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Evaluation Methods and Results of the INTERSAFE Intersection Assistants

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Abstract— **In the EU-project INTERSAFE, driver assistance systems were developed to improve safety at intersections. These systems were implemented in two demonstrator vehicles: a VW Phaeton and a BMW 5 series. According to its applicable scenarios, the systems include two assistance functions: Traffic Light Assistant (TLA) and Intersection Assistant (IA).**

In order to inspect the systems' functionality and the user acceptance, the onboard environmental sensors and the full systems have been tested. The testing approach and the results are described in this paper. The tests were carried out in three phases: sensor test, system test and user test.

Sensor test and system test have proved the functionality of the INTERSAFE system. The systems are able to fulfill the tasks of assisting the driver to avoid potential traffic accidents at an intersection. The user test focused mainly on the user acceptance of the systems and the HMI design. After driving both demonstrator vehicles and experiencing the INTERSAFE systems, the test persons rated the systems helpful and relieving. They stated that these systems could have helped them in their daily driving and would improve the traffic safety.

I. INTRODUCTION

Mobility is very important in our modern society. Industry, trade and commerce rely on the feed of goods as the gross national product is related to the transport capacity. Beyond the desired positive effects of traffic, with benefits such as the achieved value added or employment creation, one has to deal with negative aspects like killed or injured traffic participants, an increasing traffic density, traffic jams and emissions (e.g. harmful substances and noise).

Especially the increasing market penetration of active and passive safety systems play a particular role in the reduction of injured and killed traffic participants in recent years. For the future advanced driver assistant systems (ADAS) are expected to contribute to a further reduction of accidents, injuries and fatalities, as still up to 95 % of all accidents are caused by human [1]. In this context, intersections are an accident hotspot and according to [2] about 60%-72% of all accidents in intersections are related to:

- Collisions with oncoming traffic while turning left
- Collisions with crossing traffic while turning into an intersection or straight crossing an intersection
- Red light/stop sign violation

Measures to improve the intersection safety have a long history in traffic engineering. So far conducted improvements of intersection layouts and traffic light control are important factors as they effect the traffic environment and the traffic flow. But for an integrated view, the driver as the main source of error must be included in the consideration as driver distraction is expected to be the main reason for intersections accidents.

Within the field of ADAS (direct measures), intersection safety is a relatively new topic, mainly addressed by the current research projects like [3], [4,], [5], the German national initiative INVENT (Intelligent Traffic and User-Friendly Technology) and the subproject INTERSAFE of the integrated European project PReVENT.

The objective of the INTERSAFE subproject is to improve safety and to reduce (in the long term avoid) fatal collisions at intersections. Drivers shall be prevented from crossing red lights at intersections. Furthermore, a driver will be informed in case of a potentially dangerous turning off maneuver to avoid collisions with other vehicles. This is achieved by using path prediction of road users based on Laserscanner data and infrastructure to vehicle communication (I2V). These warning functions are implemented in demonstrator vehicles (BMW and VW) and in the BMW driving simulator.

In order to analyze the impact on traffic safety and assess the system's user acceptance a testing procedure for the evaluation of intersection safety systems is essential. In this paper the testing methods and results of the BMW and VW demonstrator vehicles are presented. The results of the driving simulator approach are presented in [6].

II. SYSTEM ARCHITECTURE AND THE DEMONSTRATORS

A. System Architecture

Fig. 1 shows the system architecture of the INTERSAFE system. In general, the system is composed of three different levels. At the basic level – the onboard sensors level – general data acquisition is performed. In addition to the onboard sensors, the so-called high level map (HLM) and the communication device are located on the sensor level. The HLM for INTERSAFE contains geometric information and attributes of the intersection.

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The relative localization of the host vehicle, and the tracking and classification of road users are done in the perception level. The relative localization is done using landmark navigation. The Laserscanner and the video system detect static objects. For example, poles of traffic lights or road signs are detected by the Laserscanner and lane markings by the video system. In a feature level map (FLM) – an additional layer of the HLM - the position of these landmarks is registered. A comparison of the online detected position of the landmarks with the FLM allows a relative localization of the demonstrator vehicle at the intersection.

The detection, tracking and classification of the road users are performed by the Laserscanner. These algorithms make use of the intersection geometry registered in the HLM and the calculated position of the demonstrator vehicle to ignore the objects outside the road.

