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Evaluation of Driver Input Variations for Partially Automated Lane Changes

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***Abstract*—Current partially automated driving systems enable lane following and lane changes on the motorway. Driver input and safety measures vary for these systems, as there are no legal regulations on how the human-machine-interaction should be designed. In this paper, an interaction concept for a partially automated lane change is presented. The initiation of the lane change includes a request by the driver and a feasibility check by the system. Based on the results of expert interviews, various input variations were implemented and evaluated in a driving study on the motorway. The experts generally preferred the activation of the indicator lever in combination with steering wheel contact for lane change requests. This input variation enables the driver to express his wish without active intervention in the vehicle guidance. For activation of a so-called lane change abort, which results in an automated return to the starting lane, the experts preferred steering input to the starting lane.**

I. Introduction

In recent years, an increasing functionality of driver assistance systems has lead to higher levels of automation and to a change of the role of the driver. However, there are still technical challenges and legal restrictions that prevent a use of highly or fully automated driving functions on public roads. Partially automated driving (SAE-Level 2 [1]) represents an intermediate step in automation, where the system takes over longitudinal and lateral vehicle guidance. The driver is forced to monitor the system permanently and serves as a fallback level when the system's boundaries are reached [2].

One risk of partially automated driving is that the driver mentally withdraws from the driving task. This can occur as a result of misuse or overreliance on the automation [3] and results in the driver being "out of the loop". Other effects that can occur with long periods of passive monitoring are a lack of mode and situation awareness [4], [5], which can have a negative impact on the driver's performance and decrease the quality of his decisions.

Interaction concepts H-mode [6] and Conduct-by-Wire [7] provide approaches of human-machine-cooperation that address these automation effects. H-mode intends a continuous cooperation, with both the driver and the system participating in the driving task in parallel. The approach of Conduct-by-Wire consists of event-discrete cooperation, whereby the driver requests maneuvers that are executed by the system. As the system takes over the stabilization of the vehicle, the driver can concentrate on monitoring the system and the environment [7].

A support of the driver can be especially helpful for cognitive demanding maneuvers such as lane changes [8]. In order to support the driver on the lateral and longitudinal guidance level, a partially automated lane change system must detect the driver's current maneuver decision.

On the basis of interaction guidelines and existing lane change systems, concept variations will be developed and discussed in interviews with experts from the environment of automated driving functions of the AUDI AG. The concept will then be further refined, implemented in a test vehicle and evaluated by experts in test drives. Results of the test drives are presented and discussed subsequently.

II. State of the Art

A. Lane Change Maneuver

The decision-making process of a lane change (LC) can be divided in three phases [9]. First, the wish to change lanes is made based on the satisfaction for driving on the current lane. The driver then checks if a LC is feasible and executes the desired maneuver if the feasibility check was successful. A similar approach is used for tactical LC behaviour planning for highly automated vehicles in [10].

A LC is defined as the movement of a vehicle from one (starting) lane to another (target) lane. The process can be devided in the phases forerun, maneuver and follow-up [11]. The maneuver starts when the vehicle first crosses the lane marking and ends with the last contact (Fig. 1). In specific situations, e.g. when an object is detected on the target lane during the forerun or the maneuver, it can be necessary to redirect the vehicle to the starting lane (LC-abort).

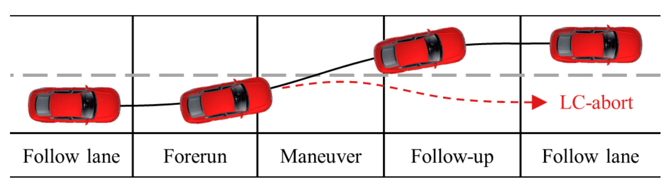

Fig. 1. Phases of a lane change [11], LC-abort in dashed line

B. Lane Change Systems

Partially automated lane change systems are available from various car manufacturers. These systems require a deliberate driver input to initiate a LC. A so-called LC-request can consist of an actuation of the indicator lever for at least 2 s [12], a long press on the indicator lever [13] or a tap on the indicator lever [14], [15]. Other systems designs require a combination of activation of the indicator and a steering torque towards the target lane [16].

