Which Scenarios Need to be Tested to Ensure Automated Driving Safety and Why?

A new methodology applying a coupled traffic and vehicle dynamics simulation

Nico Weber, Dirk Frerichs, Dr. Ulrich Eberle

Level 2 System

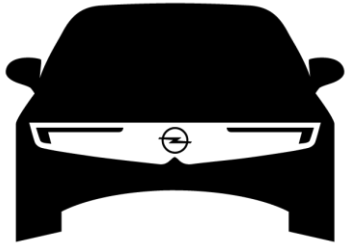
- Partial Driving Automation

Active ADS*

Object and event detection and response

Level 3 System

- Conditional Driving Automation

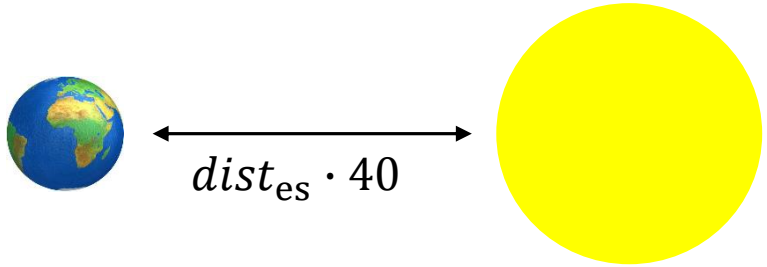


Need of validation and safety proof of the vehicle **+ intended functionality of automated driving system within predefined operational design domain**

* **A**utomated **D**riving **S**ystem

Sources: Wachenfeld, W.; Winner, H.: Die Freigabe des autonomen Fahrens (2015); SAE International: SAE J3016 (2018)

- Statistical, distance-based proof of safety cannot be accomplished by physical testing
  - Autobahn-Chauffeur → ≈ 6 Billion test kilometres
- Scenario-based approach
  - Reduction of test effort through identifying and testing exclusively critical scenarios
  - Test effort still exceeds existing capacity in practice
  - Functional scenario *cut-in* → $S_N \approx 8 \cdot 10^{23}$



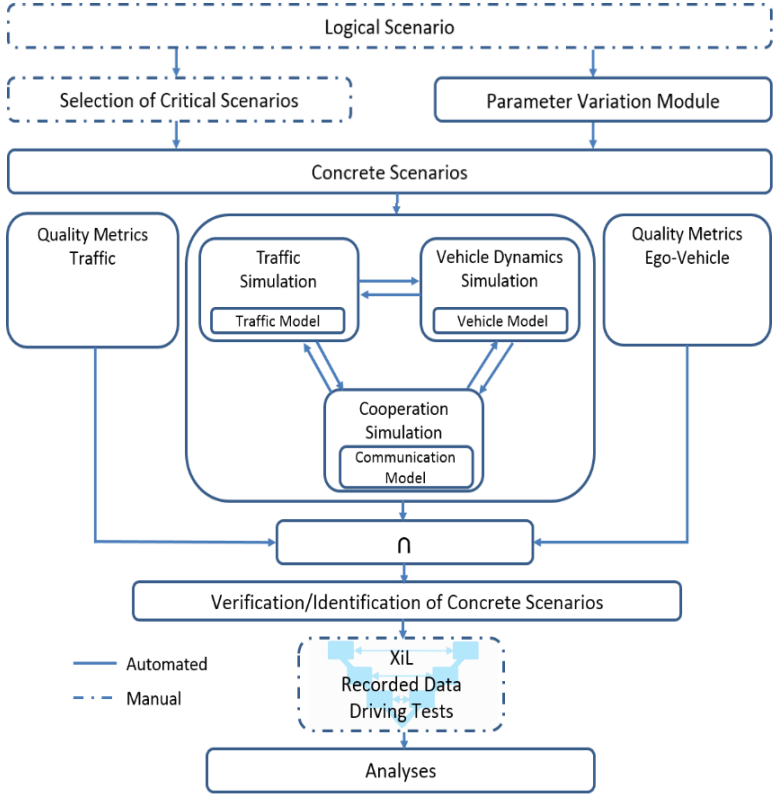
Need of further parameter space reduction

Source: Amersbach, C.; Winner, H.: Functional decomposition (2019)

Agenda

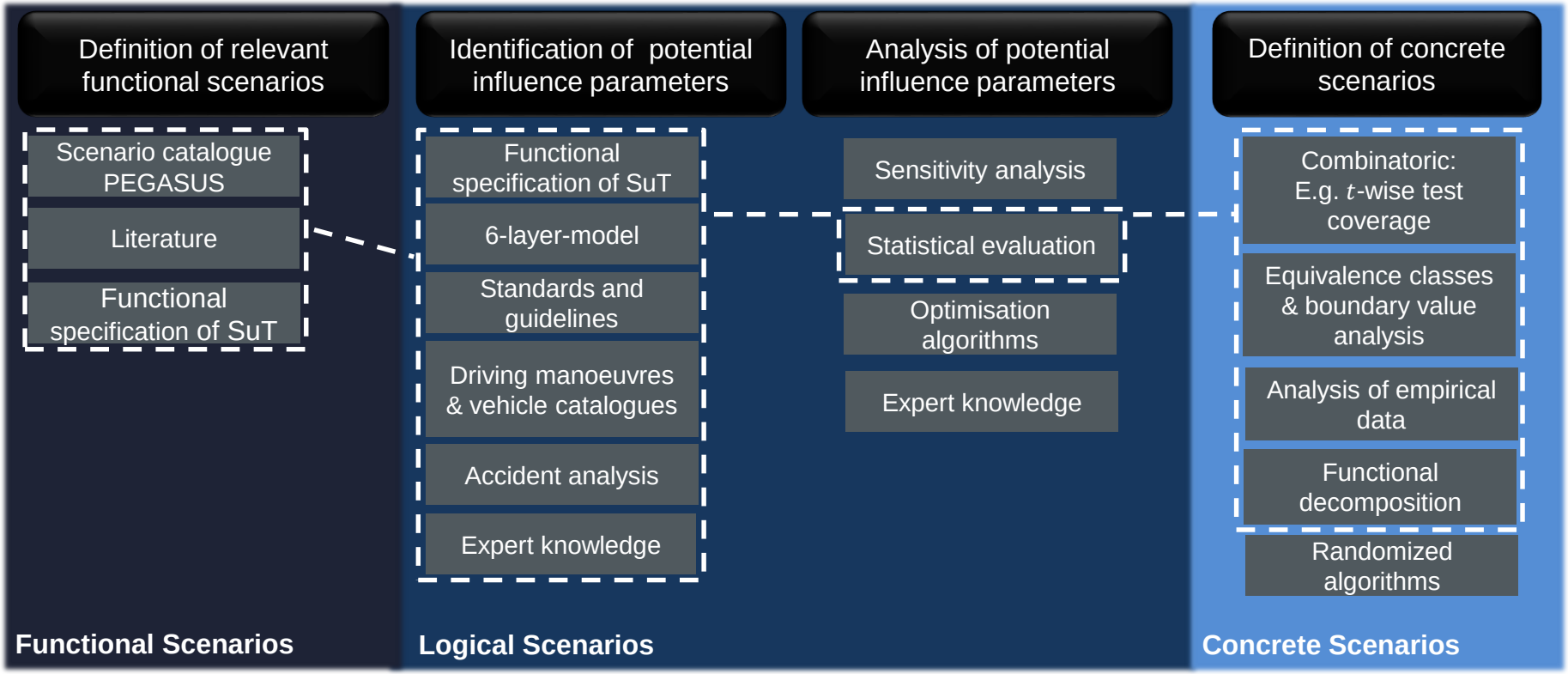
- Motivation
- Methodology
- Results
- Conclusion & Outlook

