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# Driving Experience Versus Mental Stress at Assisted Lateral Guidance

Assisted lateral guidance, such as lane keeping assistance systems, is a key to the successful introduction of highly automated driving. What does the customer feel when using lane keeping assistance systems and what psychological and physical effects are caused by the various driving scenarios? What expectations does he have in terms of driving experience? What is perceived as pleasant and unpleasant, what is accepted and what attributes are a no-go? The University of Applied Sciences Kempten and MdynamiX have investigated these questions in wide-ranging studies with a total of 120 subjects in field tests.

## 1 MOTIVATION

Customer acceptance of automatic driving functions in level 1 and 2 (Advanced Driver Assistance Systems, ADAS) is of immense importance and the key to a successful introduction of Automated Driving (AD) according to level 3+. Finally, customer acceptance will be achieved with benefits, the ease of use and a positive driving experience. The Kempten University of Applied Sciences and MdynamiX have set themselves the goal of researching the driving characteristics and driving experience of ADAS/AD and describing them with a clear evaluation and target metric. In the study, even experts complained about excessive workload and stress when using Lane Keeping Assistance Systems (LKAS). This led to the idea of using subject studies to investigate these questions in real life and to question the end user.

## 2 LKAS FUNCTION – STATE OF THE ART

There are two types of LKAS. The edge guidance (type 1) supports with an abrupt steering torque intervention only when approaching the lane boundary, **FIGURE 1** (top). In the case of central guidance (type 2), however, the central track guidance is also supported in the central area, **FIGURE 1** (middle). The steering torque intervention is comparable to that of a half pipe or a V-profile. The test vehicles used in the studies were all equipped with LKAS type 2 with steering torque control. In particular, the moderate track guidance quality and drift pendulum were noticeable in almost all benchmark vehicles, **FIGURE 1** (bottom). Due to own or road excitations, for example road restrictions, unforeseen breakthroughs of the lane boundary occurred. In addition, unpredictable sudden system drop-offs were detected, leading to the suspicion of increased stress and lower customer acceptance.

## 3 METHODS AND PROCEDURE

The subjective and objective characteristics were transferred and linked to a so-called level model, which consists of subjective customer evaluation, subjective expert evaluation and objective characteristic values (Key Performance Indicators, KPIs) [1]. At the top customer level are the main criteria such as lane tracking quality, edge guidance, vehicle reaction, driver-vehicle interaction, availability, de-stress, sense of safety and HMI, which are further detailed at the subjective expert level. To objectify the subjective expert criteria (KPIs), new measurement and test methods based on ground-truth methods have been developed [1]. Based on these results, three subject studies were conducted:

- study 1: stress study with recording of subjective stress as well as objective measurement of physiological parameters on the basis of one vehicle
- study 2: benchmark study to record customer requirements with three premium vehicles
- study 3: validation study to investigate the habituation effect on the basis of one vehicle.

In order to work on the topic as holistically as possible, a team formation was made of specialists from the areas psychology, vehicle dynamics evaluation, measurement, product management and data analysis.

But what is human stress? It is a psychological and physical reaction caused by specific external stimuli, which enable the human to perform difficult tasks [2]. In general, it is a protective reaction that

