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Discussion

Checklist for Expert Evaluation of HMIs of Automated Vehicles—Discussions on Its Value and Adaptions of the Method within an Expert Workshop

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Abstract: Within a workshop on evaluation methods for automated vehicles (AVs) at the Driving Assessment 2019 symposium in Santa Fe; New Mexico, a heuristic evaluation methodology that aims at supporting the development of human–machine interfaces (HMIs) for AVs was presented. The goal of the workshop was to bring together members of the human factors community to discuss the method and to further promote the development of HMI guidelines and assessment methods for the design of HMIs of automated driving systems (ADSs). The workshop included hands-on experience of rented series production partially automated vehicles, the application of the heuristic assessment method using a checklist, and intensive discussions about possible revisions of the checklist and the method itself. The aim of the paper is to summarize the results of the workshop, which will be used to further improve the checklist method and make the process available to the scientific community. The participants all had previous experience in HMI design of driver assistance systems, as well as development and evaluation methods. They brought valuable ideas into the discussion with regard to the overall value of the tool against the background of the intended application, concrete improvements of the checklist (e.g., categorization of items; checklist items that are currently perceived as missing or redundant in the checklist), when in the design process the tool should be applied, and improvements for the usability of the checklist.

Keywords: automated vehicles; automated driving systems; HMI; guidelines; heuristic evaluation; checklist; expert evaluation

1. Background

With the Federal Automated Vehicles Policy, the U.S. National Highway Traffic Safety Administration (NHTSA) has provided an outline that can be used to guide the development and validation of automated driving systems (ADS).

With regard to the human–machine interface (HMI), the policy proposes that an automated vehicle (AV) HMI at minimum shall inform the user that the system is either of the following [1]:

1. Functioning properly;
2. Engaged in automated driving mode;
3. Currently 'unavailable' for use;
4. Experiencing a malfunction; and/or
5. Requesting a control transition from ADS to the operator.

A suitable design of mode indicators should effectively support the driver in using an ADS and prevent a false understanding of the current driving mode. NHTSA encourages implementing and documenting a process for the testing, assessment, and validation of each element [1]. However, details on how entities can assess and validate if a specific HMI meets these requirements are not proposed. Therefore, a test procedure was developed that serves to evaluate the conformity of SAE level 3 (conditional automation) ADS HMIs with the requirements outlined in NHTSA's Automated Vehicles policy (for an overview, see [2]). Before this publication, no standardized tools for the assessment of the usability and safety of ADS HMIs existed.

The proposed evaluation protocol includes (1) a method to identify relevant use cases for testing on the basis of all theoretically possible system states and mode transitions of a given ADS (see [3]); (2) an expert-based heuristic assessment to evaluate whether the HMI complies with applicable norms, standards, and best practices (the topic of the present paper); and (3) an empirical evaluation of ADS HMIs using a standardized design for user studies and performance metrics [2]. An overview of the complete test procedure can be seen in Figure 1 (for further information, see [2]).

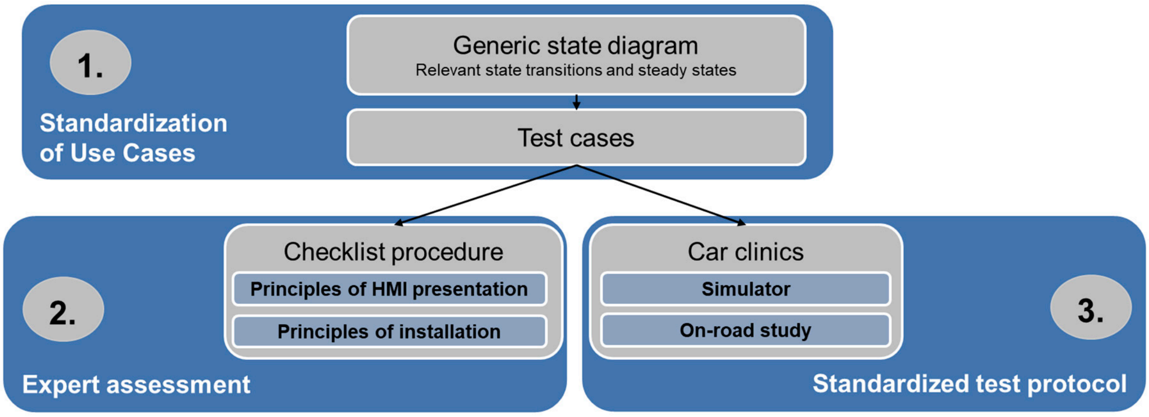

1.
Standardization of Use Cases
Generic state diagram
Relevant state transitions and steady states
Test cases
2.
Expert assessment
Checklist procedure
Principles of HMI presentation
Principles of installation
Car clinics
Simulator
On-road study
3.
Standardized test protocol

Figure 1. Overview of the test procedure for the evaluation of automated driving system (ADS) human–machine interfaces (HMIs) based on U.S. National Highway Traffic Safety Administration (NHTSA) requirements.

The present paper deals with the reviewing of the heuristic evaluation method that can be used by human factors and usability experts to evaluate and document whether an HMI meets the above-mentioned minimum requirements. In usability engineering, such heuristic assessment methods are commonly applied during the product development cycle and can be used as a quick and efficient tool to identify potential usability issues associated with the HMI [4].

The heuristic assessment method consists of a set of ADS HMI guidelines together with a checklist that can be used as a systematic HMI inspection and a problem reporting sheet. This version of the checklist and the considered HMI principles are reported in [5] and [6].

In comparison with existing approaches that test the usability via user studies/car clinics, the heuristic evaluation can be applied through rapid iteration early in the product cycle, and is thus able to correct identified issues and reduce late-stage design changes. Using experts has the advantage that inadequate mental models that might influence evaluations of naïve users can be better controlled. Furthermore, experts are trained to concentrate on single HMI aspects separately from each other in their evaluations. In addition, by means of the checklist, experts can evaluate an HMI in absolute values independently from a comparison with other HMIs. However, both heuristic evaluation and car clinics are recommended to be used as complementary methods in the evaluation protocol (see Figure 1).