- How to transfer functional scenarios into concrete scenarios as input for the coupled simulation?
  - in a systematic way
  - while reducing the parameter space

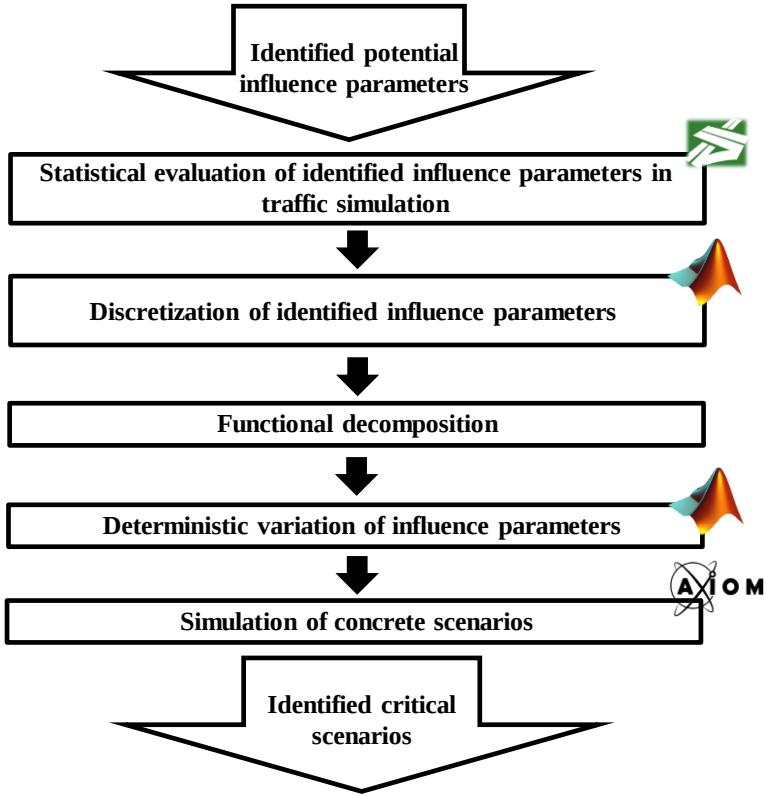


Source: Hallerbach, S. et al.: Simulation-Based Identification of Critical Scenarios (2018)

Methodology – Overall approach

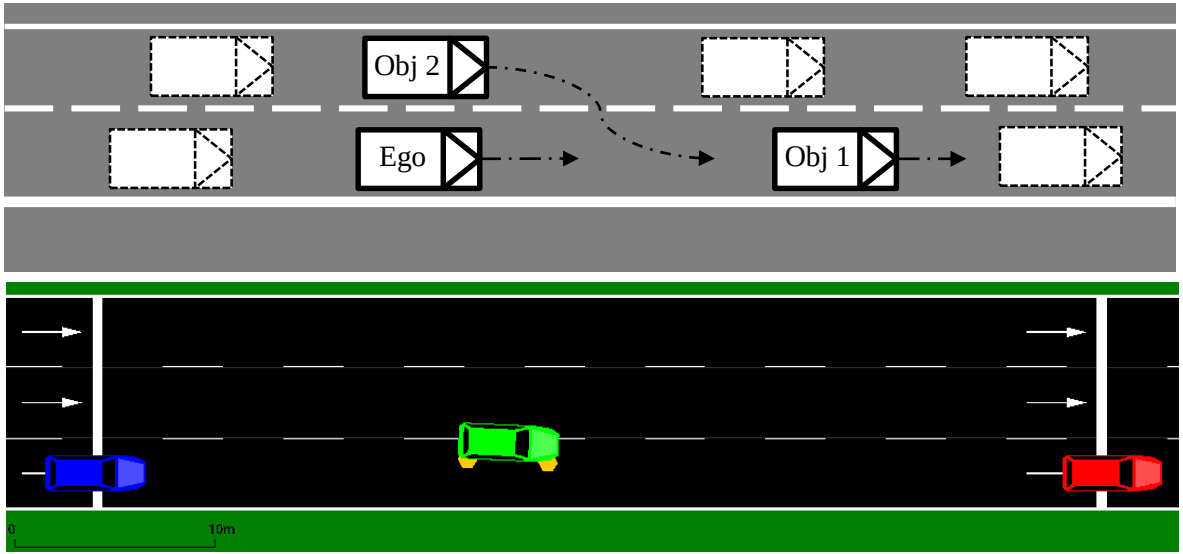


Sources: Schuldt, F.: Diss., Methodischer Test automatisierter Fahrfunktionen (2017); Weber, N.: Masterthesis, Reduzierung des Parameterraums (2019)



Sources: Frerichs, D.; Borsdorf, M.: Quality for Vehicle System Simulation (2018); Weber, N.: Masterthesis, Reduzierung des Parameterraums (2019)

- Cut-in scenario
  - Worst-Case scenario within ODD
  - Identification of 22 potential influence parameters



