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Human Factor Issues for Vehicle Automation

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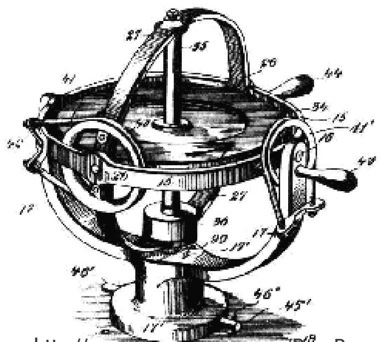
Overview

- History of automation in the transport domain
- Levels of automation
- Why vehicle automation?
- New challenges for human factors research
- Research issues for the future

Automation history



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Google

Self-Driving Car Project

Shipping
(1908, Elmer Sperry)

Aviation
(1914, Lawrence Sperry)

Automobile
(2011, Google)

https://airandspace.si.edu

https://upload.wikimedia.org/wikipedia/commons/thumb/f/fb/A340_FCU.jpg/1280px-A340_FCU.jpg

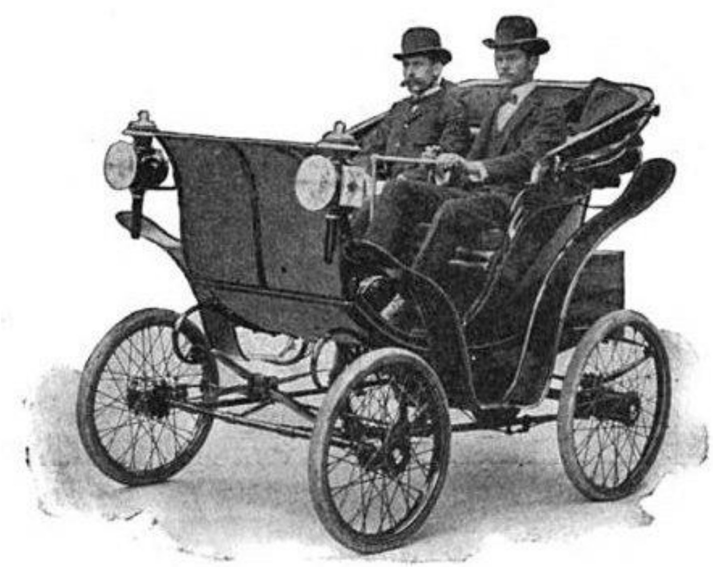
https://images.cdn.autocar.co.uk/sites/autocar.co.uk/files/styles/gallery_slide/public/images/

Automated vehicle history, a few additional details

- DARPA (Defense Advanced Research Projects Agency), 1983 -1989
- Prof. Dickmanns (Bundeswehruniversität München), 1985-1988
- PROMETHEUS (EC, 1987 – 1995)
- Broggi – MilleMiglia in Automatico

History of automation in road transport

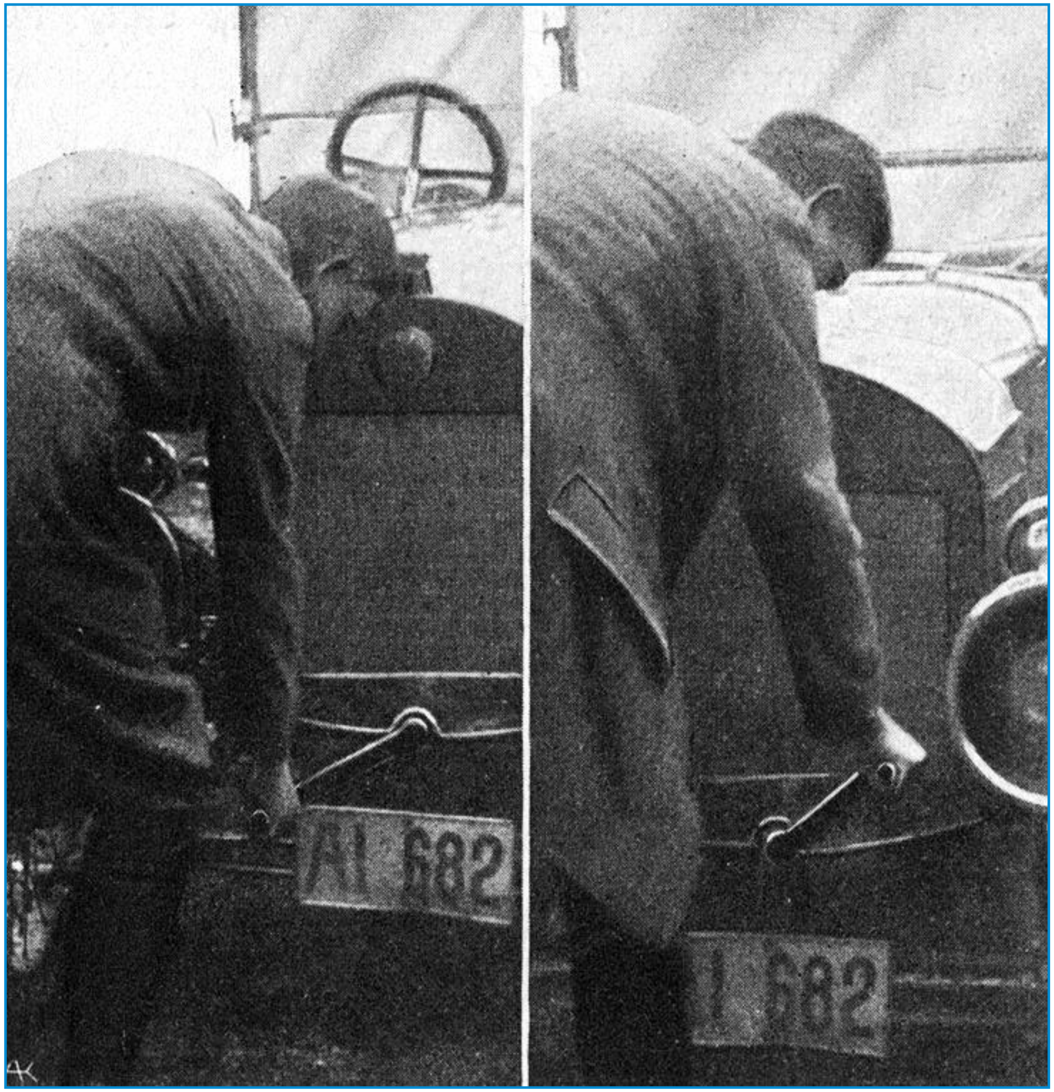
The history of the automobile is also a history of automation



(see Vollrath & Krems, 2011)

Starter - then

1. Open the petrol cock
2. Pump in the footwell
3. Flood the carburettor
4. Step on the gas halfway
5. Switch the ignition switch to “late”
6. Start the engine
7. Open the starter air flap
8. …

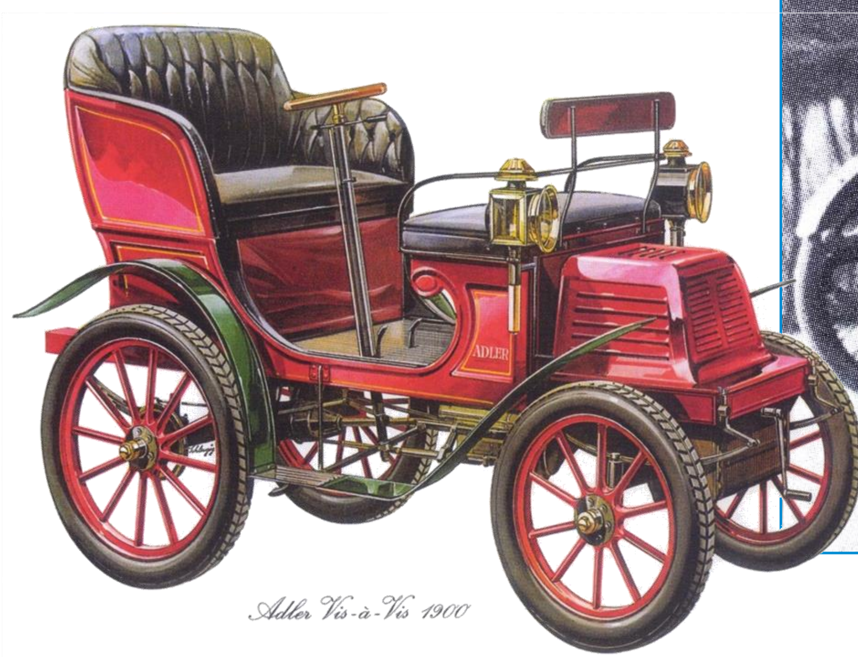


Starter - now

http://www.locktechsandiego.com/wp-content/uploads/2014/06/car-ignition-keys-san-diego-ca.jpg

http://www.ksta.de/image/22478782/2x1/940/470/d09e9[illegible]5cd5ee7cb5de5ccfb270a95/Ub/autoschluessel-dpa.jpg.jpg

The chauffeur
Der Schofför



So, what is automation?

Definitions of automation

“We define automation as the execution by a machine agent (usually a computer) of a function that was previously carried out by a human.

What is considered automation will therefore change with time. When the reallocation of a function from human to machine is complete and permanent, then the function will tend to be seen simply as a machine operation, not as automation.”

(Parasuraman & Riley, 1997, p.231)

Definitions of automation

“The classic aim of automation is to replace human manual control, planning and problem solving by automatic devices and computers. […]

[T]he increased interest in human factors among engineers reflects the irony that the more advanced a control system is, so the more crucial may be the contribution of the human operator.”

(Bainbridge, 1983, p. 775)

So, what is automation?

Definitions of automation

"Automation describes the process as well as the result of transferring tasks (or the resulting activities) that were previously carried out by a human to a machine."

(translated from Hauß & Timpe, 2000, p. 43)

- Automation = function allocation from human to artefact
- Chance of human tasks from direct actions ("control") to observation ("monitoring")

Overview

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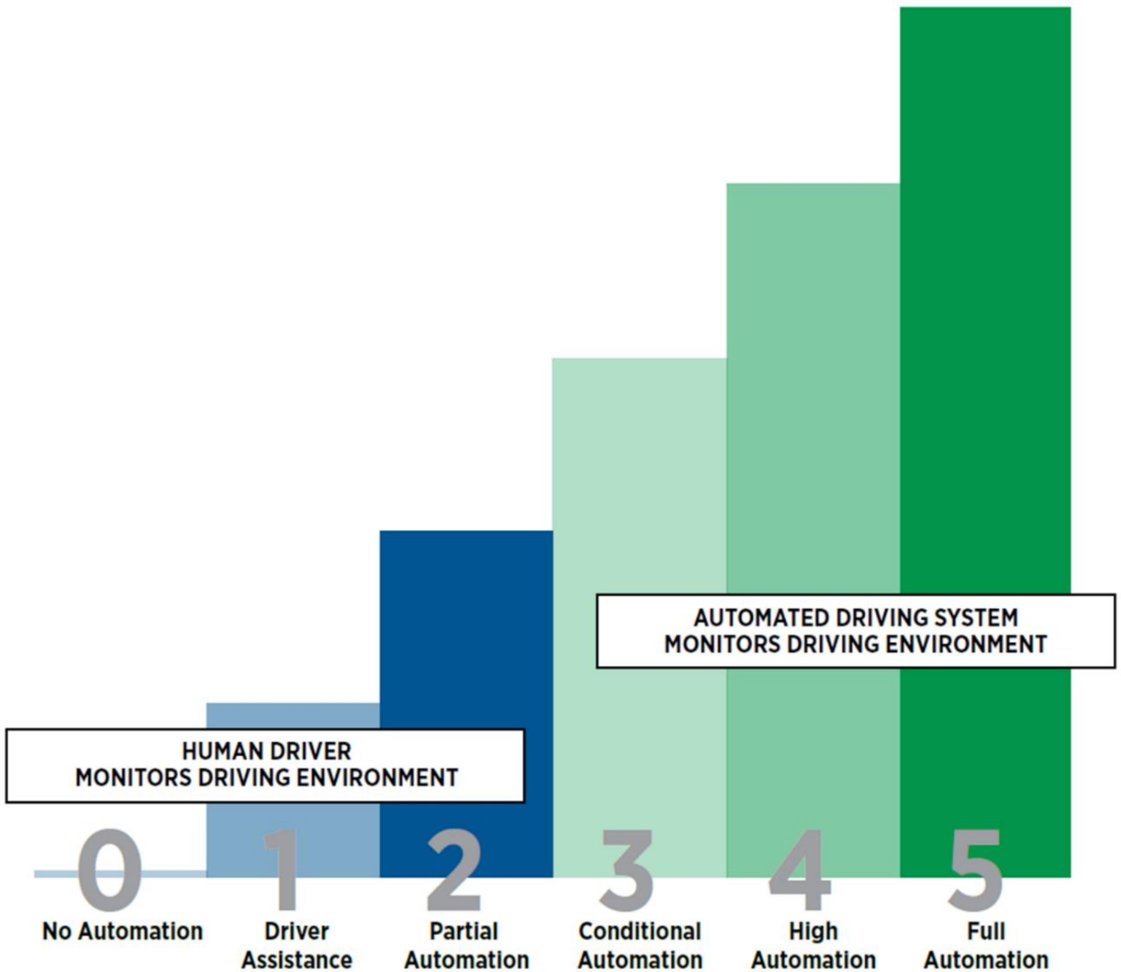
- **Levels of automation**
- Why vehicle automation?
- New challenges for human factors research
- Research issues for the future

