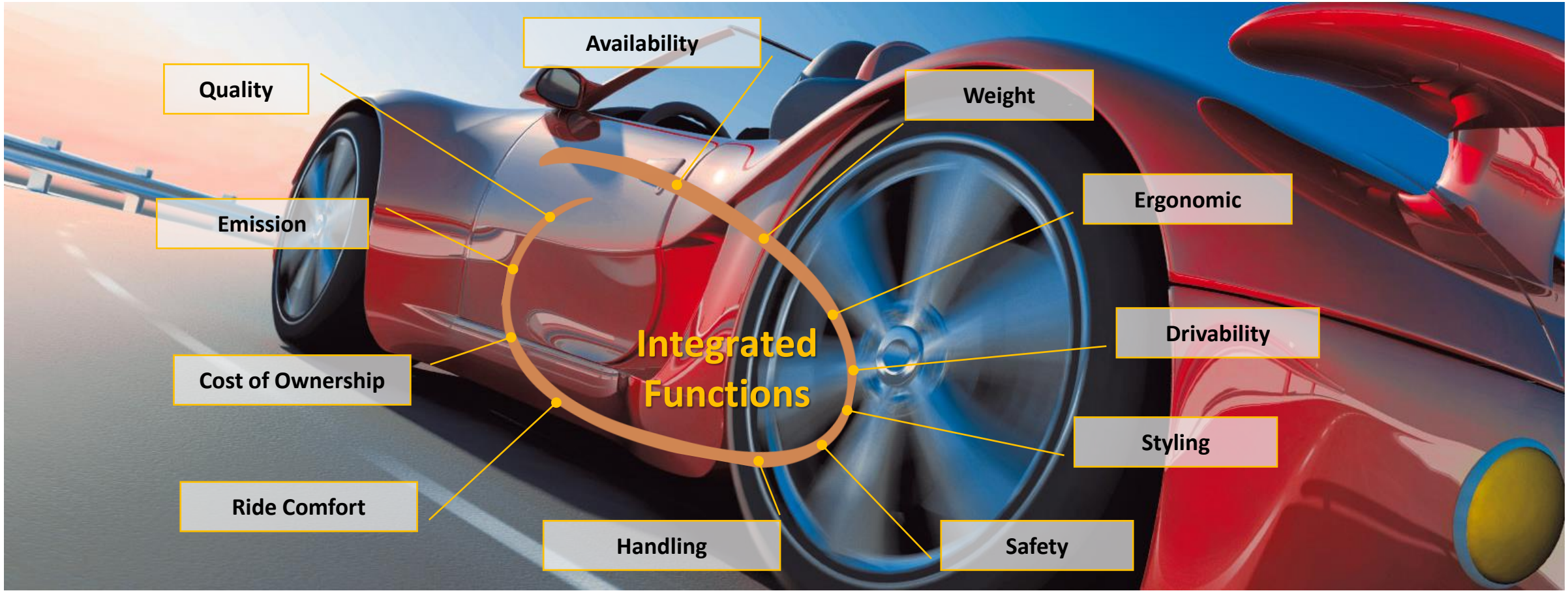
Vehicle Technology SS 21
Lecture 1

Vehicle Dynamics and Vehicle Testing.

Agenda

Nr.	Datum	Inhalt
1	19.03.	Introduction Vehicle dynamics
2	**26.03**	**Practical Training Vehicle Dynamics Simulation and Evaluation**
3	09.04.	Test and evaluation methods for vehicle attributes with practical simulation
4	16.04.	Chassis components and functions with practical simulation
5	30.04.	Basic vehicle dynamics calculation and vehicle models
6	**18.06**	**Track Day**
7	25.06.	ESP–Functions & Application & Process
8	**02.07.**	**ESP–Application & Hands-On Workshop**
9	09.07.	Project Day

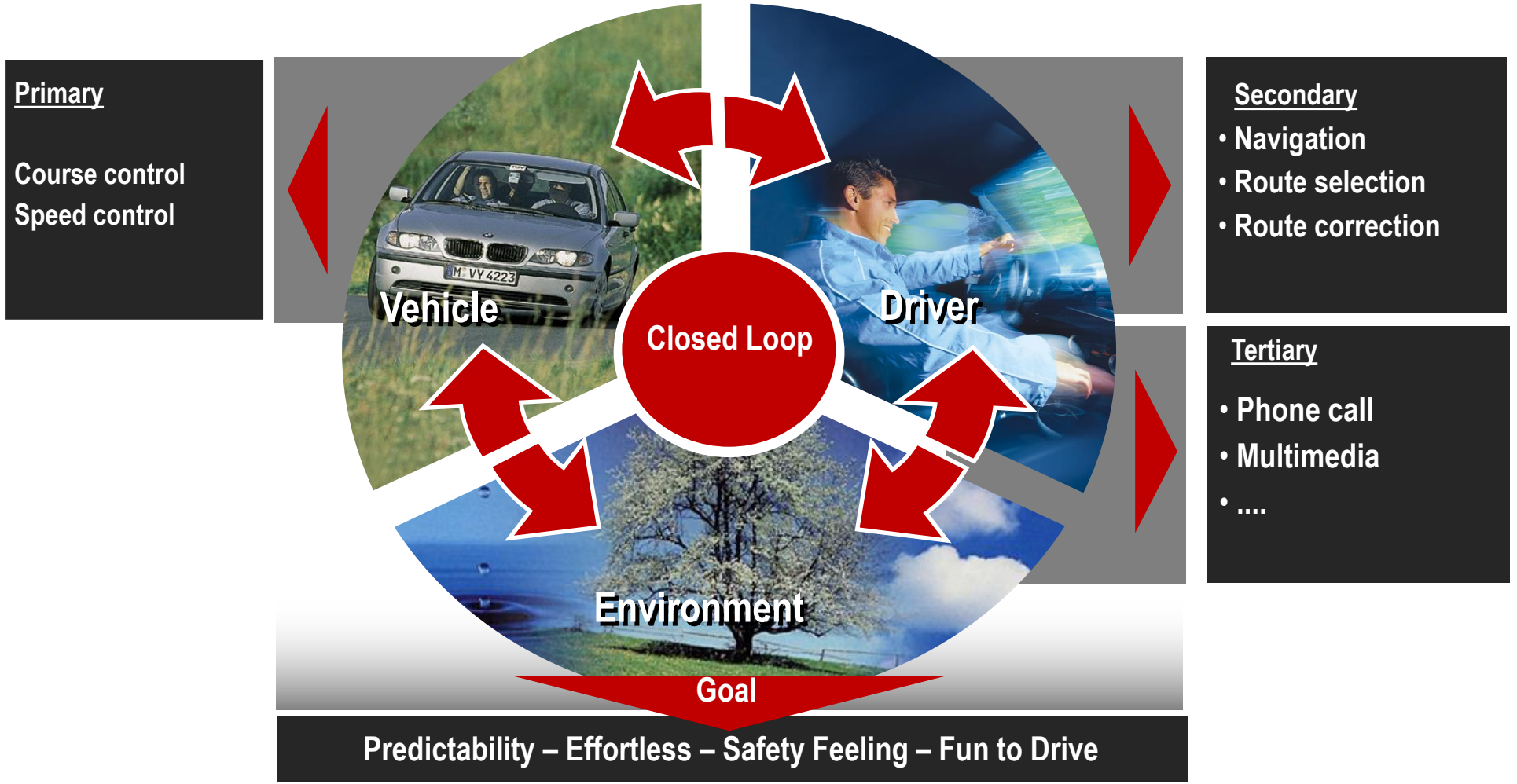
Major issue for customer values are the global vehicle attributes



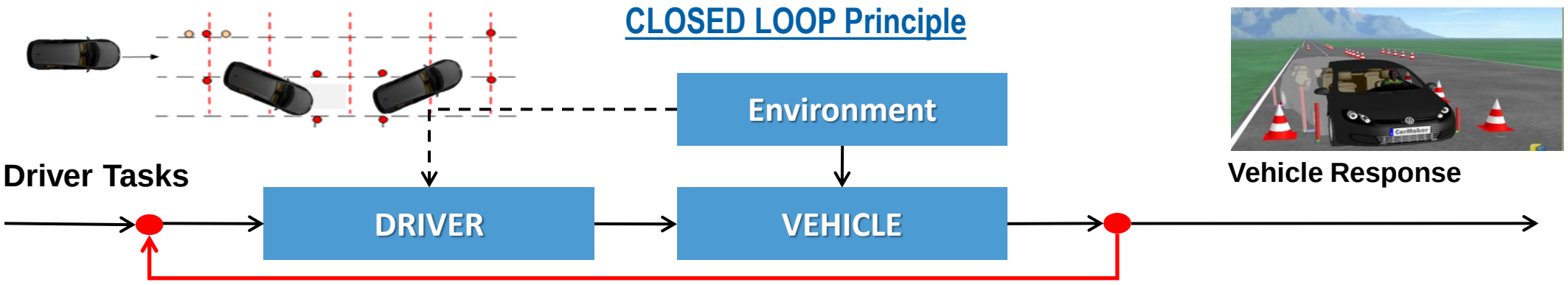
Introduction Vehicle dynamics

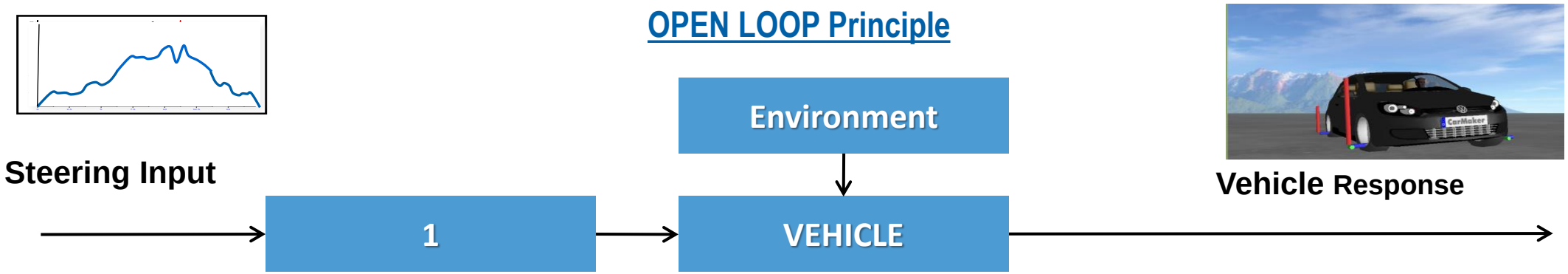
“Driver – Vehicle – Environment” – a closed loop!

“Driver – Vehicle – Environment” – a closed loop!



Open and Closed Loop Principle





Transfer to everyday situations in closed loop

	Vehicle Longitudinal control	Vehicle Lateral control
Typical maneuver	• Following driving. • Free travel. • Brake maneuver.	• Corning driving. • Lane change maneuver. • Turn-off maneuver.
Control variable	• Distance *(*Following driving*, brake).* • Speed *(*free travel*).* • Acc-/Deceleration.	• curvature of the vehicle trajectory. • Lateral deviation of the target curve • Yaw error • Lateral distance
Actuating variable	 	

Cognitive hierarchy model based on Rasmussen

Three-Level-Model of vehicle control
(Edmund Donges, 1976)

Target oriented behavior of the human
(Jens Rasmussen, 1983)

Discretization

Navigation Level

Possible routes

↓

Selected routes
chronological sequence.

Course Control Level

^Area safe command variables

↓

Performance indicators, target tracking, target speed

Stabilization Level

Dynamical vehicle reaction.

↓

Actual track, actual speed.

Knowledge base behavior

Control based behavior

Skill based behavior

Minutes up to hours

(before drive or during driving interupts)

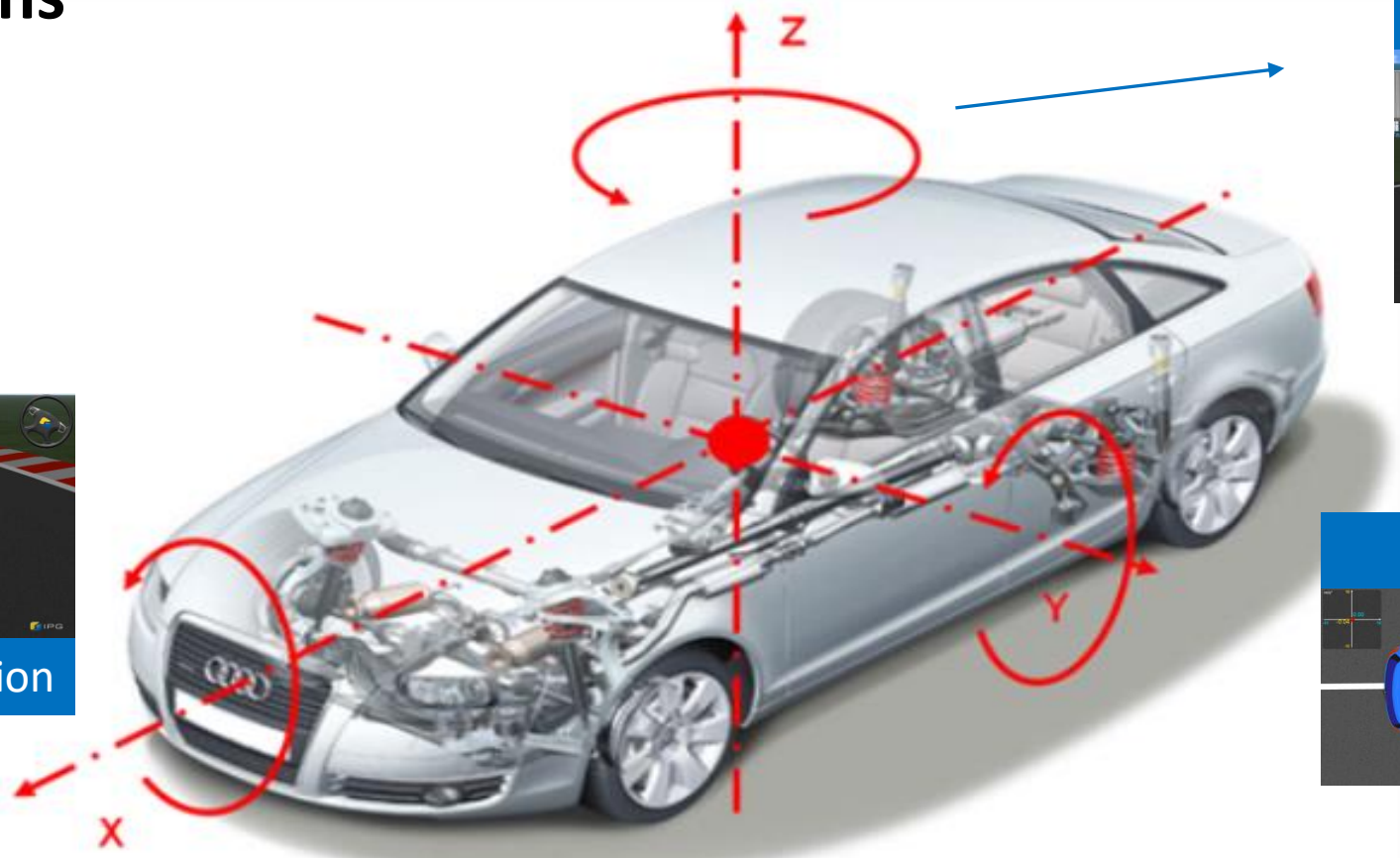
1s up to 10s

Smaller as 1s

(often assumed as continuously)

Introduction Vehicle dynamics

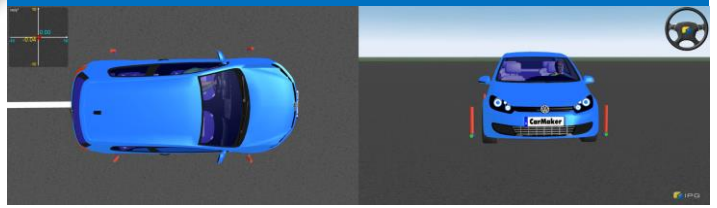
Vehicle dynamics behavior remains very important in all driving modes and situations



Vertical Motion

Longitudinal Motion

Lateral Motion



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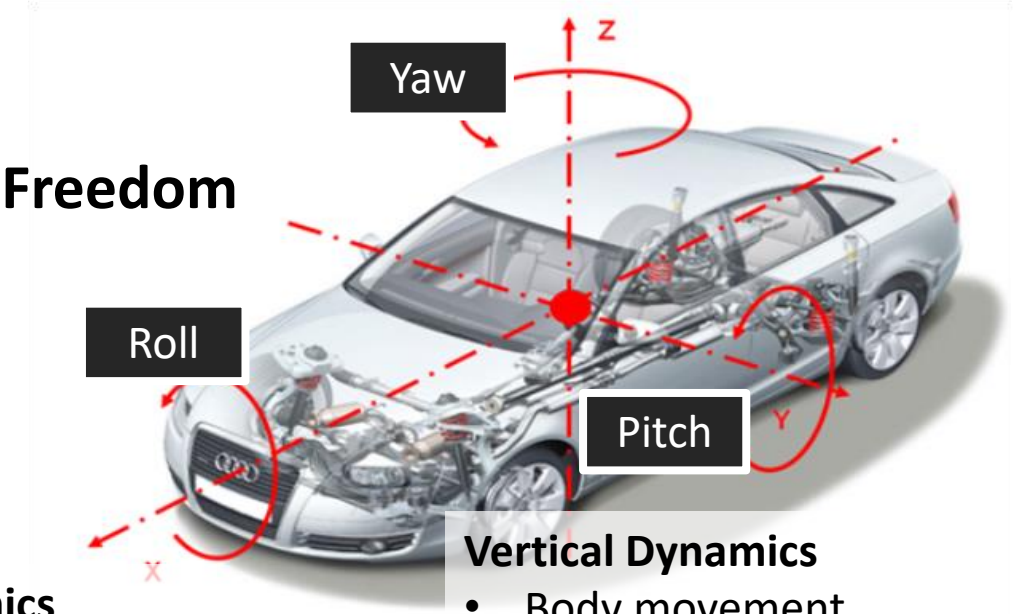
Introduction Vehicle dynamics

What is vehicle dynamics? It describes the full vehicle motion dynamics.

6 DOF - Degree of Freedom



Longitudinal Dynamics
- Driving Resistance
- Acceleration behavior
- Braking behavior

Vertical Dynamics
- Body movement
  - Primary Ride
  - Secondary Ride
- Body acceleration
  - Harshness
  - Vibration
- Wheel Load Oscillation

Lateral Dynamics
- Stationary behavior
- Transient behavior
- Steering behavior

Main vehicle dynamics behavior and attributes

Longitudinal Dynamics: Drivability Behavior

Descriptions the longitudinal vehicle behavior and performance which results due to driver control input of acceleration, speed and shifting.

