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Digital Infrastructure

Proposals to modify current skeleton document

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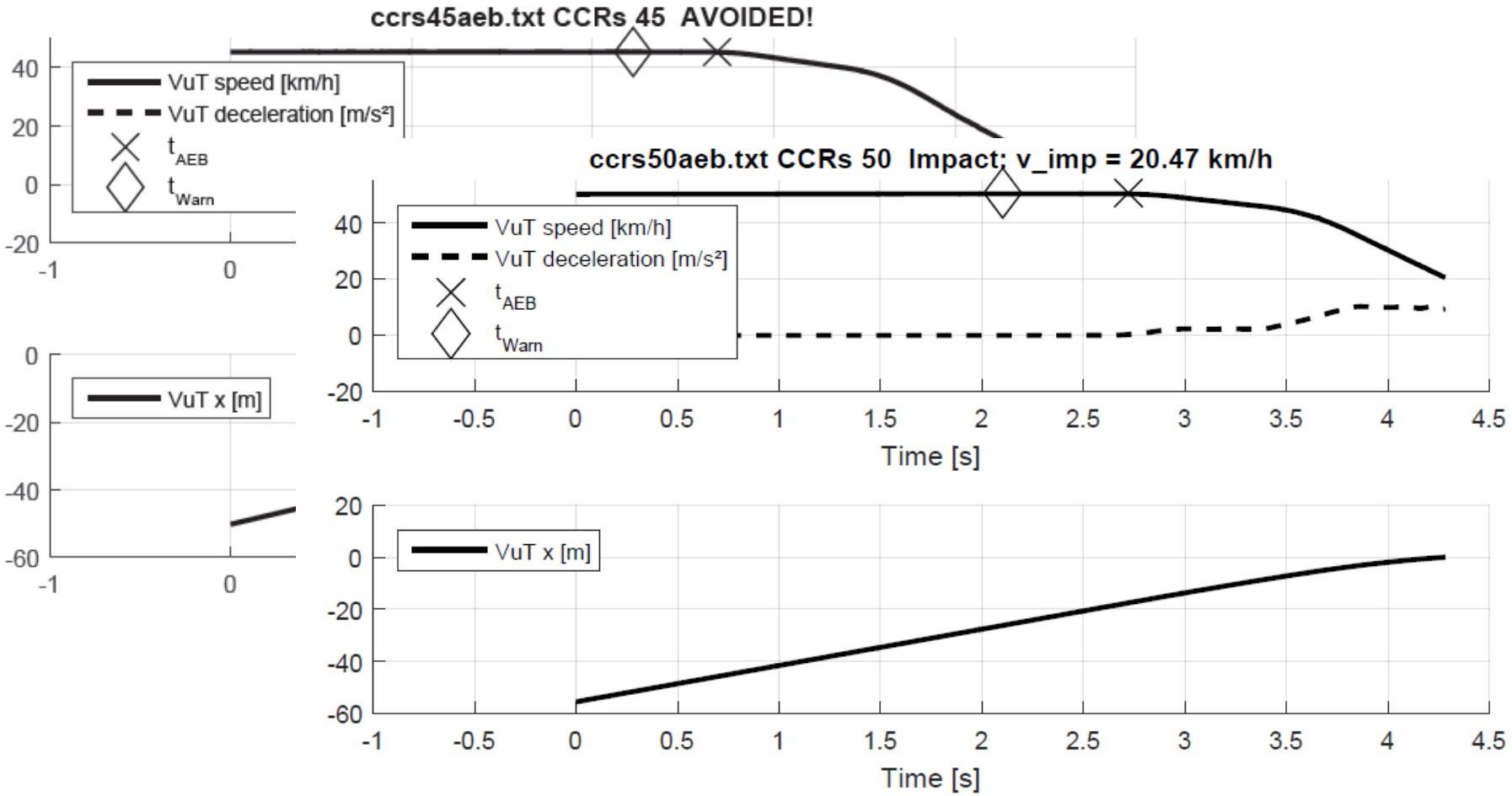
Brake Process