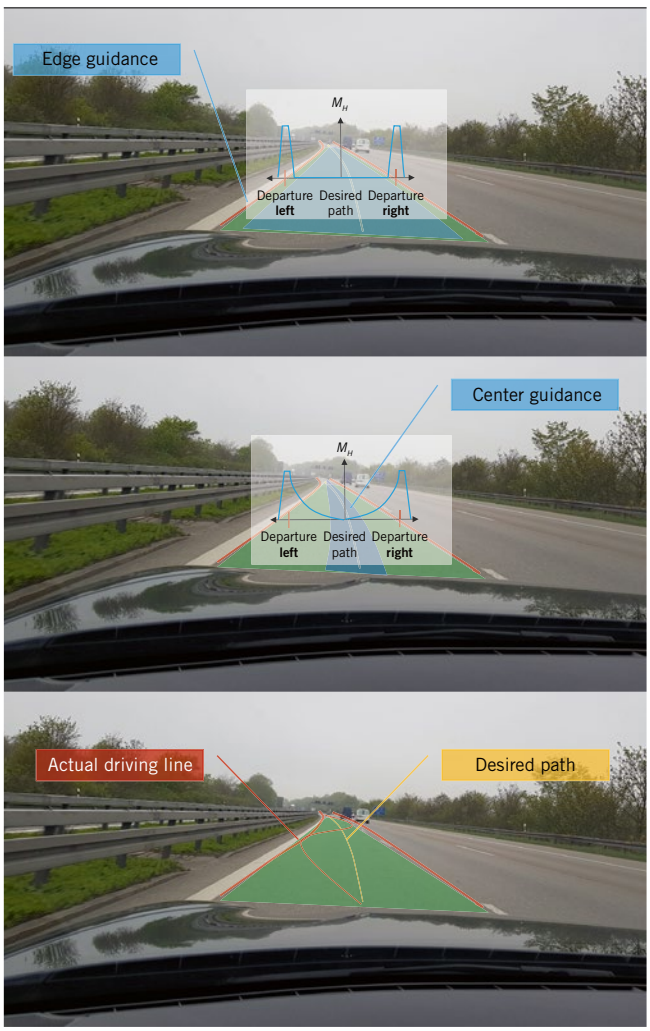


**FIGURE 1** State of the art LKAS type 1 and 2
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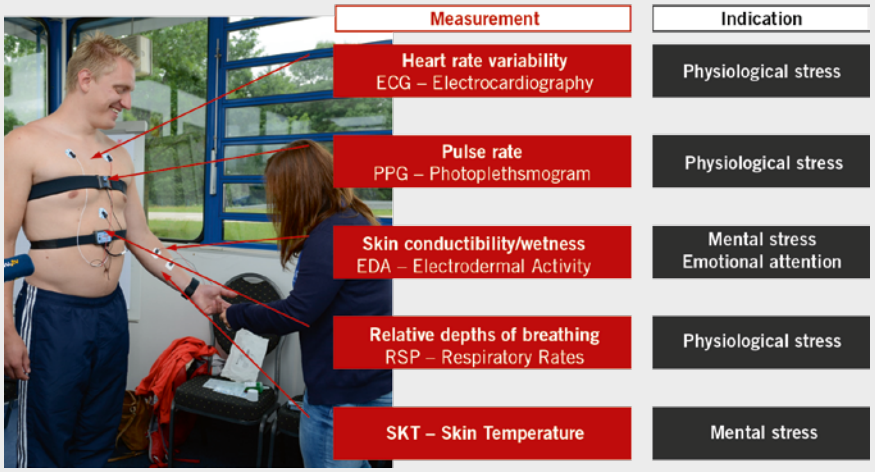


**FIGURE 2** Measurement of physiological parameters (© University of Applied Sciences Kempten)

leads to higher performance, but it is also perceived as uncomfortable and can even make us sick. In contrast, reduced stress in the context of performing the driving task means facilitating the driving task, reducing the driver's workload, increasing the ride comfort, increasing the maximum driver performance and thus increasing driving safety. This would be desired by the LKAS.

### 3.1 STRESS STUDY

Based on the given experience, the following working hypotheses were developed. The LKAS evaluation is influenced by the subjectively experienced stress, the driver's workload, the experienced driving pleasure and the experienced driving comfort. The subjective stress and driver's workload are associated with the use of LKAS. These are significantly higher with the use of LKAS than without the use of LKAS. The physiological values and objective stress indicators are related to the use of LKAS and correlate [3].

50 participants aged between 18 to 65 years were chosen for the study. The used test vehicle was a current premium luxury class vehicle, which was equipped with a high-end Inertial Measurement Unit (IMU) with Real Time Kinematic Differential-Global Positioning System (RTK D-GPS) to record the precise vehicle position and motion. Additionally, CAN/FlexRay bus signals were recorded, such as steering angle, steering torque, cockpit display and the camera's object information. Likewise, the physiological parameters of the subjects were recorded, such as heart rate variability (ECG), skin conductibility/wetness (EDA), pulse rate (PPG) and relative depths of breathing (RSP), **FIGURE 2**. Besides existing questionnaires, such as Nasa-TLX [3] and driving fun and comfort by Anna Engelbrecht [5], own questions were developed to get a complete insight into the driving activity with LKAS. All subjects underwent a uniform process with explanations, initial questions, instrumentation, introduction to the vehicle, familiarization phase, driving with and without LKAS on the highway and country road at 120 and 160 km/h, subjective stress assessment during and after the drive as well as result questions [3].

