# PREVENTING DRIVER MISUSE WITH PROACTIVE ADAS

**Robert Fuchs**
**Yuuta Sakai**
**Tsutomu Tamura**
JTEKT Corporation, R&D Headquarters
Japan

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## ABSTRACT

As a consequence of the fast adoption of driving automation systems, most vehicles available on the market are the result of a robot-centered development approach. A few decades ago, the major challenges faced by the engineers were to implement sensors and control capability enabling the vehicle to follow and remain within a lane. For safety and to ensure compliance with the evolving regulations, driver monitoring systems (hands-on detection, head and gaze cameras) and override or takeover strategies completed the necessary equipment. The human driver has been considered afterward the development of the robot-like vehicle.

Focusing on lateral control, the majority of level-2 vehicles use an override strategy, which segregates manual from automated steering operation. Sometimes, this causes confusion resulting in distrust and ultimately misuse. Consequently, the level of acceptance of ADAS functions remains under the expectation. Active interaction with the automation is proposed to leverage driver engagement, which is considered as one of the key indicators for assessing safety of ADAS functions. The concept of haptic shared control of the steering enables manual intervention over the automation without deactivation. Systematic and consistent reconsideration of level-2 ADAS functions becomes possible when haptic interaction is exploited. Two proactive ADAS functions: active lane centering assistance and assisted lane change are proposed to enhance driver engagement while reducing the risk of misuse. Furthermore, it raises the question of the relevance of the driver monitoring system.

## STATE OF THE ART

As defined by the SAE standard J3016 [1], the responsibility of the *dynamic driving task* (DDT) is shared at partial or level-2 automation: the automation operates the sustained lateral and longitudinal vehicle motion control, while the driver is in charge of performing the *object and event detection and response* (OEDR) [2]. Two advanced driver assistance systems (ADAS) are used in combination to comply with the above definition. *Adaptive cruise control* (ACC) operates a vehicle speed control, regulating a preset speed and automatically slowing to maintain a preset following distance to the slower moving vehicle ahead in the same lane. *Lane centering assistance* (LCA) provides continuous lateral support to maintain the vehicle centered in the lane. Level-0 ADAS are additional safeguards that prevent imminent risk occurrence. *Automatic emergency braking* (AEB) for the longitudinal displacement and *lane keeping assistance* (LKA) for the lateral deviations complete the active safety envelop. Therefore, the vehicle is capable of following a lane at a preset velocity, however, it does not have the ability to detect the surrounding traffic condition and will not respond appropriately. Consequently, it is the driver who is the sole responsible and he/she is required to monitor both the automated driving system and the road ahead for any objects or events, responding appropriately when needed. During a partially automated drive, there can be no period of time that the driver can disengage from the OEDR task. *Driver monitoring systems* (DMS) are used to assess the driver status and, along with an alert escalation procedure, to prevent sustained noncompliance. For level-2 vehicles, the UNECE regulation 79 requires a means of detecting that the driver is holding the steering wheel [3]. Some, so-called level-2+ vehicles enable hands free driving by using camera for head or eyes gaze monitoring. In summary, a partially automated vehicle is equipped with level-2 ADAS for reducing the driver workload while ensuring engagement, level-0 safeguard functions to prevent traffic accident and DMS to assess the driver status.

**SAFETY PARADOX**

While increasing the level of automation is regarded as a measure to meet environmental, productivity and traffic safety requirements, the role of the driver is shifted to a monitoring task, increasing risks for human to lack operational understanding. The paradox of automation (not only in automotive) is that the more proficient and reliable the system evolves, the incentive for the human to maintain attention reduces. Overreliance or complacency is created when an unjustified trust on the system ability builds up over time. The consequent loss of situation awareness results in an *out of the loop* (OOL) phenomenon or disengagement. Statistics and research suggest that automation can lead to accidents because of the OOL phenomenon. As a consequence, driver engagement has become one of the most relevant indicators for assessing safety of partially automated vehicles [4]. Although monitoring systems and attention reminders increase engagement, they are reactionary to driver behavior and do not guarantee continuous engagement. Hence, if the vehicle cannot assure OEDR is being handled, the level-2 system is incomplete and should not operate [2]. The following examples point out some actual technological inconsistencies:

- The driver can take his/her hands off the steering wheel. Under the UNECE R79 regulation, a maximum of 15 seconds is permitted before a first warning is provided, while a few seconds are sufficient for the driver to become OOL.
- The driver can activate level-2 ADAS functions while not holding the steering wheel. This demonstrates that the driver status is not being used to permit activation of the ADAS.
- Automated lane change (ALC) is triggered under the confirmation that the driver is activating the indicator and is holding the steering wheel. The combination of these two conditions does not guarantee that the driver is performing the OEDR.

