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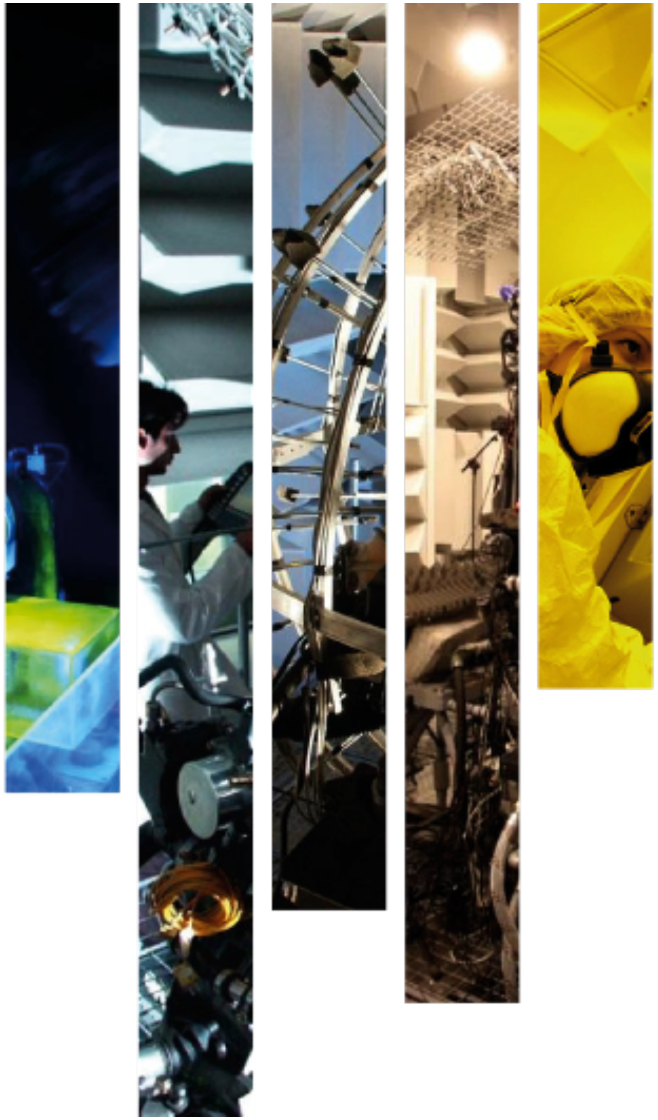

Evaluation Methods for Active Safety Systems: the eVALUE EU project

Stuttgart, May 18 2011 - Vehicle Dynamics Expo

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Vehicle Dynamics & Fuel Economy

FIAT
SOCIETÀ PER AZIONI

AGENDA

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Contents

- Introduction
- eVALUE project overview
- Active safety cluster
  - ❑ Emergency braking on asymmetric adherence
- Conclusion and next steps

Introduction

- Active safety is a key measure when it comes to decreasing traffic accidents, injuries and deaths.
- Advanced driver assistance systems are massively introduced into new vehicles, and many of them also contribute with active safety functionality.
- However, and in opposition to passive safety, the car buyer cannot judge the performance of a vehicle's active safety based on objective measures.
- It is important to focus attention on the safety of the whole vehicle (customer point of view), not only on the functionality of a specific active system (OEM point of view).

Need for objective test methods for vehicle active safety!

eVALUE project overview

Project title:

Testing and Evaluation Methods for ICT-based Safety Systems

Duration

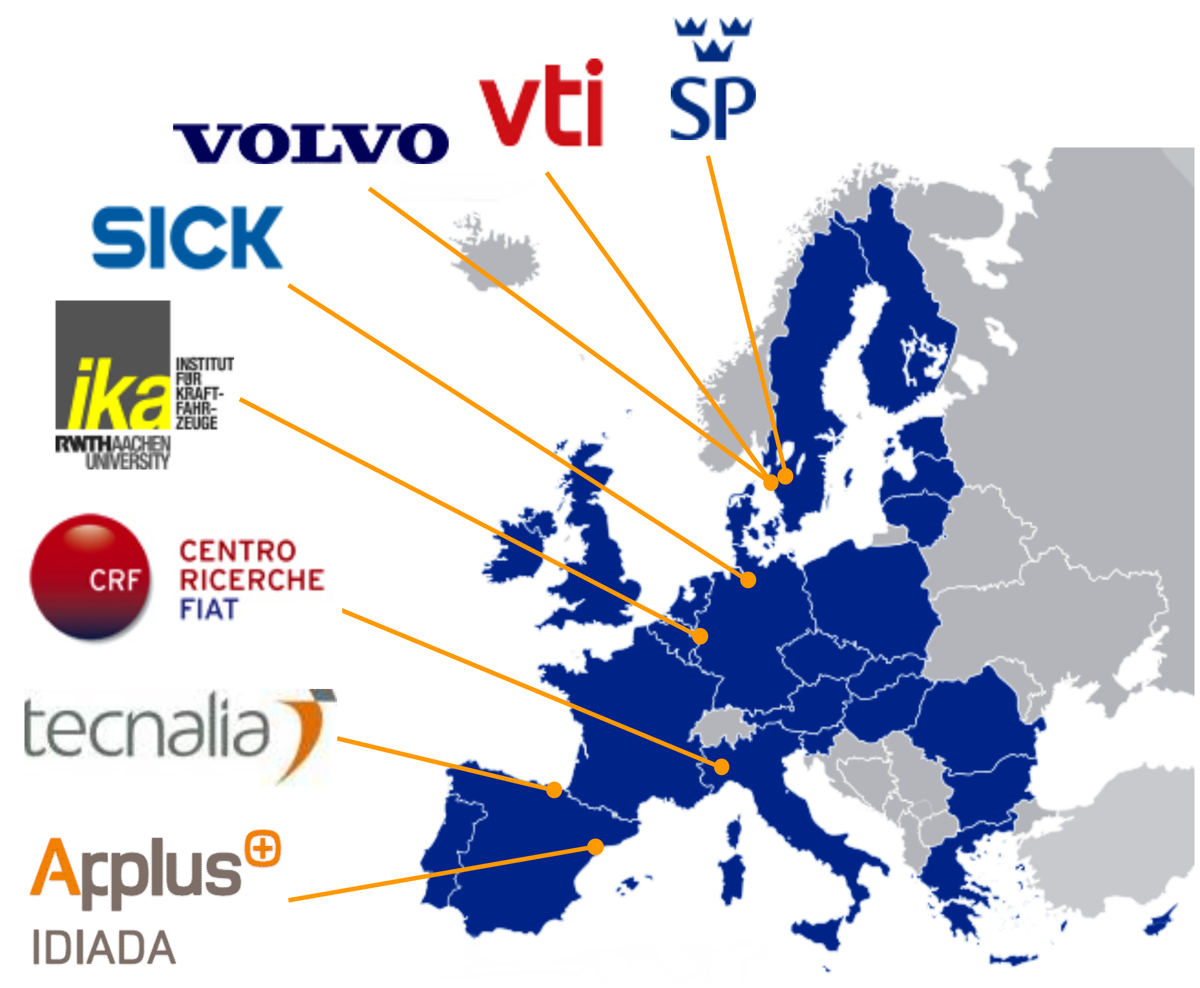
- Start: January 2008
- End: December 2010

