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“Please watch right” – Evaluation of a speech-based on-demand assistance system for urban intersections

Nadja Schoemig[1*], Martin Heckmann[2], Heiko Wersing[2], Christian Maag[1] & Alexandra Neukum[1]

[1]) Wuerzburg Institute for Traffic Sciences GmbH (WIVW), Robert-Bosch-Str. 4, 97209 Veitshöchheim (Germany)

[2]) Honda Research Institute Europe, Carl-Legien-Str. 30, 63073 Offenbach/Main (Germany)

Corresponding author: tel. +49 931 78009208; fax: +49 931 78009150; e-mail-address: schoemig@wivw.de

Abstract

In a driving simulator study we evaluated a speech-based driver assistance system for urban intersections (called Assistance on Demand AoD system) which supports the driver in monitoring and decision making. The system provides recommendations for suitable time gaps to enter the intersection based on the observation of crossing traffic. Following an „on-demand“-concept, the driver activates the assistance only if support is desired.

In one drive, drivers used the AoD system in every situation they experienced to guarantee that every driver had the same exposure to the system when evaluating it. During another drive, drivers were free to decide if they want to use the system or not. The experimental study compared the AoD system with driving manually and with driving supported by a more conventional visual-based system which was always active at intersections (system showing colored arrows in a simulated head-up display (HUD) to visualize the crossing traffic). This resulted in four drives the drivers had to perform. Every drive consisted of several intersections with varying traffic conditions. The drivers had to turn left at every intersection.

24 drivers took part in the study; one group with 14 middle-aged drivers and another group of ten high-aged drivers. Several questionnaires and online ratings were used to assess drivers’ acceptance, perceived usefulness, benefits and specific characteristics of both system variants. In addition, driving behaviour with regard to gap choice and driver’s monitoring behaviour (using head tracking data) were analysed.

The results show that the AoD system reaches high acceptance ratings and is preferred compared to the visual, always active system. Using the speech modality for communication and the on-demand concept were both highly appreciated by the drivers. With regard to driving behaviour, the AoD system is comparably safe as manual driving while at the same time making driving easier by facilitating the monitoring of vehicles waiting at an intersection.

Keywords:

Assistance system, speech-based system, on-demand, driving performance, glance behaviour, gap choice.

1. Introduction

1.1 State of the art on intersection assistance

Turning left at an unsignalized urban intersection with high traffic density arriving from the subordinate road is one of the most challenging tasks for drivers (according to subjective reports and objective workload measures, e.g. Hancock, Wulf, Thom & Fassnacht, 1990; Verwey, 2000, Stinchcombe & Gagnon, 2009). They have to monitor traffic from several directions, estimate suitable time gaps between vehicles, decide when to enter the intersection safely and finally execute the demanding left-turn manoeuvre. Therefore, both cognitive and visual load are especially high in these situations. They account for 26% of all crashes among

lightweight vehicles in the United States (Naijm, Sen, Smith & Campbell, 2003). Therefore, there seems to be a need to support the driver in such situations.
Assistance systems for urban intersections on the market are currently mainly designed as collision avoidance systems dedicated to prevent the driver from safety-critical situations. These systems monitor crossing traffic and prompt the drivers to start an emergency braking by activating visual and acoustic warnings and/or automatically engaging the brakes (e.g. systems by Toyota or Mercedes Benz). I.e. these systems correct wrong decisions or driving manoeuvers already taken either by the drivers themselves or by other road users to avoid a collision. Research on intersection assistance aims to develop systems that are able to provide earlier warnings e.g. by means of Car-to-X technologies (Naujoks & Neukum, 2014) or even prevent the driver from entering the intersection (e.g. Klanner, Thoma & Winner, 2008).
What could be a meaningful add-on to these systems is an assistance which supports the driver already in the monitoring and decision making process before entering an intersection.
Donath, Shankwitz, Ward & Creaser (2007) developed an intersection decision support system that identifies safe gaps in traffic on a high-speed rural expressway and communicates this information to drivers waiting to enter the intersection from a minor intersecting road. However, this system is designed as a Driver-Infrastructure system displaying information at an intersection outside the host vehicle on respective digital signs. An in-vehicle assistance system providing this kind of information was investigated by Dotzauer, Caljouw, de Waard & Brower (2013) in a driving simulator study with 18 older drivers. They presented information about safe gaps in form of a bar in front of the driver by means of a head-up display (HUD). Their system is a three-stage system that dynamically changes from green to amber to red and vice versa as the traffic situation changes. A gap between cars greater than 5 s indicated safe crossing (green flag). Gaps between 2.5 and 5 s were classified as marginal indicated by an amber flag, and gap sizes smaller than 2.5 s were unsafe as conveyed by the red flag. Their results show that equipped with this system, drivers allocated more attention to the road centre rather than the left and right, crossed intersections in shorter time, engaged in higher speeds and crossed more often with a critical time-to- collision value (TTC).
The present study presents an alternative approach for assistance derived from observing driver's natural behaviour: When planning to turn left at an unsignalized intersection drivers often use the opportunity to ask a present front seat passenger for support, e.g. by transferring them the task of monitoring traffic from one direction, typically the traffic from right and requesting feedback about suitable time gaps to enter the intersection. A typical dialogue sounds like this: "Can you please check the traffic from right for me?" - "Sure, I can" - "vehicle from right" - "still vehicle from right" - "still vehicle from right" – "now it's free" - "thank you". Also the passengers themselves could initiate that dialogue if they notice that the driver needs support.
In police emergency vehicle operations such a human-human cooperation proved to diminish risk, with notably more even and calm driver speed behaviour as well as significantly lower emotional workload (Neukum & Krüger, 2003).
The idea of the presented study was to develop and evaluate a system which transfers this human-human cooperation observable in natural behaviour into a human-system cooperation with the system acting as a co-passenger which is giving support when requested (i.e. only "on demand") and which is communicating with the driver via speech. Both, the question of how to design such a system as well as what benefits to expect are topics of this paper.

1.2 Concept of cooperative control

The chosen theoretical concept for the design of the system is that of shared control or cooperative control. In this concept the driver and the system are considered as one combined system in which the two agents interact with each other both taking into account the intentions, potentials and weaknesses of their partner to reach the common goal (e.g.

Sheridan, 1992; Bratman, 1992). Therefore, the task distribution between the two agents is relatively flexible, dynamic and adaptive to different influencing factors.
The term "cooperative control" is defined in a working definition by Biester (2009) by the following characteristics (p. 11):

- […] a continuous exchange process between driver and automobile, with the exchange process creating a common knowledge base and goals […]
- both participants are responsible for certain parts of the commonly defined whole task, which is the result of a continuous coordination process […]
- […] the current interaction of human and automobile is a continuously negotiated form of automation […]
- […] parameters inducing this process of negotiation are the driving situation, the driver's condition, and the environmental situation. […]
- […] In each case the realized interaction produces an identifiable profit for both sides (Biester, 2004) to create a solution, a positive result for the respective task, or to fulfill a social need […]

The potentials of this cooperative approach bears the potential to increase the quality of the interaction, to support and improve the communication (e.g. by natural spoken language), to promote the situation awareness, to optimize the workload, to measurably increase the acceptance and trust and to increase satisfaction in oneself and the overall system (Biester, 2009).