In this paper, the activation of the indicator lever will be further divided into indicator-tap, indicator-hold and indicator-lock for locking the lever in the end position (Fig. 2).

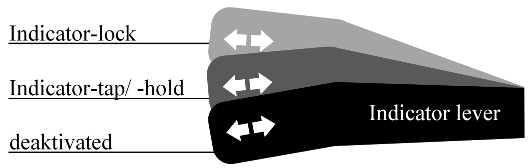

Fig. 2. Positions of the indicator lever

The before mentioned systems detect if the driver keeps his hands on the steering wheel (hands-on) with either capacitive sensors in the wheel or measurement of the driver's hand steering torque. However, it is not stated how the systems behave when no wheel contact is detected during a LC-request or during a maneuver. In [12], a LC is "cancelled" when the system no longer detects road markings, an obstacle is detected or the driver countersteers, which results in a deactivation of the system.

None of the systems seems to provide a LC-abort by the system (Fig. 1) with the return of the vehicle to the starting lane within the automation. This could be potentially useful when an object enters the vehicle's sensor range or the target lane is no longer detected during a LC. Besides, a possibility for a LC-abort by the driver without a deactivation of the system could be helpful if the LC has become needless due to a change of the traffic situation.

III. Partially Automated Lane Change Concept

In order to create an LC interaction concept that is suitable for partially automated driving, the following requirements need to be met:

- ensure a safe and comprehensive maneuver decision based on driver input and sensor information of the vehicle's surroundings
- detect the driver's wish to change lanes coming from partially automated lane following
- provide a LC-abort for system and driver, i.e. (partially) automated return of the vehicle to the starting lane

The decision-making process of a manual LC [9] can be transferred to a partially automated system in different ways. Fig. 3 shows four variations, in which the driver or the system take over a leading role in the motivation (LC-request) and the feasibility check of a LC.

In variation 1, the driver can initiate a LC without an interference of the system. Variations 2 and 3 consist of a combination of active driver input and situation analysis by the system, with either the system or the driver giving the final release of a LC. In Variation 4, the system can initiate

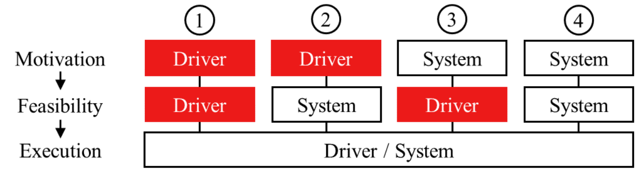

Fig. 3. Variations of the LC decision making process

LC independently. The driver's task is reduced to passive monitoring of the automation and the environment.

A. *Expert interviews*

Nine experts from the surroundings of function and interface development for automated driving of the AUDI AG participated in the interviews. These consisted of questions concerning the process of LC-decision making, driver input for LC-request and for LC-abort. For each question, the experts were asked to fill out a questionnaire and rate the proposed implementations.

B. *Results*

The experts rated the four variations of LC decision-making according to their suitability on a scale from $0-4$ ($0 \mathrel{\hat{=}}$ does absolutely not apply - $4 \mathrel{\hat{=}}$ does absolutely apply). The results are presented in Fig. 4. Variations that include both the driver and the system in a cooperative decision are preferred and are most often rated as rather suitable. One expert noted that a LC request by the system could result in high trust in the system's capability and would therefore require long sensor ranges and a high reliability. Variant 2, with driver request and feasibility check by the system, was assumed for the remaining questions.

