Automatic evasion seen from the opposing traffic - An investigation with the Vehicle in the Loop

Fabian Rüger, Verena Nitsch, Berthold Färber
Human Factors Institute, Universität der Bundeswehr München
Munich, Germany
{fabian.rueger, verena.nitsch, berthold.faerber}@ unibw.de

***Abstract*— In the field of active safety driver assistance systems, emergency steering interventions are subject to current research initiatives like UR:BAN [1]. On the one hand, such systems can potentially prohibit accidents even if it is too late to brake to a standstill. On the other hand, such interventions with a lateral component introduce new challenges to controllability assessment. Countermeasures to avoid accidents in critical situations can not only be performed by the driver with the system on board, but also by other road users [2]. Hence, a possible approach is the investigation of controllability aspects of emergency steering systems from the perspective of opposing traffic participants. To work out clear limitations for the functional design of these systems due to the accident avoiding capabilities of opposing drivers, relevant functional parameters and driving situations were identified and investigated with 48 naïve participants using the Vehicle in the Loop (VIL). The results show that the driving situation has an influence on the drivers' judgment and behavior. Drivers were able to avoid accidents with oncoming evading vehicles by steering and/or braking, if the time gap between the peak of the evasion trajectory and the drivers' vehicle was at least two seconds.**

Keywords*— *Vehicle in the Loop, Emergency Steering, Controllability, Opposing Traffic

I. INTRODUCTION

The latest developments of Advanced Driver Assistance Systems (ADAS) focus not only on warning and comfort functions but increasingly also on collision avoidance by active safety [3]. Until recently, most existing systems only used braking maneuvers; systems that employ automatically initiated emergency steering are subject to current research initiatives such as interactIVe [4] or UR:BAN [5]. These systems aim at avoiding accidents in certain speed-ranges, even if the collision object is too close for braking to a standstill. These requirements particularly apply to scenarios involving pedestrians, cyclists or cars reversing out of parking spaces, especially in the urban area. On the other hand, autonomous interventions by ADAS, even for a limited amount of time, introduce new challenges to controllability research. According to various industrial standards, such as ISO 26262 [6] or guidelines such as the RESPONSE Code of Practice [2], the human driver must achieve overall system controllability at all times, even with possible false alarms or system failures.

The work of [7] showed that, depending on the interaction design, false alarm activations of automatic steering interventions could lead to very large lateral deviations. They mentioned that especially systems with part-time decoupled driver via steer-by-wire functions did not seem to be controllable by human drivers. Even if the driver is not decoupled, the steering wheel torques used in [8] could possibly result in yaw rates, which exceed the controllability criteria published in [9]. Consequently, system failures might result in an intrusion into the opposite lane endangering oncoming vehicles. On the other hand, seeing traffic as a system of cooperating road users, it is conceivable that such intrusions can often be ameliorated by appropriate reactions of the opposing traffic. By the definition of ADAS "controllability" in [2], countermeasures in critical situations to avoid an accident can not only be performed by the driver with the ADAS on board but also by other road users. Especially active safety ADAS can affect traffic substantially [10]. For example, commercially launched automatic emergency braking systems are able to operate with decelerations over 10 m/s^2 [11]. Field operational tests and naturalistic driving studies show, that driven time gaps found in traffic could lead to hazards when automatic braking maneuvers used their full performance potential [12]. Therefore, the effects of an emergency braking system on pursuing vehicles were investigated by [13] and [14]. In these studies, participants followed a leading vehicle at a certain distance. Suddenly, an emergency braking system intervened in the leading vehicle and drivers had to brake hard to avoid an accident. Based on the results of these examinations, a maximum deceleration rate for emergency braking systems, which could be most likely controlled by following vehicles, was established [13]. Taking emergency steering systems into account, an intrusion into the opposite lane, possibly causing collisions with oncoming vehicles, is a risk that must be protected against [15]. A similar approach to the mentioned studies of [13] and [14] can be taken in the context of emergency braking systems by investigating emergency steering systems from the perspective of opposing traffic. A requirement for other road users to react adequately and initiating measures to control the situation could be a limitation of the activation of emergency steering systems to certain restricting parameters such as a maximum intrusion into the opposite lane or a minimum time gap to oncoming vehicles. Therefore, this contribution aims to provide information about these restrictions for the functional design of oncoming vehicles with an on-board emergency steering system, and to investigate whether a driver might be able to compensate a system failure in the oncoming vehicle e.g. by braking and steering to the very right of his/her lane.