Finally, the application level provides all mechanisms to

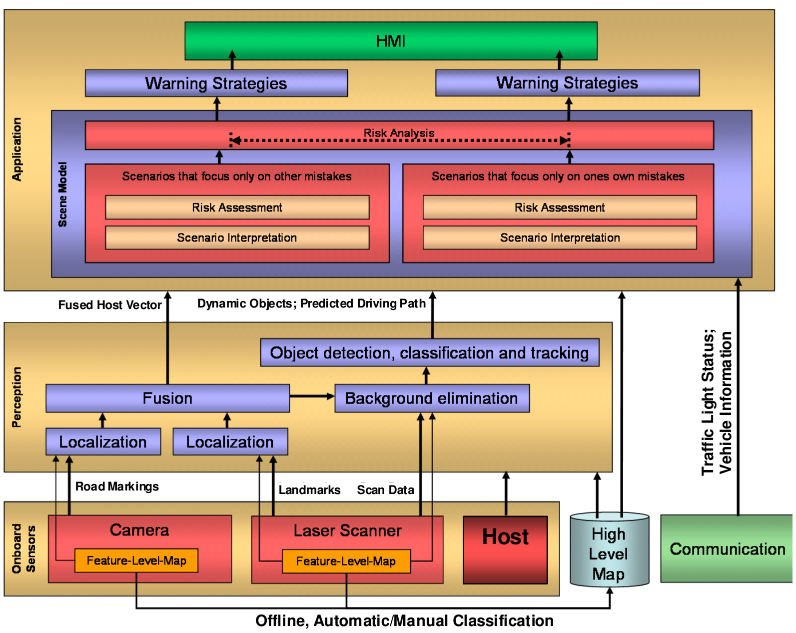

Fig. 1. IA system architecture [2]

perform the scenario interpretation and risk assessment based on the data from the perception level as well as map and communication data. Via the Human Machine Interface (HMI) the driver is supported in his driving task to avoid accidents at intersections.

B. VW demonstrator Vehicle

The VW demonstrator vehicle addresses both intersection assistance and traffic light assistance. Two IBEO Laserscanners are integrated in the front bumper of the demonstrator vehicle. The Laserscanners are used for detection of landmarks and tracking and classification of road users. A TRW video camera is mounted inside the vehicle behind the windscreen to detect the road markings at the intersection. A communication module realizes the V2I communication. The architecture of the VW demonstrator is shown in Fig. 2.

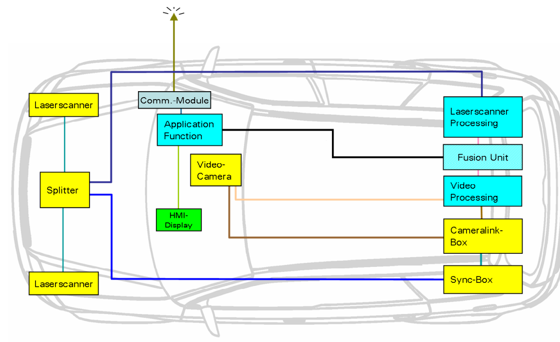

Fig. 2. Equipments and architecture of the VW demonstrator [7]

Nowadays driver assistance systems mostly use warning strategies like appearing signals or sounds to alert the driver when a situation gets dangerous, i.e. when the computed risk rises over a defined level. The system approach used at VW is a warning interface that visualizes the risk level in a continuous manner for the time of an identified situation that could become dangerous. The driver will have a direct visual link to those parameters that are difficult to estimate. For example, if the driver is approaching an intersection and intends to turn left, he has to watch out for oncoming traffic. The speed and distance of the oncoming cars is one measurement to determine, if a turn-left maneuver is save or not. The left figure in Fig. 3 shows an example of our visualization interface for an intended left-turn.

During the whole approach the driver has a direct link to the risk level computed by the system (i.e. momentary value and derivative). The expected advantage is that there is no possibility to get surprised by a flashing light that tells him suddenly that a situation gets dangerous. Due to the continuous HMI interface the driver will be prepared for the situation and can estimate the risk for his intended maneuver more easily by taking his own driving skills into account. Beside the risk level visualization there has to be additional information for which conflict the risk level is shown. The idea is to use simple pictures of well known traffic signs so that the driver does not need long time to understand what the warning is for (see Fig. 3).