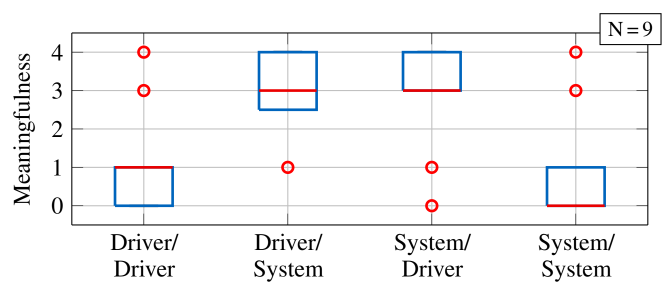

Fig. 4. Meaningfulness ratings of decision-making variations: Motivation/ Feasibility

Several LC-request input variations were then presented and rated by the experts (Fig. 5). Sole activation of the indicator is considered as rather suitable. A combination of a hands-on check and actuation of the indicator is mostly rated as absolutely suitable. Variations that include a steering wheel torque are preferred by some experts but are rejected by others. Actuation of the pedals is mostly considered as not suitable for a LC request. The recognition of a shoulder check is seen controversial as it required a driver monitoring system. Two experts would prefer a separate control element for the request of a partially automated LC. Furthermore, the experts recommend a consistent LC-request input to ensure reproducibility.

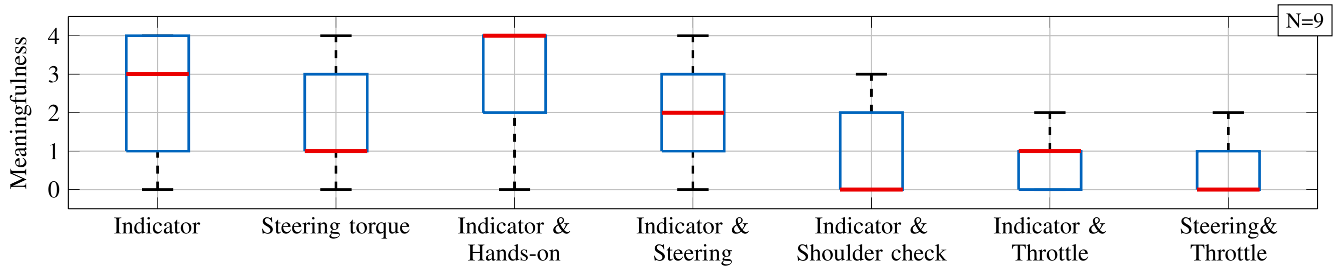

Fig. 5. Expert ratings regarding the statement: "It is meaningful to request a partially automated lane change with..."

A steering torque is generally considered as a suitable indicator for a LC abort. The steering torque threshold should be chosen carefully to avoid unintended LC-aborts. Actuation of the indicator lever is considered suitable by several participants. Multiple experts recommend test drives to investigate the suitability of indicator input in potentially critical situations.

C. System design and variations

The decision making process consists of the phases LC-request (by the driver) and feasibility check (by the system), which are added to the existing phases of a LC (Fig. 6). Due to a wide range of opinions in the expert interviews, multiple input variations shall be provided by the system.

During automated lane following, the driver will be reminded to put the hands on the steering wheel after a period of 15 s [17]. The hands-on detection is realised with a capacitive steering wheel, which detects even slight contact in different parts of the wheel. For the request of a LC, steering wheel contact with at least one hand is required.

The driver indicates the desired direction by activation of the indicator. Indicator-tap and indicator-lock are interpreted as punctual inputs whereas indicator-hold represents a continuous request. In the last case, the LC-request is considered active until the indicator lever is released. In addition to the activation of the indicator, two variations require a hand steering torque T_H of 1.2 Nm in direction of the target lane.

After a LC-request is detected, the system determines if the desired maneuver is feasible. Two criteria must be fulfilled for the initiation of a LC. A safety area, calculated by the velocity of the Ego-vehicle and the minimal time gap of 0.5 s, must be free of objects. For the second criteria, the required decelerations of other vehicles on the target lane for enabling the LC of the ego vehicle are estimated (chapter III-D).

