CARTRE Webinar Series (VIII):
’Key performance indicator (KPIs) and assessment of impacts of automated driving’
28 March 2018
Introduction: CAD Initiative and Webinar Series

- **Connected Automated Driving**: Joint Initiative by two European projects (CARTRE, SCOUT)
- **Partnership**: 30 Partners and around 40 associated partners from research, industry and authorities
- **Project Goal**: Bundle European and national actions to accelerate deployment of automated driving
- **Webinar Series**: Present existing CAD projects and explore global issues in automated driving research
Introduction: CAD Activities in Europe and Beyond

- Annual Conference
- Digital Knowledgebase
- Strategic Guidance
- Position Paper Development
- Data Sharing and Evaluation
- Stakeholder Network
Introduction: Thematic Interest Groups

Connectivity  Socio-Economic Sustainability  Industrial Production  Human Factors  Big Data and AI  Infrastructure

In-Vehicle Enablers  Safety Validation  Policy and Regulation  New Business Models  Users and Society
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:00-13:05</td>
<td>Introduction and agenda of the webinar, Satu Innamaa/VTT</td>
</tr>
<tr>
<td>13:15-13:25</td>
<td>Trilateral KPI Survey results, Satu Innamaa/VTT</td>
</tr>
<tr>
<td>13:25-13:40</td>
<td>Safety impact assessment for automated driving as in AdaptlVe project, Adrian Zlocki/ika</td>
</tr>
<tr>
<td>13:40-13:45</td>
<td>Outlook to safety impact assessment methodology for the ongoing L3Pilot project, Adrian Zlocki/ika</td>
</tr>
<tr>
<td>13:45-14:00</td>
<td>Questions and answers</td>
</tr>
</tbody>
</table>
Trilateral Impact Assessment Framework

Satu Innamaa/VTT
Trilateral activity for building the framework

- Cooperation between Europe, US and Japan in ART WG
- Subgroup for impact assessment
  - Formed in 2015
  - 40+ members
- Objective:
  “Harmonization of the high-level evaluation framework for assessing the impact of automation in road transportation”
- High-level framework intended for FOT designers, policy makers and those making impact assessment of ART
Motivation

• Potential impacts of automation are far reaching and complex
  • High expectations on what connected and automated vehicles shall be able to contribute to several societal goals

• Field tests are expensive

• International harmonization
  • Design tests and studies to maximize the insight obtained
  • Enable meta-analysis
  • Can arrange complementary evaluation across the world
  • Make better use of each other’s findings
  • Exchange best practices
Trilateral Impact Assessment Framework for Automation in Road Transportation

March 28, 2018

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System and Impact Classification

- Direct & indirect impacts
- Definition and KPIs
  - KPIs being updated based on survey
- System and design domain

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Impact Mechanisms

The potential impact mechanisms defined for ART to ensure that assessment covers systematically

- the intended and unintended
- direct and indirect
- short-term and long-term

impacts of both AV-users and non-users.

It is recommended that these mechanisms be identified for all impact areas, although, not all of them could be assessed.
AV that can deliver itself to a user

- ( + ) — increase
- ( - ) — decrease
Recommendations for experimental procedure

• Basics for setting the study design
  • Recommendations in line with the FESTA V
• Special for ART
  • It will not always be possible to test AVs in a naturalistic environment
    → Use of controlled testing and simulation discussed
  • Many (first) AD studies will be performed utilising prototype vehicles, whose performance may not be the same as in the planned production vehicle
Recommendations for Data Sharing

- Reasons for data sharing discussed
  - References to RDE and FOT-Net’s Data Sharing Framework
- Obstacles for data sharing and their solutions
  - Competitive information
  - Privacy-sensitive data
  - Different legal and ethical conditions
  - Not always easily-accessible
  - Storing, maintaining and opening data after a project has a cost
- Common dataset needs to be agreed within 1-2 years
Framework document available

Framework draft 1.0 (4 Jan 2017):

Updated version to be published in April 2018!