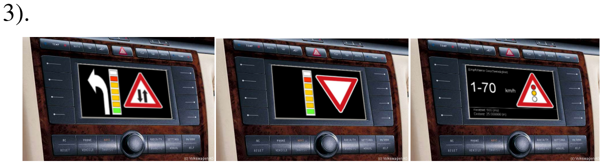

Fig. 3. HMI Display in the VW demonstrator [7]

For optical warning the system uses the existing on board equipment: navigation system/ TV display and the direction indicator lamps. On the TV display, computer prepared graphics and pictograms can be showed. The direction indicator lamps can change their color from normal green through amber to red. This depends on the degree of danger for the recognized and interpreted situation. Together with the visual support, auditory support is also necessary to direct the driver's attention to the assistance function. Sounds are given to the driver via the vehicle's audio system.

C. BMW Demonstrator Vehicle

The BMW demonstrator vehicle and its architecture are sketched in Fig. 4. This vehicle addresses the scenario of red light violation.

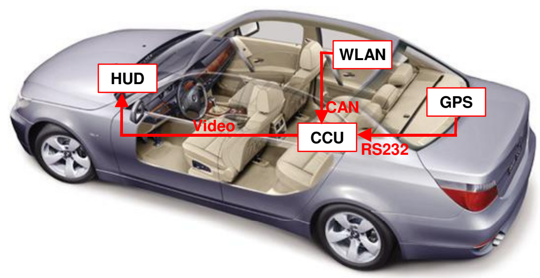

Fig. 4. Equipments and architecture of the BMW demonstrator [8]

The developed system makes use of DGPS for the localization of the vehicle and V2I communication with the traffic light. The DGPS data is transferred via an RS-232 interface to the central control unit (CCU). The V2I messages are transformed into CAN messages. The driver warning is performed visually over the head up display (HUD) and acoustically via the vehicle's audio system.

The functionality of the traffic light assistant in BMW is bivalent:

In a larger distance to the traffic light, the system can provide special information for adjusting the speed to either pass the traffic light before it switches to red (minimum speed, symbol on the top left in Fig. 5) or not to reach the traffic light before it switches to green (maximum speed, symbol on the top-right).

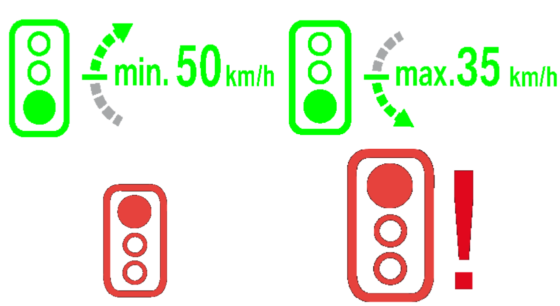

Fig. 5. Information and warning symbols in the BMW demonstrator [9]

Before reaching the latest braking point for coming to a safe stop, the driver is prepared to the emerging situation by an information symbol (on the bottom-left of Fig. 5) as early as possible and if he does not respond correctly, he will be warned with a highly visible symbol (on the bottom-right of Fig. 5) and a special tone.

The optical warning in the BMW demonstrator uses a head-up display (HUD) to give all necessary information within a small field of view. The complexity of intersections requires the driver not to look away from the scene and therefore this is an ideal location. As said above the assistance function uses discrete symbols based on static images files.

The acoustic support is necessary to gain the driver's attention to the assistance function. Sound is given to the driver via the vehicle's audio system only in case of a warning.

D. Sensors

Beyond the regular on-board sensors, three essential sensors are utilized in the demonstrators: Laserscanner, video sensor and communication module.

1) IBEO Laserscanner

The IBEO Laserscanner combines a four-channel laser range finder with a scanning mechanism. The approach in INTERSAFE focuses on road user detection, tracking and classification based on Laserscanner data. In addition, a relative localization of the host vehicle is performed based on landmarks detected by the Laserscanner. The specification of the Laserscanner is summarized in Fig. 6.

