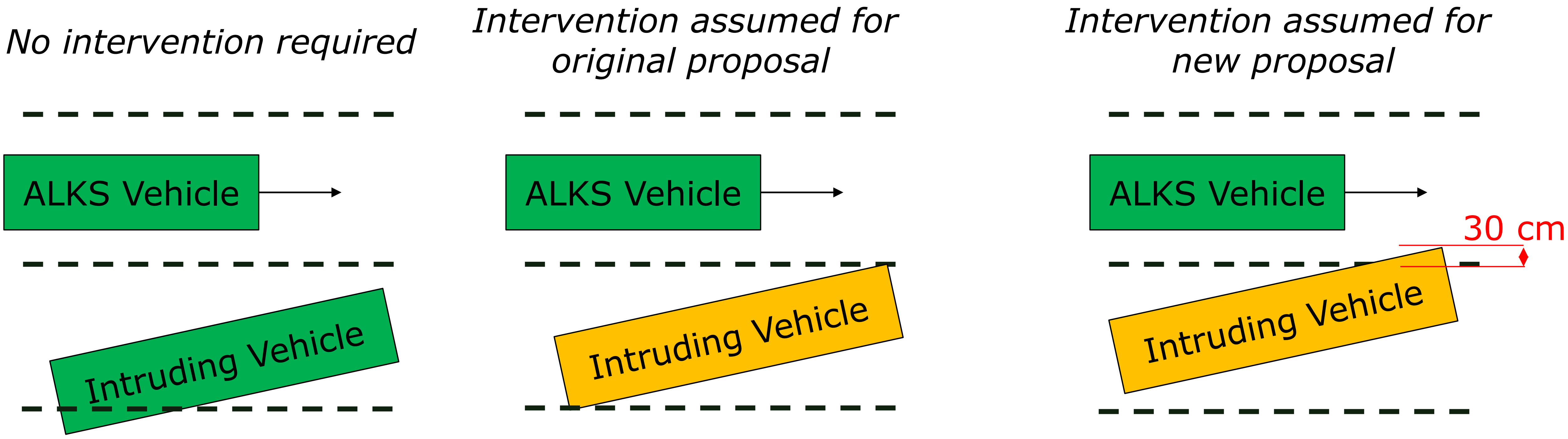
Submitted by expert from Germany

<u>Informal document</u> **GRVA-05-36**
5th GRVA, 10-14 February 2020
Agenda item 4(a)