Lateral Dynamics: Handling and Agility Behavior

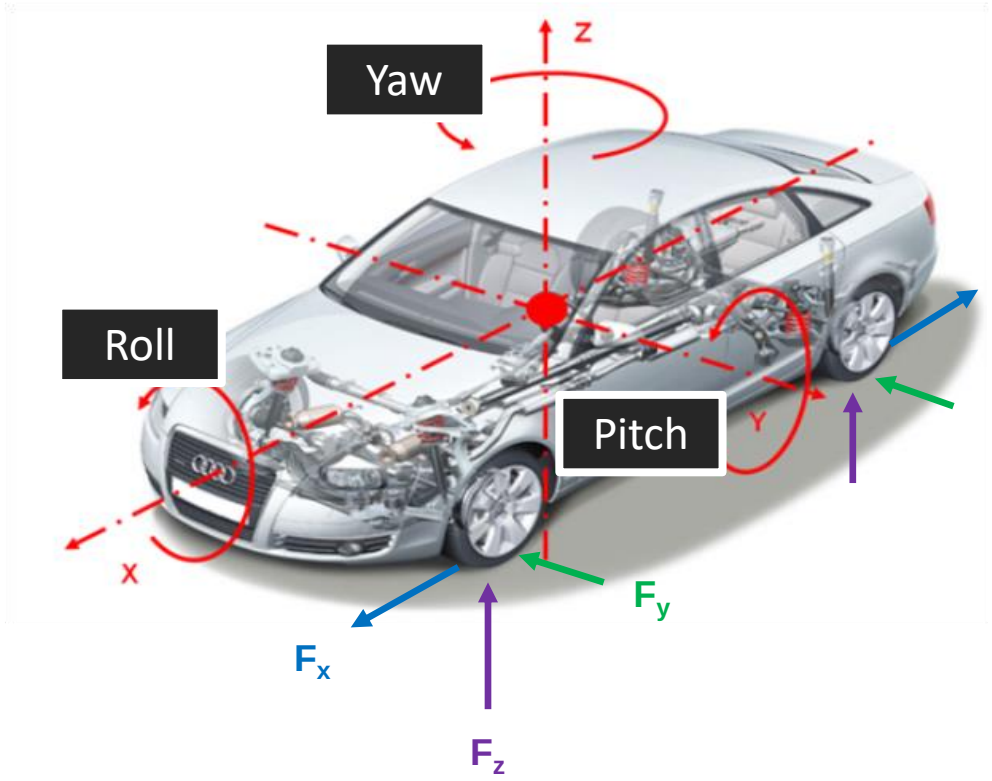
Descriptions of the way vehicles perform transverse to their direction of motion, particularly during cornering and swerving. It also includes their stability when moving in steady state as well as in transient conditions. Vehicle dynamics are one major component of a vehicle's "active" safety.

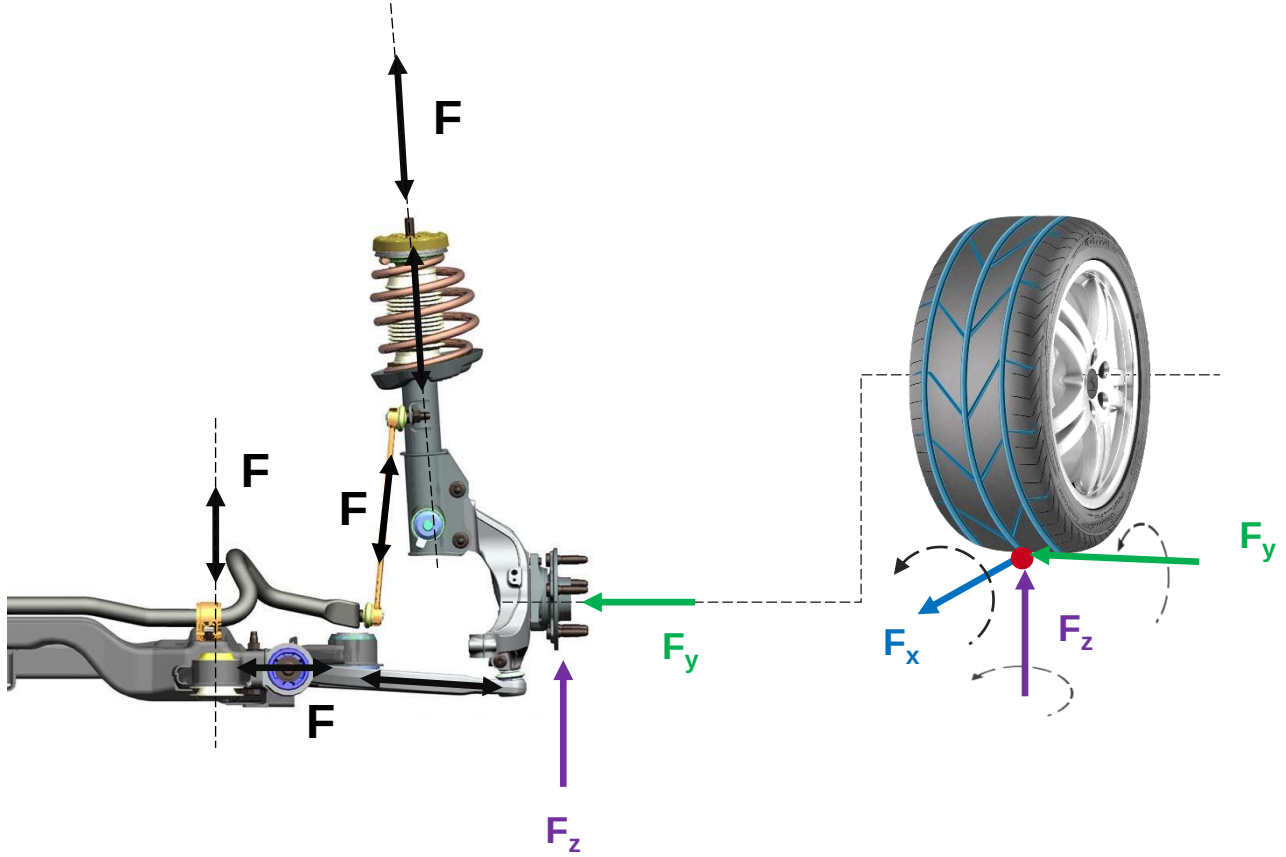
Vertical Dynamics: Ride & Comfort Behavior

Descriptions annoying driver or passenger impact dynamic due to driver effort, road excitation and vehicle vibrations, which negative influence the work load, effort, comfort feeling and healthiness.

Introduction Vehicle dynamics

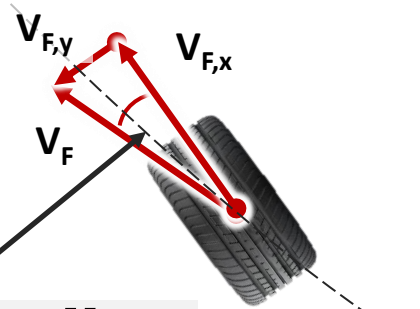
The **vehicle motion dynamics** is a result of **external forces & moments** and leads to **internal forces & moments!**



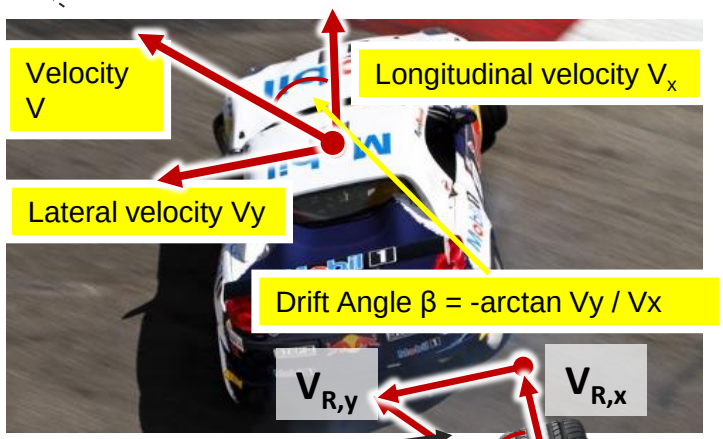


Tire lateral characteristics: side slip behavior

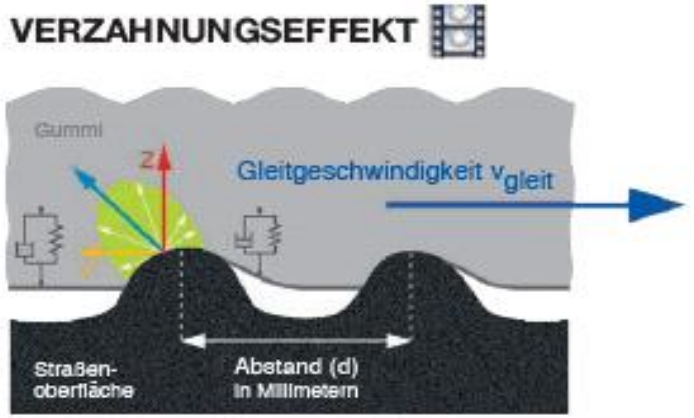
Tire lateral characteristics: side slip behavior



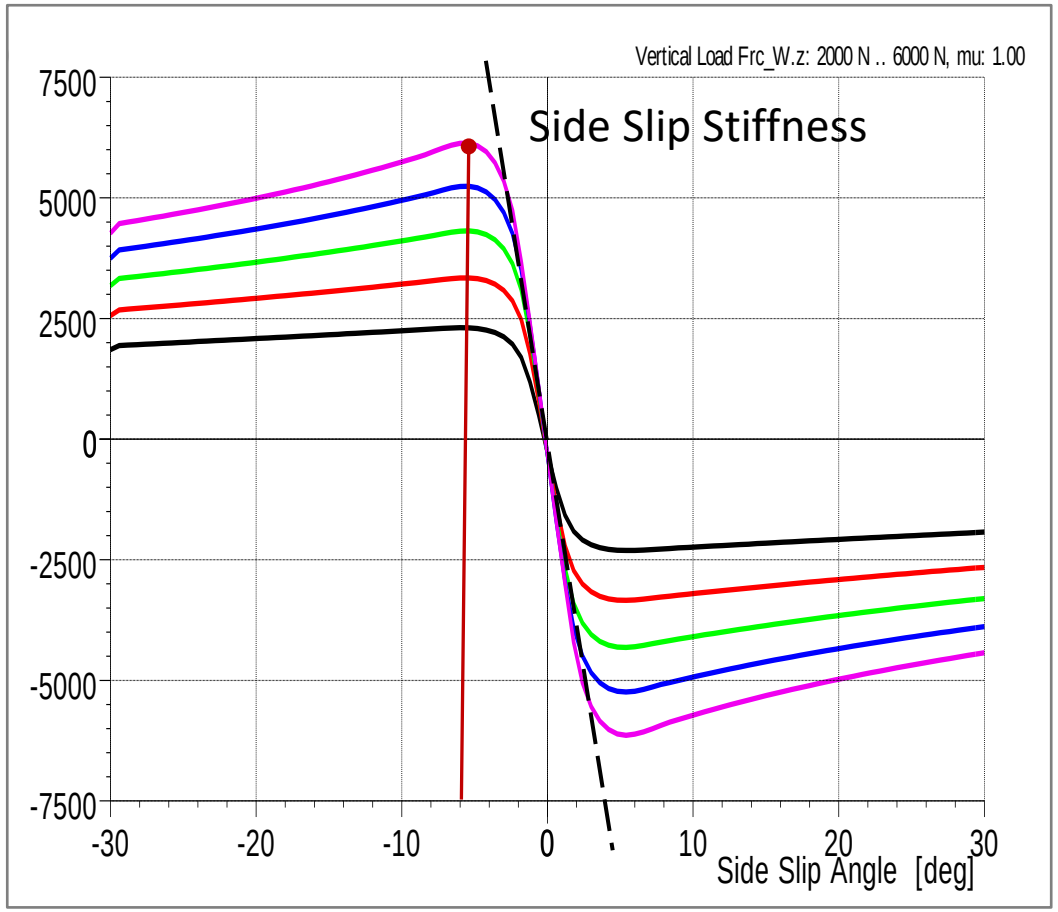
$$\alpha_F = -\arctan\frac{V_{F,y}}{V_{F,x}}$$



$$\alpha_R = -\arctan\frac{V_{R,y}}{V_{R,x}}$$

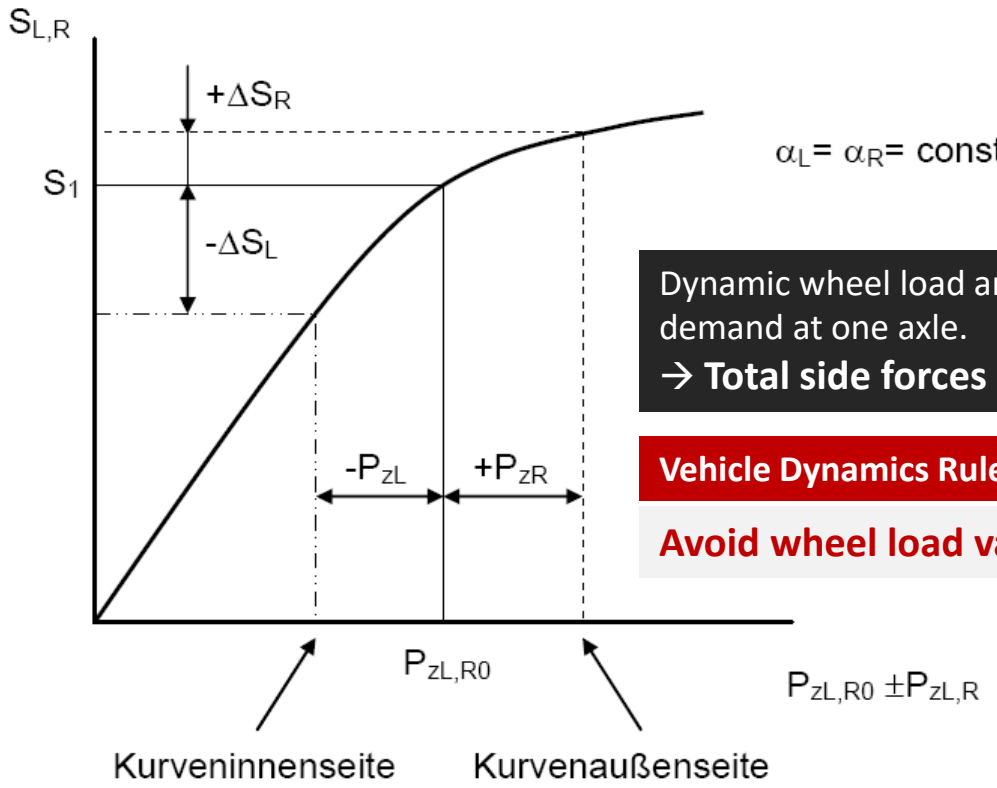


Combined tire characteristics: dynamic load distribution



$$F_R \leq \mu * F_N$$

Coulombsche Friction Rule, **but μ for tire & road are strongly non-linear**



Dynamic wheel load and side force demand at one axle.
→ **Total side forces are reduced**

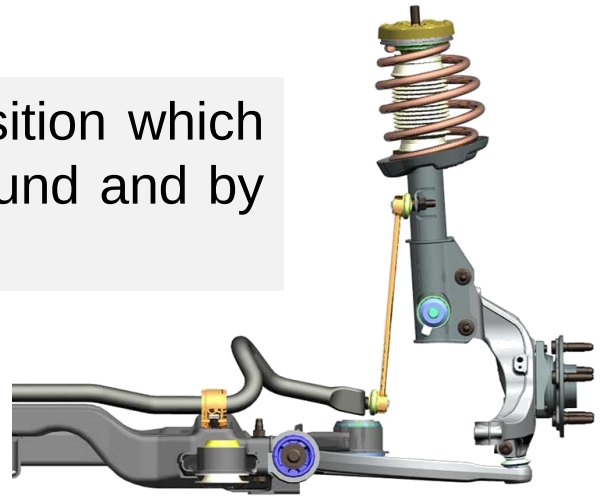
Vehicle Dynamics Rule No. 1:

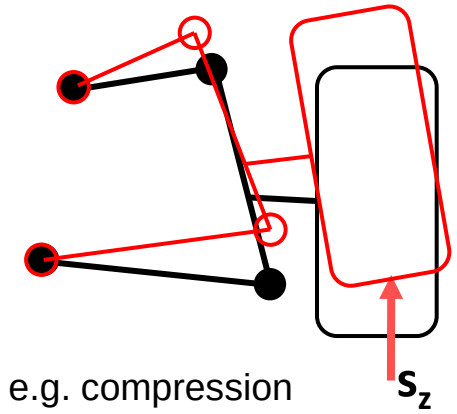
Avoid wheel load variation

Tire lateral characteristics: side slip behavior

Kinematics

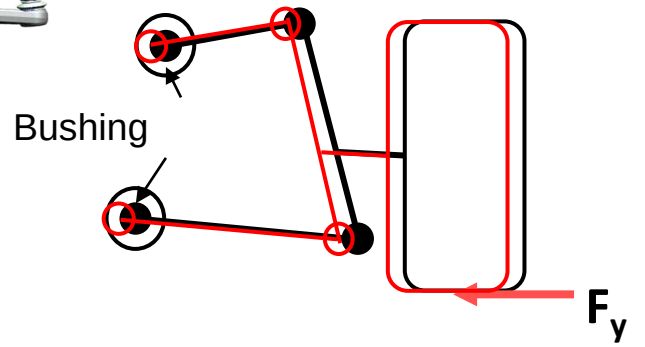
Description the change in the 3D wheel position which occur due to suspension compression, rebound and by steering movements.





Compliance (elastokinematic)

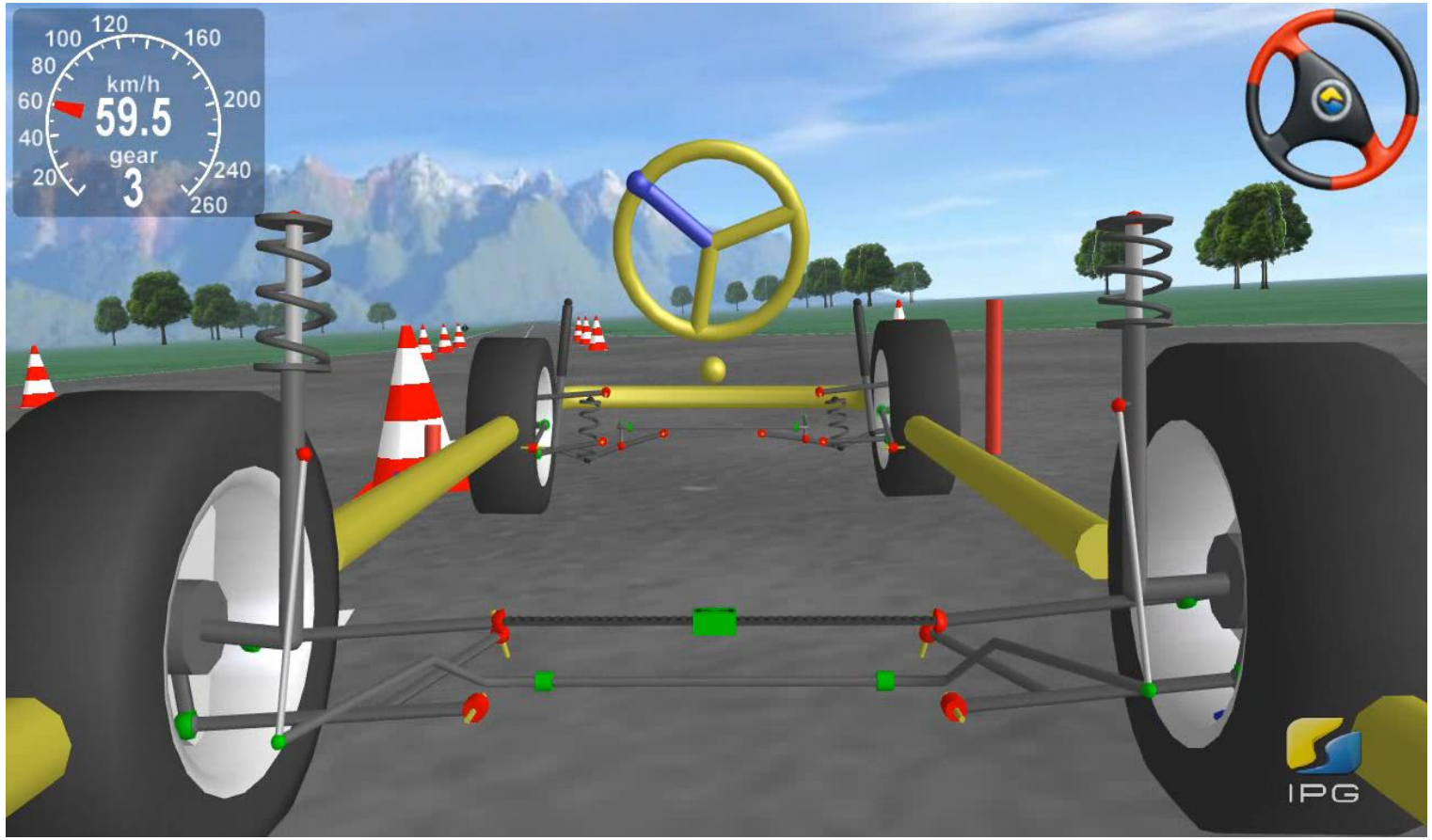
Description the change in the 3D wheel position, which occur due to the forces and torques on the wheel / tire under targeted elastic interpretation of suspension parts.