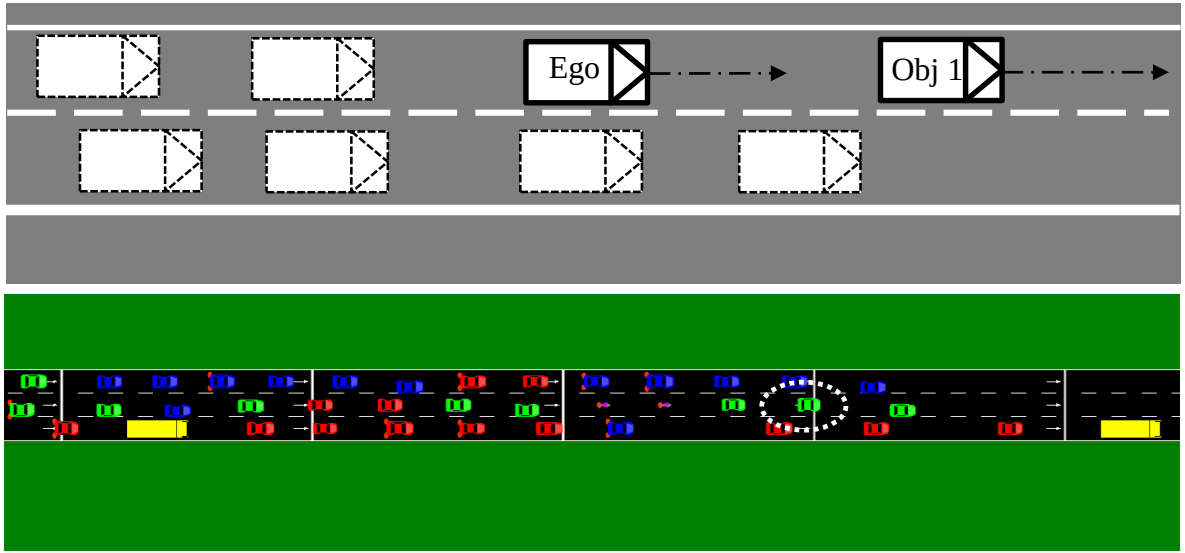
Source: Aouini, R.: Masterthesis, Reduktionspotential funktionale Dekomposition (2018)

- Cut-in scena
  - Worst-C
  - Identific

Represent-ation layer (Bagschik et al., 2018) [1]	Parameter p_i	Scenario			Influence on functional layer					
		cut in	Traffic jam dissolution	equ. class scenario	0 Inf. Access	1 Inf. Reception	2 Inf. Process-ing	3 Sit. Under-standing	4 Behavior. Decision	5 Action
		Number of discretization steps v_i								
1 Road Level	width lane 1	×	×	×	x	x			x	
	width lane 2	×	-	×	x	x			x	
	curvature	×	×	×	x	x			x	
	roadsurface	×	×	×	x	x	x	x	x	x
	slope	×	×	×	x	x		x	x	x
	superelevation	×	×	×	x	x	x	x		
2 Traffic Infrastructure	type of road marking left	×	×	×	x	x	x			
	type of road marking right	×	×	×				x	x	
	width of road marking left	×	×	×	x	x	x			
	width of road marking right	×	×	×						
4 Objects	type of object 1	×	×	×	x	x	x	x		
	type of object 2	×	-	×	x	x	x	x		
	initial speed of object 2	×	-	×		x		x	x	
	final speed of object 2	×	-	×	x	x		x	x	
	initial group speed ego+obj1	×	×	×		x		x	x	x
	initial distance ego-obj1	×	×	×	x	x		x	x	
	initial distance ego-obj2	×	-	×	x	x		x	x	
	cut-in distance	×	-	×	x	x		x	x	
	cut-in time	×	-	×	x	x		x	x	
	group acceleration ego+obj1	-	×	×	x	x		x	x	
5 Environment	sun position	×				x	x			
	precipitation (rain, snow, etc.)	×			x	x	x			x
	cloudiness	×			x	x				
	wind	×								x
	temperature	×				x				x

tionale Dekomposition (2018)

- Traffic jam dissolution
  - Takeover process → Decisive aspect concerning the controllability of the vehicle
  - Identification of 18 potential influence parameters

