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# Investigation of drivers' thresholds of a subjectively accepted driving performance with a focus on automated driving

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ABSTRACT

Lately, the development and implementation of automated driving moved to the center of interest in the automotive industry. In this context, one of the central issues – the configuration of adequate trajectories – is mainly tackled using a technical approach. However, it appears that a technically ideal driving performance does not necessarily coincide with the drivers' subjective preferences. This study strives to determine thresholds of a subjectively accepted driving performance regarding lateral vehicle control. A second objective is to analyze the influence of selected personal and situational factors on these thresholds. An empirical online survey with 161 participants rating video sequences of driving performances was conducted. The video sequences differed not only with regard to the lateral offset of the ego-vehicle but also concerning the weather (sun/rain) and traffic conditions (existence/driving behavior of oncoming traffic). Additionally, the participants' driving experience and sensation seeking were considered in the data evaluation. To analyze the data, binary logistic regression analyses were calculated. They revealed that the subjective evaluation of driving performances varies primarily depending on the lateral offset of both the ego-vehicle and the oncoming traffic. The results indicate that regarding the lateral offset certain thresholds of subjectively accepted driving performances do exist. Regarding the development of automated driving systems, two issues need to be considered in order to ultimately guarantee user acceptance. First, the subjective thresholds need to be integrated into the systems' trajectory planning. Second, the oncoming traffic's driving behavior has to be considered.



## 1. Introduction and theoretical background

Unrestricted and individual mobility evolved as an indispensable core aspect of satisfactory life quality in modern societies. Using a car allows people to reach their target destinations in a relatively short and reasonable time (Hütter, 2013). In order to optimize this way of transportation, it is subject to profound research and development until today. Regarding the improvement of road safety and driving comfort, automated driving systems lately moved to the center of attention. So far, the developmental approach has been primarily technical. One major example is the implementation of trajectories for automated driving systems. Here, the center of the lane is often used as reference point, i.e. as optimum position, for technical algorithms (Werling, 2011). However, taking a closer look, technically ideal trajectories turn out to not be subjectively

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acceptable in all cases. A good example to illustrate this issue is the situation of a car passing through a narrow right-hand curve. In case of no oncoming traffic, the driver will accept the center of his lane as trajectory. However, this presumably will change, in case an oncoming truck approaches on the other lane. In this case, the driver will probably move to the right of his own lane. This behavior presumably origins in the driver's desire to maintain safety distance to the truck (and not because e.g. the driver is afraid of crossing the centerline of the road). Thus, it emerges that the center of the lane as reference point is relative. It serves as orientation but does not necessarily correspond to a driver's subjective trajectory preference in a certain situation.

This idea of a subjectively accepted driving performance is not new. It has been brought up by several authors. The first ones to mention this are Gibson and Crooks (1938). In their field theory, they postulated the existence of two fields ahead of the car: The *field of safe travel* and the *minimum stopping zone*. The latter is located within the former and both are defined by objective parameters such as the ego-lane or oncoming traffic. By means of these fields all possible safe paths of the car can be described. Kontaratos (1974) built up on these ideas in his accident-causation-model. It is also characterized by different zones surrounding the car, namely the *crash, threat, and indifference zone*. The *crash zone* depicts the area around the vehicle, in which an accident is inevitable. In the *threat zone*, a situation appears to be dangerous but can be solved successfully. The *indifference zone* is considered to be safe, i.e. no accidents or dangerous incidents are to be expected. In contrast to Gibson and Crooks (1938), who mainly focused on objective factors and parameters, Kontaratos (1974) had a broader approach. Regarding the *threat zone*, he additionally considered the relevance of subjective and individual factors. In this context he discussed the assumption of *margins of safety* that are the result of the *crash and threat zones'* ratio: The smaller a *margin of safety*, the smaller the spatial and temporal difference between the two zones. Ohta (1993, in Teh, Jamson, Carsten, & Jamson, 2014) defined these safety margins even more precisely in terms of the temporal relationship between two cars. According to him, drivers fear a collision when a following car is at a distance of 0.6 s or less. A distance of 0.6–1.1 s is also considered as critical, whereas until 1.7 s, the *normal* or *comfort zone* is located. Every distance of more than 1.7 s is assigned to the *pursuit zone*.

Based on the literature above, the question arises how exactly the drivers' subjective assessment of a situation occurs. Furthermore, it is uncertain on which aspects or elements the drivers' decisions are based. According to Wilde (1982), drivers seek to maintain an individual target risk level. In contrast, Näätänen and Summala (1974) assumed that drivers constantly try to avoid any kind of risk, thus striving for a target risk level of zero. In his review article about driver behavior models, Vaa (2014) concluded that the common element of both models is the importance of emotional evaluations. However, these affective assessments should not be exclusively reduced to the perception of risk. Instead, Vaa described a wide range of target feelings, e.g. relaxation, safety, pleasure, vigilance, as well as excitement. It is therefore plausible to infer that the pure quality of the driving performance is often only of secondary importance. Following Hancock and Sawyer's (2015) perspective, drivers are willing to put only a minimal amount of effort into the driving task. Drivers only strive to *satisfice*, that is, to meet the absolute necessary demands for successfully solving a driving situation. Put into other words, people do not always desire to reach the technically ideal driving performance, i.e. the center of the lane, but are content with any driving trajectory guaranteeing safety.

Considering these points of view, it becomes apparent that there is a range in the driving performance that drivers subjectively rate as acceptable or sufficient. Furthermore, it appears that this evaluation strongly depends on situational and personal circumstances. Voß, Herzberger, Hoffmann, Frey, and Schwalm (2016) took up this line of thought and investigated the construct *subjectively experienced driving performance*. Based on a literature research, expert ratings, and online surveys, a questionnaire for the assessment of the construct was developed.

Returning to the point of developing automated driving systems, specifically their underlying trajectories, these literature sources indicate that a pure technical approach could not suffice to guarantee customer acceptance. It was shown that subjective evaluations have a high importance in the perception and acceptance of driving trajectories. As a result, a holistic developmental approach which combines technical and subjective parameters could provide benefits with regard to user-sided driving comfort and safety in automated driving. Such an approach could help to find answers to questions regarding the choice of a subjectively accepted automated trajectory in specific driving contexts. This, in turn, could lead to greater customer satisfaction and could prevent that drivers intervene in the vehicle guidance of their automated car. For the above-mentioned example of the right-hand curve, this would mean the following: If the automated system recognizes an oncoming truck, it should adapt to the user's preference, cut the corner instead of remaining in the middle of the lane, and as such provide a subjectively sufficient safety distance between the vehicle and the truck.

The present paper aims at providing first insights with regard to this issue. It tackles two aspects which should be considered when implementing automated driving trajectories: It tries to identify thresholds of a subjectively accepted driving performance for the lateral offset, i.e. minimally required trajectories for user acceptance, and to examine those parameters that have an impact on the thresholds.

Taking up Hancock and Sawyer's (2015) ideas, the most decisive parameters influencing the subjective driving perception are those that threaten the desired minimum driving performance in terms of an impending crash. Because the most severe accidents happen when two cars collide frontally, the lateral offset to the left – that is to the road's centerline – can be considered as one of the most central elements. Additionally, several other factors influence the risk of an accident. Therefore, these factors could also influence the subjective driving evaluation. In terms of situational factors, (oncoming) traffic (Schießl, 2008; Teh et al., 2014) and rain (Ashley, Strader, Dziubla, & Haberlie, 2015; Hautière, Dumont, Brémond, & Ledoux, 2009) appear to be relevant. However, even though rain is the weather condition having the greatest impact on