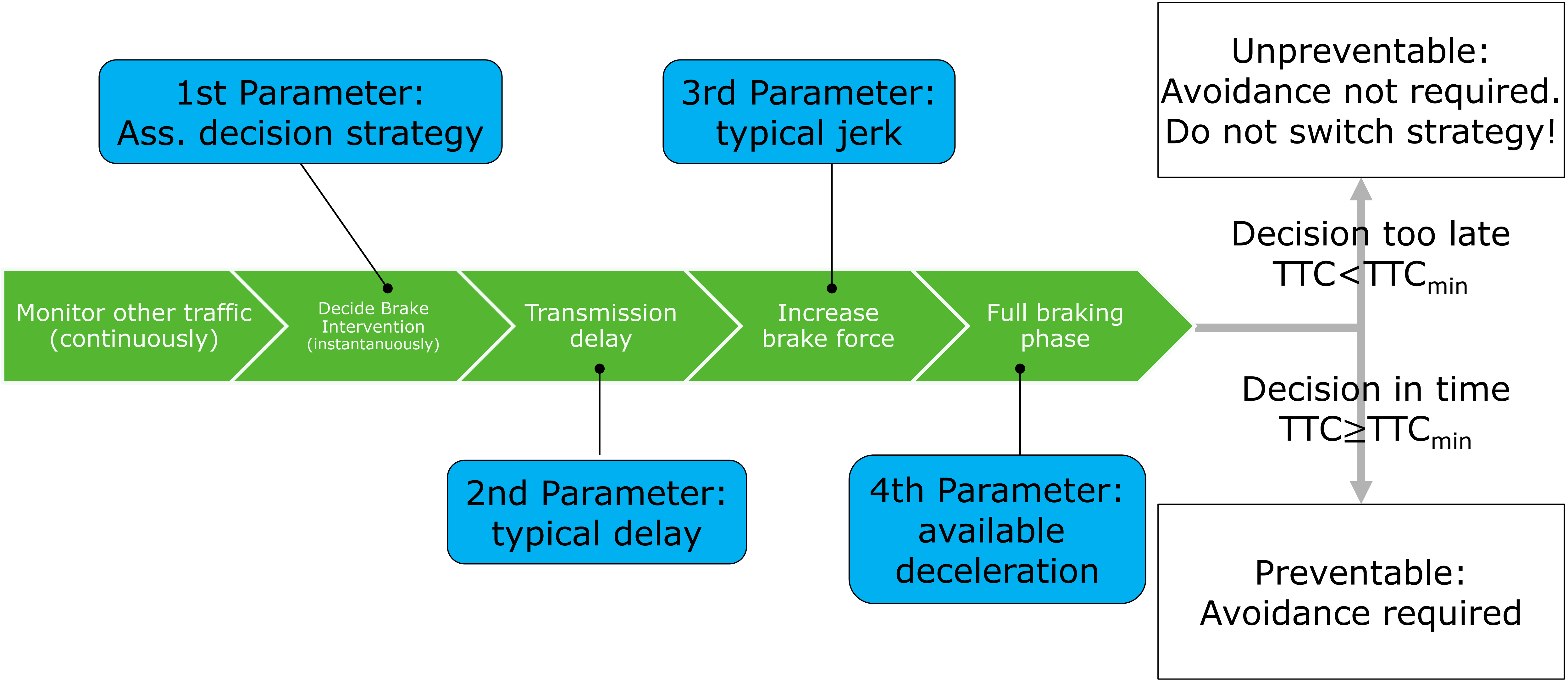
Motivation of Cut-In Requirements

Additional explanation to paragraph 5.2.5.2.
of the draft UN Regulation for ALKS (GRVA-05-07)

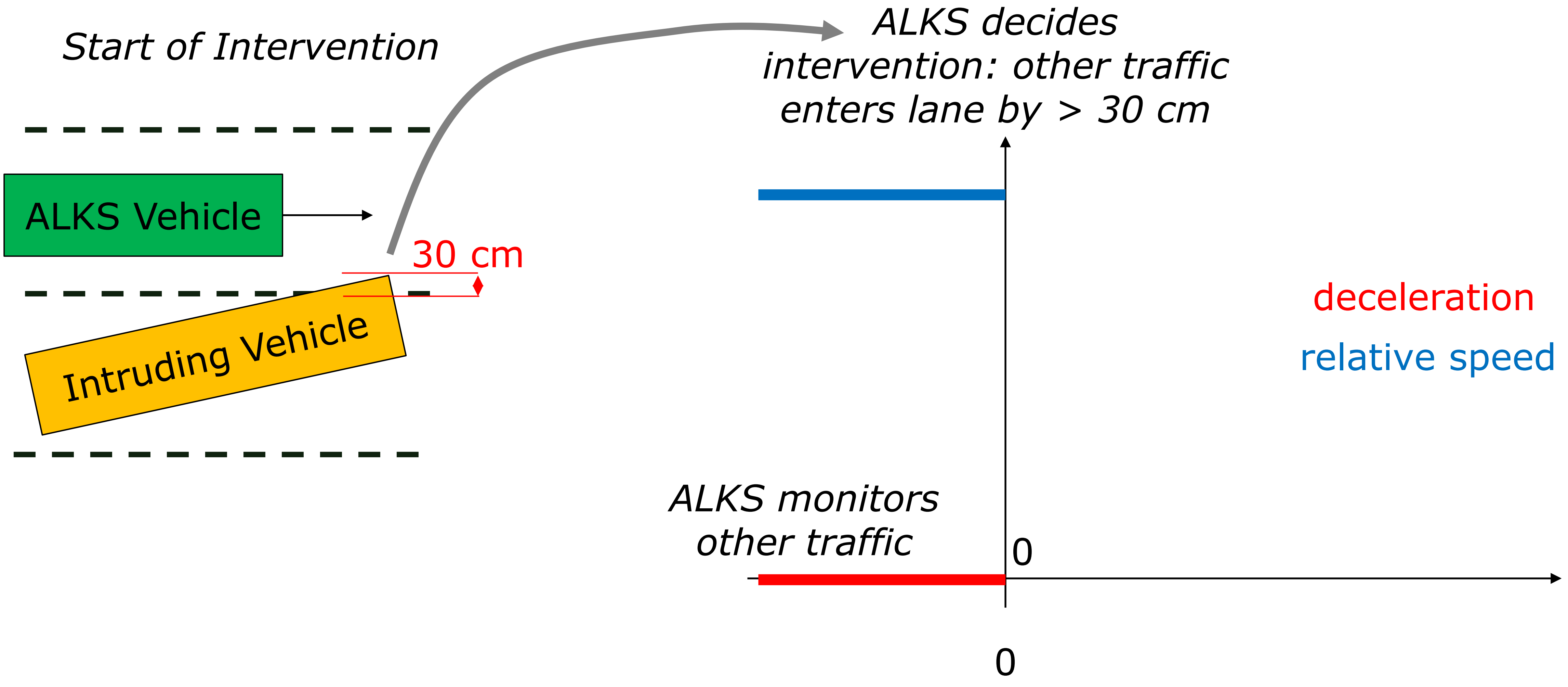
Cut-In Requirements: Model for ADS Behavior