### 3.2 BENCHMARK STUDY

The benchmark study with 50 subjects should answer the following questions: What does the customer want? Which characteristics are rated as good and are therefore accepted? Which ones disappoint and which ones are no-go? What are the differences between the systems in the tested vehicles? How is the interaction of the customers with the systems? At what maturity level is the customer ready to use the system?

Three current premium vehicles from different manufacturers were used. The test program was without physiological measurements and psychological questions. For this purpose, a questioning process based on the Quality Function Deployment (QFD) and Kano methods and a cause and effect chain analysis were developed [4]. In this way, it should be possible to work out the customer requirements for the LKAS. In order to be able to evaluate the individual criteria at the customer level, the subjects were instructed during the test ride on relevant situations and maneuvers. After each experience and evaluation, the requirements and wishes were recorded directly in an open questionnaire dialog.

Approximately 50 % of the 50 test persons were from the stress study and therefore mostly familiar with the LKAS. These were randomly divided into two groups: Each group had to evaluate one of the vehicles 2 or 3 against the reference vehicle 1. In total, 100 test drives over 4000 km were conducted. Here, the differences, strengths and weaknesses and the resulting optimization potential for current and future automatic lateral driving functions should be derived. The question about the importance of the criteria was carried out before and after the test ride in order to detect a possible sensitization of the subjects on certain criteria. Methods such as QFD [6] and Kano, as well as the Technology Acceptance Model (TAM) were applied for analysis. With QFD, the customer's wishes could be identified, differentiated with Kano and classified in the TAM and finally translated with QFD into technical features and properties [4].

## 4 RESULTS

In the following, the results of the stress study, benchmark study and validation study will be presented in more detail.

### 4.1 STRESS STUDY

The repeated measures analysis of variance with Greenhouse Geisser correction shows that the stress experiences differ greatly

