Trust Is Good, Control Is Better? – The Influence of Head-Up Display on Customer Experience of Automated Lateral Vehicle Control

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Abstract. Advanced driver assistance systems (ADAS) support the driver in certain traffic situations and can increase road safety. For this appropriate interaction, concepts between the driver and the assistance systems are required, which focuses on driver's needs. In a user-centered study with N = 48 subjects, interviews and questionnaires were conducted during a test drive in real road traffic in order to test and evaluate the lane keeping assistant system (LKAS) with head-up display (HUD). In addition, two current premium vehicles from various manufacturers were used to investigate the influence of the HUD on the user experience and to derive optimization potential for current and future automatic driving functions. In comparison to the test rides with LKAS in combination without HUD (with head-down display), it can be determined that there is a positive influence of HUD on the experience with LKAS.

Keywords: User experience · Head-up display · Lane keeping assistance system · Customer acceptance · User-centered design

1 Introduction

Mobility is constantly changing worldwide. The automobile has always been associated with attributes such as passion, commitment and high emotionality. At the same time, new developments such as Advanced Driver Assistance Systems (ADAS) and Automated Driving (AD) have introduced both solutions and challenges. To achieve high user acceptance and an emotional driving experience, a system transparency and sufficient feedback - as in conventional driving mode - are necessary. In particular, the driver has to understand the system so that they can intervene at any time, which is also currently required for level 2 automation [1, 2]. An appropriate human-machine interface (HMI), which focuses on the needs of the driver, is essential here [3–5]. The person who hands over control to a machine wants to feel well informed about the status of the system, which plays a major role in his or her wellbeing and for the user experience (UX) [6]. Man and machine should not be considered separately, but as a whole, whose

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strengths complement each other and weaknesses balance each other out [7]. Thus, the goal of the development of human-computer interaction (HCI) is a seamless interaction of devices, so that the user must do as little as possible. Because the best interaction with a device is when the device suspects what the user wants [8]. It is about non-verbal communication in which both parties "understand" each other to manage the tradeoff between over-trust and under-trust. Over-trust leads to higher risk, whereas under-trust leads to non-usage of the system [9]. Only systems that offer added value are used by people [10], and only used systems can generate their benefits.

A pilot study with N = 50 subjects, conducted by MdynamiX and University of Applied Sciences Kempten on automated lateral vehicle control respectively lane keeping assistance systems (LKAS), has shown that customer acceptance is poor for all three vehicles tested. In the case of one of the three vehicles, a better evaluation and a more positive UX by the customers compared to the experts/engineers were found. Our hypothesis: The Head-Up Display (HUD), this one vehicle was equipped with additionally, has a substantial influence on the LKAS evaluation [1].

2 User Experience with LKAS

Firstly, for a better understanding, the following section deals with the subjects walk-thru, based on the method customer walkthrough according UX [10] and related driving experience during the pilot study with LKAS in combination with a head-down display (HDD) [1, 3].

- The test person gets into the car, has a certain expectation of the system and comes into contact with the HMI of the LKAS the first time by switching it on. The first hurdles appear here, as some car manufacturer use complicated non-intuitive operating functions, such as lever functions or switching on buttons via the board menu. The respondent is overstrained and needs support. Only in a car model with a one-button operation, the respondent is able to switch on the system without support.
- System is switched on, test person drives with LKAS, which becomes active from a speed of approx. 65 km/h. They can follow the status of the system via the LKAS symbol in the HDD. A driver-vehicle interaction is created. There are differences in display and design between the manufacturers. The size of the LKAS symbol can thus vary between 1.5–3 cm depending on the manufacturer. If the system is active and the camera detects the lane, the symbol is green. In order to monitor the system status, the test person must look away from the road every few seconds to read the status in the HDD. The test person experiences a certain quality of lane guidance. The system does not follow a precise lane, so an oscillating between the lane markings is noticeable.
- The vehicle approaches the lane markings and the test person feels unsafe. The system drops for an inexplicable reason. At best, a warning comes exactly at the moment of the system drop-off (LKAS symbol in the HDD changes from green to grey, an audible warning signal is sometimes issued). In this short time, the test person cannot even watch the HDD and perceive the system status. There may also be no warning at all. The subject is surprised and asks why the LKAS dropped-off even though the conditions were perfect.

- The drop-offs are not reproducible, so that a familiarization effect can develop little or not at all. Thus the expected availability of the system is not given. This also affects the driver's safety feeling and the desired relief is not noticeable. The driver is disappointed, stressed and feels unsafe.

In summary, while driving with LKAS the drivers do not only have the task of keeping the lane:

– They also must monitor the system via the HDD all the times.
– They also must be ready to intervene at any time due to the sudden drop-offs.
– They also must adjust to the fact that transparency with regard to the system status is not given always and all the time.

2.1 Results Overview of the Pilot Study

In the preliminary customer study with N = 50 subjects, the customer wishes/acceptance of the LKAS were/is tested, evaluated and compared on public roads. In addition, three latest premium vehicles from various manufacturers were used to derive optimization potential for current and future automated driving functions. About 50% of the subjects were already familiar with the LKAS and the reference vehicle (vehicle 2). To avoid the inaccuracy caused by tiredness, the subjects were randomly divided into two groups, each comparing two of the three vehicles. In total, 100 test drives over 4000 km were conducted. The average age of the people was 35 years. One third of the participants (30%) were women [1].