The paper at hand has the goal to disseminate the already published work on the developed test procedure to a scientific community and to further adapt the checklist based on the results of the expert workshop. Suggestions for improvement from human factors experts and practitioners are discussed against the background of feasibility (keeping it an easy-to-use tool) and appropriateness for use in a checklist compared with other methods.

2. Content and Usage of the Checklist

2.1. Checklist Items

The aim of the assessment is to evaluate whether a set of pre-defined HMI principles (the "heuristics") are met. Thus, the checklist consists of 20 items summarizing the most important design recommendations for visual-auditory and visual-vibrotactile HMIs derived from existing norms, applicable standards, design guidelines, and empirical research, pertaining to in-vehicle interfaces. The complete list of items is presented in Table 1. The derivations of these items from the literature are elaborately described in [5].

Table 1. List of heuristics (see also [5]). HMI, human–machine interface.

#	Item
1	Unintentional activation and deactivation should be prevented
2	The system mode should be displayed continuously
3	Mode changes should be effectively communicated
4	Visual interfaces used to communicate system states should be mounted to a suitable position and distance. High-priority information should be presented close to the driver's expected line of sight
5	HMI elements should be grouped together according to their function to support the perception of mode indicators
6	Time-critical interactions with the system should not afford continuous attention
7	The visual interface should have a sufficient contrast in luminance and/or color between foreground and background
8	Texts (e.g., font types and size of characters) and symbols should be easily readable from the permitted seating position
9	Commonly accepted or standardized symbols should be used to communicate the automation mode. Use of non-standard symbols should be supplemented by additional text explanations
10	The semantic of a message should be in accordance with its urgency
11	Messages should be conveyed using the language of the users (e.g., national language, avoidance of technical language, use of common syntax)
12	Text messages should be as short as possible
13	Not more than five colors should be consistently used to code system states (excluding white and black)
14	The colors used to communicate system states should be in accordance with common conventions and stereotypes
15	Design for color-blindness by redundant coding and avoidance of red/green and blue/yellow combinations
16	Auditory output should raise the attention of the driver without startling her/him or causing pain
17	Auditory and vibrotactile output should be adapted to the urgency of the message
18	High-priority messages should be multimodal
19	Warning messages should orient the user towards the source of danger
20	In case of sensor failures, their consequences and required operator steps should be displayed

2.2. Method Description

The method should be conducted by a pair of HMI experts. Preferably, experts should have received formal training in human factors and usability engineering or have demonstrable practical experience in the assessment and evaluation of automotive HMIs. However, the evaluators should have no prior experience with the vehicle and features to be tested. The most suitable testing environment depends on the maturity of the product. In the very early development stages, where there is only a prototype available and series production is far away, it is recommended to use a driving simulator. For series production vehicles or high-fidelity prototypes, it is advised to conduct the study on-road as this provides the most realistic conditions for testing. Each of the two evaluators completes a fixed set of use cases, observes the visual, auditory and haptic HMI output, and records potential usability issues arising from the non-compliance with the checklist items (see Figure 2 for an example). The use case set consists of the various system states and the transitions between them (e.g., activating the system, deactivating the system, switching between system modes, required control transition from the system to the operator) and depends on the specific design of the ADS with respect to the available levels of automation (e.g., whether only manual or conditional automation are available, or if partial automation (level 2) is also available within the same vehicle). While one of the evaluators is the driver, the other one is seated in the passenger seat, providing step-wise instructions about the desired system state to the driver at appropriate times during the drive. To ensure that both observers are able to experience each use case and resulting system and user reactions and responses in a comparable way, they switch position after one driving session and repeat the drive. The aim of the heuristic assessment is twofold:

1. For the minimum HMI requirements to be fulfilled, each of the use cases should be reflected in a mode indicator or the change of a mode indicator that must be present in the in-vehicle HMI. At minimum, a persistent mode indicator should be presented visually. In addition, auditory, tactile, or kinaesthetic cues for mode transitions are recommended.
2. The design of the respective mode indicator should be in accordance with the common HMI standards and best practices that are the basis of the checklist.

Checklist compliance and identified usability issues should be initially documented independently by each of the evaluators. Each of the checklist items should be answered using the following rating categories:

- “major concerns”: non-compliance with guideline;
- “minor concerns”: partial fulfilment of guideline, but some aspects of the HMI are non-compliant;
- “no concerns”: compliance of all HMI aspects with guideline;
- “measurement necessary”/”subject to verification”: no definite conclusion can be given on the basis of the checklist and empirical testing is needed. This category should be chosen if highly innovative designs are used that are not covered by current standards and best practices. An example would be the use of other communication channels than the above-mentioned (e.g., olfactory cues);
- “not applicable”: respective design recommendation not applicable to the system under investigation (e.g., HMI without vibrotactile output).

The reasons for “major” and “minor” concerns should be documented in a separate reporting sheet. After the individual assessment, the results should be discussed between the evaluators to come to a unanimous rating decision for each item, which should also be documented. Figure 2 shows a simplified flow chart of the test procedure.

