Royal HaskoningDHV
Enhancing Society Together

Assessment of Operational Design Domain for Lane Keeping Systems Combining Objective and Subjective Risk Measures

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Motivation

- Thoughts about these situations?
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Jargon

- Level of autonomy & ODD
- Situations can either be inside, outside, not in-or-out of the ODD.
- Our focus was on LKAS (control type)

Table 1 - Summary of levels of driving automation

Level	Name	Narrative definition	*DDT*		*DDT fallback*	*ODD*
			Sustained lateral and longitudinal vehicle motion control	*OEDR*		
Driver* performs part or all of the *DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
***ADS* ("*System*") performs the entire *DDT* (while engaged)**						
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

Research question & approach(1)

*Develop an analysis method that combines **objective** and **subjective risk** measures for the assessment of the **ODD of vehicles equipped with LKAS**.*

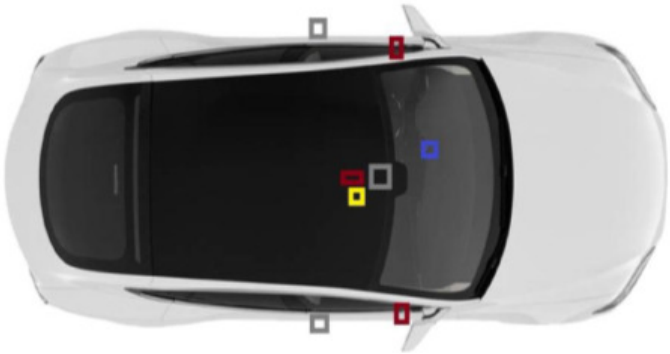
- How does the LKAS perform when it is **within** and when it is **exceeding** its pre-defined ODD?
- Is there a **mismatch in the ODD** between the one specified by the OEM's and that which is specified by the drivers? and which factors contribute to this mismatch?

Approach

- Field test: Case study of equipped Tesla Model S, **19 participants**
- LKAS performance (**MLP and SDLP**)
- Objective risk: Porbabalistic Driver Risk Field theory **(PDRF)**
- Subjective risk: Set of questionnaires (before and during test) → **Trust, behaviour, situation awareness**

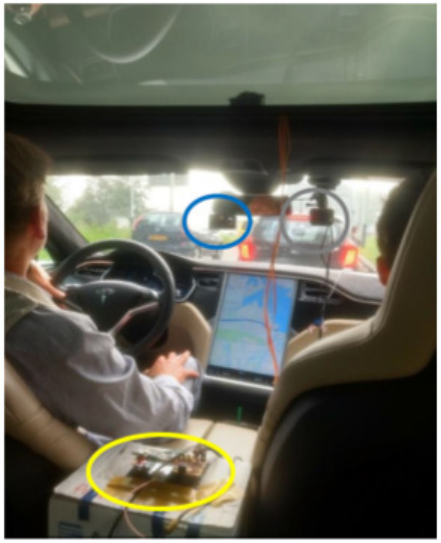
Research question & approach(2)

- Experimental setup: Equipped Tesla Model S



Key

	Go Pro cameras: Side facing and front facing
	IMU + GPS
	HD webcam : Facing driver (facial features)
	LIDAR's : Both side and front facing