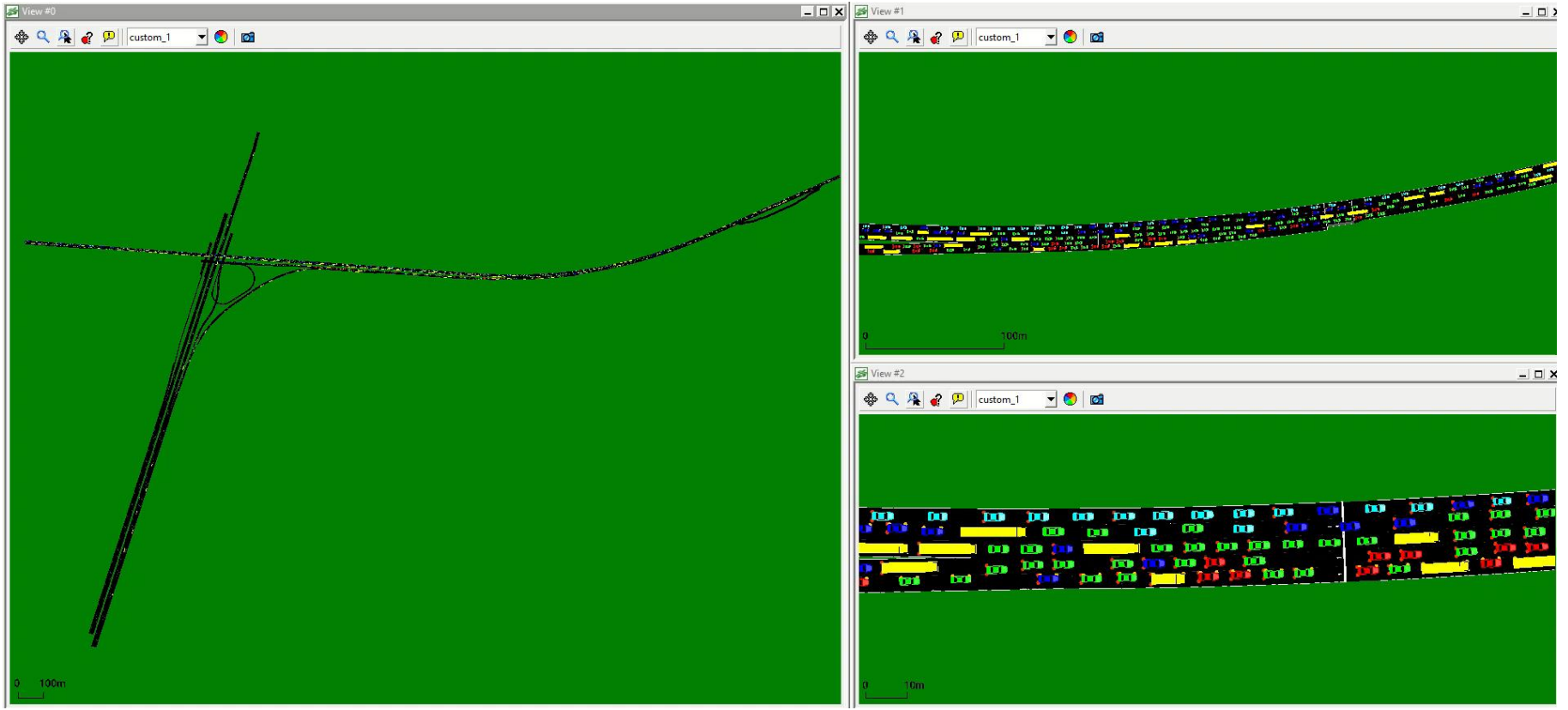


Sources: Feldhütter, A. et al.: Influences on Take-Over Performance (2017); Weber, N.: Masterthesis, Reduzierung des Parameterraums (2019)

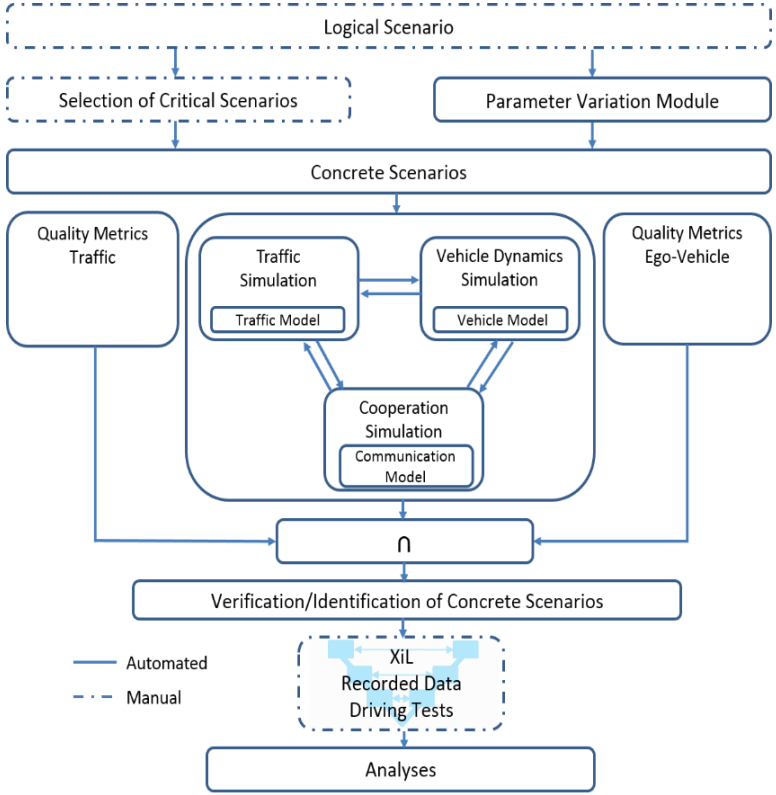
Traffic simulation in Eclipse SUMO		
Layer	**Category**	**Description**
Road & Traffic Infrastructure	Road section	OpenDrive Map of the motorway junction Frankfurt (provider: Atlatec)
	Considered length	3.7 km
Dynamic Objects	Types	Car, Truck, Motorcycle
	Demand per type	Based on traffic counting of BASt
	Variants per type	10,000
	Parameter distribution of variants	Normal with predefined limits
Environment	Out of Scope from SUMO	

Source: Weber, N. et al.: Simulation-based approach for the derivation of concrete scenarios (2020)

Results – Analysis of influence parameters



- Dynamic coupling between Eclipse SUMO and IPG CarMaker
  - Possibility to spawn and assess behaviour of AD-agents in complex traffic conditions
  - Investigation of mixed-traffic impacts
  - Prototype-in-the-Loop-Approach
    - Replacing digital twin of the vehicle with physical prototype



Source: Hallerbach, S. et al.: Simulation-Based Identification of Critical Scenarios (2018)

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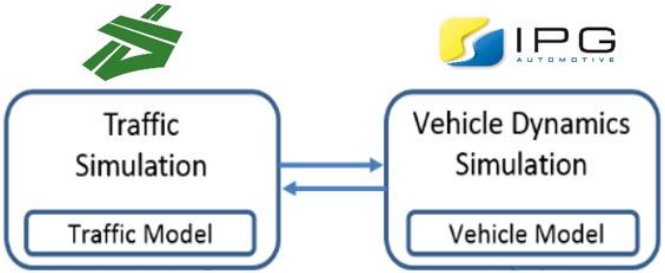
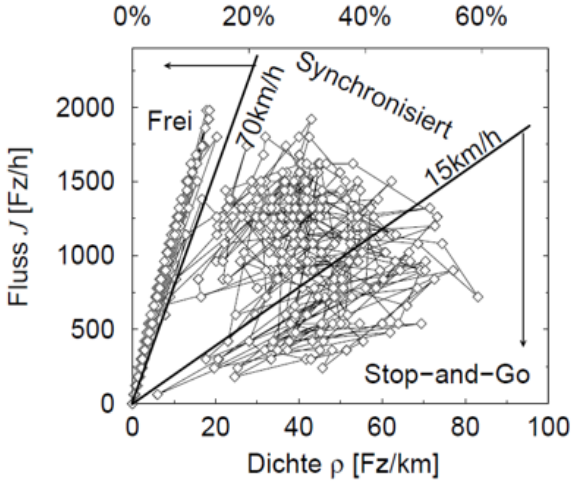
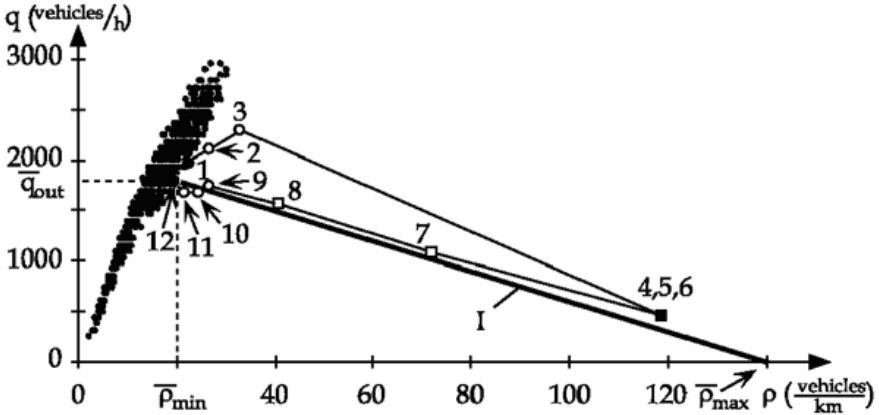