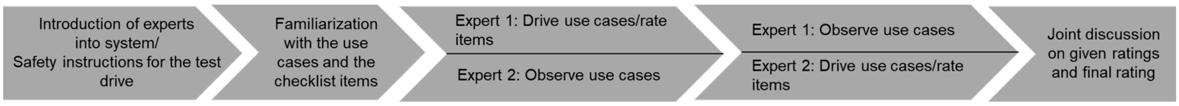
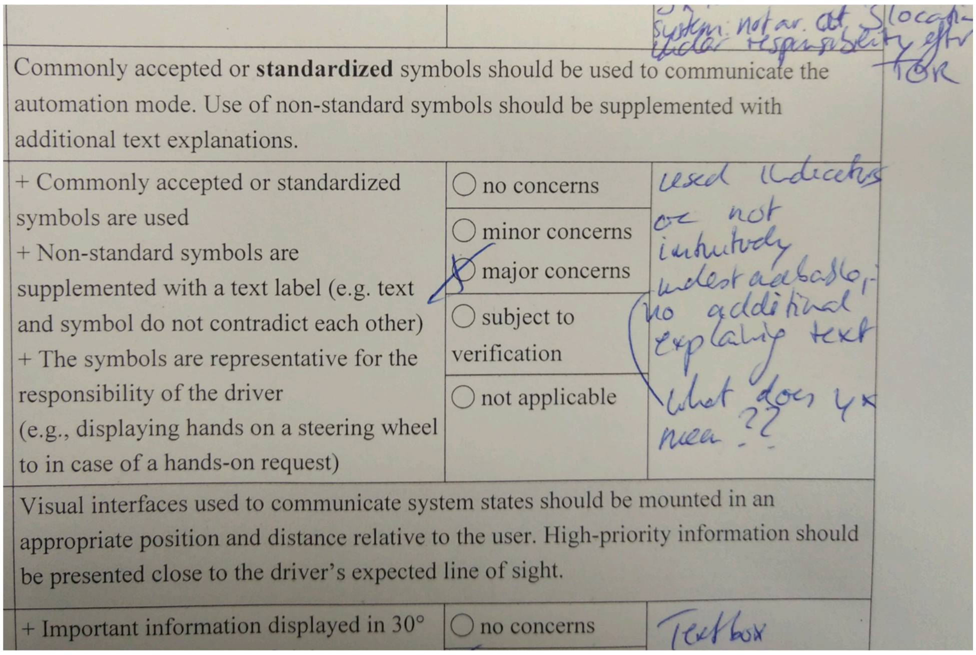

Introduction of experts into system/ Safety instructions for the test drive
Familiarization with the use cases and the checklist items
Expert 1: Drive use cases/rate items
Expert 2: Observe use cases
Expert 1: Observe use cases
Expert 2: Drive use cases/rate items
Joint discussion on given ratings and final rating

Figure 2. Simplified flow chart of the test procedure.

Figure 3 shows an example of the format/appearance of the checklist and an item notionally judged by an evaluator. Each checklist item contains the requirement. Additionally, positive and/or negative examples for a good/insufficient HMI solution of the requirement are given below the heuristic. Please note that the handwritten notes in Figure 2 do not refer to one of the systems investigated within the workshop, but do serve as exemplary problems that could potentially be identified during the heuristic evaluation. The complete checklist can be found in the Appendix A. It was used in a slightly adapted version in the workshop.



		system: not av. at S locati- unclear responsibility after TOR
Commonly accepted or **standardized** symbols should be used to communicate the automation mode. Use of non-standard symbols should be supplemented with additional text explanations.		
+ Commonly accepted or standardized symbols are used + Non-standard symbols are supplemented with a text label (e.g. text and symbol do not contradict each other) + The symbols are representative for the responsibility of the driver (e.g., displaying hands on a steering wheel to in case of a hands-on request)	○ no concerns ○ minor concerns ☒ major concerns ○ subject to verification ○ not applicable	used indicators or not intuitively understandable, no additional explaining text What does 4x mean ??
Visual interfaces used to communicate system states should be mounted in an appropriate position and distance relative to the user. High-priority information should be presented close to the driver's expected line of sight.		
+ Important information displayed in 30°	○ no concerns	Textbox

Figure 3. Example of the format of the checklist and an evaluated item.

2.3. Application Domain of the Method

In its current version, the checklist should be viewed as a living document that can be modified to account for gaps where research in the field of automated vehicles is still emerging. The checklist expresses one set of guidelines and is intended as a first step towards guideline development and vehicle-verification methods (the first version of the checklist and three validation studies were published in [6]). In addition, it should be noted that it was developed with the intention to evaluate ADS of level 3 systems. However, it may also be applied to L2 automation as most of the heuristics refer to general design guidelines that should be met by all types of automated system HMIs for ensuring proper usage. Users could misunderstand or misuse the capabilities of an L2 system, treating it like an L3 system when the automated driving mode is not clearly indicated, as demanded by the checklist items. Vehicles equipped with L3 systems may also be usable in an L2 operational state. Understanding user interactions in lower modes of automation may inform best practices in higher modes. This justifies the application towards L2 systems, as was done in the conducted workshop.

For the sake of practicability and efficiency, the list of guidelines was kept as short as possible; therefore, it is likely that it will not cover every aspect of the HMI for ADS. At this point, it is important to emphasize that new and innovative HMI designs may rely on other HMI elements than the ones covered by the sources used to compile the checklist. In this case, the evaluators are encouraged to give a positive assessment when they judge the respective guideline to be fulfilled during the on-road test and their level of expertise on this topic allows it, even if this cannot be based on the design recommendations. In the case of sufficient inter-evaluator agreement, verification of the guideline can be assumed. Otherwise, they are suggested to rate the item as "measurement necessary".

It should further be noted that the fulfilment of the HMI guidelines should facilitate regular and safe usage of the ADS, such as switching the automation on, checking the status of the ADS, or taking back manual control from the automation (either driver-initiated or as a result of a take-over request).

A more comprehensive evaluation of the ADS will most likely need to incorporate (a) usability testing with real users in instrumented vehicles or high-fidelity driving simulators and (b) investigating other domains such as the assessment of controllability of system limits or failures and foreseeable misuse of the ADS as defined in the RESPONSE Code of Practice [7] and ISO 26262 [8]. The aim of the proposed method is thus not to replace usability testing with participant samples, but to complement empirical approaches with an economical heuristic evaluation tool. It may serve as a guide or sieve to identify and improve poorly performing HMIs before going into further user studies. Further limitations of the current approach are also discussed in the corresponding sections of this paper.

3. Intention of the Workshop

The intention of the conducted workshop at the Driving Assessment 2019 symposium in Santa Fe, New Mexico was to present the developed method and its application to human factors experts in the scientific community of automated vehicle research in order to further improve the method. A higher level goal was to stimulate the discussion within a larger scientific and technical community towards future standards that may be appropriate for guiding the development of automated vehicle HMIs. Another goal is to facilitate a more rapid convergence towards an agreed-upon set of robust guidelines and verification methods that can serve the industry in the important evolution of automation within vehicles.

