EFFECTS OF ASSISTANCE OF ANTICIPATORY DRIVING ON DRIVER'S BEHAVIOUR DURING DECELERATION PHASES

Popiv[1], Darya, M.Sc., popiv@lfe.mw.tum.de
Rommerskirchen[1], Christoph, rommerskirchen@lfe.mw.tum.de
Bengler[1], Klaus, Univ.-Prof. Dr. phil., bengler@lfe.mw.tum.de
Duschl[2], Markus, Dipl.-Inf., duschl@tum.de
Rakic[3], Mariana, Dipl.-Ing., mariana.rakic@bmw.de
[1]Institute of Ergonomics, Technische Universität München
Boltzmannstr. 15, 85747, Garching, Germany
[2]Fachgebiet Augmented Reality, Technische Universität München
Boltzmannstr. 3, 85748, Garching, Germany
[3]BMW Group Forschung und Technik
Hanauer Str. 46, 80992, Munich, Germany

ABSTRACT: In this work, the investigation of the assistance of anticipatory driving is presented. The goal is to explore the effects of such an assistance system on driver's behaviour in deceleration situations. The influence of the system is derived using the comparison between assisted and unassisted drives performed in a fixed-base simulator. The benefits are evaluated via analyzing driving and visual data with respect to safety, comfort, and efficiency criteria. The results show that drivers with assistance start decelerating significantly earlier in some of the investigated situations, predominantly by coasting a vehicle. The mean maximum decelerations are reduced from 8,5m/s2 to 6,2m/s2 in the safety critical situation, and the fuel consumption tends to sink on 4% in the entire drive.

1 OBJECTIVE

The objective of the study is to investigate the effects of an assistance which expands the natural anticipation horizon of the driver on the maneuvering level. The assistance informs the driver early enough about the upcoming driving situation and suggests an appropriate action in order for the driver to benefit in efficiency, comfort, and safety.

This study deals with deceleration situations. Drivers are informed early enough about the obstacles requiring deceleration of a driven vehicle, also in the cases when they are not yet visible. The driver is notified about the emergence of the situation by visual indicators displayed in the instrument cluster, and is advised to coast a vehicle to reach the lower speed. An efficiency optimized action is assured by following the advice of the system. Comfort is increased with the driver's awareness of the upcoming situation and more moderate braking after a preceding coasting phase. In the investigated safety critical situation the assistance information helps to avoid collisions.

2 EXPERIMENTAL DESIGN

The experimental method and design complies with the requirements of the classic controlled experiment [1].

2.1 Subjects

Twenty six participants (seventeen male and nine female) took part in the experiment. All of them hold valid category B German driving licenses. The average age of the test subjects was thirty four years (standard deviation, sd = 13,6 years) at the time the experiment took place. The driving experience varies: seven participants drive less than 10.000 km per year, eleven – between 10.000 and 20.000, and eight – more than 20.000 km per year.

2.2 Hardware and tools

The experiment was performed at the fixed-base simulator located at the Institute of Ergonomics, Technische Universitaet Muenchen. The field of the driver's front view in the simulator is 180°, the rear and side-mirror views were switched off during the experiment drives.

The landscape and driving environment are simulated using SILAB software [2], which allows flexible and precise creation of the driving situations including the control over simulated traffic. The driving data of the test vehicle as well as relevant situational data, e.g. distance and speed of the other traffic participants, are recorded at 60Hz within the SILAB framework. The visual data are collected at 25Hz using DIKABLIS software [3]. The descriptive analysis of driving data is done with the help of MATLAB and Excel, the statistical analysis is performed using SPSS.

2.3 Experiment driving course

The experiment course is driven three times – without the assistance (baseline drive), with a "birds-eye view perspective" visual assistance [4], and with iconic visual assistance (see "Investigated assistance concepts"). During each experiment drive, the driver is confronted with thirteen different deceleration situations (for exact descriptions including the calculated durations of each situation depending on deceleration strategy see [5]). To avoid recognition effects, landscape and order of the situations vary in every of the three drives.