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Theory: When To Brake For Avoidance in Longitudinal Traffic

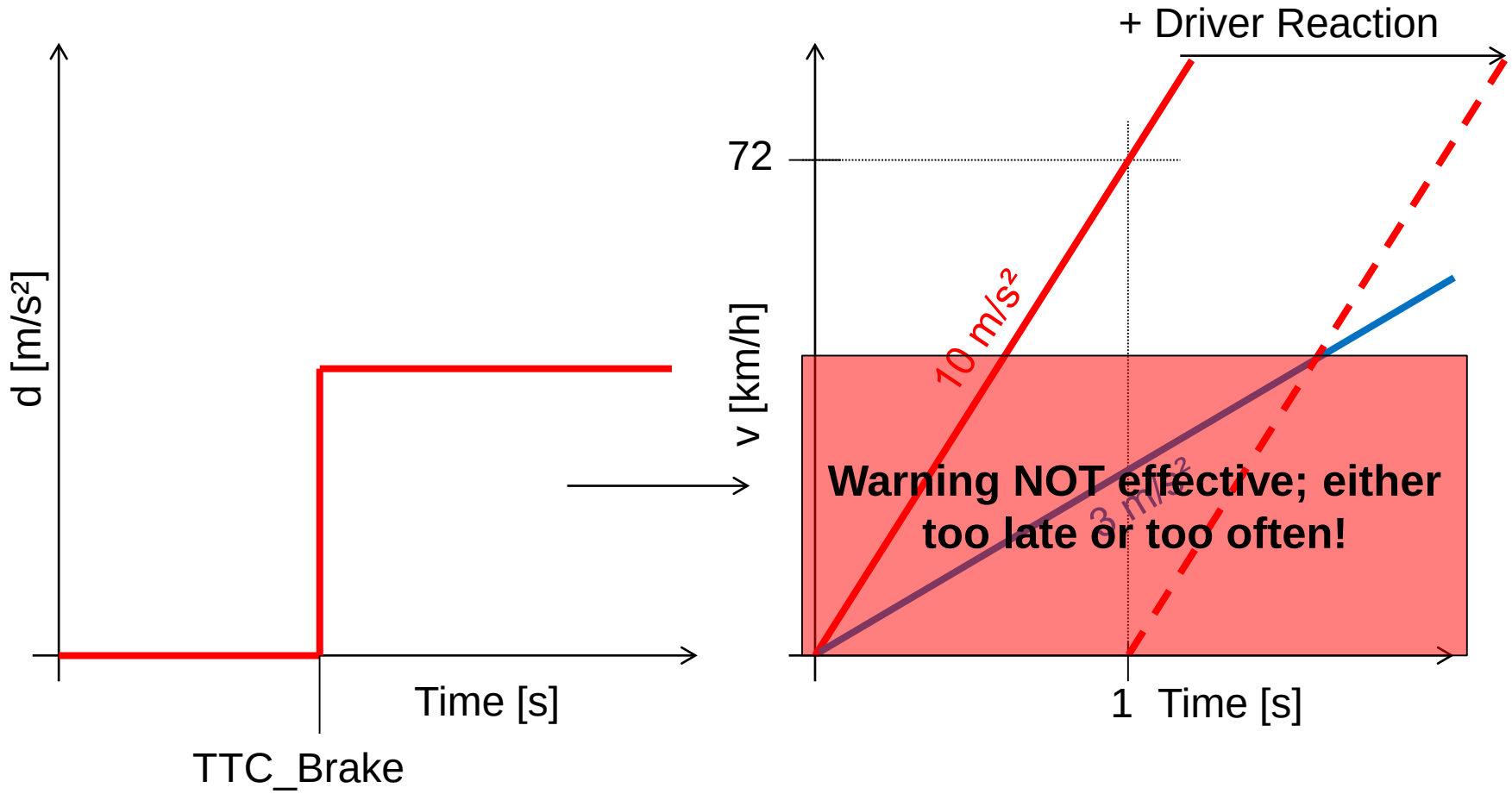
$$v = a \cdot t$$

$$s = \frac{1}{2} \cdot a \cdot t^2 \longrightarrow s = \frac{1}{2} \cdot a \cdot \frac{v^2}{a^2} \Leftrightarrow s = \frac{v^2}{2 \cdot a}$$

$$TTC = \frac{\Delta x}{\Delta v} = \frac{s}{v} \Leftrightarrow s = TTC \cdot v$$

$$TTC \cdot v = \frac{v^2}{2 \cdot a} \longrightarrow \boxed{TTC = \frac{v}{2 \cdot a}}$$

