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The Role of Simulation in Development and Testing of Autonomous Vehicles

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Where Are We Now?

Mercedes-Benz


Mercedes-Benz
Intelligent Drive
Active Distance Assist DISTRONIC
Route based speed adjustment
Active Speed Limit Assist
Car-to-X Communication
PRE-SAFE® PLUS
ATTENTION ASSIST
Beltbag
Active Steering Assist
Active Lane Change Assist
Active Emergency Stop Assist
PRE-SAFE® Sound
Active Blind Spot Assist
Active Lane Keeping Assist
Remote Parking Assist
Active Brake Assist
standard with Pedestrian Detection,
in combination with Driver Assistance
package with Cross-Traffic Function and
Congestion Emergency Braking Function
MULTIBEAM LED
ULTRA RANGE high beam
Evasive Steering Assist
Mercedes-Benz

What is the

Challenge ?

Stages of Autonomy (NHTSA Logic)

Level 0
No automation

Driver in charge

Level 1
Function-specific automation

Single control functions such as speed selection, braking or lane keeping are automated

From here:

Level 2
Combined function automation

More than one control function is automated

Driver expected to be available for control at all times and on short notice

To here:

Level 3
Limited self-driving automation

Vehicle takes control most of the time

Driver expected to be available for occasional control with comfortable transition times

Level 4 / 5
Full self-driving automation

Vehicle takes control all of the time

Driver not expected to be available for control at any time

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Safety and Automation: A Major Challenge

Accidents are almost all due to human error.

Humans do much more right when driving than they do wrong.

We have with some success automated to intervene when people do something wrong.

We now aim at automating those things that people do right.

On the German Autobahn, every 7.5 million km we may catch an error.

We have to drive those 7.5 million km and must not fail a single time.

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Safety of autonomous vehicles

Before an autonomous vehicle

will drive you anywhere,

it has to prove that

it will not drive you into trouble !

How to Manage Risk?

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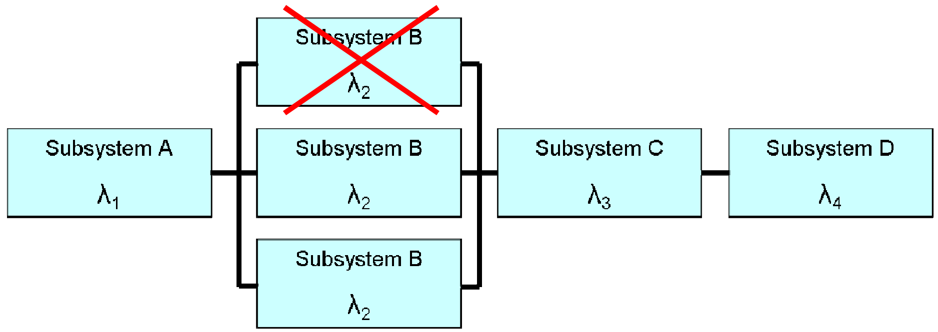
Functional decomposition of complex systems

<u>Design for high reliability:</u>

- Redundant, self monitoring components
  - fault tolerant system design
- Diverse components
  - avoid common mode (correlated) faults
- Fault tree analysis
  - avoid systematic errors
- Derive system failure rate by mathematical model

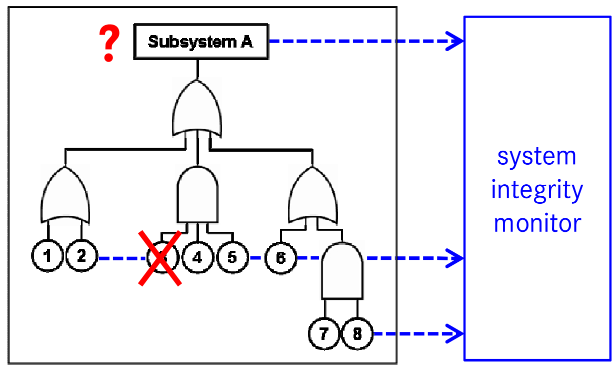


$$\lambda_{total} = \lambda_1 + (\lambda_2)^3 + \lambda_3 + \lambda_4$$

(only if all subsystems are uncorrelated !)

