Safe Transitions From Automated to Manual Driving

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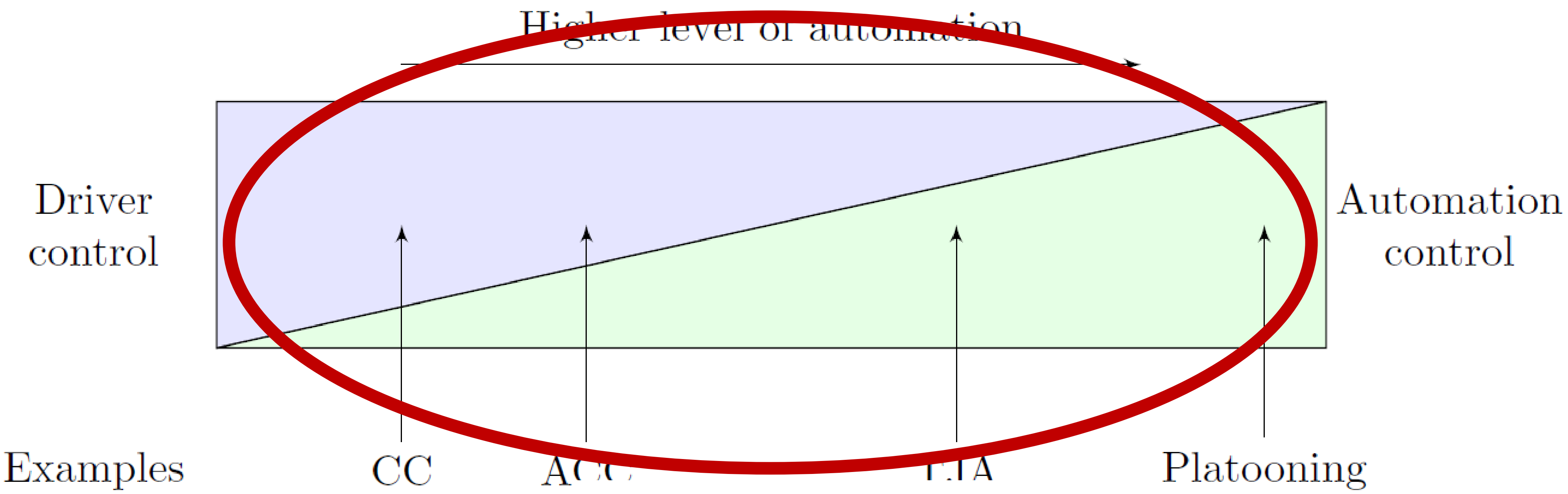
Outline

- Vehicle automation
- Experiments of driver takeover when automation fails
- Improving safety of driver takeovers
- Conclusions and future work

Changing role of the driver



The driver may be requested to take over

Levels of automation

BASt expert group[1]	NHTSA[2]	SAE J3016[3]	Role of the driver	Examples
Driver only	Level 0 – No-Automation	Non-Automated	Full control	- (information and warning systems)
Assisted	Level 1 – Function-specific Automation	Assisted	Must permanently monitor. Resume control at any time.	CC, ACC, LKA, ESC
Partial automation	Level 2 - Combined Function Automation	Partial Automation	Must permanently monitor. Resume control at any time.	ACC and lane keeping, TJA
High automation	Level 3 - Limited Self-Driving Automation	Conditional Automation	Not required to monitor. Required to resume control after a certain lead time.	Lateral and longitudinal control automated
Full automation	Level 4 - Full Self-Driving Automation	High Automation	May be asked to but is not required to resume control.	Lateral and longitudinal control automated
-		Full Automation	Driverless vehicle	Lateral and longitudinal control automated

[1] T. M. Gasser, et al., “Legal consequences of an increase in vehicle automation (English translation),”Bundesanstalt für Straßenwesen (BASt), BASt-Report F83 (Part 1), 2013.

[2] National Highway Traffic Safety Administration, “Preliminary Statement of Policy Concerning Automated Vehicles.” 2013.

[3] SAE International, “SAE J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems.” 2014.

WHAT HAPPENS WHEN DRIVERS ARE REQUIRED TO TAKE OVER WHEN AUTOMATION FAILS?

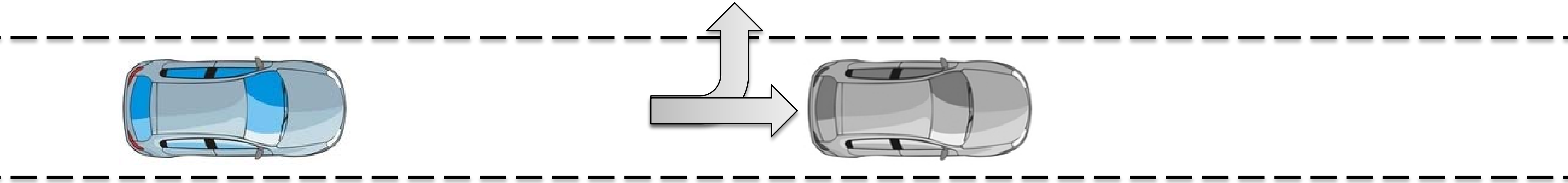
How do drivers respond to failures of longitudinal automation provided by an ACC?