Seven deceleration situations occur on the rural road, on which the permissible speed is 100km/h if not explicitly influenced by other traffic signs. Two of the deceleration situations include construction sites, in front of which the driver has to decelerate in order to let the oncoming traffic pass before overtaking ("Construction site behind a right curve" and "Construction site behind a left curve"). Both are located in the forest and are not visible at the point in time when the assistance informs the driver. In a "Construction site behind a left curve", the curve radius is 500m as opposed to 700m in case of the situation with the right curve. Another situation includes a 70km/h speed limit sign on a curvy road in the forest ("Speed limit on the rural road"). Additionally, the driver's behaviour upon and during deceleration is investigated when approaching a 50km/h speed limit sign at the town entrance ("Town entrance").

Three situations with slower vehicles in front are examined. In two situations the driver has to decelerate to 80km/h in front of a slower vehicle in the vicinity of prohibited overtaking ("Prohibited overtaking (1) and (2)"), and to 60km/h before overtaking in order to let the oncoming traffic pass ("Slower front vehicle with oncoming traffic").

On the highway, the drivers have to decelerate to 120km/h because of the imposed speed limit ("Speed limit on the highway") and to 60km/h because of traffic congestion which moves with this speed ("Stagnant traffic"). They also have to come to a full stop in front of an idle traffic jam located behind a curve ("Highway jam"). This is a safety critical situation. Without any assistance, drivers have to perform emergency braking (brake with at least -7m/s2) to come to a full stop from 130km/h (common driven speed on German highways) after the situation becomes physically visible.

Urban deceleration situations include obstacles such as a parking car, which could not be immediately overtaken because of the oncoming traffic ("Parking car"), and two traffic lights ("Traffic light (1) and (2)"). Both traffic lights are initially in the red phase, which changes to green when the driver stops in front of them.

2.4 Procedure

Before beginning the experiment drives, the test subjects were acquainted with the goal and meaning of the assistance concepts. Afterwards three drives were performed in a permuted order. Between the drives test subjects were asked to give their remarks and subjective opinions regarding the helpfulness of the assistance system.

2.5 Investigated assistance concepts

Two types of assistances are tested: visual assistance with a birds-eye view perspective (in the following called 3D), and iconic (2D) visual assistance. Both of these human-machine interfaces (HMI) are presented to the driver in the instrument cluster.

Fig. 1. 3D HMI

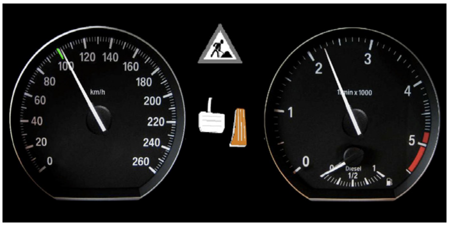

Fig. 2. 2D HMI

The 3D HMI depicts the virtual road, driven vehicle, and the deceleration situation when it emerges. This HMI possesses continuous characteristics: the presentation of the driven vehicle on the occupied lane is always displayed in the instrument cluster. The deceleration situation is superimposed on the virtual road when necessary (in Fig.1 the construction site and oncoming traffic are depicted). The legitimate traffic sign is shown at the side of the virtual road to enhance the understanding of the presented situation. The green colour of the vehicle suggests coasting in order to decrease speed. If pure coasting is not sufficient to reach the required lower speed, the colour of driven vehicle changes to orange suggesting active braking. It is left to the driver to decide with which strength to brake. The authors tried to achieve the driver's understanding of the situation, the most beneficial action at the particular point of time, and provide the feeling of the speed at which the situation emerges.

The 2D HMI is intermittent. The symbols of the traffic sign with brake/accelerator pedals appear only when the driver approaches the corresponding situation (Fig. 2). The accelerator pedal is orange and starts to move when coasting is reasonable. The brake pedal moves if active braking is necessary. No information about the remaining distance or time to the situation is provided to the driver. This HMI can be viewed as "requirement to act" due to its intermittent nature and moving pedals compared to the more "informative" 3D HMI.

2.6 Dependent measurements

In the following analysed measures and their relation to the criteria of efficiency, comfort, and safety are described.

$$TTC[s] = \frac{d_{obstacle}[m]}{v_{driven}[m/s] - v_{obstacle}[m/s]} \quad (1)$$

In (1): TTC – Time-to-Collision, also known as Time-to-Contact; dobstacle – distance between the driven car and the obstacle in front; vdriven – speed of the driven car; vobstacle – speed of the obstacle in front, in case of a static object is equalled to 0m/s.