<u>Testing for high reliability:</u>

- Evaluate system integrity indicators
- Verify component failure rates
- Verify uncorrelation of component failures
- Verify rejection of fault propagation



Safety assessment of driving situations

Drive carefully:

Look ahead,
drive predictively,
know your limits

Master extreme situations:

Detect dangers early and
react fast & appropriately

Limit the consequences:

Provide suitable
protection

$$R = E\,(1\text{-}C)\,S$$

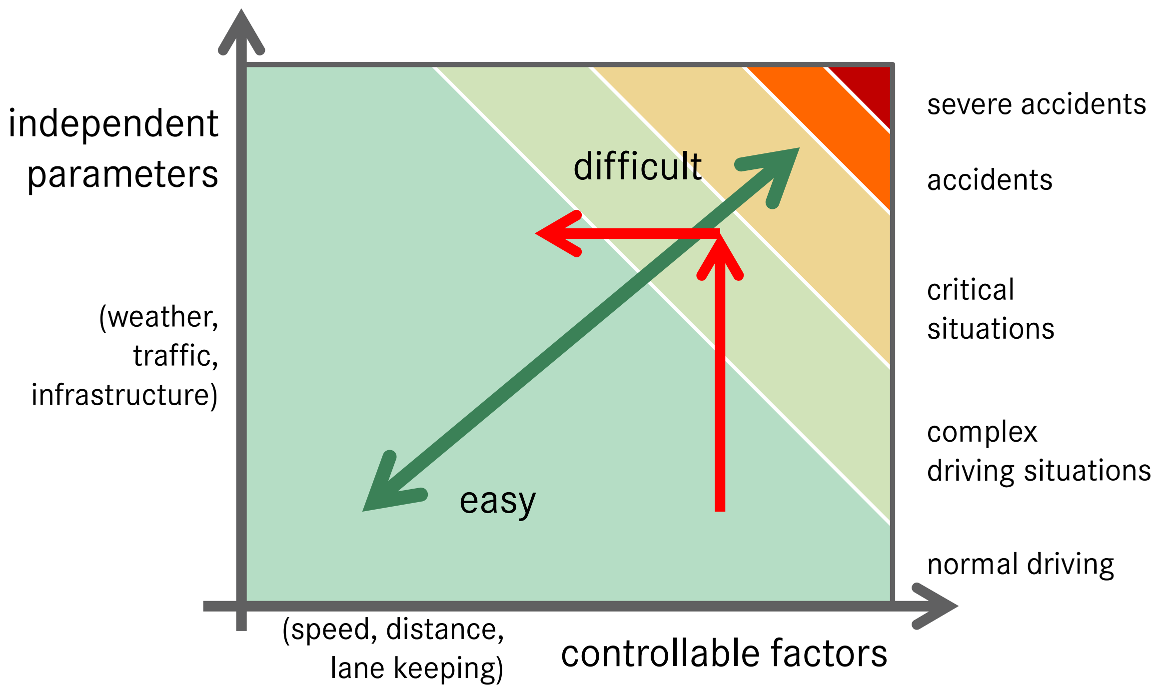
- R: Risk
- E: Exposure
- C: Controllability
- S: Severity

New option with autonomous driving | Active safety | Passive safety

Vehicle response upon changing conditions

Verify, that vehicle avoids uncontrollable situations by adequate behaviour

E



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Five Categories of Reasons for Exposure to Accidents

1. Failure of components and hardware deficiencies
2. Deficiencies in sensing road, traffic and environmental conditions
3. Deficiencies in control algorithms (complex and difficult situations)
4. Behaviour-dependant accidents (adequate behaviour and rule compliance)
5. Faulty driver and vehicle interaction (mode confusion and false commanding)

design specific **external conditions**

Source: H.P. Schöner: Challenges and Approaches for Testing of Highly Automated Vehicles; 3rd CESA Automotive Electronics Congress, Paris 2014

