Incorporating **Safety Relevance** and **Realistic Parameter Combinations** in **Test-Case Generation** for Automated Driving Safety Assessment

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SAKURA
Safety Assurance KUdos for Reliable Autonomous Vehicles

INSTITUTE OF AUTOMOTIVE ENGINEERING

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Agenda

- Motivation
- Scenario Parameters and Database
- Calculation of Parameter Dependencies
- Test-Case Generation
- Conclusion and Outlook

Motivation

Automated driving in complex urban intersections

vs.

No approval of highway pilot functions on highways

[1]

International standards and regulations for automated driving safety assessment

Ko-HAF KOOPERATIVES HOCHAUTOMATISIERTES FAHREN [2]

PEGASUS [3]

VVMethoden [4]

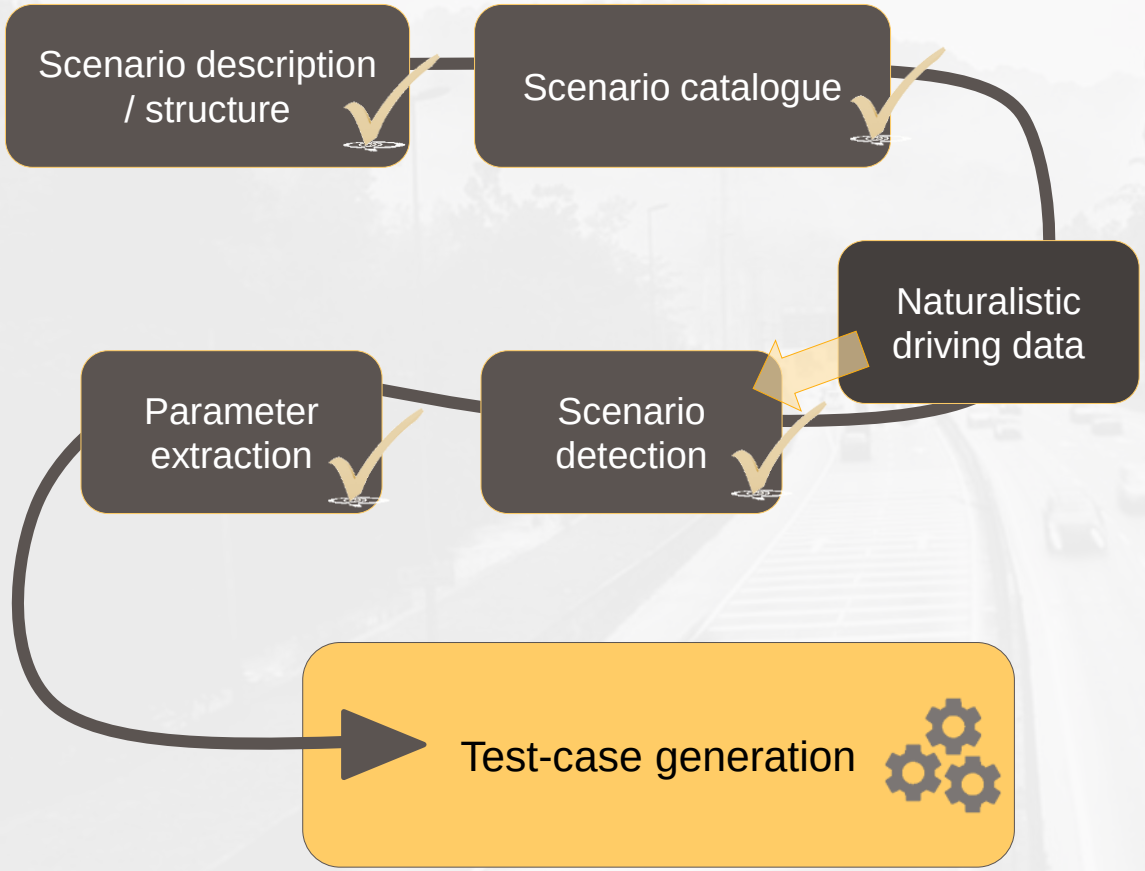
SET Level 4to5 [5]

