Evaluation of the AdaptIVe functions

User-related assessment and In-traffic behavior assessment

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Evaluation of AdaptlVe functions
AdaptlVe Subproject „Evaluation“

• Main objectives:
  – Development of an evaluation framework for automated driving systems
  – Methodology for impact analysis of automated driving systems

• Detailed objectives:
  – Apply developed methods on selected functions in order to verify the evaluation methods
  – Benefit analysis with focus on safety and environmental impact
  -> Derive first recommendations and results on the impact of automated driving applications
User-related Assessment - Evaluation tools and topics

“Highway Automation”
Real-life driving with/without
Driver behaviour
Workload
Understanding the system
Trust
Usability
Opinions about HMI
Experienced effects
Expected benefits
Willingness to pay

“Urban Automation”
Driving on test track
- Understanding the system
Trust
Usability
Opinions about HMI
- Expected benefits
Willingness to pay
Methods

Behavioural observations - two observers in the car (“Highway Automation”)

Logging of driving data - speed, distance, lane keeping (“Highway Automation”)

Questionnaires (both “Highway” and “Urban” Automation)
  • Mental workload
  • Trust
  • Usability
  • Usefulness/Satisfactoriness
  • Experienced effects
  • Expected benefits/disadvantages
  • Opinions about the HMI
  • Willingness to pay
“Urban automation” - Driver experiences and opinions

- Most participants found the system easy to learn and use.
- High System Usability Scale (SUS) score: 80 (on a scale 0-100).
- The participants were not fully aware of the system’s limitations.
- The majority would be willing to pay between 1,000 and 4,000 Euros.
- There were clear expectations in decreased fuel consumption and increased driving comport among the respondents.
- Some worries expressed:
  “does the car constantly handle new and different situations consistently in real traffic with a lot of drivers around who cannot drive a car and do a lot of stupid things”?
  “driving pleasure disappears with automated driving”.

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“Urban automation” - Usefulness and Satisfactoriness
The drivers used the system as it was intended to be used.

The system affected driving positively in several ways:
- Better speed adaptation to speed limit and conditions, less speed variation
- Better distance keeping ahead
- Better lane choice (prescribed use of the right lane)
- Better indicator usage
- Fewer dangerous lane changes
“Highway automation” - Driving behaviour II

Change in mean driving speed versus mean driving speed without the system

![Graph showing the relationship between mean driving speed with and without the system, with a correlation coefficient $R^2 = 0.7396$.](image)
Distribution of driving speed when driving with- and without the system (‘‘fast’’ driver)

- Without
- With

Speed distribution (km/h)
Distribution of driving speed when driving with- and without the system ("slow" driver)
“Highway automation” - Driving behaviour V

- Negative effects:
  - Not letting other drivers to make a lane change into own lane
  - Longer overtaking due to 130 kph system limit, hindering cars from behind
  - More conflicts due to losing the road markings due the reflection of the sun
  - Sudden braking manoeuvres due to not correctly recognising the surroundings
“Highway automation” - Driver experiences

• Positive driver experiences:
  + Driving comfort
  + Trust
  + Usability - High System Usability Scale (SUS) score: 82 (on a scale 0-100)
  + Usefulness and Satisfactoriness

• No differences with regard to subjective workload

• Negative driver experiences:
  - Self-assessed driving performance decreased
In-traffic assessment

- What is in-traffic assessment
- General framework
- Method & Example
- Conclusion
In-traffic Assessment

- How does the vehicle interact with other traffic participants?
- How do other traffic participants react on the (automated) vehicle?
Solution proposal

- Just go on the road and see what happens.
// Method - general framework

- Virtual testing
- Scenarios that resemble real-life traffic

Real-life data → Test case generation → Simulation & Evaluation

Real-life scenarios → Parameterization → Scenario database → Generation of new test cases → Simulation of test cases

Parameterization → Scenario database → Generation of new test cases → Simulation of test cases

Generation of new test cases → Fit distributions → Performance Indicator Extraction → Performance Indicator distribution

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// In-traffic Assessment

- How does the vehicle interact with other traffic participants?
- How do other traffic participants react on the (automated) vehicle?
In-traffic Assessment

- How does the vehicle interact with other traffic participants?
- How do other traffic participants react on the (automated) vehicle?
Real-life scenarios

• Compare performance of third vehicle in two different configurations.