Brake Avoidance Timing - Theory



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Conclusion (1)

Driver Warning
→For Car-Car scenarios, a driver warning is feasible only ABOVE 35 km/h (or higher, depending on brake characteristics)
→For Pedestrian and Bicycle crossing scenarios, a warning will be very uneffective
→For Pedestrian and Bicycle longitudinal scenarios, a warning is expected to be very effective
→ For Highway scenarios with relative speeds > 60 km/h, a warning is considered effective (this is reflected in UN R131).

There should be no mandatory warning, nor a limitation of speed reduction in the warning phase.

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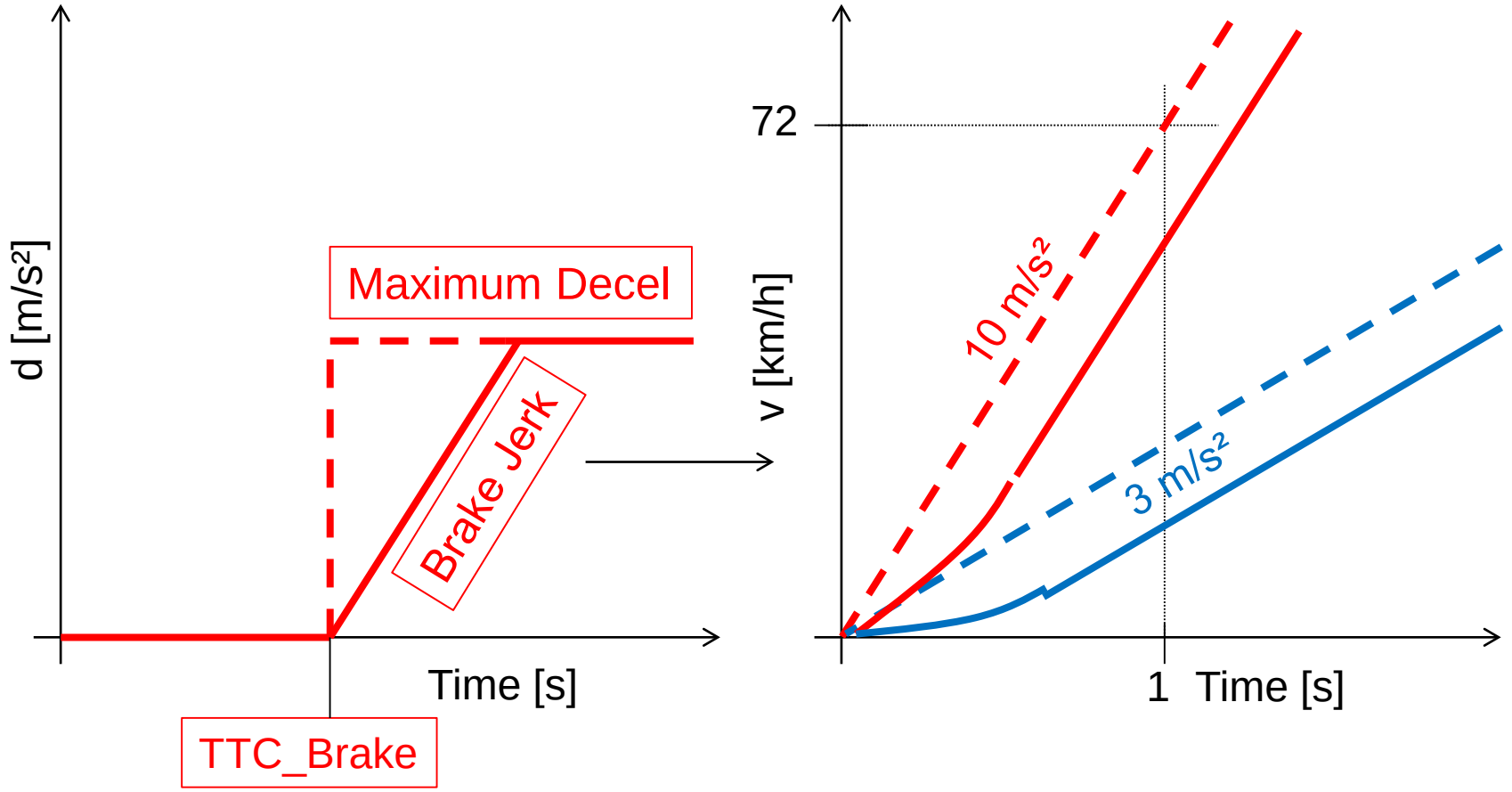
Brake Avoidance Timing – Realistic Systems