If the feasibility check is not immediately given after a LC request is detected, the system continues to check for feasibility for a period of 6 s. This should allow the driver to request a LC only once when a vehicle on the target lane leaves the safety area shortly after the request. During this period, the vehicle creates an offset of 0.2 m in lateral direction towards the target lane to indicate the LC request to other road users.

The driver must keep at least one hand on the steering wheel during the feasibility check. For variations with indicator-hold, variations with active holding throughout the feasibility check or even during the maneuver will be evaluated in the test drives.

A LC starts when the feasibility check is completed successfully. During the LC, the system continues to calculate the current feasibility rating. The LC can be cancelled by the system until the middle of the rear axle crosses the lane marking.

The driver must keep at least one hand on the steering wheel during the forerun. A LC will be aborted by the system if hands-on is not given and if the vehicle has not yet crossed the lane marking (maneuver not started). The driver can abort a LC by activation of the indicator or with a steering torque T_H in the opposite direction of the LC that exceeds 2 Nm. It should be evaluated in test drives, if an (active) release of the indicator lever should result in a LC-abort for variations that require indicator-hold. A LC-abort by the driver is possible until the end of the maneuver to prevent from unintended LC-aborts due to driver steering behaviour in the follow up phase [18].

The automation is deactivated when the steering wheel torque exceeds 5 Nm, gas pedal is used or the brake is actuated by the driver. The system states "Follow lane", "LC-request", "LC-execution", "LC-abort by system" and "LC-abort by driver" are displayed in the vehicle's central display.

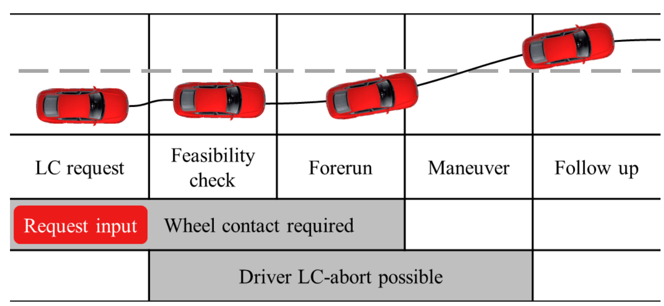

Fig. 6. Phases of the partially automated LC with driver input (up) and time span for LC-abort (down)

D. Feasibility check

To calculate whether the traffic situation allows to change lanes, it is necessary to calculate the required decelerations of other vehicles on the target lane for enabling the LC. The approximation process of a second vehicle to the Ego vehicle can be divided in two phases: reaction phase and deceleration phases. It is assumed that accelerations remain constant during the reaction phase T_R of 0.8 s. The inner distance d and the velocities of the vehicles at the end of the reaction phase can be calculated based on the measured data (Fig. 7).

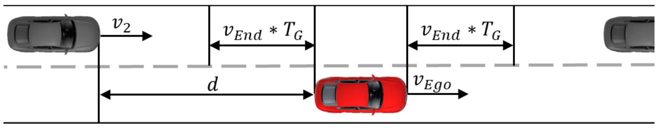

Fig. 7. Feasibility check variables at the beginning of the deceleration phase, second vehicle approaching from the left back on the target lane

During the deceleration phase, the second vehicle is assumed to break with constant (negative) acceleration a_2 until both vehicles drive at equal speed v_{end}, with the rear vehicle maintaining a minimal time gap T_G of 0.5 s. The acceleration of the Ego-vehicle a_{Ego} is assumed to remain constant during the approximation process. It follows:

$$a_2 = -\frac{(v_2 - v_{Ego})^2 - 2 * a_{Ego}(d - T_G * v_2)}{2 * (d - T_G * v_{Ego})}$$

For the feasibility check, the required accelerations are estimated for following vehicles and the Ego vehicle to front vehicles. These shall not exceed 1.5 m/s^2 to obtain a positive feasibility result. Once a LC has been initiated, a LC-abort by the system shall occur when the required deceleration exceeds 2.5 m/s^2, which can still be handled by active cruise control systems [19].