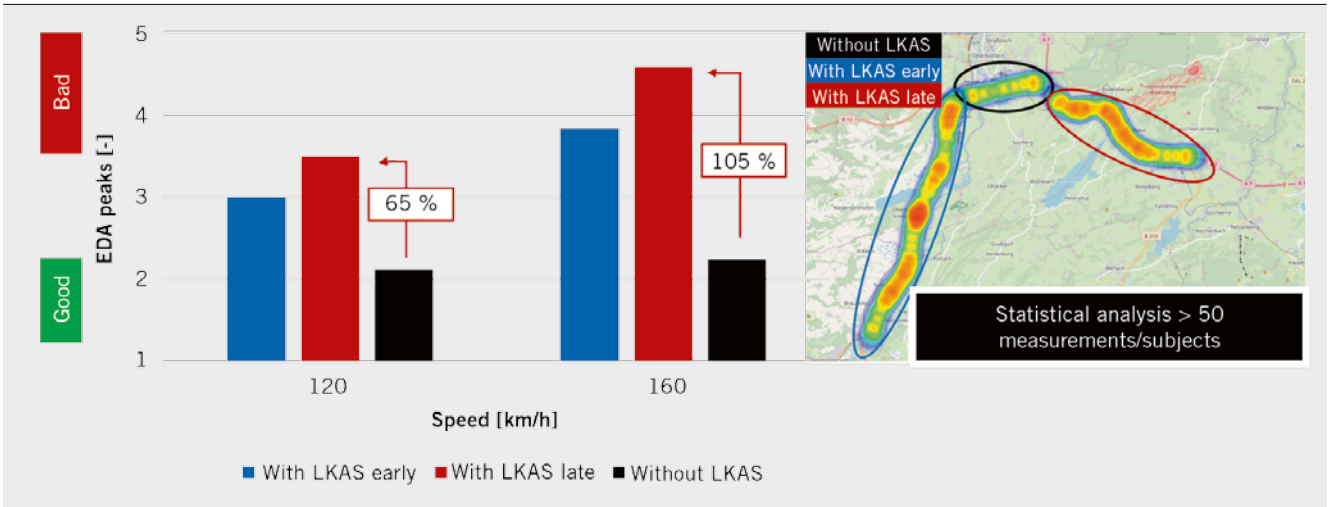


**FIGURE 3** Subjectively perceived and objective stress (© University of Applied Sciences Kempten)

depending on the test section. A Bonferroni corrected post-hoc-test indicated a significant difference in load between driving with LKAS and without LKAS at both 120 and 160 km/h. **FIGURE 3** shows the increase in stress experienced with LKAS. The statistical analysis of all objective data of the stress indicator EDA peak also states a significant increase and hotspots on certain sections of the route. In sum, the test subjects felt much more stressed with LKAS [3].

Significant correlations were also found in the items and overall comfort factor at customer level. The items calming, relieving, relaxing, uncomplicated and supportive correlate significantly with the score of the LKAS. The total comfort factor, which is composed of ten items, also correlates significantly with the score. If the LKAS is rated better, the comfort experience increases.

The feedback from the subjects and the evaluation of the questionnaires make it very clear that the perceived stress is due to a lack of trust in the LKAS. These are the results of sudden system drop-offs without warning in seemingly normal driving situations, unforeseen system limitations, malfunctions (true-negatives), inconsistent feedback, necessary ad-hoc takeovers as well as the lack of transparency and high monitoring effort. **FIGURE 4** shows an example of a typical case that has occurred repeatedly and several times per trip with all vehicles. The system drops off for

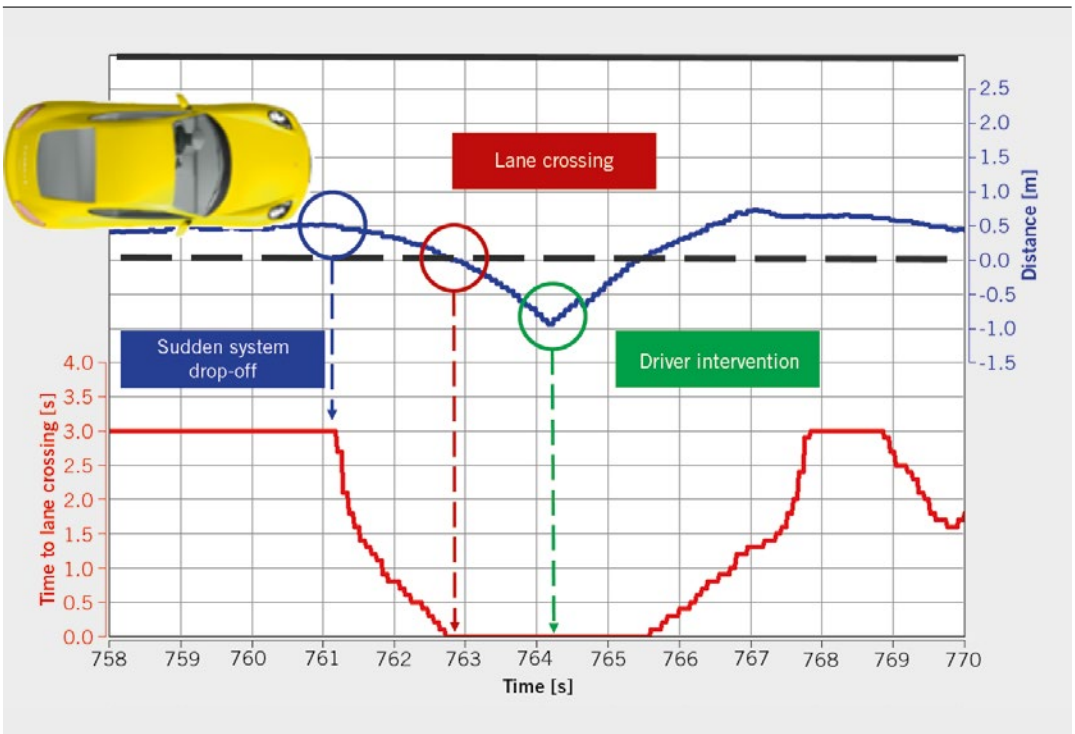


**FIGURE 4** Unexpected system drop-off leads to a sharp increase in EDA levels (© University of Applied Sciences Kempten)