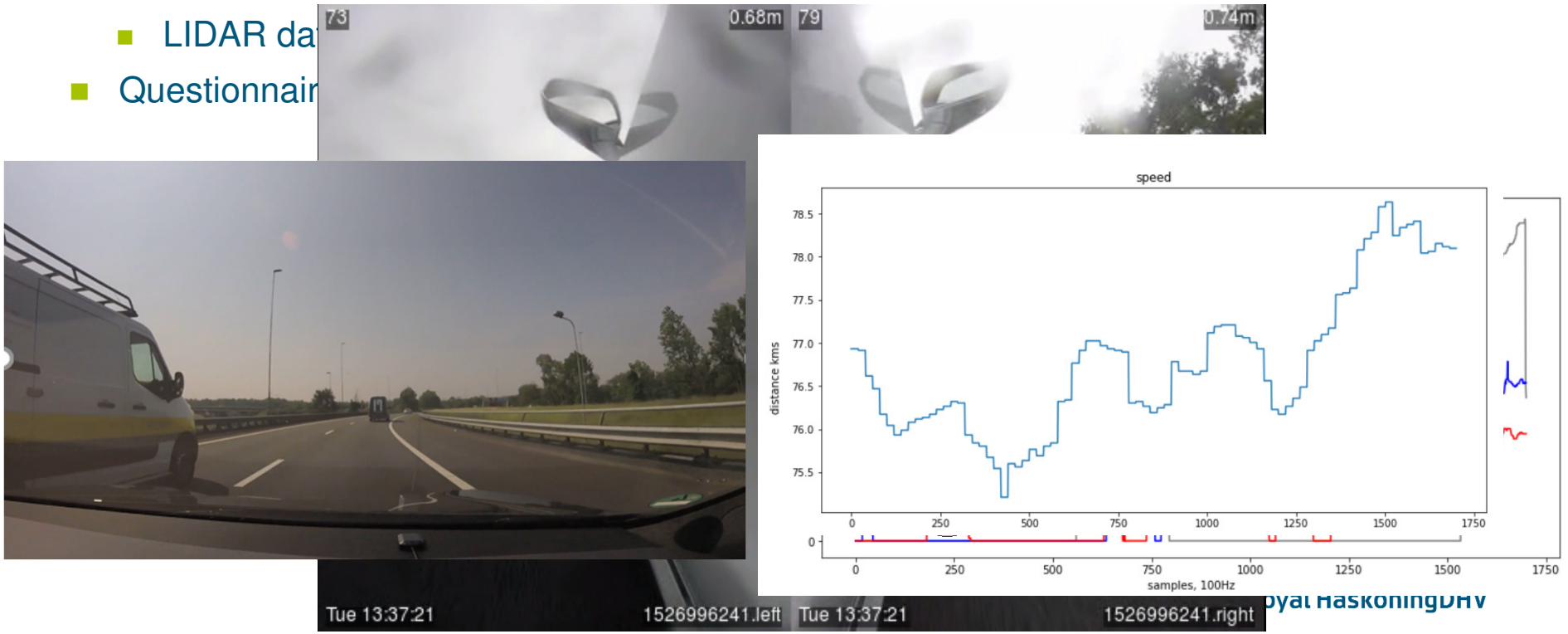
Research question & approach(3)

- Test route
- Test situations

1) In the city with no LM on the road boundary (Out of ODD)
2) Inside the tunnel (Inside ODD)
3) Close to an off-ramp (Neither in nor out)
4) In a curve on the highway (Inside)

Data analysis (1)

- PDRF (Objective risk)
  - Position in the lane → LKAS performance
  - LIDAR da
- Questionnair



Objective measurements: Lateral driving risks

The Probabilistic driver risk field method

- Based on energy transferred and probability of collision
- Potential : Non-moving road entities
- Kinetic: moving objects → not studied

Source: (Anthony-Babu, F., 2018)