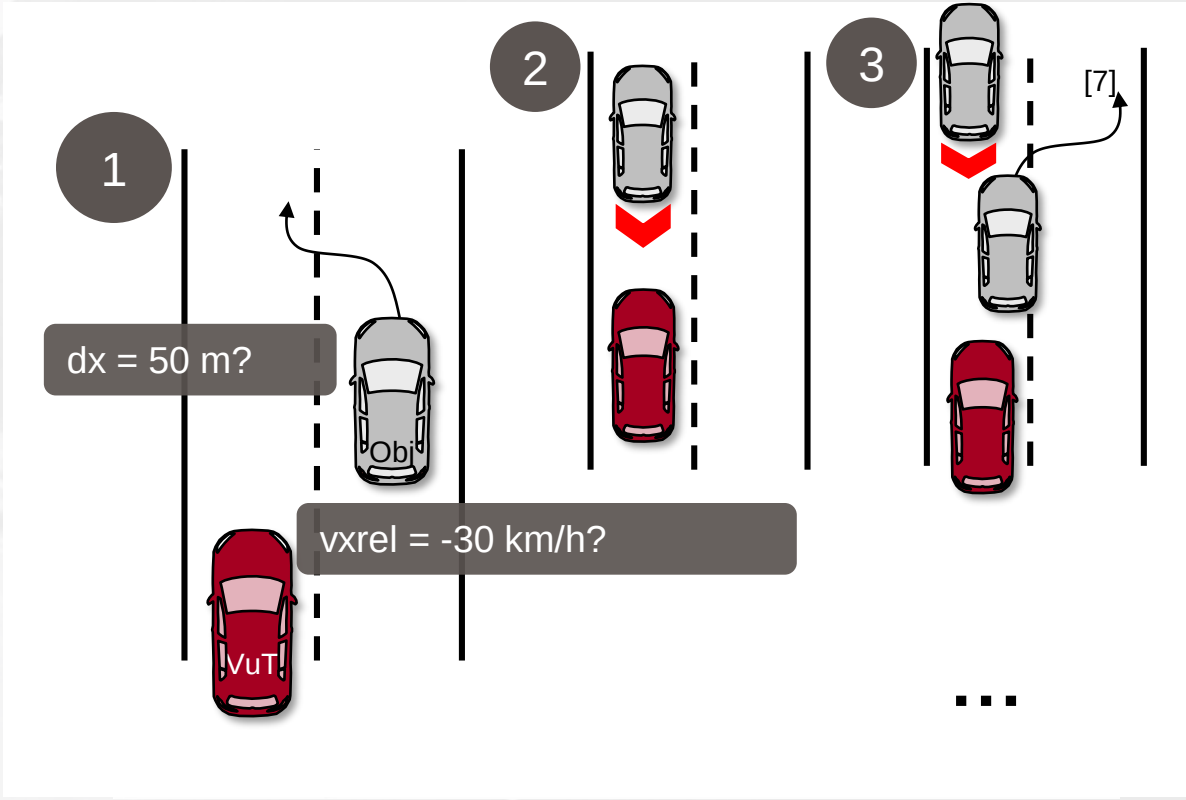
SAKURA Safety Assurance KUdos for Reliable Autonomous Vehicles [6]

Research Gap

Scenario-based testing approach

Highway domain:





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Research Gap

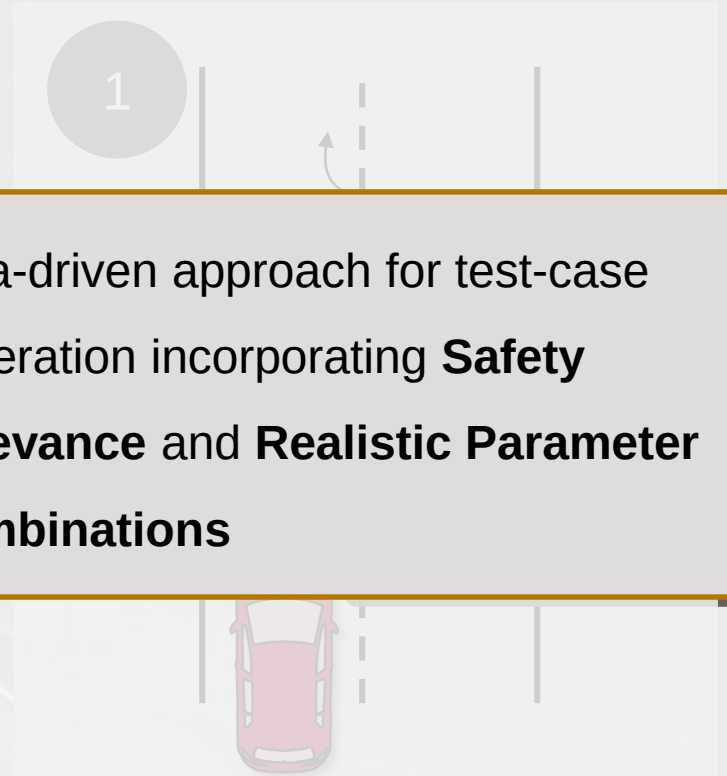
Approaches for test-case generation

Combinatorics:

- *n*-wise combination of each parameter
  = 10^2 = 100 test-cases

➡ Large number of test-cases

➡ Parameter dependencies are not considered



Data-driven approach for test-case generation incorporating **Safety Relevance** and **Realistic Parameter Combinations**

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Dataset for methodology development

TIAMO: **T**est Vehicle for **I**ntelligent **A**utomation and **M**onit**o**ring Systems

Mono-Camera

Front Radar (MRR)

1x Sick LMS511

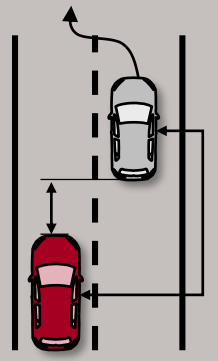
4x Ibeo Lux 2010

Raw dataset

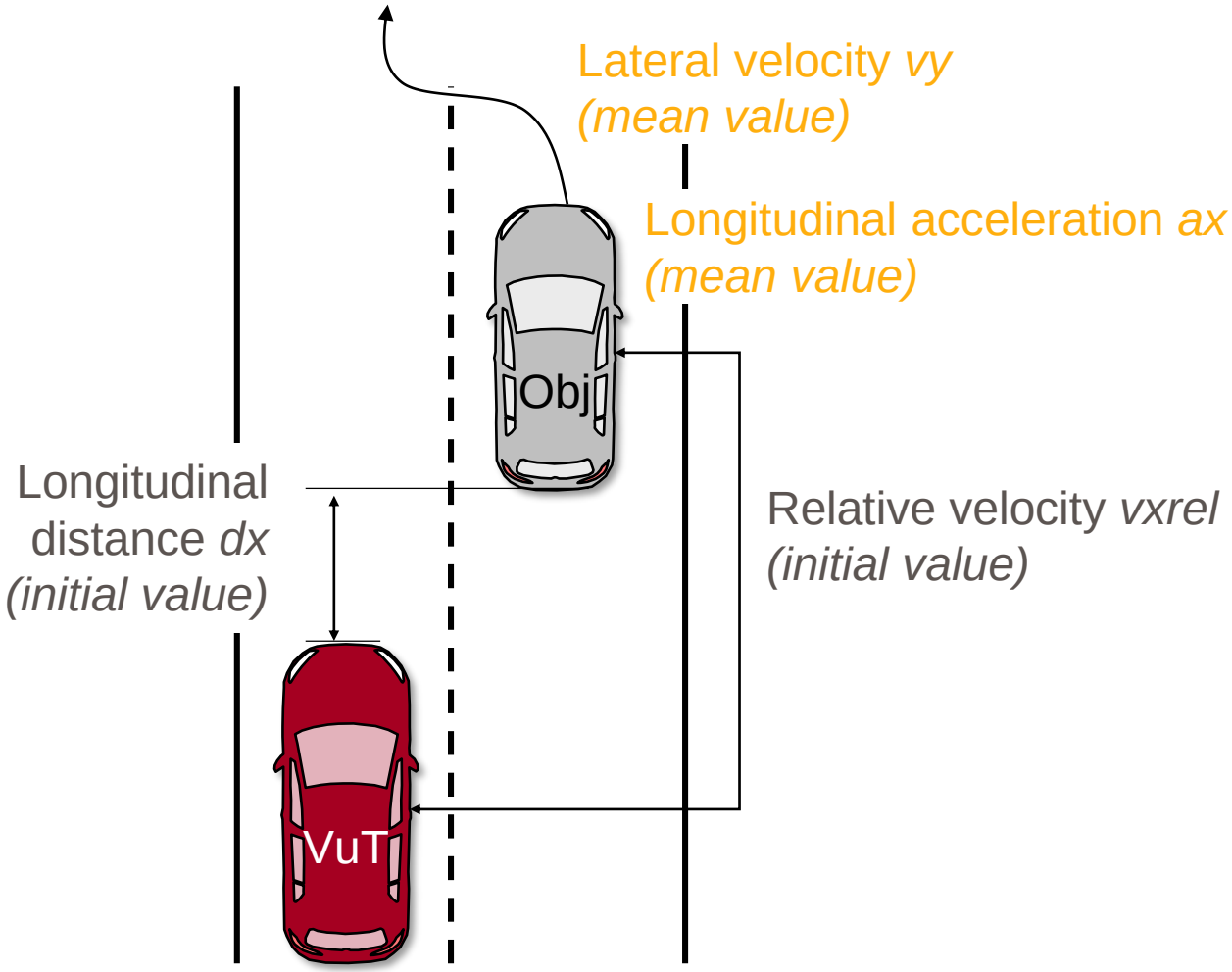
- Highway data recorded with testing vehicle „TIAMO“
- **18.500 km** on German highways with no automation
- Naturalistic driving behaviour