Cut-In Requirements: Intervention Concept

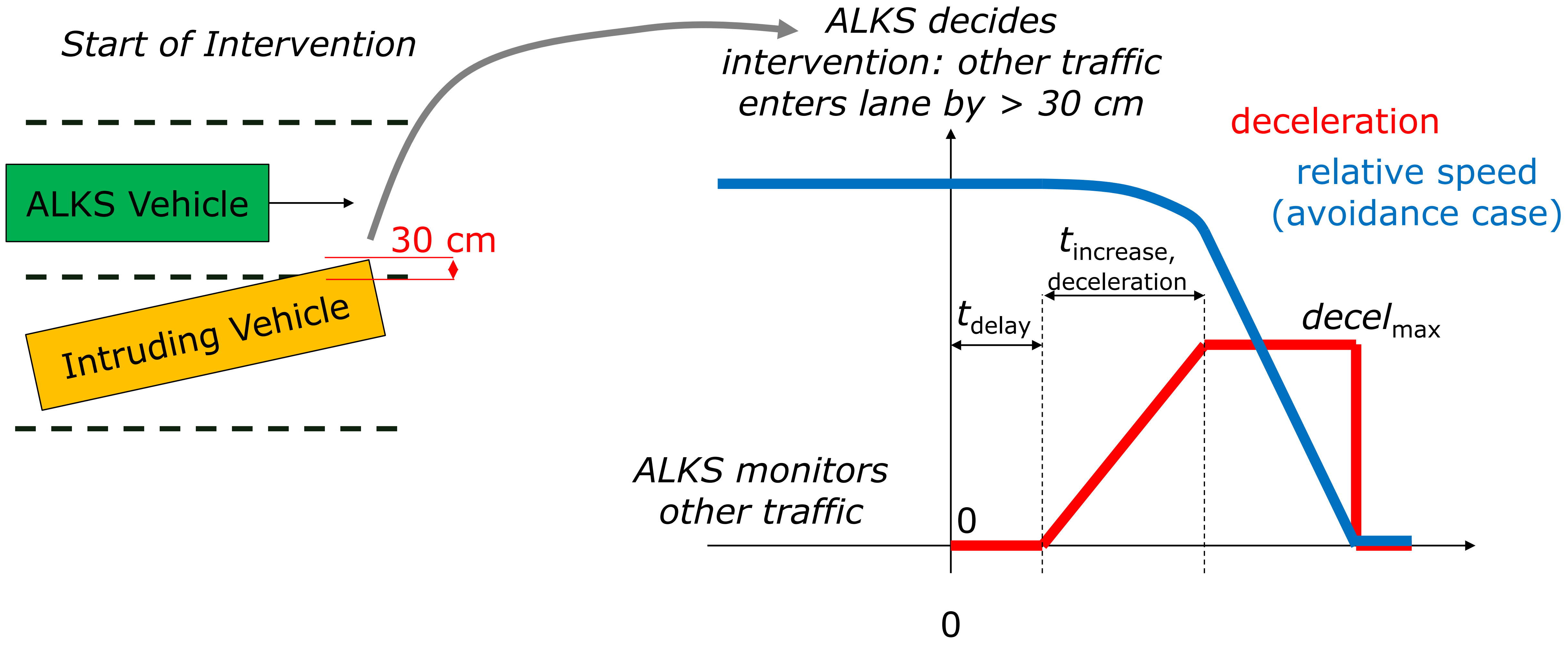


Cut-In Requirements: Intervention Model

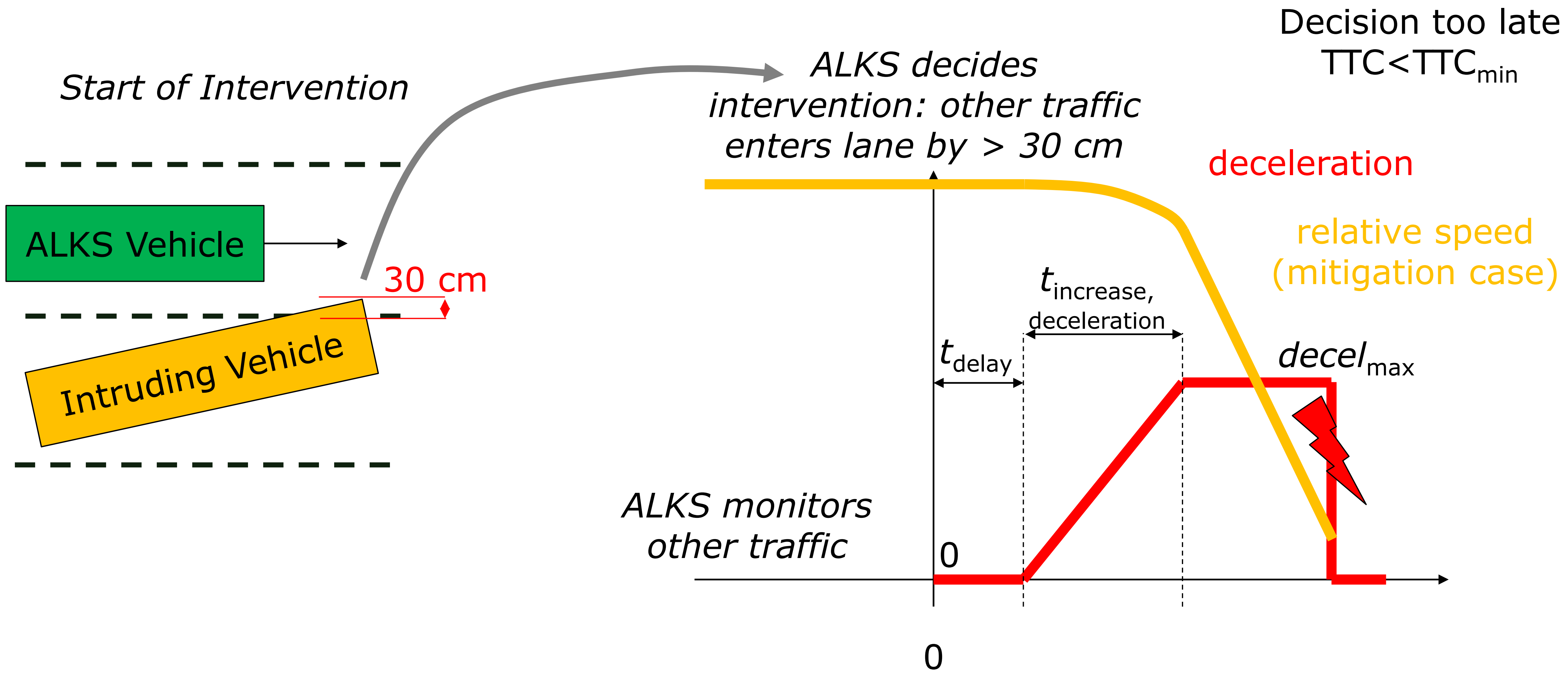


Cut-In Requirements: Intervention Model (2)

Decision in time
$TTC \geq TTC_{min}$



Cut-In Requirements: Intervention Model (3)



Mathematical Model for Edge TTC

- TTC for brake start to avoid collision with deceleration d:

$$TTC_{\text{avoidance}} = \frac{v_{\text{rel}}}{2 \cdot d} = \frac{v_{\text{rel}}}{2 \cdot |\ddot{x}_{\text{max}}|}$$

