TU Delft — Delft University of Technology | Royal HaskoningDHV — Enhancing Society Together | Rijkswaterstaat — Ministerie van Infrastructuur en Milieu | SAMEN — Safe and Efficient OperAtion of AutoMated and Human DrivEN Vehicles in Mixed Traffic

An Empirical Analysis to Assess the Operational Design Domain of Lane Keeping System Equipped Vehicles Combining Objective and Subjective Risk Measures

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1. Introduction & Research Question

- Lower levels of automation are designed to work in specific conditions referred to as Operational Design Domain (ODD);
- Beyond these conditions, the human driver is expected to take control;
- A mismatch between a driver's understanding and expectations of the automated vehicle capabilities and its actual capabilities could affect their safety and trust in automation;
- A practical and driver centric ODD assessment method of driver assistance systems is currently missing;
- Such method could support OEMs and road operators in assessing the needed changes in technology and infrastructure, respectively;

Research Question: To what extent can the ODD of vehicles equipped with lane keeping systems be assessed by understanding the subjective and objective risk of driving in pre-specified test situations?

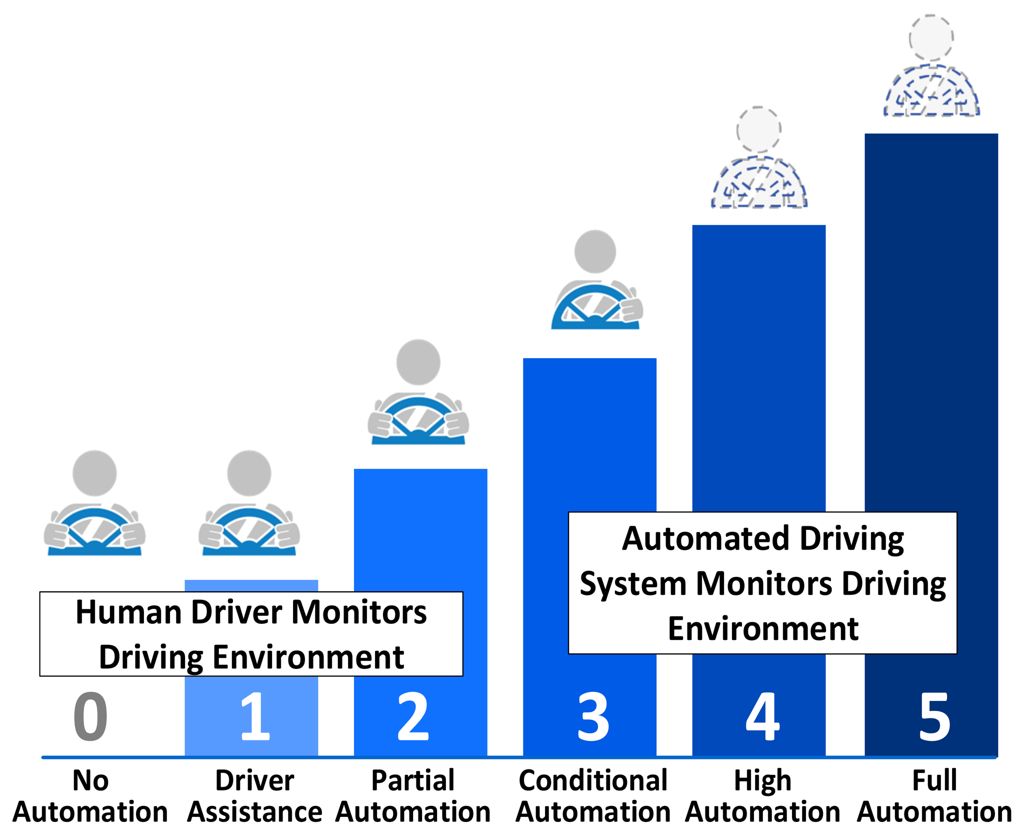


Figure 1: SAE levels of Automated driving (Based on SAE International, 2018).