4. Evaluation Procedure during the Workshop

The workshop was organized by WIVW GmbH (a company providing research services in the field of human factors, especially from the automotive sector) and was held following the closing session of the conference, on 27 June 2019 at the El Dorado Hotel in Santa Fe. In total, 14 participants took part in the workshop. The workshop was announced via the conference website and was open for application to all conference participants. The workshop attendees were selected based on their scientific background either as practitioners or academics in the automotive domain with previous experience in the HMI design, development, or evaluation methods of driver assistance systems. The resulting workshop group consisted of agents from the automotive industry, scientific institutes, and national agencies. In preparation of the workshop, the participants received publications that described the background of the checklist method [3] and its application [6].

Regarding the agenda, the workshop started with a short introduction of the organizers, who gave an outline of the workshop. Afterwards, the method and its background were presented. Then, the 14 participants were split into small groups of 3–4 people who would apply the method while riding together in two vehicles equipped with L2 driving automation systems: a Tesla Model 3 with the Autopilot system (AP) and a Cadillac with the GM Supercruise (SC) system.

These two systems were chosen as their system architecture, system operation principles, as well as their system performance (e.g., regarding the threshold required for overriding the system by steering input) are different from each other. The Tesla had a large center-stack touch screen for the HMI display, while the Cadillac used a classical instrument cluster and a light bar at the steering wheel for communicating the current system mode. The Cadillac had many of the automation controlling buttons on the steering wheel, while the Tesla system is operated by a lever behind the steering wheel. The two systems also offered different warning and alerts, different both in the type of alerts and when they occurred. Systems also differed in their approaches for driver monitoring; while the Tesla used a hands-on detection system, the SC determines whether the driver has enough visual attention on the road via a camera system. Furthermore, the Cadillac had more constraints to use than the Tesla L2 system (for further descriptions of the system, see Chapter 5).

Before starting the drive, each participant received a copy of the checklist and familiarized themselves with the items and the rating procedure. It was emphasized that the rating of the systems itself was not the relevant outcome of the evaluation process and that methodological issues emerging when applying the method were of greater importance.

The participants experienced both systems as passengers in a 30 min drive on the interstate 25 (Denver–Albuquerque). The first system was experienced while being driven in one direction on the interstate. After a stop at an exit, the groups switched vehicles and experienced the second system on the way back to the interstate exit. The drive from the conference site to the interstate took about 10 min.

Owing to safety and insurance reasons, the workshop organizers drove the vehicles. Therefore, the evaluation process during the workshop did not follow exactly the one proposed in the heuristic evaluation procedure, where the evaluators should really drive the vehicle (see [6]). On the way to the interstate, the drivers briefly explained the control elements (button, lever, and so on) used for operating the system and which HMI elements had to be observed by the evaluators. The test itself started when the vehicle reached the interstate. Up to here, the Tesla theoretically permitted to use the Autopilot, while the SC could not be used before entering the interstate. The drivers conducted several use cases in which the system could be experienced:

- The activation of the system;
- Driving with active L2 for a longer time interval (i.e., 4–5 min);
- Experiencing the driver monitoring system, which required a take-over in case the driver did not react to it;
- The deactivation of the system;
- Short-term standby modes, for example, in the case of non-detection of lane markings or lane changes;
- Planned system limits when exiting the interstate.

After getting back to the workshop room, participants were asked to fill out the checklist based on the second system they experienced. After all four groups had experienced the two vehicles, all workshop participants jointly discussed methodological issues they noticed during the application of the method.

5. Description of the Evaluated Systems

Although the rating of the systems themselves was not in the scope of the evaluation, a short description of both systems is inserted here to better understand the resulting discussions.

5.1. The GM Supercruise System

The GM Supercruise system is operated via buttons on the steering wheel. The system mode is indicated by presenting graphics, icons, and text messages at the instrument cluster (see Figure 4). In addition, there is a light bar on the steering wheel that is also used to indicate the current system mode by different colours and pulsation (static vs. flashing lights). The system is geofenced, meaning that it is only available on certain roads, such as interstates. Other preconditions for activation are that the driver has to drive in the center of the lane and that adaptive cruise control (ACC) is active. If the driver tries to activate the system outside these conditions, they receive a text message at the right side of the instrument cluster. The system state is indicated by a specific area on the left side of the instrument cluster as well as by telltales in the centre of the cluster. In order to activate Supercruise, first, ACC has to be shifted into standby mode (separate button) and activated by setting the speed. After that, Supercruise can be activated by a separate button. The activity of Supercruise is indicated by a green steering wheel together with green horizontal bars for ACC shown in the cluster. A short-term degraded standby mode (meaning lateral control is not active) is indicated by a blue steering wheel and the steering wheel light bar in blue. Lateral control is automatically resumed if the conditions are fulfilled once again. The Supercruise system does not require the driver to keep their hands permanently at the steering wheel, as UN-CE-R-79 [9] regulating this matter does not apply for the United States. However, if the driver tries to deactivate the system without having their hands at the wheel, a take-over request is triggered by a text message and red indicators. The driver monitoring system consists of a camera on the top of the steering wheel that determines whether the driver is looking towards the road. If the time not looking at the road exceeds a certain threshold, the steering wheel first flashes green before it turns red and lateral control is deactivated.