Levels of automation of decision and action selection

HIGH	10	The computer decides everything, acts autonomously, ignoring the human
	09	informs the human only if it, the computer, decides to
	08	informs the human only if asked, or
	07	executes automatically, then necessarily informs the human, and
	06	allows the human a restricted time to veto before automatic execution, or
	05	executes that suggestion if the human approves, or
	04	suggests one alternative
	03	narrows the selection down to a few, or
	02	The computer offers a complete set of decision/action alternatives, or
LOW	01	The computer offers no assistance: human must take all decisions and actions

(adapted from Parasuraman, Sheridan, & Wickens, 2000, Table 1)

Levels of driving automation (SAE International Standard J3016)

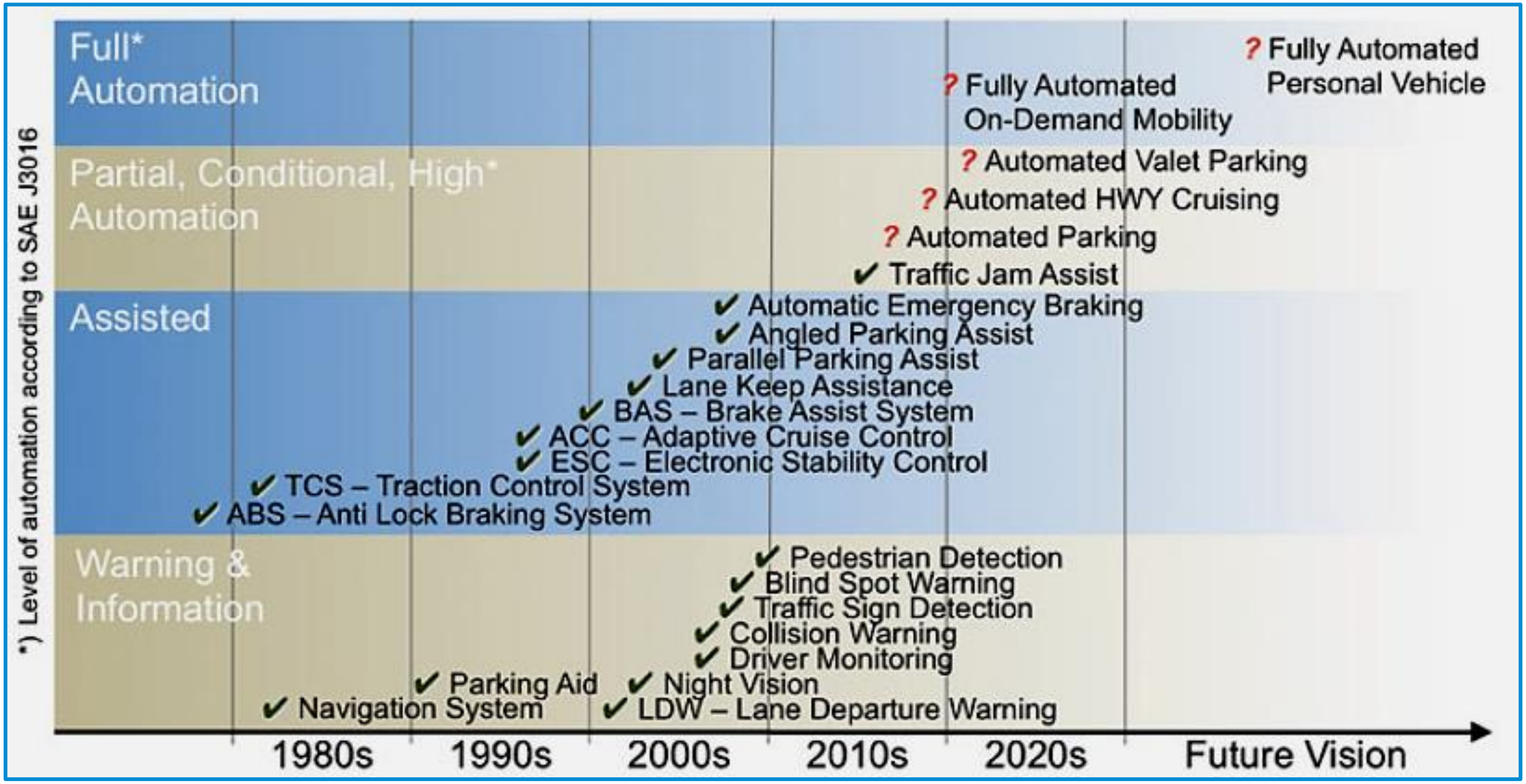


Levels of driving automation (SAE International Standard J3016)

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Roadmap: technological development of vehicle automation

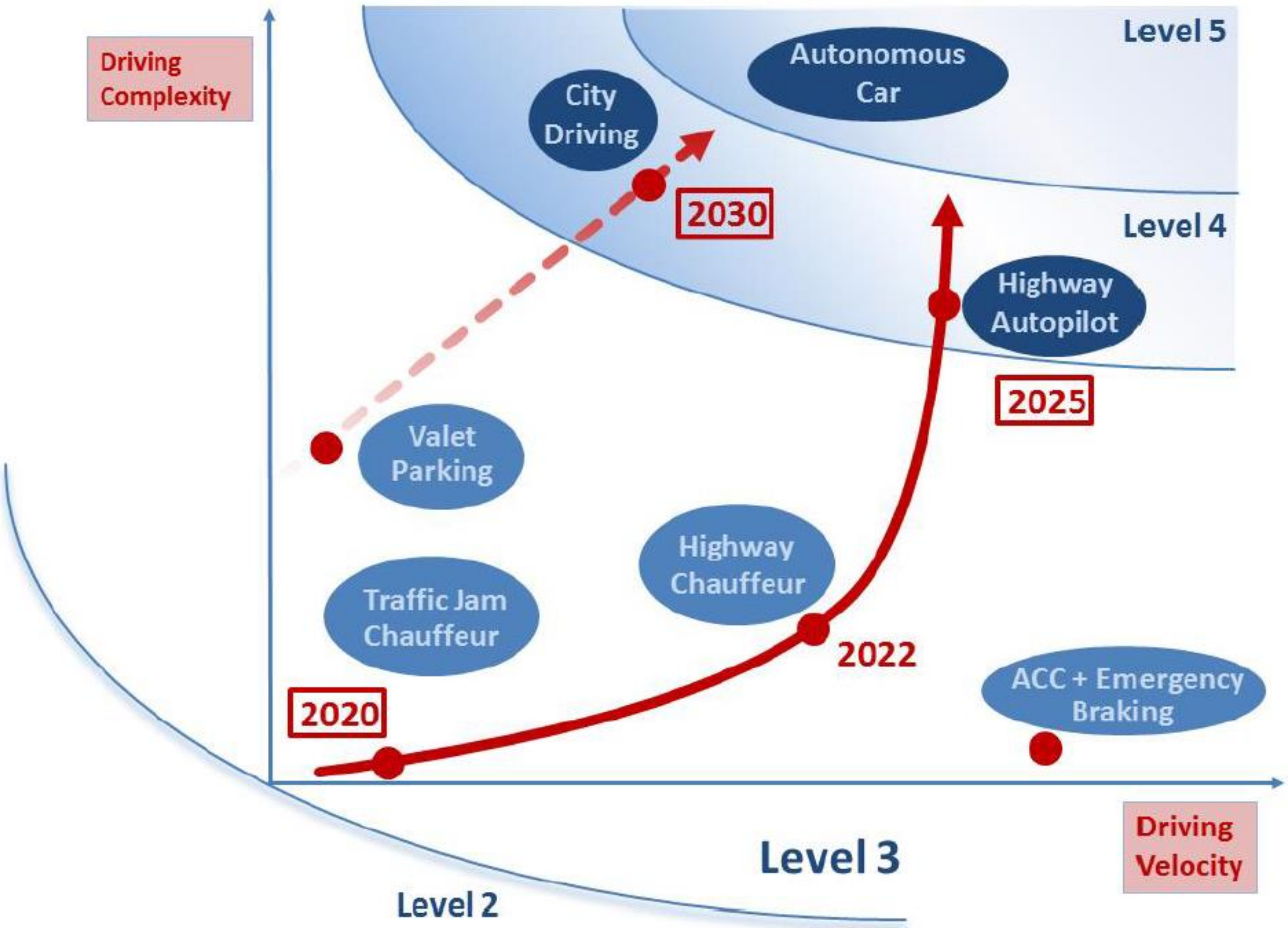
A look back: development of ADAS & potential evolution of automated driving



(Beiker, 2016, Fig. 10.1)