2. Road experiment setup

- A field experiment was conducted on the A5, Zwanenburg to A4 (E19) Schiphol using an equipped Tesla Model S (see Figure 2);
- 4 road situations were selected (see Figure 3) and classified based on the OEM manual of the LKAS into ODD-In, ODD-Out, and ODD-Not In Or Out;
- 19 licensed drivers participated in the study (16 males, 24-59 years old (M=41.32, Std.=12.24), Vehicle kilometres in a semi-automated vehicle: 100-10000 kms (M=24.74; Std. =30.74));

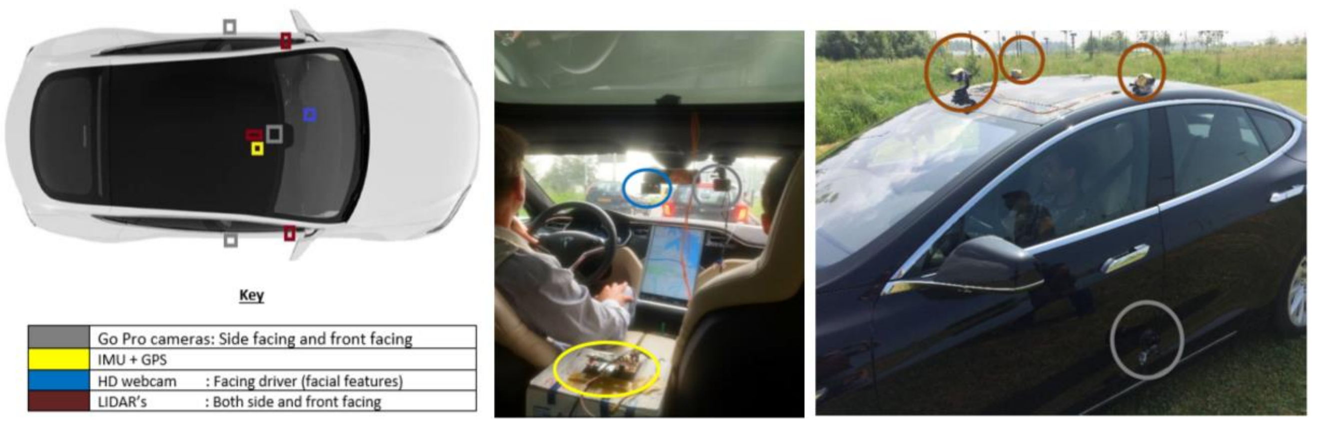


Figure 2: Illustration of vehicle instrumentation.

In addition to the field test, the participants completed:

- **Pre-drive questionnaire:** participants' personal demographics, initial trust, confidence, attitudes, and prior experience with semi-automated vehicles and LKAS;
- **During experiment questionnaire:** (a) for each situation, real-time trust in the system (scale from 1 to 5); (b) report if the situation was inside, outside or maybe in/out of ODD;