STUDY #1

Publication:
J. Nilsson, N. Strand, P. Falcone, and J. Vinter, “Driver performance in the presence of adaptive cruise control related failures: Implications for safety analysis and fault tolerance,” in *Proc. 2013 43rd Annu. IEEE/IFIP Conf. Dependable Syst. Networks Work.*, 2013, pp. 1–10.

Unwanted acceleration

Car in front drives at 105 km/h (65 mph), automation in ego car accelerates unintentionally towards vehicle ahead (fails to keep the set distance and speed)

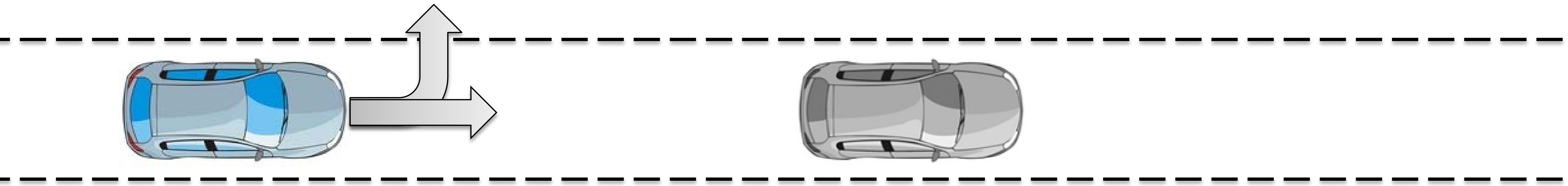


Braking or steering
required to avoid collision

Complete and partial deceleration failure

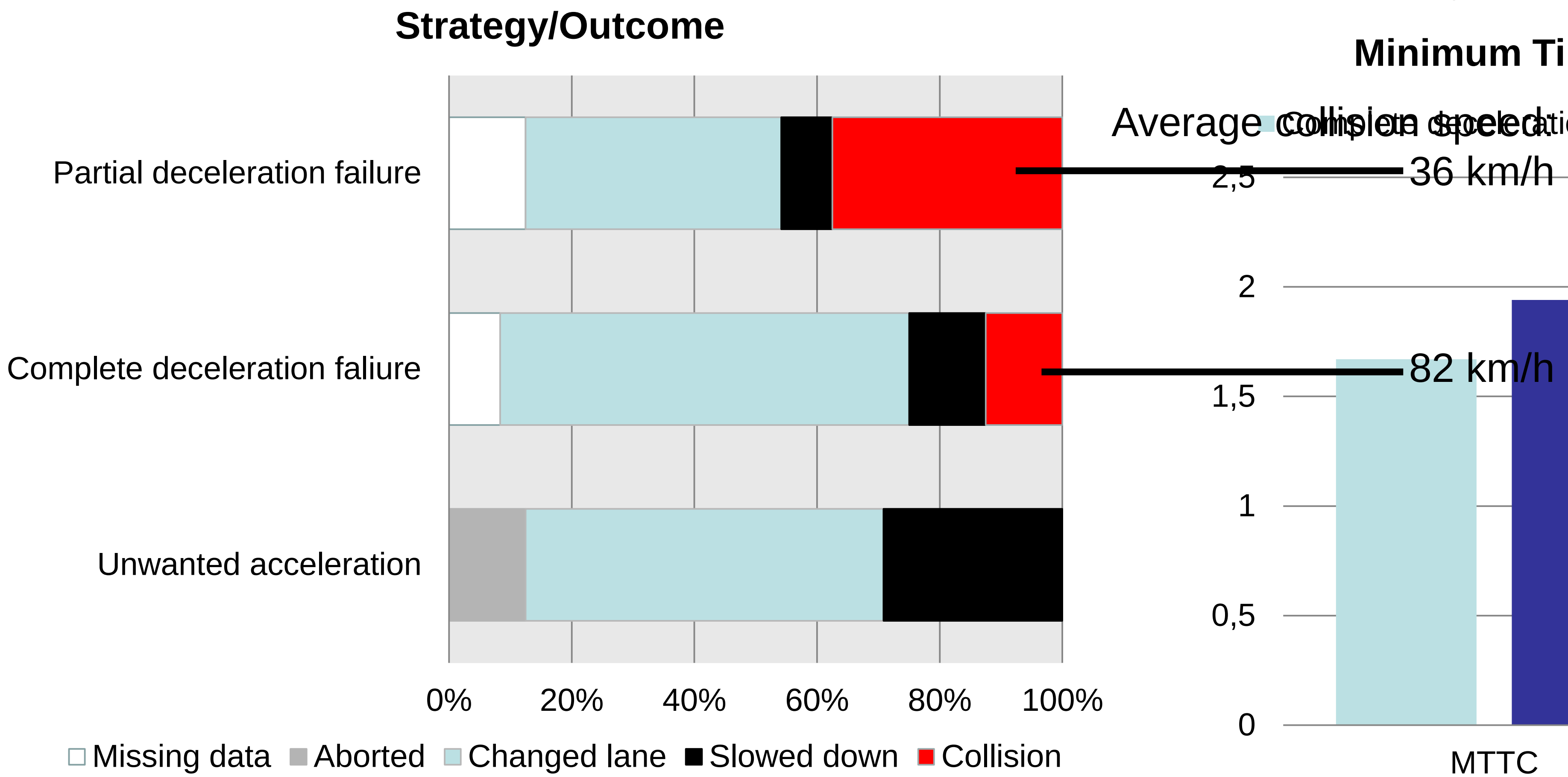
1: Car in front brakes, automation in ego car does not brake