SEVENTH FRAMEWORK PROGRAMME

European Community's Seventh Framework Programme (FP7/2007-2013), grant agreement no. 215607.

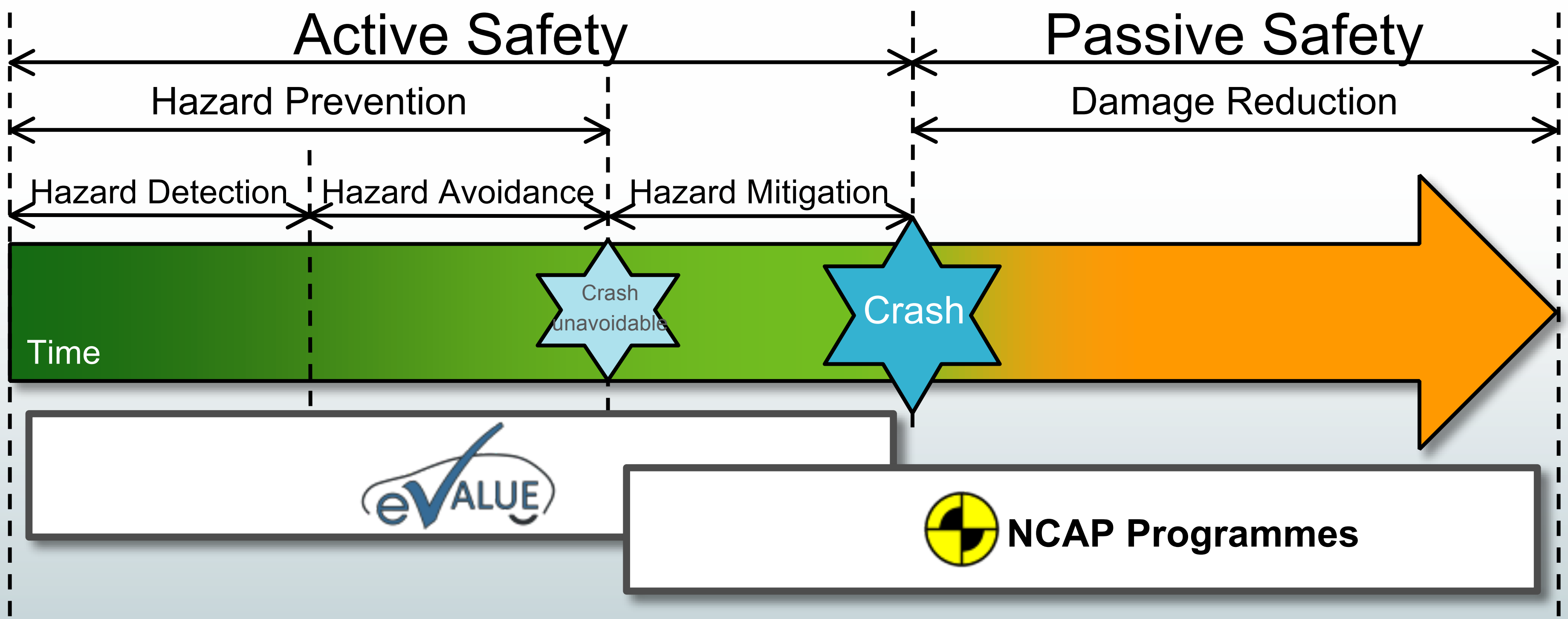
www.evalue-project.eu

Partners



eVALUE project overview

Domain of interest



Active safety performance on full vehicle rather than on system level.

eVALUE project overview

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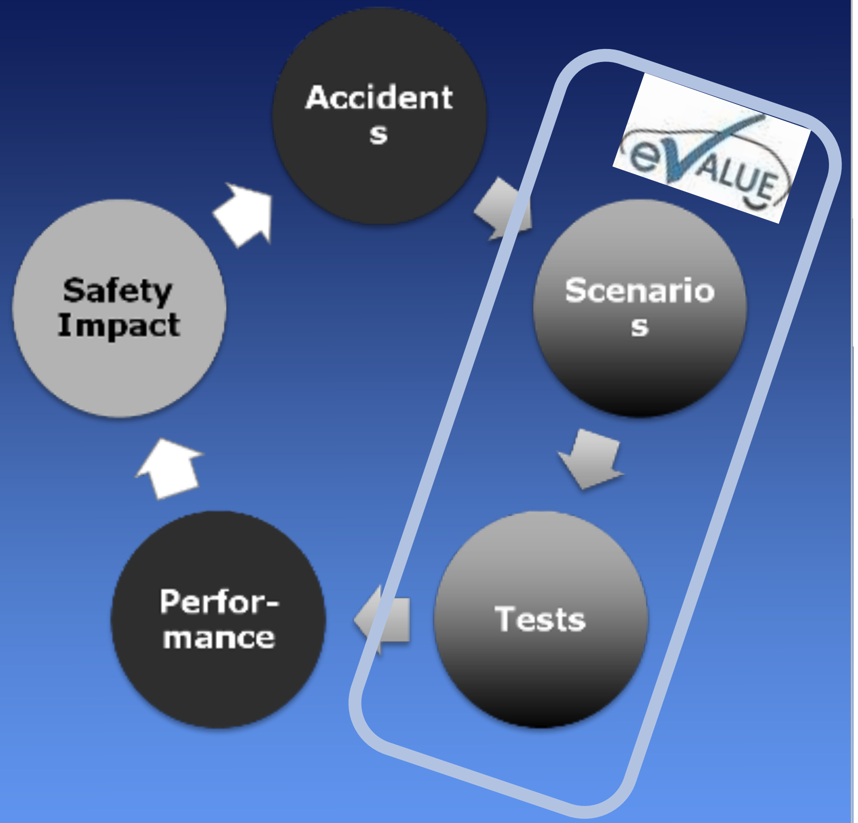
Scope and approach