Description	Value
accuracy	+/- 0.1 m
max. range	200 m
object tracking	up to 200 m
horizontal field of view	max. 240 deg./Laserscanner (due to the mounting position)
horizontal angle resolution	0.25 deg. or 0.5 deg. or 1.0 deg.
vertical field of view	approx. 3.2 deg (in driving direction)
vertical angle resolution	approx. 0.8 deg (in driving direction)
distance resolution	0.04 m
scanning frequency	12.5 or 25 Hz
sensor dimensions	The Laserscanner unit is 100x127x157 mm. The mounting weight is 1.3 kg.

Fig. 6. Specification of IBEO Laserscanner (ALASCA XT) [7]

2) TRW Video Sensor

In this project, the TRW video sensor for Lane Departure Warning (LDW) is extended and now used to sense both the lateral and longitudinal positions of intersection features relative to the host vehicle. These features are typically visible road markings e.g. lines, arrows etc. The INTERSAFE system requires short lines where at least one of the end points (or discontinuities) is visible close to the vehicle.

The main output of the camera module is the demonstrator vehicle's position in longitudinal and lateral direction and orientation with respect to the origin of the intersection's coordinate system. The specification of the video system is given in Fig. 7.

3) Communication Module

The third part of the sensor level is the communication module that directly provides information to the application level. The technological basis for information broadcast is IEEE 802.11a.

Description	Value
position accuracy	0,1 m (This accuracy will be affected by lane markings and dynamics of the host vehicle)
heading accuracy	approx 0,1 deg.
max. range	50 m
min. range	approx. 2,5 m (Determined by mounting position and vehicle dimensions.)
horizontal field of view	approx 45 deg.
imager size	640 x 480 pixels
used image	640 x 240 pixels
image acquisition rate	25 f.p.s.
target processing time	40 ms
sensor dimensions	The camera unit is approx 95 x 95 x 50mm

Fig. 7. Specification of TRW video sensor [7]

III. Validation Methodology

Fig. 8 shows a general diagram of an intersection safety system and the internal system interfaces connecting each system level. Examples for transferred signals are shown. The figure simplifies the architecture and depicts on which system level the tests evaluate the system performance.

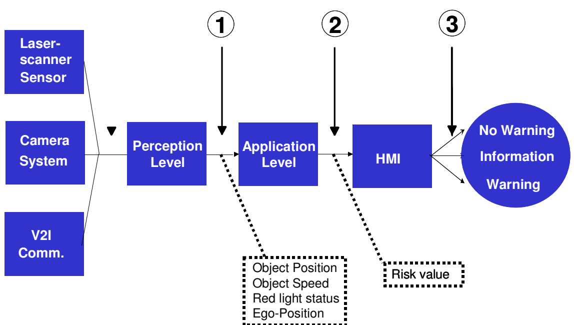

Fig. 8. General system description [8]

A. Testing Phases

Starting with the technical verification, the output of the environmental sensors (Laserscanner and video) and the communication module is monitored. Here the data are compared to the values described in the technical specification. At interface 1 (perception level) the output of the relative localization of each sensor system, the detection, tracking and classification of road users and the V2I communication is evaluated.

The second phase deals with operational verification. Here the system is inspected at interface 2 (application level). In addition, the implementation of the components is evaluated with respect to the operational specification.

Finally, the user aspects are addressed in the third part of the tests, the user test. The system is tested at interface 3 and tests with subjects are performed. The subjects include performing test drives as well as assessing the system responses and the HMIs. Within this phase the same scenarios as in phase 2 are considered.

B. Testing Scenarios

Various scenarios were defined to test the system functionality. According to the function, system tests were carried out in the following scenarios:

- Left turn scenarios (Fig. 9, left). The demonstrator vehicle turns left while an opponent vehicle comes from the oncoming direction.
- Lateral traffic scenarios (Fig. 9, middle). An opponent vehicle comes into the intersection either from left or right. Various driving directions of the demonstrator are also taken into account.
- Traffic light scenarios (Fig. 9, right). The demonstrator vehicle is approaching an intersection with a traffic light. All the four traffic light phases (red, red yellow, green and yellow) are considered in the test.

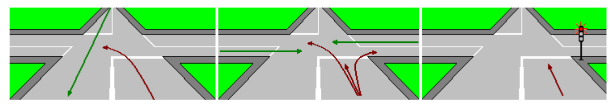

Fig. 9. Testing scenarios [8]

These scenarios were combined with the following four driving behaviors:

- Waiting at the beginning of the conflict area
- Starting up into the conflict area
- Approaching the intersection without braking
- Approaching the intersection with a defined deceleration.