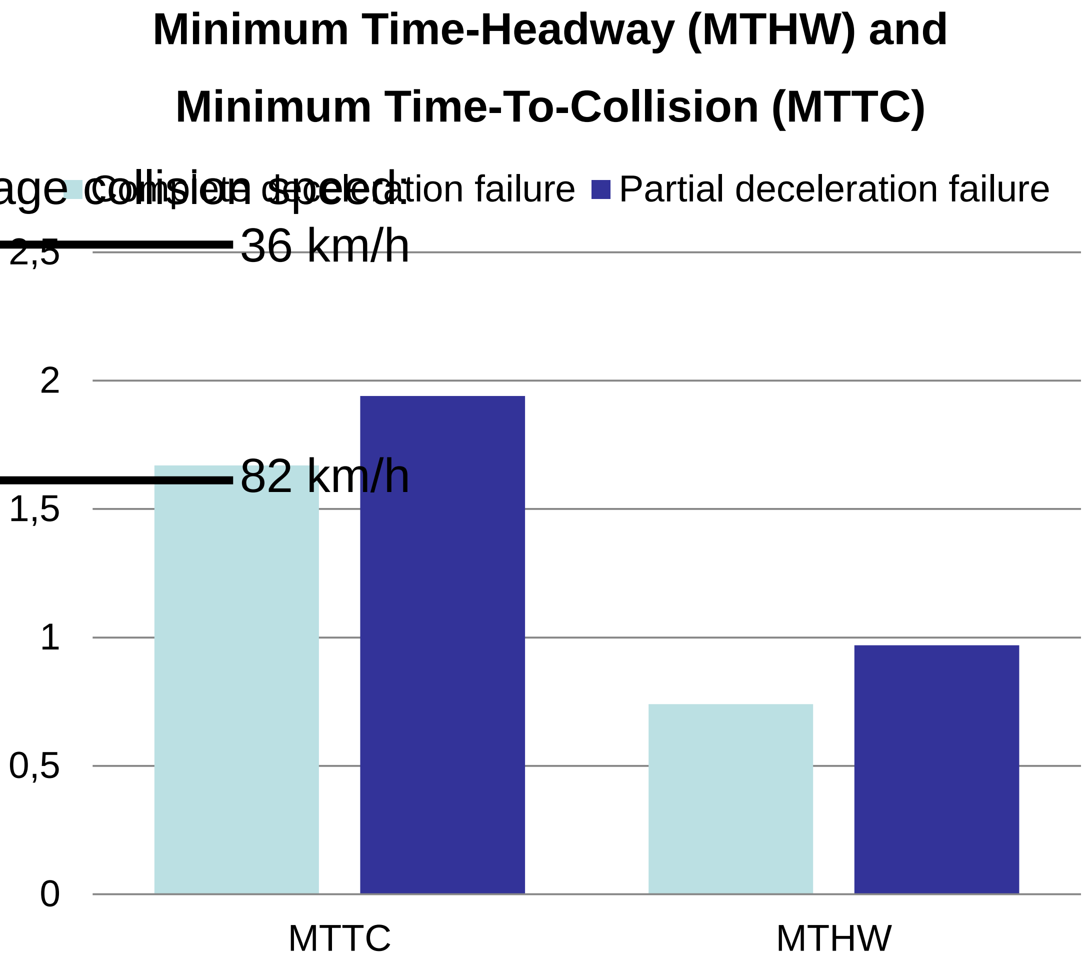
2: Car in front brakes, automation in ego car brakes less than necessary to avoid a collision



Braking or steering
required to avoid collision

Results





$t_{THW} = \frac{d}{v_s}$: Time-Headway

$t_{TTC} = \begin{cases} \frac{d}{v_s - v_t} & if\, v_s > v_t \\ \infty & otherwise \end{cases}$: Time-To-Collision

How does level of automation influence how drivers respond to failures?