CAD Webinar Series (VIII):
‘Key performance indicator (KPIs) and assessment of impacts of automated driving’
Trilateral KPI Survey Results

Satu Innamaa/VTT
Introduction

To be able to provide recommendations on the most important key performance indicators (KPIs) for measuring and expressing the impacts, the Trilateral Impact Assessment subgroup conducted an international survey:

- The survey was open for answers from June to November 2017
- In total, 77 answers were obtained from EU, US and Japan
- 56% represented research organizations, 18% policy makers or authority and 14% automotive or other industry

The resulting recommendations on KPIs will be provided in version 2.0 of the Trilateral Impact Assessment Framework which will be published in April 2018.

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‘Key performance indicator (KPIs) and assessment of impacts of automated driving’

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Structure of survey

- Region and sector
- Impact areas of interest
  - Vehicle operations / automated vehicles
  - Use of automated driving
  - Safety
  - Energy or environment
  - Personal mobility
  - Travel behavior
  - Network efficiency
  - Asset management
  - Costs
  - Public health
  - Land use
  - Economic impacts

- Vehicle type that they would assume when answering the questions: automated passenger car, shuttle bus/pod, truck or mixed traffic including VRUs
- Automation level: SAE 1-2, SAE 3 and SAE 4-5
- Rating for KPIs for areas they had indicated having expertise in
  - Scale is from 0 = 'not at all important' to 6 = 'extremely important', N/A = 'not applicable'
- Additional KPIs
### Example of results: Vehicle operations

<table>
<thead>
<tr>
<th>KPI</th>
<th>Rating</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of instances where the driver must take manual control / 1000 km or miles</td>
<td>5.69</td>
<td>29</td>
</tr>
<tr>
<td>Mean and maximum duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle)</td>
<td>5.63</td>
<td>30</td>
</tr>
<tr>
<td>Mean and maximum duration of the transfer of control between operator/driver and vehicle (turning automated driving system on/off, manual overrule)</td>
<td>5.03</td>
<td>29</td>
</tr>
<tr>
<td>Number of emergency decelerations per 1000 km or miles</td>
<td>4.97</td>
<td>32</td>
</tr>
<tr>
<td>Mean and minimum time-headway to the vehicle in front in car following situations</td>
<td>4.75</td>
<td>32</td>
</tr>
<tr>
<td>Minimum accepted gap at intersections or in lane changes</td>
<td>4.70</td>
<td>30</td>
</tr>
<tr>
<td>Mean and minimum distance to the vehicle in front in car following situations (headway 5 s or less)</td>
<td>4.63</td>
<td>32</td>
</tr>
<tr>
<td>Mean and maximum longitudinal acceleration and deceleration</td>
<td>4.48</td>
<td>31</td>
</tr>
</tbody>
</table>

Note: Only part of result table.

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### Example of results: KPIs by SAE level

<table>
<thead>
<tr>
<th>KPI</th>
<th>SAE 1-2</th>
<th>SAE 3</th>
<th>SAE 4-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rating</td>
<td>N</td>
<td>Rating</td>
</tr>
<tr>
<td>Number of instances where the driver must take manual control / 1000 km or miles</td>
<td>5.33</td>
<td>6</td>
<td>5.86</td>
</tr>
<tr>
<td>Mean and maximum duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle)</td>
<td>5.33</td>
<td>6</td>
<td>6.00</td>
</tr>
<tr>
<td>Mean and maximum duration of the transfer of control between operator/driver and vehicle (turning automated driving system on/off, manual overrule)</td>
<td>5.17</td>
<td>6</td>
<td>5.29</td>
</tr>
<tr>
<td>Number of emergency decelerations per 1000 km or miles</td>
<td>4.50</td>
<td>6</td>
<td>5.00</td>
</tr>
<tr>
<td>Mean and minimum time-headway to the vehicle in front in car following situations</td>
<td>4.50</td>
<td>6</td>
<td>4.88</td>
</tr>
</tbody>
</table>