II. METHOD

A. Relevant Test Cases

As mentioned above, use cases for emergency steering systems abound, including those involving pedestrians or complex traffic situations. According to [16], relevant test cases should be selected out of possible combinations of environmental, functional and driver aspects to reduce testing efforts. In an interdisciplinary expert panel including engineers and human factors specialists, a number of relevant parameters were identified in preliminary tests, which are specified in the following.

Environment and Situation

Emergency steering functions are designed to avoid accidents when it is too late for braking to a standstill. Such scenarios can be found in rural areas with pedestrians stepping onto the street, vehicles reverting out of parking spaces or braking suddenly due to appearing obstacles. These types of critical situations are likely the result of a chaining of single events of unattended traffic participants. Hence, the investigated scenarios should also be of comparable complexity. Considering aspects of plausibility and the expected impact of certain factors on driver behavior, three driving situations were selected for investigation. In all situations, a busy rural environment was chosen with lanes of 3.5 m width.

In the first situation, a car turning right has to stop suddenly due to a pedestrian running across the street (see Fig. 1). The driver in the red vehicle behind did not expect such a hard braking maneuvre and is too close to stop in time. An emergency steering assist intervenes and leads the vehicle around the obstacle. On the right handside, seen from the investigated view of oncoming traffic (like in Fig. 1), a car is waiting on the crossroad prohibiting the driver to leave his lane to the right.

Fig. 1: Emergency steering situation 1.

In the second situation, a child, playing with other children between two houses, suddenly runs onto the street (compare Fig. 2). Again, an emergency steering system leads the red car around the collision object. As it was the case in situation 1, the area adjacent to the right side of the lane is blocked, this time by a parking car, thus prohibiting the use of the sidewalk as a maneuvering space.

Fig. 2: Emergency steering scenario 2.

The last of the three investigated situations is a typical false alarm intervention of an ADAS. The sensor control unit might interpret the waste containers on the roadside as an obstacle and triggers an automated steering maneuver (as shown in Fig. 3). Comparable to the other situations, a parking car occupies the sidewalk adjacent to the right lane.

Fig. 3: False alarm emergency steering scenario.

Emergency Steering Function

Parameters of an emergency steering function, that could be relevant for the perception of oncoming vehicles (Ego), are shown in Fig. 4.

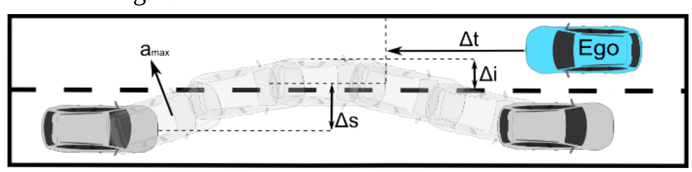

Fig. 4: Relevant emergency steering function parameters.

In the preliminary expert panel tests, a range of parameters was investigated that was underlying two constraints: first, a trajectory should be designed and limited according to actual developments of such systems in the UR:BAN project [1]. Second, the parameters should be selected to require a reaction of the Ego in order to avoid a collision. That results in lateral displacements between $1.0\ \text{m} \leq \Delta s \leq 2.0\ \text{m}$, maximum lateral accelerations of $5.0\ \text{m/s}^2 \leq a_{max} \leq 10.0\ \text{m/s}^2$ and time gaps to the peak of the trajectory of $1.0\ \text{s} \leq \Delta t \leq 2.0\ \text{s}$ (compare Fig. 4). The results of the expert panel testing showed that the differences in the perception of different lateral accelerations by oncoming traffic are negligible and lateral displacements should be at least 1.5 m (resulting in an intrusion of $\Delta i = 0.75$ m into the opposite lane) for further investigation. Based on these findings, the parameter sets shown in Tab. 1 were considered as relevant for user studies.

TABLE I. INVESTIGATED PARAMETER SETS.

Set	Δs	Δi	Δt	a_{max}
1	2.0 m	1.25 m	1.0 s	7.5 m/s²
2	1.5 m	0.75 m	1.0 s	7.5 m/s²
3	2.0 m	1.25 m	2.0 s	7.5 m/s²
4	1.5 m	0.75 m	2.0 s	7.5 m/s²

Based on the fact that the evading vehicle is about two meters and the lane 3.5 m wide and an initial position in the middle of the lane, a Δs of 2.0 m results in an intrusion into the opposite lane of $\Delta i = 1.25$ m. The two different Δs result in gaps of 2.25 m and 2.75 m width on the right of the Ego driver´s lane.