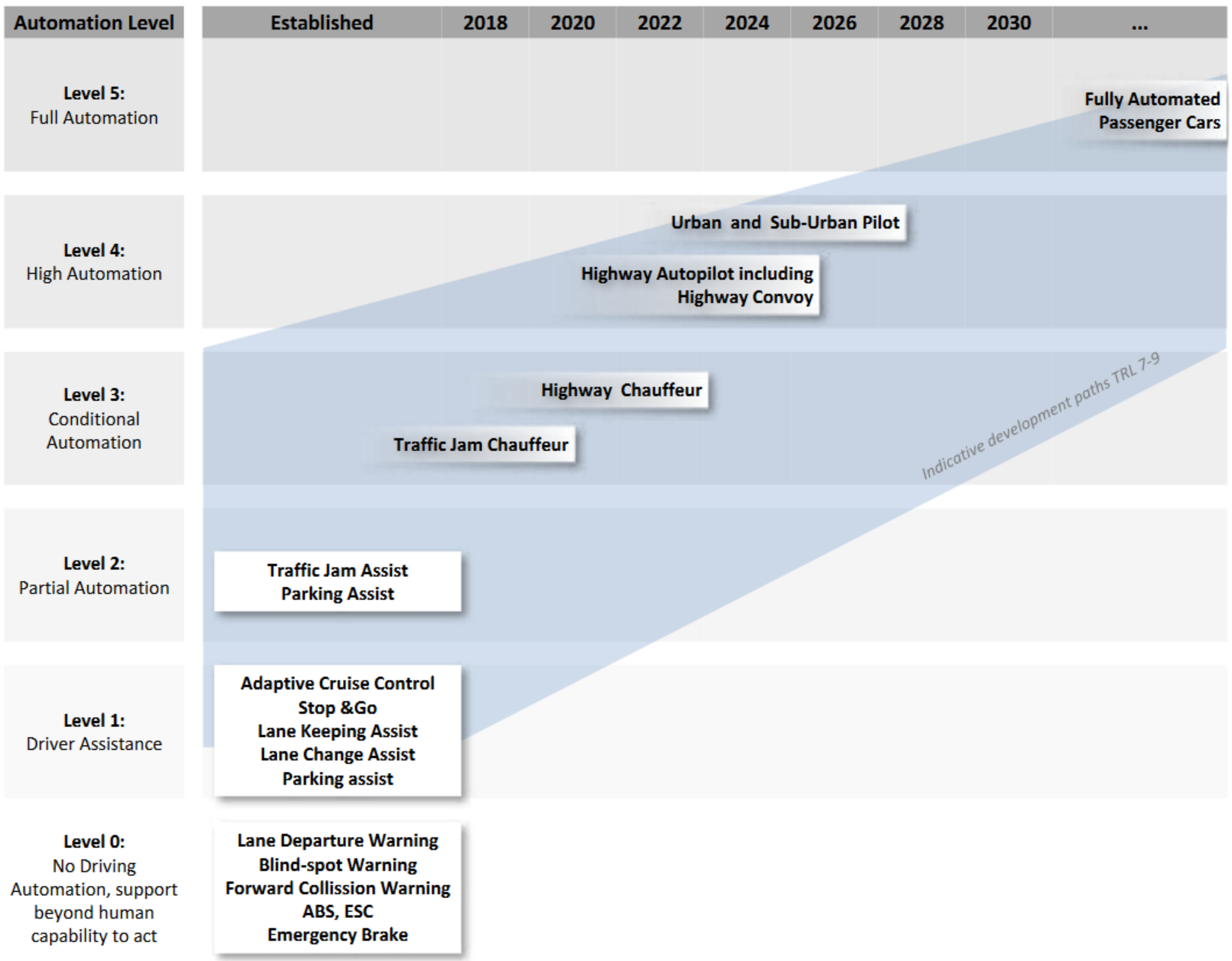
Roadmap: technological development of vehicle automation

A look ahead: potential developmental paths



(EPoSS, 2015, p. 19)

A look ahead: automated passenger cars path



(ERTRAC, 2017, Fig. 3)

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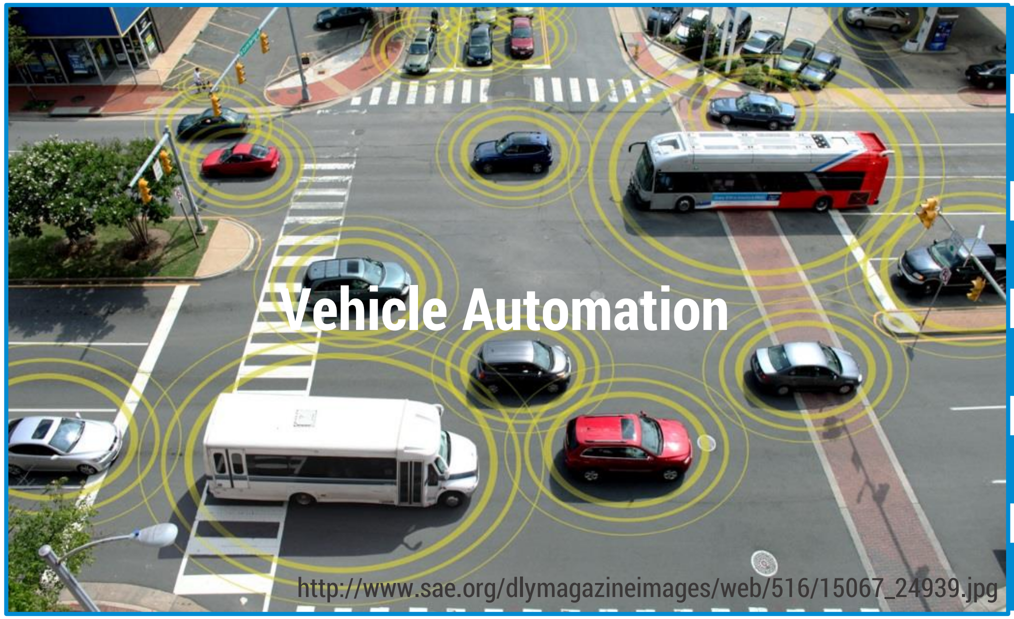
Why vehicle automation?

Expected benefits of vehicle automation

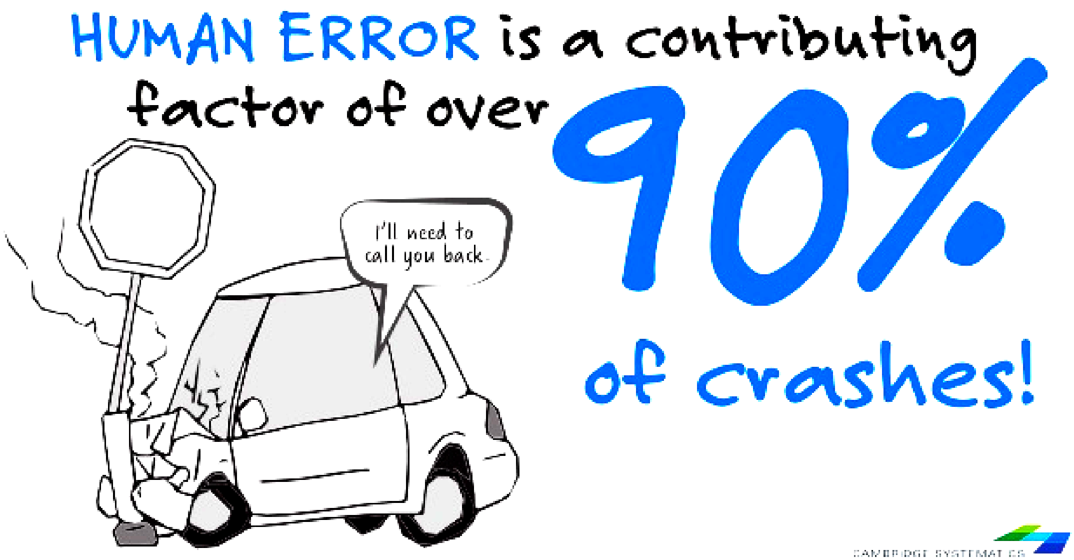


- Improved road safety
- Optimised traffic flow
- Lower pollutant emissions
- Driver relief and higher driving comfort
- Enhanced mobility (e.g. elderly drivers)
- Higher product attractiveness

(Diels, 2014; Meyer & Deix, 2014; Vollrath & Krems, 2011)

Improved road safety

- Background:



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- Missing recognition of hazards
- Wrong evaluation of traffic situations
- Too slow or wrong reactions

(Stankowitz, 2012)

Why vehicle automation?

Improved road safety

- Benefits of in-vehicle technologies:

  More than **70%** of all severe accidents could be avoided by **ADAS**.

  - Intersection assistant → 21.2 %
  - Assistance for speed regulation and lateral control (steering) → 20.4 %
  - Collision avoidance system with situational regulation of distance and speed → 17.5 %

  (Vollrath, Briest, Schließl, Drewes, & Becker, 2006)

- Crucial requirement:

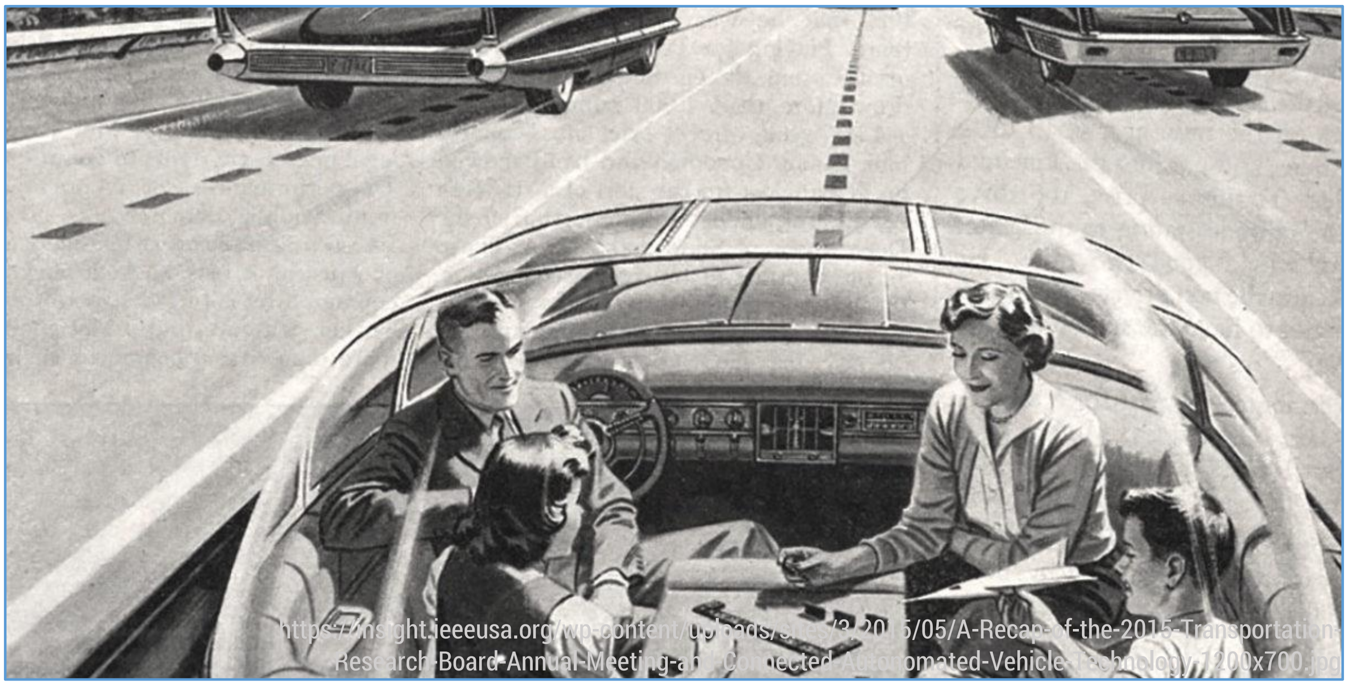
  “The robot needs to be at least as good as the human driver.” (translated from Gern, 2016)

  BUT: Severe accidents (with personal injury) occur only every 12.3 million km!

Why vehicle automation?

Driver relief

- Avoidance of overload (e.g. navigation)
- Increase of driver's well-being and driving performance
- But also avoidance of underload or annoying situations (e.g. stop & go, parking)



https://insight.ieeeusa.org/wp-content/uploads/sites/3/2015/05/A-Recap-of-the-2015-Transportation-Research-Board-Annual-Meeting-and-Connected-Autonomated-Vehicle-Technology-1200x700.jpg

Why vehicle automation?

Enhanced mobility (e. g. elderly drivers)

- Compensation of human errors associated with age-related impairments

  (e.g. overlooking relevant information, selecting inappropriate actions, executing reactions too slow)
- Enabling individual mobility in demanding traffic situations which are avoided by human drivers

  (e.g. high speed roads , rush hour traffic, darkness, bad weather)

- ➢ Facilitation of elderly drivers' access to social activities, shopping facilities, medical services
- ➢ Reinforcement of an independent and connected lifestyle up to old age
- ➢ Contribution to a physically and psychologically healthy aging process

(Meyer & Deix, 2014; Polders et al., 2015; Reimer, 2014)

Why vehicle automation?