The three vehicles were equipped as follows:

- Vehicle 1 with LKAS (center guidance) in combination with HDD
- Vehicle 2 with LKAS (center guidance) in combination with HDD
- Vehicle 3 with LKAS (center guidance) in combination with HUD

The results show that for all LKAS criteria, such as "human-machine-interface" (HMI), "lane tracking quality", "edge guidance", "vehicle reaction", "driver-vehicle-interaction", "availability", "safety feeling" and "degree of relief" [3], each manufacturer has a "GAP" of importance to the degree of fulfillment. However, it is also shown that the LKAS of one vehicle performs better than the competitor vehicles in seven of the eight criteria. In summary, it can be seen that the importance of the criteria is not fulfilled in the implementation. On the basis on one example result of the Market Opportunity Map (MOM) the main findings of the study should be illustrated. This map shows serious deficits of individual manufacturers in a different way. The MOM is an illustrative opportunity for customer management to gain an overview of the areas in which action is needed to optimize the performance. It is based on the customer satisfaction portfolio and the strengths and weaknesses portfolio [11]. It represents the mean values for each LKAS criterion for each test vehicle.

It becomes clear that the better the criterion HMI (circled with dotted stitches) is evaluated, the better the criterion degree of relief (circled with continuous stitches) is evaluated. The statement that the LKAS of vehicle 3 performed best in this benchmark study was confirmed by other questions and is illustrated by the following figure.

It should be noted that vehicle 3 was additionally equipped with a HUD compared to the other two test vehicles. This led to the assumption whether the HUD was the reason for a better assessment of the LKAS.

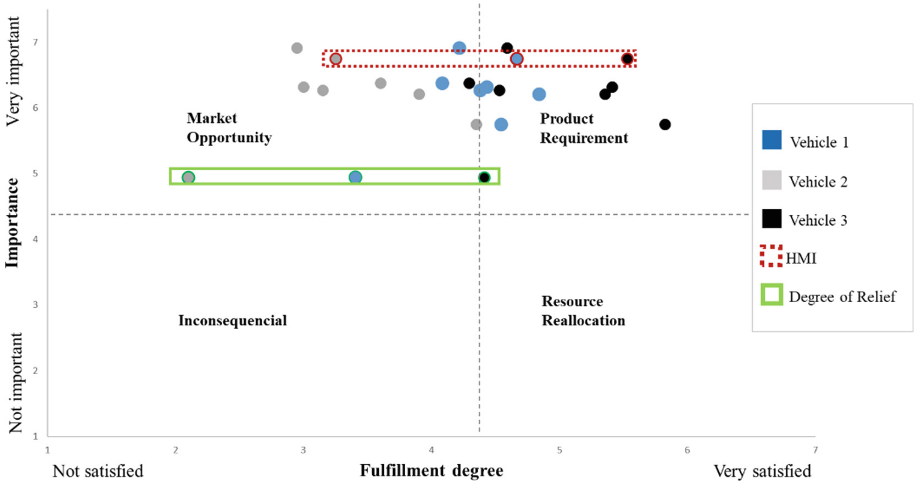


Fig. 1. Market Opportunity Map (MOM) for the LKAS criteria of all tested three vehicles of pilot study

3 Experimental Design

To verify our hypothesis, the customer experience and evaluation of the LKAS with and without HUD were tested on public roads over more than 5900 km. Two current premium vehicles from different manufacturers (equipped with LKAS and HUD) were used to examine the influence of the HUD on a test drive with LKAS as benchmark.

3.1 Participants

In total, N = 48 subjects (M_Age = 37.67; SD = 15.69, Range: 19–70), 11 females (23%) and 37 males (77%), participated in the test drives. The employment status of the sample was composed as follows: 31% of the subjects were college students, 30% employees, 15% professors. Participants were not paid for completing the experiment. They were recruited through a call for tenders at the University of Applied Sciences in Kempten. The remaining 24% of the participants were three pensioners, one journalist, one engineer, an office clerk and one person was engaged in purchasing. 41 test persons (85%) had an annual mileage more than 6000 km.

38% of the test persons had already participated in at least one study with the LKAS of MdynamiX and the University of Applied Sciences Kempten. All subjects had normal visual acuity or visual acuity correction.

3.2 Vehicles and Equipment

In order to test the two ADAS in the benchmark, two premium vehicles from different manufacturer were used. Both vehicles are equipped with HUD that can be switched on and off via board menu while driving with LKAS.

For the present experiment, LKAS (type 2) with an early, continuous steering support, a so called "center guidance", was used. The center guidance is also supported in the central area of the road. The steering torque intervention is comparable to that of a half pipe or a V-profile [12]. The subjects could activate the system in vehicle 1 via board menu or, as in vehicle 2, via button on the steering wheel.

The HUD used for the experiment contained the following information, which could also be seen in the HDD:

- recognized and currently valid traffic sign
- the actual speed travelled
- currently active ADAS and its state (in this case LKAS)

In preparation for the study, both systems were examined by the test manager and a more detailed functional survey was carried out, e.g. whether a step-by-step warning had been issued.

Figures 2 and 3 show the used two systems. Figure 3 is intended to illustrate visually the display information in the HUD compared to a HDD, which was tested by participants while driving.