- The scope of eVALUE is to define testing protocol and evaluation methods for ICT-based safety systems.
- The protocols for physical testing are based on relevant traffic scenarios, analysed in the beginning of the project.
- Each protocol follows a standardised format and deals with:
    - ❑ Test principle and objectives
    - ❑ Drivers and equipment
    - ❑ Environment
    - ❑ Required input
    - ❑ Vehicle preparation
    - ❑ Test procedure
    - ❑ Data processing
    - ❑ Uncertainties
    - ❑ Result generation



eVALUE does not define any fail or pass criteria.

eVALUE project overview

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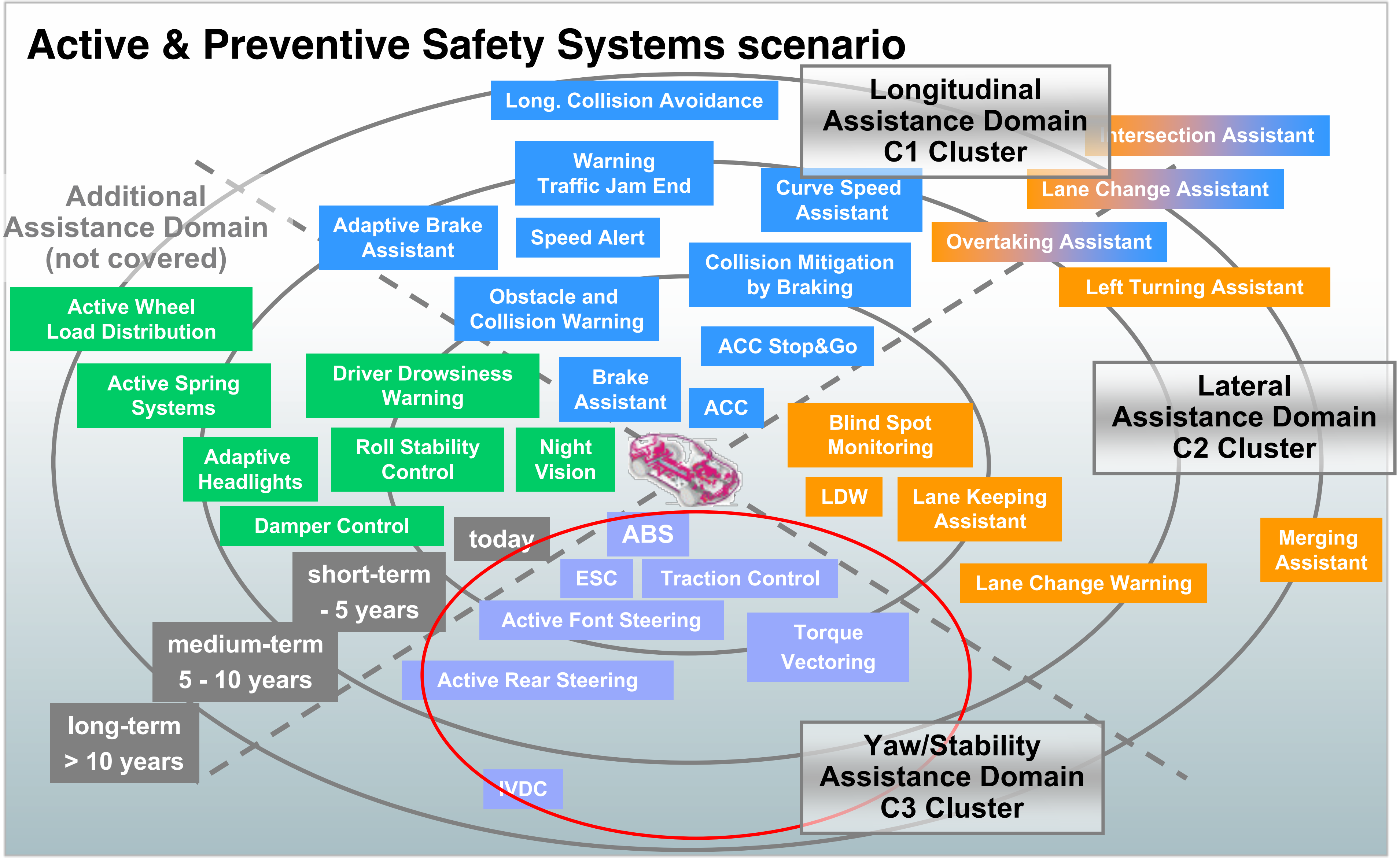
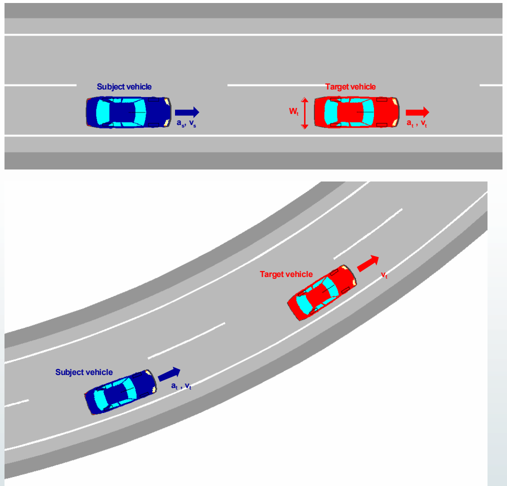


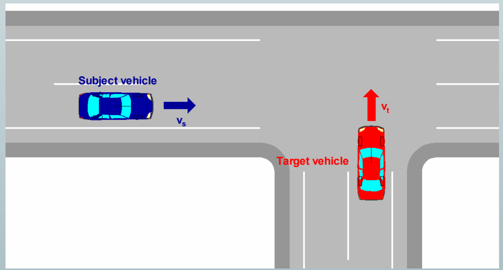
eVALUEproject overview
Targeted functionalities