The focus placed on robotizing the car has relegated the driver to a peripheral role. To guarantee engagement and safety, reactionary solutions are currently being used: for disengagement, DMS and for ALC, blind spot warning and intervention. Consequently, these safety oncost seem justified for achieving compliance with the regulations and reaching top ranking in safety assessment.

## TECHNICAL LIMITATIONS

ADAS control is often seen as the computation of a trajectory to be followed by the vehicle based on a set of exogenous sensors. Although it is one of the prerequisites for partial automation (and automated driving in general), it is the control of the power steering that renders the ADAS as a reaction torque to the driver. This study assumes that a trajectory corresponding to the centerline of the driven lane is available and focuses on the steering control only.

A single control structure is applied virtually to all available steering systems (Figure 1a). It takes the form of a combination of an assistance control loop for manual driving and of an angle control loop for automated driving (ADAS). Weights are used to adjust the control authority. Higher weight on the angle control results in stronger centering support that is effective on straight drive as well as curves but tends to reject manual input. Whereas, lower weight prioritize manual intervention at the expenses of lower angular tracking performance. This steering control for ADAS, called *blended control*, is characterized by a tradeoff between tracking performance and manual intervention. Additionally, an override strategy is used to manage this conflict by switching the weights depending on the torque applied by the driver. While level-2 ADAS aim at reducing the driver workload and ensuring engagement, override biased the concept of “driver assistance” as the notion of working together by giving the impression that the driver can be replaced by the automation. The discontinuous operation of ADAS with the override strategy is assumed to be one of the causes of driver misuse and disengagement occurrence.

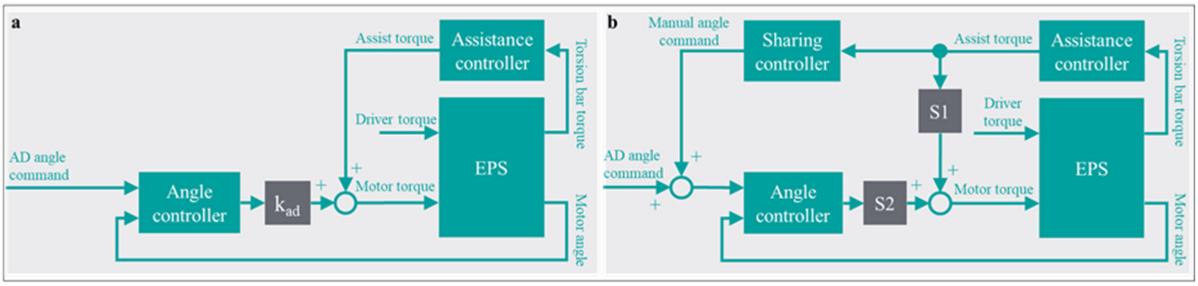


***Figure 1. Two control structures for steering HSC. a. Blended control where the torque commands from the driver and the angle controller output are mixed. The gain $K_{ad}$ is used to manage the conflict between driver and automation. b. Admittance control where the angle commands from the driver and the automation are mixed. The gains S1 and S2 are employed for setting the operating mode of the steering to manual, automated or shared mode.***