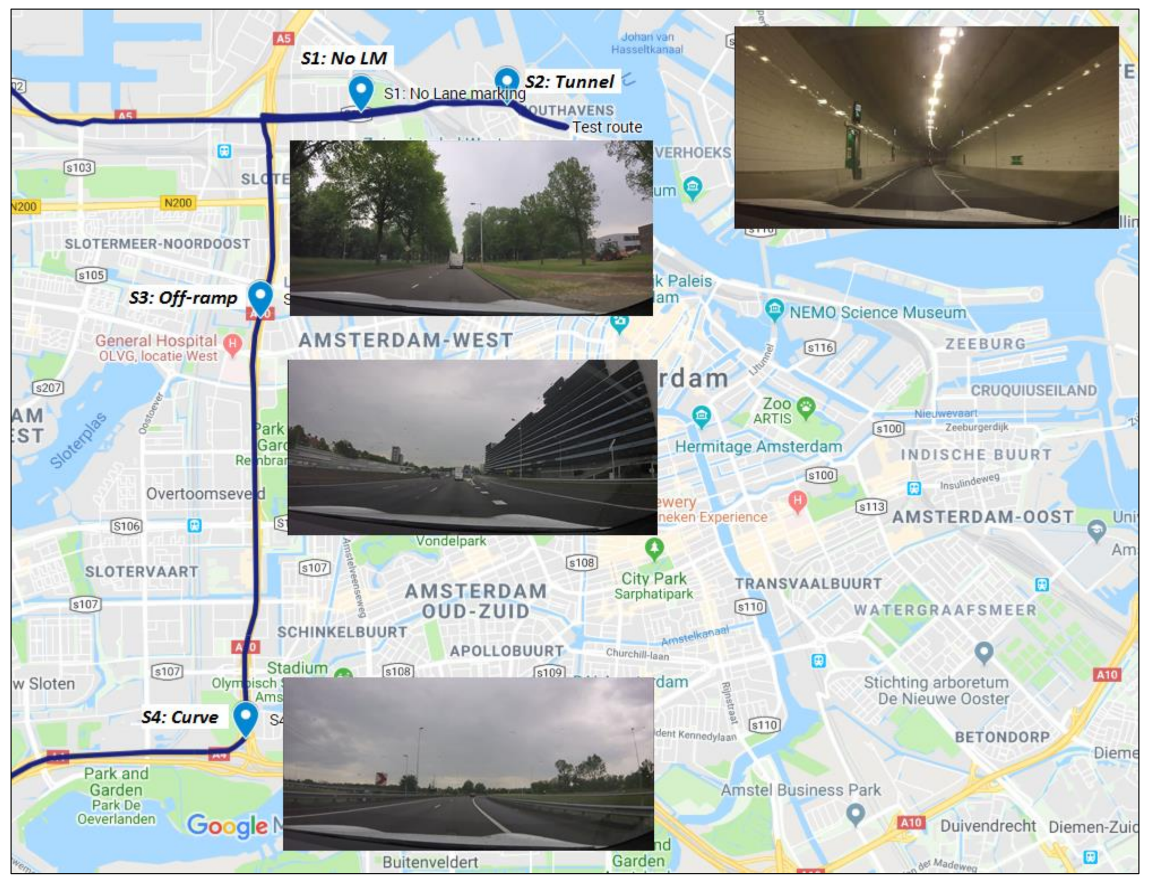
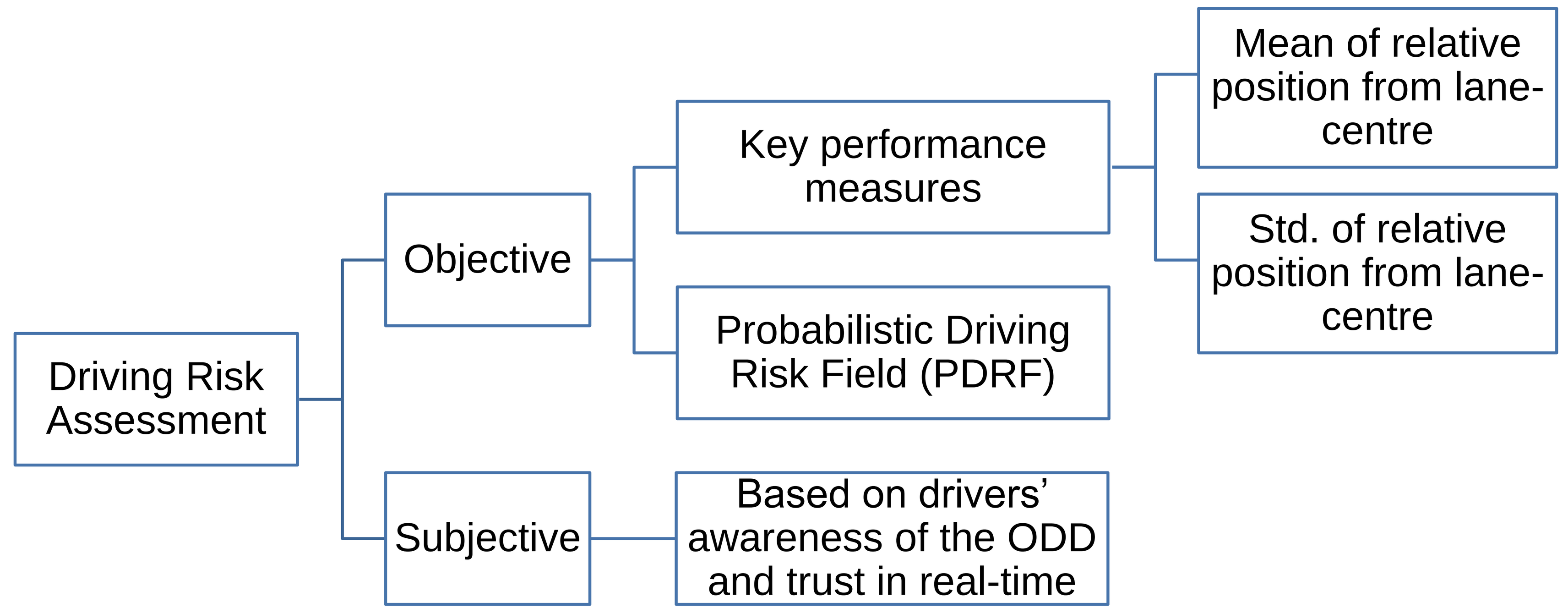