Driver

In compliance with the industrial standard ISO 26262, an ordinary collective of drivers considering age, gender or driving abilities is sufficient [6]. In order to elicit natural driving behavior, the participants should not expect the tested situations, but do not need to be distracted on purpose [17].

B. *Pass-/Fail-Criteria*

According to [2], appropriate binary criteria must be found to assess whether a test case is controllable or not. Therefore, a collision with other traffic participants (leaving the lane would also result in a crash due to the character of the test cases) or an activation of the electronic stabilization program in the Ego car is considered to be an objective fail criteria. Additionally, subjective criteria based on judgments of the participants according to the scale for criticality assessment of driving and traffic scenarios may be considered, as shown in [9]. If more than 15 percent of all participants' ratings classify a situation as subjectively dangerous, a test case is considered to be not controllable. If 15 percent or fewer of the ratings classify the test case as dangerous, the ratings are cross-referenced with the objective data, before a decision regarding controllability is made.

Fig. 5: Scale for criticality assessment of driving and traffic scenarios [9].

C. *Testing Environment*

Since methodically sound research of these situations requires the use of accurately timed and reproducible scenarios, driving simulators constitute the preferred research environment. Moreover, driver behavior during highly dynamic maneuvers is likely to be more natural, if the driver is provided with realistic kinesthetic and vestibular feedback. Both requirements are met in the Vehicle-In-the-Loop (VIL), which constitutes a hybrid testing environment, as it combines a test track vehicle with a driving simulator (see [18]). Driving with the VIL, the participant is wearing a head mounted display, which shows a fully virtual world while s/he is moving a real car on a test field [19]. In Fig. 6, the picture on the top right shows the driver´s view. The position and orientation of both the driver's head and the car itself is calculated in real-time and fed into the simulation software "Virtual Test Drive" [20], thus producing the actual picture of the virtual world.

Fig. 6: Vehicle in the Loop (VIL).

The VIL had been previously validated for the investigation of ADAS in urban areas [21],[22]. The results showed, that driving situations are experienced as slightly more critical in the VIL than in a real car environment, while the overall driving behavior is valid, which causes conservative and reliable statements for controllability investigations [21].

D. *Study Design*

In order to investigate the controllability of the presented test cases, a mixed-subjects design was chosen. Each participant experienced all three driving situations with the same parameter set in a systematically varied order. The number of required participants was identified with the method suggested in [23]. Accordingly, twelve participants were needed for each parameter set resulting in a total number of 48 participants. As it was suggested in [17], a coverstory was used to elicit natural behavior from the participants. They were told to take part in an experiment that explores human machine interface (HMI) aspects of a cruise control system while driving the VIL. After a short familiarization with the vehicle, the participants experienced five situations: the three relevant ones and two fake situations relating to HMI aspects to sell the coverstory. The use of cruise control ensured that every driver had a speed of 50 km/h at the beginning of each scenario. After each situation, they were asked about their criticality according to the scale for criticality assessment of driving and traffic scenarios and some "fake" questions relating to HMI aspects. In each situation, vehicle and simulation data were recorded synchronously.

E. *Participants*

48 persons with at least 10.000 km of driving experience between the ages of 21 and 58 years took part in the experiment. The sample´s mean age was 27.2 years with a standard deviation of 9.1 years.

III. RESULTS

Though binary results would be sufficient to make a judgment with regard to controllability, more detailed analyses will be presented to provide further information on driver behavior. Analyses of variance (ANOVA) were calculated for the factors driving situation (within-subjects-design) and steering function parameter sets (between-subjects-design) for each of the dependent variables. If statistically significant differences were found ($\alpha = .05$), post-hoc tests were computed between the individual situations or parameter sets with a Bonferroni correction of the accepted level of significance to adjust for multiple comparisons (situations: $\alpha = .017$, parameter sets $\alpha = .014$).