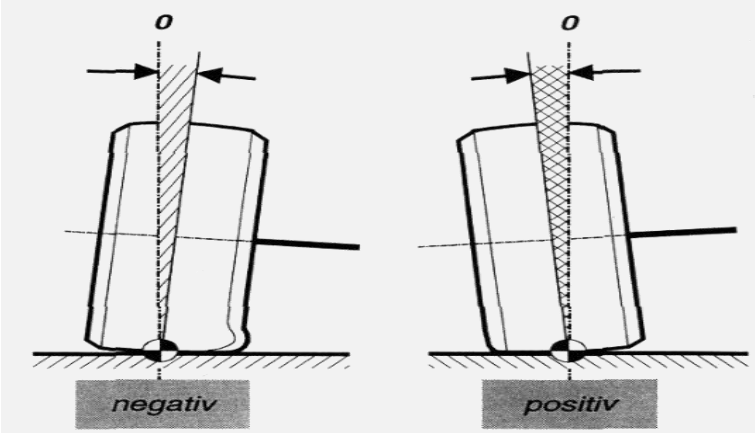


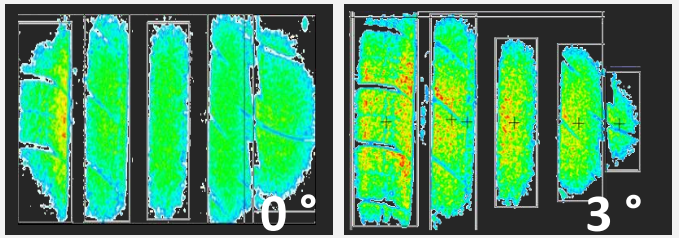
e.g. compliance under side forces

Introduction Vehicle dynamics

The suspension has the task of making the tire work.



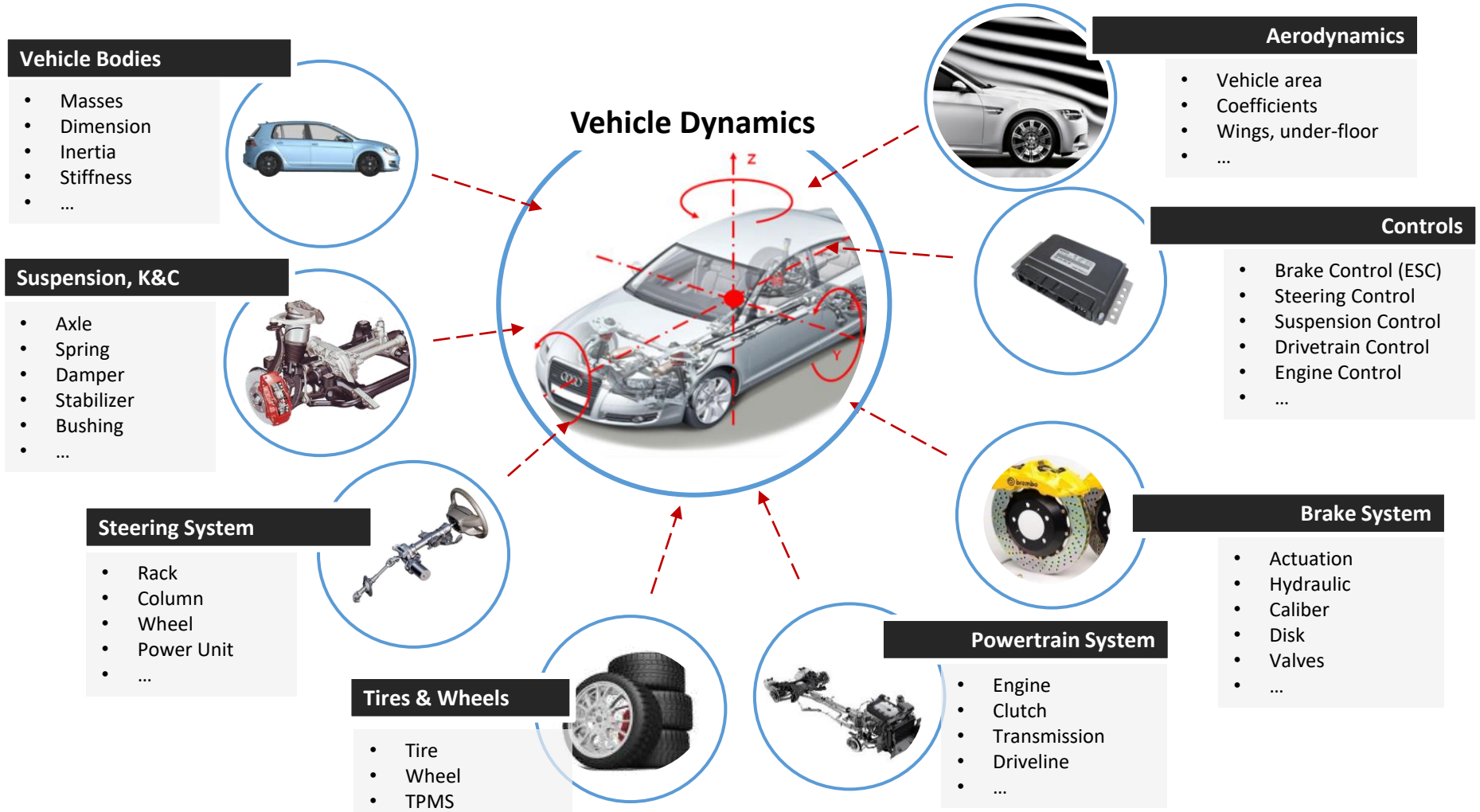




Vehicle Dynamics Rule No. 2:

Produce a harmonic foot print

Vehicle dynamics behavior is impact by numerous components



What is a test?

Ein **Test** ist ein Versuch, mit dem Sicherheit darüber gewonnen werden soll, ob ein technischer **Apparat** oder ein **Vorgang** innerhalb der geplanten Rahmenbedingungen **funktioniert** beziehungsweise ob bestimmte **Eigenschaften** vorliegen.

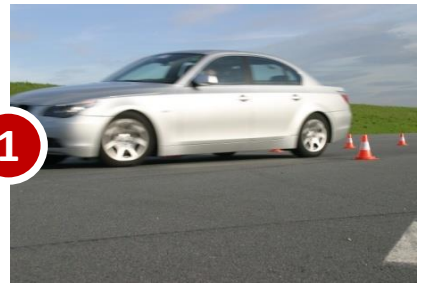
Nachbildung des realen Einsatzes im Fahrversuch, Prüfstand oder Simulation.

Im Allgemeinen **kein Beweis**! Nicht absolut gültig sondern stellt „nur“ eine **Näherung** dar.


John B. Kennedy reports —
"LOOKING FOR TROUBLE"
-- BEFORE IT LOOKS FOR
YOU, IS ANOTHER BIG JOB
IN THIS ONE INDUSTRY

Vehicle dynamics attributes and their target conflicts

Testing and evaluation methods



1

Driving Tests with subjective evaluation of vehicle behaviour → **„Closed Loop“**

Driving Tests with subjective evaluation of vehicle behaviour → **„Open Loop“**

2

Driving Tests with measurement & analysis of vehicle response → **„Closed Loop“**

Driving Tests with measurement & analysis of vehicle response → **„Open Loop“**

3

Simulation & analysis of vehicle response →„Closed Loop“

Simulation and analysis of vehicle response → **„Open Loop“**

Vehicle dynamics attributes and their target conflicts

Subjective and objective evaluation language

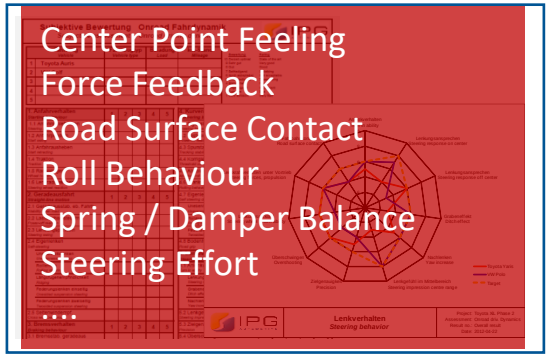
Customer Wishes

Subjective Language

Subjective evaluation

Subjective evaluation criteria in a rating system

Center Point Feeling
Force Feedback
Road Surface Contact
Roll Behaviour
Spring / Damper Balance
Steering Effort
....



Objective Language

Objective measurement data

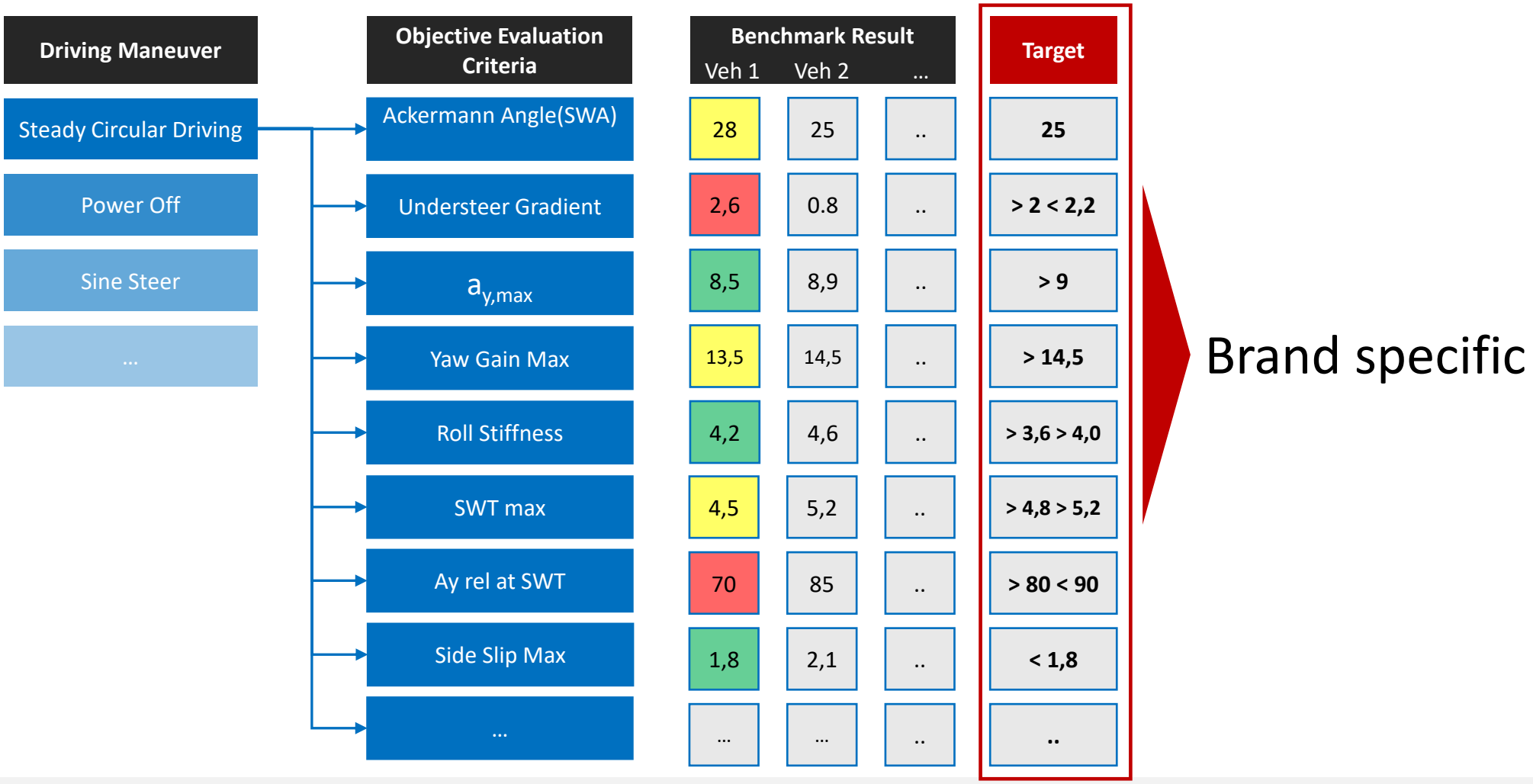
Characteristic values for vehicle behavior

Yaw Gain
Understeer Gradient
Roll Stiffness
Frequency Response
Maximum Force
Linearity
....

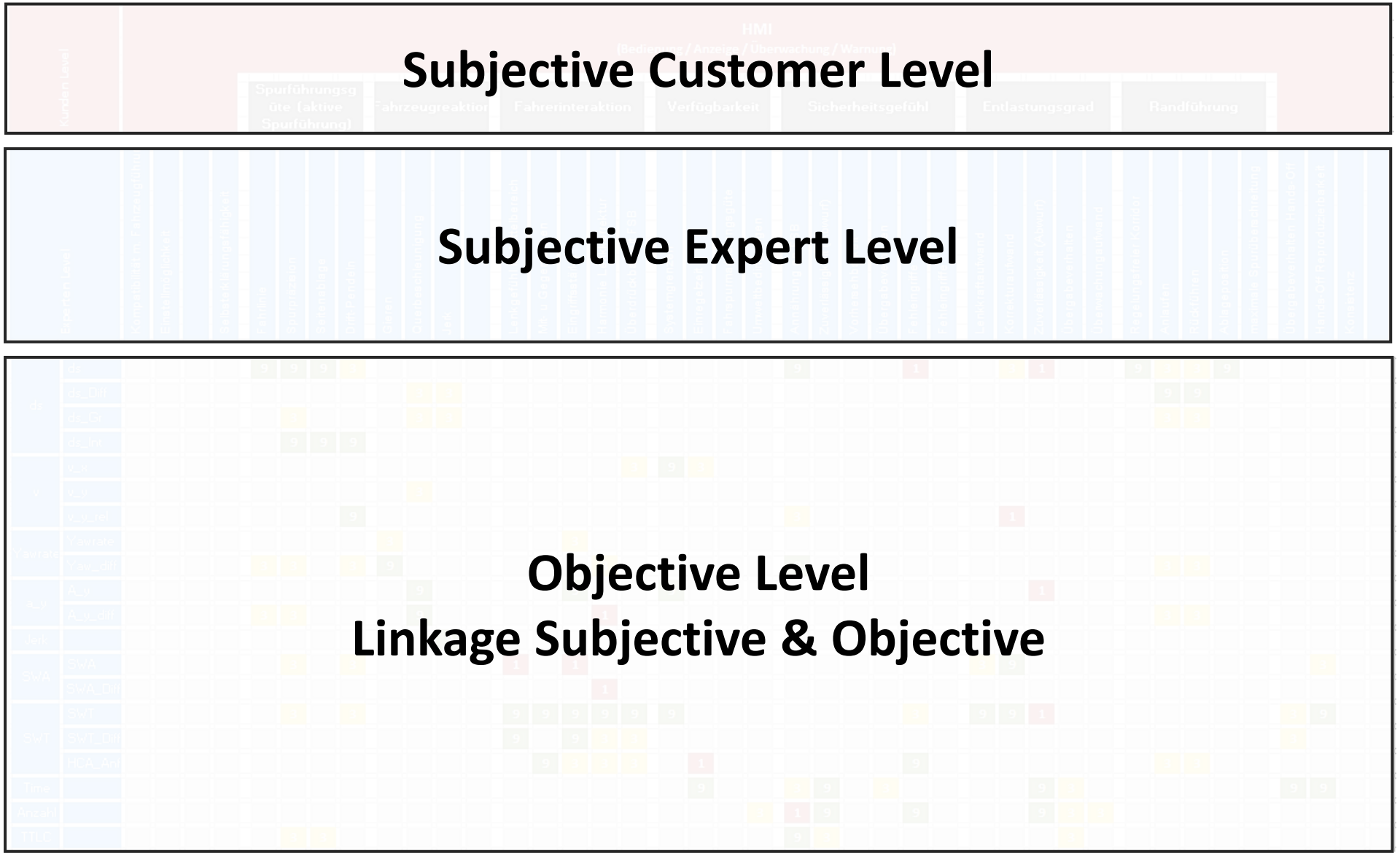
Correlation and linkage between both languages are important

Vehicle dynamics attributes and their target conflicts

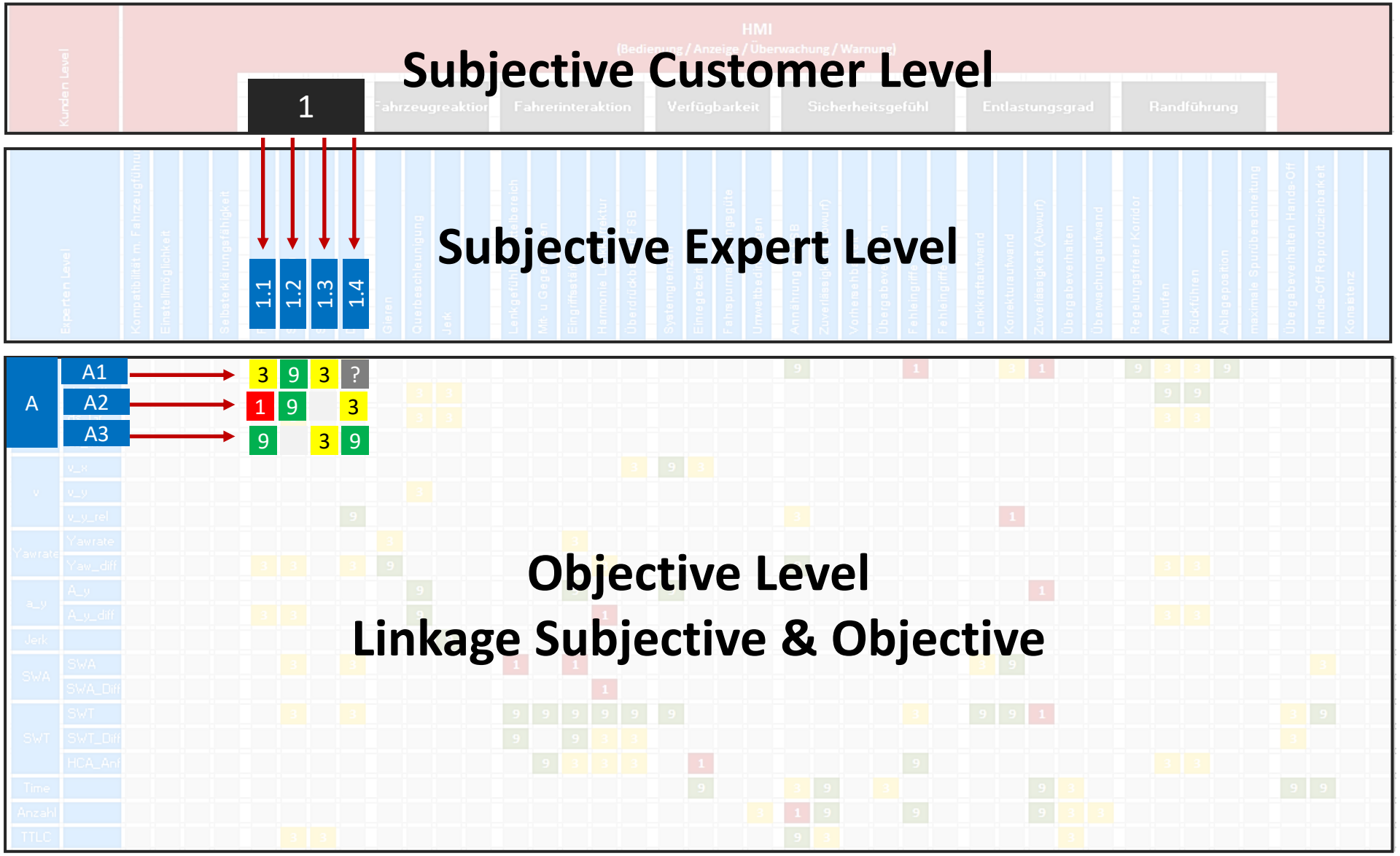
KPI and target matrix within a consistent development process