What Are The Brake Process Parameters?

Brake Timing
- Strategy
- Sensor Range (not relevant as long as > ca. 33m)
- Last Time to Steer (approximately constant over speed)

Brake Jerk
- Performance of ESC Pump (16 – 25 m/s^3)
- Performance of Active Booster (Future: up to 66 m/s^2)

Deceleration Level
- Friction Tire-Road
- Capacity of Brakes

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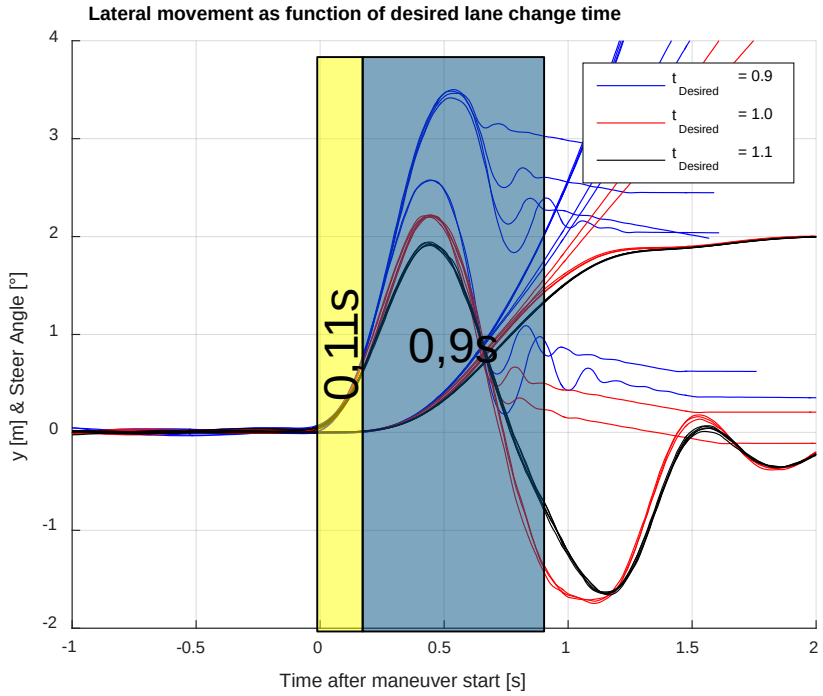
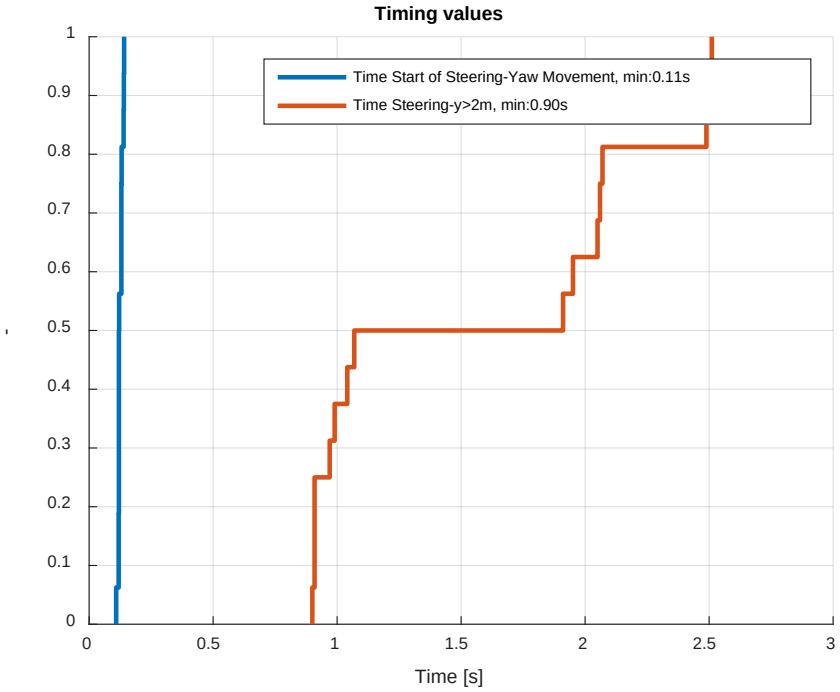
Last Point to Steer





