# How Can We Improve the Driving Experience with Human-Machine-Interface for Automated Driving?

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**Abstract.** The head-up-display (HUD), which reflects driving information into the windshield has the goal to lower driving effort from the information uptake and thereby, increase our safety by reducing risks associated to e.g., fatigue and stress. This motivated us to test the HUD in combination with the lane keeping assistant system (LKAS) from n = 48 subjects who drove in real traffic conditions two premium vehicles in a highway in Germany. Subjects then rated the Human-Machine Interaction (HMI) from an assessment about the perceived feelings of safety, degree of relief, information displayed, displays design, and monitoring procedures. Results from CMP regressions show that the HUD has a significant effect on the driving effort and safety feelings, and on the overall subjects' driving experience. Moreover, we find that this effect is stronger among elderly drivers, students, and females who feel significantly less driving effort. In particular, women felt significantly safer while the HUD was activated.

**Keywords:** Human-Machine-Interface (HMI) · User experience · Advanced Driving Assistance Systems (ADAS) · Head-up Display (HUD) · Driving effort · Safety

## 1 Introduction

The information displayed while driving gains increasing attention from the automotive industry due to its implications on safety and sales. In essence, the amount of information to the driver has grown in direct proportion to the booming of advanced driving assistance systems (ADAS). The traditional dashboard display (head-down-display, HDD) has not been removed from the latest models; instead, it has been complemented with a head-up-display (HUD) which reflects driving information into the windshield. In general, the HUD shows us driving-related content with the goal to lower driving effort from the information uptake and thereby increase our safety by reducing the risks associated to e.g., fatigue, stress, and distractions (e.g., [5, 10, 11]). A natural consequence is that customer expectations and preferences about what and how this new information is displayed have become more relevant for both, safety policy-making and customer satisfaction purposes.


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Although nowadays we are used to adjust our devices e.g., smartphone, laptop, notepad, etc., to meet our personal preferences, twenty years ago Gish and Staplin [7] already proposed to study the customers preferences and attitudes towards the in-car displays. This literature, however, is considered in an emerging stage and to some extent limited to the classical HDDs (e.g., [6, 14]). Most importantly, the relationship between the drivers' expectations and preferences on their mental workload, safety, and customer satisfaction are still largely unknown or not fully understood (e.g., [3, 15, 16]). Moreover, several of our studies on LKAS confirm the aforementioned findings (e.g., [1, 2, 9]). This has motivated us to conduct a real-world driving study with 48 subjects who were asked to drive and evaluate the ADAS from two premium vehicles equipped with HUD.

The rest of the paper is organized as follows, in the next section we present the methodology, in Sect. 3 we summarize our main results, and later on, we conclude.

## 2 Methods

The study was conducted under a within-subject design in which each subject was asked to drive two different vehicles: a prototype Porsche Panamera Turbo, 2016 (A) and a BMW 520d, 2017 (B), both equipped with HUD and LKAS (see Fig. 1 and 2). In order to distinguish the effects of driving with HUD compared with driving without it, each subject drove a route with the HUD activated, and the same route without HUD, first driving vehicle A and immediately after the vehicle B. Therefore, each subject drove the route four times, twice with vehicle A –with and without HUD activated- and twice with vehicle B –with and without HUD activated- The order of the vehicle to drive first, and whether the HUD is activated or not was randomized to account for potential order effects. The route consisted of a well-known federal highway in the Allgäu region in Germany. This has a length of approx. 61 km which was traveled at a speed of 100–130 km/h and taking an average driving time of 45 min each vehicle. To avoid the formation of expectations or strategic responses, subjects were not informed about the aim of the study. They were simply informed that the main goal was to test the vehicles and make a general assessment i.e., after each of the four rides, each subject responded a set of questions to evaluate their overall driving experience.

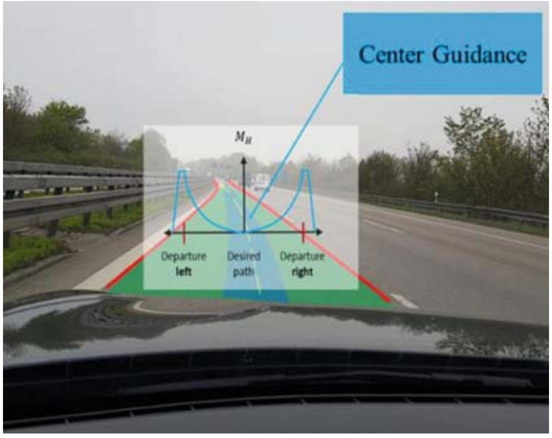


Fig. 1. Lane keeping assistant system with early support (center guidance)


Fig. 2. Head-up display and head-down display (picture bmw.de guidance)

## 2.1 The Driving Experience Assessment

In order to place the human being at the center of the development, methods such as Quality Function Deployment (QFD) by Saatweber, and KANO [8] as well as the Technology Acceptance Model (TAM-Davis 1985 [4]), 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. For simplicity, here we focus only on those that respond our HMI research purposes: the perceived feelings of safety, degree of relief, operability, information displayed, displays design, monitoring procedures, warning displays and the overall HMI interaction.