Optimised traffic flow

- Reduction of traffic jams (e.g. by routing)
- Reduction of unnecessary trips
  (e.g. by searching for a parking space)


https://i.ytimg.com/vi/_nRRDe9lqlQ/maxresdefault.jpg

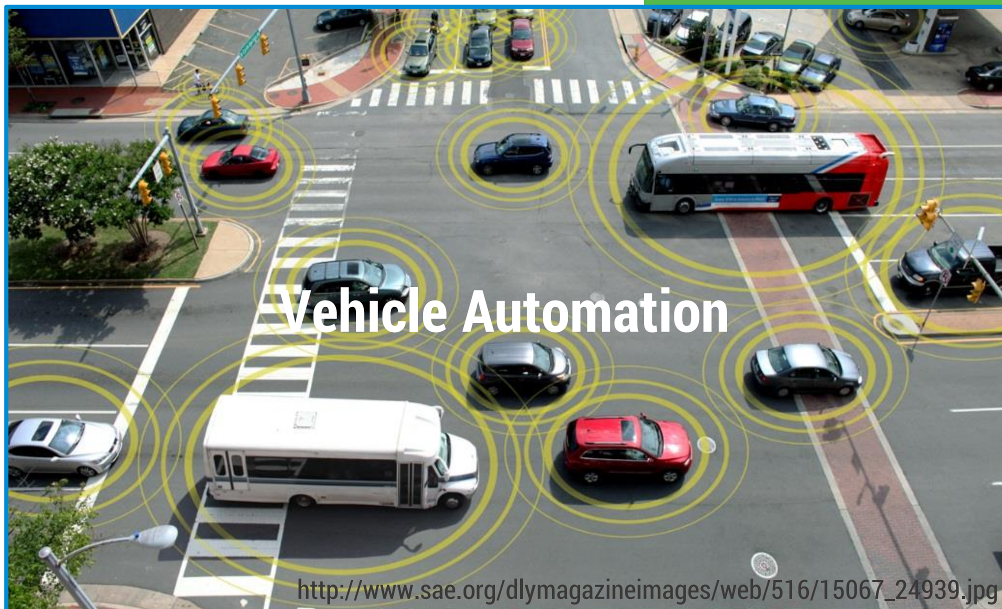
Higher product attractiveness

- Increase of sales numbers


https://static01.nyt.com/images/2015/03/19/multimedia/mercedes-driverless-car/mercedes-driverless-car-facebookJumbo-v2.jpg

Why vehicle automation?

Expected benefits of vehicle automation



- Improved road safety
- Optimised traffic flow
- Lower pollutant emissions
- Driver relief and higher driving comfort
- Enhanced mobility (e.g. elderly drivers)
- Higher product attractiveness

High demand for research on human factors of vehicle automation (Gasser, 2013)

Precondition:
safe and satisfying human-automation-interaction

(Diels, 2014; Meyer & Deix, 2014; Vollrath & Krems, 2011)

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- **New challenges for human factors research**
- Research issues for the future

New topics for Human Factors – Overview

Take-over requests

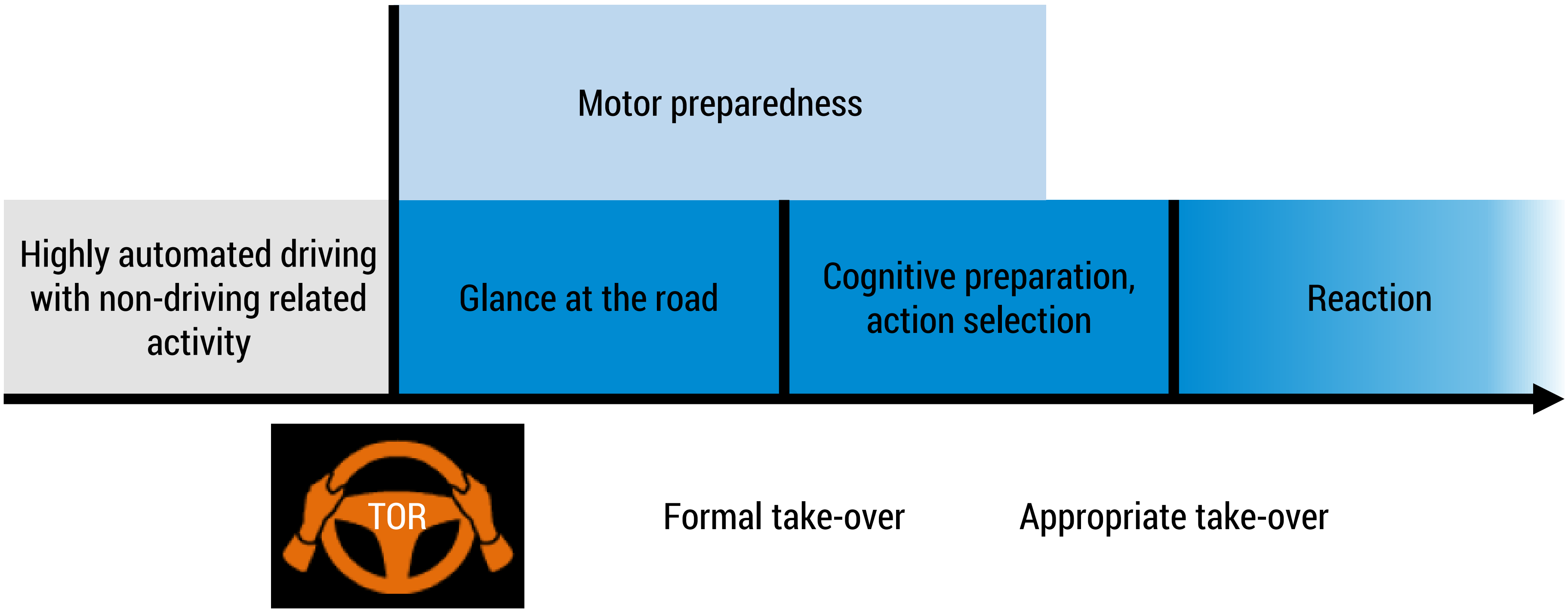
Driving style and comfort

Trust and acceptance

Communication

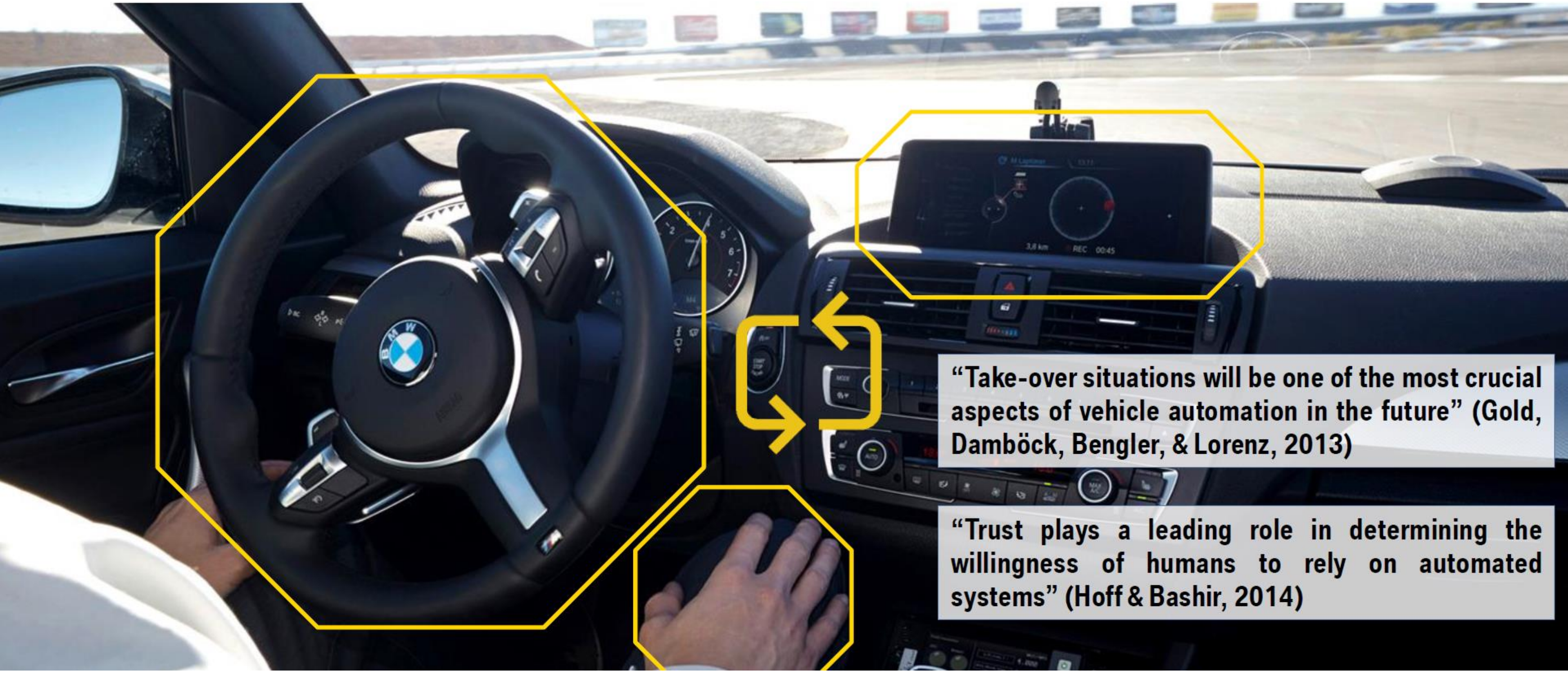
New challenges for human factors research

Take-over procedure



(adapted from Zeeb, Buchner, & Schrauf, 2015)

Take-over request (TOR)



“Take-over situations will be one of the most crucial aspects of vehicle automation in the future” (Gold, Damböck, Bengler, & Lorenz, 2013)

“Trust plays a leading role in determining the willingness of humans to rely on automated systems” (Hoff & Bashir, 2014)

Take-over request (TOR)

Background

- Increasing levels of automation → change of the driver's role from active driver to controller
- Out-of-the-loop-phenomenon in autonomous driving, but…
- Change of the driver's role from controller to active driver in cases of functional limits or non-automatable functional areas
- Informing the driver about state and actions of the system and the driving situation is pivotal
  - Transparent automation → appropriate mental model
  - **Situation awareness** (Baumann & Krems, 2007)
  - Development of trust and acceptance

➢ **Which information does the driver need at different levels of automation?**

https://www.mercedes-benz.com/wp-content/uploads/sites/3/2015/01/06-Mercedes-Benz-Autonomous-Truck-Logistic-Future-Truck-2025-680x3791-680x379.jpg

New topics for Human Factors– Overview

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Driving style and comfort

Trust and acceptance

Communication

New challenges for human factors research

Trust and acceptance

The problem

- From “active” to “passive”: Will it really work, at all times?
- Are the actions of an automated vehicle understandable and predictable for passengers and other road users? If not, how will this affect trust?
- Automation will fail from time to time: How will this affect acceptance and usage?
- Will over-reliance in automated vehicles lead to misuse?