1.3 Using speech interface for communication between driver and assistance

In the last years, a growing number of car manufacturers provide speech interfaces in their vehicles. The use of speech in the HMI design for in-vehicle entertainment systems (such as music selection and tasks related to smartphone use) and navigation systems came up due to the large distraction effects associated with performing visual manual tasks while driving, causing drivers to look away from the road and heavily increasing crash risk (see for example the results of the 100 car study Klauer et al. 2006). Several authors revealed positive effects of speech-based systems on driving performance and eyes off-road measures (e.g. Tijerina, Parmer & Goodman, 1998; Tsimhoni, Smith & Green, 2004; Schömig et al., 2015; Owens et al. 2010, 2011).
In contrast, using speech-based interfaces for assistance system is not very common. For warning systems for example it turned out that speech is less effective than pure tones or auditory icons (Tan & Lerner, 1995; Lerner, Steinberg & Perel, 1997 cited from Lee et al., 2007). Therefore Dingus et al. (1998; from Lee et al., 2007) suggest to avoid speech displays for attentional warnings. An exception is the study by Lee et al. (2007) about the design of an intersection warning system. He found a speech-based STOP warning (STOP for stop sign) to be more effective in eliciting a stopping behaviour from drivers than the tone-based warning and explains this by the specific context in which it is presented. Mental processing requirements might be higher in determining the meaning of a tone-based warning under an intersection approach context than in identifying and understanding a verbal command.
Campbell (2007) recommends using speech for simple informational or status messages that are not time-critical. Despite its low usability for warning messages he considers it as an effective means for communicating information to the driver in applications that require a high degree of message detail or flexibility in terms of the message content.
Therefore it seems to be an adequate modality for different use cases where especially complex and diverse information might be transmitted to the driver in order to support him in the decision making process for a driving maneuver.

1.4 Description of basic system functionality

Based on these theoretical assumptions, the system concept was developed as an assistance system for urban intersections which acts like a co-pilot with which the driver can interact by speech communication (Heckmann & Wersing, 2015). The goal in the specific situation of urban intersections is to find suitable time gaps to cross the intersection comfortably and safely. In contrast to a more conventional assistance system this system was based on an "Assistance on demand" (AoD) concept meaning that the system is not always active but the driver activates the system in situations where he/she wants to have support.

The system is thought as a comfort system which should support the driver while waiting at an intersection and monitoring the traffic. In the present study the monitoring taken over by the system was restricted to only monitor one direction, namely the traffic from the right, although the system would be able to also observe other directions and multiple directions simultaneously.

Furthermore, it assists in manoeuver decision by recommending a suitable time gap for turning or crossing the intersection. The final decision and manoeuvre execution remains in the responsibility of the driver. The modality of interaction between the driver and the system is speech, as speech is thought to be the most flexible, natural, and interactive tool for the communication between the two agents. The driver will give an explicit assistance request to the system by speech input (e.g. "please check right") whereupon the system will react by specific speech outputs.

Biester (2009) already evaluated the concept of a cooperative intersection assistance for the use case "turning left on urban and country roads with oncoming traffic". He compared driving manually with driving while using the cooperative system in a between-subjects design. The dialogue between the driver and the system was simulated by using the wizard-of-oz-technique (meaning the experimenter is simulating the behaviour of the system). This dialogue could therefore be relatively flexible and extensive. Biester (2009) found that drivers perceived an increase in the interaction quality, that the system was well-accepted and highly attractive with an even higher trust in high traffic density compared to low density conditions. He could not find any effects on physiological measures and on critical gap choices. Drivers in the cooperative condition chose suitable gaps sooner.

Biester's system supports the driver in estimating time gaps in oncoming traffic when turning left. Oncoming traffic was the only traffic in his scenario. Such a scenario can be easily solved at least by experienced drivers. However, there is effectively a transfer of responsibility from the driver to the system for solving the task. In order to still perceive the system as useful the driver has to fully rely on the system's recommendations which should compensate for driver's weaknesses in perception and decision making. In the present study however, the distribution of the task between the driver and the system is more pronounced as the system takes over the monitoring of traffic from the right while the driver monitors the traffic from the left. For highly crowded intersections, this is a situation which requires full attention even from a high experienced driver. In contrast to Biester's approach, in the current system architecture the driver initiates the interaction with the system by requesting support at a specific intersection. The system does not give advice without being asked.

1.5 Study questions

The specific research questions are:

- Will such an AoD system be accepted, trusted and used by the drivers?

- Which benefit do drivers perceive compared to unassisted driving and more conventional assistance concepts?

- How do drivers evaluate specific HMI features?

- How do drivers interact with the system if they have the freedom to use it as they prefer?

- How does the system affect driver's behaviour in terms of monitoring the traffic environment and the gaps used for entering the intersection?

- Which factors influence system usage and acceptance, e.g. personal trait factors (age, attitude towards technology) or factors affecting situation complexity (traffic density)?

In order to investigate the benefits of specific characteristics of the system, namely the "on-demand" concept and the advantage of using the speech modality, it was decided to compare it with manual driving as well as with a more conventional intersection assistance system. This conventional system was an "always active visual assistance system" that used visual information presented a via head-up display (HUD) to inform the driver comparable to that described in Dotzauer et al. (2013).

2. Method

2.1 Participants

N=24 drivers took part in the study. They were recruited from the WIVW test driver panel. They all had participated at least in a 2.5 h training session in the simulator before. Two subsamples of drivers were compared: One group of 14 middle-aged drivers between 25 and 53 years (M=34.6; SD=9.6 years). Their average mileage driven in the last 12 months was 8000 km (SD=3018 km). The other group consisted of n=10 drivers with an age above 60 years (M=69.3; SD=6.5 years) and an average mileage of 20789 km (SD=9593). The sample size is unequal because two older drivers had to quit the study due to simulation sickness and could only be replaced by two middle-aged drivers.

The two age groups had a comparable attitude towards technology in vehicles (derived from a separate questionnaire). However, the older group had less experience with speech-based systems in general (group 1: 79% vs. group 2: 60% - derived from a separate questionnaire).

One test driver from group 2 cancelled the last of the four conducted drives. As this person answered all questionnaires, it was decided to not exclude the subject from the sample.

2.2 Study environment

The study took place in the static driving simulator of the Wuerzburg Institute for Traffic Sciences (WIVW GmbH). The mock-up is an Opel Insignia for which outside rear-view mirrors are replaced with LCD displays (see Figure 1). The scenery is projected on five screens displaying a 300° field of view. The scene is presented with an update rate of 60 Hz. The steering wheel has an integrated steering force simulator. Six cameras for monitoring the driver are mounted in the mockup, two for collecting visual data of the driver, four integrated in the SmartEye eye tracking system analyzing driver's head and gaze direction as well as eye lid movements. Furthermore, the mockup interior includes two integrated LCD-displays, one replacing the speedometer, the other in the center console to display navigation information or visual secondary tasks. For the present study however, visual assistance was displayed directly on the front screen simulating a head-up system.