A. Ego´s distance to evading vehicle

A repeated-measures ANOVA showed significant differences between driving situations in the minimum Euclidian distance between the Ego and the oncoming evading vehicle that participants reached during each scenario ($F(2,94) = 30.673$, $p < .001$). Furthermore, a one-way factorial ANOVA indicated that this distance varies significantly between different parameter sets ($F(3,143) = 72.877$, $p < .001$). Those differences are illustrated in Fig. 7 with boxplots, where the situations are in different colors and the parameter sets are grouped on the lateral axes. Appended collisions are counted in red numbers below each box.

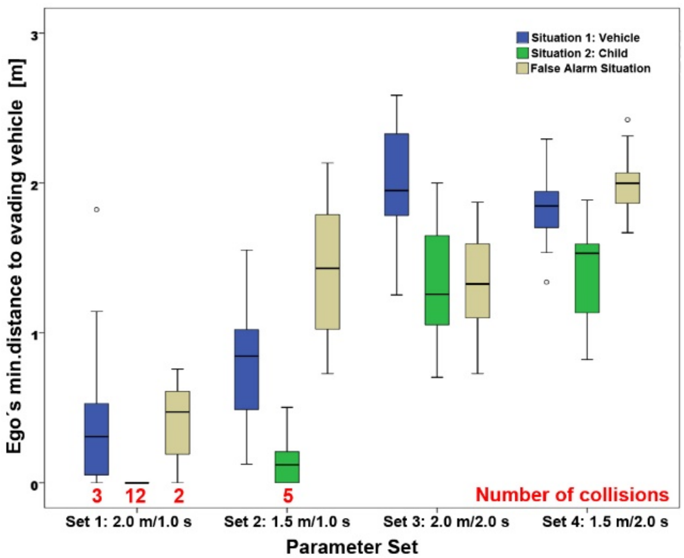

Fig. 7: Ego´s min. distances to evading vehicle.

17 out of 22 accidents happened in situation 2. Accordingly, post-hoc t-test results confirm that the second situation differs significantly from the others with respect to the minimum distance that participants reached between Ego and evading vehicle with large effect sizes (Tab. 2).

TABLE II. POST-HOC DEPENDENT-SAMPLES T-TESTS

Sit1 – Sit 2	*Sit1 – Sit3*	*Sit2 – Sit3*
$t(47) = 8.087$ $p < .001$ $r = .763$	$t(47) = -.238$ $p = .813$ $r = .035$	$t(47) = -6.660$ $p < .001$ $r = .697$

Between all parameter sets except sets 3 and 4 post-hoc t-tests show, that the minimum distances between Ego and evading vehicle are significantly different (Tab. 3). Collisions were only registered in the sets with $\Delta t = 1s$.

TABLE III. POST-HOC INDEPENDENT-SAMPLES T-TESTS

Set1 – Set 2	*Set1 – Set3*	*Sit2 – Set3*
$t(70) = -4.011$ $p < .001$ $r = .433$	$t(70) = -12.212$ $p < .001$ $r = .825$	$t(70) = -5.836$ $p < .001$ $r = .572$
Set3 – Set 4	***Set2 – Set4***	***Set1 – Set 4***
$t(70) = -1.923$ $p = .059$ $r = .224$	$t(70) = -7.988$ $p < .001$ $r = .690$	$t(70) = -16.453$ $p < .001$ $r = .891$

B. Ego´s lateral displacement

The Ego driver reacted to the oncoming evading vehicle either by braking, or by steering to the right, or both. When the driver reacted by steering, this resulted in a lateral displacement, which was measured during the relevant maneuver. The boxplots in Fig. 8 show that most drivers veered their vehicle at least 0.2 m to the right.

A one-way factorial ANOVA shows significant variance between the parameter sets ($F(3,143) = 5.906$, $p = .001$), whereas a repeated-measures ANOVA found no significant variance between situations ($F(2,94) = 2.721$, $p = .071$).