Testing Platforms and the Importance of Simulation

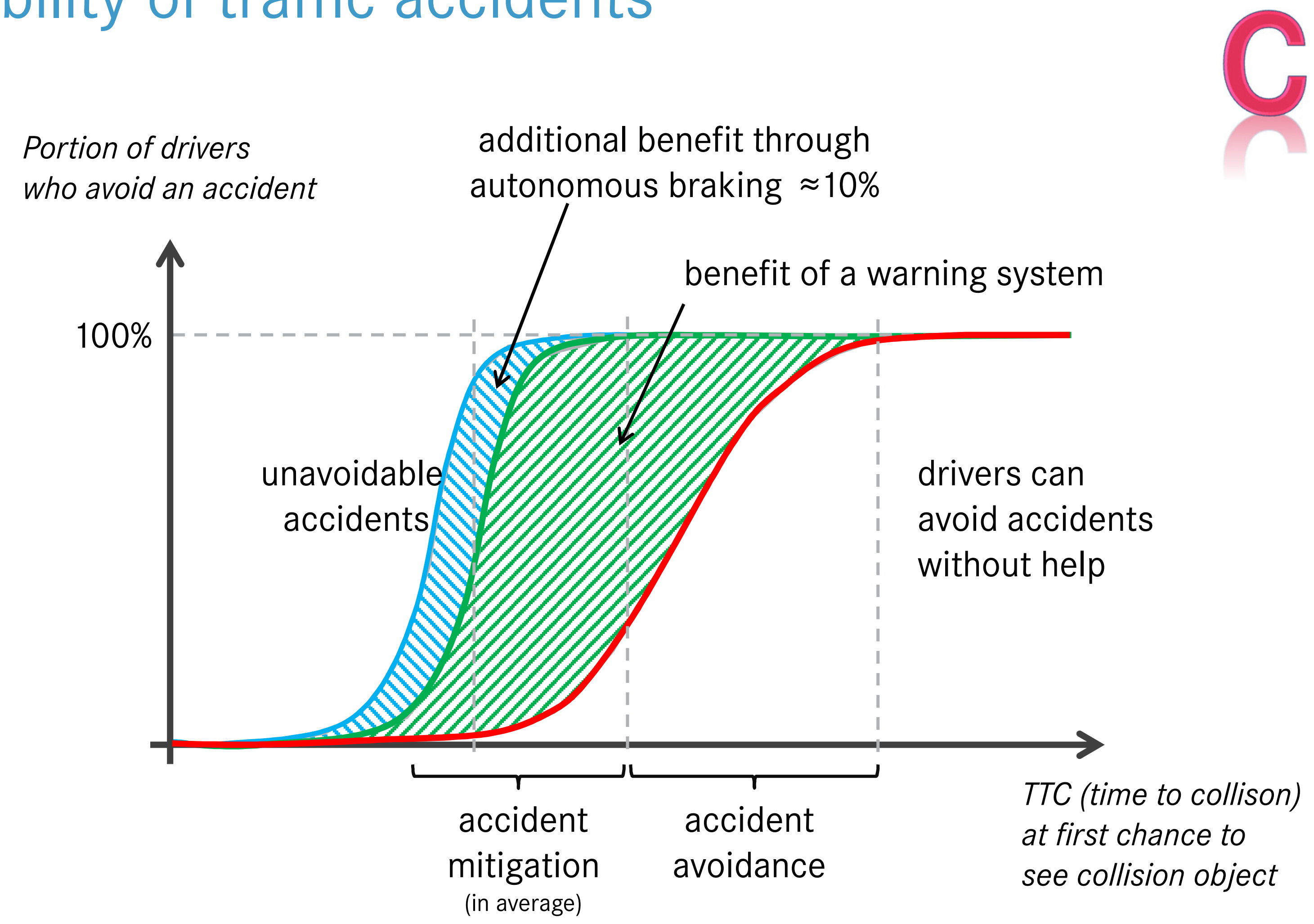
Category Platform	1	2	3	4	5
HIL	**X**	X 1)	X		
SIL		X 1)	**X**	**X**	
Test Area	X	X 2)	X	X	X
Field Test		**X**		X	X
Driving Simul.					**X**

1) requires sensor models
2) requires specific test modules

How to Measure Controllability ?

Dynamic Simulator in Sindelfingen

Controllability of traffic accidents



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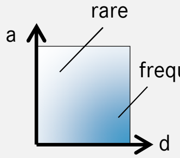
How to Verify Driving Functions ?

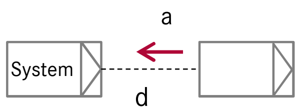
Verification and validation at the end of the process requires careful specification in the early system design phase

System functional specification:
Investigation of properties of the system environment

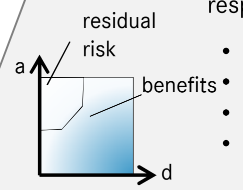


typical behaviour and parameters of
- infrastructure, traffic, environment
- sensors, actuators
- drivers

Illustration for example:

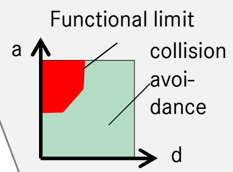


Validation: Assessment of implementation with respect to desired functionality



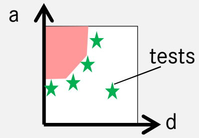
- Confirmation of design assumptions
- Confirmation of risk assessment
- Examination of retroactive effects
- Safety in use, customers‘ benefits and acceptance

System design: specification of system performance



- Risk assessment & management
- Functional limitations
- Functional requirements including fault management
- Define performance criteria and tests

Verification: Comparison of implementation with respect to design specification



- Perform system tests
- Evaluate test coverage

Implementation

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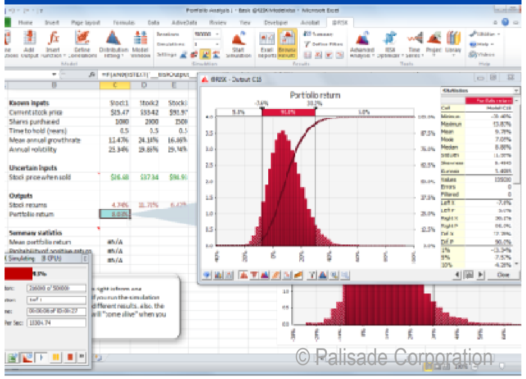
Testing of Autonomous Functions

Virtual tests



☑ Analysis of a huge number of scenarios, environments, system configurations and driver characteristics