Table 1: Driving performance measures

Variable	Description
TTC_{decel} [s]	Time-to-Contact with the situation, calculated for the point of time when the driver starts to decelerate by releasing the accelerator pedal – bigger values imply lower fuel consumption during a deceleration phase, as well as more comfort and safe deceleration strategy
a_{min} [m/s^2]	Minimum acceleration, or maximum deceleration – values lower than -3m/s^2 signify the subjectively uncomfortable feeling during the deceleration phase, and lower than -7m/s^2 indicate driver's emergency action [6]
a_{SD} [m/s^2]	Standard deviation of the mean deceleration – comfort indicator. The lower the value, the smoother the deceleration is performed
$N_{collision}$	Number of collisions – safety indicator
$b_{e\%}$ [%]	Fuel consumption, in % compared to a baseline drive (which is taken as 100%) – efficiency indicator
v_{end}[km/h]	For the situations with speed limit signs: speed, at which the traffic speed limit sign is bypassed – safety indicator

To investigate the visual distraction due to the provided assistance, the following measures are analysed:

Table 2: Visual behaviour measures

Variable	Description
T_{first} [s]	Time until the diver first looks on the superimposed situational description
D_{avg} [s]	Average duration of the gaze directed on the instrument panel during the situation is displayed
D_{max} [s]	Maximum duration of the gaze directed on the instrument panel during the situation is displayed
Part [%]	Percentage of time, spent looking on the instrument panel during the situation is displayed

3 RESULTS

The analysis of subjective data shows that the birds-eye view based representation of the situation is preferred to the iconic one. The detailed analysis of the subjective evaluation will be presented by Duschl, M., at the FISITA conference, 2010 [7]. The results described in this work deal with the driving and visual behaviour.

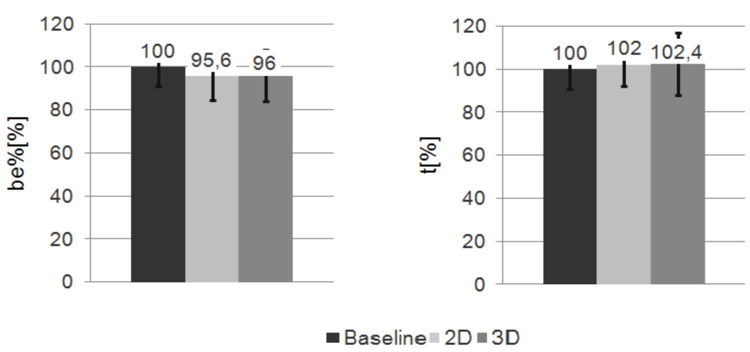

Fig. 3. Results of driving behaviour – fuel consumption and duration of the entire drive

Regarding efficiency, the drivers consumed on average 4% less fuel throughout the entire journey when using assistance compared to baseline drives (Fig. 3, left diagram). At the same time, the duration of assisted journeys increased by 2% (Fig. 3, right diagram). Also in the safety critical situation no collisions have occurred when driving with assistance as opposed to four collisions in the baseline drives.

3.1 Driving behaviour

The results are given for each of the investigated situations. For the representative situations, where the improvement in efficiency, comfort, or safety is significant, the diagrams are provided with mean values and standard deviations. The repeated-measures analysis of variance is performed with post hoc comparisons using Bonferroni corrections due to the normal distribution of the collected data. 0,05 is the chosen significance level.

3.1.1 Construction site behind a right curve

The visual assistance has a significant influence on a start of a coasting phase (F[2;20]=6,971; p=0,005) and fuel consumption (F[2;24]=30,064; p<0,01). The driver starts coasting significantly earlier with both concepts of assistance, at the point of time when mean TTC is 16s, compared to 13s without any assistance. The gain in earlier reaction results in the significant reduction the fuel consumption compared to a baseline: up to 22% with 2D, p=0,014, and 47% with 3D, p<0,001.