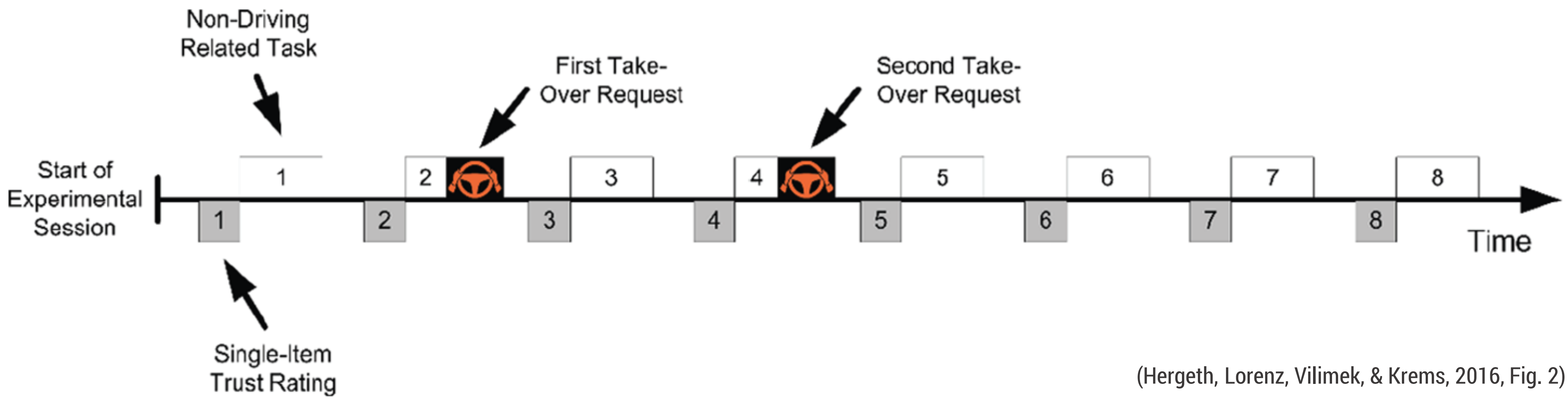
Trust and acceptance (BMW: Hergeth, 2016)

Research questions

- How are trust in automation and monitoring activities related to each other?
- How do take-over situations affect trust in automation?
- How does system experience affects trust in automation?

Methods

- Schematic sequence of events during the experimental session:



(Hergeth, Lorenz, Vilimek, & Krems, 2016, Fig. 2)

Results

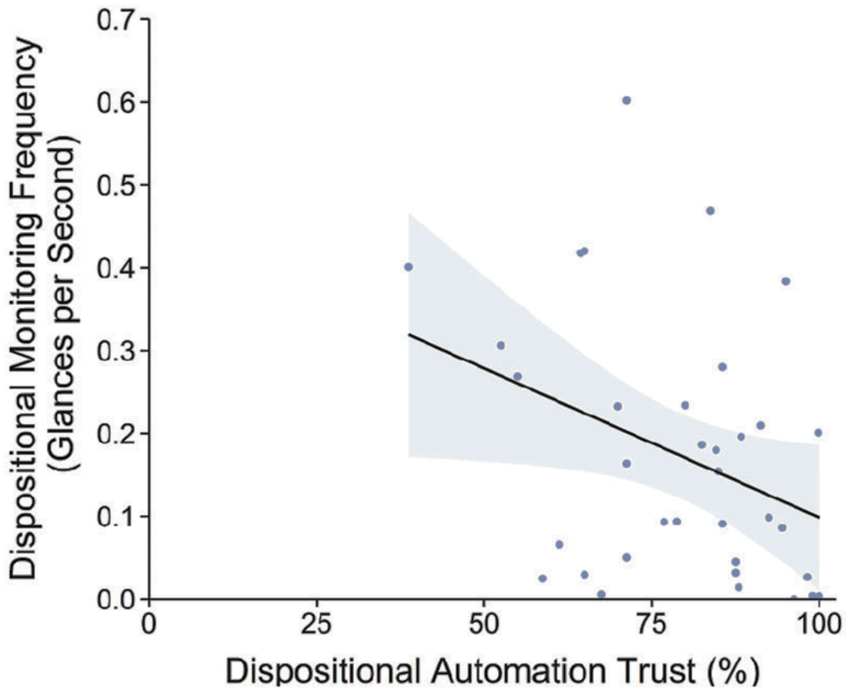


Figure 3. Correlation between dispositional self-reported automation trust and monitoring frequency averaged for each participant over non-driving-related tasks.

(Hergeth, Lorenz, Vilimek, & Krems, 2016, Fig. 3)

Trust and acceptance (BMW: Hergeth, 2016)

Results

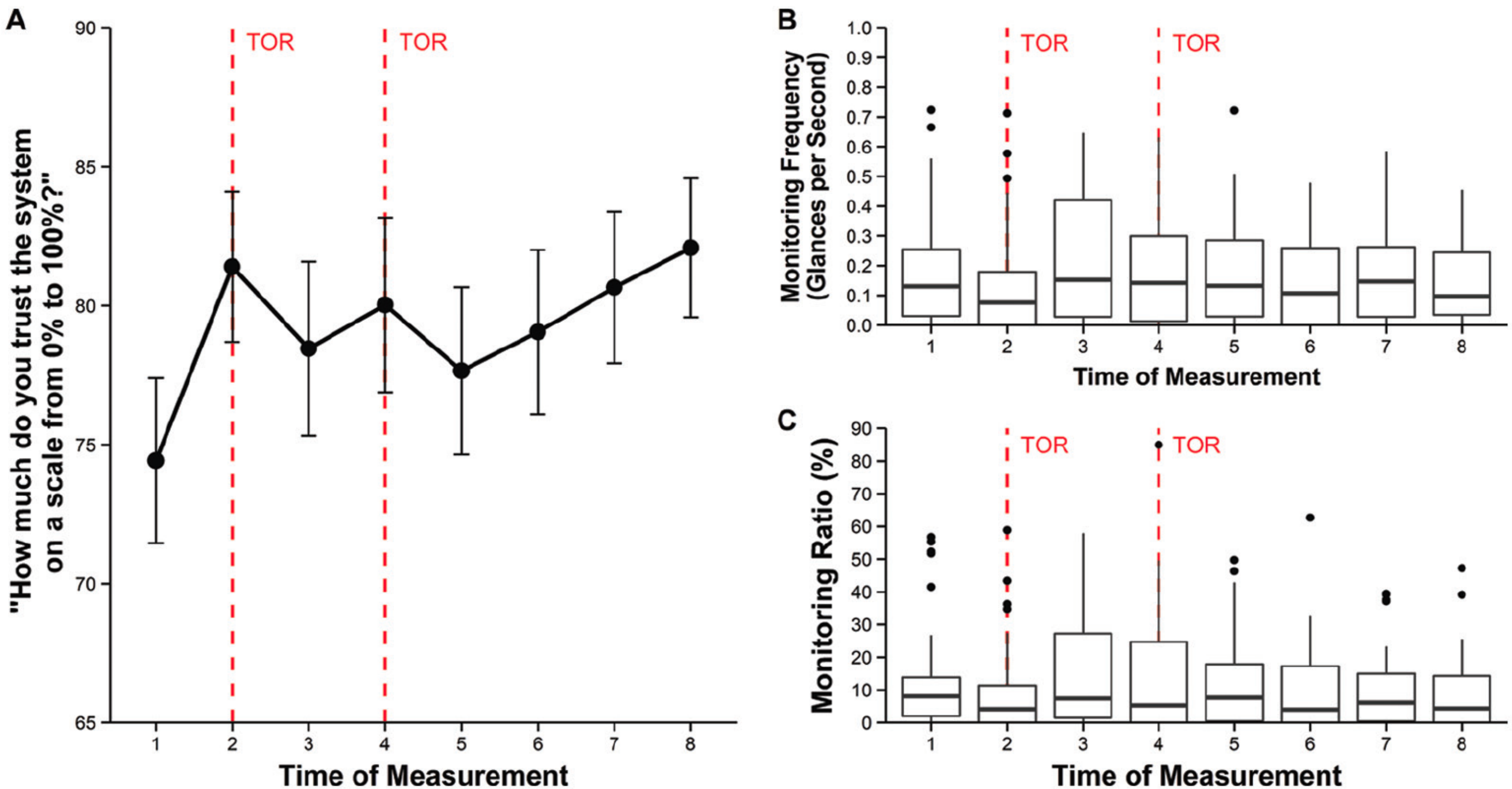


Figure 5. Mean self-reported automation trust (A, showing standard errors bars), median monitoring frequency (B), and median monitoring ratio (C) during non-driving-related tasks.

(Hergeth, Lorenz, Vilimek, & Krems, 2016, Fig. 5)

Conclusions

- Monitoring activity as non-invasive behavioural measure of trust in automation (see Muir & Moray, 1996)
- Experiencing functional limits of the system does not impair trust in automation significantly (Parasuraman & Manzey, 2010)

(Hergeth, Lorenz, Vilimek, & Krems, 2016)

New topics for Human Factors– Overview

Take-over requests

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New challenges for human factors research

Driving style and comfort (Hartwich, Beggiato, Dettmann, & Krems, 2015)

Research questions

- How are driving comfort and enjoyment affected by vehicle automation?
- Is highly automated driving more comfortable if the automated driving style corresponds to the drivers own manual driving style?
- ➢ Are there any differences between younger and older drivers?

Method

- Driving simulator study
- 20 younger drivers (25-35 years) vs. 20 older drivers (>65 years)
- Comparison of manual vs. highly automated driving
- Comparison of different highly automated driving styles: each drivers individual manual driving style vs. several other driving styles

Driving style and comfort (Hartwich, Beggiato, Dettmann, & Krems, 2015)

Assessment of driving comfort and enjoyment

- After driving
- Interviews & questionnaire: "I experienced this drive as relaxing / dull / fun / …" (Engebrecht, 2013)

➢ Comfort = a pleasant state of relaxation based on apparent trust safety and trust

➢ Enjoyment= the pleasure of the driving task

Assessment of driving discomfort

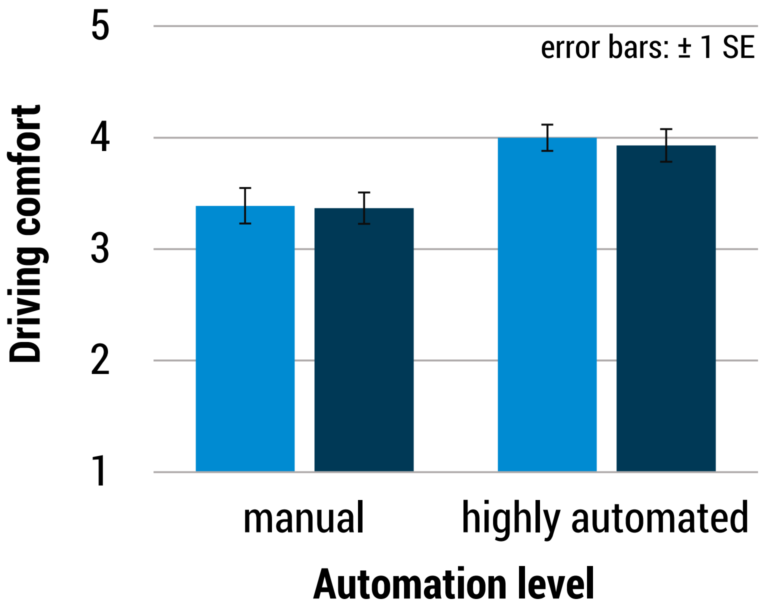
- Online during driving
- Handset control

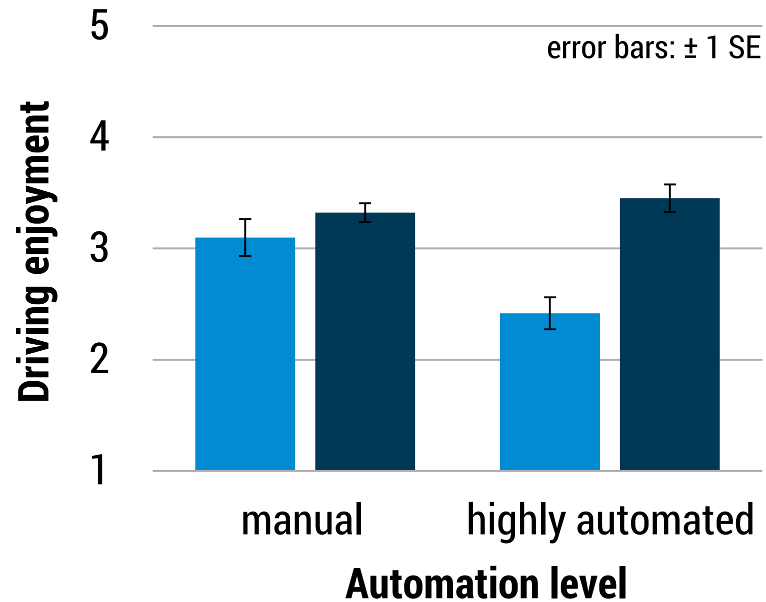
➢ Discomfort = an unpleasant state of tension in cases of missing apparent safety or trust