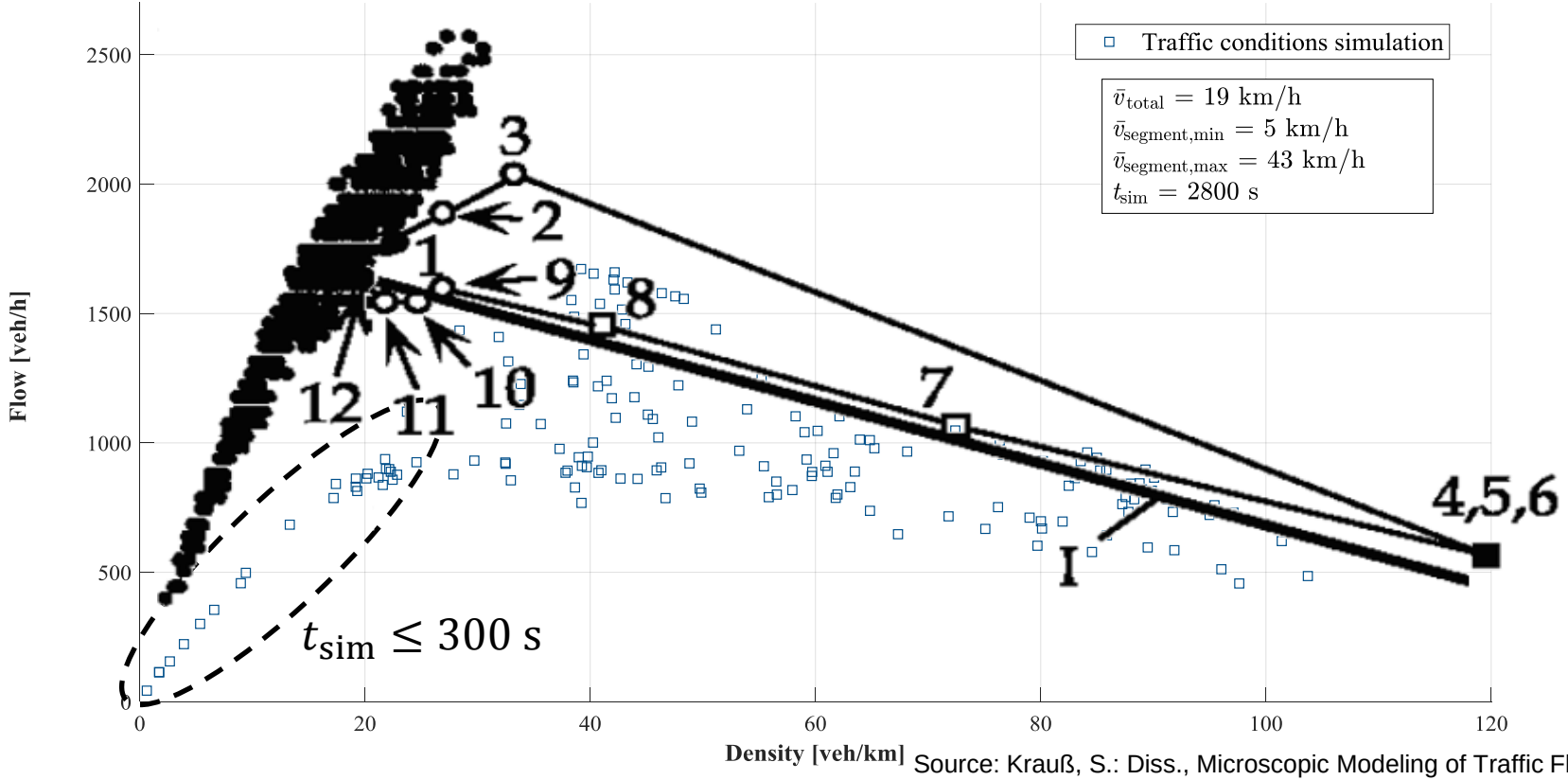
Source: Hallerbach, S. et al.: Simulation-Based Identification of Critical Scenarios (2018)

- Plausibility check of traffic simulation
  - Comparison between synthetic data generated by traffic simulation and data recorded in real traffic
  - Macroscopic traffic metrics flow J, density ρ and average speed $\bar{v}$





Source: Krauß, S.: Diss., Microscopic Modeling of Traffic Flow (1998)



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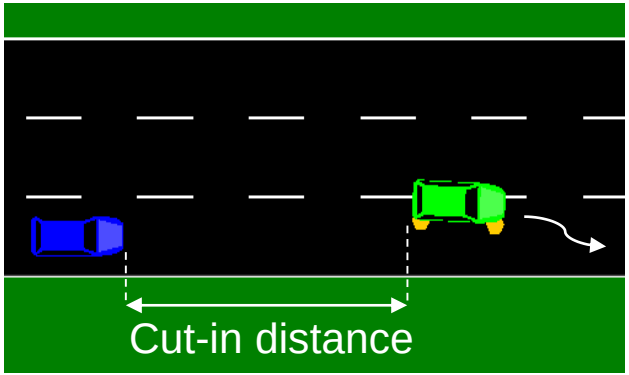