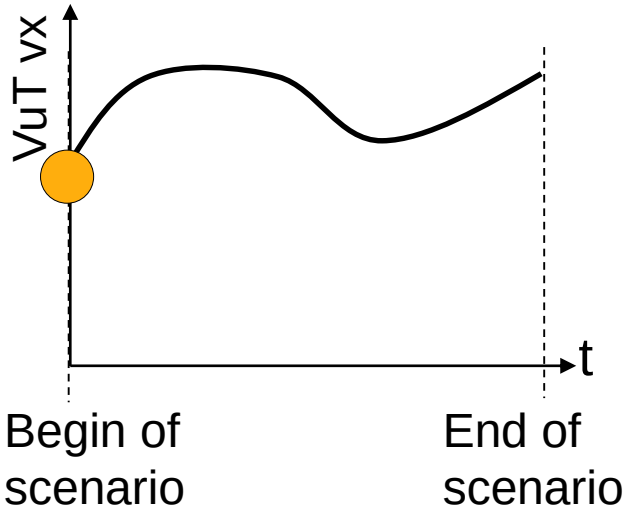
Scenario database

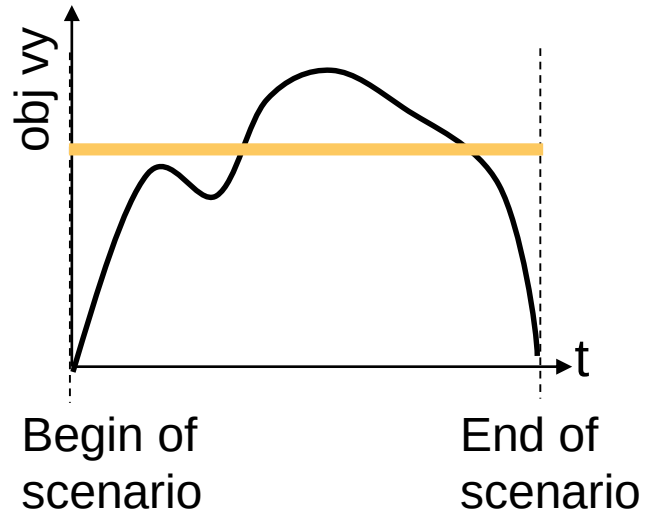
- Detection of **834 „slower“ cut-in from right** scenarios



Modelling of the Cut-In Scenario







Global vs. Scenario-based Parameter Distributions

- Distribution of all mean decelerations from cut-in objects (scenario-based)
- Distribution of all mean decelerations from all braking maneuvers (global)