Intelligent Driver Model (IDM) [1]

IDM or Traffic Jam Assist (TJA)

Other traffic participant  Vehicle under test  Cut-in
Test case generation

- Summarizes scenario in only a few parameters.
- Why?
  - Probabilistic results
    - No need to ‘drive’ all kilometres to make claims!
  - Emphasize critical scenarios
    - Without a-priori knowledge of what might be critical
  - Prevent repetition
- Cut-in scenario → 5 parameters.
- Some assumptions, e.g. constant velocity

Real-life scenarios
Parameterization
Scenario database
Fit distributions
Generation of new test cases
Simulation of test cases
Performance Indicator Extraction
Performance Indicator distribution
Test case generation

- Store parameters in database.
- No need to store all data of a scenario.
Test case generation

- Kernel Density Estimation [2], [3]:
  \[ f_h(x) = \frac{1}{nh} \sum_{i=1}^{n} K \left( \frac{x - x_i}{h} \right) \]

- Bandwidth \( h \rightarrow \) cross-validation
  - Let the data speak for itself!

- No assumptions
- Multivariate data
- Easy to draw random samples
Test case generation

- Histogram: original data
- Red lines: Kernel Density Estimation
Test case generation

- Generation of new test cases:
  - Draw sample
  - Transform to real-life test case
- Importance sampling → emphasize performance-critical scenarios
  - Ask me for more details
Method - simulation and evaluation

Real-life scenarios
Parameterization
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Generation of new test cases
Simulation of test cases
Performance Indicator Extraction
Performance Indicator distribution

Scenario → Sensors
Scenario → Drivers
Scenario → Vehicles
Scenario → Controllers

Vehicles

Drivers

Controllers

Sensors

Scenario database
Fit distributions
Generation of new test cases
Simulation of test cases
Performance Indicator Extraction
Performance Indicator distribution
Example - simulation and evaluation

- Real-life scenarios
- Parameterization
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- Performance Indicator distribution
Method - simulation and evaluation

- Performance Indicators are extracted from a simulation, e.g.
  - Time Headway (THW)
  - Time-To-Collision (TTC)
  - Distance
  - Velocity
  - Acceleration
  - etc.
Method - simulation and evaluation

When a large number of simulations are performed, we can make distributions of the resulting Performance Indicators.
// Example - simulation and evaluation

- Red: both following vehicles are human driven (IDM)
- Blue: second car equipped with Traffic Jam Assist
Example - simulation and evaluation

- Red: both following vehicles are human driven (IDM)
- Blue: second car equipped with Traffic Jam Assist

![Cumulative probability graph](image)
// Example - simulation and evaluation

- Red: both following vehicles are human driven (IDM)
- Blue: second car equipped with Traffic Jam Assist

![Cumulative probability graphs for maximum deceleration, minimum distance, minimum TTC, minimum THW, RMS(acceleration), and RMS(jerk)]

- Maximum deceleration [m/s²]
- Minimum distance [s]
- Minimum TTC [s]
- Minimum THW [s]
- RMS(acceleration) [m/s²]
- RMS(jerk) [m/s³] × 10⁻³

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Conclusion

• Methodology to assess the performance of an Automated Driving Function has been developed.
• Through parameterization of the real-life scenarios, test cases are generated.
• The framework is mostly data driven.
• It provides quantitative results on
  – how a system will perform in real-life traffic and
  – how other traffic participants will react on the system.
• More information ➔ check our stand
Thank you.

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