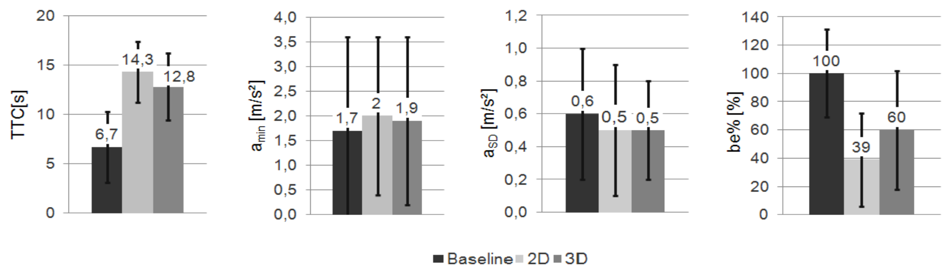

Fig. 4. Results of driving behaviour – construction site behind a right curve

3.1.2 Construction site behind a left curve

In this situation, the assistance has significant influence on sharp decelerations (F[2;24]=8,668; p=0,001) and standard deviations of mean decelerations (F[2;24]=3,760; p=0,038). While driving with 3D, significant reduction in sharper decelerations is observed, p=0,001, and smoother decelerations, p=0,042. No fuel reduction is detected during the assisted drives. The drivers are informed via the assistance about the construction site early enough to reduce their speed, let the oncoming traffic pass, and accelerate before coming too close to a construction site, as opposed to the unassisted drives, where the drivers come to a full stop just before the construction site.

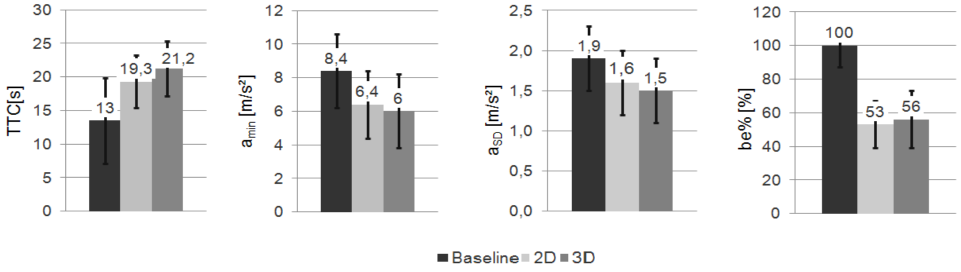

Fig. 5. Results of driving behaviour – 70km/h speed limit on the rural road

3.1.3 Speed limit on the rural road

Figure 5 depicts the results of this deceleration phase. The driver starts coasting the vehicle after the assistance information at TTC of 15s-16s and does not accelerate any more, even if the road conditions allow so. During the unassisted drive, subjects start decelerating with TTC of 2,7s only after the traffic sign can be clearly seen. By avoiding the unnecessary accelerations in assisted drives, participants are able to save up to 50% of fuel, significantly decrease maximum decelerations with 3D and significantly reduce standard deviations with both concepts. Also vend is improved with assistance: baseline – 87km/h (sd = 10), 2D – 76km/h (sd = 8), 3D – 78km/h (sd = 13).

3.1.4 Slower front vehicle with oncoming traffic

When the drivers are advised to coast the car down to 60km/h because of a slower moving vehicle in front with the explanation that the oncoming traffic prohibits immediate overtaking, the fuel consumption is significantly reduced ($F[2;24]=8{,}641$; $p=0{,}001$): by 30% with 2D, $p=0{,}002$, and 35% with 3D, $p=0{,}001$. During the unassisted drive, the test subjects accelerate in hope of overtaking the vehicle in front, and abruptly brake when the oncoming traffic becomes apparent. With the assistance, they prefer to coast when coming closer to the vehicle until the oncoming traffic passes and the overtaking maneuver becomes possible.

3.1.5 Town entrance, prohibited overtaking (1) and (2)

Drivers have to decelerate to 50 km/h when entering the town. The entrance is visible from a large distance. In this case, no improvement in fuel consumption with assistance is determined. Also no reduction in fuel consumption is established when decelerating to 80km/h in front of slower moving vehicles in the vicinity of prohibited overtaking. Drivers possess all the needed information without assistance: they see the slower front vehicles early enough to start coasting and they are aware that overtaking is impossible due to traffic regulations. No strong or uncomfortable decelerations are observed in any of the three situations during the drives with or without the assistance.