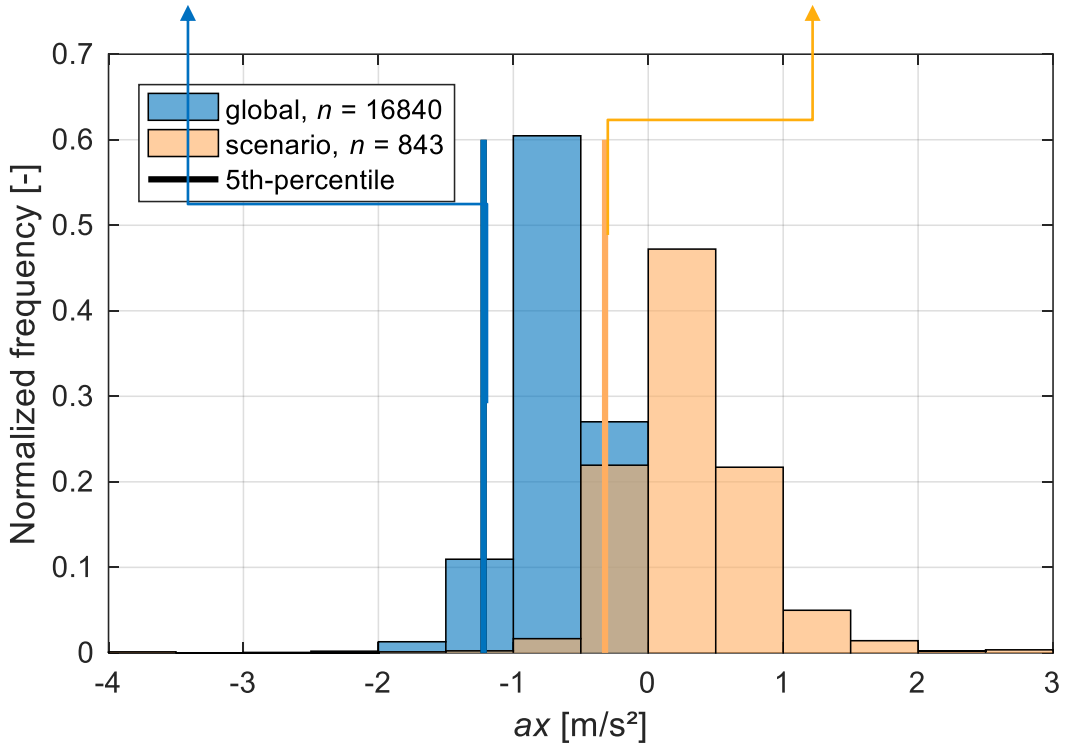
Scenario-based parameter extraction

- Parameter values occured in reality
- More realistic test-cases

Global parameter extraction

- Increased coverage of parameter space
- More critical test-cases

Global 5th percentile = **-1.22 m/s²** ***vs.*** Scenario-based 5th percentile = **-0.32 m/s²**



Global vs. Scenario-based Parameters

Scenario-based parameter extraction

- Parameter values occured in reality
- More realistic test-cases

Global parameter extraction

- Increased coverage of parameter space
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Research hypothesis:

- Scenario-based parameter distributions must be used when a **dependency to other parameters** is found
- Globally extracted distributions are allowed for **independent parameters**