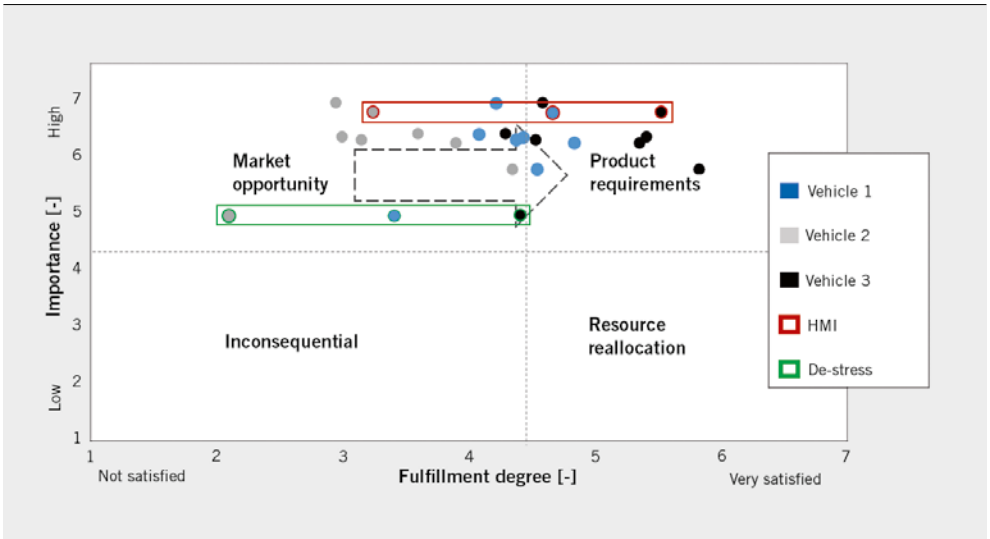


**FIGURE 5** Market opportunity of rated criteria (© University of Applied Sciences Kempten)

some reason or stops working without being displayed. The drivers realized this only when they left the lane. They intervene and lead the vehicle by strong steering back into the lane.

### 4.2 BENCHMARK STUDY

The majority of participants of the benchmark study would like to see increased road safety (65 %) in the context of LKAS. Thus, the customers expect that the LKAS is able to keep the lane reliably at all times (when symbol is green) of the purpose of use. On the given Likert scale (1 = not important to 7 = very important), six of the eight criteria were evaluated with an importance of at least six. The criteria with the highest importance were the feeling of safety, the human-machine interface (HMI) and the edge guidance. This result is in line with the experience gained during the expert test rides. Also subjects complained the workload and stress by using the LKAS. Strong tracking offset to the outside of the curves were perceived as extremely unpleasant. Sudden unpredictable system drop-offs were rated as absolute no-go. Non-transparent system boundaries and high monitoring effort were rated poor in the sense of safety feeling and comfort. The degree of fulfillment shows considerable deficits to all criteria. **FIGURE 5** clearly shows the results in a Market Opportunity Map (MOM). Overall, it is assumed that a good head-up display has a positive interaction with other criteria because of the necessary function transparency and simple monitoring. According to subject statements, drivers can relax more and focus on traffic environment and events.