Longitudinal functionality

C1.1 Avoidance of Rear End Collision

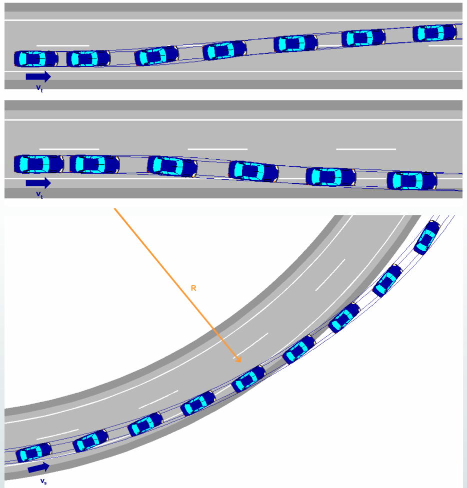


C1.2 Avoidance of Collision with Transversally Moving Target

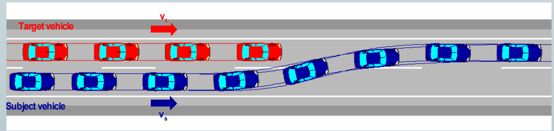


Lateral functionality

C2.1 Avoidance of Lane Departure

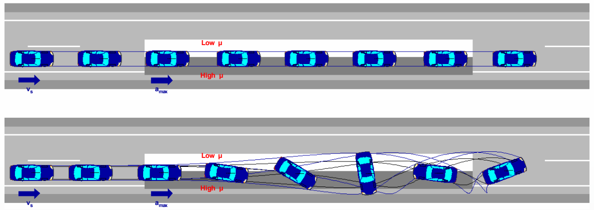


C2.2 Avoidance of Lane Change Collision

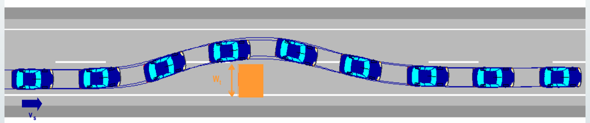


Safety functionality

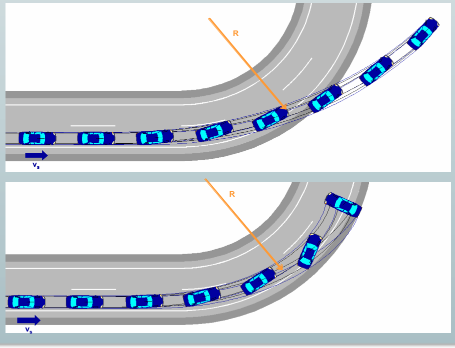
C3.1 Emergency Braking on µ-split



C3.2 Obstacle Avoidance



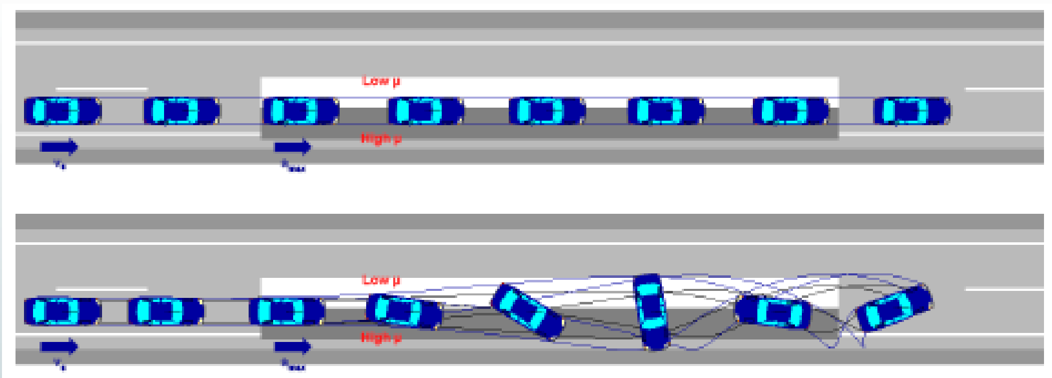
C3.3 Highway Exit



Active safety cluster C3.1
Emergency braking on asymmetric adherence

The scenario: braking manoeuvre on a μ-split surface.

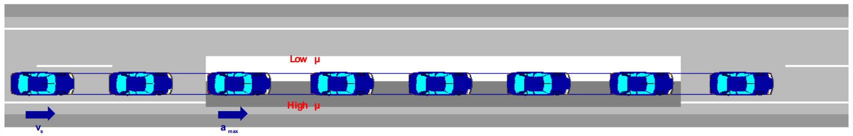
The μ-split surface is such that the left hand side wheels of the subject vehicle are exposed to a significantly different coefficient of friction (μ) with respect to the right hand side wheels (or vice versa).



During a braking manoeuvre on a μ-split surface a driver may be surprised by the first vehicle reaction. Consequently the driver starts acting on the steering wheel creating a closed loop configuration between the driver and the vehicle.

Active safety cluster C3.1
Emergency braking on asymmetric adherence

The scenario: braking manoeuvre on a μ-split surface.

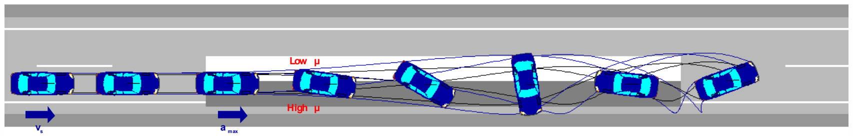


<u>Criteria privileged: Stability</u>

High-mu wheel pressures are too much controlled.

Low braking forces on the high-μ side imply that braking performance is not maximized.

Vehicle remains stable and easy to control but the braking performance is very poor.



<u>Criteria privileged: Stopping distance</u>

Adhesion on the high-μ side fully exploited.

More aggressive braking implies a higher yaw moment disturbance.

The vehicle is less stable and fast and big steering correction may be requested by the driver to keep it under control.

A good compromise between stopping distance and stability is desirable, but evaluation criteria are needed.

Active safety cluster C3.1
Emergency braking on asymmetric adherence

Definition of testing protocol

Three actors influence the braking performance:

- Driver
- Vehicle
- Road

Two different type of tests are performed:

- The **closed loop** test is commonly used by OEM to evaluate their vehicles in this kind of scenario. Nowadays this evaluation is mainly based on an expert driver‟s subjective assessment. The stopping distance can be calculated according to international standard ISO 21994.
- The **open loop** test is used to minimise the driver influence on the braking manoeuvre result. During the first phase of the braking action the vehicle undergoes not only a deceleration but also a yaw motion. Without the driver's influence it is possible to evaluate the trade-off between braking performance and stability during this first phase of the braking manoeuvre.