## HAPTIC SHARED CONTROL (HSC)

We argue that enhancing human-machine interaction with the steering system encourages driver engagement and is relevant in preventing misuse [5]. Continuous sharing of the steering control bonds the driver with the automation by mean of intuitive haptic communication. HSC of the steering enables manual intervention over the automation without deactivation. Two control configurations are available for HSC: blended control and admittance control (Figure 1). In some vehicles of the latest generation, driver engagement has been improved by lowering the angle controller weights of blended control enabling shared steering with the driver but with low trajectory tracking performance. Interestingly, this limited tracking performance is regarded as another contribution to better driver engagement because it refrains trust building on the capability of the automation. Nevertheless, dynamic adjustment of the weights of blended control as a function of the torque applied by the driver is technically challenging and consequently narrows the shared steering operation [6]. Rather than mixing the torque commands from the driver and the angle controller, admittance control mixes the angle commands. It features the advantage that the inner position control loop is purposefully made stiff so as to ensure high tracking performance in the absence of interaction. Conversely, the outer torque loop is naturally closed in the presence of interaction. The target position of the automation is corrected with an estimated manual displacement computed from a virtual admittance representing the steering system. Ideal lane centering function is achieved with admittance control based HSC because it enables driver intervention while ensuring high trajectory tracking performance [7]. Hence, admittance control is an alternative to blended control because it is not impaired by the tradeoff between tracking performance and manual intervention, and it enables continuous shared steering.

## PROACTIVE ADAS

While conventional ADAS feature limited capability for manual intervention without deactivation and rely on reactionary DMS, proactive ADAS aim at enhancing driver interaction within an override free control framework. Rather than providing unconditional support unless misuse is detected, assistance is provided upon confirmation of engagement. This approach complies with the concept of assistance as working together and questions the relevance of DMS.

### Active Lane Centering Assistance (aLCA)

Admittance control based HSC is appropriate for hands-free lane centering control as it enables driver intervention while providing high trajectory tracking performance. However, it is inappropriate for partially automated operation because of the potential risk increase of unjustified trust building on the capability of the automation. aLCA is based on the observation that a driver is tempted to take his/her hands off the steering wheel when sufficient safety margins are confirmed around the vehicle. It is assumed that this condition occurs primarily on straight drive and when the vehicle is well centered in the lane so that the driver is confident enough to let, intentionally or not, the automation take the drive. The condition relates to the lateral control of the vehicle as neither the driver nor the automation are needed to operate the vehicle. When the vehicle is centered in the lane, the driver does not need to apply torque and the output of the angle controller vanishes. aLCA consists in deactivating the centering support when the vehicle is well centered in the lane and when the driver applies no force. Conversely, it provides guidance only when the driver applies torque, similarly to power steering delivering torque assistance upon driver input. Hence, the driver is not tempted to take his/her hands off the steering wheel reducing the risks of misuse. While steering, the driver is continuously interacting with the ADAS providing intuitive haptic information in the form a torque directed towards the lane center (AD trajectory). In this way, the UNECE regulation 79 can be fulfilled without oncost related to DMS such as hands off detection (HOD). In the case of sustained hands-off driving with aLCA not providing the centering effort, steering based LKA remains to prevent lane departure like in manual operation. Figure 2 shows how the steering control switches between assisted and manual drive when using aLCA with the gain relation $S1+S2=1$. The torque threshold is small enough so that the switching is virtually seamless to the driver.