- Approximation (avoiding numeric integration) for jerk influence:

$$TTC_{\text{avoidance}} = \frac{v_{rel}}{2 \cdot |\ddot{x}_{\text{max}}|} + \frac{1}{2} t_{\text{increase}} \qquad t_{\text{increase}} = \frac{\ddot{x}_{\text{max}}}{\dddot{x}_{\text{available}}}$$

- Take „dead time" delay (command transmission etc) into accout:

$$TTC_{\text{avoidance}} = \frac{v_{rel}}{2 \cdot |\ddot{x}_{\text{max}}|} + \frac{1}{2} t_{\text{increase}} + t_{delay}$$

Parameter Derivation

1st Parameter: Ass. decision strategy

Assume an intrusion of 30 cm into lane can be considered critical (intrusion continuously monitored!)

2nd Parameter: typical delay

Transmission in bus system, overcome actuator friction, …
100 ms (confirmed by manuf.)

3rd Parameter: typical jerk

Typical (own measurement): 0.4 – 0.6 s from 0 to 10 m/s²
New brake systems (own measurement): 0.15 s from 0 to 10 m/s²
Assumed (conservative!) in DE/FR prop.: **0.5 s from 0 to 6 m/s²**

4th Parameter: available deceleration

Typical value from field data: **6 m/s²** availabe also on wet roads.

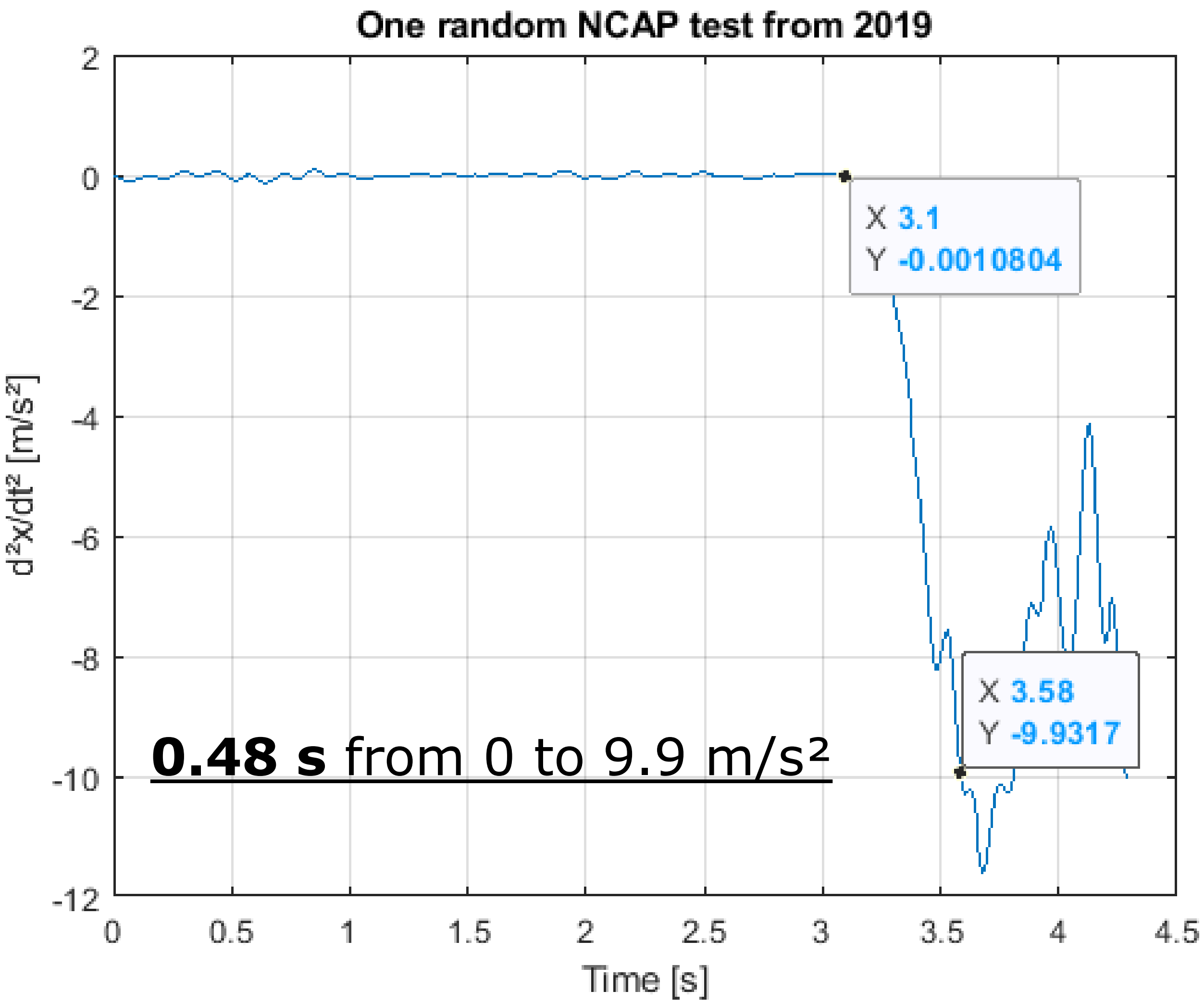
$$TTC_{\text{avoidance}} = \frac{v_{rel}}{2 \cdot |\ddot{x}_{\max}|} + \frac{1}{2} t_{\text{increase}} + t_{delay}$$