Vehicle dynamics attributes and their target conflicts



Vehicle dynamics attributes and their target conflicts



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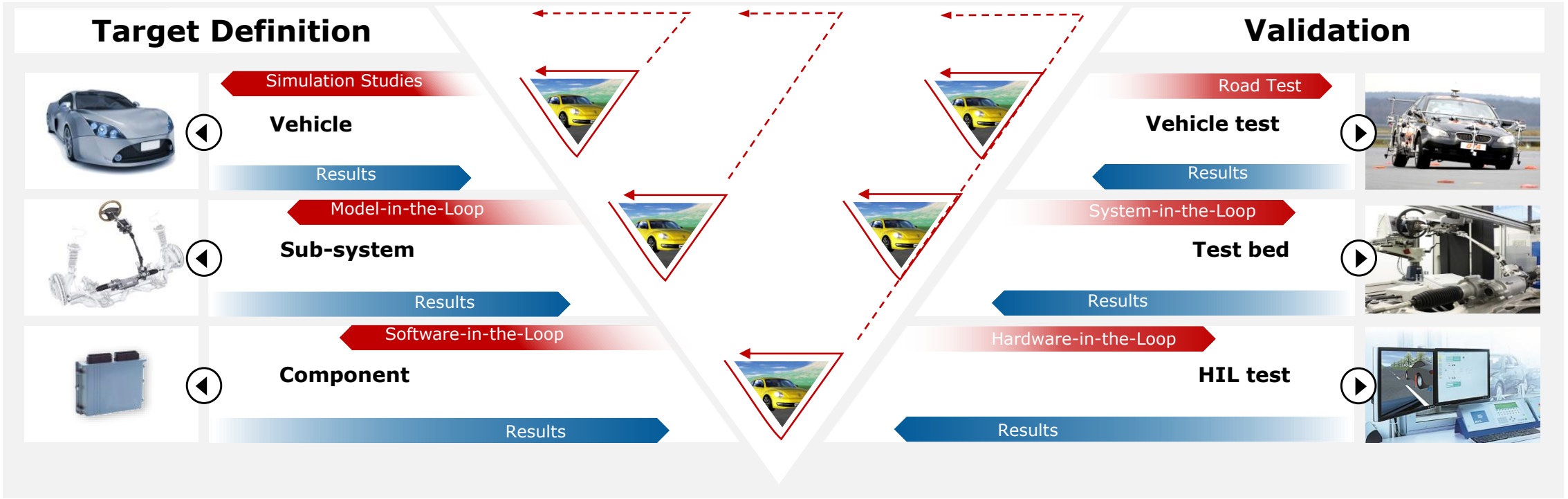
Vehicle dynamics attributes and their target conflicts

Continuous attribute validation during the development



What is the difference between verification and validation?

Verification = Have we done the things right?

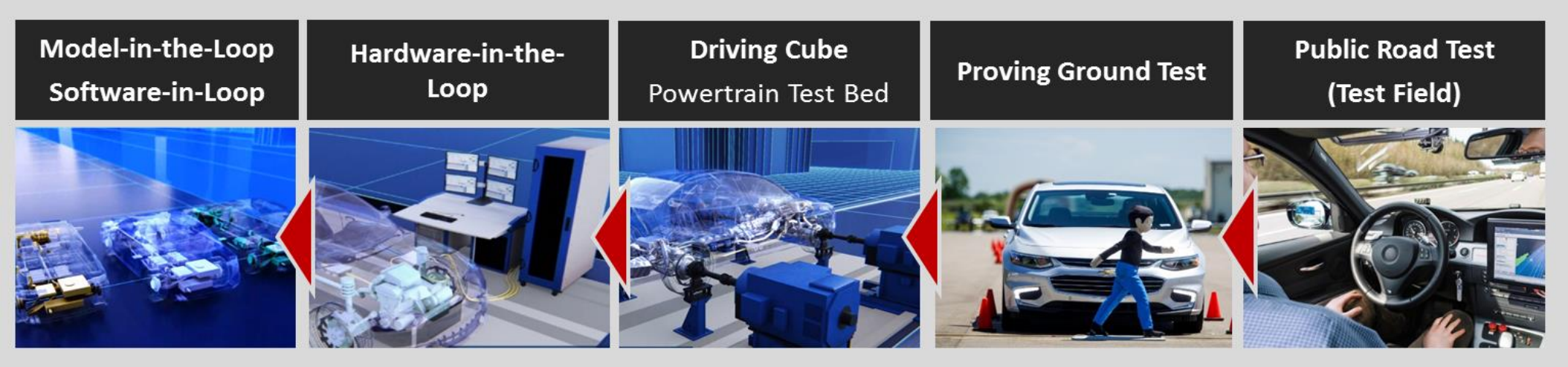
➡ **Fulfillment of specification without errors.**

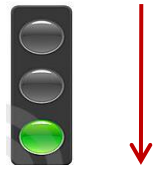
Validation = Have we done the right things?

➡ **Is the customer happy with the driving behavior of the car?**

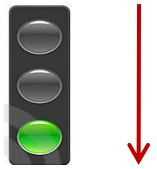
Vehicle dynamics attributes and their target conflicts

KPI’s as an enabler for simulation use, efficient development & comparison





Objective Evaluation Criteria's
Expected Result
(passed/failed)



Objective Evaluation Criteria's
Expected Result
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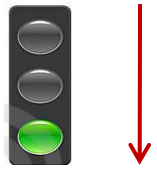
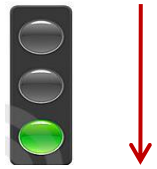
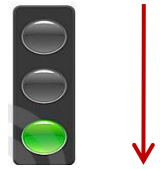


Objective Evaluation Criteria's
Expected Result
(passed/failed)



Objective Evaluation Criteria's
Expected Result
(passed/failed)



Objective Evaluation Criteria's
Expected Result
(passed/failed)

Vehicle dynamics attributes and their target conflicts

Continuous attribute validation during the development

Subjective Customer Wishes

Vehicle Target Behavior
in realistic driving situation

Vehicle Target Behavior
in realistic driving situation

Virtual Vehicle

Simulation

Virtual Vehicle with real systems

Road Test

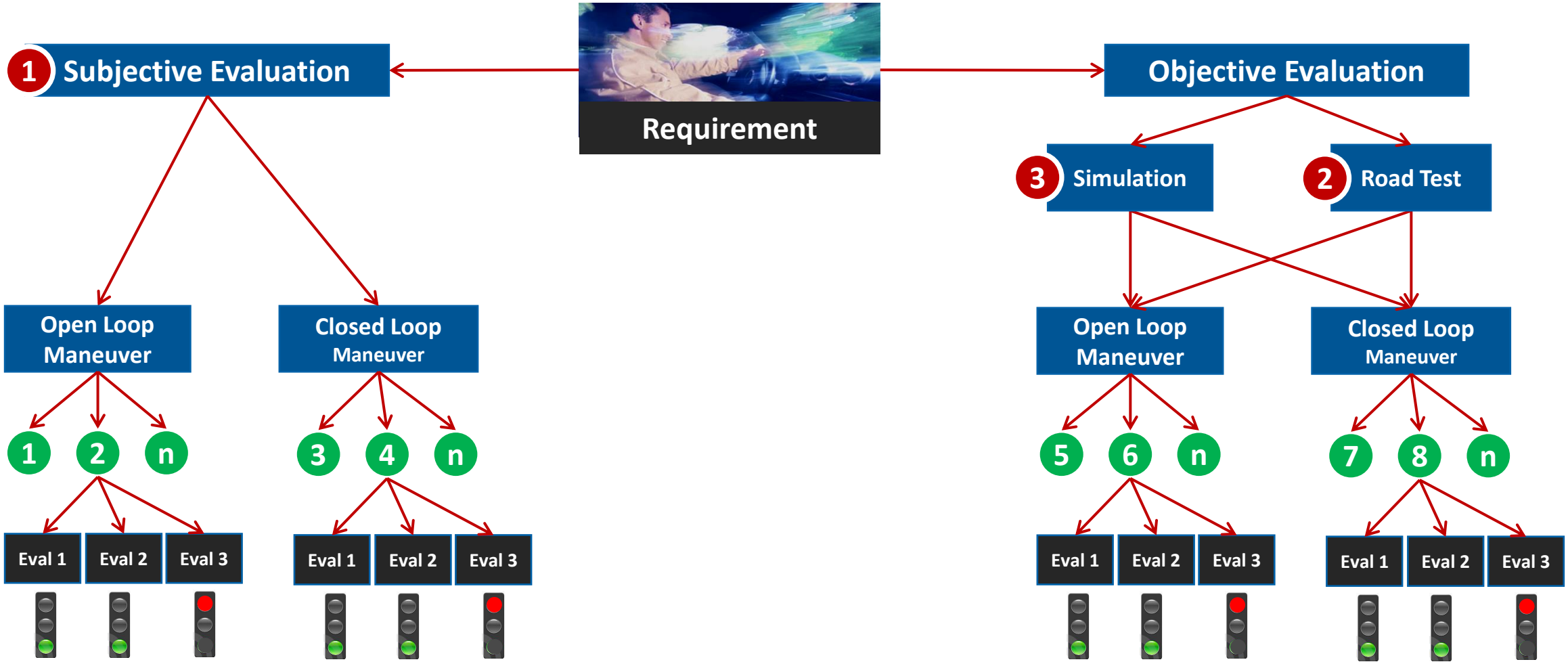
Real Vehicle

Objective Evaluation Criteria's
Expected Result
(passed/failed)

Objective Evaluation Criteria's
Expected Result
(passed/failed)

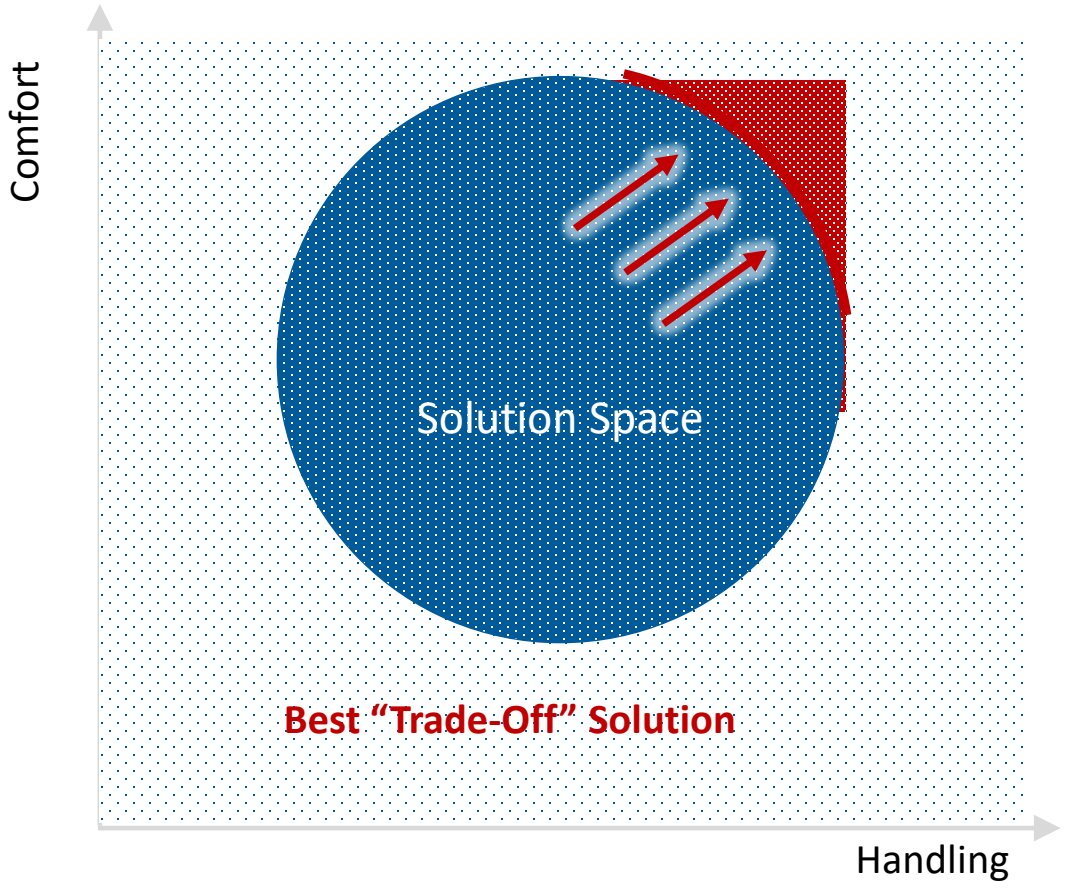
Objective Evaluation Criteria's
Expected Result
(passed/failed)

Summery of testing and evaluation methods

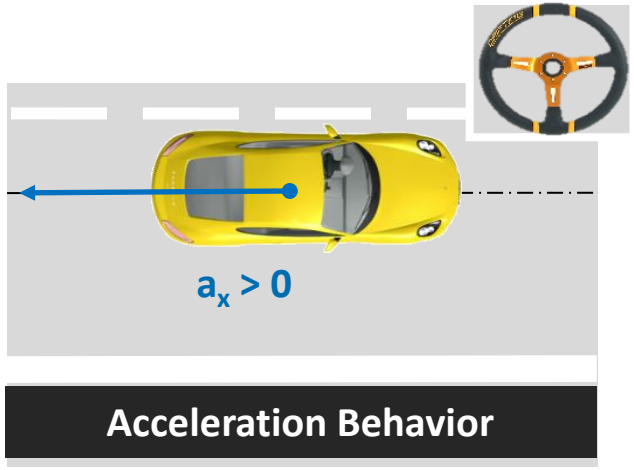


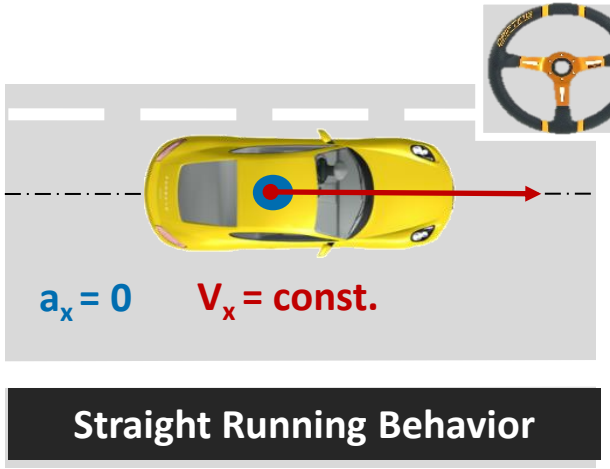
Vehicle dynamics attributes and their target conflicts

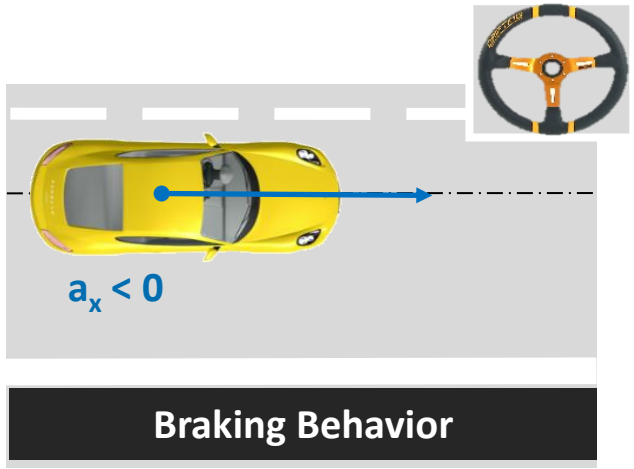
What will be the impact of any change in terms of agility, safety, comfort, emission and costs? Which global vehicle attributes cab lead to a target conflicts?