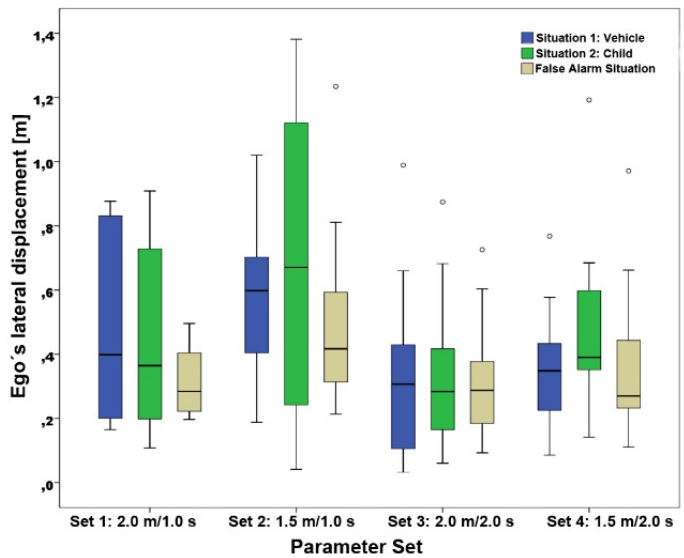

Fig. 8: Ego´s lateral displacement.

Except for differences in variance, which might be explained by a few drivers' extreme steering reactions, lateral displacement does not significantly differ between driving situations, as was indicated by post-hoc tests (Tab. 4).

TABLE IV. POST-HOC DEPENDENT-SAMPLES T-TESTS

Sit1 – Sit 2	*Sit1 – Sit3*	*Sit2 – Sit3*
$t(47) = -.974$ $p = .335$ $r = .140$	$t(47) = -1.413$ $p = .164$ $r = .202$	$t(47) = 2.333$ $p = .024$ $r = .322$

In some cases, especially with parameter sets 1 and 2, great variance is found (compare with Fig. 8).

TABLE V. POST-HOC INDEPENDENT-SAMPLES T-TESTS

Set1 – Set 2	*Set1 – Set3*	*Sit2 – Set3*
t(70) = -2.515 p = .013 r = .288	t(70) = 1.406 p = .164 r = .166	t(70) = 3.703 p < .001 r = .405
Set3 – Set 4	***Set2 – Set4***	***Set1 – Set 4***
t(70) = 1.360 p = .178 r = .160	t(70) = 2.602 p = .011 r = .297	t(70) = 0.071 p = .944 r = .008

Post-hoc t-test results in Tab. 5 show that parameter set 2 differs significantly from the other parameter sets, while the others do not significantly differ from one another in terms of lateral displacement.

C. *Ego´s lateral acceleration*

Steering behavior is not only characterized by the lateral displacement but also by the dynamic of the driver´s maneuvering, which is indicated by the lateral acceleration. Fig. 9 shows the maximum lateral acceleration of the Ego vehicle for each situation and parameter set.

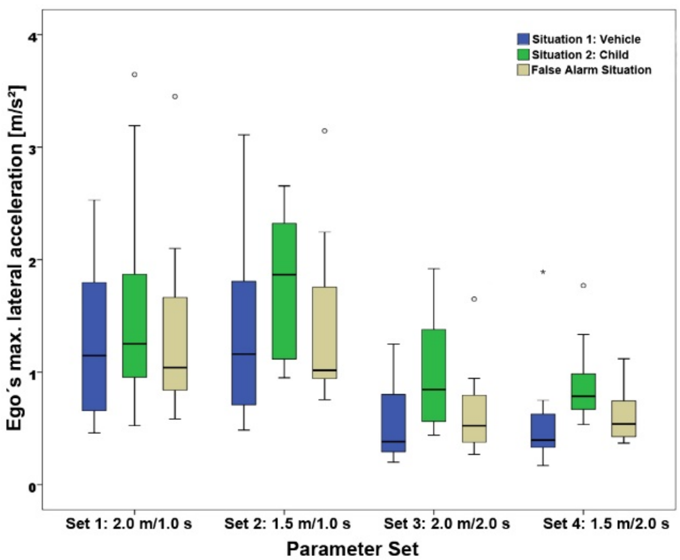

Fig. 9: Ego´s max. lateral acceleration.

During the course of the study, no ESP-interventions were detected, indicating that no driver executed an uncontrollable steering maneuver. However, one-way factorial and repeated-measures ANOVA indicated significant variance in the lateral acceleration between parameter sets and situations (parameter sets: $F(3,143) = 17.885$, $p < .001$, situation: $F(2,94) = 5.827$, $p = .004$). The maximum lateral acceleration differs significantly between the situations 1 and 2, as well as 2 and 3, with medium effect sizes, as summarized in Tab. 6.

TABLE VI. POST-HOC DEPENDENT-SAMPLES T-TESTS.