3.1.6 Speed limit on the highway

The coasting phase when approaching a speed limit of 120km/h starts significantly earlier and results in efficiency gain with assistance (F[2;24]=30,690; p<0,001; Baseline<->2D: p<0,001; Baseline<->3D: p=0,006). Results for vend: with no assistance – 140km/h (sd = 26), 2D – 124km/h (sd = 15), 3D – 130km/h (sd = 21).

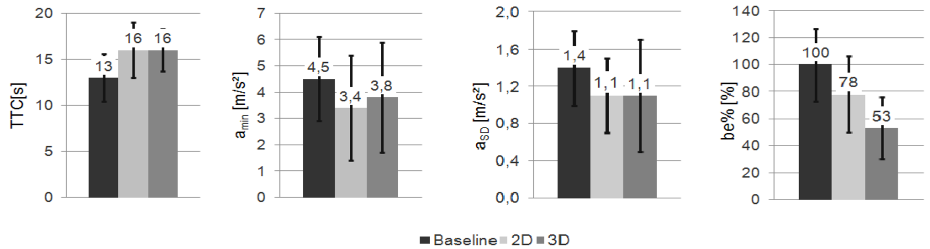

Fig. 6. Results of driving behaviour – 120km/h speed limit on the highway

3.1.7 Highway jam

Figure 7 presents the results of the situation on the highway, in which the drivers approach a jam behind a curve and have to come to a full stop. In this particular situation, the efficiency gain is less important than the issue of safety. Without the assistance, four collisions occurred, while with assistance – none. The coasting phase without the assistance starts because of the curve with TTC of 13s, followed by hard braking with TTC=6,4s once the jam tail can be seen. With assistance the driver starts coasting significantly earlier with mean TTC of 19s (2D) and 21s (3D), after the assistance information is presented. The braking phase for assisted drives begins with TTC 13s-15s in the curve. As a result, maximum decelerations are significantly reduced and collisions are avoided.

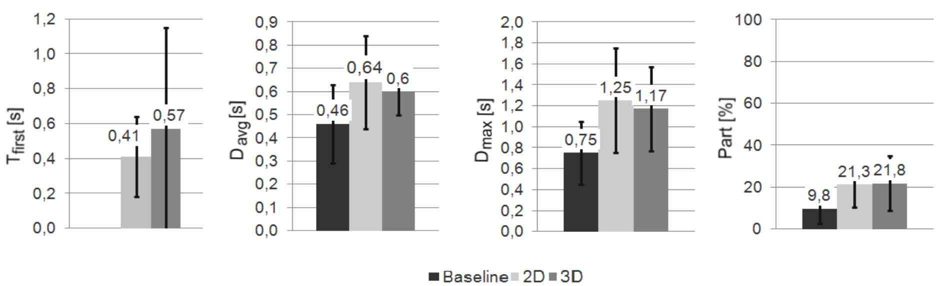

Fig. 7. Results of driving behaviour – highway jam

3.1.8 Stagnant traffic

No improvement in fuel consumption is established. This situation is well-visible and the assisted reaction of the driver does not significantly differ from the unassisted one. The drivers are able to reduce their speed in all of the drives in efficient and comfortable manner.

3.1.9 Urban road situations: traffic light (1) and (2), parking car

No improvements are detected in decelerations and in fuel consumption in the investigated urban situations. However, it is not to state that the results would be the same under real life conditions. Traffic lights as well as rear lights of a parking car are hard to simulate realistically, which might be one of the reasons why the results do not show any improvement.

3.2 Visual behaviour

The first ocular fixation of drivers on the displayed situational description follows in 0,41s for 2D and 0,57s for 3D (Fig. 9). The slight difference can be explained by the fact, that in 2D the icons are completely removed if there is no relevant situation detected, and shown anew otherwise. In 3D, the representation of the virtual road and the driven vehicle is kept throughout the entire drive. Mean glance duration does not exceed 0,64s and 0,6s for 2D and 3D, respectively. Maximal glance duration also does not reach critical values (more than 2s according to [8]) either for 2D or for 3D. Slightly higher 2D mean values and standard deviations for both Davg and Dmax can be explained by the test subjects' reports stating that animated pedals were sometimes confusing, which might be the reason why they were looking longer on the 2D symbols.