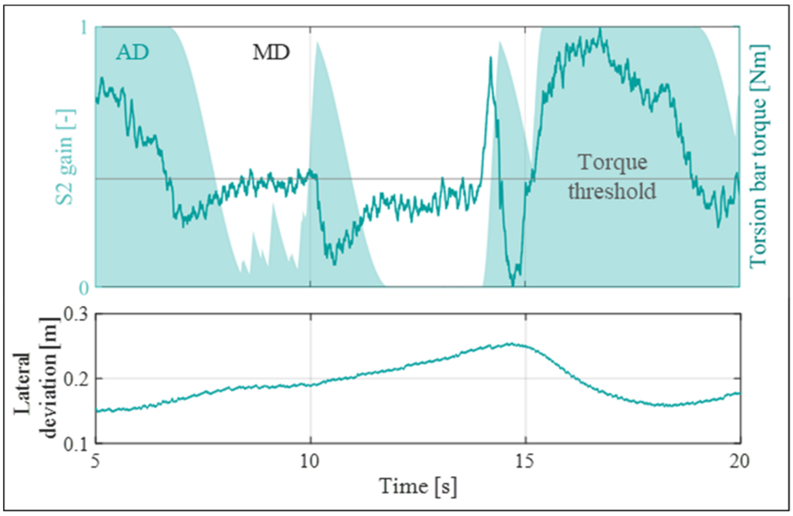


***Figure 2: Operation of aLCA. Top figure: Relation between driver torque (torsion bar torque) and the control authority transfer between manual (MD) and centering assistance (AD) with the gain S2. Bottom figure: Vehicle lateral deviation from the planned trajectory. Between 7 and 13 s, the vehicle is relatively well centered, the driver activity is low and the centering support is inactive (MD). Because the driver hands are in contact with the steering wheel, engagement events are eventually occurring as observed at 10 s. From 13 s, the driver is actively steering trying to reduce the lateral deviation with the support of the centering function (AD).***

**Assisted Lane Change (aLC)**

The aLC function requires the driver to manually initiate the lane change upon activation of the indicator. While steering, the driver encounters torque resistance at first. Overcoming this resistance triggers a trajectory shift to the adjacent lane. The driver is then guided towards the center of that next lane (Figure 3). Compared to the ALC function, driver engagement is enhanced because it is reasonable to assume that the driver will proceed to the OEDR during the initiation phase similarly to while changing lane manually. The need for safeguards like blind spot intervention becomes obsolete and safety oncost can be reduced.

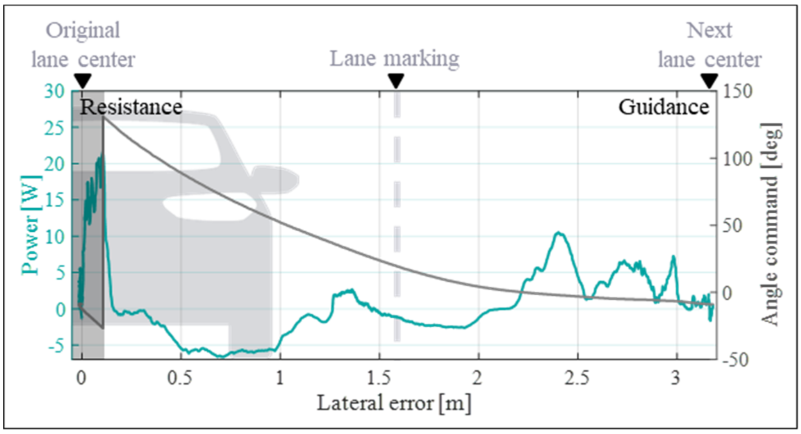


***Figure 3: Steering system performance during a lane change maneuver while using the aLC function. Driver activity is required to deviate the vehicle away from the planned trajectory. When the lateral error increases above 0.2 m, the planned trajectory is shifted to the adjacent lane center (angle command trace). Guidance is then provided, which translates into negative driver power. As the vehicle gets closer to the center of the new lane, the driver proceeds to final adjustment of the lateral position (positive power from 2.2 m of lateral error).***

## ASSESSMENT OF DRIVER ENGAGEMENT

An evaluation made on a test vehicle across several individuals is presented to quantify the usefulness of the proposed proactive ADAS functions. The test vehicle is equipped with trajectory planning, tracking control and the steering shared control. The evaluation is made along a 1 km two-lane straight road portion. The nominal trajectory of the automation lies on the center of the right lane and the vehicle is controlled to track this nominal trajectory at 50 km/h using the Stanley path tracking model [8]. A high precision GNSS system (Global Navigation Satellite System) is used for the position feedback.

Six participants took part in the experiment with an average age of 44 (from 31 to 60) years old. All participants were experienced drivers and reported an average annual travel distance of 22,000 km. They were required to operate the steering wheel only and to keep their hands in contact with the steering wheel during the whole duration of the experiment. The drivers had to maintain a straight drive centered in the right lane for the assessment during lane centering and to perform a single lane change maneuver within a distance of about 100 m for the evaluation during lane change (Figure 4). Following accustomation with the different functions, each participant repeated the maneuvers three times in each operating mode of manual, conventional ADAS and proactive ADAS.