Sit1 – Sit 2	*Sit1 – Sit3*	*Sit2 – Sit3*
t(47) = -3.019 p = .004 r = .403	t(47) = -.552 p = .584 r = .080	t(47) = 2.656 p = .011 r = .361

All parameter sets except sets 3 and 4 differ significantly from one another with regard to lateral acceleration (Tab. 7).

TABLE VII. POST-HOC INDEPENDENT-SAMPLES T-TESTS

Set1 – Set 2	*Set1 – Set3*	*Sit2 – Set3*
t(70) = -.612 p = .543 r = .073	t(70) = 4.371 p < .001 r = .463	t(70) = 5.506 p < .001 r = .550
Set3 – Set 4	***Set2 – Set4***	***Set1 – Set 4***
t(70) = .396 p = .693 r = .044	t(70) = 6.050 p < .001 r = .586	t(70) = 4.806 p < .001 r = .498

D. *Ego´s longitudinal deceleration*

Driver´s braking reaction is characterized by the longitudinal deceleration, which corresponds to the minimum longitudinal acceleration shown in Fig. 10. Accelerations below 8 m/s² can be considered as a full braking.

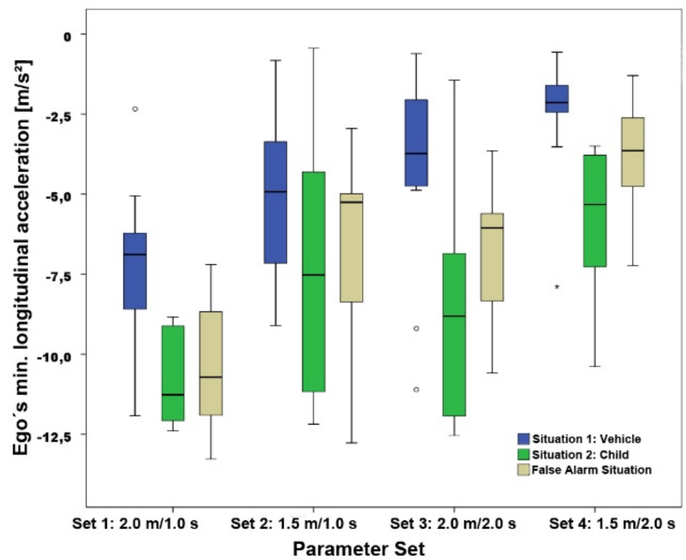

Fig. 10: Ego´s longitudinal deceleration.

A repeated-measures and a one-way factorial ANOVA show significant variances for the factors situation ($F(2,94) = 34.538$, $p < .001$) and parameter sets ($F(3,143) = 21.734$, $p < .001$). Post-hoc tests indicated that the differences in longitudinal deceleration are statistically significant between the three situations, with large effect sizes (Tab. 8).

TABLE VIII. POST-HOC DEPENDENT-SAMPLES T-TESTS

Sit1 – Sit 2	*Sit1 – Sit3*	*Sit2 – Sit3*
t(47) = 8.383 p < .001 r = .774	t(47) = -11.885 p < .001 r = .866	t(47) = -3.505 p = .001 r = .455

All parameter sets except sets 2 and 3 significantly differ from one another, as specified in Tab. 9.

TABLE IX. POST-HOC INDEPENDENT-SAMPLES T-TESTS

Set1 – Set 2	*Set1 – Set3*	*Sit2 – Set3*
t(70) = -4.555 p < .001 r = .478	t(70) = -4.056 p < .001 r = .436	t(70) = -.348 p = .729 r = .042
Set3 – Set 4	***Set2 – Set4***	***Set1 – Set 4***
t(70) = -3.888 p < .001 r = .421	t(70) = -3.587 p < .001 r = .394	t(70) = -9.617 p < .001 r = .754

E. Driver reaction time

Driver reaction time was estimated from the point of time when the evading vehicle was leaving its lane until the Ego driver´s first response by braking or steering, as illustrated in Fig. 11. A repeated-measures and a one-way factorial ANOVA show significant variance for the two factors situation ($F(2,76) = 25.514$, $p < .001$) and parameter sets ($F(3,133) = 3.232$, $p = .025$).