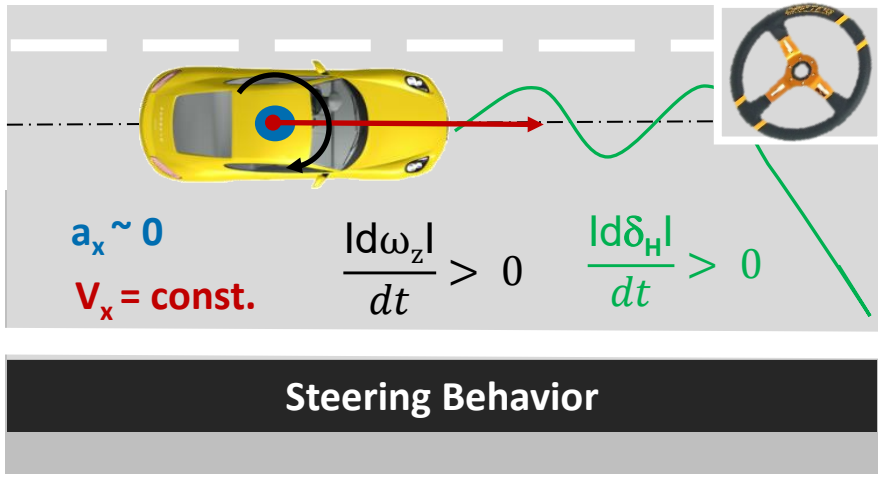


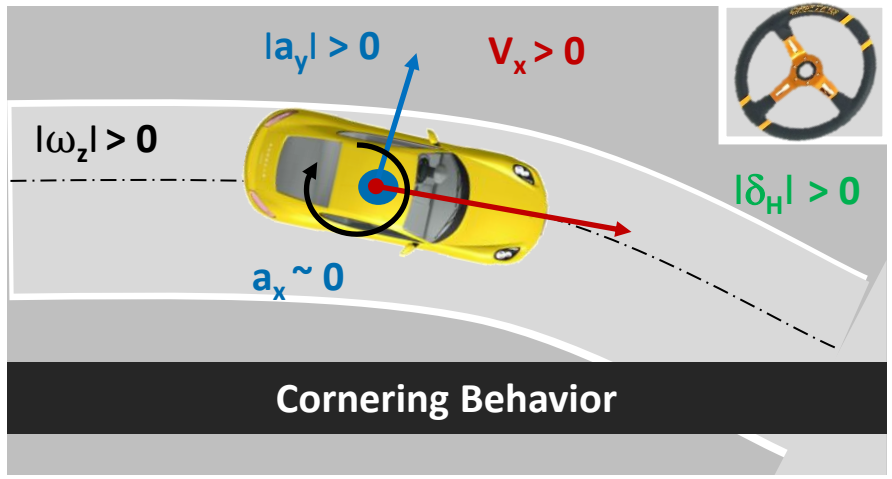
Lateral Dynamics: Handling and Agility Behavior



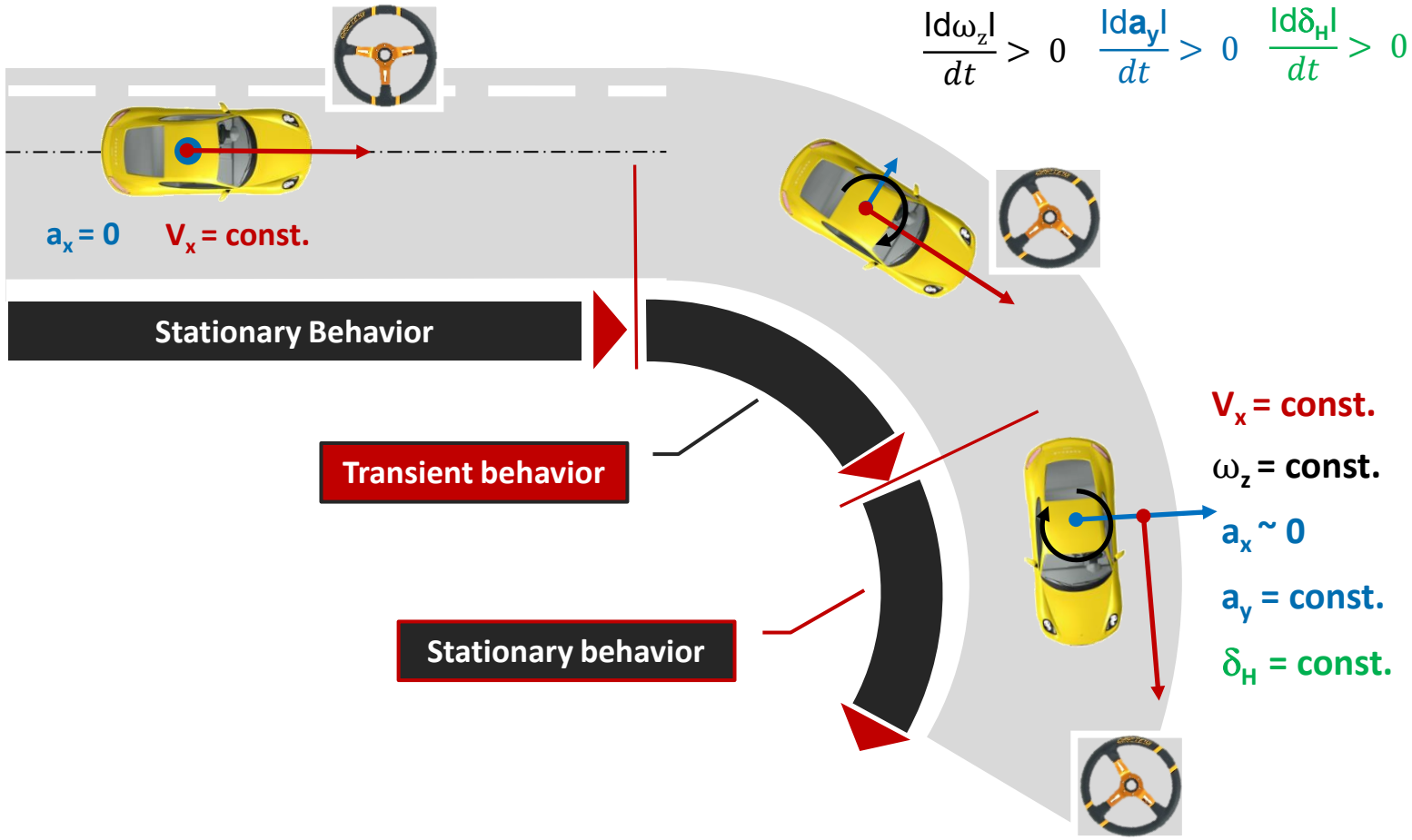




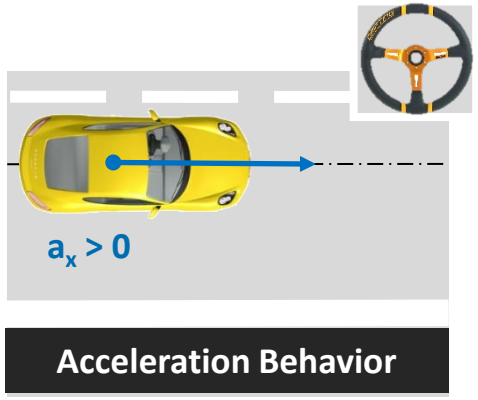




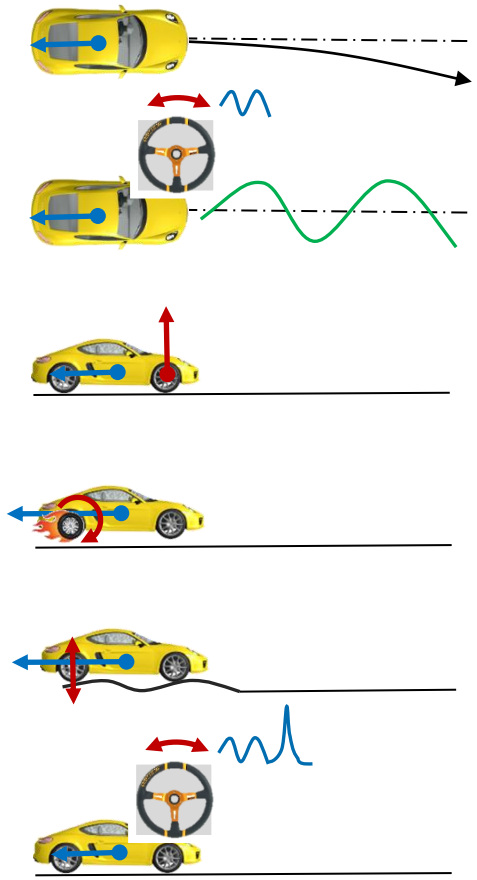
Lateral Dynamics: Stationary and transient behavior



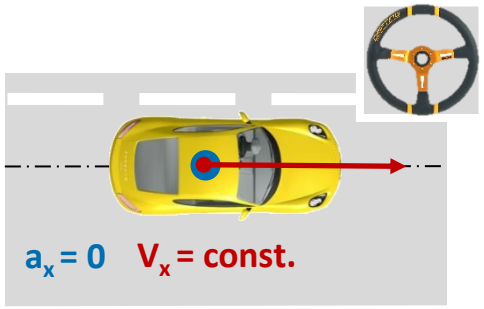
Acceleration Behavior



- Steering drift
- Start swing
- Start retracting
- Traction
- Wheel hopping
- Steering wheel reaction

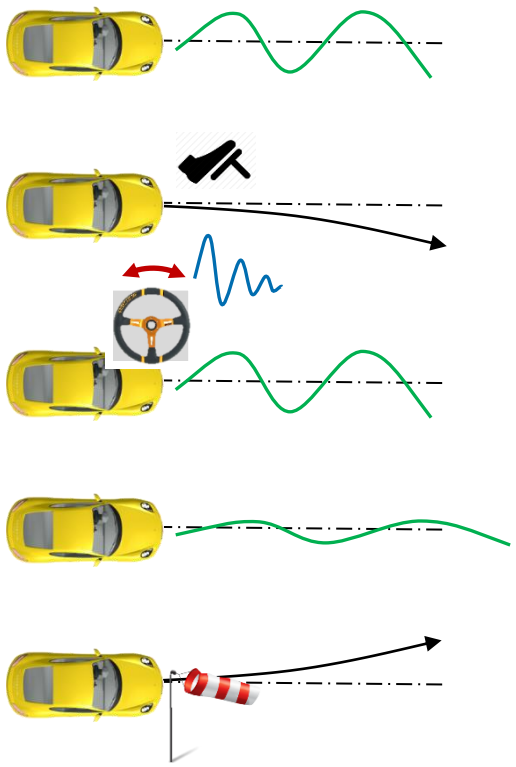


Straight Running Behavior



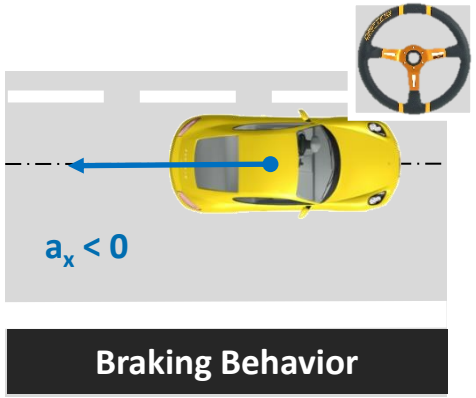
Straight Running Behavior

- Stability even road
- Power-off reaction
- Steering swing
- Self-steering
- Cross wind behavior

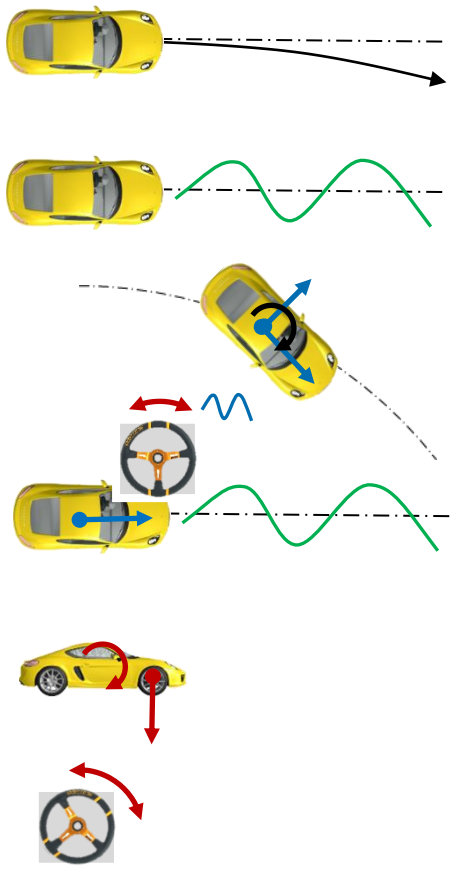


Vehicle dynamics attributes and their target conflicts

Braking Behavior



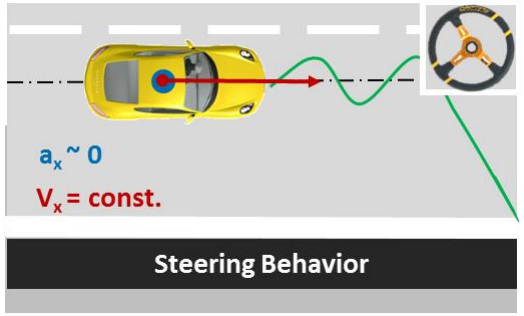
- Brake drift
- Braking stability straight
- Braking behavior cornering
- Braking swing
- Brake pitch
- Steering wheel reactions



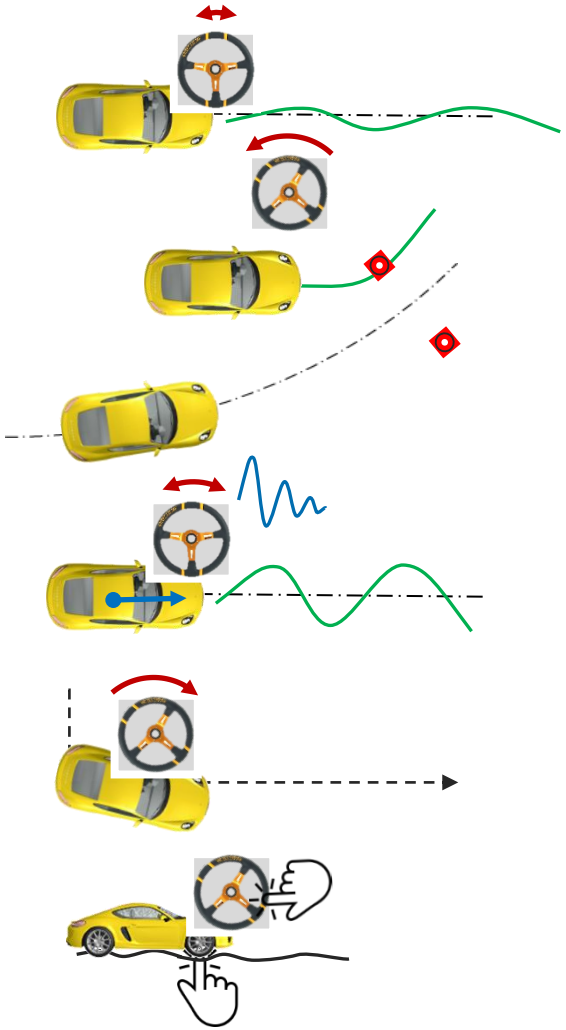
Vehicle dynamics attributes and their target conflicts

Vehicle dynamics attributes and their target conflicts

Steering Behavior

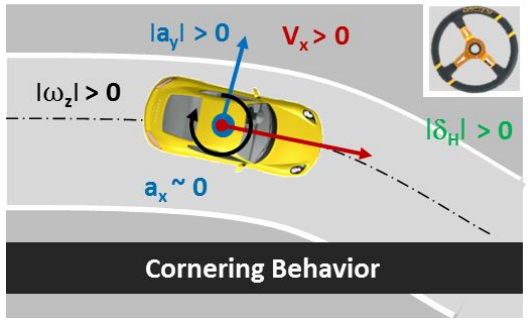


- On-Center Feeling
- Turn in ability
- Precision
- Over-shooting
- Steering wheel return ability
- Road surface contact

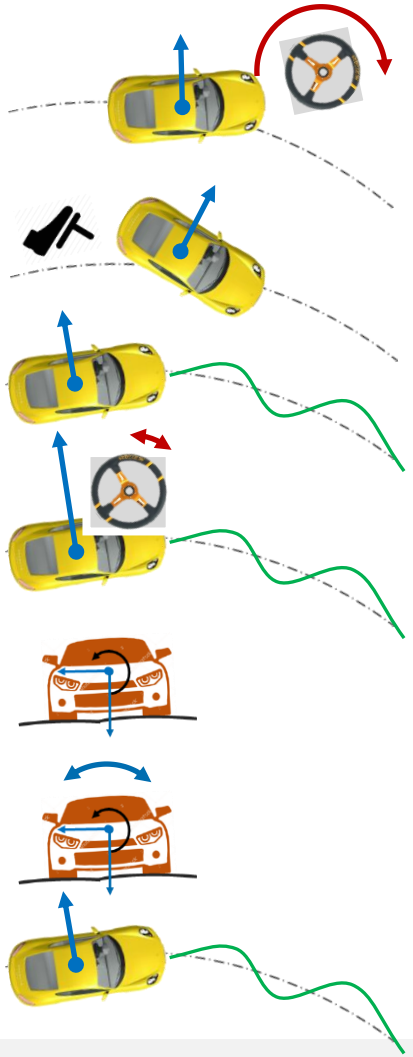


Vehicle dynamics attributes and their target conflicts

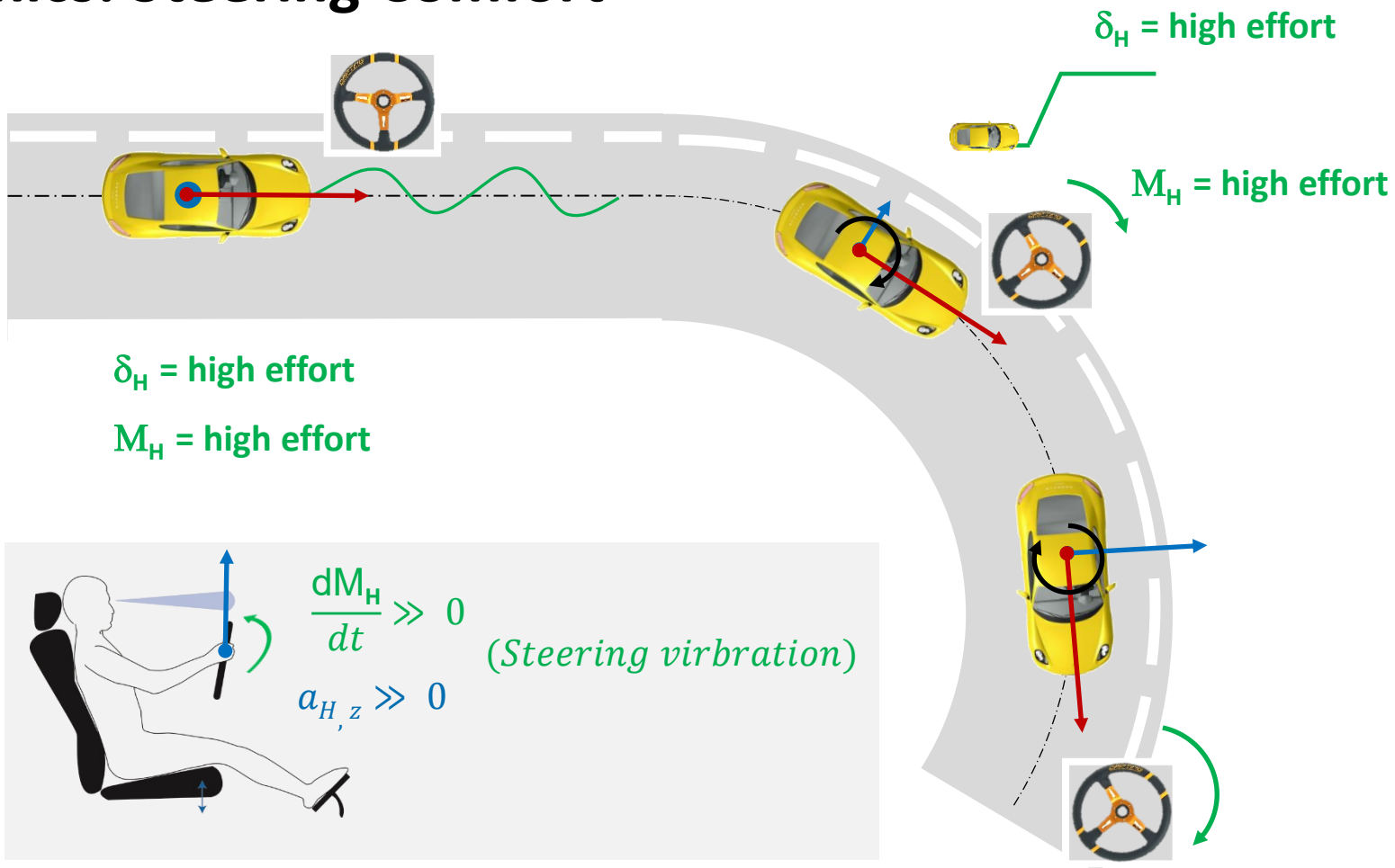
Cornering Behavior



- Understeering behavior
- Power-off reaction
- Tracking stability
- Controllability at the limit
- Absolute roll angle
- Rolling behavior
- Self steering during cornering