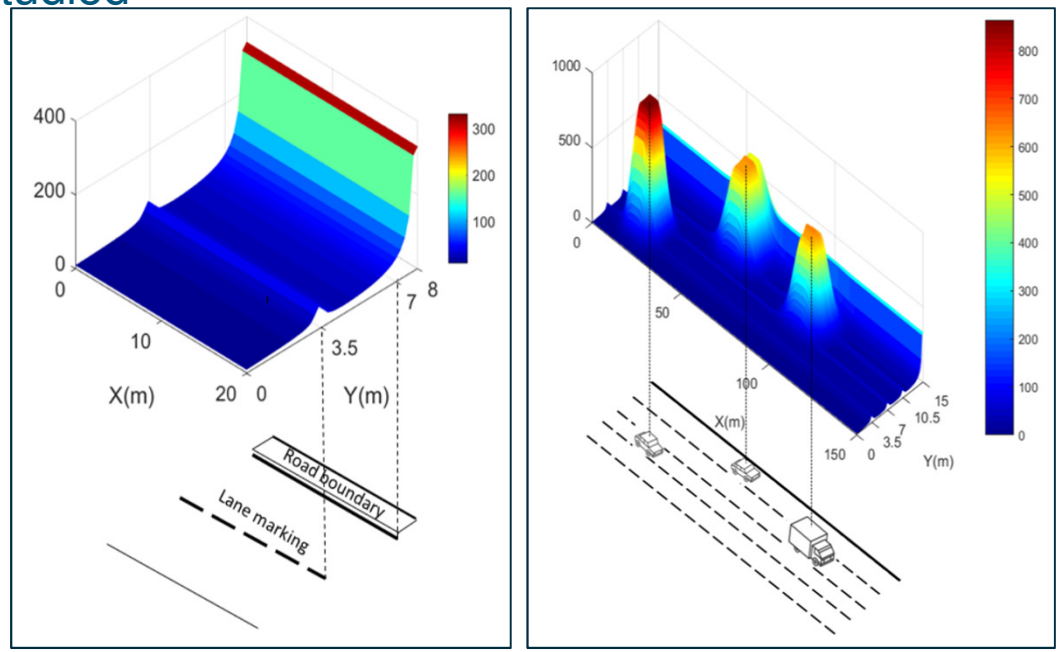
$$R_{b,s} = 0.5kM\left(V_{s,b}\right)^2 \cdot \max\left(e^{\left(\frac{-|r_{s,b}|}{D}\right)}, 0.001\right)$$

Sensitivity factor

Energy transfer

Probability

Lateral distance
Lane width



Results

Test Situation	Lane Keeping System Performance	Risk of Driving	ODD mismatch	Main Subjective Relationships
S1-No-LM *(ODD-Out)*	- High bias towards left of lane centre; - Considerable variation.	Highest	Second highest (68.7%);	ODD mismatch dependent on real time trust.
S2-Tunnel *(ODD-In)*	- Aligned close to lane centre; - Bias away from left lane marking strip, avoiding left tunnel wall.	Second highest	Second lowest (12.5%).	Real-time trust negatively correlated with perceived risk.
S3-Off-ramp *(ODD-Not In Or Out)*	- Slight bias to left of lane centre; - Highest variation.	Second lowest	Highest (81.2%);	ODD mismatch dependent on perceived risk and initial trust in AVs.
S4-Curve *(ODD-In)*	- Closest to lane centre; - Smallest variation.	Lowest	Lowest (6.25%).	Awareness about vehicle's ODD is dependent on perceived risk.

Conclusions

- LKAS performance: Differences identified; **deviation from centre & variation in deviation**

Aid OEMs in deciding if a situation should remain inside or moved outside the lane keeping system's ODD while keeping the drivers' safety and awareness of the system capabilities at the core of the decision-making process.

is most important.

- Proposed method → **compare test situations, not making decisions of ODD**
  - Thresholds for assessment component vary btn OEMs

Since 24th October 2018…..

- Projects at RHDHV
  - I-AT project → Cyclist interaction with AV (static and kinetic PDRF)
  - Performance in curves and provincial roads → Prov. Noord Holland
  - MSc thesis project: using this approach for performance of LKAS on curves
- Product/services within RHDHV
  - Infrastructure readiness for AV's → Kansen kaart
  - CyleRAP extension with risk measurements → safety on the road and fietspad.
- TRB Annual meeting: poster presentation 2020

Vision: *Harmonization among OEMs → detailed ODD description for each SAE level.*

Thank you for your attention!