STUDY #2

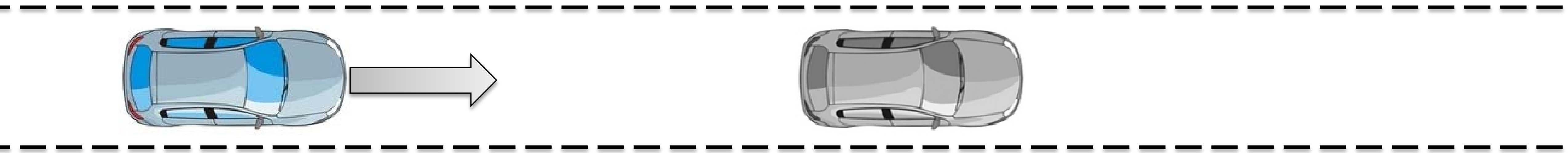
Publication:
N. Strand, J. Nilsson, I. C. M. Karlsson, and L. Nilsson, “Semi-automated versus highly automated driving in critical situations caused by automation failures,” Accepted for publication in *Transp. Res. Part F Traffic Psychol. Behav.*

Complete and partial deceleration failures

CDF: Car in front brakes, automation in ego car does not brake

SDF: Car in front brakes, automation in ego car brakes less than necessary (~30% of full brake capacity) to avoid a collision

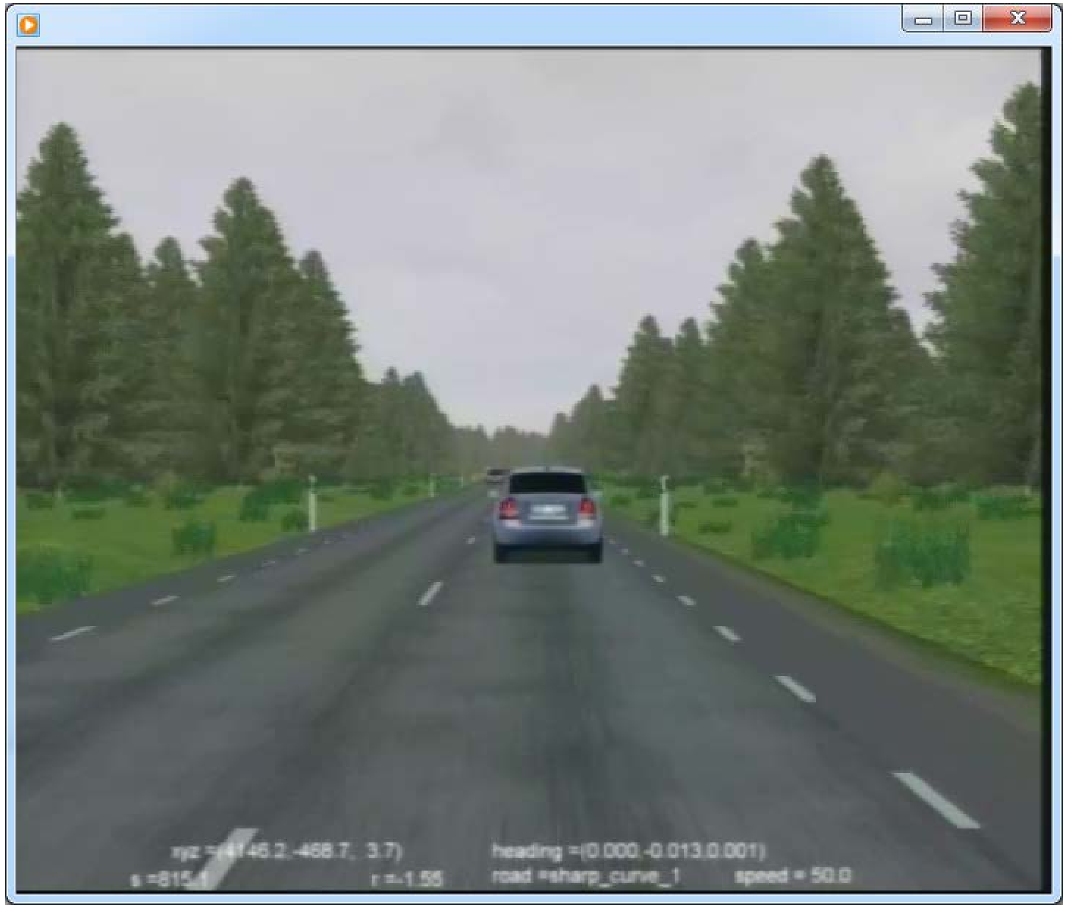
MDF: Car in front brakes, automation in ego car brakes less than necessary (~60% of full brake capacity) to avoid a collision