The driver power, which is defined as the power input by the driver into the steering wheel, is employed for the assessment of engagement. Although there is no established way of measuring driver engagement, the choice of this indicator is motivated by its practical and non-intrusive aspects. The power input is a measure of how much involved is the driver in the operation of the lateral control of the vehicle. Positive power indicates that the driver is actively steering (driver active), while negative values represent situation where the human arms are driven by the automation through the steering wheel (driver passive). Inactivity is defined as when the power vanishes. Disengagement is not strictly captured with steering inactivity because zero power is obtained when either the torque or the velocity crosses zero, for example during a slalom maneuver. Furthermore, engagement cannot be assessed merely with the input power because it is a broader concept that is not limited to the physical contact of the driver with the steering wheel. Another acceptable level of engagement that satisfies the OEDR condition is obtained when the driver monitors the automation and the traffic (but this increases the risk of OOL as discussed in the Safety Paradox Section). Nevertheless, DMS are challenged in their intention of detecting the ill-defined concept of disengagement. For example, steering wheel touch sensor and camera for head or eyes gaze monitoring provide limited performance in assessing driver disengagement because neither hand in contact with the steering wheel nor the orientation of the driver sight are reliable indicators [9]. Hence because proactive ADAS are activated upon confirmation of physical activity, power is a pertinent and sufficient indicator to evaluate the driver engagement.

Technically, the driver power $P_d$ is defined as $P_d = T_d\ \omega_{sw}$, where $T_d$ is the driver torque input and $\omega_{sw}$ is the angular velocity of the steering wheel. Typically, power steering is equipped with a torque sensor in the form of a torsion bar. The measurement represents the torque difference at both extremities of that torsion bar, which is equivalent to the driver torque in steady state condition only. Estimation of the driver torque dynamics is obtained with an observer as detailed in [10]. While the input power captures driver activity, the lateral deviation away from the trajectory is another indicator, used in combination to assess how well the driver performs the task of controlling the vehicle position along the road. This deviation corresponds to the error between the planned trajectory and the actual position of the vehicle obtained from the GNSS.

Standard deviations of these indicators are used to quantify the driver performance. These were computed for each participant and averaged for the display in Figure 5 and 7.

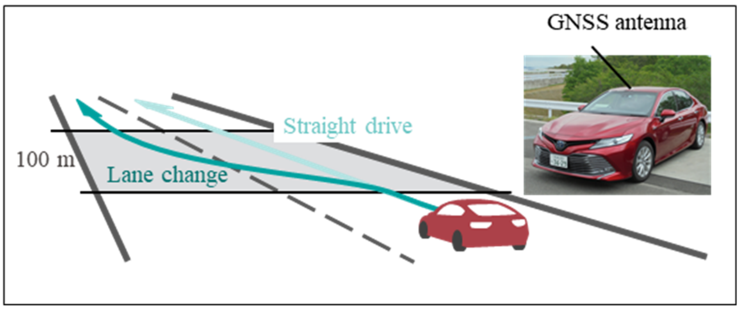


***Figure 4. Test vehicle used for the assessment of the driver engagement. It is equipped with the Stanley path tracking model, the steering shared control and a high precision GNSS for the position feedback. Two driving scenarios are used for the assessment of the driver engagement during manual drive as well as when conventional and proactive ADAS are activated. The straight drive is used during lane centering. The driver is required to execute a lane change within a distance of 100 m for the assessment with lane change support.***

**Assessment during Lane Centering**

Measurement examples of driver activity during manual drive, conventional LCA and the proposed proactive aLCA are shown in Figure 5. Technically, the driver can remain passive when using the LCA function because the vehicle is centered continuously. The remaining low activity observed is caused by the driver holding the steering wheel. Practically, it is only following a disengagement alert that the driver has to display activity temporary, such as touching or applying force on the steering wheel depending on the detection method. As shown in the top-right bar graph of Figure 5, less power is required for aLCA than during manual operation but higher than with LCA. This confirms that proactive aLCA reduces the driver workload compared to that measured during manual operation while ensuring a greater degree of engagement in comparison to that observed with conventional LCA. This assessment of engagement during lane centering correlates with the performance of tracking the lane center as displayed in the bottom-right bar graph of Figure 5. Hence, aLCA provides a compromise between LCA and manual operation. It reduces driver workload without impairing safety.