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Emergency braking on asymmetric adherence

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Definition of testing protocol

The effect of the braking surface must be taken into account too, as a major factor to deal with when comparing results of test performed on different tracks

- Global friction coefficient → Mean deceleration
- Difference of friction coefficient between high-μ and low-μ sides → Yaw moment

The “global” friction coefficient represents the actual use of adherence of the vehicle, being strictly related to the average deceleration.

Need for additional tests to evaluate the behaviour of the vehicle on the high-μ and low-μ surfaces

- Braking on high adherence surface → μ_{HIGH} global coefficient
- Braking on low adherence surface → μ_{LOW} global coefficient

Normalization

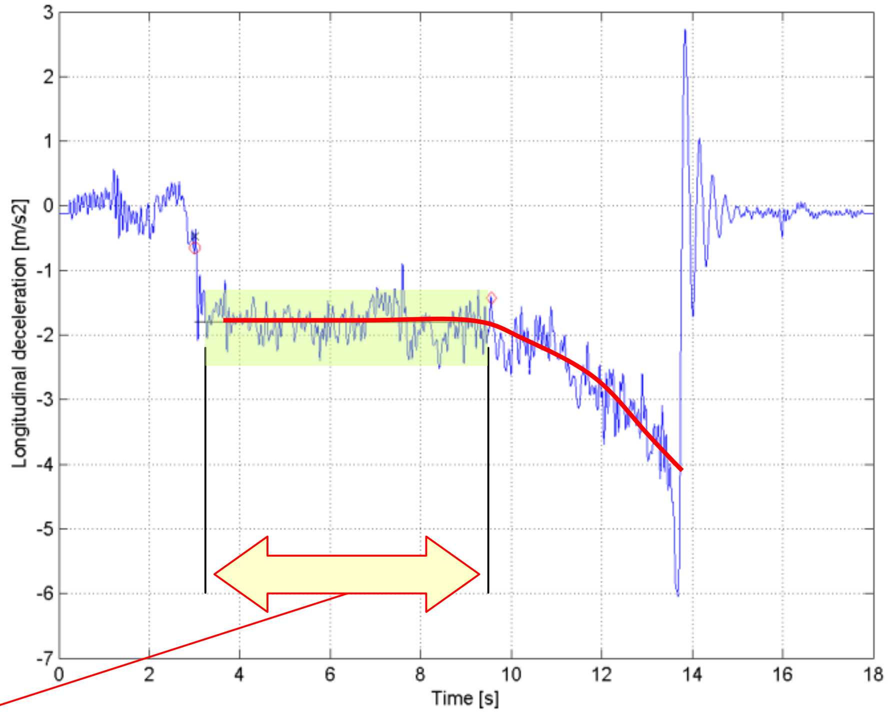
Active safety cluster C3.1
Emergency braking on asymmetric adherence

Definition of testing protocol

Further aspects to be taken into account: speed dependent coefficient of friction.

Variation of longitudinal deceleration as a function of speed.

On low friction wet surface, the deceleration may increase as the speed drops down, since the water film plays a relevant role in the interaction between tire and ground.



Calculation of used friction (μ_{LOW} global) in this interval

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Emergency braking on asymmetric adherence

Definition of testing protocol

Synopsis of pro & cons of closed loop vs. open loop test procedure

	Closed loop		Open loop	
Driver effect	Relevant	↓	Negligible	↑
Braking performance evaluation	Full (whole manoeuver)	↑	Partial (build up only)	↓
Stability evaluation	Full (whole manoeuver)	↑	Partial (first reaction only)	↓
	Driver affected	↓	Not driver affected	↑

Open loop and closed loop tests are complementary

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Emergency braking on asymmetric adherence

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Definition of testing protocol

Open loop test procedure

Test manoeuvre	Surface	Speed	Conditions for valid runs
1. Preliminary braking on high mu	Wet asphalt	80 to 0 kph	<u>0.5 seconds before brake application</u> Initial brake temperature ≈ 100 ºC Yaw rate within ± 1 deg/s Steer angle within ± 3 deg <u>Panic brake application</u> Pedal force build up to more than 50 daN Pedal application rate over 300 daN/s <u>Driver steering correction</u> Not allowed. Steering Wheel hold at straight position.
2. Preliminary braking on low mu	Wet ceramic	60 to 0 kph	
3. Mu split braking **Normalisation**	Split: wet asphalt/wet ceramic	50 to 0 kph	

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Emergency braking on asymmetric adherence

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Definition of testing protocol

Closed loop test procedure

Test manoeuvre	Surface	Speed	Conditions for valid runs
1. Preliminary braking on high mu	Wet asphalt	80 to 0 kph	<u>0.5 seconds before brake application</u> Initial brake temperature ≈ 100 °C Yaw rate within ± 1 deg/s Steer angle within ± 3 deg <u>Panic brake application</u> Pedal force build up to more than 50 daN Pedal application rate over 300 daN/s <u>Driver steering correction</u> 0.3 seconds after brake application and/or after initial yaw response (no anticipation)
2. Preliminary braking on low mu	Wet ceramic	60 to 0 kph	
3. Mu split braking **Normalisation**	Split: wet asphalt/wet ceramic	100 to 0 kph	

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Emergency braking on asymmetric adherence

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Proposed safety indicators

Open loop

Indicator	Formula	Description
Mean longitudinal deceleration	$a_{F10} = \frac{1}{T_2 - T_0} \int_{T_0}^{T_2} \lvert a_x \rvert dt$	Mean deceleration from brake action T_0 to T_2 when velocity drop is 10 kph
Equivalent deceleration	$a_{ED} = a_{F10} \left(1 - \frac{\int_{T_0}^{T_2} \lvert \dot{\Psi} V_X \rvert dt}{\int_{T_0}^{T_2} \lvert a_x \rvert dt} \right)$	Combination of longitudinal deceleration and yaw stability
Equivalent deceleration (normalised)	$a_\eta = \left(\frac{a_{F10}}{\eta_{HIGH} + \eta_{LOW}} \right) \cdot \left(1 - \frac{1}{g} \frac{1}{\eta_{HIGH} - \eta_{LOW}} \frac{1}{T_2 - T_0} \int_{T_0}^{T_2} \lvert \dot{\Psi} \cdot V_X \rvert dt \right)$ **Normalisation**	Includes normalisation for different track adherences

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Emergency braking on asymmetric adherence