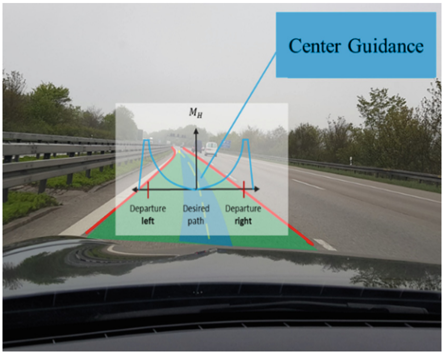


Fig. 2. Lane keeping assistant system with early support (center guidance) [3]

Fig. 3. Head-up display and head-down display (picture bmw.de)

3.3 Test Route

The test route should reflect a "real and customer-oriented car journey" and enable the test persons to recognize the potentials and advantages of the two assistance systems as well as weak points and disadvantages. This enables an overall evaluation of the display concept. It had a length of 61.1 km (per vehicle) and the average driving time was 45 min (including an acclimatization period). It contained 16 cornering events and consisted of two sections (federal highway B12 and B19) that were 90% identical.

Only the length of the test drive on B19 with LKAS combined with HUD was extended by one exit. This should give the subject a sufficient time slot to test the two assistance systems. Each test person drove the two vehicles immediately one after the other on the defined test route, with defined maneuvers and a speed of 100 km/h–130 km/h during their test participation.

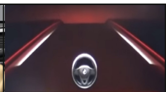
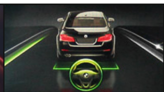
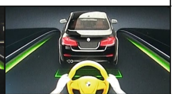
3.4 Methods

In order to place the human being at the center of the development, methods such as Quality Function Deployment (QFD) [11] and KANO [13] as well as the Technology Acceptance Model (TAM) [14] and Rodgers Diffusion of Innovation Model were applied.

In addition product specific criteria were developed. Therefore, the LKAS evaluation matrix, so called “Level Model”, was extended by HUD evaluation criteria for a structured HUD assessment on customer and expert level. Main customer criteria of the LKAS-Level Model are “human-machine-interface” (HMI), “lane tracking quality”, “edge guidance”, “vehicle reaction”, “driver-vehicle-interaction”, “availability”, “safety feeling” and “degree of relief” [3]. The main criterion Human-Machine-Interface (HMI) has been replaced by the extended user-oriented HUD Level Model, which has been developed under consideration of different situations the driver is confronted with when driving with LKAS. For each evaluation criterion, the influences of the driver, the vehicle and the environment must be taken into account.

Following use cases were identified during a test ride with LKAS, which the driver experienced during the journey (Table 1).

Table 1. Method of the use case-oriented development (pictures bmw.de)

	Use case 1	Use case 2	Use case 3	Use case 4	Use case 5
Use cases					
What is happening ?	**LKAS off:** Driver steers	**LKAS on:** No line detected; Driver steers	**LKAS on:** One line detected; Driver steers	**LKAS on:** Two lines detected; Vehicle steers	**LKAS on:** Hands-off time reached; Vehicle steers Intervention necessary
Driver Vehicle Environment	What must appear in the display? What kind of warning must be given? What must be taken into account during monitoring?	What must appear in the display? What kind of warning must be given? What must be taken into account during monitoring?	What must appear in the display? What kind of warning must be given? What must be taken into account during monitoring?	What must appear in the display? What kind of warning must be given? What must be taken into account during monitoring?	What must appear in the display? What kind of warning must be given? What must be taken into account during monitoring?

Furthermore, a detailed description of the criteria “operation”, “display”, “design”, “monitoring” and “warning” has been developed, that have been included in the Level

Model (Fig. 4) with sub criterions. This matrix enables a holistic evaluation of the HUD in combination with an LKAS. To illustrate the methodology, the following figure shows a section example of the Level Model with regard to the criterion "warning".

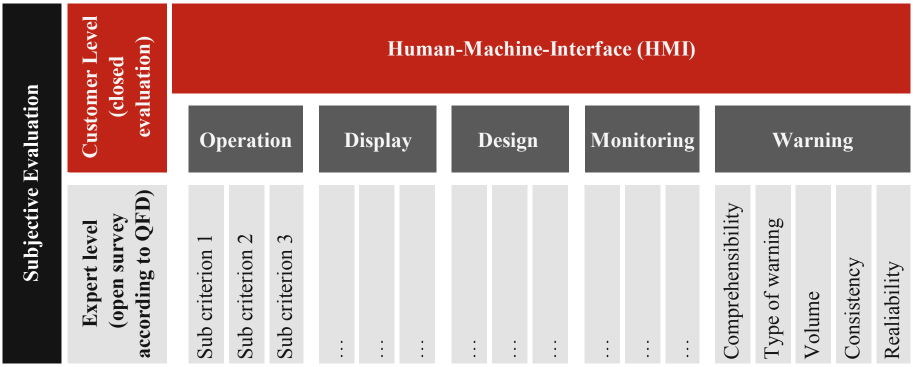


Fig. 4. Level Model to evaluate head-up display or head-down display

3.5 Procedure

The philosophy of the study was based on gaining knowledge in driving situations that were as real as possible. Such studies are not yet known for the LKAS. In most cases, comparable studies are carried out only in driving simulators. The environmental situations and vehicle reactions as well as the risk potential and the resulting feeling of safety for subjects are sometimes perceived completely differently than in the real world test ride. The driving study should gain valuable insights in this respect. The higher implementation effort, the increased risk as well as the comparability of the results represent a special challenge for real test rides. Traffic and weather conditions, driving maneuvers, special events, number of driver interventions and the resulting LKAS system behavior are more difficult to control and plan. This randomness, however, offers valuable insights. In order to achieve comparability even of real test rides, the route selection was fixed, a uniform time window under consideration of the traffic conditions, driving instructions such as speed limit, lane selection, lane excitations and the framework for comparable weather conditions were defined. All of these aspects were summarized in a so-called road book (guideline) based on test routes. All instructors and interviewers were trained in this context.