Note: Only part of result table
### Example of results: KPIs by vehicle type

<table>
<thead>
<tr>
<th>KPI</th>
<th>Automated passenger car</th>
<th>Mixed traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rating</td>
<td>N</td>
</tr>
<tr>
<td>Number of instances where the driver must take manual control / 1000 km or miles</td>
<td>5.64</td>
<td>14</td>
</tr>
<tr>
<td>Mean and maximum duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle)</td>
<td>5.69</td>
<td>16</td>
</tr>
<tr>
<td>Mean and maximum duration of the transfer of control between operator/driver and vehicle (turning automated driving system on/off, manual overrule)</td>
<td>5.07</td>
<td>15</td>
</tr>
<tr>
<td>Number of emergency decelerations per 1000 km or miles</td>
<td>4.94</td>
<td>16</td>
</tr>
</tbody>
</table>

Note: Only part of result table

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Discussion

- None of the KPIs received very low ratings
  - This is most likely due to having a large expert group selecting the KPIs for the survey and dropping irrelevant KPIs during survey design
  - As the impacts of automation are still partly unknown, the experts are interested in many potential impacts
- In order not to have too long a list of alternative KPIs to rate, some KPIs were not precisely defined
  - They will need additional work on making them unambiguous before use in practice
- Recommendations and a full list of potential KPIs (a KPI repository) will be added to version 2.0 of Trilateral impact assessment framework (expected in April 2018)
Safety impact assessment for automated driving as in AdaptIVe project

Adrian Zlocki/ika
Evaluation Methodology
Determination of Test Level

Sensor Level
- Sensor 1
- Sensor n

Perception Level
- Fusion

Function Level
- Function

Interaction Level
- Human Machine Interface

Impact Level (Impact Assessment)
## Evaluation Methodology

### Different Methodologies

<table>
<thead>
<tr>
<th>Methods</th>
<th>Driver</th>
<th>Vehicle</th>
<th>Environment</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Operational Test</td>
<td>![Person]</td>
<td>![Car]</td>
<td>![Road]</td>
<td>+ trajectory &amp; interaction 1:1 perceptible</td>
<td>- reproducibility limited</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- relevant situations occur rarely</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- extensive effort</td>
</tr>
<tr>
<td>Controlled Field</td>
<td>![Person]</td>
<td>![Car]</td>
<td>![Road]</td>
<td>+ trajectory &amp; HMI quite well perceptible</td>
<td>re reproducibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- situation space limited</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- high effort</td>
</tr>
<tr>
<td>Dynamic Driving Simulator</td>
<td>![Person]</td>
<td>![Car]</td>
<td>![Road]</td>
<td>+ trajectory &amp; HMI well perceptible</td>
<td>+ critical situations possible</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>o medium effort</td>
</tr>
<tr>
<td>Simulation</td>
<td>![Person]</td>
<td>![Car]</td>
<td>![Road]</td>
<td>- trajectory bad perceptible</td>
<td>o interaction limited perceptible</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ reproducibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ low effort</td>
</tr>
</tbody>
</table>
Evaluation of AdaptIVe Functions

Impact Assessment

- User-Related Assessment
- Technical Assessment
- In-Traffic Behaviour Assessment

Real-traffic

Test track

Simulations

March 28, 2018
Baseline for Assessment of Automated Driving

• Description of the baseline for the evaluation
  • Objectives of automated driving functions
    • Objective is a collision free traffic
    • Operation in mixed traffic conditions (not disturbing normal traffic)
      The functions have to be operated within range of normal driver behaviour

• What is normal driving behaviour?
Analysis of Automated Driving Field Test Data
Scenario Classification of Real-World Data

- **Rule-based Classification**
  *Benmimoun (2011)*
  - Offline classification
  - Uses decision trees parameterized by hand
  - No easy adaptation, no consideration of time series

- **Machine-learning based Classification**
  *Reichel (2010), Roesener (2016)*
  - Proficient using of Machine Learning Techniques
  - Partial automated
  - Choice of classifier based on expert knowledge