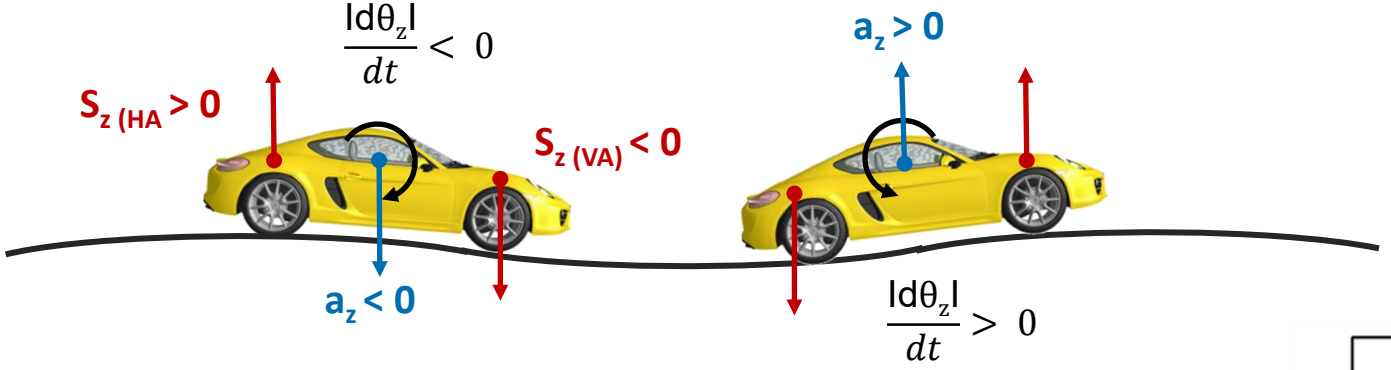
Lateral Dynamics: Steering Comfort



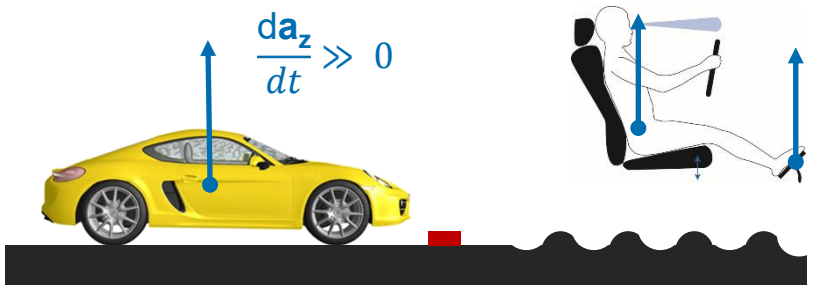
Vehicle dynamics attributes and their target conflicts

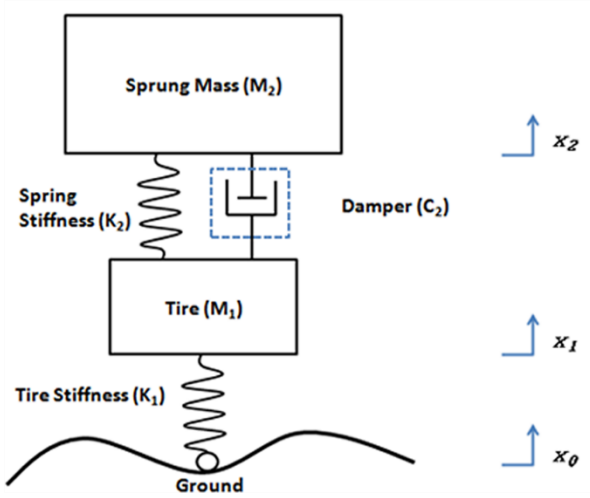
Vertical Dynamics: Ride & Comfort Behavior

Body Movement (Primary & Secondary Ride)



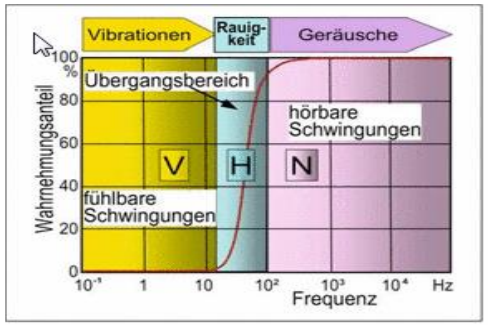
Body acceleration (Harshness, Vibration)





Vehicle dynamics attributes and their target conflicts

Open and Closed Loop Principle



Power off reaction

Brake Jitter

Powertrain noise

Bouncing

Tire roll noise

Steering Vibration

Jitter

Freeway Hop

Axle Osc.

Roaring

Body Movement / Oscillation

Shake

Axle harshness

Primary Ride

Secondary Ride

Harshness

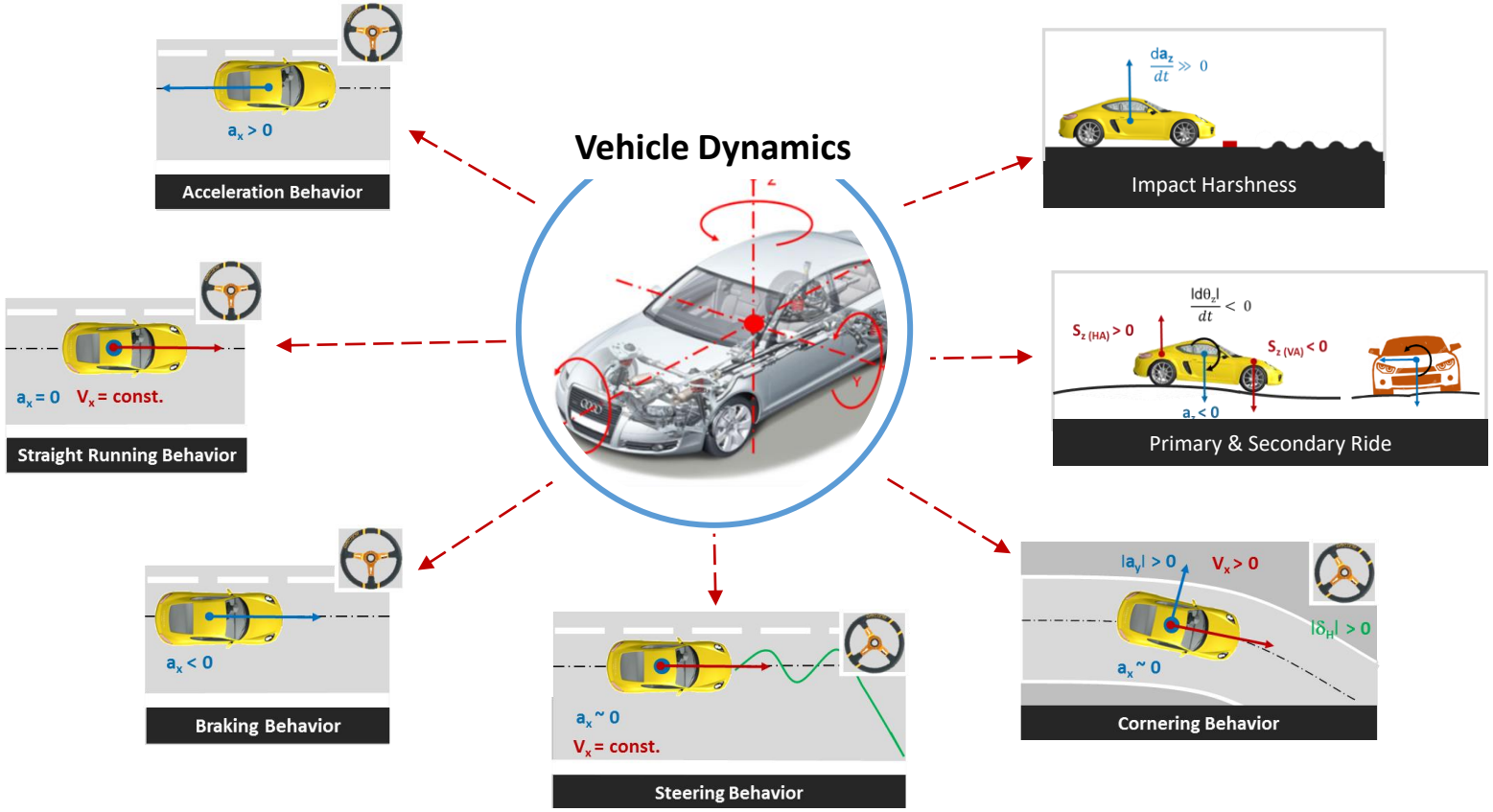
Noise

Vibration

1 2 4 8 16 32 64 128 256 512 Hz

Vehicle dynamics attributes and their target conflicts

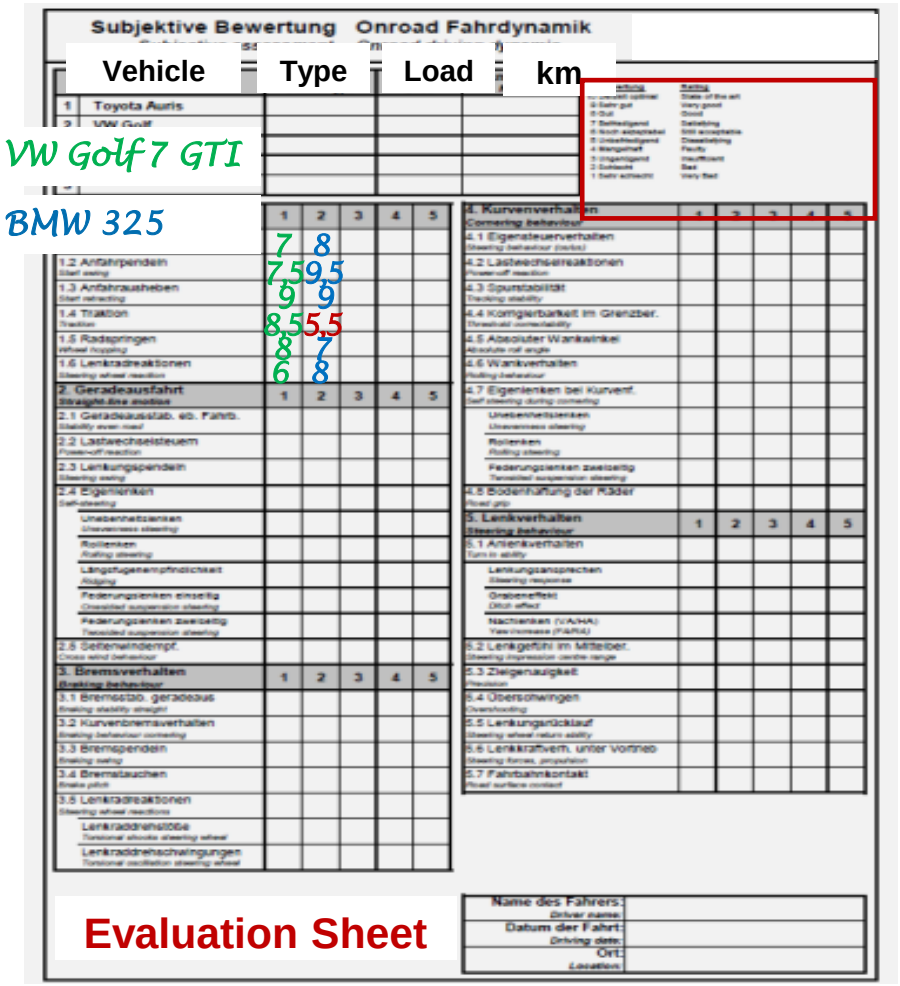
Different groups of ride & handling behavior



drive livinglab

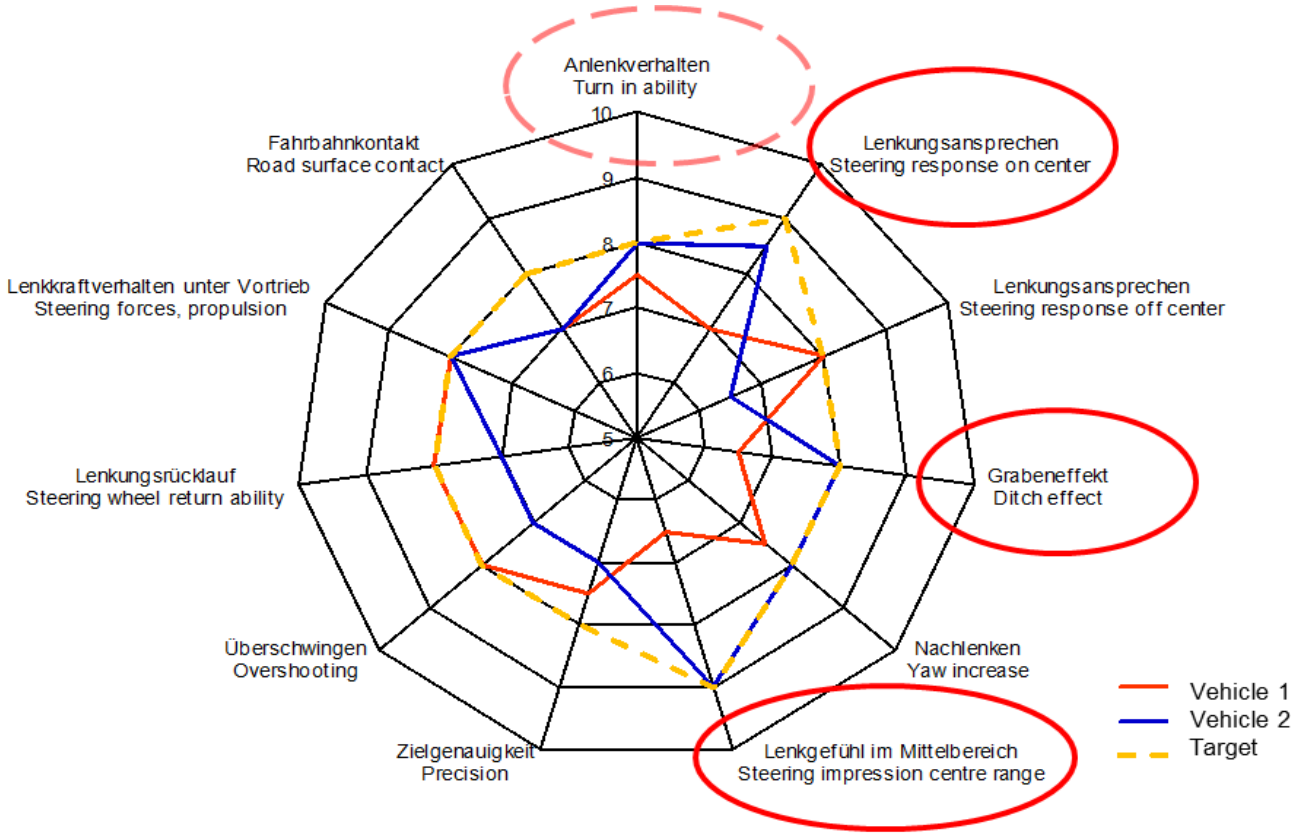
Test and evaluation methods for vehicle attributes

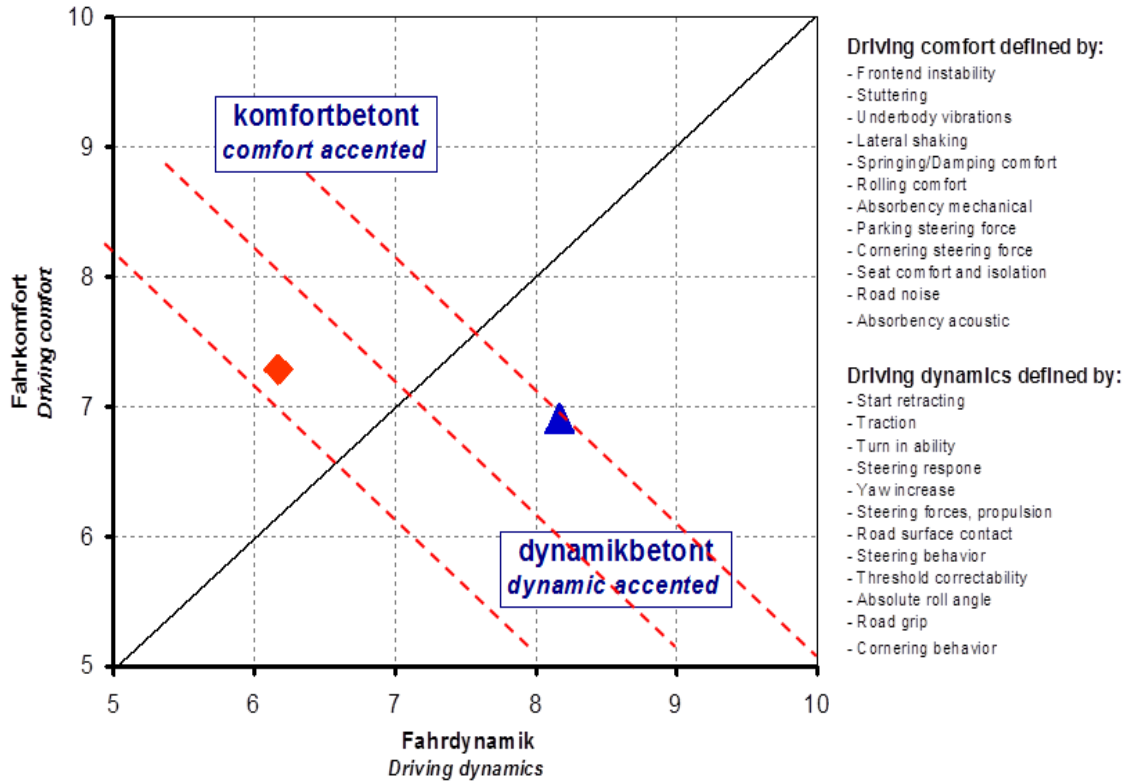
Subjective (quasi-objective) evaluation methods



	Bewertung	Beobachter/Mängel
10	Derzeit optimal *(state of the art)*	von Experten nicht wahrnehmbar
9	Sehr gut	von Experten kaum wahrnehmbar
8	Gut	von Experten äußerst gering wahrnehmbar
7	Befriedigend	von kritischem Kunden gering wahrnehmbar
6	Noch akzeptabel	von kritischem Kunden wahrnehmbar
5	Unbefriedigend	von Normalkunden gut wahrnehmbar
		GRENZFALL
4	Mangelhaft	für Normalkunden unangenehm (Reklamation)
3	Ungenügend	für keinen Kunden akzeptabel (Bauteil fehlerh.)
2	Schlecht	für keinen Kunden akzeptabel (bedingte Funk.)
1	Sehr schlecht *(very bad)*	für keinen Kunden akzeptabel (ohne Funktion)