Since the LKAS system is essentially stimulated by the road (road markings, topology, etc.) and the vehicle speed, the system behavior and the events of system drops were reproducible in this respect. Due to the clear position reference, the events for the selected route sections could be planned very well. For all sections, highly accurate Ground Truth maps were also available.

The adaptation of a product does not happen instinctively, but it rather is a process that lasts over a period and contains certain actions. People only speak of an innovation when they themselves acquire knowledge and know-how about a product. Everett Rodgers' Diffusion of Innovation Model divides the adaptation process into five phases, "Knowledge", "Persuasion", "Decision", "Implementation" and "Confirmation", which this study has taken into account [15].

The design of the study was based on the driver-vehicle-environment closed loop principle as well as on specific driving scenarios, respectively on driving maneuvers, which were exactly described in a guideline. At the beginning of the study, the test persons were welcomed, their driving license checked and a declaration of liability issued. An explanation of the procedure was given before the test persons received the first part of the questionnaire. As an introduction, two video clips was shown which demonstrated and explains the HUD and LKAS. The following test drive was carried out with two premium vehicles in which both systems were installed. Additionally the test persons were instructed in the test vehicles. After the subjects have adjusted their driver's seat, the side mirrors, the rear-view mirror, width, height and inclination angle/rotation of HUD, the test drive began after a short familiarization period. The HUD standard setting, the time of intervention of LKAS (early) and the volume of the warning (middle) could not be changed in order to ensure equal weighting.

The test persons were divided into 2 groups, so that 24 test persons first started with LKAS in combination with HUD, the other 50% started with LKAS in combination with HDD. Each test person drove both vehicles immediately one after the other as part of his test participation, so that the defined test route was driven four times. To support the test persons, the interviewers explained various possibilities for testing the LKAS and the HUD while driving. Crossing the lane without indicating and the resulting warning was one maneuver. The interviewers guaranteed the proper use of both systems for the complete test drive.

The defined test drives were conducted randomized on the test route as follows:

- Lap 1: with LKAS in combination with HDD
- Lap 2: with LKAS in combination with HUD
- and vice versa

3.6 Questionnaire and Interview

For the type of survey, the personal interview (called paper and pencil interview or face-to-face interview [11]) beside several fix question sheets before and after the test ride was chosen. With fixed questions before the trip it was essential to learn a lot about the test persons and their attitude to the technology. During the ride, the main aim was to reproduce the test persons' driving experience and to collect requirements and wishes based on interview, and after the ride to compare the systems and evaluate the overall impressions based on a fixed evaluation sheet of the LKAS level model [3]. The interview method while real test ride was chosen in order to obtain as much information as possible from the real experiment. Sudden events, which were predictable for the instructor due to the route stimulation and driving instructions, generated very different reactions and vocabulary of the test persons. These were processed by questions and re-questions in the following rout sections so that the customer's needs and suggestions can be recorded better and can be compared. The conversation can be directed in certain directions and possible misunderstandings are dealt with directly. A refusal or omission of certain questions is excluded and ambiguities in content can be clarified [2]. The questionnaire/interview was designed in such a way that the customer has the possibility to formulate his thoughts and ideas in detail according to the QFD principle through many open questions [11]. No fixed psychological questionnaires were used, because the study was conducted on real routes and the questions were triggered by external influences. It was important to observe the reactions of the driver, their gestures and facial expressions just in time as an interviewer and to formulate the questions specifically. Existing user experience questionnaire sheets are too general and hardly applicable for LKAS during a real test rides, because of their special function and the clarity of the terms for the subjects. Furthermore, the procedure should provide insights into how a user experience questionnaire could be designed in the future in the context of the ADAS/AD driving functions.

The questionnaire/interview for the study was divided into three parts (before, during, after test ride) in order to obtain a comprehensive picture of the usability of HUD and LKAS and to capture its user experience (UX). Because UX is not only limited to the time of use, but also the time before and after the use of the product [10]. UX thus focuses on the holistic view of subjectively experienced product quality [15].

The evaluation criteria of the LKAS (lane tracking quality, edge guidance, vehicle reaction, driver-vehicle interaction, availability, safety feeling, degree of relief, which have been extended with HUD criteria (operation, display, design, monitoring, warning), form the basis of the interview. In the expert level of the level model, an interview was conducted with the test persons according to the survey method of the QFD procedure. Like that, all customer wishes and requirements could be recorded directly. All interviews - both spoken and written - were conducted in native German.

The following research questions should be answered within the scope of the study:

Research question: How does the HUD influence the driving experience and the rating of the different evaluation criteria?

- Will LKAS be better experienced and evaluated by customers due to HUD usage?
- What will the human-machine interaction of the subjects look like when driving with and without HUD?

4 Results

53% of subjects said they had a mediocre (4) to no (1) level of knowledge. A Likert scale from 1 (no knowledge) to 7 (excellent knowledge) was used.