→

$$TTC_{\text{avoidance}} = \frac{v_{\text{rel}}}{2 \cdot 6\ \text{m/s}^2} + \frac{1}{2} 0.5\text{s} + 0.1\text{s} = \frac{v_{\text{rel}}}{2 \cdot 6\ \text{m/s}^2} + 0.35\text{s}$$

Parameter

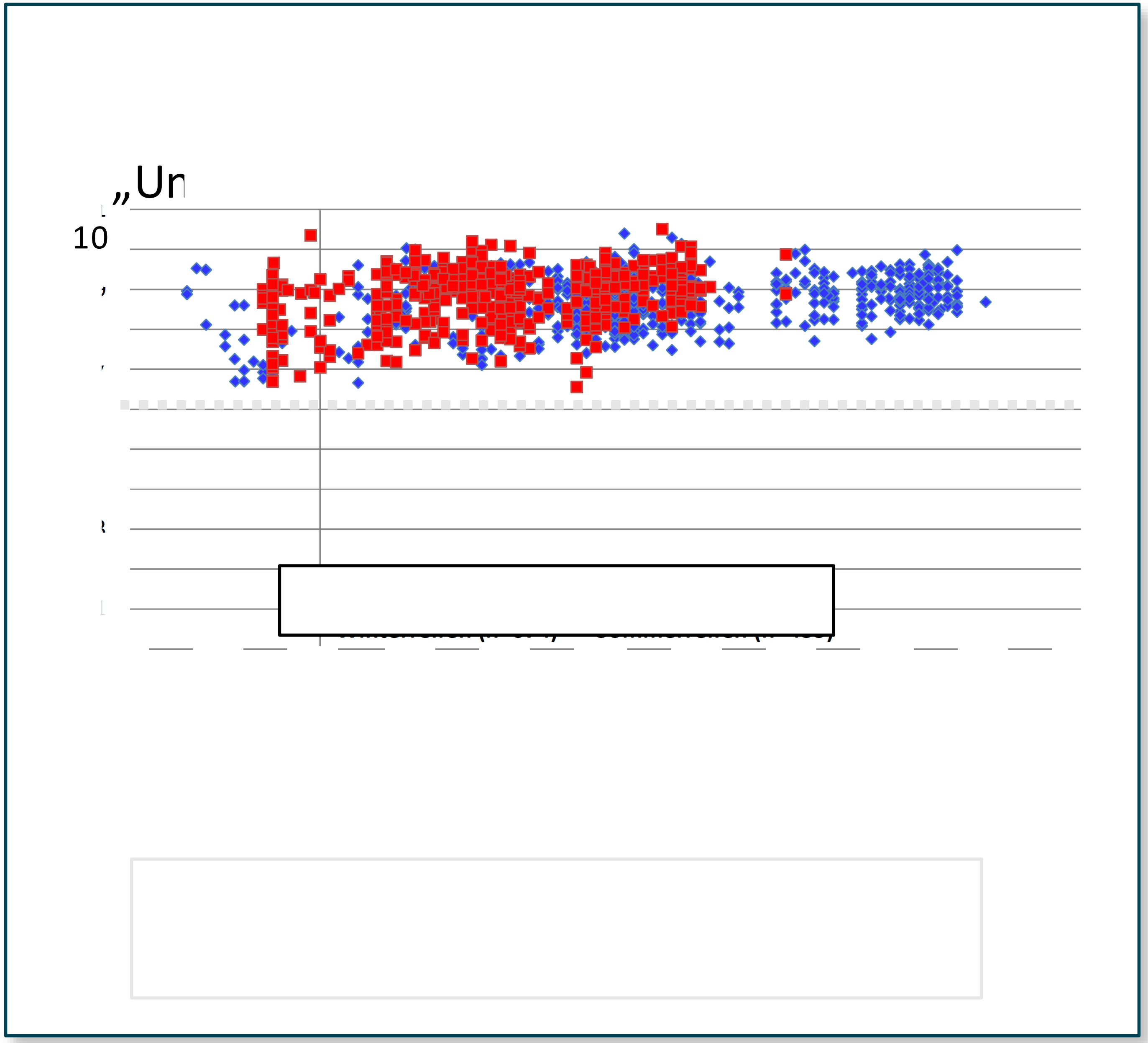
3rd Parameter:
typical jerk



0.48 s from 0 to 9.9 m/s²

Parameter

4th Parameter: available deceleration



Summary

- DE/FR model assumes a continuous monitoring of traffic in adjacent lanes
- DE/FR model assumes a critical condition and consequently a brake intervention when other traffic enters > 30 cm into ego lane
- DE/FR model assumes a plausible delay (transmission, actuator friction) of 0.1 s
- DE/FR model assumes a brake intervention with $6\ m/s^2$ reached in 0.5 seconds
- These values have been shown to be realistic
- DE/FR position: Automated vehicles should not be required to have a weaker perfomance than current ADAS-equipped vehicles

Comparison of JP and DE/FR DTC values

V_{rel} (km/h) / $V_{Lateral}$ (m/s)	0	10	20	30	40	50
0	N/A	N/A	N/A	N/A	N/A	N/A
0.5	5.0	9.6 **3.28**	19.8 **7.85**	31.0 **13.7**	45.0 **20.84**	N/A **29.27**