IV. Evaluation

A. Procedure

Five of the nine experts took part in test drives on the public motorway. Each of them had prior experience with partially automated driving. The participants were instructed to keep at least one hand on the steering wheel and monitor the system permanently. Following a settling-in phase, the test drive consisted of three parts: LC-request inputs, required driver status and LC-abort input variations (Tab. I).

TABLE I
METHOD OF THE EXPERT TEST DRIVES

Subject	**Variant**
Input for LC request	No instruction
	Indicator-tap & Hands-on
	Indicator-tap & Steering
	Indicator-hold & Hands-on
	Indicator-hold & Steering
Driver input during	Hands-on
feasibility check & maneuver	Indicator-hold
Input for LC abort	No instruction
	Indicator-tap
	Steering

The order of the parts was consistent for all experts. Following each variation, the experts had to rate the items intuitivity, safety of use and meaningfulness. The items were selected to investigate if intuitive, easy to use inputs could result in unintended maneuver requests. A rating scale was presented on a printed sheet on the display in the center of the dashboard. Hands-on times, steering behaviour and pedal usage were recorded during the test drives to compare system usage among the experts.

B. Results

1) Lane Change Request: In the beginning, the experts were asked to request a LC in a suitable way without further instructions. Four experts used indicator-tap, one participant chose indicator-hold (holding time 1 s) and a steering torque of up to 2 Nm towards the target lane. Fig. 8 shows ratings of the item ratings of LC-request variations on a scale from 0-4 (0 $\widehat{=}$ does absolutely not apply - 4 $\widehat{=}$ does absolutely apply).

Variations with indicator-tap or -hold and hands-on are considered highly intuitive and rather meaningful. Additional steering torque results in overall lower ratings, especially in combination with indicator-hold. Several experts noted high coordinative workload and inferior experience with steering torque.

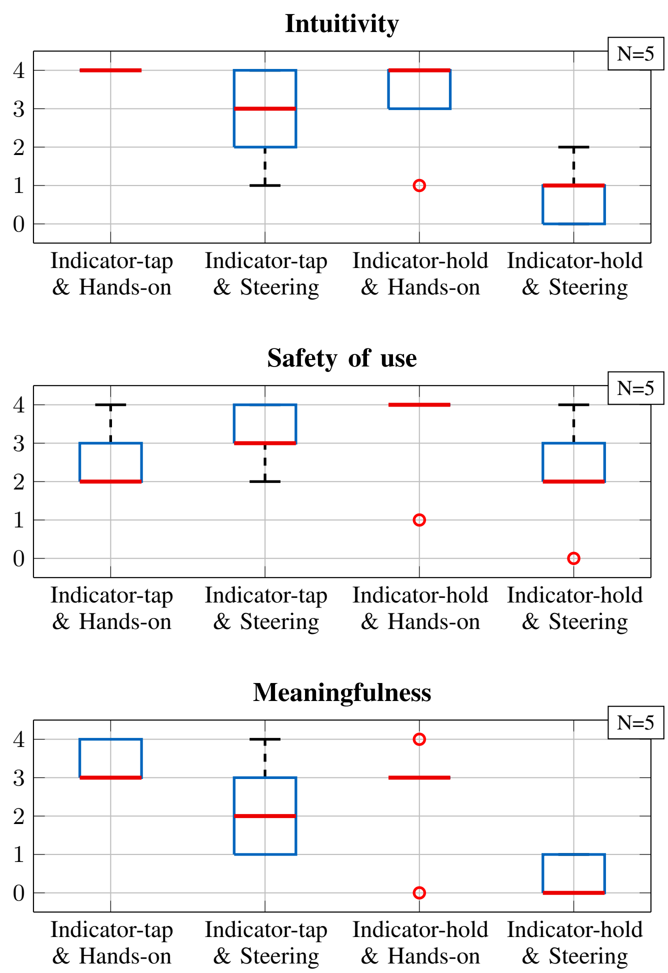

Fig. 8. Ratings of intuitivity, safety of use and meaningfulness of LC-request input variations

Indicator-hold receives high ratings for safety of use with wheel contact and mixed results in combination with steering. Indicator-tap is rated rather not safe to use by three experts, as a tap on the indicator lever required small attention resources and could result in unintentional LC-requests.