IV. Validation Results

Some of the main validation results achieved in this project will be described in the following sections.

A. Sensor Test

In the first evaluation phase, the sensors were tested to check the function of the INTERSAFE system at the perception level. In order to get a representative result, diverse objects were used as sensor targets in the tests. These targets were: Honda VFR800 (silver motorcycle), VW Lupo (black compact car), VW Golf (silver estate car), BMW 325i (red mid-size car), BMW 728i (black large size car), pedestrian (dark clothing) and a wooden dummy target for the test of position accuracy.

1) Detection Range of the Laserscanner

In this test the Laserscanner maximum detection range for all five test vehicles and the pedestrian was determined. The test started with the target vehicle moving towards the standing demonstrator vehicle.

Three different approaching directions of the target vehicles were applied in this test: frontal, 45° and 90°. If the opponent vehicle is perpendicular and far away from the host vehicle, it will typically leave the intersection before the host vehicle enters. Therefore the maximum detection range of perpendicular vehicles was just additional and performed with the VW Golf.

In order to avoid coincidences with regard to repeatability, every test was carried out twice for each target and approaching direction.

The maximum detection ranges of all the frontal and 45° tests are illustrated in Fig. 10.

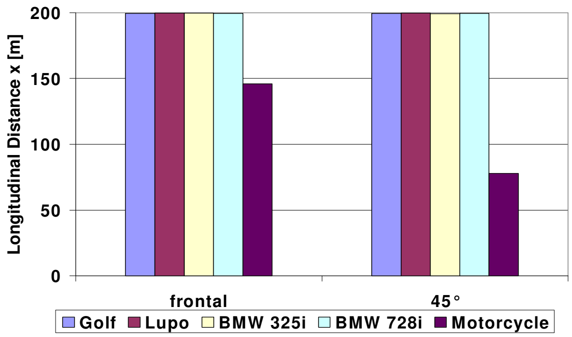

Fig. 10. Detection range of the Laserscanner

The CAN specification in the VW demonstrator was limited to 200 m; a higher distance was not foreseen. Therefore in this test, the detection range of the Laserscanner reported via CAN was limited to 200 m.

During the tests, all the vehicles were correctly classified immediately after detection. All the cars could be detected at a distance of more than 200 m both in frontal and 45° tests. Just the maximum detection range of the motorcycle was slightly shorter.

The detection of pedestrian was also tested. Result showed that the pedestrian could be detected and correctly classified as a pedestrian at distances of 110 m. In the 90° tests, the VW Golf was detected at about 165 m.

2) Lateral Detection of the Laserscanner

In the test, the demonstrator vehicle stood still at four positions: 10 m, 20 m, 40 m and 60 m to the intersection. The target vehicle - VW Golf - moved from left to right and right to left for each demonstrator vehicle position.

The size of the test intersection was quite limited, the target vehicle could only move between 50 m to the left to 40 m to the right. All the tests showed that the Laserscanner could detect the target vehicle form leftmost (50 m) to the rightmost (40 m). The lateral detection range of the Laserscanner system would be much higher, if the target vehicle could move further.

3) Localization Accuracy

This test was applied to inspect the localization accuracy of the Laserscanner, the video system and the fusion output. The Laserscanner system localizes the vehicle position by detecting landmarks while the video system utilizes road markings. As an example, the test for evaluation of longitudinal distance was described here.

In order to determine the demonstrator vehicle's distance to the intersection, a microwave sensor and a light barrier sensor were mounted at the rear end of the car. Four reflectors were put on the ground as reference positions for the light barrier. The distances to the intersection of these references were 10 m, 30 m, 50 m and 70 m respectively. According to the vehicle speed measured by the microwave sensor and the reference positions by the light barrier, the vehicle position could be calculated precisely.

The test was carried out five times. The average absolute errors of each test as well as the average of all the tests are summarized in Fig. 11. The outputs of all localization systems were continuous, meaning no signal drop-outs occurred.