Subjective Identification of Weaknesses and Positioning



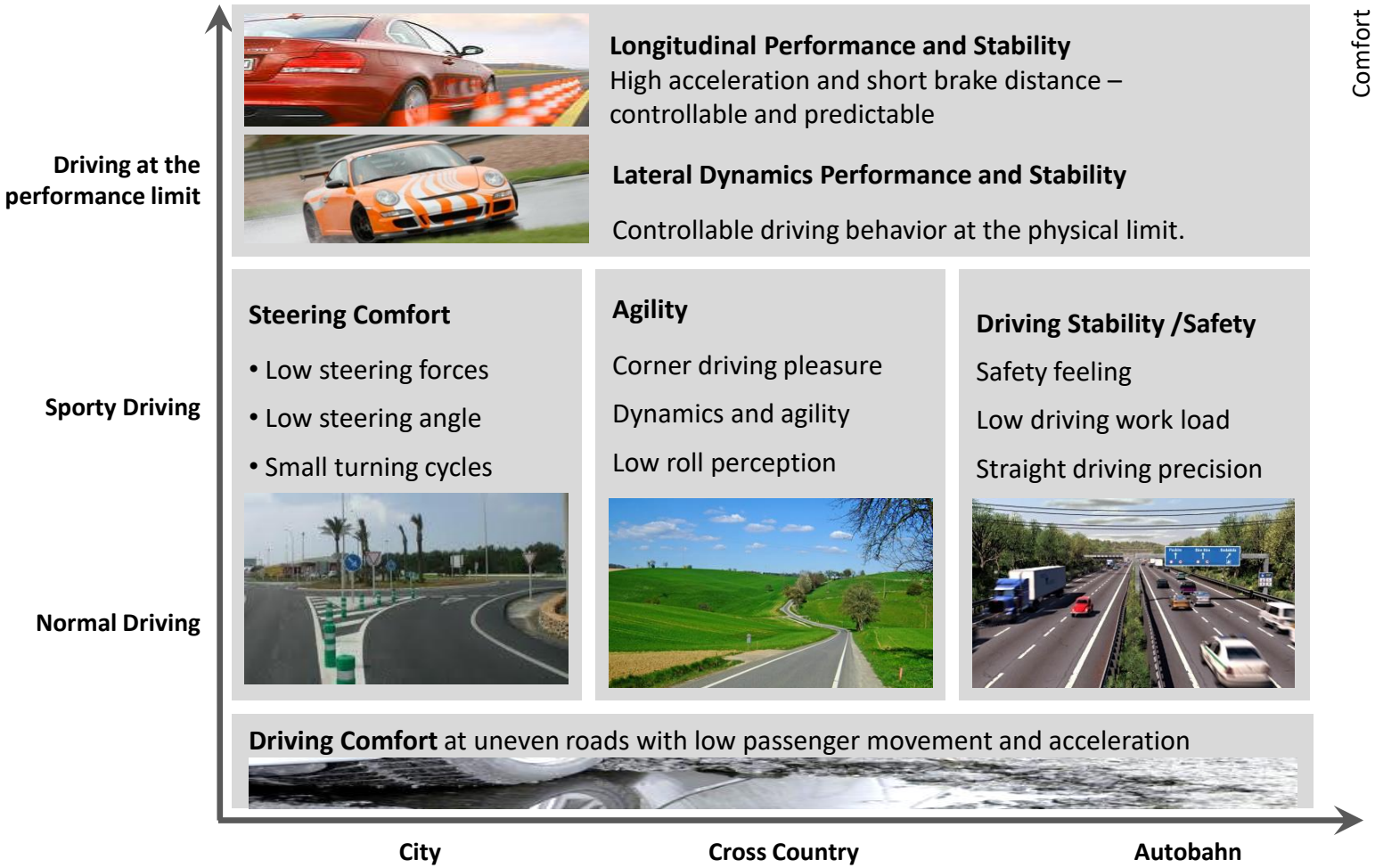


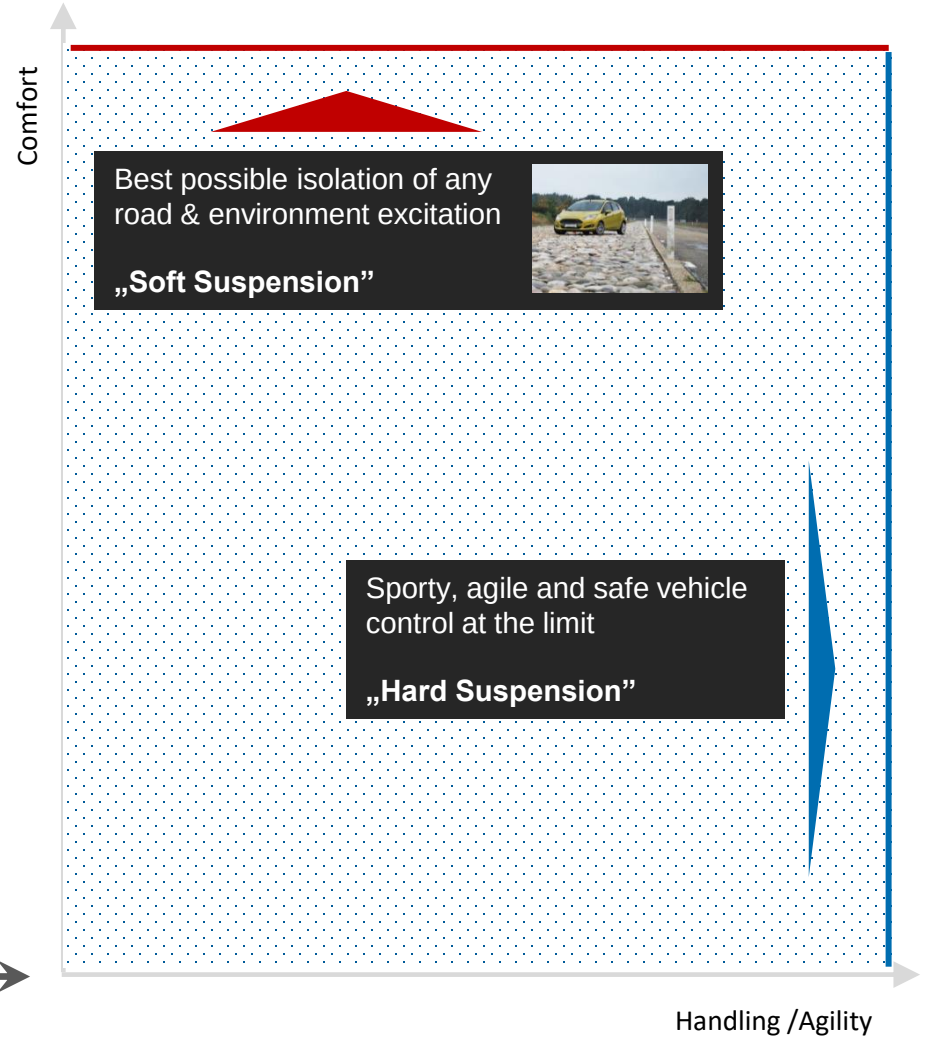
Vehicle dynamics attributes and their target conflicts

Performance	The accomplishment of a given task measured against preset known standards of accuracy, completeness, costs, acceleration and speed.
Agility	Agility is the ability to change the direction of the vehicle based on drivers steering input.
Stability	The vehicle ability of being enduring on the driver given path and free from non-desirable change or variation.
Comfort	Descriptions annoying driver or passenger impact dynamic due to driver effort, road excitation and vehicle vibrations, which negative influence the work load, driver effort, comfort feeling and healthiness.
Safety	Safety is the condition of being protected against physical, social, spiritual, financial, political, emotional, occupational, psychological, educational or other types or consequences of failure, damage, error, accidents, harm or any other event which could be considered non-desirable.

Vehicle dynamics attributes and their target conflicts

Customer key requirements to vehicle dynamics





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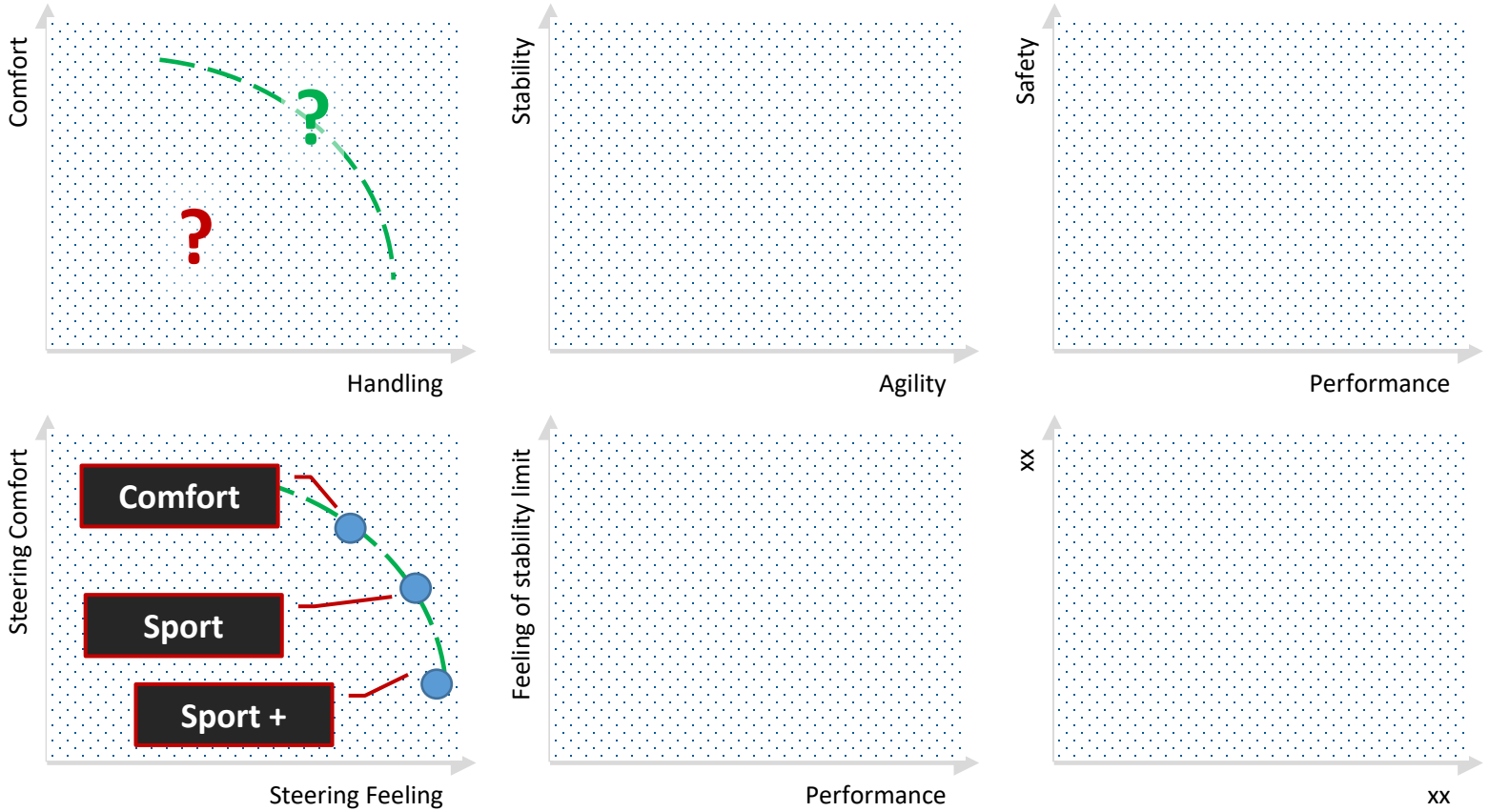
Kempten University of Applied Sciences

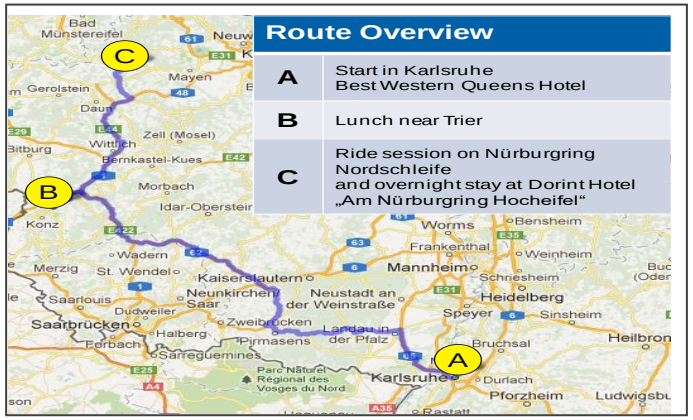
Vehicle dynamics attributes and their target conflicts

Which target conflicts do you know?



Test and evaluation methods for vehicle attributes

Test tracks for subjective and objective evaluation



Ride session on different public road types

Nürburgring Nordschleife
Handling Performance

Proving Ground
e.g. Bosch Boxberg

- Handling Performance Evaluation
- Ride & Comfort Evaluation
- Acceleration Performance & Drivability Evaluation
- General Impression under Customer Usage

IDIADA China Proving Ground

Typical test modules at a modern proving ground

Off-Road

Off-Road

High-speed oval

Driving-dynamics area

Brake-measurement tracks

Typical test modules at a modern proving ground


Fording and splash water basin


Handling course


Multi-functional area


Rough road tracks


Uphill tracks (5% up to 30%)


ISO noise-measurement track

Test and evaluation methods for vehicle attributes

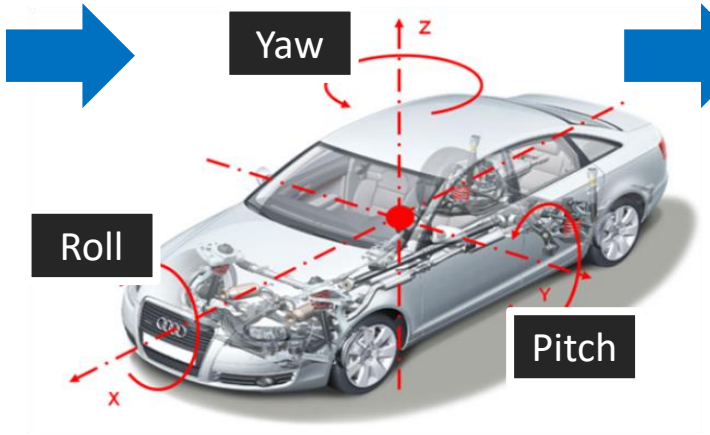
Nuerburgring the “Green Hell”

Vehicle dynamics attributes and their target conflicts

Objective Measurement is based on the drivers input and vehicle response

Drivers Input

Steer Angle (SWA)	δ
Steer Moment (SWT)	M
Brake Force	F^{BP}
Gas & Clutch Position, Gear	



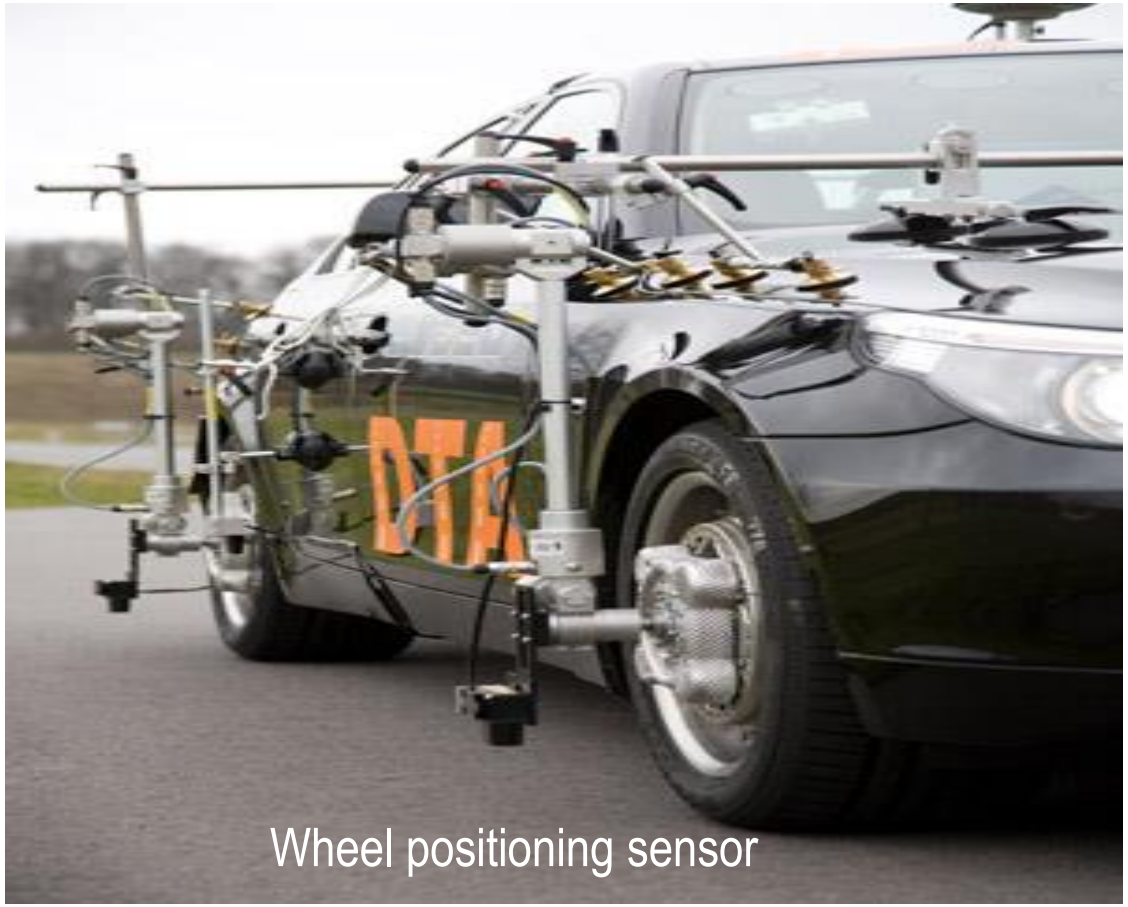
Most relevant

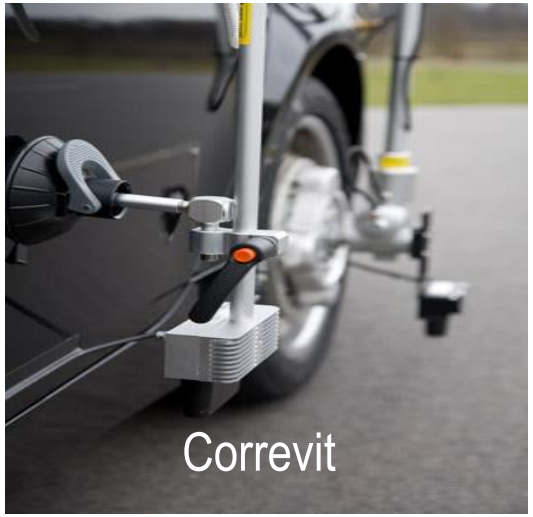
Vehicle Response

Roll Angel φ (Vehicle Rotation x-Axle)
Pitch Angle θ (Vehicle Rotation y-Axle)
Yaw rate dψ / dt (Vehicle Rotation z-Axle)
Longitudinal acceleration a_x
Lateral acceleration a_y
Vertical acceleration a_z
Longitudinal velocity V_x
Lateral velocity V_y
Drift Angle $\beta = -\arctan V_y / V_x$
Position x,y,z

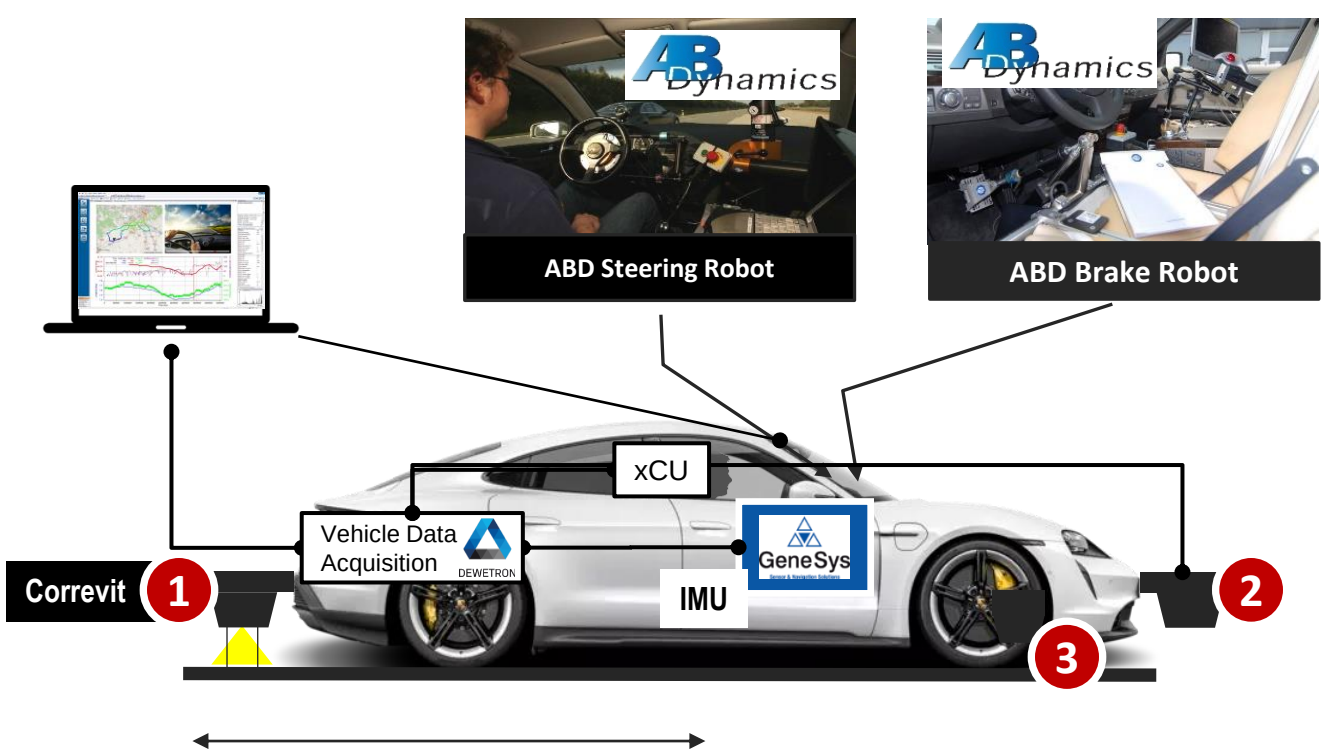
Vehicle test and objective evaluation: Working space vehicle