Driving style and comfort (Hartwich, Beggiato, Dettmann, & Krems, 2015)

Results: Effects of vehicle automation

Younger drivers Older drivers



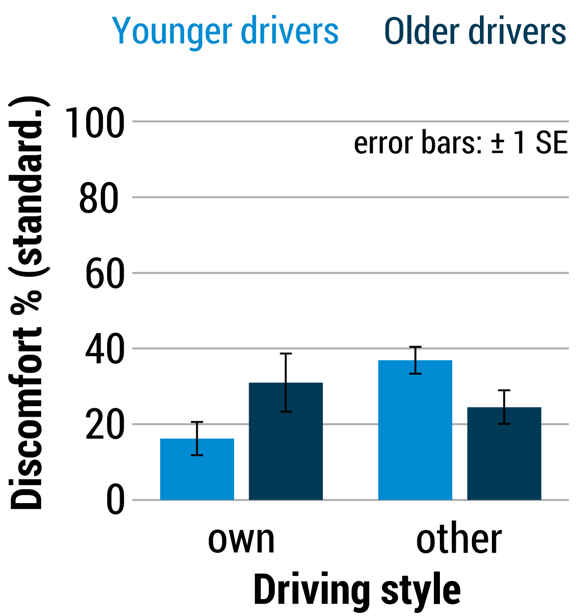


- Both age groups experienced highly automated driving as more comfortable than manual driving
- In contrast to older drivers, younger drivers experienced less enjoyment when driving highly automated than manually

Driving style and comfort (Hartwich, Beggiato, Dettmann, & Krems, 2015)

Results: Effects of the automated driving style

- Same significant interaction (driving style x age group) for all dependent variables:
  - Younger drivers preferred their own driving styles over others
  - Older drivers preferred other driving styles over their owns



- The less similar the automated driving style to their own styles, the more uncomfortable for younger drivers
- The less similar the automated driving style to their own styles, the more joyful for older drivers

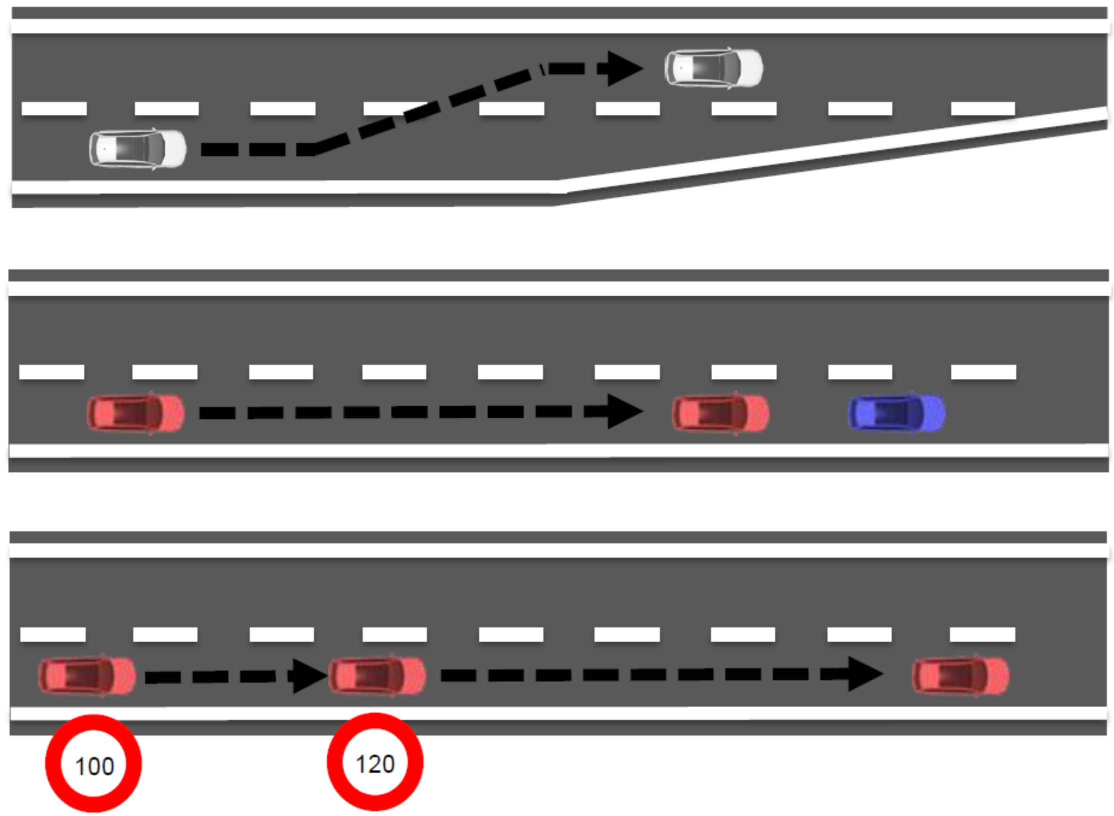
➢ Driving style individualisation not useful for all driver groups!

How do we want to be driven? (Bellem, Thiel, Schrauf, & Krems, 2016)

Research aim

DAIMLER

- Identify the optimal parameterization of automated manoeuvres
  - Lane change
  - Deceleration to a slower truck
  - Acceleration to target speed



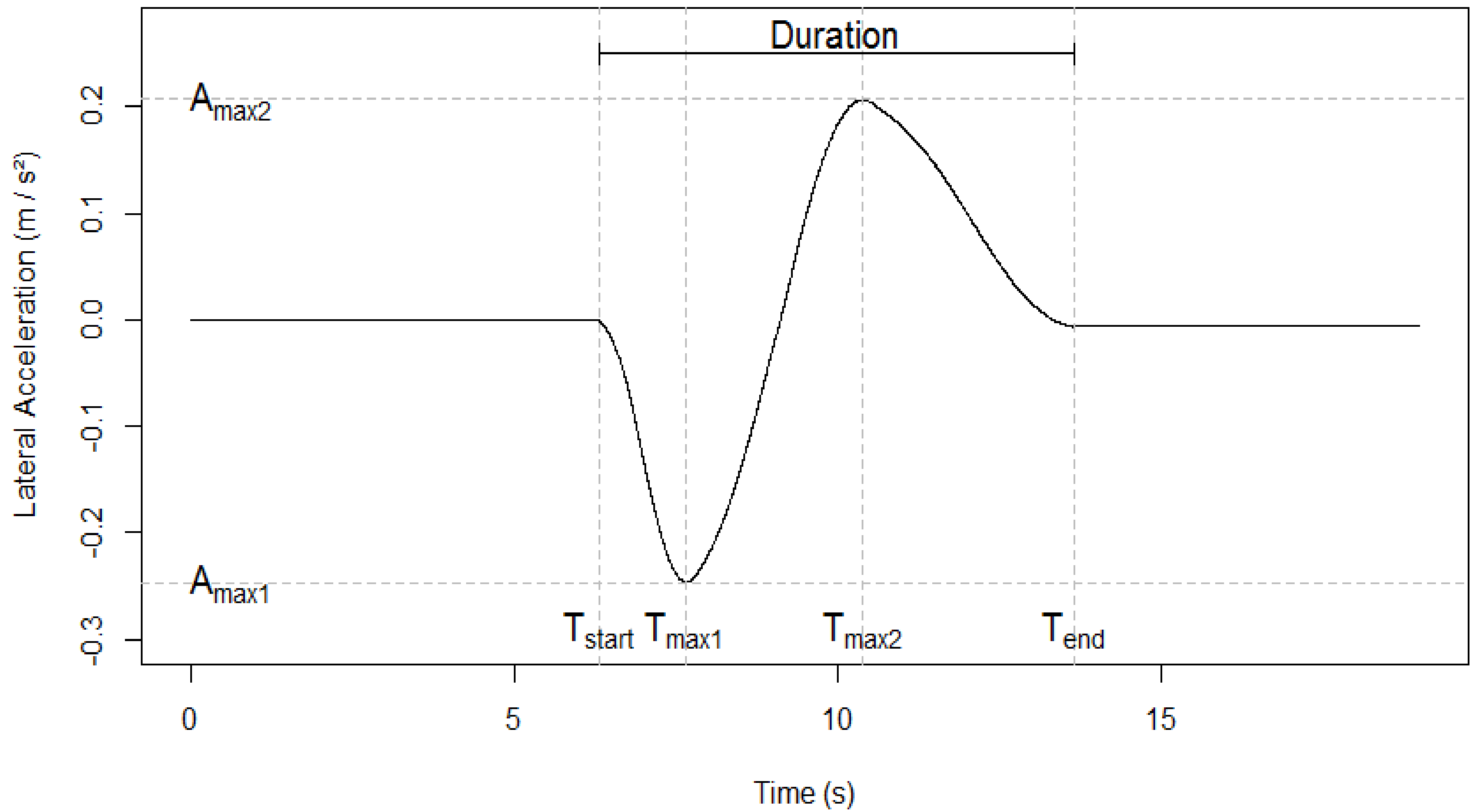
Hypotheses

- There is a most comfortable variation of each manoeuvre
  - Lane change: symmetrical variation with the smallest jerk
  - Acceleration: symmetrical variation with the smallest jerk
  - Deceleration: variation with the smallest jerk

- Driver preferences regarding manoeuvre variation are dependent on personality traits
  - Willingness to take risks (Beierlein, Kovaleva, Kemper, & Rammstedt, 2014)
  - Locus of control (Rotter, 1966)
  - Sensation seeking – thrill and adventure seeking (Beauducel, Strobel, Brocke, 2003)
  - Self-assessed driving style (Tauberman-Ben-Ari, Mikulincer, & Gillath, 2004)

How do we want to be driven? (Daimler: Bellem, Thiel, Schrauf, & Krems, 2016)

Exemplary lane change to the left



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How do we want to be driven? (Daimler: Bellem, Thiel, Schrauf, & Krems, 2016)

Test track vs. driving simulator

SimCity:

- 280 m straight
- Coordinated robotic drives possible

Driving simulator:

- Hexapod on 12 m linear rail system
- Longitudinal and lateral orientation

Both:

- Identical predefined trajectories

How do we want to be driven? (Daimler: Bellem, Thiel, Schrauf, & Krems, 2016)

Method

- High-fidelity moving base simulator
- Simulated highway scenario

- Within-subjects design
- Forced-choice paired comparisons
- Bradley-Terry-Luce model

  (Bradley & Terry, 1952; Luce, 2012)

How do we want to be driven? (Daimler: Bellem, Thiel, Schrauf, & Krems, 2016)