Steering Input → Yaw rate response **(>0,11s)** → Lateral shift (0,79s Robot) (0,68/**0,77s** Human)

Total time for steering avoidance: >0,79s / **>0,88s**

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Conclusion (2):

„Brake Timing at the earliest“
→Could be taken from 3 m/s², 3 m/s³ line
→**Should not be specified (our preference)**

„Brake Timing at the latest“
→can be selected by manufacturer as long as the requirements are met.
→**Should not be specified**

Conclusion (3)

Speed Reduction should be specified only (!)

→LPS assumed to be 0.9 seconds for Car-Car-Scenarios
→Braking starting when pedestrian is 30 cm before path (pedestrian crossing scenarios)
→Braking starting when bicycle is [100] cm before path (bicycle crossing scenarios)

→Deceleration level 9 m/s² (should be possible on track, to be checked)
→Brake Jerk 16,67 m/s² (=0,6 seconds to reach 10 m/s²)
→Tolerance of plus [5] km/h acceptable

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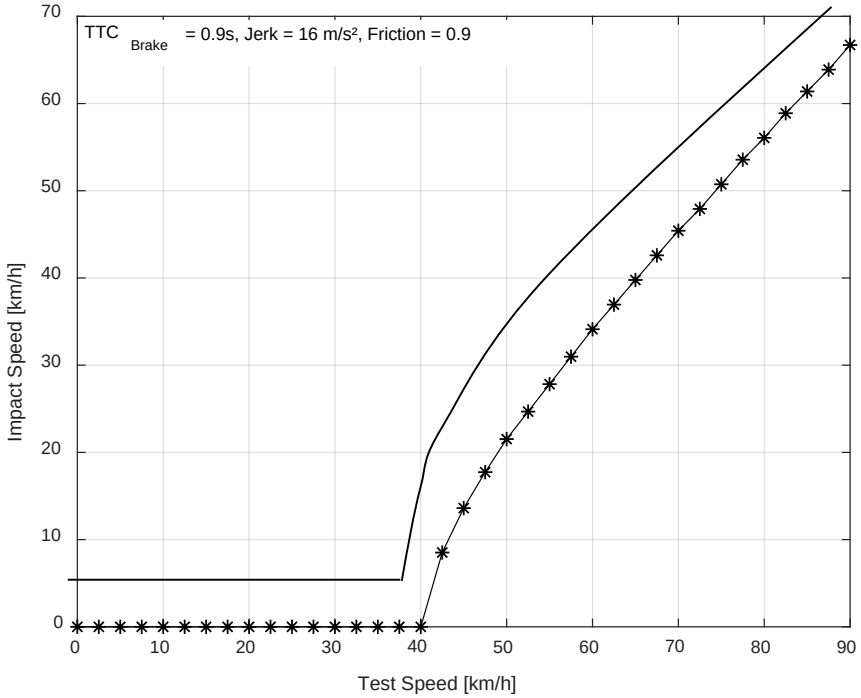
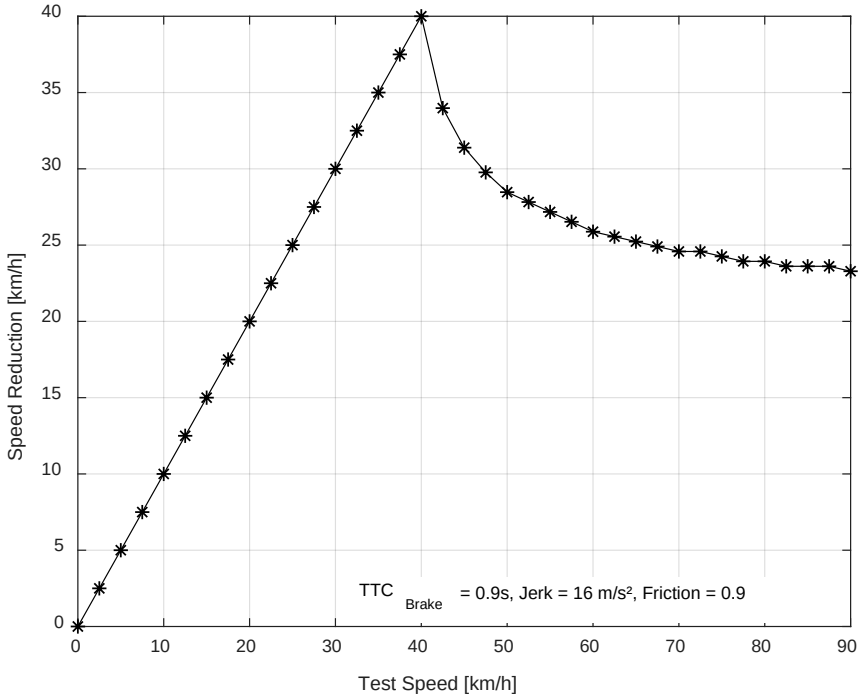
Example System on High Friction: Brake Test Results As Function Of Initial Speed AEB Car-Car