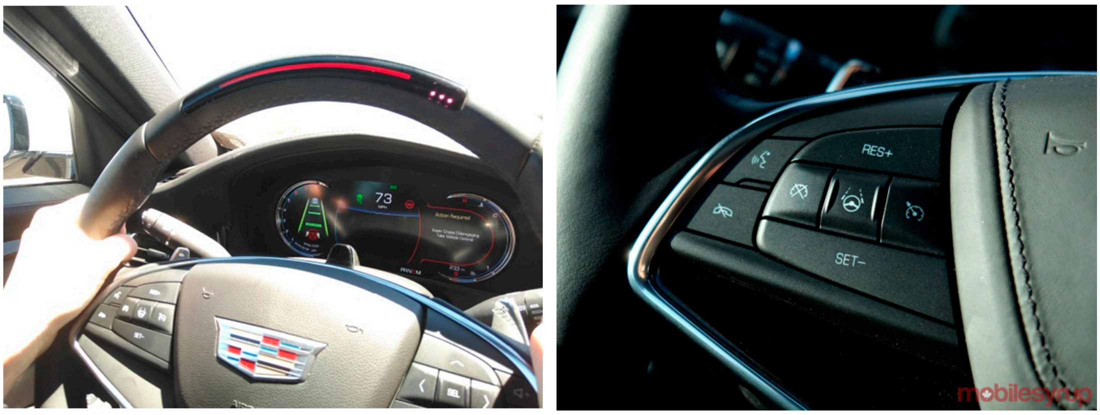


Figure 4. HMI elements of the GM Supercruise system.

5.2. *The Tesla Autopilot*

The Autopilot function by Tesla can theoretically be activated on all roads without any restriction (other than laws). In order to use the additional lane change assistance function, the navigation system has to be active. The system state is exclusively indicated on the left area of the touch display in the center stack console, which is used for all driving-related and non-driving-related information (replacing the instrument cluster; see Figure 5 left). The active L2 system is indicated by a blue trajectory on ego lane. The dynamic display additionally shows adjacent lanes and other vehicles surrounding the ego-vehicle. The system is activated by pulling the gear switch twice towards the driver (see Figure 5 right). After each activation process, the driver is requested to keep the hands on the steering wheel by a text message. In the case in which the system detects no steering interventions of the driver for a longer time interval, it requests the driver to exert a slight force on the steering wheel with the display flashing in blue and a symbol indicating a steering wheel with hands on it. If the driver does not react to such a hands-on request, the system will be switched off completely and can no longer be used for the remaining drive. Lateral control can be easily deactivated by a steering wheel intervention of the driver. There is no standby mode, meaning that lateral control has to be activated by the driver each time after it has been deactivated.

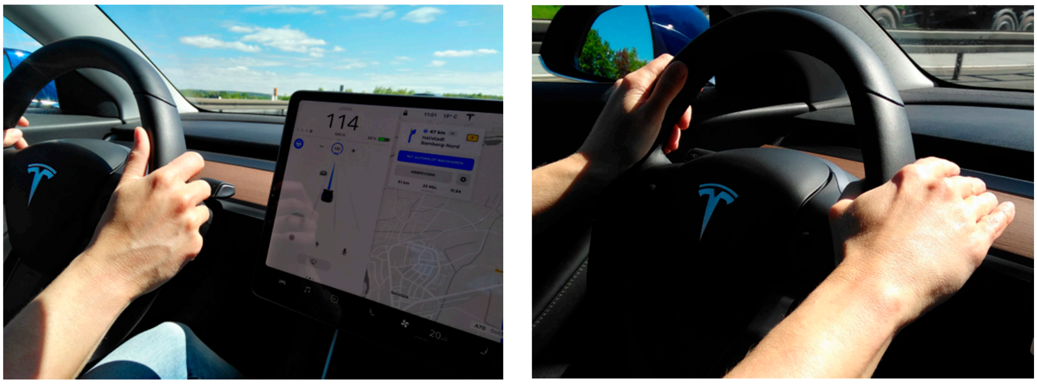


Figure 5. HMI elements of Tesla Autopilot.

6. Methodological Issues Discussed during the Workshop

After having experienced the two vehicles and after having applied the checklist, several methodological aspects arose from the discussions between the workshop participants that were grouped into the following topics.

6.1. Design Issues of the Checklist

With regard to better usability of the checklist, it was proposed to reorganize its design. For a better overview, some items could be grouped together into higher-level categories (e.g., with regard to color usage). Another suggestion for grouping the items was to categorize them with regard to use cases, for example, group all items with regard to change of system mode together. However, with the intention of the checklist to only test the minimum requirements set by NHTSA policy, this idea would prove as impractical as this would mean repetitions of some items that are valid for several use cases, which would unnecessarily stretch the checklist. The idea of shifting the positive and negative design examples to an appendix as added material was judged as not appropriate as the raters could profit from the current position of the examples, while there is a chance that an appendix tends to be overlooked during the rating process.

In addition to the current rating categories, it was proposed to add a category for "suggested improvements", not only in the final reporting sheet, but also on the item level to encourage experts to think about better solutions instead of simply marking "concerns".

6.2. Missing and Redundant Items

One concern regarding the selection of the checklist items was that some of them should not be evaluated subjectively by experts, but must be better objectively measured by technicians. These items comprise the following:

- Displaying HMI elements close to the line of sight (part of item 4);
- Checking color contrast (item 7);
- Checking text size (character height and stroke width, item 8);
- Design of auditory or vibrotactile feedback with regard to length, loudness, and frequency (item 17).

It is agreed that, for later stages of the HMI development, objective measurement by a technician is necessary, while in an early stage, a heuristic assessment of these items might be acceptable. Therefore, methods used for early stage and later stage assessment of the HMI might differ. It was discussed whether only those items should remain in the checklist, which must be subjectively assessed by experts. Other objectively measurable items could be deleted from the checklist and inserted into a separate technical checklist. Finally, there was some discussion about items that should be added to the checklist as they seem to cover aspects that are currently not adequately addressed.

Regarding extensions of the checklist, the greatest benefit, but also the greatest challenge, would be to rate the overall complexity of the system/HMI. The (perceived) complexity in using a system will heavily influence acceptance and trust in the system (e.g., [10]). The term includes two types of complexity. First, the system complexity, meaning the logic behind the various system modes and its transitions (e.g., are lateral and longitudinal control separate sub-functions that can be used in combination as well as independently of each other? Are standby modes included?). The system complexity will likely influence the complexity of system operation (e.g., sequence of operational steps to be performed or number of possible operation steps in order to reach a certain system state) or the demands on the distinctiveness of the several system modes (how many different indicators are necessary and how are they designed in order to clearly identify the current system mode). The latter is linked to the second type of complexity, the display complexity, which can be described by the arrangement of the information elements on the display, for example, in terms of display layout, number of display elements relative to display size (so-called visual clutter), spatial proximity of elements (e.g., in terms of overlapping), and so on.