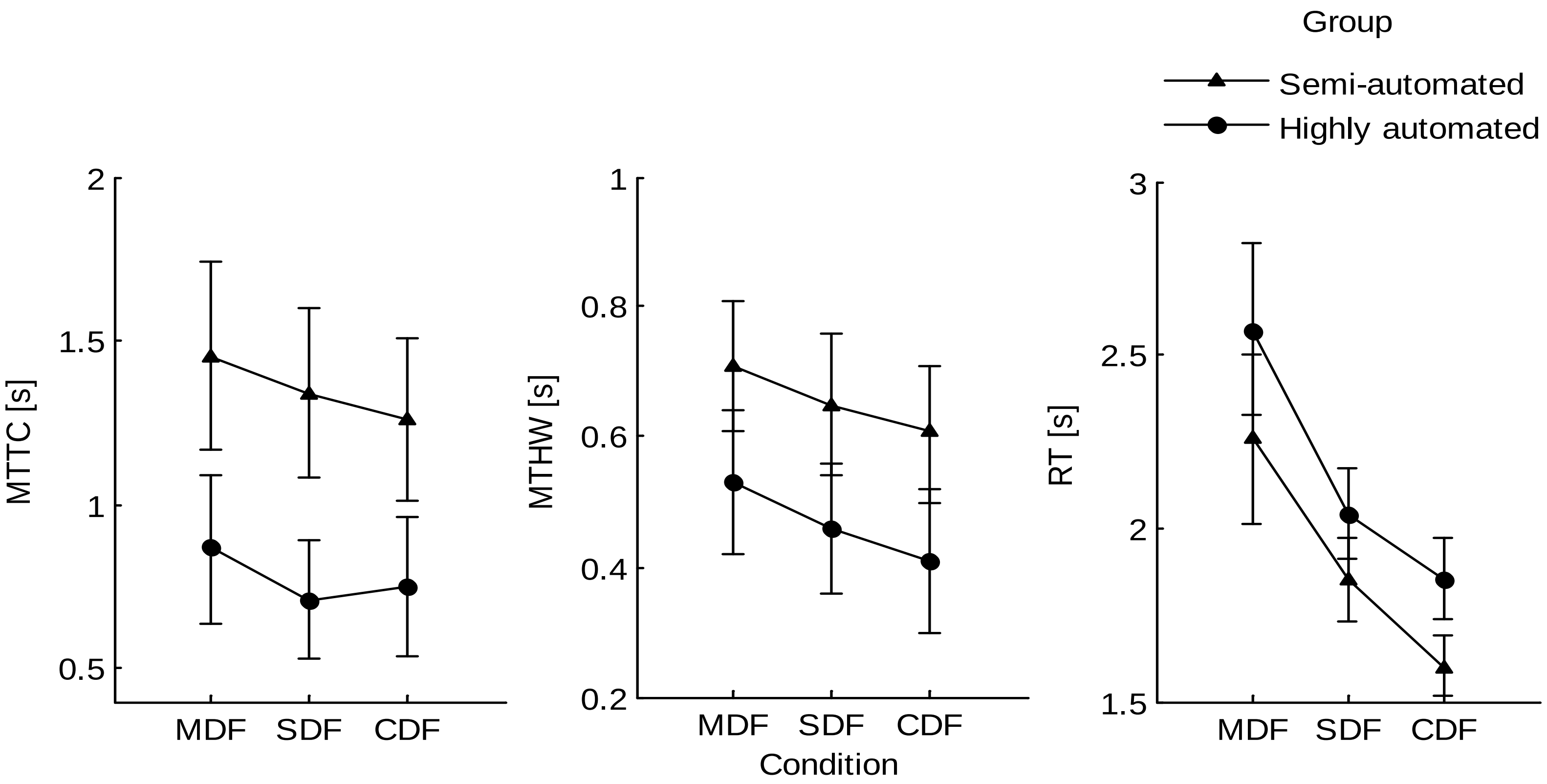
Braking required to avoid collision

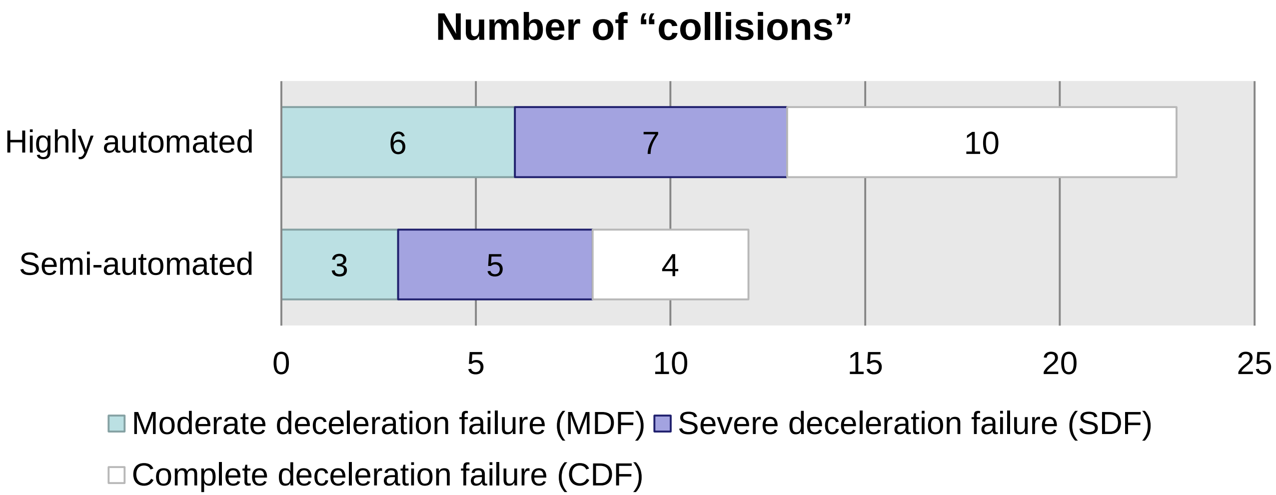
Study 2
How does level of automation influence how drivers respond to failures?