Figure 1: Outside view of the static driving simulator of WIVW used for the study

2.3 System specification

2.3.1 AoD system

For the AoD system a radar or laser scanner is assumed that is able to detect vehicles, pedestrians and cyclists that approach an intersection. Hidden obstacles or vehicles are not perceived. In principle, the system would be able to observe traffic from all directions, also multiple directions simultaneously. For the simulator study however, it was decided to concentrate on the use case "turning left at an intersection" as this situation requires a high cooperation between a driver and an assistance system which was one of the core principles of the AoD system that should be demonstrated. To highlight this cooperative character it was decided to restrict the monitoring by the system to only one direction, namely traffic coming from the right as it was expected to put higher demands on monitoring than traffic from the left. Traffic from the left still has to be monitored by the drivers themselves.

Requests for system activation can already be given when the driver approaches the intersection. The driver activates the system by a speech input whereupon the experimenter starts the system by pressing a button (as real speech recognition was not implemented). After having crossed the intersection, the system is automatically deactivated. The output of the system is triggered by an algorithm using a combination of different parameters (for a visualization see Figure 2):

- V_{ego}: Minimum defined speed of the host vehicle when approaching the intersection [in m/s]

- $TPOI_r$: Time distance of crossing vehicles [in s] to the center of the intersection (called POI - point of interest)

- $Tgap_r$: Time gaps between successive vehicles arriving at the intersection from the left and/or the right [in s]

Speech output was generated by a software that converts written text into audio files. The speech samples created resemble natural speaking. The voice used was a female one.

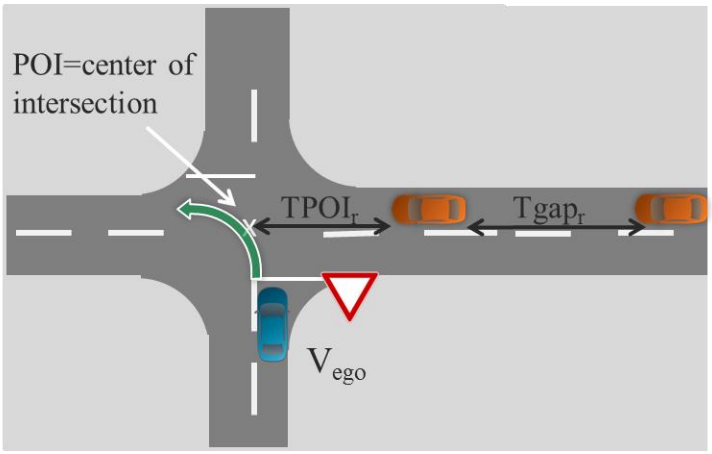


Figure 2: System parameters for AoD system (description see text).

Several system states were defined according to which different system outputs were triggered. Figure 3 shows a simplified version of the most important system states. In approaching the intersection the driver's request (e.g. „Please watch right") activates the system. In the simulator study this state was triggered by a button pressed by the test leader immediately after the request[1]. The system confirms the successful activation by answering "okay - I will watch". When the driver reaches the intersection (defined by driving below a certain minimum speed), the system starts giving recommendations based on different conditions. If the time distance of the closest vehicle from right to POI (parameter $TPOI_r$) is above a defined threshold (defined with 10 s), the system will interpret this as a state where there is no vehicle present (at least none in the sensor range of the system) and triggers the output "no vehicle from the right". It was deliberately decided to not announce "right is free" as this could be interpreted as a permission to drive without further monitoring the actual traffic and therefore creating potentially hazardous situations.

If this condition is still valid after 8 s the information is repeated with "still no vehicle from the right". If a vehicle is approaching from right and reaches a critical time distance $TPOI_r$ (defined with 6 s) to the intersection and simultaneously another vehicle is following with a time gap $Tgap_r$ below a certain threshold (defined with 6 s), the system interprets this as a sequence of vehicles which does not allow entering the intersection for turning. The linked speech output is "vehicle from the right". If the time gap to the next oncoming vehicle is again below $Tgap_r$_crit, and 8 s have elapsed the information is repeated with "still vehicle from the right".

If a vehicle is approaching from the right and reaches a certain time distance $TPOI_r$ ($TPOI_r$_ant defined with 3 s) to the intersection and simultaneously the time gap to the next oncoming vehicle is large enough (> 6 s), the system interprets this as a suitable time gap for entering the intersection. The system output is therefore already given before the previous vehicle has passed the intersection, in order to create a certain preparation time so that the driver can optimally benefit from the recommended gap. Therefore the speech output is "gap after approaching vehicle". If the time gap has elapsed and the next vehicle is approaching with the same conditions, the output is repeated with "gap after the next vehicle". All speech outputs (translated into German language) were at least pretested with regard to the maximum allowed duration to avoid timely interferences with another and the global understanding of their meaning.

[1] This is the only manual action of the experimenter. It could be replaced by a standard ASR system.

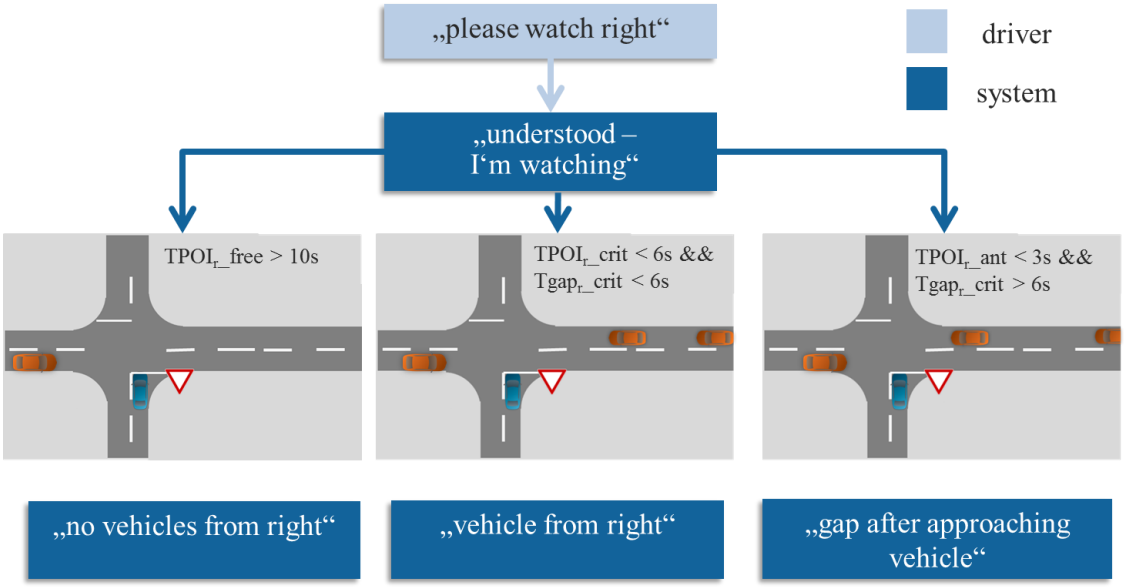


Figure 3: Most important system states for AoD system.

The time gap of 6 s which the system recommends as suitable was derived from a literature reference cited in the handbook for the dimensioning of road systems (FGSV, 2005, Weinert, 2001). The so-called critical time gaps, i.e. the minimum time gap in a superior traffic stream used by a subordinate vehicle for executing the intended manoeuver was derived from the distribution of time gaps observed under real traffic conditions and for different road systems. For the respective situation studied here a critical time gap of 6.6 s was measured. Comparable numbers are reported in Donath et al. (2007) with an actual mean of about 6 s for gaps that are selected by drivers.