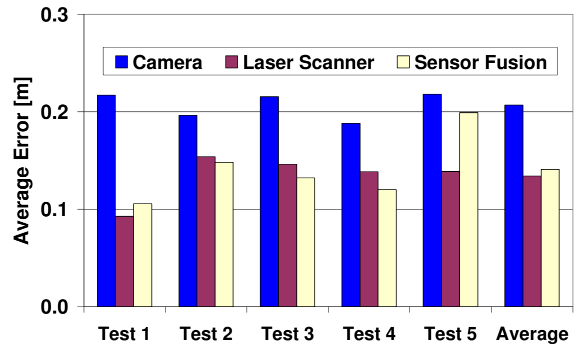

Fig. 11. Localization accuracy

B. System Test

The system tests were carried out to check the system's functionality before the user test. The tests were designed on the one hand to find out the functional boundaries and on the other hand show the potential with today's available prototype equipment. Various scenarios illustrated in Fig. 9 were applied in the test.

During the left turn scenario, the demonstrator achieved very good results with an average correct alarm rate (CAR) of 93% in combination with a very low average false alarm rate (FAR) of 7%. In the scenarios with lateral traffic, no false alarms occurred and the system achieved perfect 100% correct alarms rate. Traffic light assistant systems achieved good results with an average of 90% correct alarm rate and an average of 10% false alarm rate. There was no missed alarm in all tests.

C. User Test

Sixteen subjects had been selected by taking their age, gender and driver experience into account (see Fig. 12). Each subject took around 2.5 hours to drive the demonstrator vehicles on ika's test track and to assess the performance of the INTERSAFE systems.

gender	Driving experience	Age 18-25	Age 26-35	Age 36-45	Age >45
male	experienced	No. 1	No. 2	No. 3	No. 4
	inexperienced	No. 5	No. 6	No. 7	No. 8
female	experienced	No. 9	No. 10	No. 11	No. 12
	inexperienced	No. 13	No. 14	No. 15	No. 16

Fig. 12. Subject categories

The assessment was realized by means of questionnaires. Subjects were asked to fill out a pre-questionnaire before the driving test, three questionnaires during the test and one post-questionnaire after the test.

The results regarding the helpfulness of the systems are shown in Fig. 13. The centre line means the average value while the lower and upper lines mean the average value minus and plus standard deviation respectively.

As can be seen from Fig. 13, these subjects rated the INTERSAFE systems helpful and relieving, stated especially by male and older subjects. Traffic light assistant was rated more helpful than intersection assistant. Further analysis showed that the subjects thought the intersection assistant for left turn was more useful than for lateral traffic. They judged that INTERSAFE could have helped them in their daily driving and it was agreed that it can improve the traffic safety.

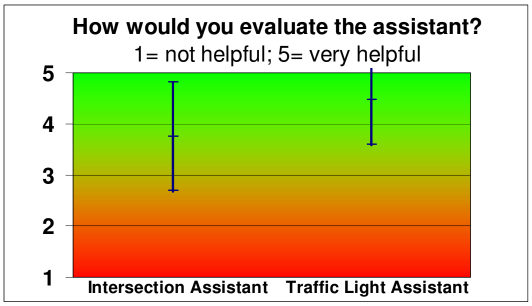

Fig. 13. Helpfulness of the systems

V. CONCLUSION

This paper describes the evaluation and testing of the two INTERSAFE demonstrator vehicles developed and implemented for intersection driver assistance. The tests were carried out in three evaluation phases:

- Sensor test
- System test
- User test

During the sensor test, sensors (Laserscanner and video system) and the communication module were under investigation. The focus of this phase was to verify the sensor performance required for the INTERSAFE functions. The chosen sensors were fully suitable to fulfill the tasks in the INTERSAFE driver assistance system.

The system test was carried out to check the system's functionality before the user test. In average, the correct alarm rate of the intersection assistant at left turn was 93% and 100% at lateral traffic. The average correct alarm rate of traffic light assistants was 90%. There was no missed alarm in all tests.

In the last testing phase, sixteen subjects had driven the demonstrator vehicles on the test track and assessed the performance of the INTERSAFE driver assistance systems. Generally (and in particular, male and older subjects) think the INTERSAFE systems are helpful and relieving. Subjects think traffic light assistant is more helpful than intersection assistant. Intersection assistant in left turn scenarios is rated more useful than in lateral traffic scenarios.

The INTERSAFE systems would have helped the subjects in their daily driving and it was agreed that it would improve traffic safety and that they want to have them in their car.

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