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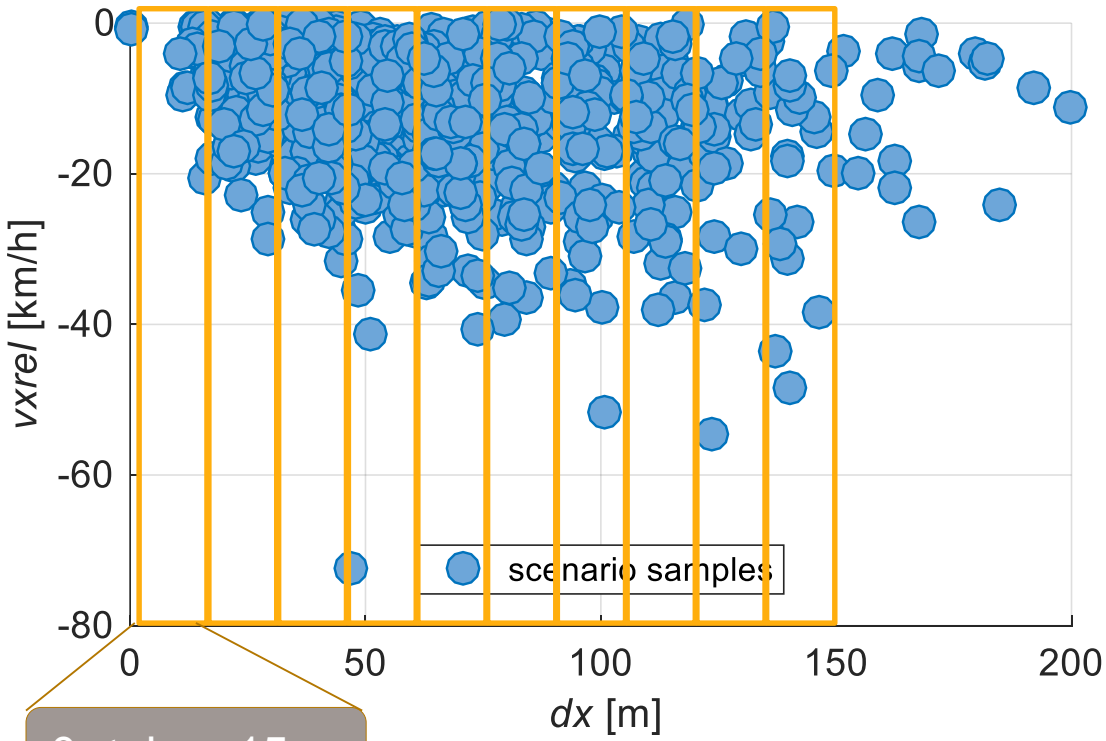
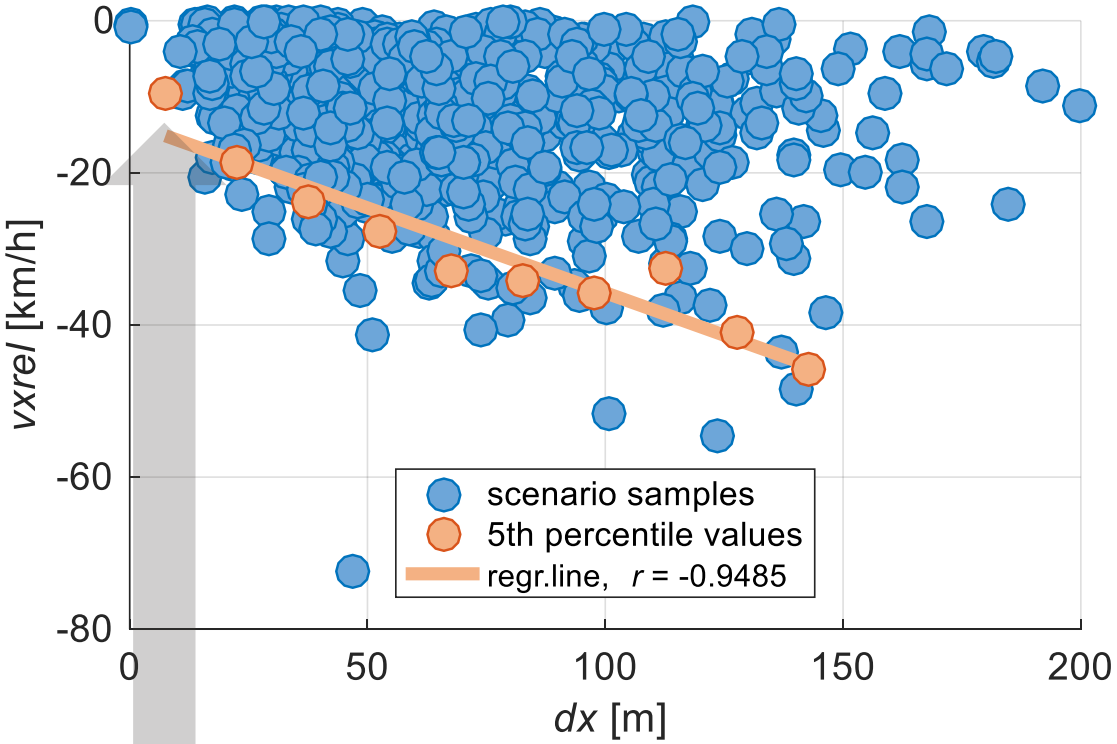
Demand for Consideration of Parameter Dependencies