2.3.2 HUD system

In order to evaluate the AoD system’s specific characteristics, i.e. the speech-based interaction modality and the on-demand activation, it was compared with a reference system. However, there is no system on the market with comparable features supporting the driver in monitoring and manoeuver decision at urban intersections. Therefore, the decision was to create a reference system that is always active and that uses the visual modality for giving feedback about upcoming traffic at the intersection. This was implemented via coloured arrows in the HUD resembling the traffic coming from the right or left (Figure 4).



Figure 4: Simulated HUD display in the driving simulator with the colored arrows visualizing traffic information from the left and right direction at an urban intersection

It was decided that this system should be able to monitor both directions (i.e. left and right). Comparable system states, comparable conditions and identical parameter specifications as in the AoD system were used. Conditions now refer also to distances and time gaps for vehicles from left. The speech output "vehicle from the right" in the AoD system is replaced by a red arrow either from the right or left or both. The system state connected with the speech output "gap after approaching vehicle" is now replaced by a yellow arrow either from right or left or both. The decision for entering the intersection has to be made by the driver by combining the information from both directions (e.g. a yellow and a red arrow means it is not possible to enter the intersection). It was deliberately decided not to display a green arrow in the system state where no vehicles are in the sensor range of the system (in contrast to the system described in Dotzauer et al. 2013) for the same reasons that the AoD system does not announce "right is free". Instead, the red or yellow arrow simply disappears, if the respective condition is valid.

2.4 Driving course

In each drive the drivers had to drive through a set of several scenarios all containing an urban intersection. As basic layout for this scenario an X intersection was chosen with the host vehicle approaching from the subordinate road. Give way signs are placed at the roadside. A stop line should assure that all drivers stop at a comparable distance away from the intersection entrance. The surrounding at the intersection is created in a way that the drivers cannot see the arriving vehicles on the superordinate road when they approach the intersection. When having stopped at the intersection the sight distance is about 8 s to the right and 10 s to the left (taking 50 km/h as a basis). The instruction asks the driver to turn left at the intersection.

In each scenario there was continuously approaching traffic at the intersection. This traffic was operationalized by a sequence of 10 vehicles arriving from the right and/or left. The vehicles were driving with a constant speed of 50 km/h and defined time gaps between each other. The last time gap in a sequence was defined sufficiently large such that every driver was able to pass the intersection. Traffic density for both directions was varied on four levels (no, light, variable, high). The high traffic density was obtained by time gaps of 2 s between the vehicles, the light one by 7s between vehicles. Variable traffic was created by varying the time gaps between 5 s and 7 s. By varying and combining traffic density from left and right a set of eight basic scenarios was created. To investigate the influence of the different conditions on the time gaps drivers accepted when turning, intersections with increasing time gaps between vehicles were created. The resulting time gap sequence between vehicles was: 2 s, 2 s, 2 s, 4.5 s, 5.5 s, 6.5 s, 7.5 s, 8.5 s, 20 s. The first time gap recommended by the system is the 6.5 s gap, as 6 s is set as threshold. To avoid influences from other factors, in these scenarios vehicles were approaching either only from the left or the right direction.

These ten scenarios were put together to one driving course meaning that the driver drove from one intersection to the next by always turning left. The scenarios were randomly assembled and the order of the scenarios was permuted in the different drives to avoid sequence effects.

2.5 Experimental plan

All 24 drivers performed four subsequent drives (each with a different experimental condition – within-factor design, see Table 1). The first drive was always a manual drive (MAN) where the drivers had to complete the scenarios without any assistance. In the second and third drive drivers drove with the two system variants AoD and HUD. In order to assure that all drivers have a comparable basis for system evaluation during this first AoD drive the drivers were

instructed to use the system in all scenarios (even though the system's basic idea is to be activated „on demand"). This drive was called the AoD-forced drive. In order to avoid sequence effects the sequence of drive 2 and 3 was counter-balanced between the drivers.

In the fourth and final drive the drivers should then again drive with the AoD system but could now use it according to their own preference only in those situations where they want to have support (AoD-free drive).

Table 1: Four conditions varied as within-factor in four different drives.

no	drive	instruction
1	manual	without any assistance
2	AoD - forced	AoD instructed to be used in all scenarios
3	HUD	visual assistance system (always active)
4	AoD – free	AoD used according to driver's preference

2.6 Test procedure

All drivers first started the test session with a 5 minutes introduction drive to get familiar with the simulator environment in the city. The next drive was the manual drive without any assistance. After this drive, drivers answered a short questionnaire. The drivers then received a description of the AoD-forced or HUD system (depending on the sequence of drives) and conducted the according drive. This was followed by the other drive (AoD-forced or HUD). Both drives started with a short practice run for getting used to the assistance system. After each scenario of the AoD-forced and HUD drive the drivers shortly rated how helpful the system had been in the previous scenario. They could either shortly stop for the answer or – after getting more familiar with the rating scale – also proceed driving. Both drives (AoD-forced and HUD) were followed by a questionnaire evaluating again the drive and the assistance system on different dimensions. After having completed both system drives drivers compared both system variants in a separate questionnaire. The final drive was the AOD-free drive where drivers could decide when to activate the system. This drive was followed by a questionnaire specifically regarding the "on-demand" concept. The total session took about 120 minutes. Drivers received a compensation of 30 € for their participation in the study.

2.7 Measures

Several measures were used to assess the acceptance of both system variants as well as specific system features. In this paper, only the ones which are reported are explained in detail.

First, the drivers rated the usefulness of the system online during the drive after each scenario. They should answer the question „how helpful had the system been in the previous scenario?". The used rating scale was a 16-point scale with verbal categories from "not at all" (0), over "very low" (1-3), "low" (4-6), "medium" (7-9), "high" (10-12), up to "very high" (13-15) helpfulness (Heller, 1985). After deciding for one verbal category, drivers are requested to further define their rating by numbers from 0 to 15 in total.

After each of the two drives with the system variants AoD-forced and HUD the drivers received questionnaires for the evaluation of the system (e.g. acceptance, trust, usability, ease of use, perceived workload, emotional aspects, safety aspects, HMI features).

After having driven both system variants, a questionnaire was given for a direct comparison between them. Drivers should state which system variant (either AoD or HUD) and which drive they preferred and why. For the latter they should give a ranking from 1-3 (with 1 as the most preferred) to the manual, the AoD and the HUD drive.