Another possibility to operationalize the term complexity would be the categorization into different types of demands that are put on the operator of the system and that result in a certain level of perceived complexity in system usage. One possibility would be to define dimensions according to typical categorizations of workload based on Wicken's multiple resource model [11]. This model categorizes workload based on the following:

- Visual demands that result from the design of the visual displays, including content and arrangement;
- Motoric demands that result from the number and arrangement of the operational devices;
- Cognitive demands that result from the system logic and the difficulty in understanding the various system modes and the conditions for the transitions between them;
- In addition, temporal demands, meaning the requirements on the reaction to hazards play an important role and are influenced by the design of warning messages and the take-over request.

To sum up this issue, in the general discussion about the aim of the checklist, workshop participants tended to agree that complexity can be reasonably assessed by experts. Therefore, it was proposed to consider the system complexity in future iterations of the checklist. It is recommended to reflect the multidimensionality of this item in the checklist. One way would be to define multiple items addressing the defined sub-dimensions from the chapter above and group them together in the more global category of "complexity". The other option (which might be more appropriate as concrete standards for the assessment of complexity are missing) would be to formulate one single more generic item with the defined sub-items as positive/negative examples.

With regard to the evaluation of system operation, currently, there is only one item included that deals with the avoidance of unintentional activation and deactivation of the system (see also, for example, currently ongoing work by UNECE on the ACSF regulation (automatically commanded steering function) [12]). The reason for the limitation to only this item is that, at the creation of the checklist, there were no clear design guidelines or recommendations on how system operations should be designed. At the moment, there are some concrete specifications on activation, deactivation, and driver input principles under ongoing consideration in the UNECE ACSF document (e.g., the system should be deactivated when the driver overrides the system by steering, braking, or accelerating while holding the steering control). However, issues concerning the system logic are outside the scope of the checklist. However, the design of operational devices might be an extension of the checklist when more research and valid guidelines on this topic are available.

Highly correlated to the term complexity is the learnability of the system's logical operation and the HMI. Learnability is said to be one major attribute of usability (beside effectiveness, error tolerance, satisfaction, and memorization; for example, see [4]) and will be influenced by interface design (e.g., visibility of successful operations, feedback, continuity of task sequences, design conventions, information presentation, user assistance, error prevention) and conformity to users' expectations to the car manufacturer's philosophy (differences in functionality, differences in interaction style, concept clarity, and completeness of information [13]). Beside an intuitive first contact with a system, the concept of learnability should also include the aspect of re-learning the use of the system again after a longer interval of non-usage and the resources involved. However, it seems difficult for experts to provide a meaningful rating regarding learnability as an expert involved in system design, and assessment is likely biased when it comes to learnability owing to their experience. The same will be true for in-house testers who have extensive knowledge about currently developed products. This aspect should thus better be tested with naïve users. A small sample may be enough, and may include people not involved in ADS design. According to Nielsen [4], most of the usability problems can be identified by a number of five experts.

Another issue that could be considered by the checklist is the evaluation of other display elements beside the conventional ones, such as instrument cluster and head-up displays. This should contain not only the mere presence of peripheral displays, which are considered as an example in item 4 ("peripheral displays supporting noticing of mode changes, e.g., by movement or size of displays"), but also more concrete items referring to the design of those displays (e.g., steering wheel light bars). However, up to now, there are no concrete design guidelines, but a few empirical studies exist on the positive effects of ambient displays on mode awareness and take-over performance (e.g., [14]). Beside concrete design aspects, it can be requested that such elements should be congruent with the ones displayed in the instrument cluster, as otherwise, this might be problematic for understanding of system modes.

For the design of warnings, it was discussed whether to consider additional aspects beside the ones that are already included dealing with the communication channels to be used (in multiple modalities; item 18) and the desired effect of not distracting the driver (item 19). Such aspects are, for example, nomenclature choices and linguistic complexity (i.e., fault messages based on engineering nomenclature vs. easily comprehensible names of system modes). In addition, the content of the warning could be defined more explicitly. It was proposed to positively evaluate if the potential consequences of a system limit are displayed (e.g., what would happen if the user does not intervene and how can the user recover or reactivate the system, for example, in the case of repeated hand-off warnings).

American National Standards Institute (ANSI) suggests that a safety warning should include the following (ANSI Z353 [15]):

1. Identification of the hazard;
2. Identification of a means to avoid the hazard;
3. The consequences of not avoiding the hazard.

While there is not a need to adhere closely to the ANSI warning standard, such a standard could be considered as a guideline. In the context of automated driving, warnings can occur owing to less time critical hazards such as sensor failures that do not inevitably require an immediate action like a forward collision warning. However, reaching system limits can be interpreted as imminent hazards that require the driver to immediately take over the driving task to avoid an accident. Signal words that can be used for describing the identification of the hazard are "Danger", "Warning", "Caution", or "Notice". Then, a notice of what to do next to avoid a hazard should be given.

In the case of an urgent take-over request, these first two aspects are probably the most critical points. Typically, the HMI addresses them by displaying a short text such as "Take Over" together with a warning sign. The third aspect, conveying the consequence of inaction, seems to be the most problematic point in the case of take-over requests, as it is not always clear what happens in the case in which the system is deactivated without the immediate reaction of the driver. This information might be better explained by a user manual of the system instead of by the HMI in the imminent situation.

Finally, there were some suggestions for new items to be included in the checklist. One example was about the usage of a dynamic environment display that shows the surrounding traffic. Such a display is currently included in the Tesla Autopilot HMI. However, up to the current state-of-art, the benefit of such a display has not yet been established, and it is thus not clear how such an additional display should be evaluated. Does it have a positive effect on situation awareness or might it distract the driver from extracting relevant status information from the display and promote over trust in the system? It is possible that displays utilizing motion/animation may blunt the driver's response to warnings as motion is a powerful attention grabber, and thus a driver may start filtering out display content that is more relevant in the respective situation (i.e., notices, state changes). Owing to the lack of empirical evidence on the potential effects, the formulation of a checklist item regarding such a display is problematic, and will thus be postponed until more research is available.