- Driving simulator study with 36 participants
- Compared two levels of automation
  - Semi-automated: Longitudinal automation
  - Highly automated: Longitudinal and lateral automation
- Each subject experienced all three failures
  - Point-of-no-return events instead of collisions (see video)



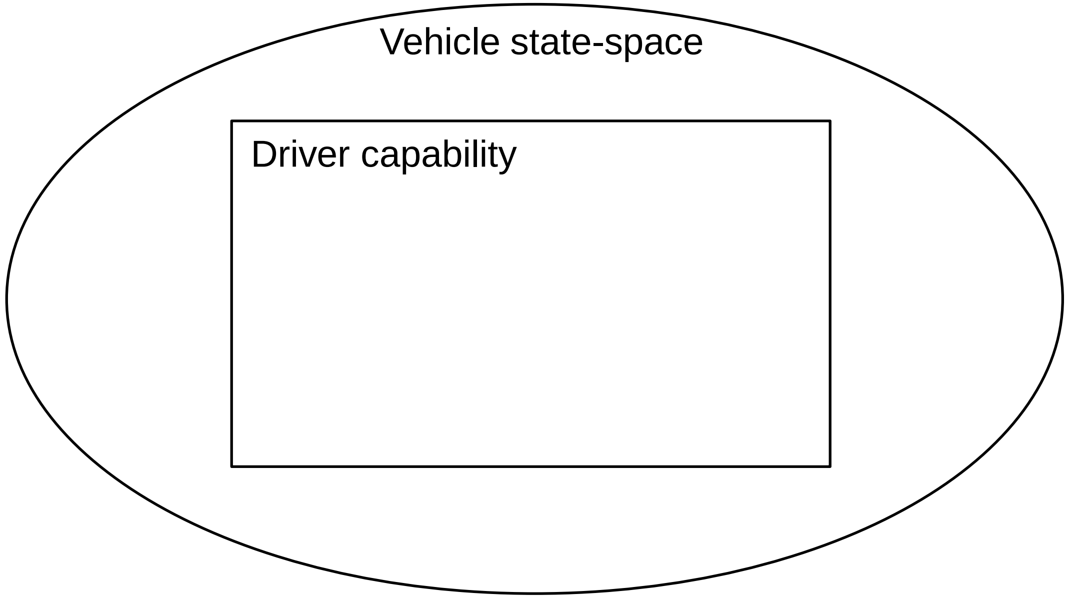
Results

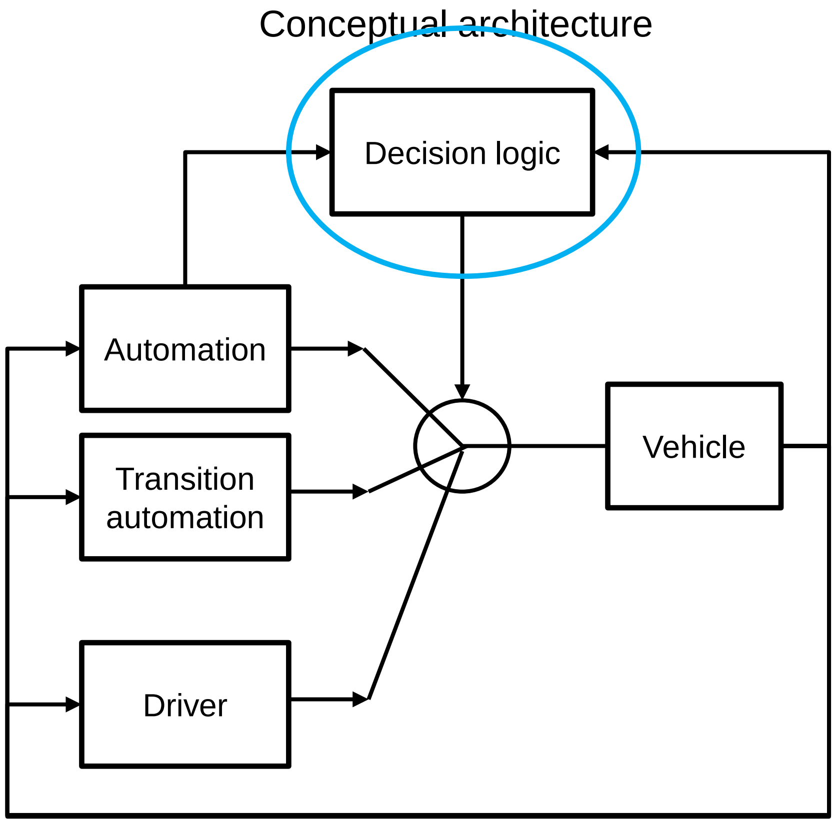

Group
Semi-automated
Highly automated
MTTC [s]
2
1.5
1
0.5
MDF
SDF
CDF
MTHW [s]
1
0.8
0.6
0.4
0.2
Condition
RT [s]
3
2.5
2
1.5


Number of “collisions”
Highly automated
Semi-automated
6
7
10
3
5
4
0
5
10
15
20
25
Moderate deceleration failure (MDF)
Severe deceleration failure (SDF)
Complete deceleration failure (CDF)