1.0	5.0	6.6 **2.45**	13.7 **6.18**	22.0 **11.20**	32.3 **17.51**	N/A **25.1**
1.5	5.0	5.6 **2.17**	11.6 **5.63**	18.4 **10.37**	26.4 **16.40**	N/A **23.71**
1.8	N/A	N/A **2.08**	N/A **5.44**	N/A **10.09**	N/A **16.03**	N/A **23.25**

Threshold [m]	0,3	Combined delay [s]	0,35	decel [m/s²]	6
v_{lat} [m/s]	v_{rel} [km/h]	TTC_{min} [s]	Distance [m]	TTC_{min} [s] after lane crossing	Distance [m]
0,5	10	0,58	1,62	1,18	3,28
0,5	20	0,81	4,52	1,41	7,85
0,5	30	1,04	8,70	1,64	13,70
0,5	40	1,28	14,18	1,88	20,84
0,5	50	1,51	20,94	2,11	29,27
0,5	59	1,72	28,12	2,32	37,95
1	10	0,58	1,62	0,88	2,45
1	20	0,81	4,52	1,11	6,18
1	30	1,04	8,70	1,34	11,20
1	40	1,28	14,18	1,58	17,51
1	50	1,51	20,94	1,81	25,10
1	59	1,72	28,12	2,02	33,04
1,5	10	0,58	1,62	0,78	2,17
1,5	20	0,81	4,52	1,01	5,63
1,5	30	1,04	8,70	1,24	10,37
1,5	40	1,28	14,18	1,48	16,40
1,5	50	1,51	20,94	1,71	23,71
1,5	59	1,72	28,12	1,92	31,40
1,8	10	0,58	1,62	0,75	2,08
1,8	20	0,81	4,52	0,98	5,44
1,8	30	1,04	8,70	1,21	10,09
1,8	40	1,28	14,18	1,44	16,03
1,8	50	1,51	20,94	1,67	23,25
1,8	59	1,72	28,12	1,88	30,85