Another example is a potential item for the ease of overriding the system. This item would address the controllability of a system, which was not the initial scope of the checklist. Currently, it is not clear whether it is good or bad if a system can be easily overridden by the driver. In addition, it is argued that such highly complex interactions between various factors (e.g., the degree of lateral control will play an important factor on this issue) seem to be better assessed in user studies. Therefore, no item regarding this issue will be included for now.

6.3. Human Factors Aspects to be Considered by Other Methods

All workshop participants jointly agreed that other aspects such as differences in system behaviour, system logic, system operation logic (beside some describable specific aspects in the item of complexity), and their effects on system usability require additional evaluation methods, as the correlation between these different factors is not yet clear in order to formulate concrete design recommendations. Moreover, their effects on system acceptance and system trust must be assessed by user studies. User experience (UX)-related aspects such as the hedonistic quality of the system and the HMI are also recommended to be evaluated by user studies. In this way, real users can experience the system and report their emotions and attitudes towards the system.

High agreement was also achieved for the fact that, especially on the type of control, user studies are needed (e.g., operation via steering wheel buttons vs. touch screen) with regard to performance times or distraction potential before checklist items can be deduced.

6.4. Test Procedure

Regarding the test procedure, the workshop participants recommended to put more emphasis on the fact that the experts should take the perspective of naive users. A naive user can be defined as "a person that tests the ADAS under evaluation with no more experience and prior knowledge of the system than a later customer would have" ([7], p. 7). This should allow that the requirements are valid for the average population. The inclusion of certain items also makes it possible to address the needs of certain specific driver groups, for example, drivers with colour-blindness.

Nevertheless, it should be kept in mind that this method should not replace, but rather supplement other approaches like user studies that allow for eye tracking, reaction time testing, and performance measurement on tasks dealing with the handling of the system. Both methods are proposed to be conducted within the complete evaluation protocol (see Figure 1).

The proposed test procedure (a team of two experts rates the system after having once experienced the use cases themselves as a driver and having watched the other evaluator driving) was rated as a reasonable approach. This approach has the advantage that both experts do not merely observe someone interacting with the system, but really experience that interaction themselves. In addition, the fact that one evaluator can directly document their first impression while the other evaluator is driving (compared with a retrospective documentation) avoids negative effects such as memory decay. For later reference, it is suggested to capture video of the driving experience (by scenario and system response) using small video cameras mounted in locations that capture cluster, head unit, and other displays and controls, while not covering the rater's view on these elements.

It was further proposed to conduct the evaluation with a larger group of experts if no time and resource constraints object to this approach. However, as this might complicate the process, to reach an agreement in a joint discussion, we would recommend only consulting a third external evaluator if no such agreement can be made between the evaluators even after a longer discussion.

Owing to the variety of systems that can be evaluated and the fact that new and innovative HMI designs are currently not covered by the checklist items, there will be situations in which adaptations need to be made by the experts to accommodate for specific circumstances. In this case, we suggest that experts follow the following approach.

1. Search for common published standards;
2. If 1 does not apply, evaluate the system by extrapolating those concepts from the checklist that seems to be transferable to the innovative HMI;
3. If 1 and 2 do not apply, conduct empirical testing.

6.5. General Value of the Checklist

It was jointly agreed that the developed method is a useful tool in the design process of AV HMIs. It is primarily intended to facilitate the assessment of system usability. It is able to check whether the minimum requirements proposed in the NHTSA policy are fulfilled. It is also reasonable as the current rapid evolvement of automated systems makes it extremely difficult to identify the "best design" of such a system and its HMI. This method serves as a tool to guide and make quick changes during the development process, that is, testing several concepts and narrowing down options, as well as ensuring a "basic" compliance throughout the design loops.

As said above, for a global evaluation, the assessment of aspects such as different system logics, different concepts for system operation (e.g., longitudinal and lateral control as separate systems, L2 as add on to L1, stepwise activation of L1, then L2, and so on), and different design philosophies should be considered, which are better answered by user studies.

7. Conclusions and Outlook

On the basis of the discussions with the workshop participants, the following adaptions of the checklist were decided:

- The structure of the checklist will be revised in order to achieve a better usability for the experts. This will mainly refer to a re-arrangement of the items into more global categories and underlying subcategories.
- Items regarding measurable aspects such as text sizes, line of sight, or colour contrasts will remain in the checklist to be assessed subjectively by the experts (as confirmation from a user perspective based on technical tests that will be conducted later in the design process). Absolute measurable numbers will be removed from the examples list.
- A new category of perceived complexity will be included in the checklist. This category will comprise several items/examples, which still have to be defined. Issues that should be considered are
    - the visual demands of the HMI in general;
    - the cognitive demands resulting from the complexity of the system's logic;
    - the motoric demands resulting from the number, positioning, and arrangement of operational devices;
    - the ease of learning the interaction with the system.
- The following new items will be included in the checklist
    - An item on the appropriate design of other display elements;
    - An item on the content of a warning/take-over request.
- The test procedure itself will remain in the proposed manner with two experts experiencing the system to be evaluated within a defined set of use cases in real drives, first separately filling out the checklist, and finally give a global rating based on a joint discussion.

It is planned to transfer the checklist into a computer-application that can be used, for example, on tablets in order to support the experts in the documentation of the tests, the discussion of its output, and the recommendations for system improvements.

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Appendix A

Table A1. Extended checklist items (see [5]). NHTSA, U.S. National Highway Traffic Safety Administration. Abbreviations in the table: NDRT = Non-driving-related task; DDT = Dynamic Driving Task.