IMPROVING SAFETY OF TRANSITIONS FROM AUTOMATED TO MANUAL DRIVING

Concept improving safety of transitions





Decision logic

$\mathcal{V}$: All possible states

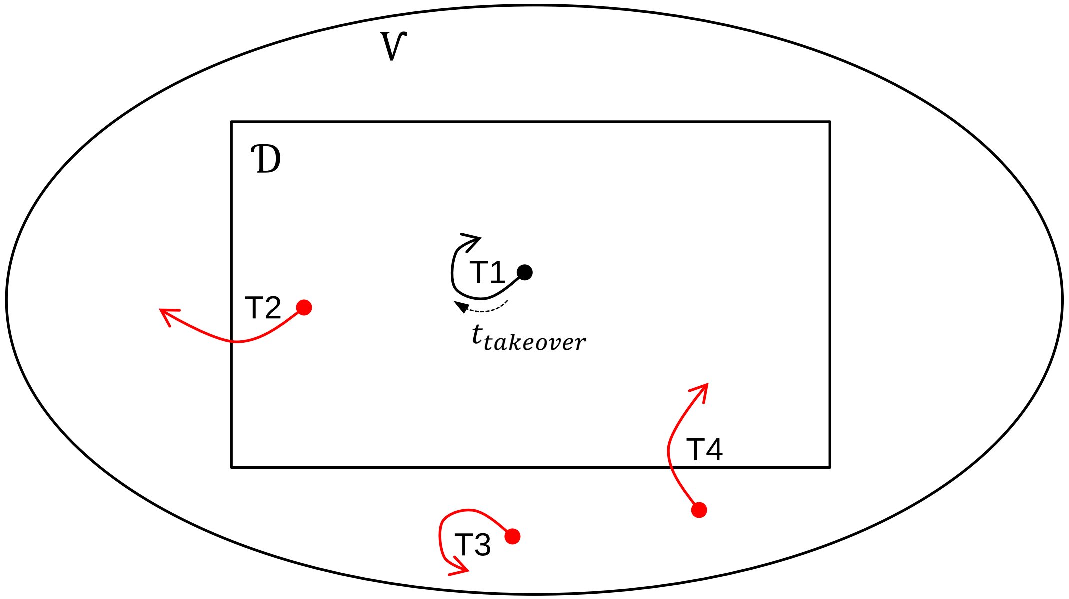
$\mathcal{D}$: Set of states controllable by the driver

Give control to driver if states are within and stay within $\mathcal{D}$ for $t_{takeover}$ seconds

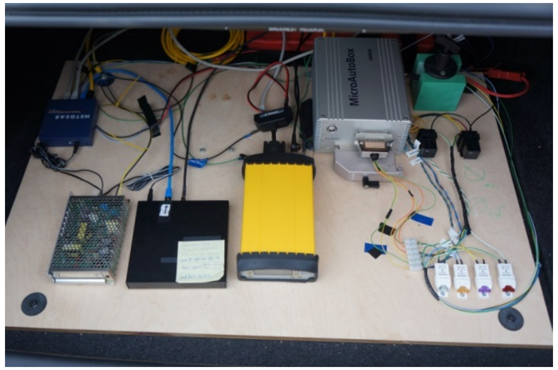
Examples

- T1: States start and stay within $\mathcal{D}$
- T2: States start within $\mathcal{D}$ but leave
- T3: States start and stay outside $\mathcal{D}$
- T4: States start outside but enter $\mathcal{D}$

Only T1 is considered safe for a driver takeover



Demonstration on longitudinal automation (adaptive cruise control)



d

a_s
v_s

a_t
v_t

a : longitudinal acceleration
v : longitudinal velocity
d : inter-vehicle distance

Procedure to estimate driver capability

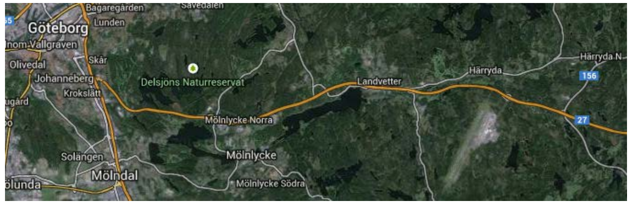
Collect and filter out relevant data from manual driving