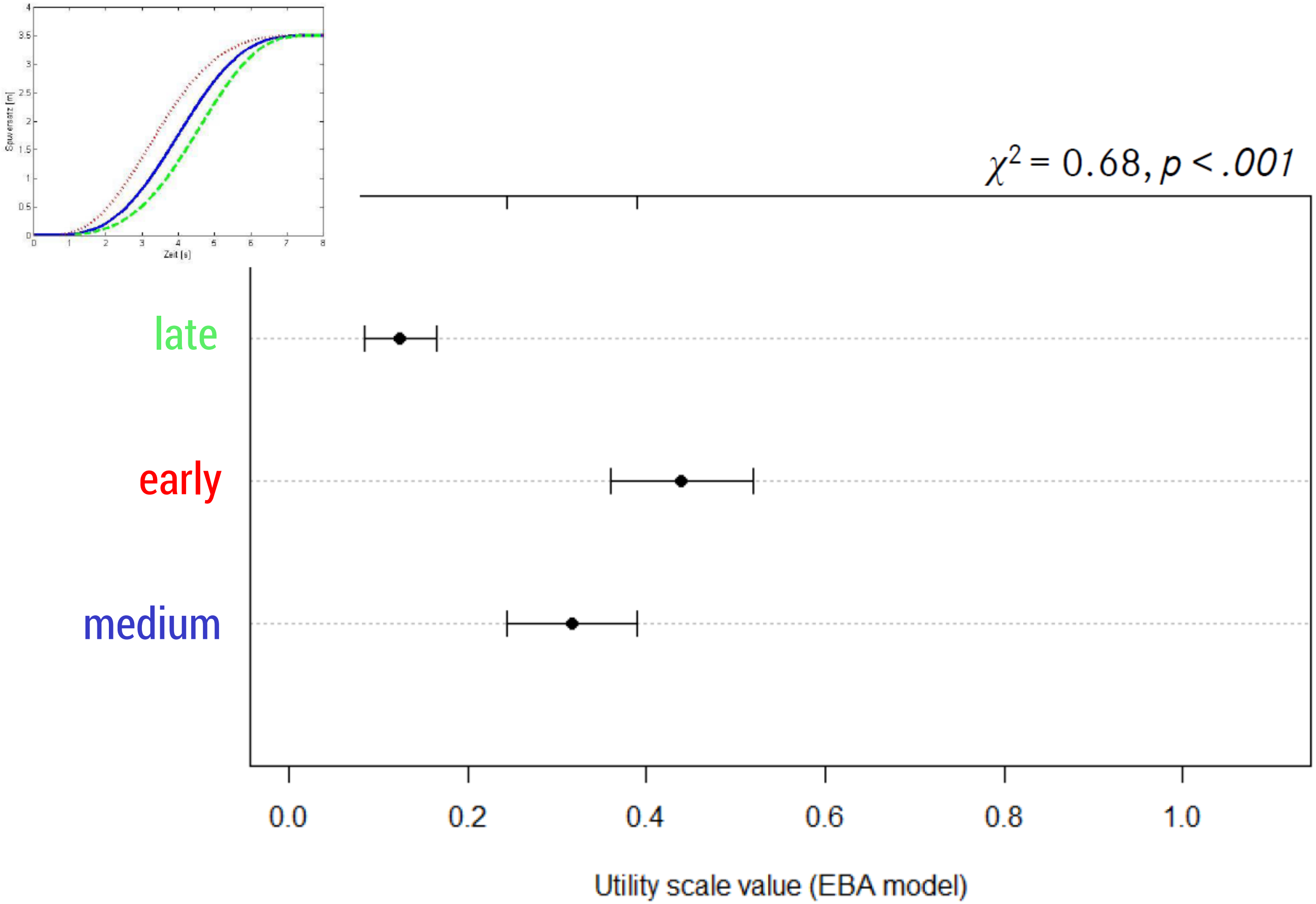
Method

Lane change maneuver	Acceleration maneuver	Deceleration maneuver
a – b b – c a – c	a – b b – c a – c	a – b b – c a – c

- Which variation was comfortable for you?
- How large was the difference between the variations (large, medium, small)?

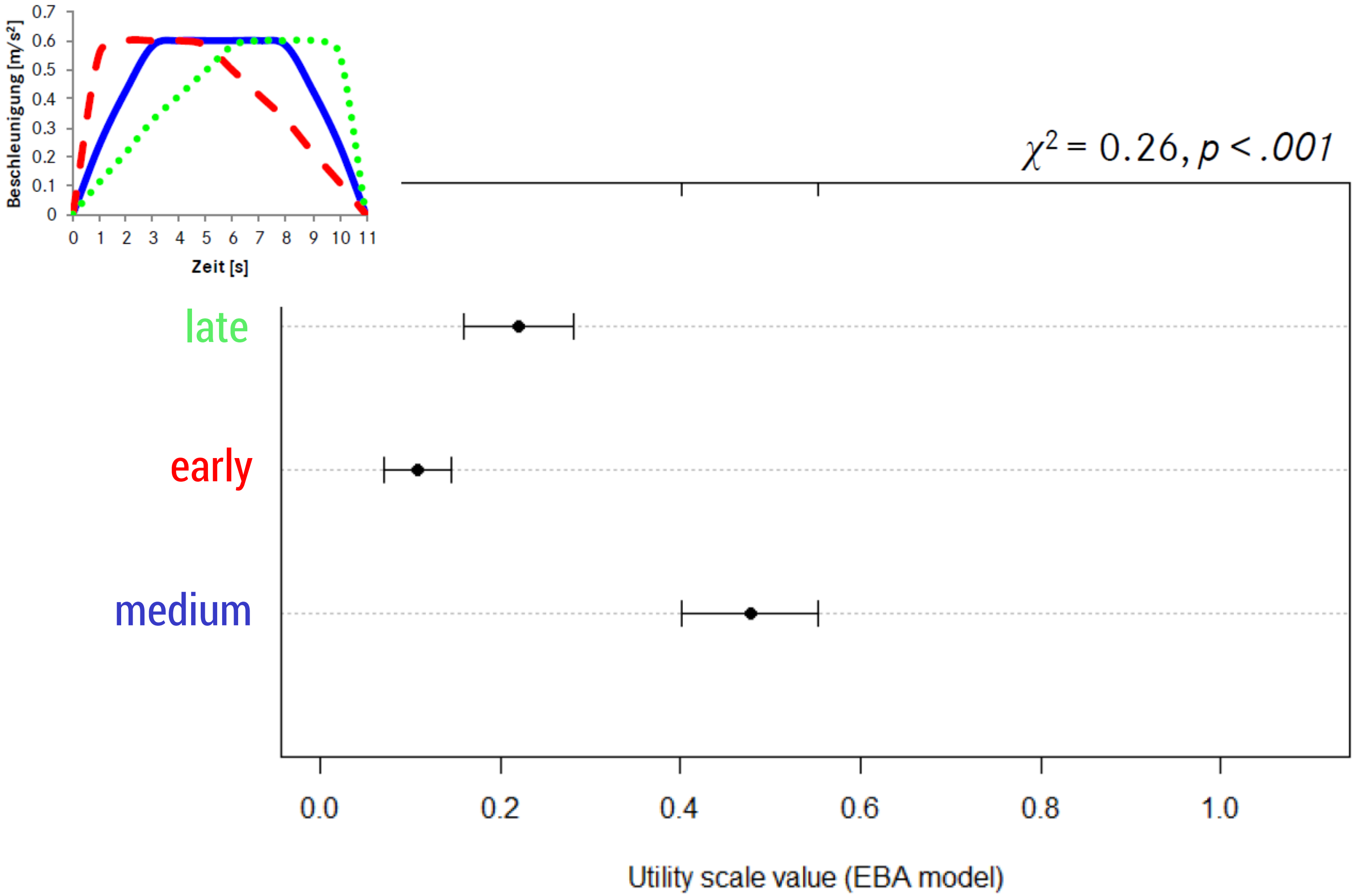
How do we want to be driven? (Daimler: Bellem, Thiel, Schrauf, & Krems, 2016)

Results: Lane change



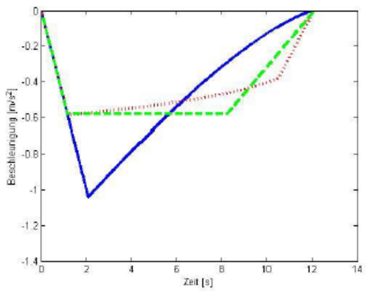
How do we want to be driven? (Daimler: Bellem, Thiel, Schrauf, & Krems, 2016)

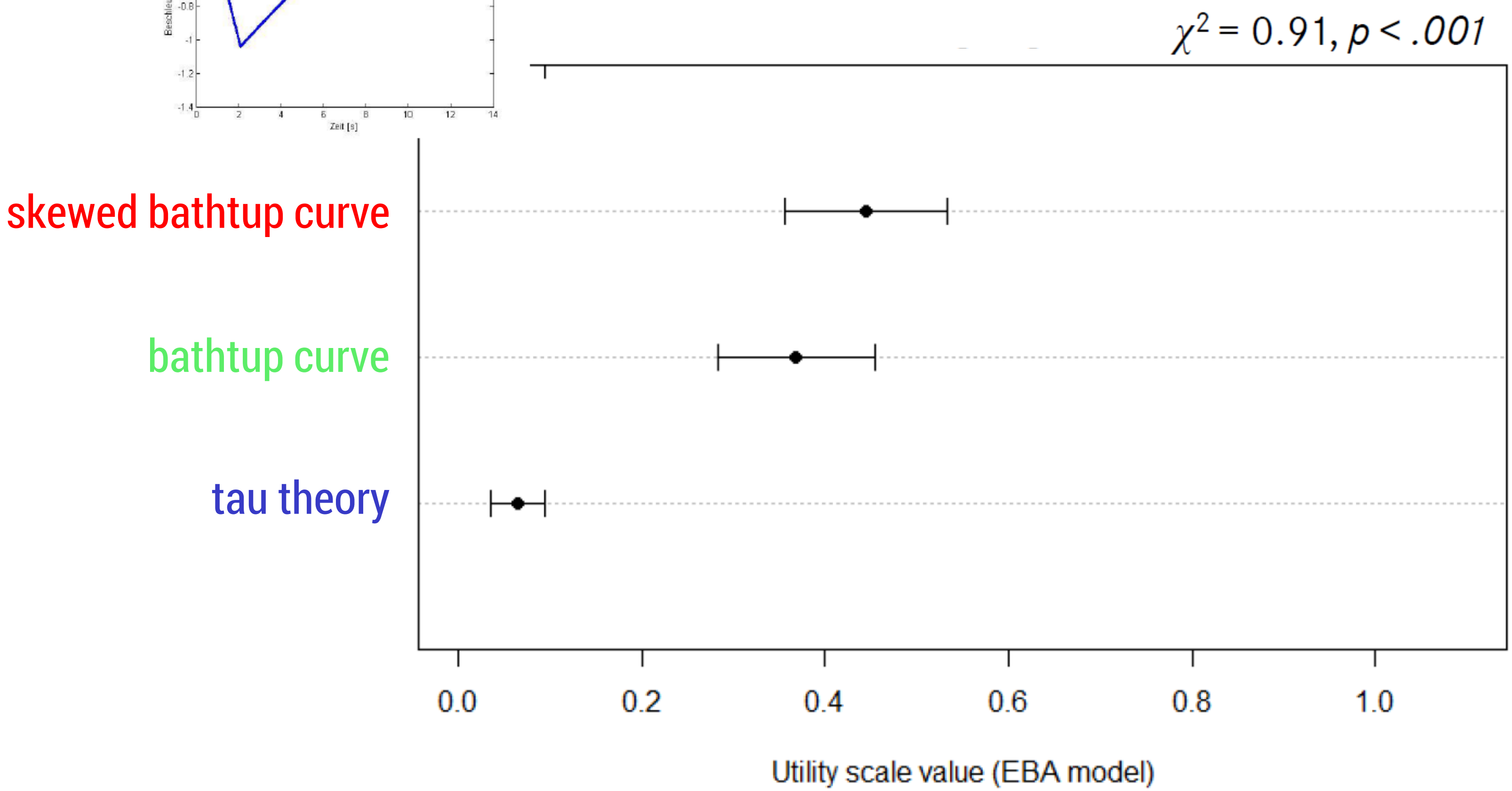
Results: Acceleration



How do we want to be driven? (Daimler: Bellem, Thiel, Schrauf, & Krems, 2016)

Results: Deceleration





How do we want to be driven? (Daimler: Bellem, Thiel, Schrauf, & Krems, 2016)

Summary

- Acceleration and deceleration as jerk-free as possible
- Deceleration behaviour does not have to correspond to the manual driving style
- Lateral acceleration of lane changes as symmetrical as possible
- No effects of personality traits (locus of control, sensation seeking, trust) in this study

New topics for Human Factors– Overview

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New challenges for human factors research

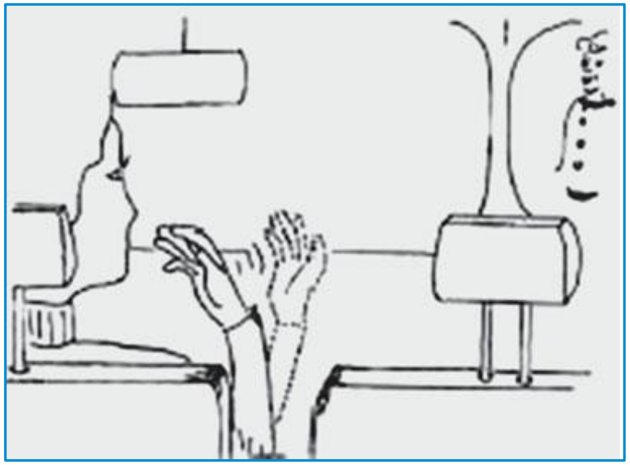
How to communicate?