As behavioral measure the interaction with the AOD system was assessed in the AoD-free drive by investigating in which situations drivers activated the system and requested its assistance.
With regard to objective driving behaviour it was analyzed which concrete time gap drivers chose when driving manually compared to the assisted conditions (in the specific scenarios with increasing time gaps from left and from right).
In order to estimate the criticality of drivers' behavior, the minimal Time to Collisions (TTCs) and post encroachment times (PETs- i.e. the time between the first road user leaving the common spatial zone and the second road user arriving at it) between the host vehicle and crossing vehicles during the turning manoeuver were calculated. Different reference points for vehicles from left and right were used here. From left, the moment was used when the front bumper of the host vehicle was in the middle of the left lane when turning. From the right, the moment was used when the rear bumper of the host vehicle had arrived on the right lane.
As the criticality of the scenarios depends on the design of the traffic at the simulated intersections it seemed to be most adequate to define criticality not by using absolute values but based on the distribution of values occurring in this specific simulator study. Therefore the 5% most critical TTCs and PETs in the manual drive are chosen as a basis for the comparison with the assisted drives.
Drivers‘ monitoring behaviour was analyzed in selected scenarios by the number and duration of glances to the right and the left. One scenario with variable traffic both from left and right was chosen for this analysis as in this situation most drivers waited the complete sequence of vehicles to pass resulting in a relatively long and stable waiting time at the intersection. Drivers' eye tracking and head tracking was assessed with a four camera system manufactured by SmartEye. As eye tracking data proved to be unreliable in the context of this specific study (due to strong head movements), head tracking was used instead to infer the glance behaviour. This procedure is justified due to the large viewing angle required to monitor the oncoming traffic from the left and the right. Drivers had to turn their head together with the glances to the right and the left. For defining glances the parameter head heading (in degree) was selected. Minimal head heading per glance was defined with +/-20°, the minimal time distance between two glances must be 100 ms and the minimal duration of head heading must be above 100 ms.

3 Results

3.1 Online ratings of usefulness

For the online ratings of usefulness rated after each scenario the lowest (minimum), the average (mean) and the highest rating (maximum) were calculated per drive and averaged across all drivers. The average online rating (see Figure 5) across all ten scenarios shows a significant higher usefulness ($t(23)=3.242$; $p=.004$) for the AoD system ($m=8.6$, $sd=3.84$) compared to the HUD system ($m=6.2$, $sd=3.89$) on the 16-point-rating scale. The absolute value however, is only in the medium range of the scale. This is reasonable as the system might be perceived as differently useful depending on the traffic scenario. This interpretation is supported when looking at the highest and lowest ratings per drive. The maximum rating is 11.3 ($sd=3.81$) for the AoD system and 9.2 ($sd=3.82$) for the HUD system ($t(23)=2.412$; $p=.024$). The minimum usefulness rating is also significantly higher for the AoD ($m=4.4$, $sd=3.78$) than for the HUD system ($m=2.3$, $sd=3.87$; t-test: $t(23)=2.414$; $p=.024$). There is no significant effect of age on the ratings ($F[1;20]=.011$; $p=.916$).

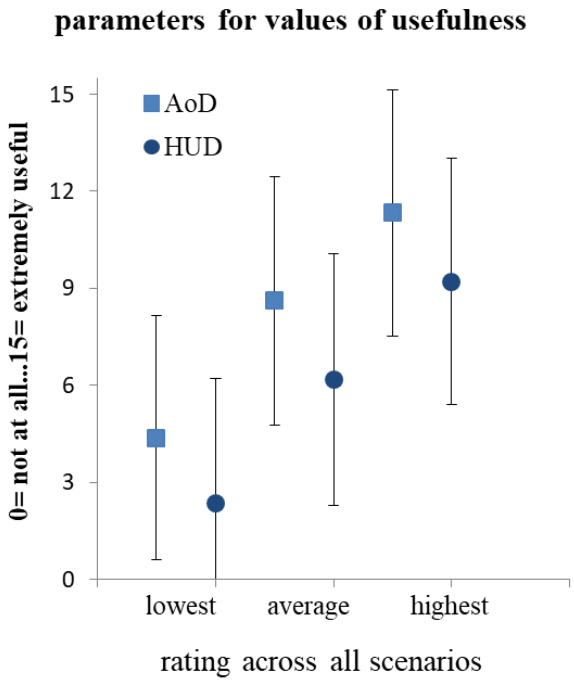


Figure 5: Lowest, average and highest usefulness rating (with standard deviations) across one drive with ten scenarios for the AoD_forced drive and the HUD drive

3.2 Preference of drives and system variant

After the three drives MAN, AoD-forced, and HUD drivers are asked to rate the preferred drive by ranking them from 1 (highest preference) to 3 (lowest preference). Results (Figure 6 left) indicate a clear preference for the AoD system, followed by driving manually. The lowest preference is given to the HUD system. Analyzing comments by the drivers give a hint that this was mainly due to the higher distractibility of the visual feedback.

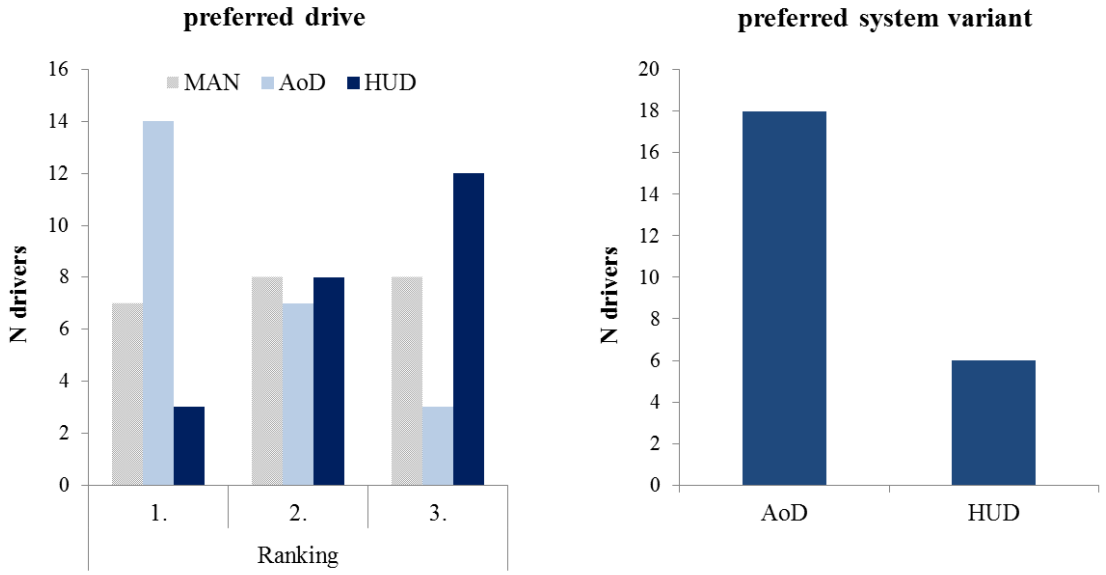


Figure 6: Ranking of the three drives Manual; AoD-forced and HUD (left) and preference of the 2 system variants AoD vs. HUD (right).

Drivers report a clear preference for the AoD system (see Figure 6 right): 18 drivers (meaning ¾) prefer the AoD system while six drivers (1/4) prefer the HUD system. There is no influence of age on these effects. In the middle-aged group 71% (10 out of 14 drivers) prefer

the AoD system, in the higher-aged group 80% (8 out of 10 drivers). Furthermore, distribution of drive rankings is comparable for both age groups.

3.3 Detailed system evaluation

The results of the detailed system evaluation show that the AOD system is rated significantly more positive compared to the HUD system (Figure 7).