Figure 3: Snapshots of the four selected road situations

Selected situations: *ODD-In*: moderate and mild road curve (S4: Curve); inside a well illuminated tunnel (S2: Tunnel). *ODD-Out*: road inside the city with no lane marking on its boundary (S1: No LM). ODD-Not In Or Out: near an off-ramp (S3: Off-ramp).

Procedure: (1) Signing the informed consent form and completing the pre-drive questionnaire; (2) Introduction by Tesla safety driver about the LKAS and familiarization with the Tesla Model S; (3) participating in the road test and completion of real-time questionnaire.

3. Analysis method



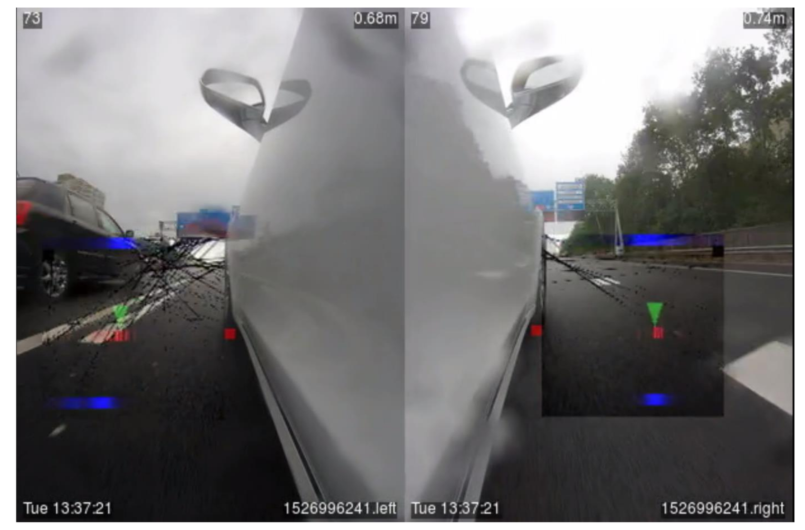


Figure 4: Position of vehicle within its lane.

Potential risk field:

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

$R_{b,s}$ - risk to subject vehicle due to road boundary b
$r_{s,b}$ - shortest distance between s and b
M - mass of s
$V_{s,b}$ - velocity of s along $r_{s,b}$
k - sensitivity to road boundary type.