43 participants (90%) of the benchmark want to be supported by a HUD in any situation. Considering the sense and purpose of this technical supplement, not to distract the driver from the actual driving situation, this result is pleasing. Very few drivers will switch off the HUD when entering city traffic in order to use the head-down display again. Thus, the HUD can be used as complementary support to many other ADAS such as Adaptive Cruise Control (ACC) or LKAS. For this reason, the development of the HUD requires a holistic use case-oriented approach together with other

assistance systems. A completely separate development of the system would not be target-oriented and would not be tailored to the needs of the customers.

The subjects expect the main benefit of a HUD to be that all important information is displayed on the street (42%) and thus the view remains focused on the street (42%). 24% also hope for more safety and 17% less distraction by no longer having to rely on the display behind the steering wheel. In order to be able to assess the importance of different ADAS from the test persons' point of view, ten assistance systems are to be evaluated by awarding points. For this purpose, a total of 100 points are available, which are allocated proportionally in steps of ten. With an average of 15.9 points, Adaptive Cruise Control is the ADAS with the highest importance. The Emergency Brake Assistant (15.2 points) and the Blind Spot Assistant (15 points) occupy the places behind them. The Head-up Display with 11.7 points and the Lane Keeping Assistant with 10.4 points are less important, but are still in the upper midfield. Fatigue monitoring (5.9 points) and the night vision system (4.4 points) are not very important for the test persons and are in the last two places.

In order to assess a warning concept that makes sense from the customer's point of view, the test persons are asked how they would like to be warned if the LKAS is unavailable (LKAS switches suddenly off). 43% of the participants stated that they had missed a warning at least once when driving without HUD (in vehicle 2) and 37% with HUD (in vehicle 2), which did not occur despite the system being dropped.

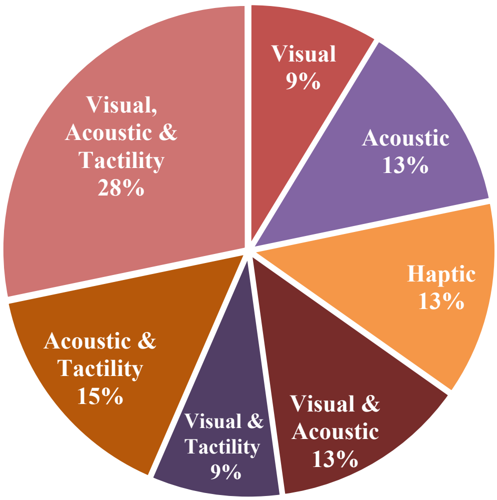


Fig. 5. Preferred warning concept for unavailability of lane keeping assistant system

As shown in Fig. 5 the triple warning is most frequently selected (visually & acoustically & tactile) with 28%. In 69% of the answers, at least the acoustic warning is desired, in 65% the haptic and in 59% the visual. This result is very interesting in view of the fact that people perceive 83% through sight, 11% through hearing and only 1.5% through touch [16] even if the haptic channel is the fastest to perceive [17]. The reason for the warning over three sensory channels could be the dropping of LKAS during the journey without any warning. Because the more senses are addressed, the greater is the effect of the recording [18]. 43% of the participants stated that they had missed a warning at least once when driving without HUD (in vehicle 2) and 37% with HUD (in vehicle 2), which did not occur despite the system dropped. The fear of being distracted and therefore not perceiving the warning visually probably explains this result. Nevertheless, it is important to reduce the amount of information to a minimum in order not to overload the short-term memory.

The questioning after QFD provides for example for the criterion “warning” following results:

According to the test persons, an intensive and clear warning must be given before the system switches off. A warning at the same time as LKAS has dropped is unacceptable. A written warning that the system has shut down is not effective, as the time for the driver to comprehend is too long. In addition, open windows or motorway journeys, for example, must not drown out the warning. Important for the participants is the triple warning in visual & acoustic & tactile form, which is standardized.

The questioning of the importance of the criteria for LKAS and HUD was carried out before and after the test drive on the given Likert scale (1 = not important to 7 = very important). Thus, a feeling for a sensitization of the test person during the test drive could be detected. The following Table 2 shows the mean values and the standard deviations of the importance before and after the test drive.

Table 2. Importance of the evaluation criteria before and after the test ride

	Before test ride			After test ride		
	Mean value	SD	Ranking by rating	Mean value	SD	Ranking by rating
Lane tracking quality	6.31	0.97	3	6.58	0.92	4
Edge guidance	6.00	1.21	8	6.62	0.75	3
Driver-vehicle interaction	5.58	1.42	10	6.40	0.81	9
Availability	5.80	1.39	9	6.47	0.94	6
Safety feeling	6.49	1.10	2	6.87	0.51	1
Degree of relief	4.89	1.68	12	5.56	1.20	12
Vehicle reaction	6.07	0.96	5	6.47	0.76	6
Operation	6.07	1.12	5	5.96	0.95	10
Display	6.07	1.10	5	6.42	0.62	8
Design	5.07	1.54	11	5.73	1.10	11
Monitoring	6.29	0.92	4	6.58	0.54	4
Warning	6.69	0.63	1	6.82	0.44	2

The results show that the “feeling of safety” and the “warning” before and after the test drive are in the top two places. The “design” and the “degree of relief” prove the least important criteria. “Driver-vehicle interaction” experienced the largest increase with 13% after the test drive. The subjects have become much more interested in communicating the functional intention of the system. The interaction between ADAS and the driver is not only of great importance with regard to acceptance and trust, but also in order to avoid possible operating errors, regular, comprehensible feedback is of immense importance.