Proving ground tests

☑ Reproducibility by use of driving robots, self driving cars and targets; critical manoeuvres are possible

Field tests

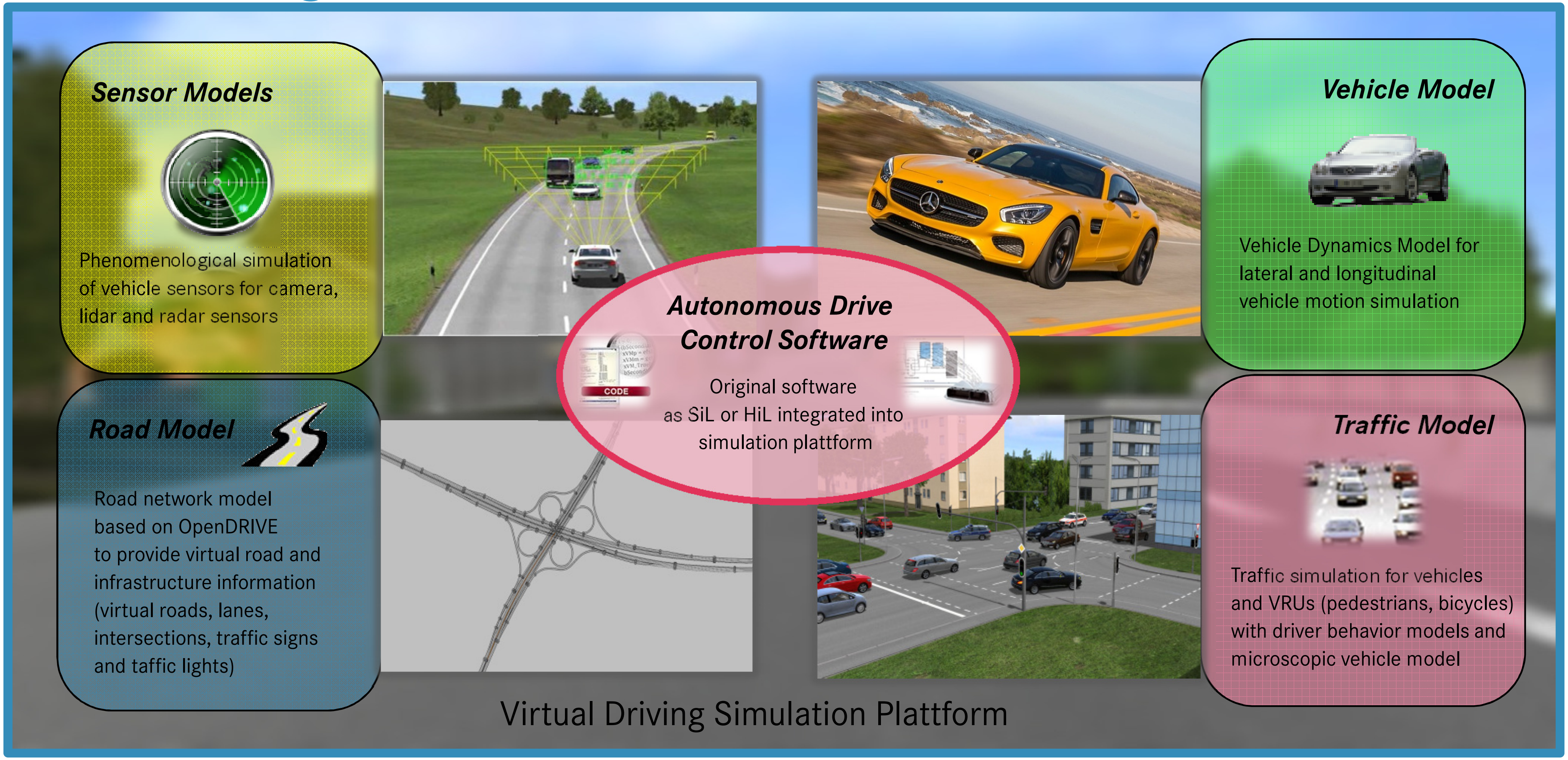
☑ Investigation of real driving situations and comparison with system specifications

Effort for coverage of all relevant scenarios & environments

Uncertainties & simplifications

Source: U. Steininger, H.P. Schöner, M. Schiementz: Requirements on tools for assessment and validation of assisted and automated driving systems, 7. Tagung Fahrerassistenz, München, Nov. 2015

Virtual Driving with Model Based Simulation



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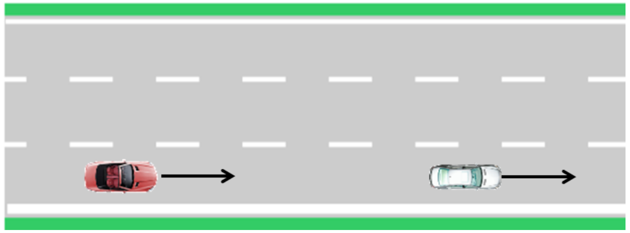
Example: Real world scenario and its simulation