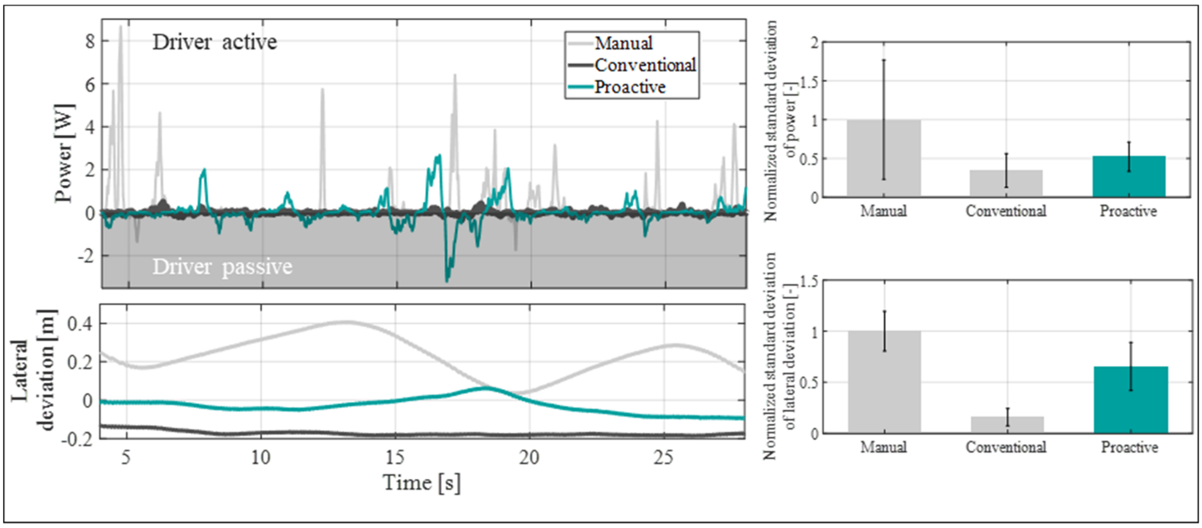


***Figure 5. Assessment of driver engagement during lane centering. The time plots show a measurement example of one driver performance. The bar graphs give averaged standard deviations of the power and lateral error of the 6 participants including the one-sigma error. Virtually no driver activity is required when the conventional LCA function is activated. Less power is required while using the proactive aLCA function than during manual drive but more than with the LCA activated. A similar trend is observed for the accuracy of lane tracking. Greater engagement is observed when using the proactive aLCA function while still significantly reducing the workload.***

**Assessment during Lane Change**

The data of three lane change maneuvers during manual drive as well as with conventional ALC and the proposed proactive aLC activated are depicted in Figure 6. Like most conventional ADAS, the ALC function does not require driver activity to execute the maneuver. Rather, the human is driven by the automation (negative power). However, driver activity is necessary to perform the lane change manually and with the aLC function. In this example, the aLC has been tuned so that the driver power required to initiate the lane change is even greater than that in manual operation. After this initial engagement, guidance is provided resulting in negative power until the vehicle approaches the center of the next lane where the driver proceeds to a final adjustment of the vehicle position (positive power, also observed with ALC). Figures 7 shows the standard deviation of the driver power. It has been split into two parts. The first part is composed of the data starting from the initiation of the indicator (assuming that the vehicle is centered in the initial lane) until a lateral deviation of 1 m is reached. The driver power of this portion of the maneuver is assumed to represents the initial engagement. The second part uses the data remaining until the vehicle attains the center of the new lane. Here, the driver power indicates the activity required to complete the maneuver. Considering the power for the manually executed lane change as baseline, the data of Figure 7 confirms that the lowest power required to the driver occurs while using the ALC function. In both, manual and with ALC, similar power levels are observed during the initial and guidance phases. Conversely, the aLC function features the compromise of ensuring initial driver engagement (highest initial power) while reducing the workload during the guidance phase (power lower than that in manual drive). The initial engagement level is tunable as shown with the markers in the left bar plot of proactive ADAS in Figure 7. Fine tuning of this initial power should be considered carefully. Indeed, a too high initial resistance might be misunderstood as a denial of the lane change, whereas a too low value would not guarantee engagement.