4.1 Results of the Evaluation for Vehicle 1

The rating of the LKAS in combination with HUD or with HDD was rated on the given Likert Scale from 1 = "very bad" to 7 = "very good".

A positive influence of the HUD is recognizable for all evaluation criteria except the edge guidance and lane tracking quality. A significant positive influence of the HUD in the sense of a better evaluation of the criterion with versus without HUD was proven with a t-test for dependent samples. The following criteria were evaluated significantly better: "Monitoring effort" (+31%; $p < .001$), "warning" (+17%; $p < .001$), "display" (+17%; $p < .001$), "feeling of safety" (+12%; $p < .001$), "driver-vehicle interaction" (+11%; $p < .001$), "degree of relief" (+10%; $p < .001$) and "design" (+8%; $p = .007$). Figure 6 shows the evaluation for vehicle 1 with both conditions (with HUD/without HUD = with HDD).

With over 31% increase, the point of monitoring experiences the largest increase by switching on the HUD. With 5.86 points, it achieves the highest rating of all criteria. This makes it clear how important the monitoring of the system is for the subject.

The other criteria, which are increasing by a double-digit percentage, are also related to monitoring. The HUD makes the visual warning that the LKAS has switched

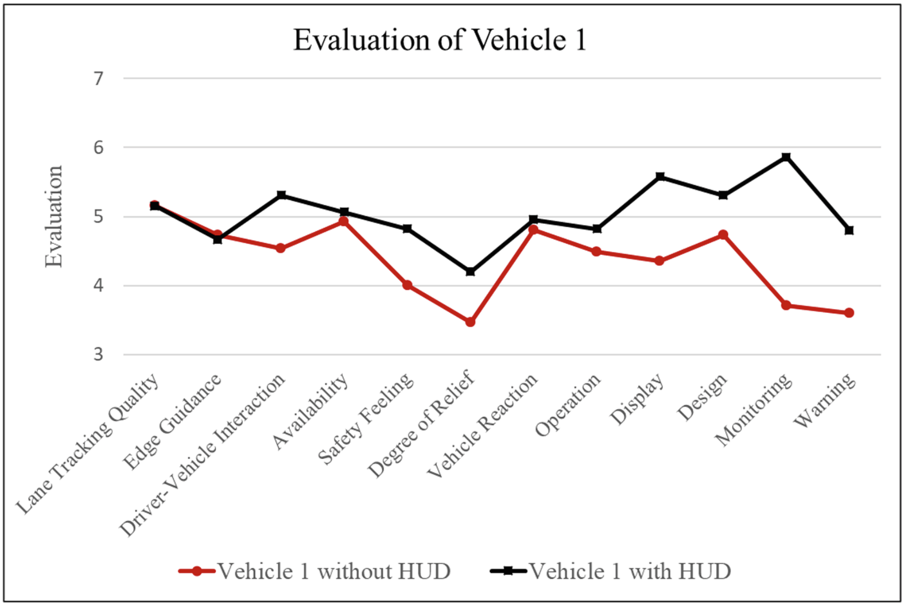


Fig. 6. Evaluation of the criteria for vehicle 1 with and without Head-Up Display

off much easier to perceive. The degree of relief and the driver-vehicle interaction also increase significantly, which is accompanied by a better feeling of safety. (Focusing of the eye on HDD not required can perceive everything more quickly).

The display of LKAS, which is directly in the test person's field of vision when the HUD is switched on and is no longer significantly more inconspicuous in the HDD, can achieve the second highest increase of 17% together with the warning.

4.2 Results of the Evaluation for Vehicle 2

The following section deals with the evaluations for vehicle 2.

A positive influence of the HUD is recognizable for all evaluation criteria except the lane tracking quality and operation. A significant positive influence of the HUD in the sense of a better evaluation of the criterion with HUD versus without was proven with a t-test for dependent samples. The following criteria were evaluated significantly better: "Monitoring effort" (+22%; $p < .001$), "warning" (+8%; $p < .001$), "display" (+16%; $p < .001$), "feeling of safety" (+10%; $p < .001$), "driver-vehicle interaction" (+12%; $p < .001$), "degree of relief" (+11%; $p < .001$) and "design" (+4%; $p = .017$).

The evaluation of the operation without HUD refers to the operation of the LKAS and with HUD to the operation or setting of the HUD (Fig. 7).

Significantly more negative evaluation has been found for the criterion "operation" (–13%; $p < .001$). This is because switching LKAS on/off with a button directly on the steering wheel was easier. The HUD, on the other hand, was operated via the board menu.