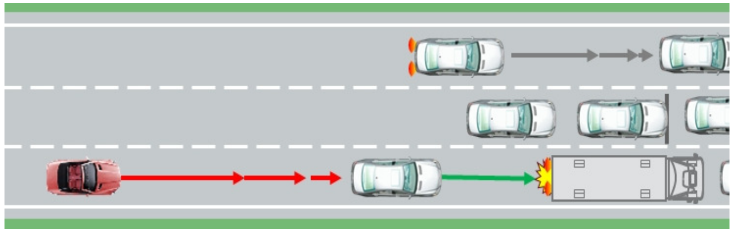
Use Case: function development for complex traffic scenarios

Challenging Traffic Situations

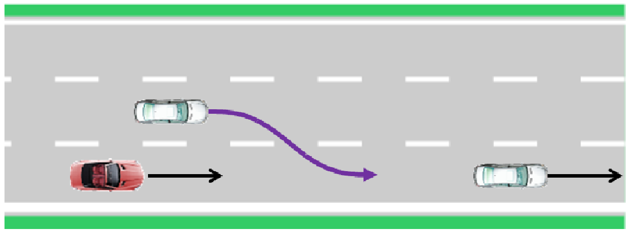
Following



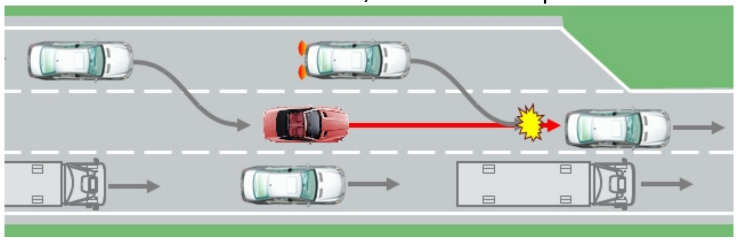
Preceeding car drives into traffic jam without braking



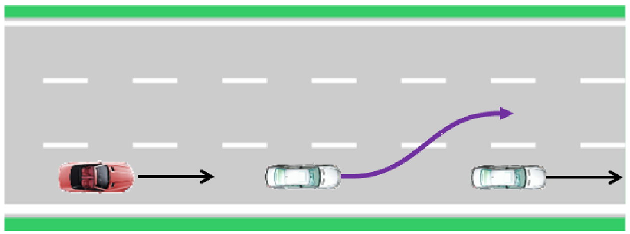
Cut-in



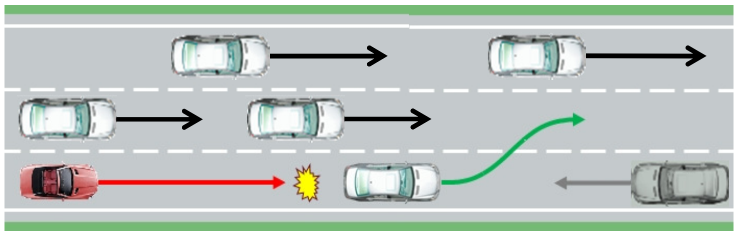
Cut-in vehicle brakes hard, no evasion space