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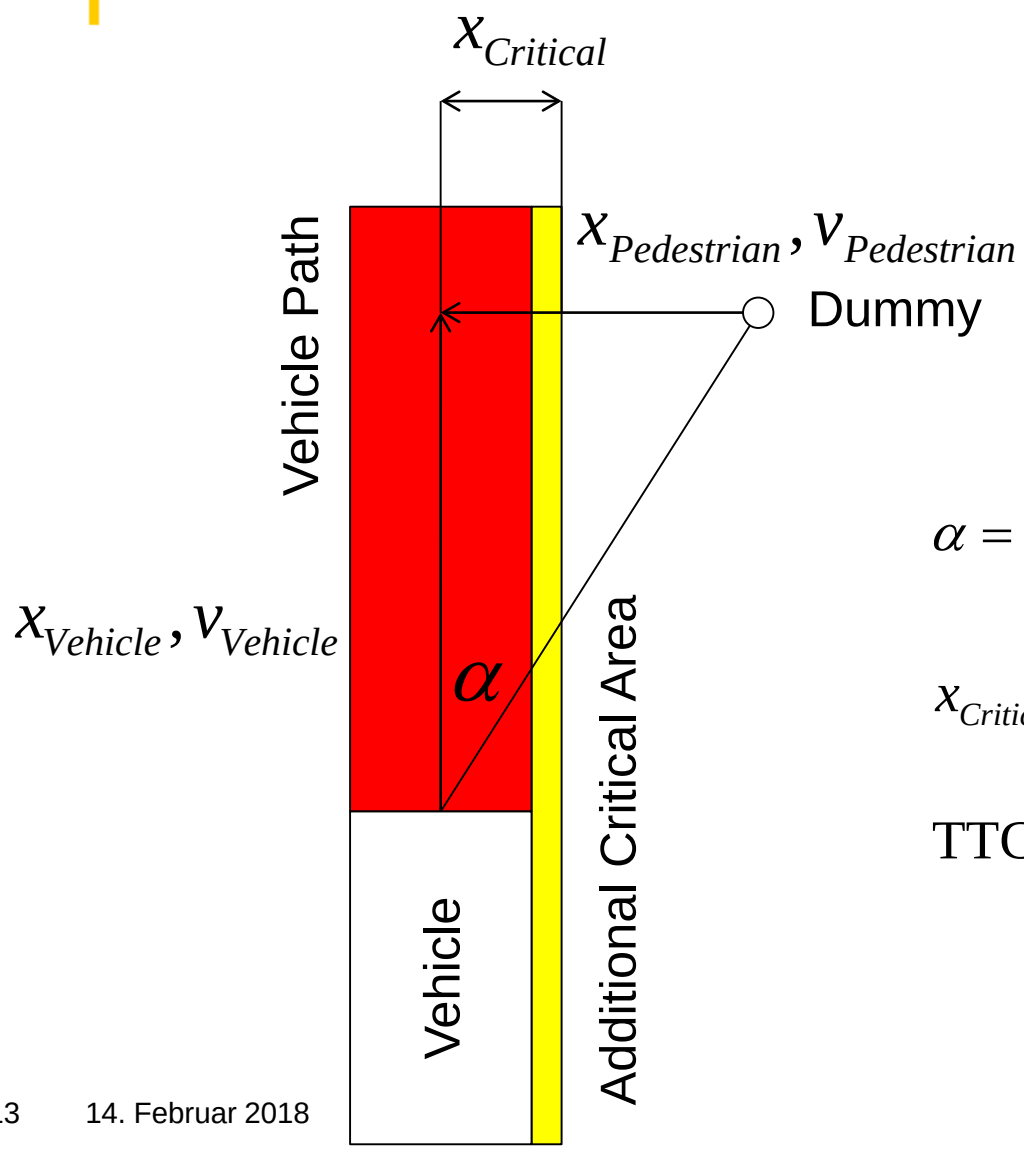
Scenarios

Car-Car Rear Braking → [12/40]
Car-Car Rear Moving → [30-70] vs. [20]
Car-Car Rear Stationary → [10-50]
Car-Pedestrian [10-50] vs. [5], Dummy?, Impact Point?
Car-Bicycle Crossing [10-50] vs. [10]
Car-Bicycle Longitudinal?

Theory of Cross-Traffic Accidents



$$\alpha = \arctan \frac{v_{Pedestrian}}{v_{Vehicle}}$$

$$x_{Critical} = \frac{1}{2} w_{Vehicle} + x_{Safety} \approx 1.3\text{m}$$

$$\text{TTC}_{\text{Critical}} = \frac{x_{Critical}}{v_{Pedestrian}} \approx 0.9\text{s}$$

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Conclusion (4)

Brake Timing comparable for AEBS Car and AEBS Pedestrian
Warning not feasible due to the pedestrian becoming critical very late

Requirements for AEB Car-Car and AEB Car-Pedestrian should be the same.

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Other

Deactivation of the AEB by the driver is not acceptable for Germany

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Summary

- There should be no mandatory warning *for relative speeds below 50 km/h*, nor a limitation of speed reduction in the warning phase.
- Brake timing requirements (e.g. not later, not earlier) should not be specified
- Speed reduction as function of test parameters should be specified
- Speed reduction should be calculated on the basis of
  - a brake timing (LPS, time pedestrian becomes critical) of 0.9s
  - a friction value of 0.9, allowing a deceleration of 9 m/s^2
  - a brake jerk of 16.67 m/s^3 (equiv. 0.6 s to 10 m/s^2)
  - However we would be open to specify degradation of performance for low friction / low offset tests
  - A tolerance of 5 km/h is acceptable
  - Degradation for N1 vehicles due to other brake systems could be acceptable
- Deactivation of the AEB by the driver is not acceptable for Germany.

Thank you for your attention!

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