2) Required driver status: In the beginning of this section, the feasibility check was temporally set to deny any LC. Thus, after a LC-request, the experts experienced the maximum duration of the feasibility check. While some experts rated this interval as rather suitable, two experts found 6 s to be rather long, as the traffic situation could change meanwhile. In contrast, two experts would prefer a longer check period in case the current status was displayed clearly in the central display.

The experts rated a LC-abort as meaningful when wheel contact is not given during the feasibility check. After the maneuver has been started (line crossed), three experts consider a return to the starting lane as absolutely not useful. One of the experts noted that he expected the system to finish the LC without further driver input once the lane marking had been crossed. Another expert would rate a return to the starting lane as useful if there was a visual indication that wheel contact was required to continue the LC.

It is considered meaningful to require Indicator-hold during the feasibility-check by three experts. The maximum duration of 6 s could be extended in case the driver keeps holding the indicator lever. Two experts prefer a consistent holding time of 1 s to a duration based on the LC progress. The experts do generally not prefer to hold the indicator lever until the end of the maneuver.

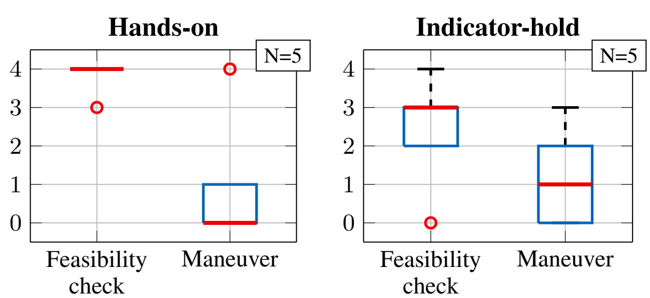

Fig. 9. Suitability ratings of wheel contact (left) and indicator-hold (right) as a requirement to continue LC during feasibility check and maneuver

3) LC abort: Four experts intuitively used a hand steering torque (2.6 - 4.5 Nm) in direction of the starting lane. One expert used indicator-tap and noted that he preferred to use the same control element for LC-request and -abort. None of the experts exceeded the system's torque threshold for deactivation or used gas or brake pedal.

A steering torque LC-abort is rated highly intuitive, safe and meaningful by all experts. Activation of the indicator lever to abort a LC receives mixed ratings. Three experts would recommend activation of the indicator for a LC-abort as an additional input variant. No accidental LC-abort by the drivers occurred during the test drives.

4) User behaviour: Although the participants were asked to maintain steering wheel contact, two experts repeatedly took their hands of the steering wheel during lane following. Four experts at least once requested a LC that was not considered feasible by the system. Two experts resigned themselves to the system's decision. Two experts ignored the system status that was displayed in the vehicle's display and steered the vehicle towards the target lane. In three occasions, the system aborted a LC during the execution. One expert submitted to the system's decision and took his hands of the steering wheel. In two occasions, the experts overruled the system's decision with a continuous hand steering torque the vehicle towards the target lane.

The steering behaviour varied across the participants: Four experts raised only minor steering torque during lane following and LC ($T_H < 1.5$ Nm). However, one expert showed a pronounced steering behaviour during lane following and LC ($T_H \approx 2.5$ Nm), particularly in the first half of the test drive (Fig. 10).