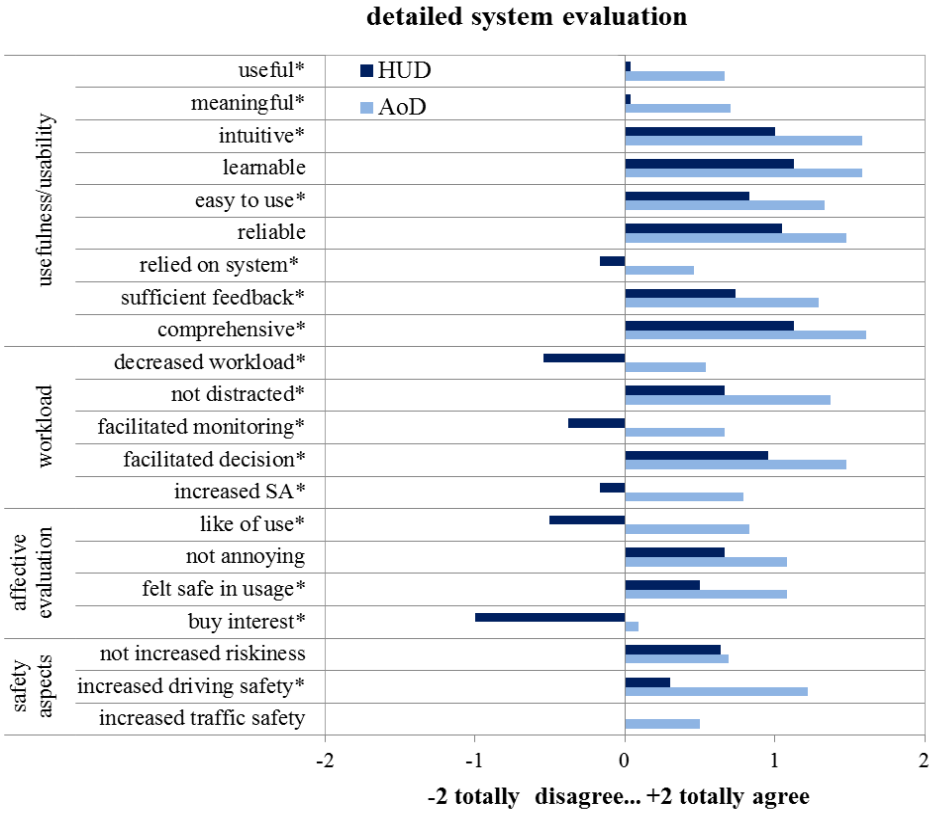


Figure 7: Detailed system evaluation of both systems AoD and HUD on different dimensions rated on a 5-point-scale with agreement/disagreement towards a statement. * mark significant differences in t-tests for repeated measures.

With regard to perceived usefulness and usability, the AoD system is rated as quite useful and meaningful, highly intuitive, learnable and reliable. However, drivers trust the system to a moderate degree. The system gives sufficient feedback and is rated highly comprehensible.
In contrast, the HUD system is rated significantly less useful and meaningful, less intuitive and less easy to use. In addition, drivers are not fully satisfied with the feedback and the system's comprehensibility. Drivers' reliance on the system is much lower.
With regard to workload aspects the AoD system tends to decrease workload. The opposite is true for the HUD system. However, drivers answer that both systems do not distract them. Both monitoring and decision making are rated to be quite highly facilitated by the AoD system. On the other hand, the HUD system makes monitoring even more difficult (probably due to the fact that information for both directions is displayed). Drivers rate their general Situation Awareness (SA) as increased by the AoD system while they report that the HUD slightly decreases SA.
Furthermore, the AOD system provokes clearly positive emotions. Drivers report that they like using the system, feel not annoyed by it and feel safe when using it. The expressed buying interest is on average ranked as neutral. The HUD system contrasts here in the negative feeling when using it and in the unwillingness to buy the system.

When analyzing the perceived safety aspects drivers rate the AoD and the HUD system as not leading to risky driving behaviour. The AoD system increases their personal safety but to a lower extent the general traffic safety. The HUD system's potential to increase driving safety is rated significantly lower.

3.4 Activation of the AoD system in the AoD-free drive

Figure 8 left shows how often drivers activated the AoD system in the AoD-free drive depending on their system preference (AoD vs. HUD vs. MAN). Drivers preferring the AoD system use it in 70% of the scenarios. Drivers who prefer driving manually use the AoD system much less. Figure 8 right illustrates the dependency of system usage on the traffic scenario: In situations with lower traffic density fewer drivers use the system.

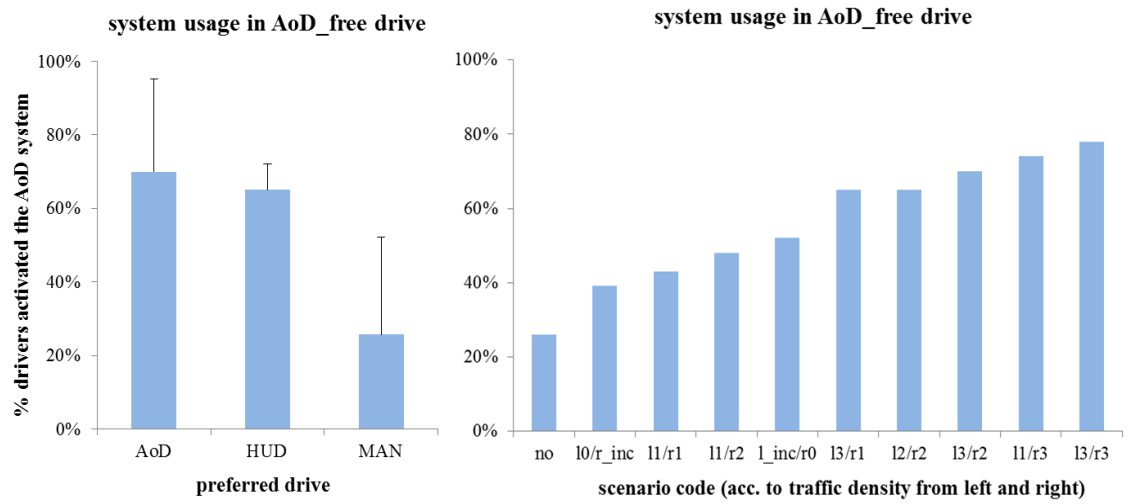


Figure 8: Percentage of system usage in the AoD-free drive depending on driver's preference (left) and depending on the traffic scenario (right; coding: l=left; r=right, 0=no traffic,1=light, 2=variable, 3=dense; inc=increasing time gaps).

3.4 Gap choice

In two scenarios time gaps between vehicles from left and right increased systematically from 4.5 s to 8.5 s. This allows measuring which time gaps drivers choose when driving manually or when being assisted by the AoD or HUD system. According to the functionality of the systems, the time gaps 6.5 s, 7.5 s and 8.5 s are recommended as suitable (in AoD only from the right, in HUD both from the left and the right). Time gaps of 4.5 s and 5.5 s are interpreted as being too small for safely entering the intersection.

Figure 9 shows that only the time gaps 4.5 s, 5.5 s and 6.5 s are chosen for entering the intersection. This means that drivers either chose time gaps smaller than the time gaps recommended during the assisted drives or exactly the recommended gap. None of the drivers waits for a larger time gap in order to negotiate the intersection.