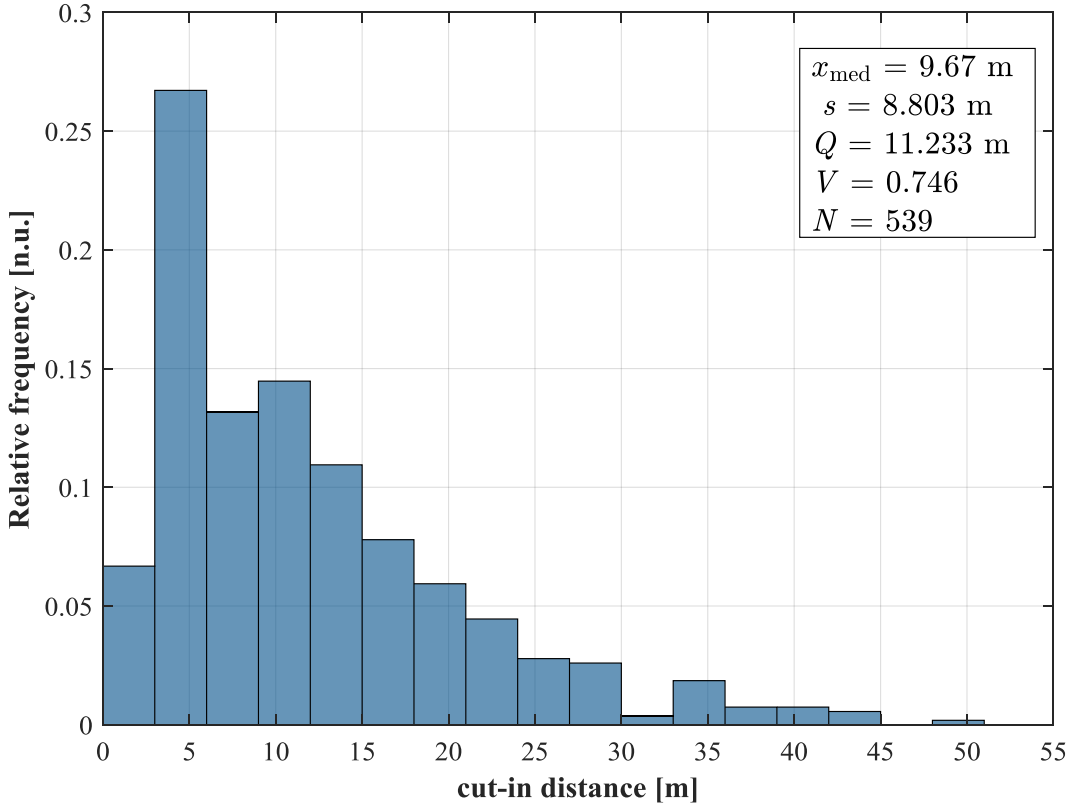

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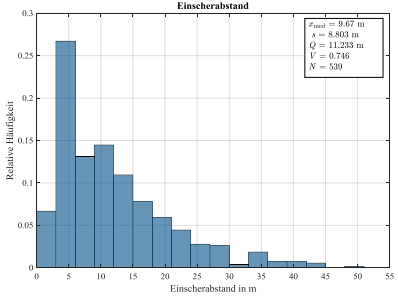
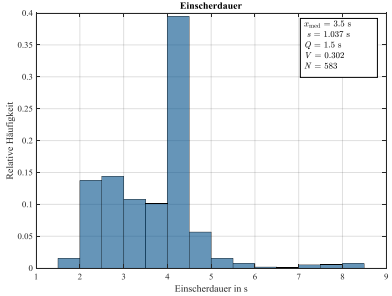
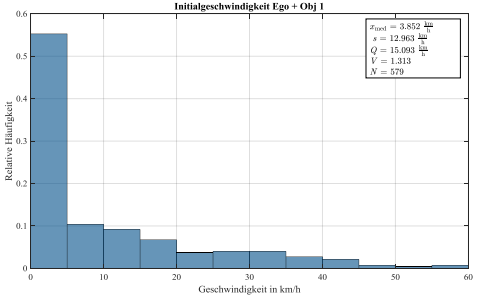
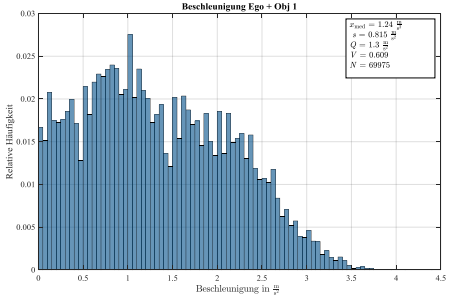
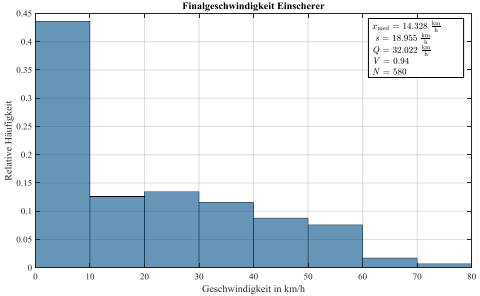
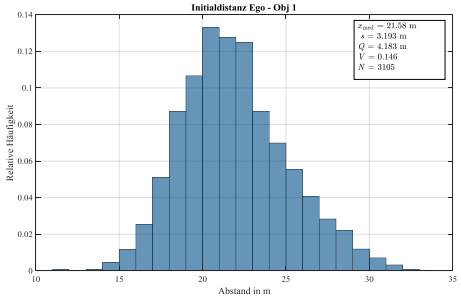