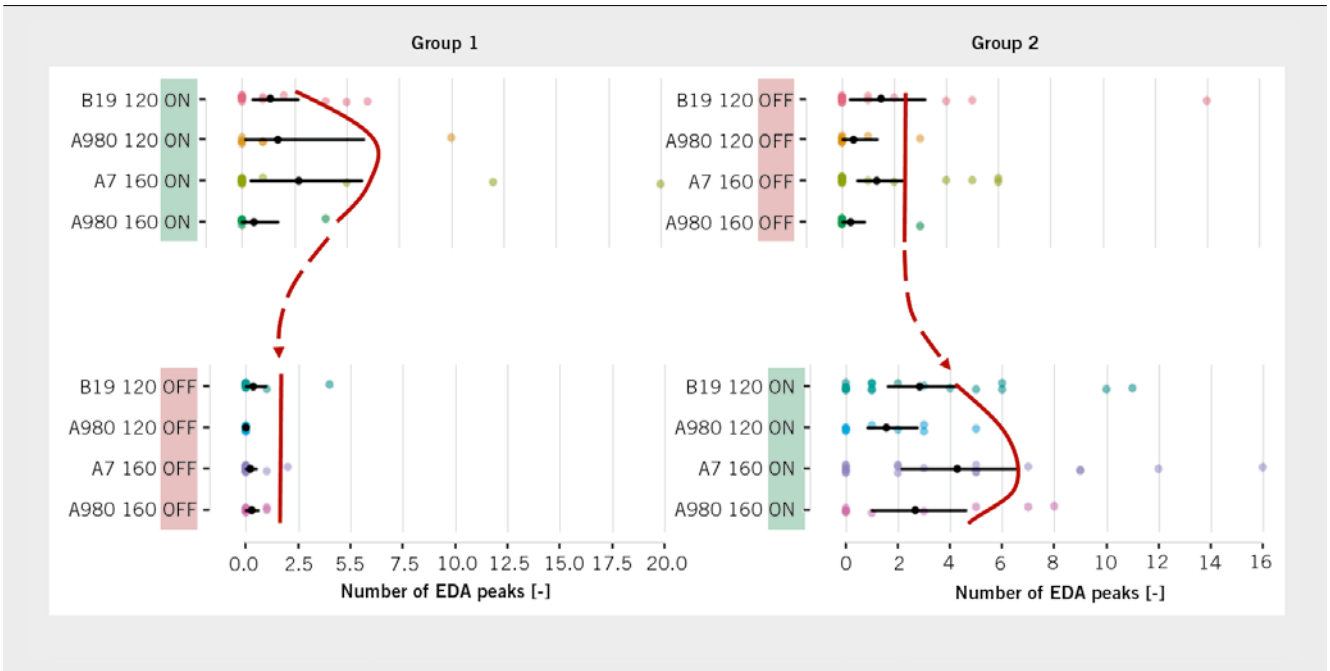


**FIGURE 6** EDA peaks at LKAS on and LKAS off on various federal roads and highways at 120 and 160 km/h respectively (© University of Applied Sciences Kempten)

### 4.3 VALIDATION STUDY

In order to investigate the acclimatization effect and the influence of the test sequence and to confirm the results of study 1, the study 3 was conducted. 20 subjects from studies 1 and 2 were admitted and drove exactly the same routes with and without LKAS. One group started with and continued without LKAS and vice versa. **FIGURE 6** shows the level of mental stress based on EDA peaks. This clearly shows an increase with LKAS, no matter in which order and confirming the results of study 1. An acclimatization effect can only be observed very little, if at all.

## 5 SUMMARY

A statistical analysis of all 50 subjects from the stress study showed that the LKAS significantly reduces the steering effort while driving. In the classic objective driving comfort assessment, however, only the physical strain of the human being in terms of (muscle) effort is assessed. This is far from sufficient for ADAS/AD. The consideration of psychological stress for a holistic comfort assessment is of immense importance here, as the studies 2 and 3 showed. Even experts and subjects complain about the mental stress when using LKAS. Unpredictable system drop-offs, non-transparent system boundaries, high monitoring effort and poor tracking quality led in particular to poor rates in the sense of safety feeling and comfort. Here, trust and the associated customer acceptance play a central role. Ultimately the breakthrough of automated driving will decide on customer acceptance. The findings show that in ADAS/AD development, the human being should be placed much more in the center of development. Furthermore, it is necessary to focus on driving attributes and the driving experience in the sense of an attribute-based development. Therefore, measures shall be derived that increase the customer's acceptance. The clear and always transparent communication between human and machine, a positive subjective driving experience (for driver and passengers), reliable availability and predictability form the basis of a good customer assessment. A good HMI based on the principle "trust is good, control is better" can be very effective here, too.

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