An analysis of the distribution of chosen time gaps from the left reveals that the drivers choose larger time gaps in the assisted drives compared to the manual drive (Chi^2-test: 18.001; df=4; p=001). The time gaps most often chosen from the left are 4.5 s during the manual (79%) and AoD drive (58%). Note that, as the AoD system gives no recommendation for gaps from the left, this gap is the one selected by the drivers themselves. In the HUD condition, the system recommends a larger time gap than chosen during the manual drives. However, this is most often the 5.5 s gap that is smaller than the recommended one of 6.5 s meaning that drivers very often ignored system's recommendations.

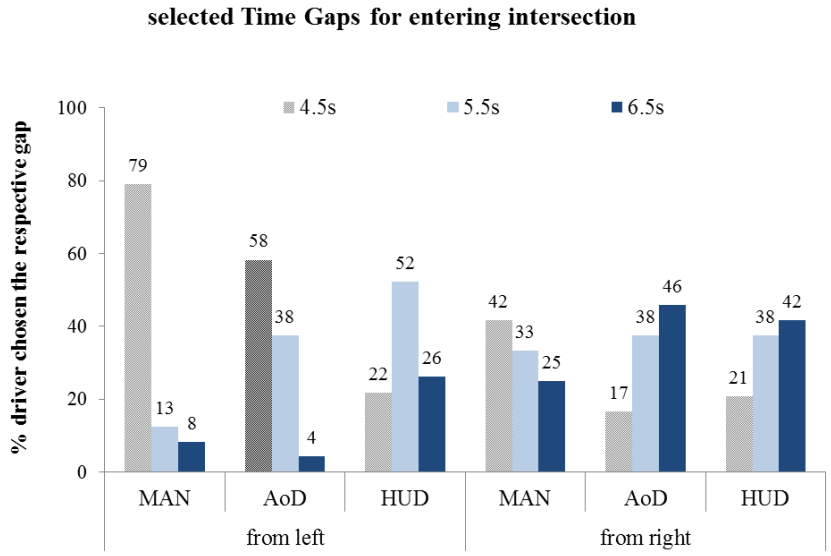


Figure 9: Selected time gaps for entering the intersection in Situations 9 and 10 with increasing time gaps between vehicles from either the left or the right direction.

For time gaps from the right there is no significant difference in the distribution of time gaps between the three experimental conditions (Chi²-test: 4.896; df=4; p=.298). Nevertheless, a descriptive analysis shows that drivers chose larger time gaps in the assisted drives compared to the manual drive. Whereas drivers most often opt for 4.5 s time gaps during the manual drive, there is a slight preference for the 6.5 s time gap in the assisted drives. This is in accordance with the recommendations given by the AoD as well as the HUD system indicating that driver's followed the recommendations although they would intuitively chose smaller time gaps.
When analyzing the effect of age group on gap choice, statistical tests for neither experimental condition show a significant effect (time gaps from left: MAN: Chi²-test=2.454; df=2; p=.293; AoD: Chi²-test=1.665; df=2; p=.435; HUD: Chi²-test=2.450; df=2; p=.294; time gaps from right: MAN: Chi²-test=3.531; df=2; p=.171; AoD: Chi²-test=0.551; df=2; p=.759; HUD: Chi²-test=0.046; df=2; p=.977). Therefore, older drivers do not chose other time gaps compared to the middle-aged group.

3.5 TTCs and PETs when crossing the intersection

In contrast to the analysis of gap choice in the chapter before, the subsequent chapter describes the effective time gaps resulting from driving behavior when entering the intersection. In order to estimate the number of critical situations that occurred when drivers entered the intersection the percentage of TTC and PET values during the assisted drives that are smaller than the 5% TTC and PET percentile of the manual drive (defined as critical values) were taken (Figure 10). For minimal PET during manual drives with traffic from right, the 5% percentile of the distribution is 1.64 s (6 out of 138 valid cases lie below this value). In the AoD drive, 10.9% of the cases are below this as critical defined threshold (14 out of 128 valid cases). In the HUD drive, 10.8% of the cases are below this threshold (13 out of 120 valid cases). Statistically, this difference between the conditions is not significant (Chi²=4.850; df=2; p=.088).

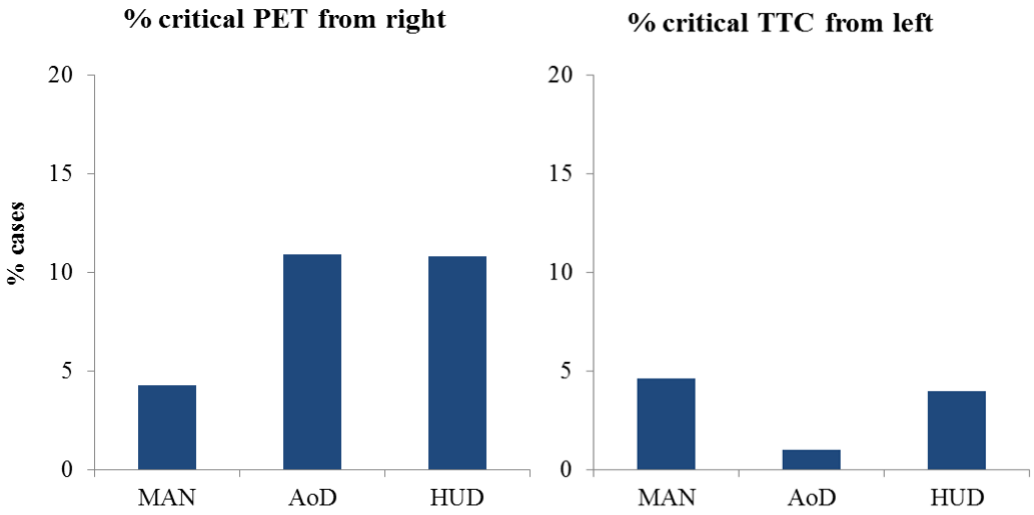


Figure 10: Percentage as critical defined TTCs from left (left) and PETs from right (right) across the three conditions.

For minimal TTC during manual drives with traffic from left the 5% percentile of the distribution is 2.43 s (5 out of 108 valid cases lie below this value). In the AoD drive, 1% of the cases are below this as critical defined threshold (1 out of 102 valid cases; please note: there was no assistance for traffic from the left in this condition). In the HUD drive, 4% of the cases are below the threshold (4 out of 99 valid cases). Again, this difference between the experimental conditions is statistically not significant (Chi^2=2.532; df=2; p=.282).

3.6 Monitoring behaviour

In the analyzed situation the number of glances to the left and the right does not differ significantly between the conditions (Friedman-test; left: p=.625; right: p=.202). The glance duration to the left differs almost significantly between the conditions (F[2;44]=3.117; p=.054) with longer glances in the AoD drive compared to the HUD drive (t=3.068; df=22; p=.006). Glance duration to the right also differs as an effect of the experimental condition (F[2;36]=3.405; p=.044) with shorter glances during the AoD drive compared to the manual drive (t=2.580, df=18; p=.019). The results reveal that drivers still execute a comparable number of glances to check the traffic at the intersection although they are supported by an assistance system. However, with the AoD monitoring the traffic from the right, drivers reorient their attention and show shorter looks to the right and more extended glances to the left.