Cut-out

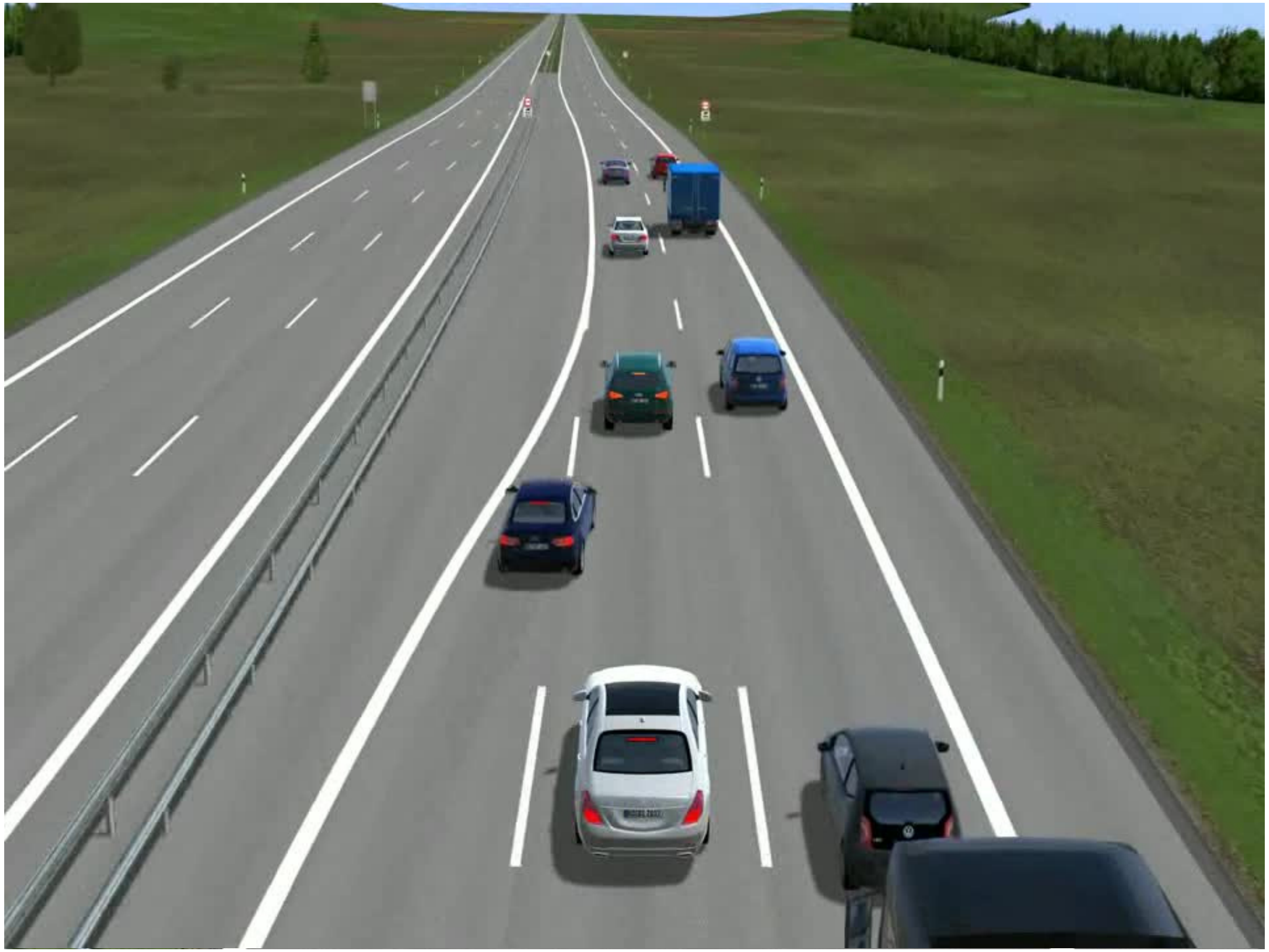


Car cuts out just before obstacle or oncoming car



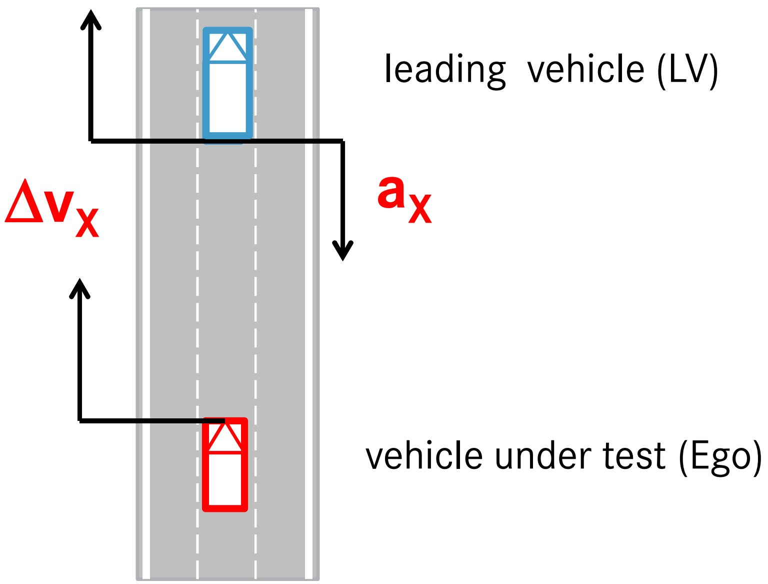
Use Case: function development for collision avoidance scenarios