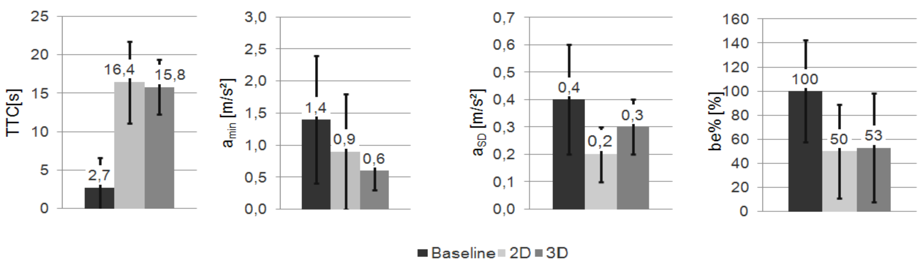

Fig. 8. Results of visual behaviour

Percentage of time spent looking on the instrument cluster Part[%] increase with both concepts of assistance, but no critical situations caused by this fact are observed.

4 DISCUSSION AND CONCLUSIONS

In the fixed-base simulator experiments, the quantity values for some of the driving measures may differ from those of real drives. However, the quality tendency can be derived. The presented results of experienced maximum decelerations, standard deviation of the mean decelerations and fuel consumption are to be viewed in comparison, in which the exact values are important to derive the tendency of change in assisted versus unassisted drives. To further suit this purpose, the comparison of estimated fuel consumption is presented in percents, where 100% is always the fuel consumption during the unassisted drive. Reaction times, e.g. what is the time distance to the object when the driver starts to decelerate by releasing the accelerator pedal, are comparable to those which can be obtained from the real drives, provided one considers visibility conditions. This is also validated by the unpublished experiments [9].

The results show the potential in reduction of estimated fuel consumption in several of the investigated situations, especially on the rural and highway roads, where the upcoming reduction of the speed is not visible from larger distances. The early notifications and propositions to coast the vehicle in front of the emerging construction site and speed limits amount to an approximately 50% reduction in fuel consumption. Also the early information about the oncoming traffic which excludes the possibility of immediate overtaking of the slower front vehicle on a two-lane rural road results in a 30%-35% reduction of fuel consumption.

Safety can be significantly increased by providing the information early enough to the driver about unexpected driving situations which require a considerable reduction of speed. While approaching a traffic jam behind a curve on a highway, drivers experienced four collisions without the assistance. With the assistance, the drivers start to reduce their speed by active braking earlier to prepare for the possibility of a full stop.

However, in the situations where the speed reduction can be clearly seen by the driver from larger distances, the additional information of the assistance system does not help to reduce the fuel consumption. Such situations include entering a town, approaching traffic congestion on the highway or slower moving vehicles in the vicinity of the prohibited overtaking. Results of the assisted drives also do not show any improvement in urban situations, but this might be due to the difference between real and simulated conditions.

Another important observation is that no critical visual behaviour and distraction are observed because of the proposed visual assistance.

5 REFERENCES

[1] Heller, K., and Rosemann, B.: ‘Planung und Auswertung empirischer Untersuchungen’ (Ernst Klett Verlag, Stuttgart, 1974, 1st edn.)

[2] http://www.wivw.de/ProdukteDienstleistungen/SILAB/index.php.de, accessed January 2010

[3] http://www.ergoneers.com, accessed January 2010

[4] Nestler, S., Duschl, M., Popiv, D., Rakic, M., and Klinker, G.: ‘Concept for visualizing concealed objects to improve the driver’s anticipation‘. Proc. 17th World Congress on Ergonomics IEA, Beijing, China, August 2009

[5] Popiv, D., Rakic, M., Nestler, S., Bengler, K., and Bubb, H.: ‘Timing concept for assistance of anticipatory driving‘. Proc. 17th World Congress on Ergonomics IEA, Beijing, China, August 2009

[6] Farid, M., Kopf, M., Bubb, H., Essaili, A. (2006). Methods to develop a driver observation system used in an active safety system. In Proceedings of 22. Internationale VDI/VW-Gemeinschaftstagung, Wolfsburg

[7] http://www.fisita2010.com, accessed January 2010

[8] ISO 15007-1 (2002): Road vehicles – Measurement of driver visual behavior with respect to transport information and control systems – Part 1: Definitions & parameters

[9] Farid, M., 2008, unpublished work of BMW Group Forschung und Technick