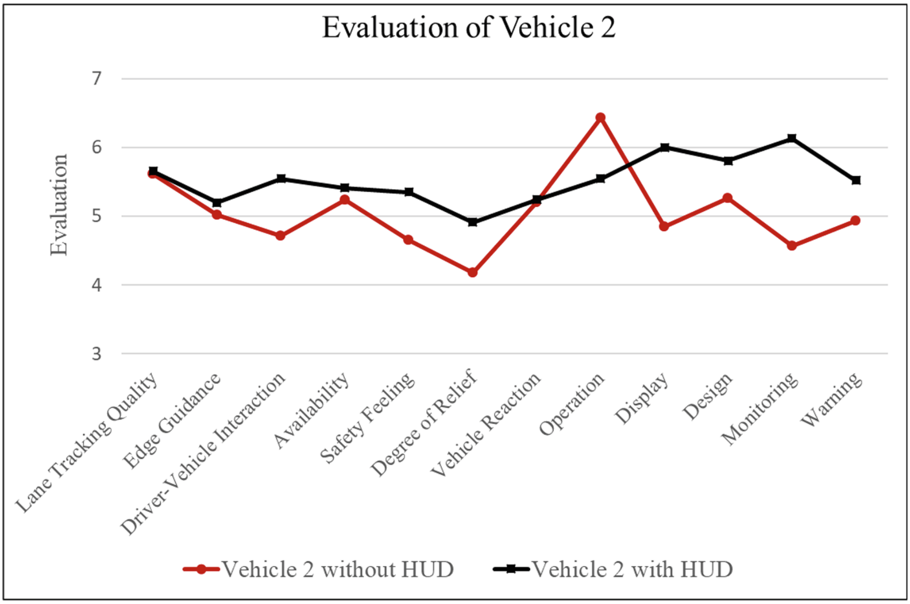


Fig. 7. Evaluation of the criteria for vehicle 2 with and without Head-Up Display

4.3 Results for Vehicle 1 and Vehicle 2

To verify the assumption that the order of the test conditions (1st round with HUD/2nd round with HDD or 1st round with HDD/2nd round with HUD) has an influence on the evaluation of the test persons, the evaluations of the 48 test persons were considered separately. In the figures below, the mean values were calculated for all criteria except lane tracking quality, edge guidance, availability and vehicle reaction. With these LKAS criteria, the difference in evaluation proves to be small (see Sects. 4.1 and 4.2).

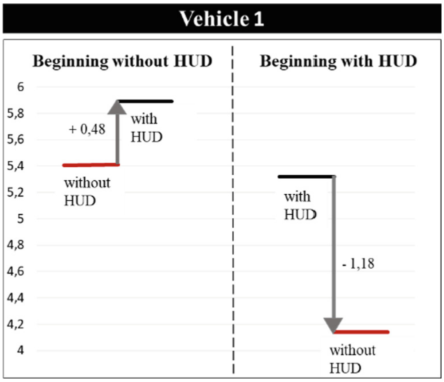


Fig. 8. Comparison of evaluation according to initial condition for vehicle 1

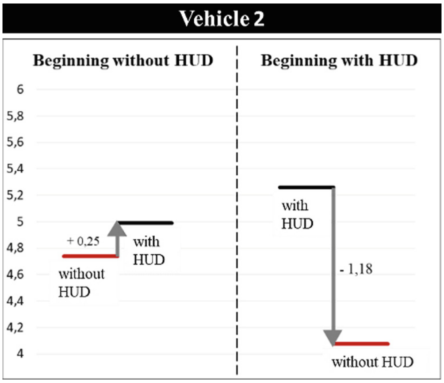


Fig. 9. Comparison of evaluation according to initial condition for vehicle 2

For vehicle 1 as well as for vehicle 2 the difference of the evaluation becomes visible especially when starting with HUD. With over 1.18 points, both vehicles are rated worse. At the beginning without HUD (with HDD), vehicle 1 scores on average 0.48 points better, vehicle 2 0.25 points better. There are also differences in the entry-level scores (Figs. 8 and 9).

Switching off the HUD takes away the easier monitoring of the system from the test persons, which is accompanied by worse evaluation of the criteria. The HDD is located - depending on the vehicle type - at a distance of approx. 0.5 to 0.8 m, the projected image of the HUD at a distance of approx. 2.20 m. A rapid change of view between the HDD and the road thus has a maximum possible accommodation time (focusing the eye on an object), as this means a change between infinite and near focus. The human eye needs for this process up to 0.5 s. [18]. This represents an increased potential of danger, as the driver is distracted from the actual driving task. Added to this is the strain caused by the constant adaptation of the eyes between road traffic (distance) and HDD (proximity). During the test drives, it was also possible to record and observe how difficult it was for the test persons to continue the test drive without HUD.

After Davis TAM a technology to be used by users, must be perceived by them as useful and simple to use [14]. The subjects were therefore asked whether they would recommend the systems to their friends, family or acquaintances because they fulfilled the TAM criteria. Table 3 shows the results.

Table 3. Recommendation of ADAS for vehicle 1 and vehicle 2 in [%]

	LKAS in combination with HDD	LKAS in combination with HUD
Number of recommendations in vehicle 1 [%]	12%	88%
Number of recommendations in vehicle 2 [%]	17%	83%

A total of 88% of the subjects would recommend LKAS of vehicle 1 in combination with HUD. The two assistance systems of the vehicle 2 would also only be recommended in combination. These results show once again that LKAS can generate its benefits in combination with HUD.

5 Summary and Discussion

As a result, a clearly positive influence of the HUD on the driving experience, comfort feeling and assessment of the LKAS can be determined across almost all evaluation criteria. In particular, a positive influence of the HUD could be observed in the LKAS monitoring effort. With an improvement of the rating by 31% (vehicle 1) and 22% (vehicle 2), the criterion "monitoring" had the largest impact. Simple and intuitive monitoring is very important, especially for ADAS that switches off regularly due to the condition of the road, weather influences or system boundaries that a non-expert cannot understand. It was discovered that a HUD can compensate the weaknesses of LKAS. On average, the evaluation criteria of vehicle 1 are almost 10% better and those of vehicle 2 with 7% better the HUD being switched on. In particular, the HUD's highly rated criteria of "feeling of safety" (6.87 out of 7 points after driving) and "monitoring" (6.58 out of 7 points after driving) in the importance survey increased the degree of fulfillment. With Rogers' "Diffusion of Innovations", the participants of the benchmarking study were made aware of the potential of a HUD.