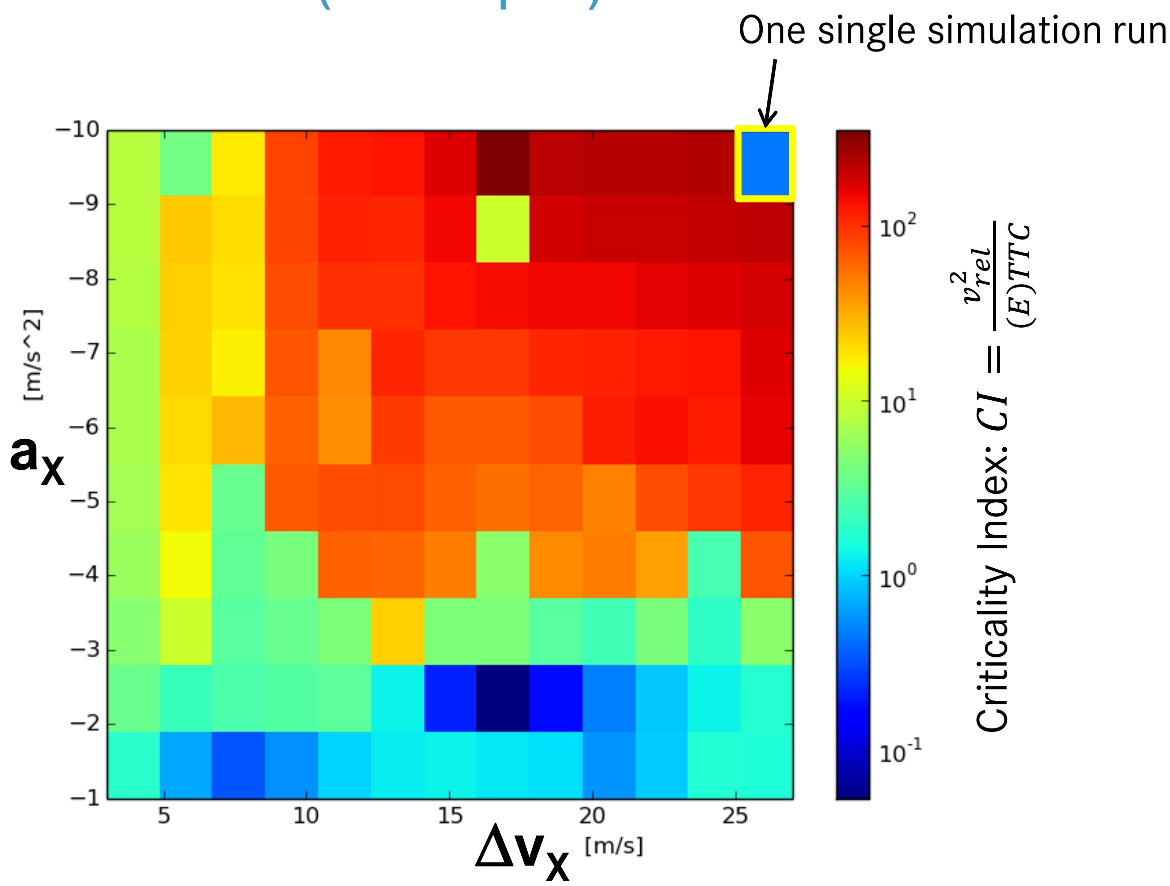
Simulation:
Cut-in scenario



Validation of Simulation: Cut-in with high relative speed

Batch Simulation of Collision Avoidance (example)





Use Case: verification of collision avoidance and quality measure for safe driving