► Machine learning techniques provide an efficient & automated data clustering

Available Literature:
- ika PhD thesis: M. Benmimoun 2015
Testing Automated Driving in Field Tests
Scenario-based Assessment of Automated Driving

Data Source
Demonstrator Function

Classification of Scenarios

Classroom Scenario 1
Classroom Scenario 2
Classroom Scenario x

Assessment

△ Frequency (Scenario)
△ Effect (Scenario)

Reference: FOT
► Human driving as a baseline

► Classification of scenarios by using time series classification algorithms (Hidden Markov Models)

► Assessment of △frequency and △effect induced by system in scenario

Calculation of:
- Derived Measures
- Performance Indicators

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The AdaptIVe Highway-Chauffeur is showing a control capability similar to human driving from euroFOT. Two results stand out:

- Top figure: duration of lane change is much more uniform with automation
- Bottom figure: time headway in vehicle following shows much less variability with automation
Application of Method – Frequencies for Highway

- Small increase of lane change scenarios
- More cut-in of other vehicle scenarios with automation

Frequency of occurrence [km⁻¹]

<table>
<thead>
<tr>
<th></th>
<th>Lane change</th>
<th>Cut-in of other vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>euroFOT</td>
<td>0.35</td>
<td>0.2</td>
</tr>
<tr>
<td>AdaptIVe Highway Automation</td>
<td>0.4</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Safety Impact Assessment - Methodology

- Accident data (e.g. GIDAS) / Critical situations (FOT)
- Description of function
- Simulation of traffic scenarios

Top-Scenario

Simulation of driving scenarios
Safety Impact Assessment – Example Obstacle in Lane

Setup of the scenario:

• Three lane motorway of length of 4 km
• The obstacle is placed in the central driving lane at a position of $s_x = 350$ m. Position can be adjusted via GUI in order to be able to place the obstacle also in a curve
• The surrounding traffic is generated by means of stochastic approaches (start position & characteristics of the driver)
• The first three vehicles that approach the obstacle are considered as the “relevant vehicles”
• The relevant vehicles are either driven by the automated driving function or manually (SCM-driver model)
• Variation of parameters
Safety Impact Assessment – Limitation of Study

Aspect that limit the analysis:

- Situations (transition of control) with potential negative effects are not considered
- Effects along the penetration rate are not considered, however will limit the overall effect
- Usage is not considered → function is not necessarily used although it is available
- Available data → currently, the relevant and available data set (detailed accident data & NDS and FOT data) is quite limited
Outlook to safety impact assessment methodology for the ongoing L3Pilot project

Adrian Zlocki/ika
Piloting Automated Driving on European Roads
L3Pilot – Real World Data for Impact Assessment

- Large-scale Level 3 piloting
- 1,000 test drivers, 100 vehicles in 11 European countries
- EC funded in Horizon 2020
- 34 partner

Website: http://www.l3pilot.eu
Objectives:
- Overall evaluation of automated driving function with respect to the influence on technical, user & acceptance and driving & travel behavior aspects.
- Assessment of long-term effects of automated driving on user attitudes and acceptance.
- Investigation of interactions between different traffic participants in different automation modes.
- Assessment of the readiness and reliability of automated driving functions.
Questions & Answers
Questions & Answers Session
Conclusion: Stay in touch with us

• **Get involved**: CARTRE builds a diverse expert network across Europe and beyond

  • Revisit the recording of this session and further material: [www.connectedautomateddriving.eu/webinars](http://www.connectedautomateddriving.eu/webinars)

  • Share your thoughts and opinions on Twitter: [@Europe_CAD](https://twitter.com/Europe_CAD)

  • Subscribe to our newsletter: [www.connectedautomateddriving.eu/news](http://www.connectedautomateddriving.eu/news)

  • Become an associated partner to the project: [partnership@connectedautomateddriving.eu](mailto:partnership@connectedautomateddriving.eu)
Thank you!