The study results make it clear that a better user experience is possible by using both assistance systems. Meanwhile, 52% of the subjects were the opinion that LKAS and HUD should only be sold in combination. On average, the test persons stated that they had 35% more system transparency when driving with LKAS in combination with HUD than when driving with LKAS in combination with HDD. The resulting transparency and feedback made it easier for subjects to recognize the status of LKAS. Thereby the driver can focus more intensively to the environmental and traffic scenarios. Other studies have also revealed the importance of system transparency during a journey with LKAS [19]. Furthermore, such positive evaluation and user experience would lead to an increasing use of LKAS to reach initial goal of ADAS for more safety and comfort.

The following illustration shows the most important and most frequently mentioned product characteristics during the pilot study with regard to the LKAS. These were structured again according to Maslow's pyramid of needs (Fig. 10).

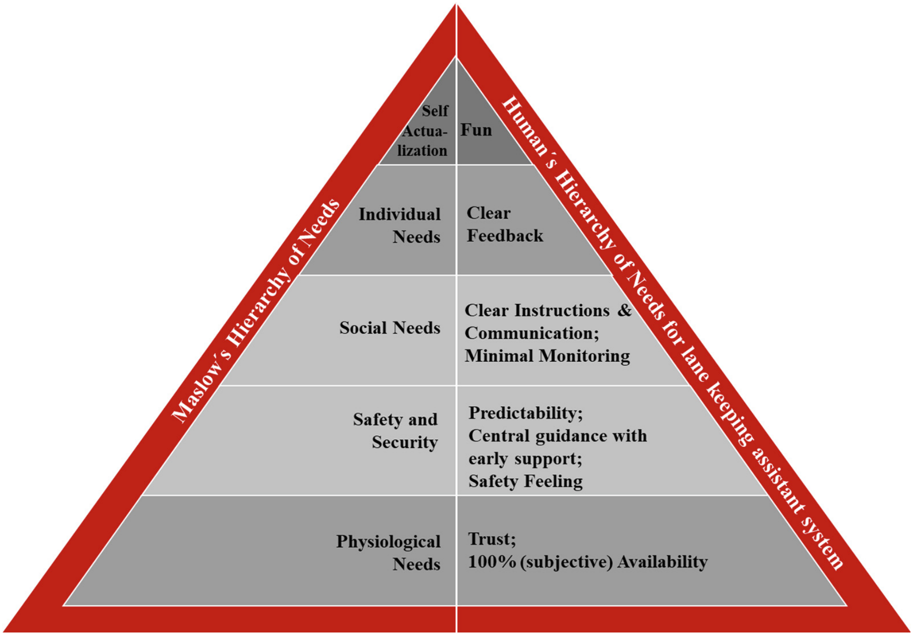


Fig. 10. Pyramid of needs for lane keeping assistant system [1] according to Maslow [20]

Eight out of 10 of the test persons' requirements above could be met with a HUD. The subject wants a predictability of the system, so that they can feel safe. Clear instructions and continuous communication whether the system is actually active or not are necessary. They need minimal monitoring so that he can concentrate on the driving situation and can immediately perceive and respond in case of failure. Subjects want to be able to trust the system, which only works if all requirements are met. Trust can only be built if the system behaves in the same way, the driver has transparency and receives feedback at all time. Without confidence in the system, no acceptance and driving pleasure can arise [1]. Arndt (2011) also points to the importance of the emotional experience for the acceptance of the systems [21].

In summary, it can be concluded from the available results that a HUD is a meaningful addition in the area of ADAS/AD. However, an ergonomically designed display concept that takes into account the functionality and capacity of human information processing is essential and may help to compensate for limitations of the technology to a certain extent in the future. In spite of increasing levels of automation in the vehicle, people must continue to be able to understand the processes and action steps of the vehicle at all times. System understanding, transparency, trust and the feeling of "indirect" control are essential for acceptance, well-being and the associated positive user experience.

The "Ironies of Automation" according to Bainbridge (1983) must also be considered here. The more automated a system is and the smoother it works, the less often humans have to intervene themselves. However, it is precisely this loss of practice and potential loss of attention that makes it all the more difficult for them to do so [22]. In addition, drivers can distract themselves if the load caused by the driving task is low. Accidents can therefore occur more frequently if the demands placed on drivers are low [19]. Therefore, it is recommended to maintain the driver's attention through adapted HCI.

The study is based only on subjectively collected data and was carried out on public roads in order to achieve the most realistic customer journey possible. During the interview, it was possible to collect essential requirements for a HUD when driving with LKAS. For objectification and higher reproducibility of the results, a driving simulator study in combination with gaze recording and recording of physiological data is recommended. The study clearly shows that the subjective perception of ADAS plays an indispensable role for humans.

In order to record the subjective experience of driver in dealing with ADAS and to incorporate the findings into the development of ADAS, use case-oriented acceptance studies with potential end user are of central importance. Here, the focus should be on the needs of the human and a holistic view of the systems should also be carried out with regard to AD. At the end of the day, the human being alone will decide on the success of the systems.

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