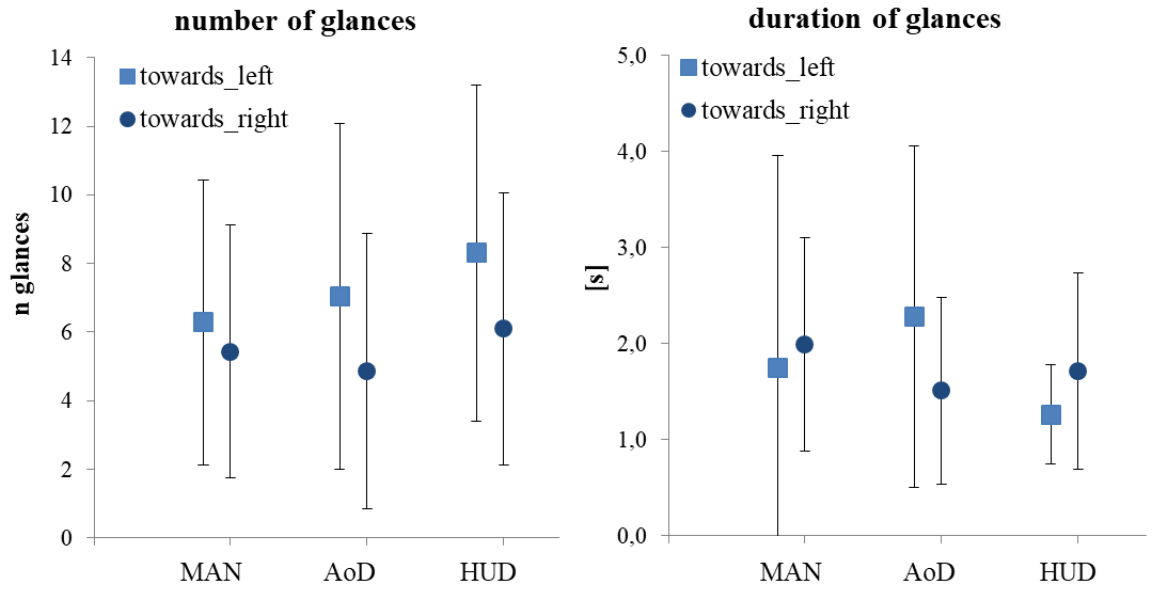


Figure 11: Number (left) and duration (right) of glances to the right and the left in the drives manual, AoD_forced and HUD, analyzed for the selected scenario l2/r2 (left_variable/right variable traffic).

4. Discussion and Conclusions

Altogether, it can be stated that the AoD system reaches high acceptance ratings both in groups of middle-aged as well as higher-aged drivers. It is rated better compared to a visually, always active system on many different dimensions. With regard to driving behaviour it is comparably safe as manual driving while at the same time facilitating driver's monitoring of crossing traffic.

This result is remarkable as the system has some constraints that might have reduced acceptance of the drivers – but actually did not. The first constraint was the decision to design the system as a supporting system for monitoring and decision making that leaves the final responsibility whether and when to cross the intersection with the driver. This "cooperative approach" was highly accepted by the drivers indicating that sharing different driving tasks between the driver and the system is appreciated by the drivers. This is somewhat in contrast to the current strong trend towards automating as many driving tasks as possible. Especially in the case of urban traffic where automated driving will remain a very challenging task over the next decade this cooperative concept might be a promising strategy.

The second constraint was that the AoD system used in the study was able to monitor only one direction. Another approach would be a system that is also able to monitor more than one direction and might combine this information to a more global statement about the general traffic situation at an intersection. This increase in system functionality might further decrease workload and increase acceptance. However, the low acceptance of the HUD system that provided a higher level of information by combining recommendations for traffic from the left as well as from the right indicates how difficult this approach will be. Future research is required on understanding to what extent the increased functionality of the system might require an even clearer communication between the driver and the system. The collected comments by the drivers show that many drivers explicitly favored the idea that they are allowed to concentrate their attention to only one direction (while the AoD system monitors the other direction). Drivers' glance behaviour further indicated that as the system only monitors one direction the drivers still scan and observe the traffic environment. At the same time, their workload is reduced, because the task of just checking the system recommendation

may be easier than identifying a suitable gap among complex incoming traffic. It is also plausible that the active selection of a single supervisory direction prepares the driver for an action based on the expected system speech feedback. This preselection narrows the possible action alternatives and thereby may reduce the overall workload. Taking these results into consideration the strategy of monitoring only one direction worked fine – although the system might be able to provide even more information. However, it would be important to consider potential risks of increased exposure such that the driver might completely stop checking the driving environment and overly on the system`s output.

The third constraint was that the recommended time gaps might have been somewhat too conservative compared to the time gaps selected by some drivers. Especially for traffic from the left smaller time gaps might be recommended. However, in order to guarantee safe driving and taking into account drivers' reaction time the decision for a more conservative approach is highly justified. In addition, drivers gave high acceptance ratings. The acceptance might further increase if the time gaps are adapted to the individual driver. In Orth, Kolossa et al 2017 we investigated individual driver's gap acceptance and found that there is a large variation from driver to driver. Furthermore, we also derived an algorithm to estimate this personalized gap acceptance from few observations. In Orth, Schömig et al. 2017 we used this algorithm to provide personalized gaps to the drivers. First results confirm the hypothesis that these personalized recommendations increase the acceptance of the AoD system.

Using speech for communicating with the driver was highly appreciated by the drivers. It has the potential to promote the integration of the highly increasing number of assistance functions on one common platform. This common platform could be a "speech interface". With more assistance in a vehicle the driver needs more know-how to comprehend and use them appropriately. In order to simplify the interaction between the driver and the vehicle, an integrated interface could be useful. This interface should combine functions and contents of all available assistance systems and data bases, both from the vehicle as well as from external devices such as smartphones (see Biester, 2009). This approach would allow the user to access all different functions and applications while giving him/her the impression to interact with only one partner. This concept would have the potential to increase systems' usability thus increasing driver acceptance of assistance systems. However, it has to be noted that the positive ratings of speech were derived in a well-controlled setting of a simulator study, where no disturbing noise such radio or crying children in the back were present. Future research is required to get insight into how acceptance will be in natural exposure over time.

The on-demand concept is a well-accepted feature. This is supported by the result that the usefulness ratings given by the drivers strongly depend on specific factors, e.g. the traffic density at an intersection. Therefore, the opportunity to activate the system only if support is really desired increases driver acceptance. However, this is only one aspect of the concept of cooperative control. A further advance would be, if the system itself would start the interaction with the driver in case it perceives a potential need for support. In this case, the system would offer the driver some assistance and he/she could decide whether to accept or reject the offer. Biester (2009) already studied the resulting bidirectional communication between the driver and the system - however, in a non-controlled way and by using the wizard-of-oz-technique.

Further studies could analyze whether a realistic system using a formal algorithm for this bidirectional interaction would be accepted by drivers and how it should be designed in detail. Furthermore it would be interesting whether a system solution which monitors both directions (but with the challenge to mentally assign system feedback to the respective direction) would lead to comparable positive results regarding workload and acceptance.

6. Acknowledgments

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