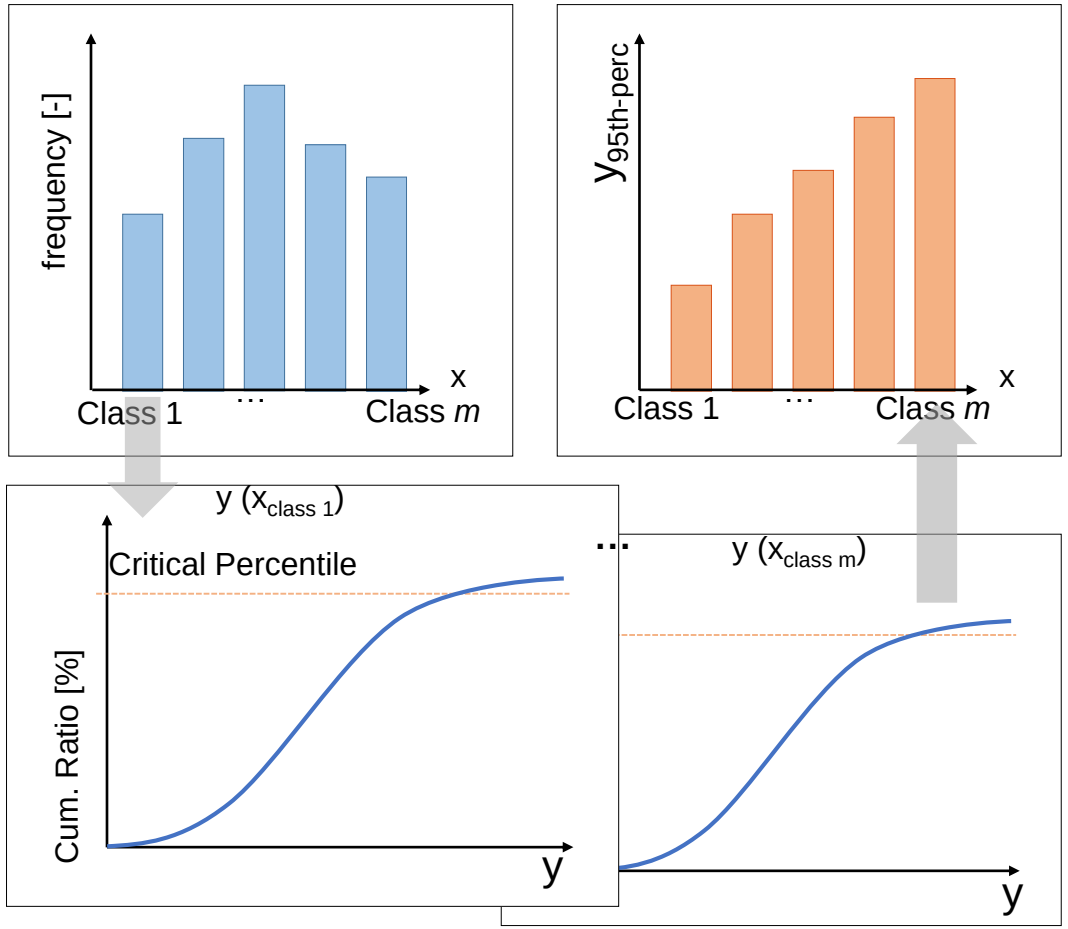


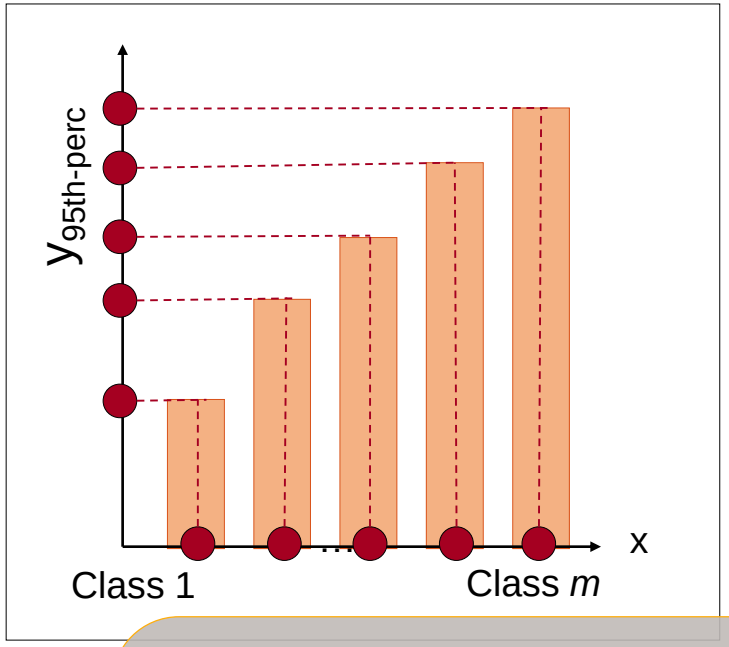
0 ≤ dx < 15 m



5th percentile of vxrel(0 ≤ dx < 15 m)