Objective evaluation methods with vehicle dynamics measurement

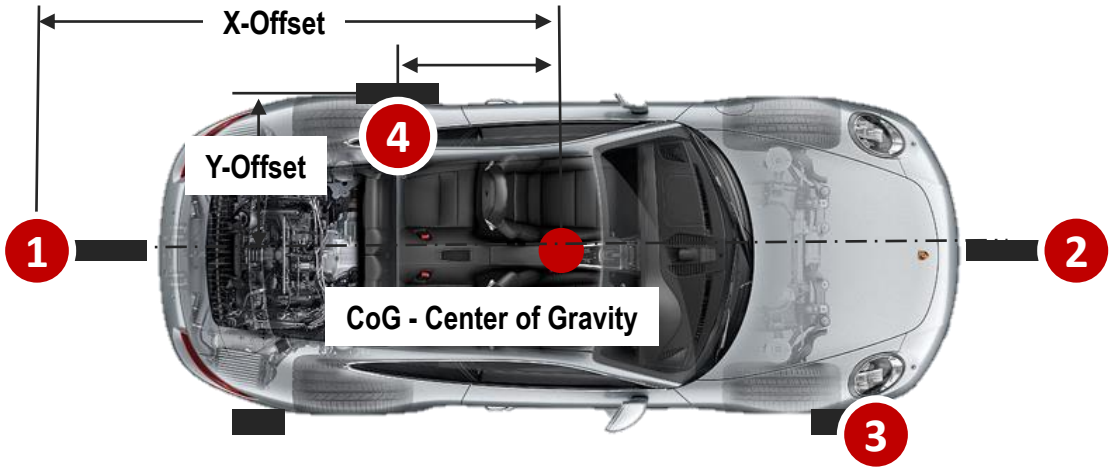




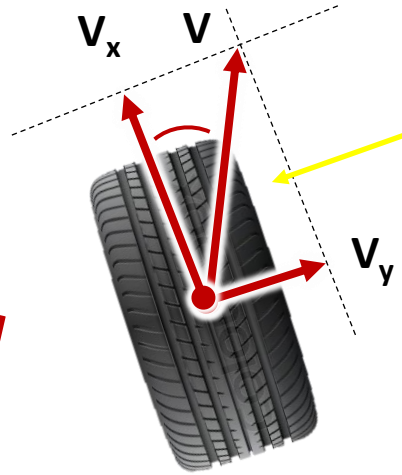
Objective evaluation methods with vehicle dynamics measurement



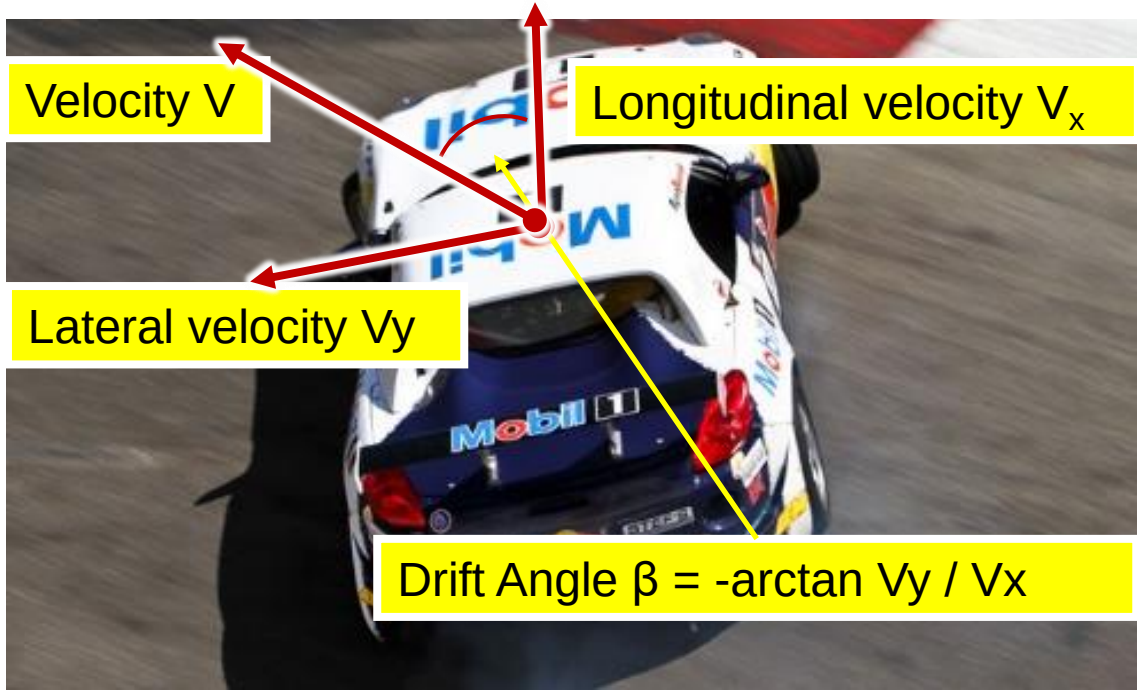
Correvit speed must be corrected to the CoG!



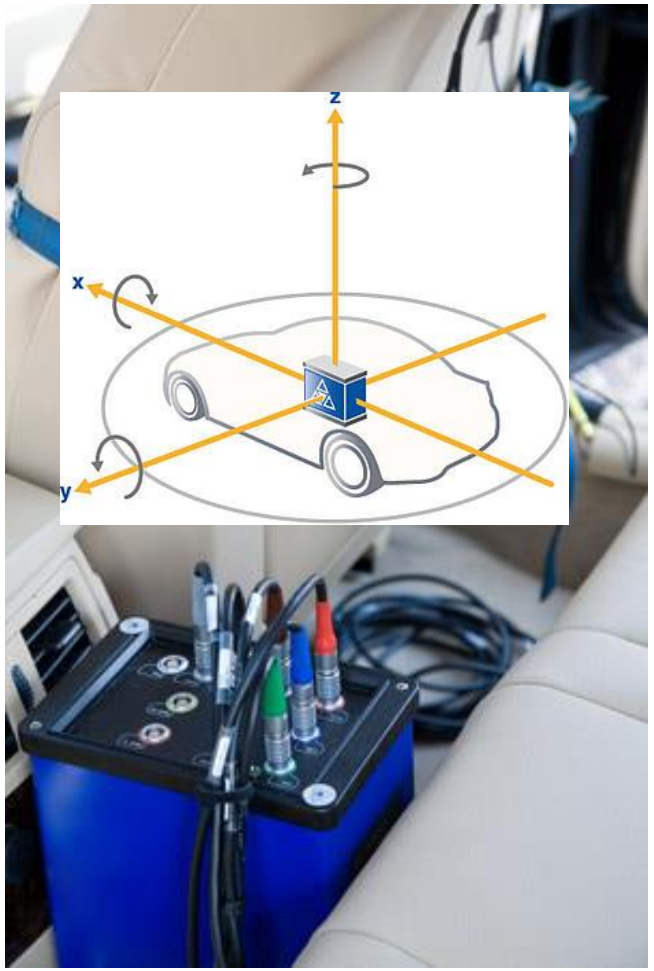
Speed Vx/Vy and calculation of drift and side slip angle



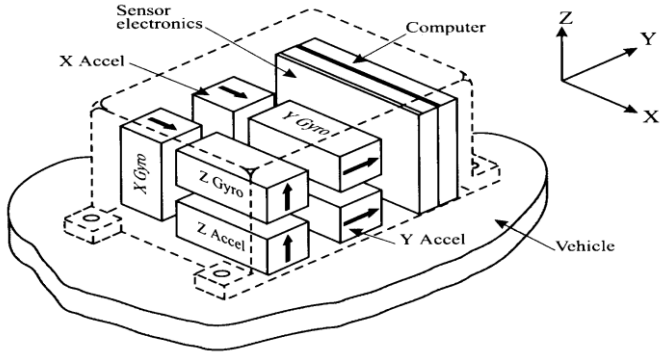
Side Slip Angle α = -arctan Vy / Vx



IMU – Inertia Measurement Unit: Genesys ADMA



Analytisch (Strapdown)



Basics of the gyro technology for the vehicle 3D motion measurement

- **3 gyro measurement axles**
- **3 acceleration measurement axles**

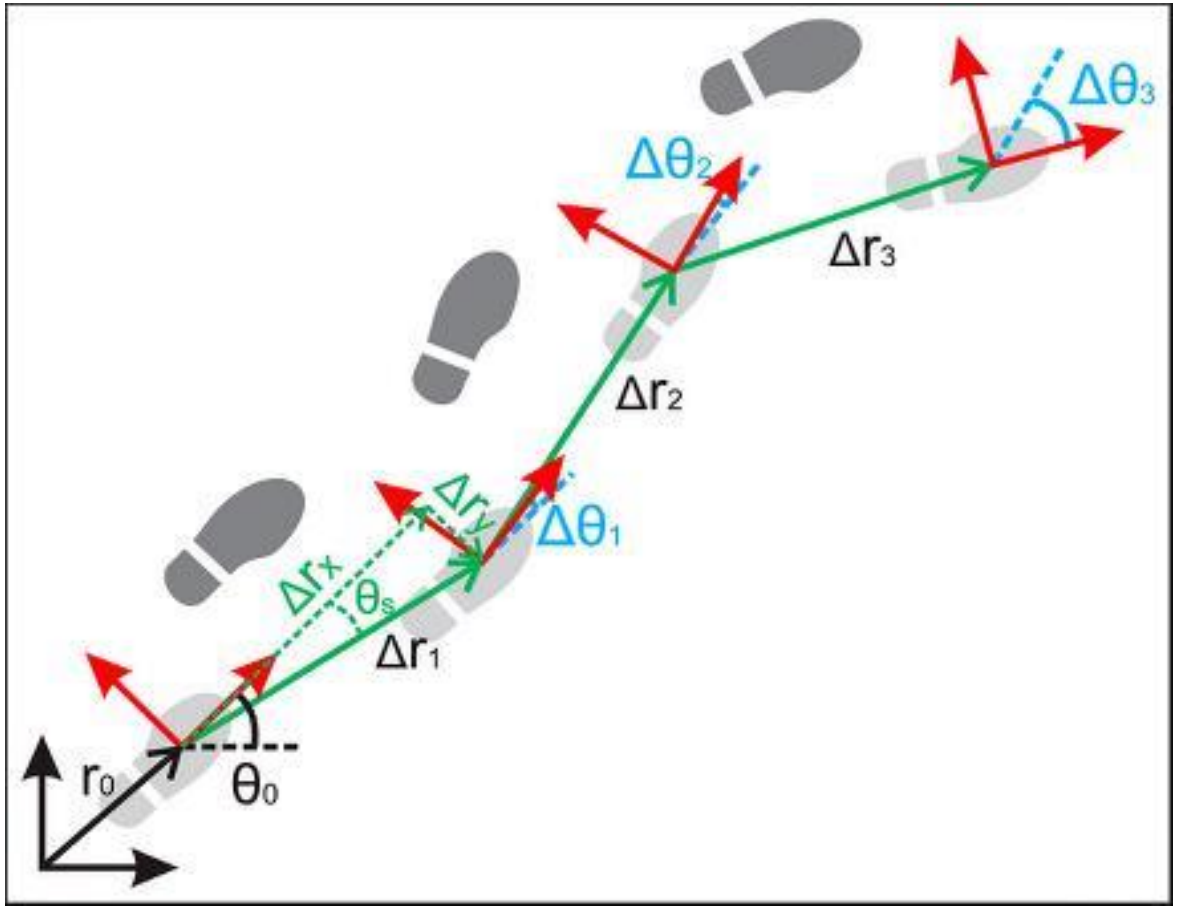
Challenge Integration

$$\alpha = \alpha_0 + \int \omega \, dt$$

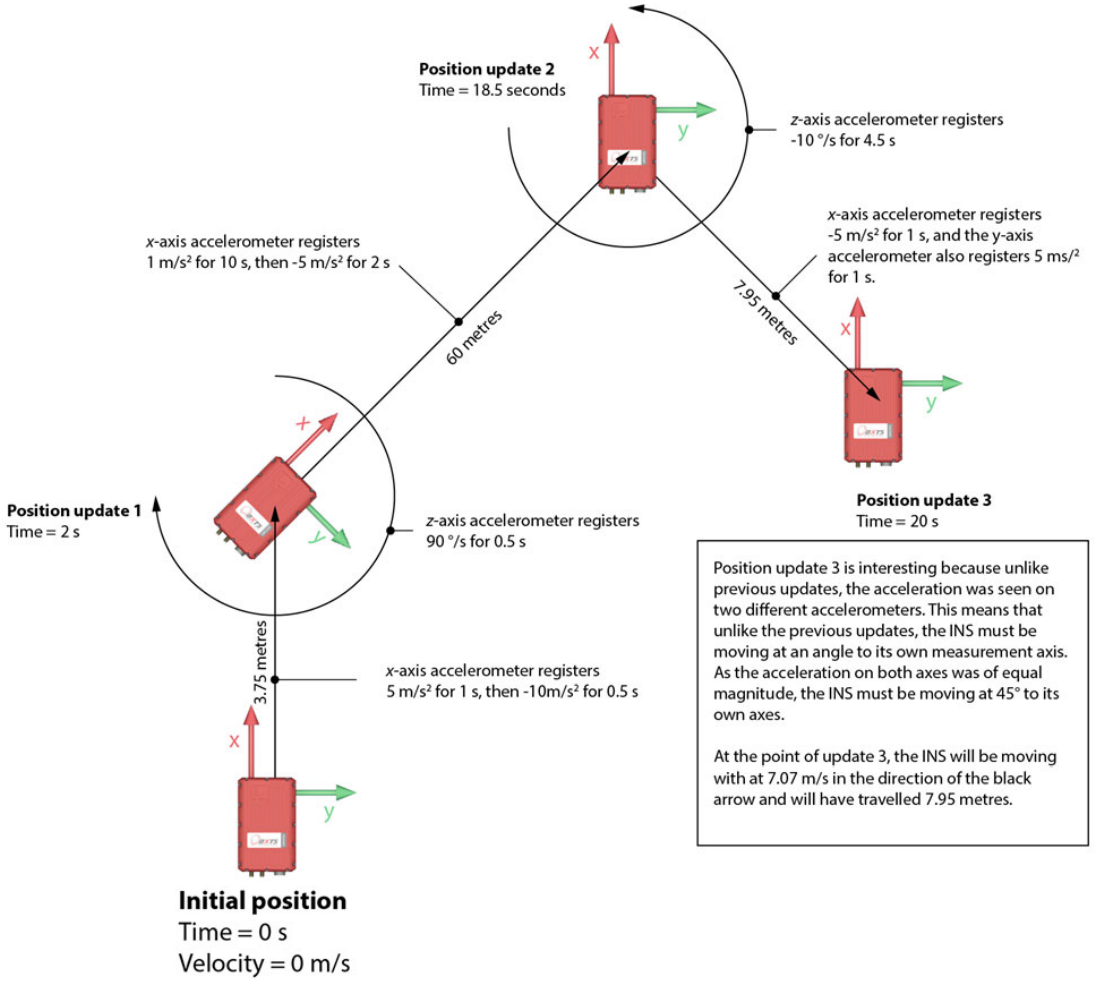
$$v = v_0 + \int a \, dt$$

$$s = s_0 + \int \int a \, dt \, dt$$

Principle of Inertial Measurment Units - Dead reckoning (Koppelnavigation)

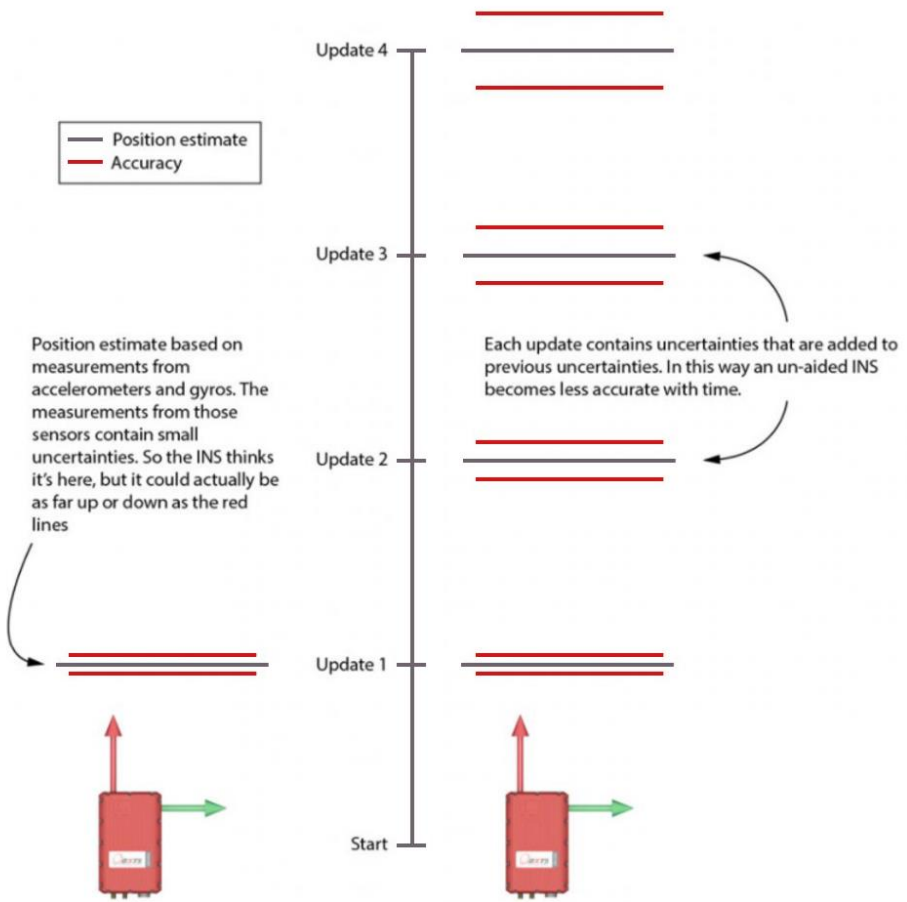


Principle of Inertial Measurment Units - Dead reckoning (Koppelnavigation)



Position update 3 is interesting because unlike previous updates, the acceleration was seen on two different accelerometers. This means that unlike the previous updates, the INS must be moving at an angle to its own measurement axis. As the acceleration on both axes was of equal magnitude, the INS must be moving at 45° to its own axes.

At the point of update 3, the INS will be moving with at 7.07 m/s in the direction of the black arrow and will have travelled 7.95 metres.



Genesys ADMA is based on the same principal as the inner ear.