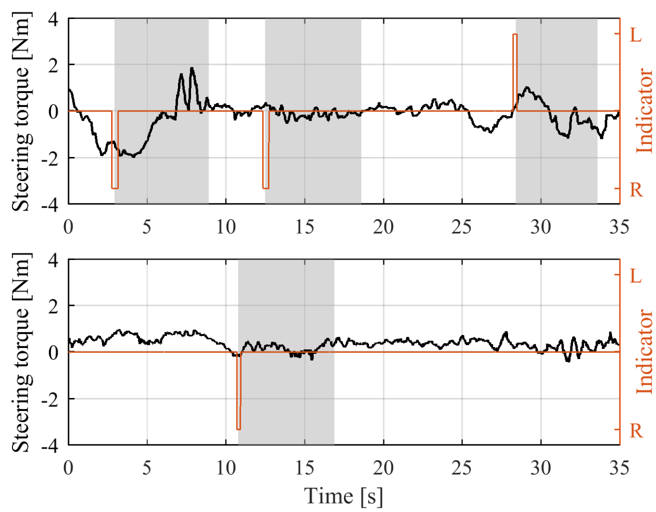

Fig. 10. Hand steering torque T_H and indicator activation during the test drives of expert 3 (up) and expert 4 (down). The time span of an active LC is coloured grey, steering torque is positive counterclockwise

V. Discussion and Conclusion

The experts prefer LC-request inputs that do not require active intervention in the vehicle guidance (steering). Steering wheel contact seems to be acceptable, as none of the experts complained during the test drives. However, the driver should be reminded that steering wheel contact is required for the request and execution of a LC.

Indicator-tap was the preferred way for a LC-request for three experts, compared to two experts that gave preference to indicator-hold (Tab. II). Holding the indicator enables a continuous expression of a LC-request and differs from the usage during manual driving. As the activation of the indicator lever requires little cognitive resources, the drivers can instead concentrate on the state of the automation and the surroundings of the vehicle. However, the experts' answers and driving behaviours differed from each other. Subjective ratings from more experts are needed for solid conclusions. It should also be considered that the participants of the test drives were all technically skilled and had prior experience with automated driving functions. Coordinative challenges of the interactions could affect the drivers' performance and should therefore be investigated with a larger user group in the future.

TABLE II
PREFERRED SYSTEM VARIATIONS (5 EXPERTS)

Subject	**Preferred Variation**
Input for LC request	Indicator-tap (3 experts)
	Indicator-hold (2 experts)
Hands-on requirement	Until maneuver (line-crossing)
Indicator-hold duration	During feasibility-check (3 experts)
	Fixed time span of 1 s (2 experts)
Input for LC abort	Steering torque (4 experts)
	Indicator-tap (1 expert)

A hand steering torque is preferred for LC-aborts, potentially due to its resemblance to manual driving. Acceptance of LC-aborts by the system must be considered as low, especially when they occur after the beginning of the maneuver. Although LC-aborts by the system cannot be completely avoided (due to limited sensor range), their appearance should be minimized by system design. In addition to visual information, the auditory or vestibular channels can be used to transfer information to the driver more effectively [20].

Besides a LC-decision process with a request by the driver and a feasibility check by the system, another implementation could be a LC-recommendation by the system that is subsequently confirmed by the driver. However, this would require a more precise analysis of the traffic situation.

In addition to driver input within the system's borders, it should be further investigated how the driver can enable or disable the automation. While a hand steering torque or pedal use might be meaningful in critical situations, it is presumably not ideal for a take over on schedule.

In summary, it can be stated that the indicator lever is a suitable input device for the request of partially automated lane changes. Holding the indicator lever can prevent from unintended LC-requests and enables the driver to express his wish to change lanes continuously. In test drives, the experts preferred request inputs that do not require active intervention in the vehicle guidance. Instead, they mainly chose to request maneuvers and supervise the system's execution.

VI. ACKNOWLEDGMENT

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