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Proposed safety indicators

Open loop

Indicator	Formula	Description
Mean longitudinal deceleration	$a_N = \left(\frac{a_{F10}}{\eta_{HIGH}+\eta_{LOW}}\right)\cdot\left(1-\frac{1}{g\,\eta_{HIGH}-\eta_{LOW}}\,\frac{1}{T_2-T_0}\int_{T_0}^{T_2}\lvert\dot{\Psi}V_X\rvert dt\right)$	Mean deceleration from brake action T_0 to T_2 when velocity drop is 10 kph
Equivalent deceleration	$a_{ED} = a_{F10}\left(1-\frac{\int_{T_0}^{T_2}\lvert\dot{\Psi}V_X\rvert dt}{\int_{T_0}^{T_2}\lvert a_x\rvert dt}\right)$	Combination of longitudinal deceleration and yaw stability

Normalisation

$$a_{ED} = a_{F10}\left(1-\frac{\int_{T_0}^{T_2}\left|\dot{\Psi}V_X\right|dt}{\int_{T_0}^{T_2}\left|a_x\right|dt}\right)$$

The <u>Equivalent Deceleration</u> is intended as a synthesis parameters expressing the trade-off between performance (deceleration) and stability.

The maximum theoretical value, in case the yaw rate disturbance (ψ’) is null, equals AF10.

The greater the yaw disturbance, the lower the AED.

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Emergency braking on asymmetric adherence

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Proposed safety indicators

Open loop

Indicator	Formula	Description
Mean longitudinal deceleration	a_{F10}	Mean deceleration from brake action T_0 to T_2 when velocity drop is 10 kph
Equivalent deceleration	$a_{ED} = a_{F10}\left(1 - \frac{\int_{T_0}^{T_2}\lvert\dot{\Psi} \cdot V_X\rvert dt}{\int_{T_0}^{T_2}\lvert a_x\rvert dt}\right)$	Combination of longitudinal deceleration and yaw stability
	Normalisation	

$$a_{\eta} = \left(\frac{a_{F10}}{\eta_{HIGH} + \eta_{LOW}}\right) \cdot \left(1 - \frac{1}{g}\frac{1}{\eta_{HIGH} - \eta_{LOW}}\frac{1}{T_2 - T_0}\int_{T_0}^{T_2}\left|\dot{\Psi} \cdot V_X\right| dt\right)$$

The Equivalent Deceleration normalised is intended as a synthesis parameters expressing the trade-off between performance (deceleration) and stability, including normalisation for:

- The mean friction between high and low μ (max theoretical performance)
- The difference of friction between high and low μ (max theoretical yaw disturbance)

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Emergency braking on asymmetric adherence

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Proposed safety indicators

Closed loop

Indicator	Formula	Description
Use of adherence	$Use.of.adh. = \frac{2 \cdot Decel_{\mu-split}}{Decel_{low\mu} + Decel_{high\mu}} 100$	teorSD: theoretical stopping distance calculated using the average deceleration between high and low mu preliminary braking manoeuvres musplitSD: stopping distance using the deceleration in the mu split braking manoeuvre Note: both deceleration and stopping distance are calculated according to ISO 21994
Steering correction factor	$SCF = \frac{Decel_{low\mu}}{Decel_{high\mu}} MaxSWA \cdot MaxSWR$	MaxSWA: maximum steering wheel angle MaxSWR: maximum steering wheel rate

Normalisation

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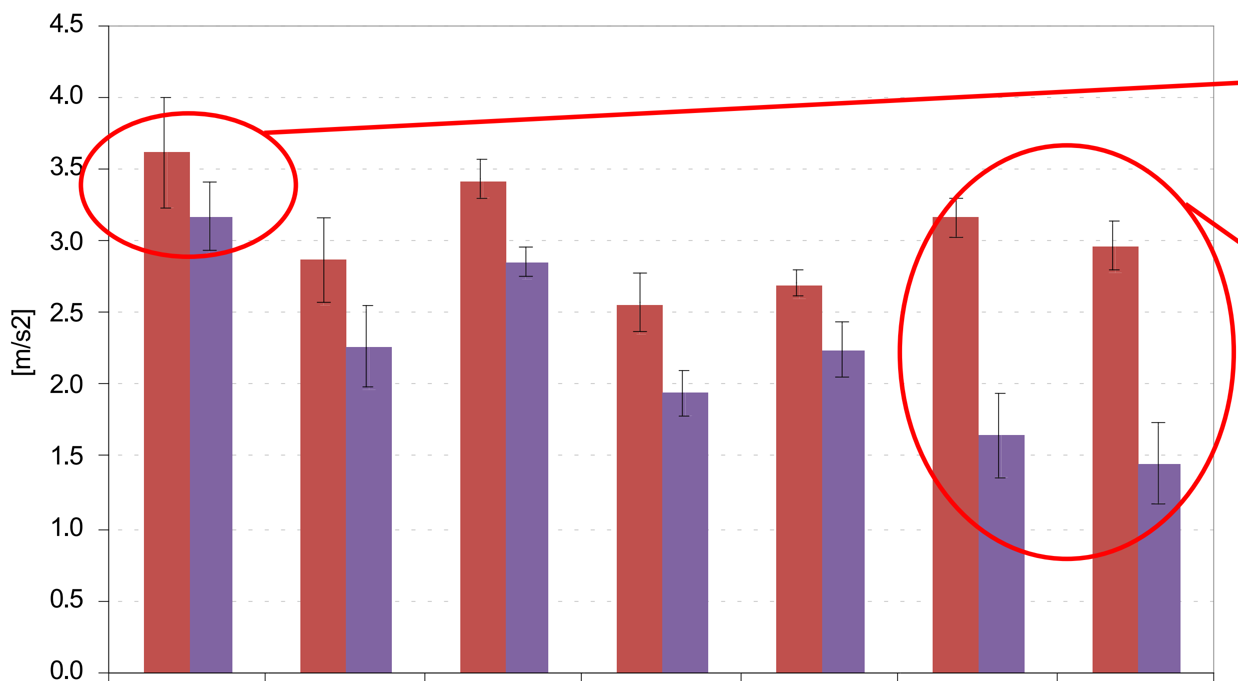
Emergency braking on asymmetric adherence

Tests results. Open loop procedure

Seven vehicles on the same test track



	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5	Vehicle 6	Vehicle 7
AF10	3.62	2.87	3.43	2.57	2.70	3.16	2.96
AED	3.17	2.26	2.84	1.94	2.24	1.65	1.45