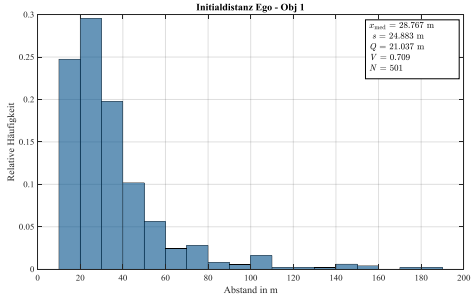


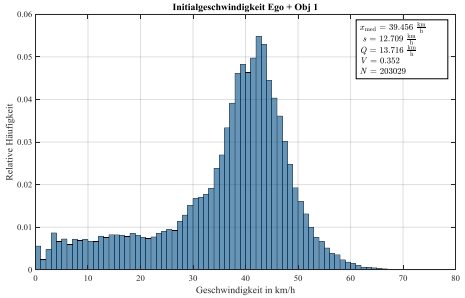












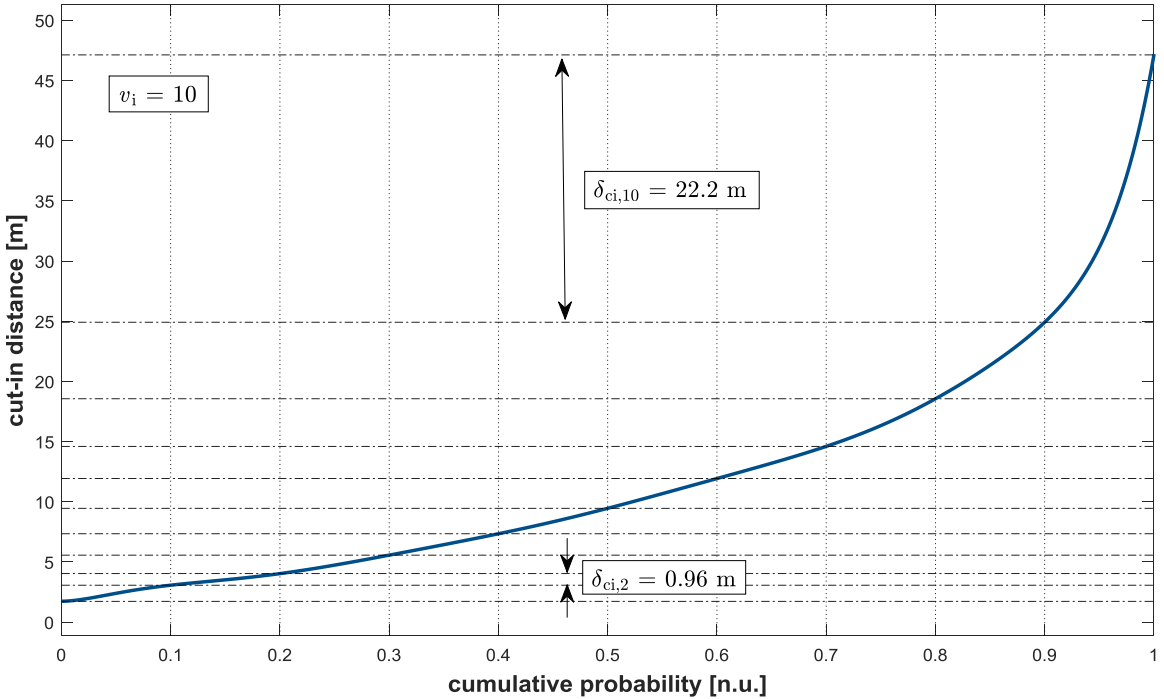
Prediction of occurrence probabilities and value ranges by expert knowledge seems to be extremely challenging

Source: Weber, N. et al.: Simulation-based approach for the derivation of concrete scenarios (2020)

- Discretization

Equidistant division of cumulative probability

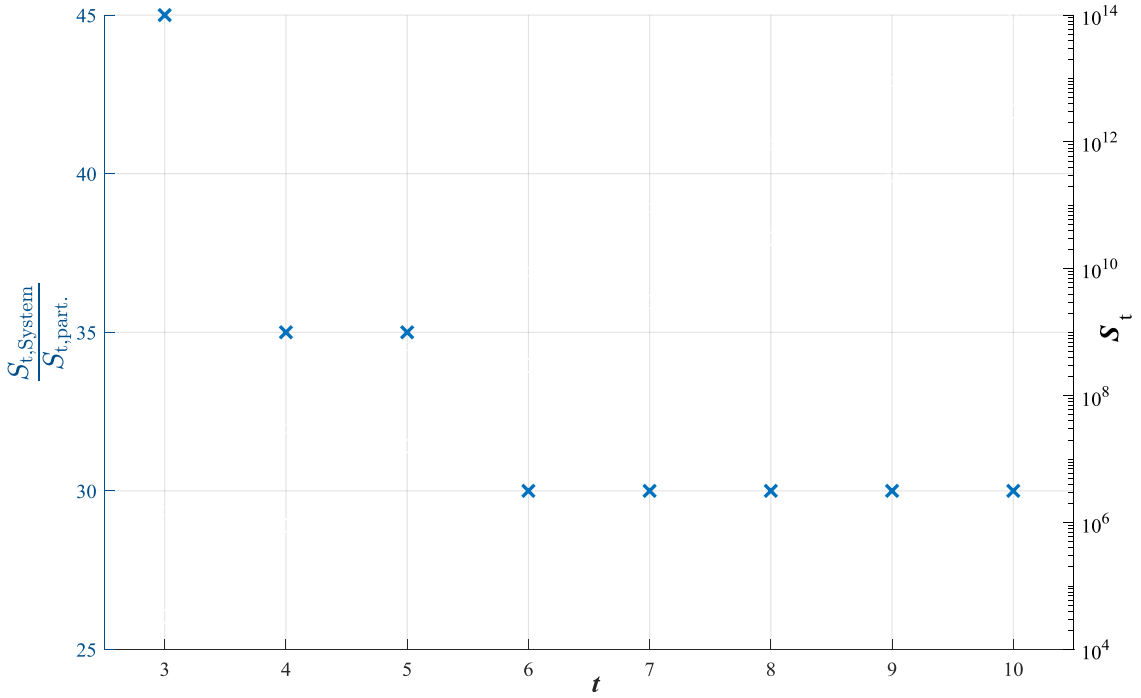
Variable discretization in absolute value range



Source: Weber, N. et al.: Simulation-based approach for the derivation of concrete scenarios (2020)