Methodology for Calculating Linear Parameter Dependencies





Correlation calculation after Pearson:

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2} * \sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}$$

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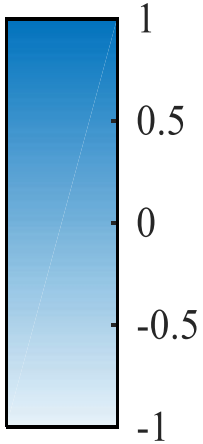
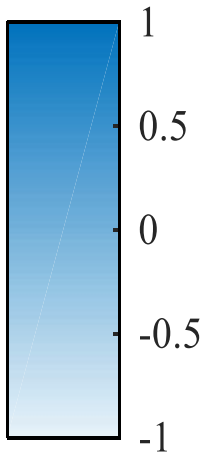
Results from Prototypical Application on Highway Dataset

	vx	vy	ax	dx	vxrel
vx	0	-0.0596	0.0073	0.1233	-0.15
vy	-0.0596	0	0.0205	0.1624	-0.0642
ax	0.0073	0.0205	0	-0.0043	-0.0819
dx	0.1233	0.1624	-0.0043	0	-0.2143
vxrel	-0.15	-0.0642	-0.0819	-0.2143	0



Correlation coefficients of all parameter samples

	vx_{class}	vy_{class}	ax_{class}	dx_{class}	$vxrel_{class}$
vx_{perc}	0	-0.1408	0.9559	0.4803	-0.1859
vy_{perc}	-0.8893	0	0.3759	0.5054	0.1947
ax_{perc}	-0.1739	-0.07167	0	0.5201	-0.2813
dx_{perc}	0.7053	0.09149	0.7171	0	-0.9163
$vxrel_{perc}$	-0.8921	0.542	-0.5136	-0.9307	0



Correlation coefficients of the critical percentiles calculated for each class of a parameter

Relevant after verification

Implications for Test-Case Generation

1. Iteration through all parameters to ensure parameter coverage

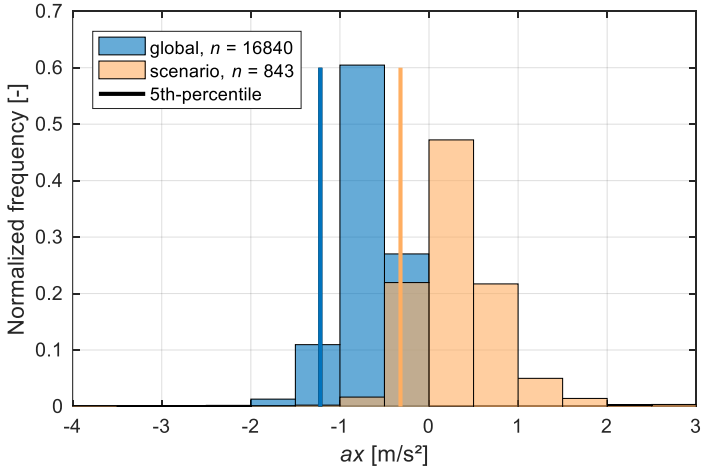
2. The parameter with the highest correlation is set first

3. 3-dimensional parameter dependencies must be considered

4. For independent parameters: Globally extracted distributions can be used

5. Parameters showing a dependency must be set accordingly

No.	1	2	3	4	5	6	7	8	9	10
dx [m]	7.5	22.5	35.7	52.5	67.5	82.5	97.5	112.5	127.5	142.5
vxrel [km/h]	-9.5	-18.8	-23.9	-27.6	-32.8	-34.2	-35.7	-32.6	-40.9	-46.0



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Conclusion and Outlook

- Test-case generation: Parametrization of quantitative test-cases
- Methodology for calculating **linear dependencies between parameters**
- **Implications for test-case generation** can be derived
- Extendable towards other operational domains or towards including further influences (e.g. road geometry, perception)

- Application on large radar dataset to generate representative test-cases
- Only linear dependency is regarded → Extension to include **higher-polynominal dependencies**
- Strong impact of classes division → Demand for **a validation framework** for test-cases

Thank you for your attention!

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