How to communicate?

Gestures

Slow down.

(Risser, 1988)



Go ahead.

(Risser, 1988)

Go ahead (offering gesture).

(Färber, 2015, p. 132)

Problem / challenge

- Automated vehicles part of existing transport system → handle situations requiring cooperation with other road users
- Cooperation with vulnerable road user (VRU) essential because of safety / injury risk
- Parking areas: shared space, less regulated   higher demands of cooperation communicate intentions
- **Formal (explicit) communication:** defined/regulated communication procedures and means, e.g. turn signal, emergency lights, brake lights, the horn, warning lights…
- **Informal (implicit) communication:** non-regulated signals, e.g. eye contact, gestures, facial expressions, body movements, "anticipatory behavior" = small actions that make intentions predictable for others (Färber, 2015)
  - Examples pedestrian: changes in walking speed, head movements, placing a foot on the street...
  - Examples vehicle: trajectory, e.g. slowing down as "gentle" cooperative signal to let pedestrians cross




Communication and interaction behavior between VRUs and drivers

- **Formal communication** prescribed by laws (light and sound signals)
  → Facilitation of expectations (Gasser, 2015)

- **Informal communication** is not regulated by law:

VRU
eye contact, gesture, facial expression
walking behavior, walking speed, distance behavior

Driver
eye contact, gesture, facial expression
velocity of the vehicle, distance, acceleration/deceleration

Individual variables
age, gender, secondary activities, personality traits

Environment
visual conditions, noise level, weather, infrastructure, group size

(Färber, 2015; Lagström & Lindgren, 2015; Šucha, 2014; Trimpop et al. 2014)

- Previous research on automated vehicles focuses on technical aspects and/or special driver features, such as, for example, trust
  (e.g. Beller, Heesen & Vollrath, 2013; Gasser, 2013; Ju & Mok,2014)

- Interactions and communication between automated vehicles and VRUs is regarded as an important research focus in order to generate a high level of acceptance of automated vehicles in the future, and little research has been done in this field so far.
  (Lagström & Lundgren, 2015; Schindel-de Nooij et al. 2011)

Crossing behavior of pedestrians - Intention and communication

- **Eye contact** is crucial for the crossing decision: pedestrians explicitly seek the eye contact in contrast to the driver
  (Kloeden et al. 2014; Šucha, 2014)

- **Head movements** are used most frequently by drivers in order to estimate the crossing intention of the pedestrian
  (Schmidt & Färber, 2009)

- **Dynamic variables** such as the speed of walking or entering the road are also indicative of a crossing intention:
  - pedestrians generally wait until the vehicle stops or decelerates
    (Šucha, 2014)
  - the movement of the car is also used by the driver to assess a crossing intention
    (Schmidt & Färber, 2009; Šucha, 2014)

- In addition: TTC, infrastructure, group size, speed and distance of the vehicle, gestures
  (e.g. Hagen et al., 2012; de Lavalette et al., 2009; Šucha, 2014; Schweizer et al. 2009)

Examination of pedestrian crossing behavior (Witzlack, Beggiato & Krems, 2016)

Aim of the study

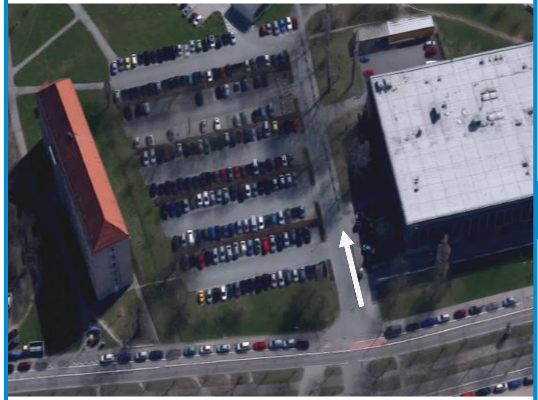
- **Exploratory observation**, in which the naturally crossing- and interaction-behavior is focused
- **The parking contexts** are central, since there is a high proportion of mixed traffic in the low speed range

Research aims:

- Identification of (typical) interaction sequences during the crossing between VRUs and drivers in a parking context
- Definition of parameters that describe the communication behavior or, as the case may be, interaction types
- Implications for the interaction between VRU and automated vehicles with regard to comfort and HMI design

Examination of pedestrian crossing behavior (Witzlack, Beggiato & Krems, 2016)

Data recording



(White arrow represents the recording perspective)

Video annotation

1. Pedestrian variables: e.g walking behavior, head position
2. Driver variables: e.g. velocity (acceleration, deceleration)
3. Further variables: e.g. group size

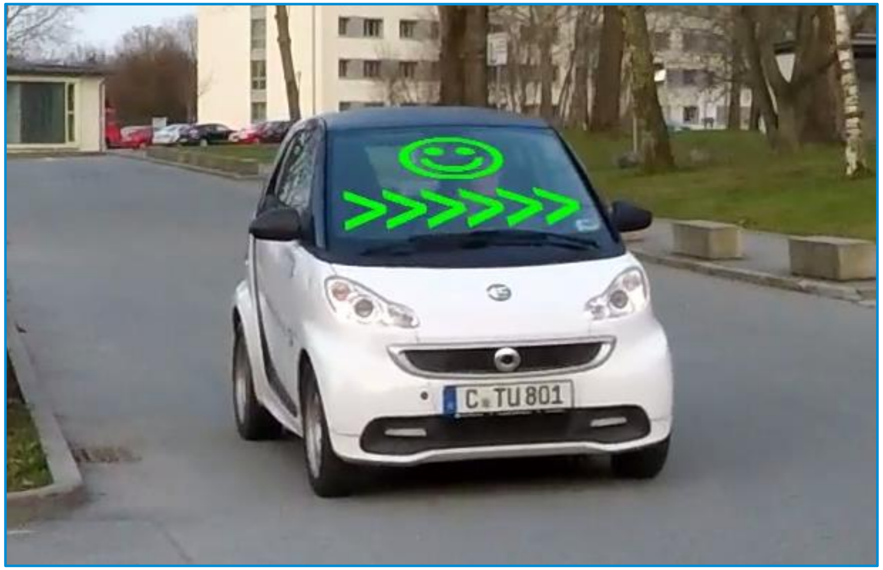
Results

1. **Three types of interaction** depending on the safety behavior (e.g. turning the head towards the car or waiting at the curb)
2. Important parameters: head movement and walking speed

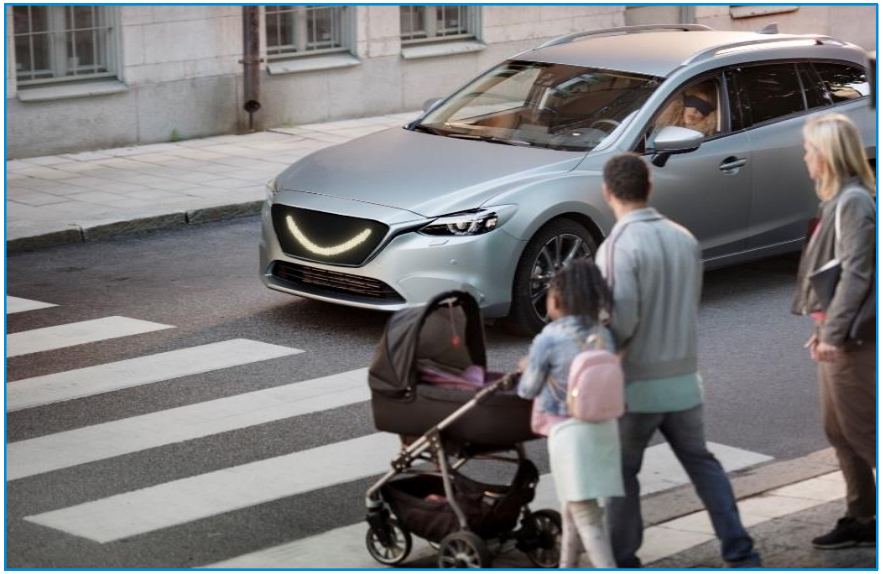
Conclusions and recommendations

- In addition to pedestrian detection and interpretation, the automated vehicle should also have communication facilities, so that interactions can take place comfortably and safely.
- Possibilities for formal and informal communication, which can provide the pedestrian feedback on the recognition and actions of the autonomous vehicle, should be specifically investigated with regard to safety, comfort and acceptance.

The HMI part



(Witzlack, Beggiato & Krems, 2016)



The smiling car

(https://blogs-images.forbes.com/jimgorzelany/files/2016/09/11-The-Smiling-Car-interacts-by-smiling-%C3%A2%C2%80%C2%93-a-message-that-is-readily-understood-by-everyone-1200x800.jpg)

The HMI part

(https://farm6.staticflickr.com/5732/21673095400_b73ff43644_c.jpgb)

(Witzlack, Beggiato & Krems, 2016)

Overview

- History of automation in the transport domain
- Levels of automation
- Why vehicle automation?
- New challenges for human factors research
- **Research issues for the future**

Human Factor issues for vehicle automation – summary

Ironies of automation
- mode confusion
- out-of-the-loop unfamiliarity
- loss of driving competence
- new driver tasks (e.g. monitoring, take over)
- misuse

System acceptance
- user acceptance (driver)
- public acceptance

Trust in automation
- mistrust → non-usage
- overreliance

Environmental issues
- choice of transportation means
- extended individual mobility

Interaction with other road users
- non-automates vehicles
- vulnerable road users

Ethical & societal issues
- societal effects
- decision algorithms for emergencies

Legislation
- responsibility in cases of failures/ accidents

Privacy
- connectivity/ individualisation vs. privacy
- cyber security

Driving comfort
- naturalness
- apparent safety
- disturbances
- motion sickness

(Bainbridge, 1983; Elbanhawi et al., 2015; Gasser & Schmidt, 2016; Kyriakidis et al., 2017)

Human Factor issues for vehicle automation – summary

Design of take-over
- request
- procedure
- HMI-design

Internal information design
- content (automation state, vehicle behaviour)
- HMI-design

Innovative mobility concepts
(e.g. car sharing)

Driving style parametrisation
- comfortable
- transparent
- prevention of motion sickness

Driver skill preservation
- system description & introduction
- user training

Driver Monitoring
- readiness for take-over
- non-driving activities
- comfort

External information design
- automation state
- vehicle behaviour

(Bainbridge, 1983; Elbanhawi et al., 2015; Gasser & Schmidt, 2016; Kyriakidis et al., 2017)

Mobility of the future?

Thanks to my team

Franziska Hartwich, Matthias Beggiato, Claudia Witzlack and all the others

TECHNISCHE UNIVERSITÄT CHEMNITZ

Thank you for your attention!

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