- Functional Decomposition

Reduction factor
→ 45 for 3-wise
→ 30 for 10-wise test coverage

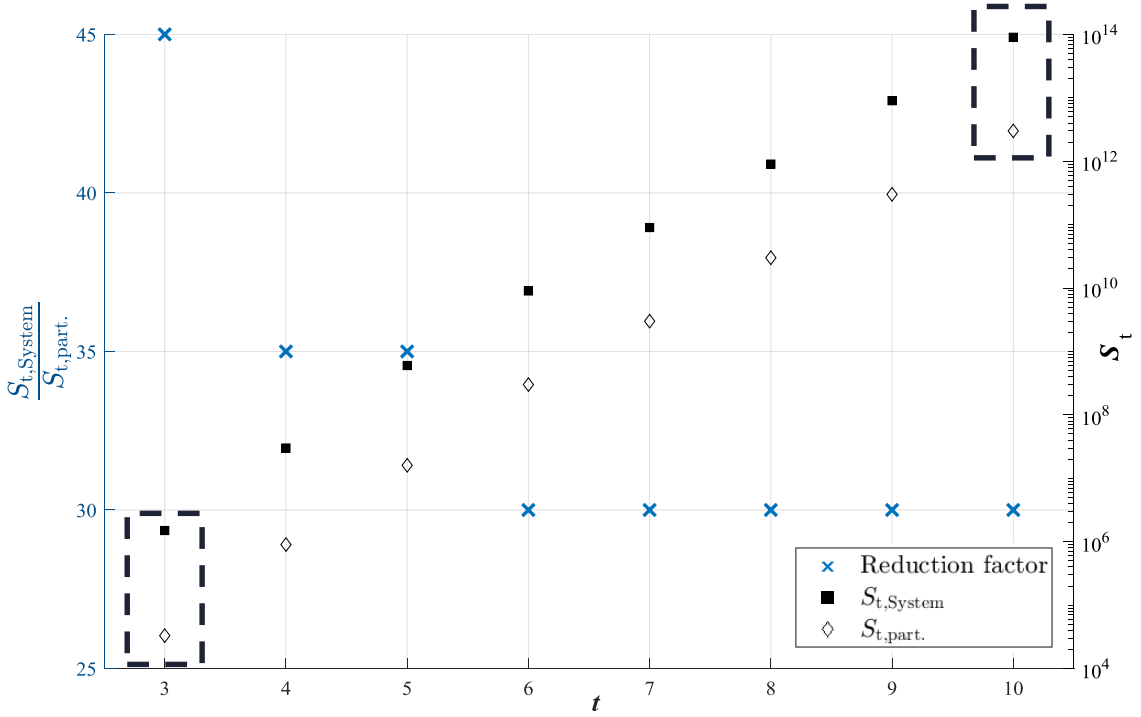


Source: Weber, N. et al.: Simulation-based approach for the derivation of concrete scenarios (2020)

- Functional Decomposition

Dimension of remaining test suite is still challenging

t	$S_{t,\text{System}}$	$S_{t,\text{part.}}$
3	$1.4 \cdot 10^6$	$3 \cdot 10^4$
10	$9 \cdot 10^{13}$	$3 \cdot 10^{12}$

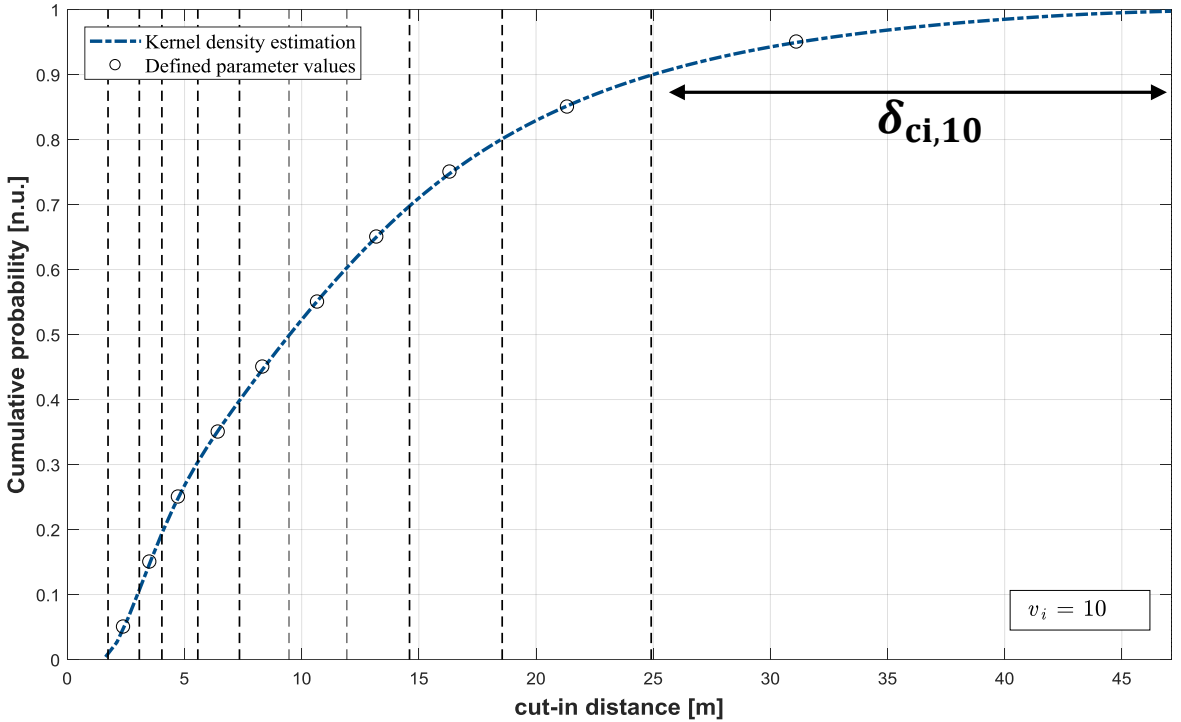


Source: Weber, N. et al.: Simulation-based approach for the derivation of concrete scenarios (2020)

- Deterministic parameter variation

Median-based definition of parameter values within discretization stage $\delta_{\mathrm{ci},i}$

Test suite definition through entirety of parameter values over all influence parameters and functional scenarios



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- Quantifiable reduction of parameter space by a factor between 30 and 45 depended on the test coverage is achieved
- Second non-quantifiable reduction effect through limitation of value range of identified influence parameters
- Developed methodology allows a systematic derivation of concrete scenarios
- Time saving factor of ≈ 2000 illustrates potential of simulation-based approach

- Increase the number of considered functional scenarios
- In-depth investigations regarding model plausibility and microscopic traffic conditions
- Examination if there are other factors in addition to the occurrence probability, which influence the relevance of a scenario
- Benefit analysis of hybrid-reality approaches like Prototype-in-the-Loop
- Investigation of applicability of methodology in urban areas


PSA
GROUPE

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  Amersbach, Christian; Winner, Hermann: Defining Required and Feasible Test Coverage for Scenario-Based Validation of Highly Automated Vehicles, in: 22nd IEEE Intelligent Transportation Systems Conference (ITSC) 2019, 2019
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  N. Weber, D. Frerichs and U. Eberle, "A simulation-based, statistical approach for the derivation of concrete scenarios for the release of highly automated driving functions," *AmE 2020 - Automotive meets Electronics; 11th GMM-Symposium*, Dortmund, Germany, 2020, pp. 1-6.