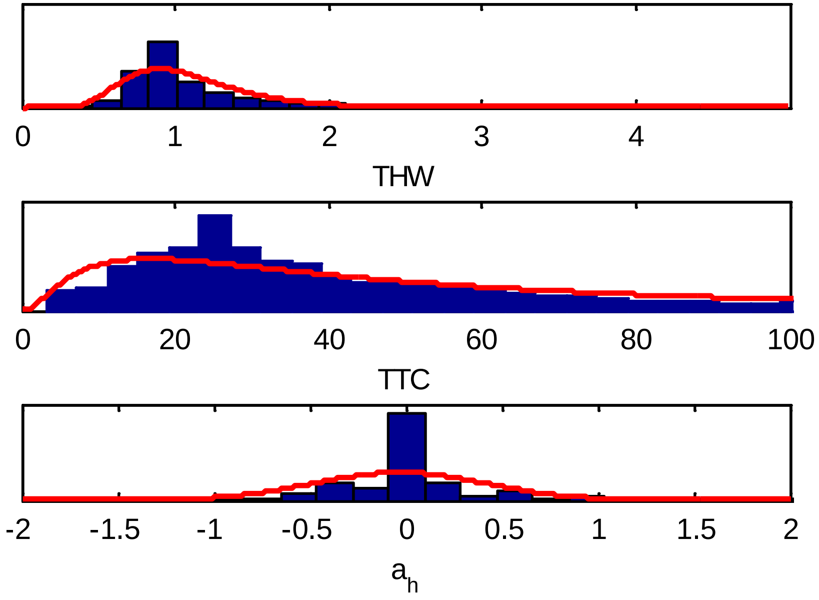
⇨

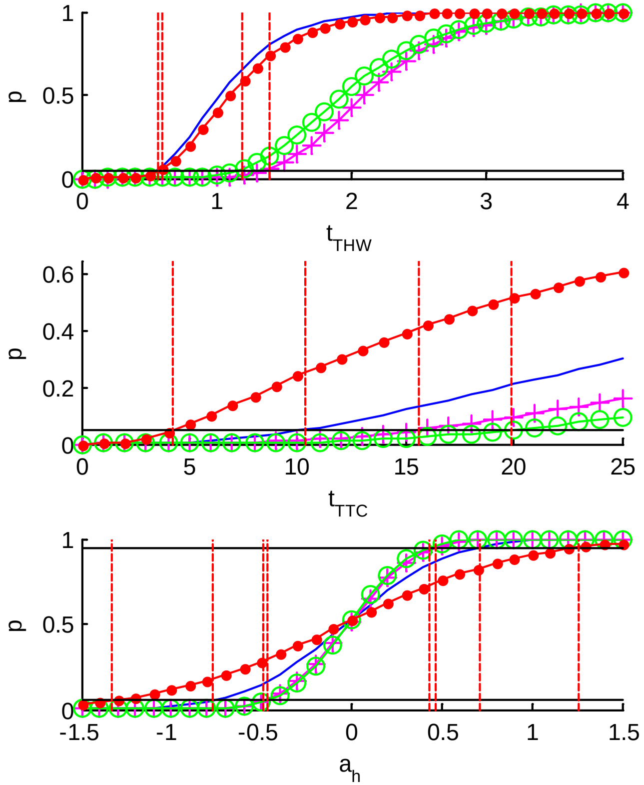
Estimate distribution functions system states

⇨

Identify bounds of driver capability at predefined limits in distributions



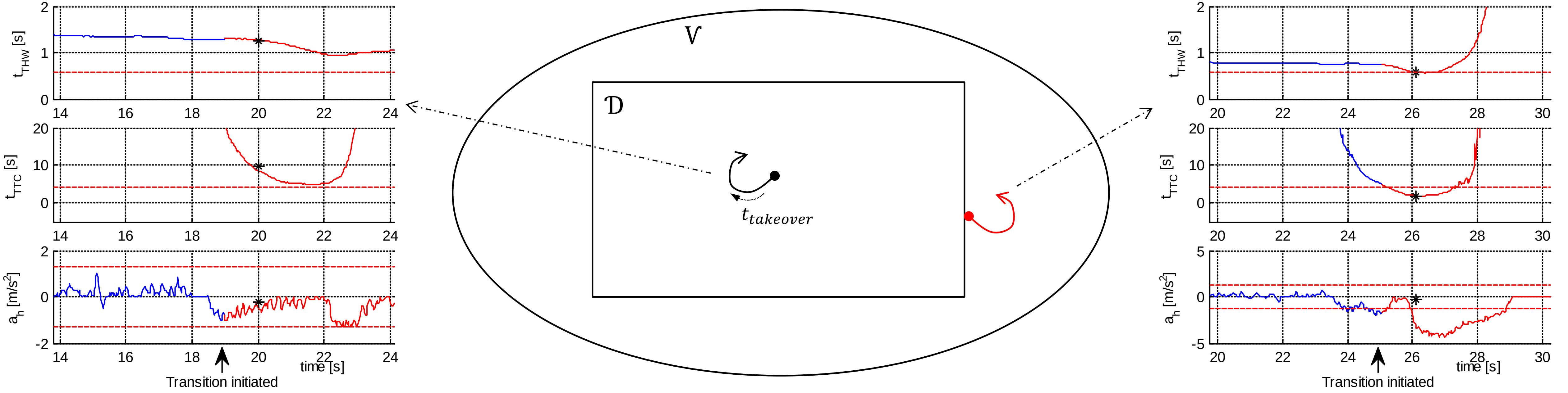




Evaluation on real world data

Transition initiated inside DCS

Transition initiated outside DCS



Conclusions and future work

- Drivers are more successful in controlling longitudinal automation failures when lateral automation is a manual task
- Partial deceleration failure may be less controllable than complete deceleration failure
- Driver capability estimation is a promising tool for preventing unsafe transitions to manual driving
- Need to further investigate what makes a transition to manual driving safe

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