## 2.2 Questionnaire and Interview

As for the survey type, a personal interview (called paper and pencil interview or face-to-face interview), beside several fixed question sheets, before and after the test ride, was chosen. From the fixed questions, before the trip, it was essential to learn about the subjects’ characteristics, including their attitudes toward technology. During the ride, the main aim was to reproduce a real driving experience and thus collect the drivers’ claims and wishes based on a detailed personal interview. After the ride, to compare the systems and evaluate the overall impressions, we employed a fixed evaluation sheet from the LKAS level model using a Likert-Scale. Thus, the wording of the questions is as follows:

> *“From a scale where 1 = not satisfied and 7 = very satisfied, rate the following evaluation criteria for the LKAs”*

HMI Interaction: "*To what extent have you met your expectations regarding the communication, functionality, and aim of ADAS during the steering maneuvers, which possibly leads to driving corrections?*"

Safety: "*To what extent have you met your expectations regarding a reliable, trustworthy and predictable ADAS that can drive you safely?*"

Degree of Relief: "*To what extent ADAS helped to meet your expectations regarding the driving effort?*"

Operability: "*To what extent have you met your expectations regarding a self-explanatory and easy to operate ADAS?*"

Information Display*: "To what extent have you met your expectations regarding a self-explanatory, comprehensive and easy ADAS display?"*

Design: "*To what extent have you met your expectations regarding a comprehensible ADAS design?*"

Monitoring: "*To what extent have you met your expectations regarding simple and intuitive monitoring actions from the system?*"

Warnings: "*To what extent have you met your expectations regarding comprehensible, coherent, and opportune warning displays from ADAS?*"

### 2.3 Procedure

In total, 48 subjects participated in the study, invited through e-mail using the mailing list from the University of Applied Sciences Kempten. Those who accepted the invitation participated voluntarily without any type of payment or incentive. Participants were received at the Adrive Living Lab facilities which is part of the Mechanical Engineering Faculty. Before the rides, subjects were instructed in detail about the route, the vehicles to be tested, and common procedures. In addition, they answered a questionnaire about general demographics such as gender, age, occupation, etc. They had the time to get familiar with each vehicle i.e., adjust the seat, mirrors, steering wheel, etc., and to briefly drive it before the actual test.

The composition of the sample is: 11 females (23%) and 37 males (77%) with an employment status composed by 31% students, 30% employees, 15% professors and 24% others.

All sessions were conducted in German language.

## 3 Results

In this section, we summarize our main results. The following table shows the coefficients for the variables of study. First, we see that the positive coefficient for *HUD* shows that its activation outperformed significantly the use of the HDD alone in: the perceived *Driving Effort* and *Safety Feeling*, and on the overall HMI assessment.

The interaction terms, on the other hand, suggest three main forms to reinforce the *HUD* positive effect on driving: differentiate preferences in terms of *Gender, Age* group, and *Occupation*. More specifically, the *HUD* effect i.e., when the *HUD* is activated, becomes stronger among elderly drivers, students, and females who felt significantly less driving effort compared to when they drove with HDD only. In particular, women felt significantly safer while the *HUD* was activated. Finally, the coefficients for *Monitoring* and *Warning Displays* indicate that a simple and intuitive monitoring system, as well as a comprehensible and opportune warning display are especially important for drivers while experiencing ADAS (Table 1).

**Table 1.** Conditional mixed-process regressions[a]

| Variable | Degree of relief | | Safety feeling | | HMI gral. rate | | Controls | P > $X^2$ |
|---|---|---|---|---|---|---|---|---|
| HUD | 0.736*** | (0.121) | 0.758*** | (0.131) | 0.802*** | (0.149) | Yes | <.001 |
| HUD*Gender | 0.865*** | (0.321) | 0.571** | (0273) | 0.116 | (0.274) | Yes | <.001 |
| HUD*Age | 0.017** | (0.007) | 0.009 | (0.008) | −0.005 | (0.005) | Yes | <.001 |
| HUD*Occupation | 0.451** | (0.205) | 0.136 | (0.271) | −0.543 | (0.332) | Yes | <.001 |
| Monitoring | 0.222* | (0.114) | 0.342*** | (0.117) | 0.293*** | (0.102) | Yes | <.001 |
| Warning displays | 0.202** | (0.083) | 0.137 | (0.109) | 0.157** | (0.074) | Yes | <.001 |

Notes. [a]CMP models (Roodman 2011 [12]) with robust std errors clustered at subject level in ()
HUD = 1 when HUD was activated, Gender = 1 for female driver, Occupation = 1 when student, and 0 = otherwise.
***p < .01, **p < .05, *p < .10; *n* = 182

The comments stated from the participants during the interviews, confirm the results above. The most frequent comments captured by the interviewer during the test drives (LKAS in combination with HUD) are summarized as follows: less distraction, more focused driving, easier monitoring, better understanding of the system, faster response to take-over request, greater feeling of safety, more control, more confidence, and more comfort.

## 4 Discussion

Recently, the HUD has open an important debate among manufacturers and users in general about how and what type of information is presented to the driver. On the one hand, engineers have a particular "showcase" to present to the users which HUD design is the most attractive and functional. Yet, on the other hand, the advances on driving assistance systems create on the drivers, high expectations and preferences about the information displayed. Therefore, in this study we aim to bridge the gap between what is offered so far, and what the drivers expect and prefer regarding the HUD. For this purpose, we conducted a user-centered study where 48 participants drove, under real-traffic conditions, two premium vehicles equipped with LKAS and HUD.

Our findings suggest three main strategies to improve the existing HUD: differentiate drivers' preferences in terms of Gender, Age group, and Occupation. In addition, a simple and intuitive monitoring system, as well as a comprehensible and opportune warning display are especially important for drivers while experiencing ADAS.

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.

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