Good performance with good stability

Intermediate performance (a_{F10}) with low a_{ED} indicates high yaw disturbance

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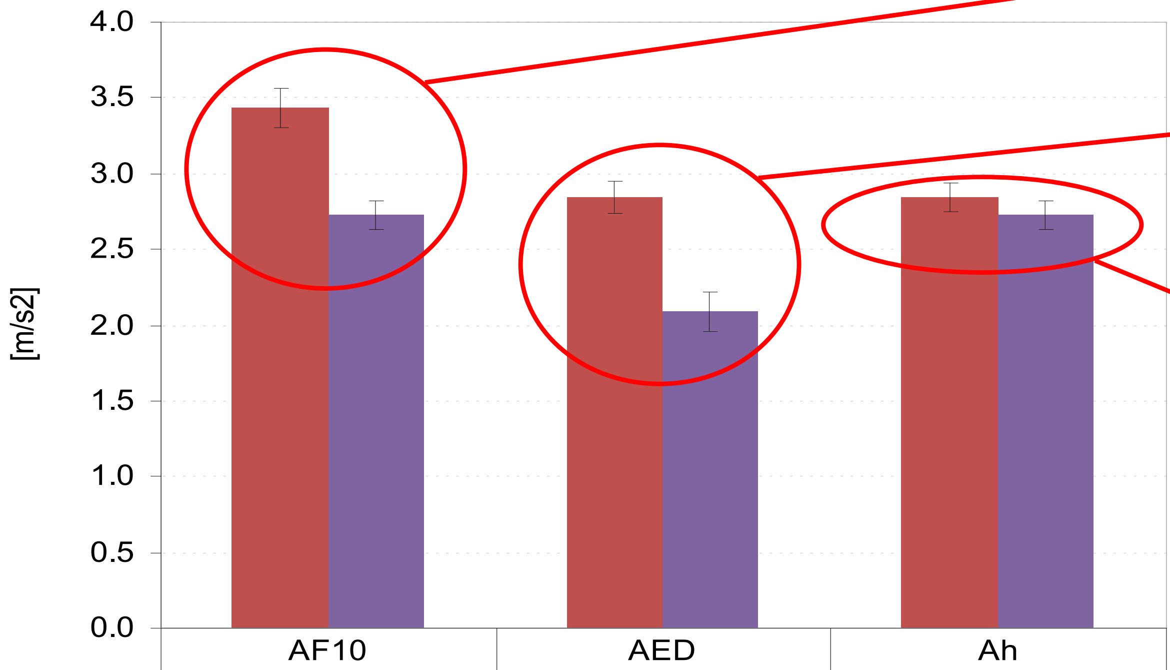
Emergency braking on asymmetric adherence

Tests results. Open loop procedure

Same vehicle on two different test tracks



	AF10	AED	Ah
Track 1	3.43	2.84	2.84
Track 2	2.73	2.09	2.72

Difference in absolute performance (deceleration)

Difference in combined evaluation (deceleration and yaw disturbance)

Normalised combined evaluation: results from two tracks are harmonised

Track1: Concrete/Pavement

Track2: Asphalt/Granite

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Emergency braking on asymmetric adherence

Tests results. Closed loop procedure

Same driver, same car, same test surface: several run

The steering wheel activity by itself does not look like a robust quantity to describe the vehicle behaviour, whereas the longitudinal deceleration looks quite stable despite the driver's actuation.

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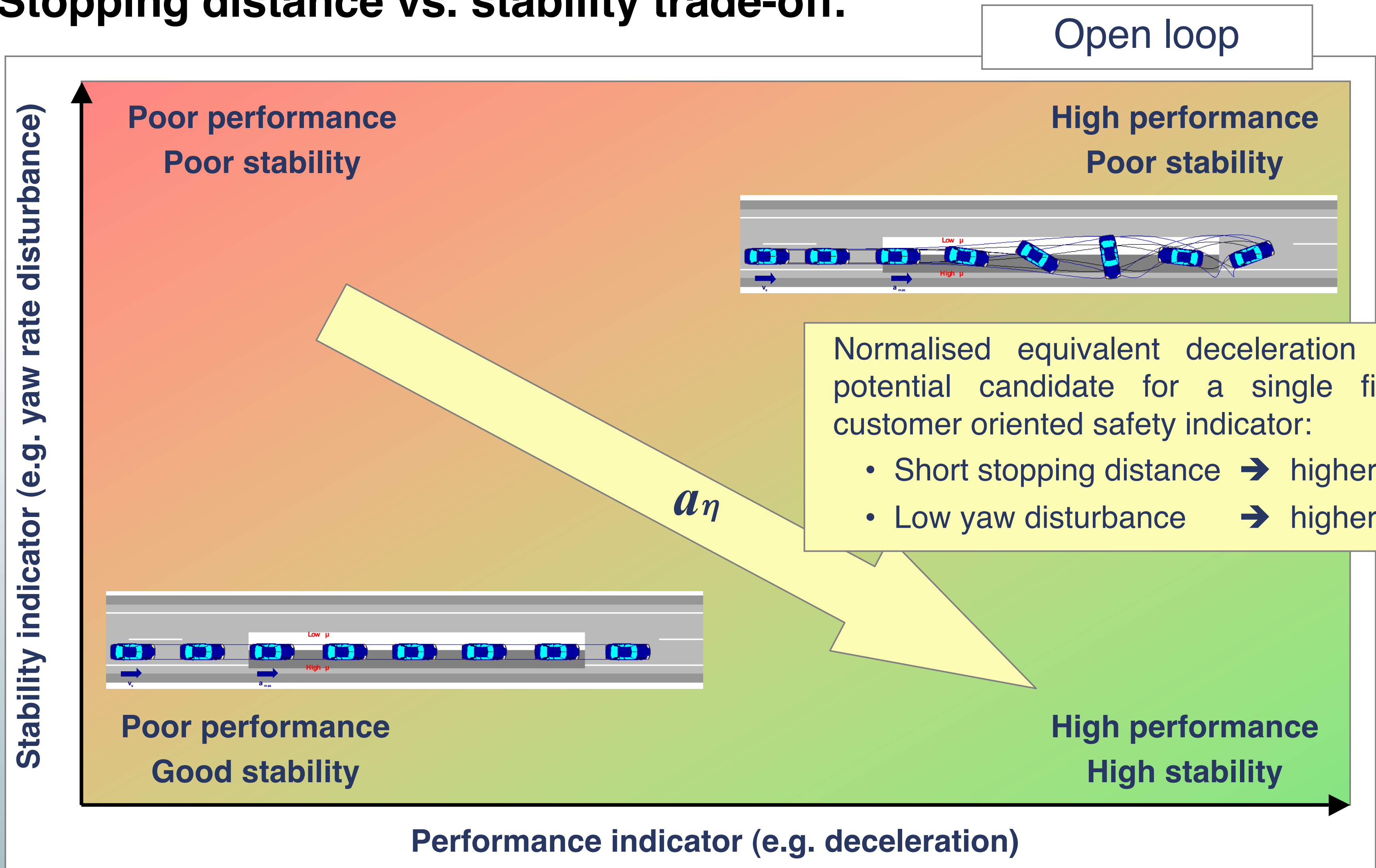
Emergency braking on asymmetric adherence

Stopping distance vs. stability trade-off.