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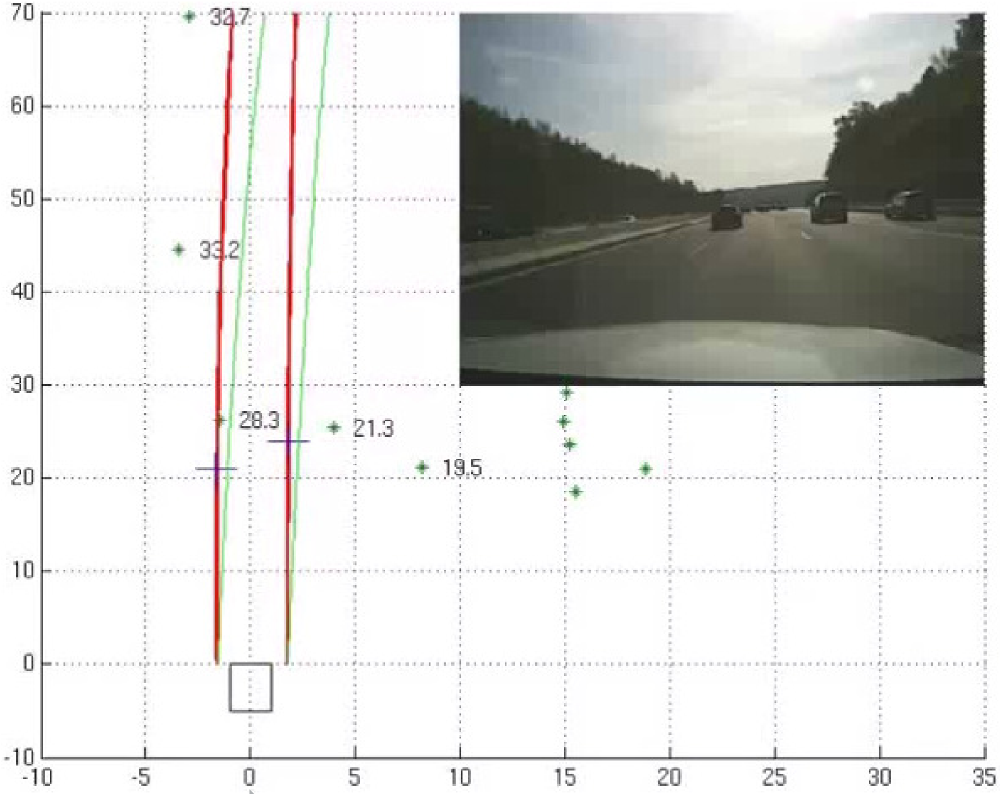
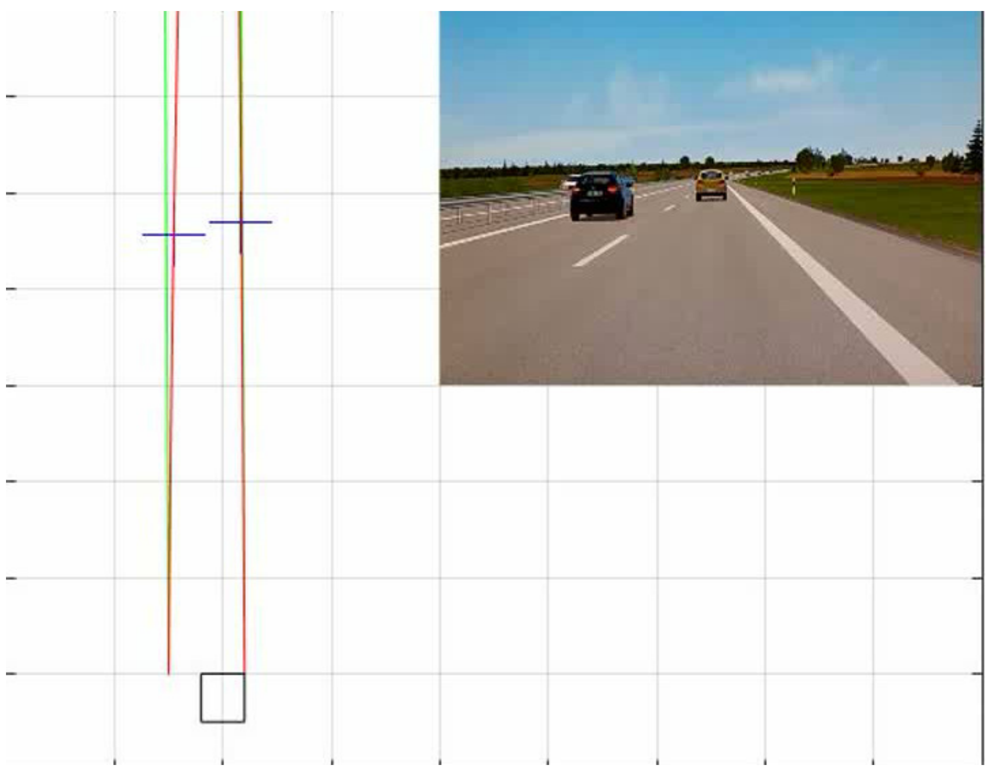
Simulation of Lane Detection

Estimation based on sensor data
Information provided by map

Real Data



Simulated Data



Long distance interpretation of sensor signals requires precise maps !

So what is essentially new for testing of autonomous vehicles ?

Methods

- Much more simulation, esp. for verification of control algorithms and rule compliance
- Systematic search for rare functional deficits, instead of just driving test kilometers

Functions

- Continuous assessment of and adaptation to external conditions and rules
- Judging reliably whether the limits of vehicle autonomy are close
- Announce the end of autonomous mode early enough for the driver to take over (Level 3)
- Bring the vehicle to a safe stop, if (in Level 3) the driver should fail to take over

It requires simulation to efficiently verify the vast amount of functional requirements !


Thank You Very Much
for Your Attention!

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The Author

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in Daimler's R&D Center „Driving Dynamics Functions and Vehicle Testing";
he is responsible for development and supply of methods for testing and validation for future chassis and assistance systems, including autonomous driving functions. This includes methods to provide reproducible testing situations on proving grounds with automatically driven coordinated vehicles, simulation methods for function development and testing, and operating the Driving Simulation Center of Daimler AG.

Dr. Schöner (born 1956 in Düsseldorf) studied Electrical Engineering at RWTH in Aachen (Germany) and has also a degree „Master of Engineering" of Purdue University (Indiana, USA). He received his doctorate degree in 1988 with a thesis on methods for „Monitoring and Charge Control of Batteries in Electric Vehicles" from RWTH Aachen.

From 1989 to 2004 (from 1991 on as senior manager) he worked in the field of „Actuators and Mechatronics" as well as new automotive power supply systems at Daimler Research in Frankfurt. Since 2004 he has been heading the development of testing methods for chassis and assistance systems as well as setting up test vehicles in Sindelfingen, since 2012 in addition he is head of the Driving Simulation Center of Daimler AG.

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