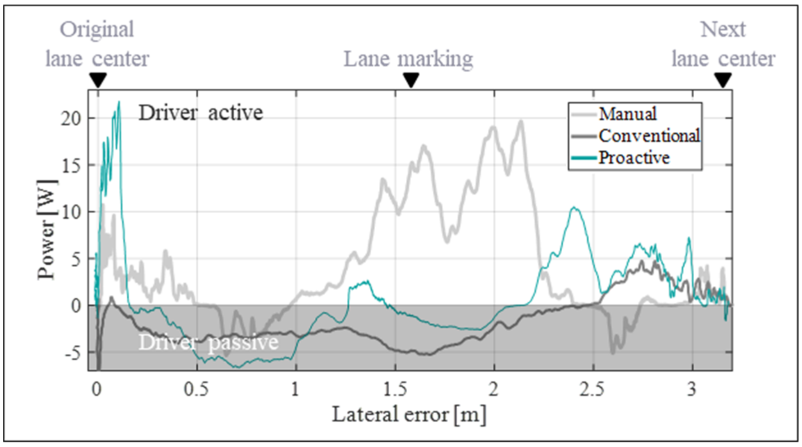


***Figure 6. Measurement example of one participant over three lane changes: manual and with ALC and aLC activated. Driver activity is not required when the conventional ALC is activated resulting in negative power. The power required to initiate the lane change is highest with the proactive aLC (tuned as such) to force engagement. Then, as the AD trajectory shifts towards the next lane, guidance is provided and the driver becomes passive similarly to when using the ALC function.***

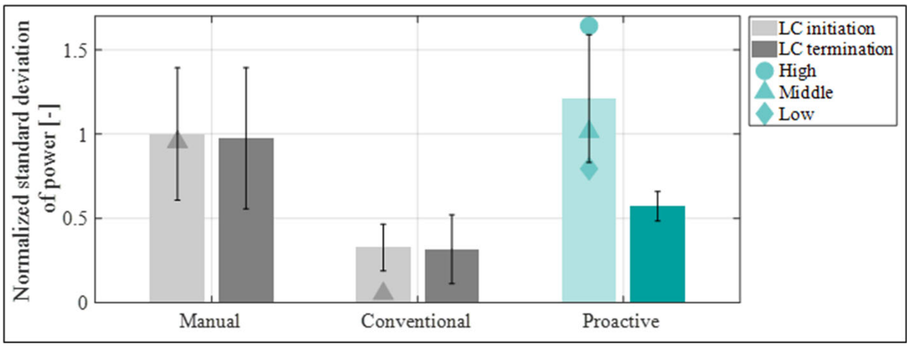


***Figure 7. Standard deviations of the driver power over the lane change maneuvers (manual and with conventional ALC and proactive aLC activated). The experimental data is split into two parts: lane change initiation (from 0 to 1 m of lateral deviation) and termination (rest of the maneuver). Similar power levels at both initiation and termination phases are observed in manual operation and with conventional ALC respectively. However, they differ because virtually no driver activity is necessary when using the conventional ALC. The proactive aLC represents an alternative that guarantee initial engagement while reducing the workload during the termination phase. The markers indicate the standard deviation of one participant. Three different initial engagement levels of the proactive aLC function (low, middle and high) are displayed to demonstrate the tuning capability. The middle tuning has been used for the bar graphs.***

## CONCLUSION

Interestingly, most contributions on ADAS gravitates around a limited scope of human-machine interaction, which results in known safety challenges (OOL, disengagement, misuse, etc.). This paper is an attempt to demonstrate practically how enhanced human-machine interaction enables the development of ADAS that prioritize safety while still reducing significantly the driver workload. Override free and continuous ADAS are essential design requirements that enable intuitive haptic communication between driver and automation. Proactive ADAS, which provide assistance upon confirmation of driver engagement, enable the fulfillment of safety regulations (e.g. UNECE Regulation 79 for partial automation) without oncost related to DMS. In consequence, the relevance of DMS is questioned. The resulting cost reduction represents a significant contribution potential for the democratization of ADAS to all vehicle platforms so that the original road and traffic safety objective aimed by the automated driving technology can become reality.

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