1	Unintentional activation and deactivation should be prevented.	Assessment
	+ System design ensures driver readiness before transfer of control (e.g., pushing of two buttons simultaneously, need to have both hands on the steering wheel, need to have eyes on the road) - Surprising or inexplicable driver-initiated activation/deactivation during regular use	o major concerns o minor concerns o no concerns o measurement necessary
2	The system mode should be displayed continuously.	
	+ Minimum set of mode indicators present (1) functioning properly (2) currently engaged in an automated driving mode (3) currently unavailable for automated driving (4) experiencing a malfunction (5) requesting a control transition from the automated driving system to the operator - Indicators missing - Indicators not distinguishable from each other - Indicators only displayed for short periods of time - Mode indication discontinued (e.g., through pop-ups)	o major concerns o minor concerns o no concerns o measurement necessary
3	System state changes should be effectively communicated.	
	+ Recognizable change of pictorial indicator + Auditory/haptic feedback + Communication of responsibility (e.g., by disclaimer) + Pop-up messages + Error messages are provided in case (e.g., failed activation) + Delayed reaction to control input displayed in HMI	o major concerns o minor concerns o no concerns o measurement necessary
4	Visual interfaces used to communicate system states should be mounted to a suitable position and distance. High-priority information should be presented close to the driver's expected line of sight.	
	+ Important information displayed in 30° cone about normal line of sight + Safety-critical information displayed in 20° cone about normal line of sight + Peripheral displays support noticing of mode changes (e.g., movement or size of displays) + Status information mirrored on NDRT device	o major concerns o minor concerns o no concerns o measurement necessary
5	HMI elements should be grouped together according to their function to support the perception of mode indicators.	
	- Unnecessary glances to retrieve information from display (e.g., to interpret a symbol and perceive accompanying text) + Indicators pertaining to the automation are grouped together + High priority messages are easily distinguished from low-priority messages	o major concerns o minor concerns o no concerns o measurement necessary
6	Time-critical interactions with the system should not afford continuous attention.	
	- Important information is displayed too shortly (e.g., only for a few seconds) - While the driver is responsible for the DDT, sustained attention (longer than 1.5 s) is needed to accomplish an interaction	o major concerns o minor concerns o no concerns o measurement necessary
7	The visual interface should have a sufficient contrast in luminance and/or color between foreground and background.	
	+ Sufficient color and/or luminance contrast to identify different automation modes	o major concerns o minor concerns o no concerns o measurement necessary
8	Texts (e.g., font types and size of characters) and symbols should be easily readable from the permitted seating position.	
	+ Displayed text and symbols are big enough to be easily readable + Display resolution is good enough to be easily readable + Character width and stroke width appear to be appropriate + Text-fonts are easily readable	o major concerns o minor concerns o no concerns o measurement necessary
9	Commonly accepted or standardized symbols should be used to communicate the automation mode. Use of non-standard symbols should be supplemented by additional text explanations.	
	+ Commonly accepted or standardized symbols are used + Non-standard symbols are supplemented with a text label + The symbols are representative for the responsibility of the driver (e.g., displaying hands on a steering wheel to in case of a hands-on request)	o major concerns o minor concerns o no concerns o measurement necessary

Table A1. *Cont.*

10	The semantic of a message should be in accordance with its urgency.	
	+ Use of notification-style to present non-critical information + Use of command-style to present critical information + Wording in accordance with criticality of the situation (e.g., “caution”, “danger”, “warning”)	o major concerns o minor concerns o no concerns o measurement necessary
11	Messages should be conveyed using the language of the users (e.g., national language, avoidance of technical language, use of common syntax).	
	+ Use of national language + Use of simple language + Avoidance of abbreviations + Displaying functionality rather than SAE/NHTSA/BASt-level	o major concerns o minor concerns o no concerns o measurement necessary
12	Text messages should be as short as possible.	
	+ Messages are as short as possible + Not more than four chunks of information are displayed	o major concerns o minor concerns o no concerns o measurement necessary
13	Not more than five colors should be consistently used to code system states (excluding white and black).	
	+ Colors are used consistently throughout an automated driving mode + Not more than five colors are used	o major concerns o minor concerns o no concerns o measurement necessary
14	The colors used to communicate system states should be in accordance with common conventions and stereotypes.	
	+ Colors are in accordance with common stereotypes of the user population + Red = imminent danger, yellow/amber = caution, green = hazard-free operating state	o major concerns o minor concerns o no concerns o measurement necessary
15	Design for color-blindness by redundant coding and avoidance of red/green and blue/yellow combinations.	
	+ green/red and yellow/blue combinations are avoided + system states are redundantly coded in a suitable way	o major concerns o minor concerns o no concerns o measurement necessary
16	Auditory output should raise the attention of the driver without startling her/him or causing pain.	
	Generic auditory output + suitable length (100 ms–500 ms) + suitable loudness (50 dB–90 dB, should be 15 dB above background noise) + frequencies between 500 and 4000 Hz	o major concerns o minor concerns o no concerns o measurement necessary
	Vibrotactile output + suitable length (50 ms–200 ms) + comfortable stimuli 15–20 dB above threshold + frequencies between 150 and 300 Hz	o major concerns o minor concerns o no concerns o measurement necessary
17	Auditory and vibrotactile output should be adapted to the urgency of the message.	
	Generic auditory output + Auditory output of varying urgency is distinguishably different by pulse rate, frequency, or loudness + Low-priority information is either unobtrusive or without auditory output	o major concerns o minor concerns o no concerns o measurement necessary
	Vibrotactile output + urgency is coded through a variation of location and timing, not frequency and amplitude	o major concerns o minor concerns o no concerns o measurement necessary
18	High-priority messages should be multimodal.	
	+ high priority information is presented in more than one modality + auditory or vibrotactile stimuli are also visually presented	o major concerns o minor concerns o no concerns o measurement necessary
19	Warning messages should orient the user towards the source of danger.	
	+ warning messages lead to an orienting response to the source of danger, causing the driver to look in the direction of the hazard + warning messages to not focus the driver’s attention to a display	o major concerns o minor concerns o no concerns o measurement necessary
20	In case of sensor failures, their consequences and required operator steps should be displayed.	
	+ unavailability of sub-systems because of sensor degradation is displayed + consequences of sensor degradation are displayed + required operator behavior is displayed	o major concerns o minor concerns o no concerns o measurement necessary

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