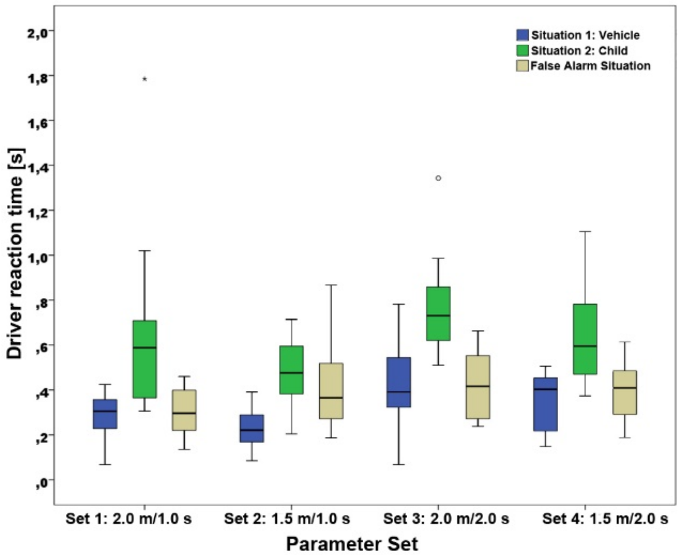

Fig. 11: Driver reaction time.

The difference between situation 2 and the other ones in driver reaction time is statistically significant, with large effect sizes (Tab. 8).

TABLE X. POST-HOC DEPENDENT-SAMPLES T-TESTS

Sit1 – Sit 2	*Sit1 – Sit3*	*Sit2 – Sit3*
t(38) = -6.120	t(43) = -1.814	t(42) = 4.861
p < .001	p = .077	p < .001
r = .705	r = .267	r = .600

Only parameter sets 2 and 3 differ from one another significantly, as specified in Tab. 9.

TABLE XI. POST-HOC INDEPENDENT-SAMPLES T-TESTS

Set1 – Set 2	*Set1 – Set3*	*Sit2 – Set3*
t(69) = .776	t(67) = -2.028	t(66) = -3.403
p = .441	p = .047	p = .001
r = .093	r = .240	r = .386
Set3 – Set 4	***Set2 – Set4***	***Set1 – Set 4***
t(63) = 2.361	t(65) = -.845	t(66) = .862
p = .021	p = .401	p = .451
r = .274	r = .104	r = .106

F. Participant´s subjective ratings

The subjective ratings of the drivers' perceived situation criticality were collected using the scale of [9] shown in Fig. 5 directly after each situation. The results are illustrated in Fig. 11.

For the statistical analysis of the subjective data, non-parametric tests were conducted. A Friedman´s ANOVA revealed significant variance for the factor situation ($H(2) = 43.443$, $p < .001$) and a Kruskal-Wallis test indicated that the criticality ratings varied significantly between the four investigated parameter sets ($H(3) = 41.268$, $p < .001$). In situations 1 and 3, ten of 48 ratings (app. 21%) scored above 6 (=dangerous or uncontrollable) on the scale. In situation 2, even 58% of all ratings are in the "dangerous"-sector (28 of 48).

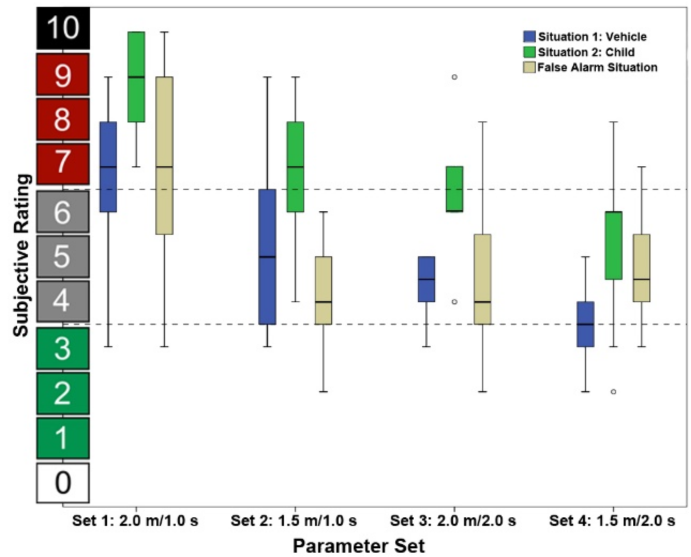

Fig. 12: Driver´s subjective rating.

Post-hoc tests also show significant differences with high effect sizes between situation 2 and the other two (Tab. 10).