Normalised equivalent deceleration is a potential candidate for a single figure, customer oriented safety indicator:

- Short stopping distance ➔ higher a_η
- Low yaw disturbance ➔ higher a_η

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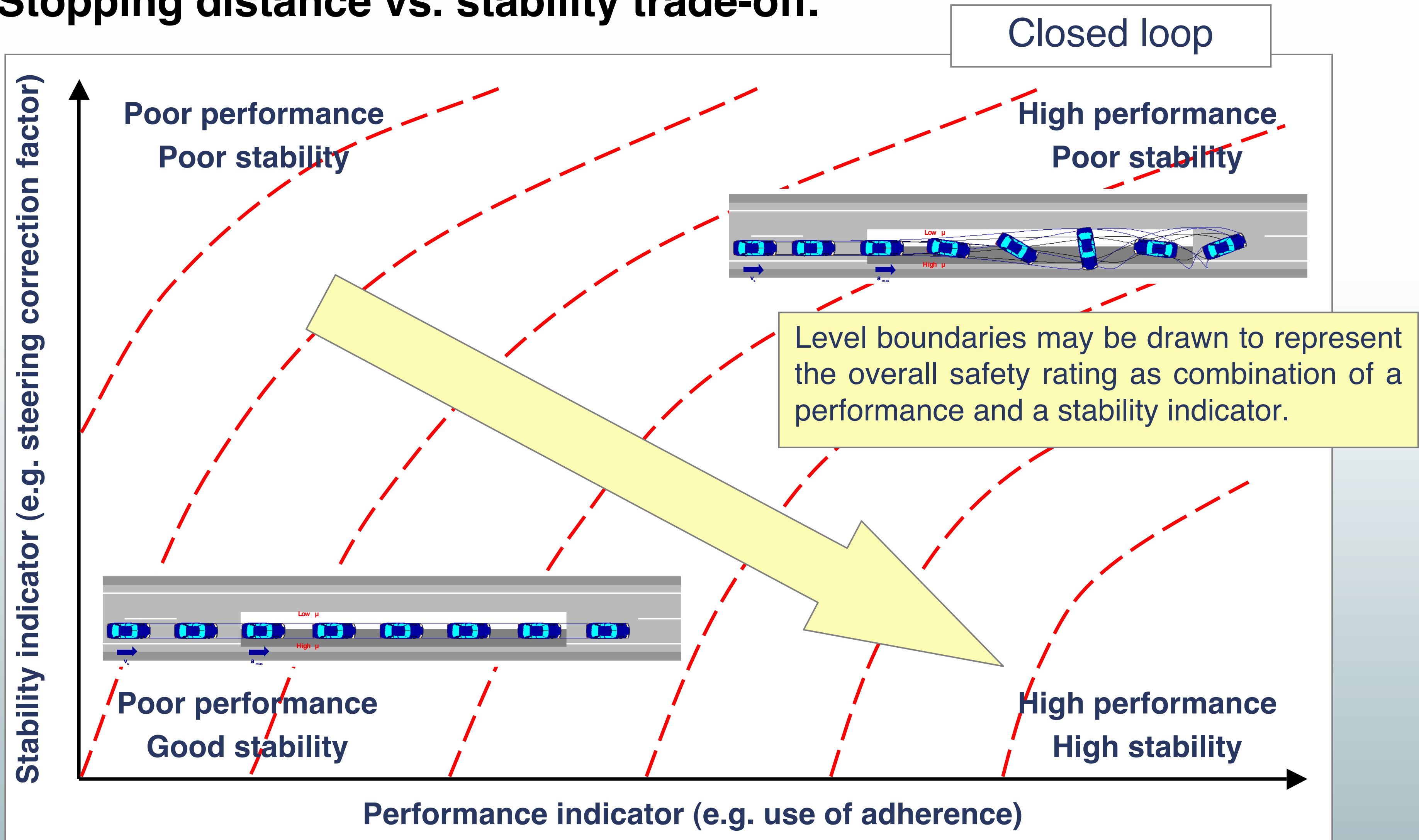
Emergency braking on asymmetric adherence

Stopping distance vs. stability trade-off.



Conclusions. . .

- For the **open loop test** the *“Mean deceleration”* and *“Equivalent deceleration”* are reliable safety performance indicators in order to describe the vehicles and ranking them both in terms of braking performance and trade-off with stability. The *”Equivalent deceleration normalised”* tends to harmonize each vehicle on different tracks but on the other hand it does not highlight so much the performance differences between vehicles. Further testing is required in order to improve the understanding of these phenomena.

- The **closed loop test** allows to analyse the whole braking manoeuver, its main drawback being the strong influence of the driver steering input, which makes quite hard to assess stability. The *“Use of adherence"* safety performance indicator gives good result in terms of braking performance evaluation, since it minimises the influence of the different tracks. On the other hand, the driver influence on the *“Steering correction factor”* could be reduced by setting additional conditions for the test execution but has to be analyzed deeper with further tests and different drivers.

. . . and next steps

- Objective indicators were developed and tested from both closed loop and open loop test procedures, providing a good basis for the assessment of the vehicle safety in the μ-split emergency braking scenario.

- Additional test campaigns are needed for validation or further refinement of the proposed test procedures and safety indicators, with the following goals
    - ❑ To verify and improve the ranking capability of the normalised equivalent deceleration from the open loop test procedure
    - ❑ To reduce the driver influence in the assessment of vehicle stability from the closed loop test procedure

Thank you for your attention

Questions