4. Experiment results

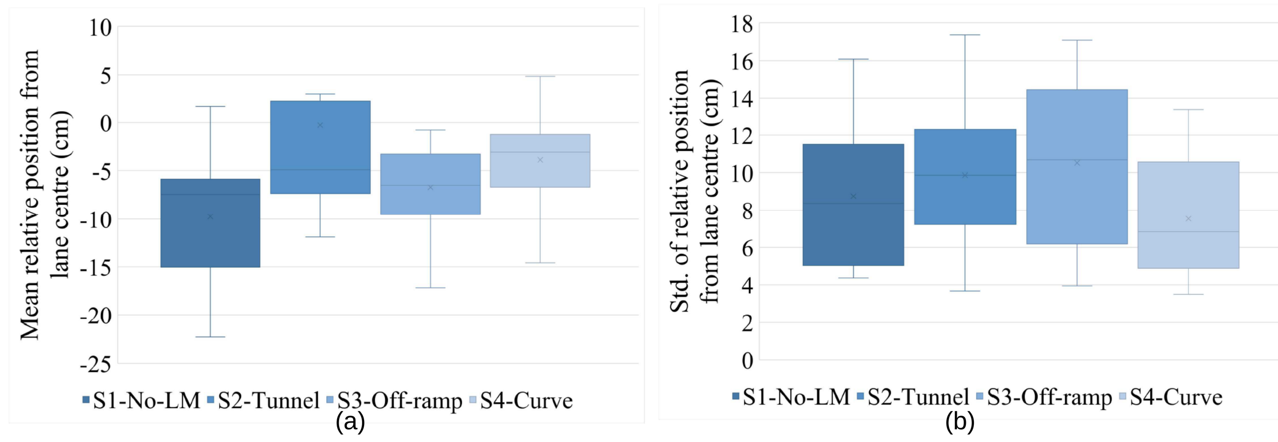


Figure 5: (a) Mean relative position from lane center; (b) Standard deviation of relative position from lane center.

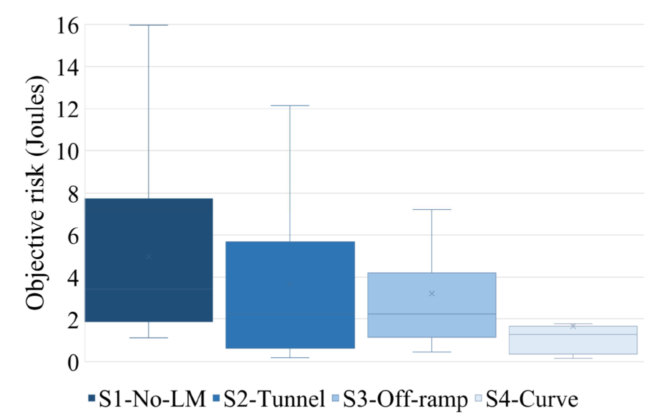


Figure 6: Maximum objective risk derived with potential risk field.

5. ODD Assessment

Table 1: ODD assessment of the selected situations

Test Situation	Lane Keeping System Performance	Risk of Driving	ODD mismatch
S1-No-LM (ODD-Out)	▪ High bias towards left of lane centre; ▪ Considerable variation.	Highest	Second highest (68.7%);
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%).
S3-Off-ramp (ODD-Not In Or Out)	▪ Slight bias to left of lane centre; ▪ Highest variation.	Second lowest	Highest (81.2%);
S4-Curve (ODD-In)	▪ Closest to lane centre; ▪ Smallest variation.	Lowest	Lowest (6.25%).

6. Conclusions

- Clear differences were identified between LKAS performance and objective driving risks across selected test situations;
- A mismatch between ODD specified by the OEM and that by the drivers was observed across all selected situations;
- Prior driving experience in a Tesla did not have significant impact on the mismatch in ODD awareness of drivers;
- The proposed assessment method is useful for comparing different situations and not for making decisions regarding inclusion/exclusion of situations from the LKAS's ODD.

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