TABLE XII. POST-HOC WILCOXON-TESTS

Sit1 – Sit 2	*Sit1 – Sit3*	*Sit2 – Sit3*
Z = -5.296	Z = -.309	Z = -5.105
p < .001	p = .813	p < .001
r = -.764	r = -.045	r = -0.737

For parameter set 1, 28 of 36 ratings (78%) scored above the limit of 6, with eleven ratings (31%) for set 2, six for set 3 (17%), and only three (8%) for set 4. For sets 3 and 4, the subjective ratings were compared with the associated objective data, where no collisions or uncontrollable events were found. The large gap between set 1 and the others is also reflected by significant differences as indicated by post-hoc Mann-Whitney-U-tests (Tab. 11).

TABLE XIII. POST-HOC MANN-WHITNEY-U-TESTS (A = .014).

Set1 – Set 2	*Set1 – Set3*	*Sit2 – Set3*
U = 261.500	U = 225.000	U = 628.000
z = -4.395	z = -4.818	z = -.229
p < .001	p < .001	p = .819
r = -.518	r = -.567	r = -.027
Set3 – Set 4	***Set2 – Set4***	***Set1 – Set 4***
U = 488.000	U = 496.500	U = 141.000
z = -1.830	z = -1.736	z = -5.755
p = .067	p = .082	p < .001
r = -.216	r = -.205	r = -.678

IV. SUMMARY AND DISCUSSION

In the present study, controllability aspects of emergency steering systems were investigated from the perspective of opposing traffic participants. The goal was to work out clear limitations for the functional design of emergency steering systems due to the accident avoiding capabilities of opposing drivers. The results should be valid for different traffic situations if possible, including the test case of false alarm activations. In preliminary tests with an expert panel, relevant situations and parameter sets were identified. These were investigated with 48 naïve participants using the VIL as a testing environment. The results show that the situation has an influence on the driver´s judgment and behavior. Especially in situation 2, which involved a car veering around a playing child, driver reaction times were significantly longer than in the other situations causing more accidents and provoking pronounced reactions in steering or braking. According to self-reports, many drivers focused on a pedestrian leaving a building on the right and expected this pedestrian to enter the street (see Fig. 2). As a consequence of this distraction, they realized the real threat too late to prohibit a collision or had to perform very intense maneuvers such as emergency braking.

Parameter sets 1 and 2 generated uncontrollable events in form of collisions as well as subjective ratings. In parameter set 4, no objective fail-criteria was exceeded and only eight percent of subjective ratings were above the accepted limit. This parameter set, with a minimum time gap of $\Delta t = 2s$ and an intrusion into the opposite lane of $\Delta i = 0.75m$, can be classified as controllable in all situations. Parameter set 3 also indicated no uncontrollable event by objective criteria but should be rejected based on drivers' judgments. 17% classified the test case as dangerous which is slightly above the 15%-limit. Nevertheless, all ratings above the limit except one were given in situation 2. That means for non-distracted drivers, set 3 can also be classified as controllable. Summing up, if time gaps to the peak of an emergency evading trajectory are at least $\Delta t = 2s$ at a lane width of 3.5m, an intrusion of $\Delta i = 0.75m$ is controllable for opposing drivers. For non-distracted drivers, even intrusions of $\Delta i = 1.25m$ may still be considered controllable. Emergency steering systems must not be activated when estimated time gaps from the peak of the trajectory to the oncoming vehicle are shorter than two seconds, if an intrusion into the opposite lane is possible. Furthermore, it seems that the context of the situation in which ADAS are triggered and the attention of other traffic participants can also have a measurable effect on the results of ADAS controllability investigations and should therefore be considered in future studies. Such complex scenarios with many traffic participants and a crowded rural environment are very similar to the conditions in real traffic. As these issues can only be considered on test tracks at the expense of time and effort, the VIL seems to be a good alternative for controllability assessment of future driver assistance systems. As the VIL-system can be integrated easily into almost every test vehicle, the latest ADAS can be evaluated by normal drivers safely and in complex traffic situations, even in early stages of the system development process.

ACKNOWLEDGMENT

This study was conducted in the context of the project UR:BAN [1] (Urban Space: User oriented assistance systems and network management). The project UR:BAN is supported by the Federal Ministry for Economic Affairs and Energy due to a decision of the German Bundestag.

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