

# 特集 Development of an Intersection Assistant\*

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An approach to communication-based intersection assistance is described in this paper. Different technology scenarios were analyzed in a realistic traffic simulator to cover a wide time period and a wide area of system complexity. The proposed specifications of the necessary communication technology are presented. The different technology scenarios were assessed for their expected user acceptance and effect on traffic safety.

The intersection assistant was tested in a driving simulator and on a test vehicle. In addition to the development of the control algorithm and the definition of different technology layouts, diverse Human Machine Interfaces (HMI) have also been designed. Subjects, of different ages, gender and driving experience were selected to evaluate the intersection assistant on its safety enhancement characteristics, user acceptance and ability to relieve the driver of driving related tasks, as well as the most suitable HMI. The test results show that the system can relieve drivers of driving related tasks and significantly improve traffic safety.

**Key words:** Intersection assistance, Traffic simulator, Communication technology, Driving simulator, Real world test

## 1. INTRODUCTION

Nowadays, road traffic plays a more and more important role in human being's daily live and social economy. Due to the increasing traffic density and complexity, driving becomes also a stressful task. In order to relieve the driver's load and even to prevent traffic accidents, diverse advanced driver assistance systems have been developed in recent years.

Researches on traffic accident 1) and 2) have shown, that around 34.7% of all accidents in Germany occur in the range of intersections. Therefore a driver assistance system, which supports the driver at intersections, would have great potentials to increase traffic safety.

Because of the physical principle of conventional sensors like radar, lidar or image processing system, other road users at an occluded intersection (caused by buildings, trees or other vehicles) cannot be detected. In these situations, the most suitable technology to detect other vehicles is the wireless communication. Inter Vehicle Communication (IVC) and Roadside Vehicle Communication (RVC) are two applications of this technology. Together with GPS or roadside measuring equipments, the detection of other vehicles in the range of an intersection can be realized.

In this paper, an Intersection Assistance (IA) system based on IVC/RVC is presented. It is designed to release the driver from the situation assessments and also to prevent accidents in critical situations.

This IA can be applied in all intersections (especially the intersections without traffic lights) and to all kinds of vehicles.

When the vehicles approach an intersection, they exchange their positions, speed and other data by communication. The intersection assistant receives this information, processes it and takes corresponding reactions:

- provide it directly to the driver to inform him about the presence of other vehicles at the intersection (informing system)
- assess this information and warn the driver in case of a conflict situation (warning system)
- assess this information and intervene into the brake, if

the driver does not react by himself (intervening system)

The first approach for such an assistance system is to define the specification of the communication technology needed for an intersection assistant based on IVC and RVC. For this purpose the main technology characteristics like communication range, equipment rate or data contents are analyzed for different traffic situations and conditions using the traffic simulation tool PELOPS. For the assessment of the potentials of the intersection assistance different IVC/RVC-based intersection assistant concepts were regarded depending on available and future technologies. The assessment of the defined concepts is done regarding the both criteria: Enhancement of traffic safety and expected user acceptance.

In the driving simulation study and real world test, subjects with different age, gender and driving experience have been selected to evaluate this intersection assistant. The main aspects of the evaluation are the system performance, user acceptance, the influence of IA on the driving behavior and the preference of HMI.

## 2. SIMULATION CONCEPT

Accident analyses show that the reasons for accidents at intersections are versatile. Often the view on other vehicles is barred whereas in many cases despite of free view the driver is distracted and unwary. To support the driver, especially in these situations, firstly the other vehicles in the surrounding have to be detected. Due to the aspect of occlusion an approach utilizing inter-vehicle-communication instead of a vision-based system is chosen. Different technology scenarios and layouts are defined to cover a wide time horizon and a wide area of system complexity. Therefore available technologies as well as expected future developments with varying technology effort and complexity are regarded (see 3) and 4)):

- Low-tech "Simple IVC": Only IVC with available positioning systems and digital maps
- High-tech "Simple IVC": Only IVC with for the future expected positioning systems and advanced digital maps (e.g. with right of way (ROW) information)

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- Low-tech “Sophisticated IVC”: IVC combined with RVC and available positioning systems and digital maps
- High-tech “Sophisticated IVC”. IVC combined with RVC and for the future expected positioning systems and advanced digital maps

The parameters for these four technology concepts are presented in Fig. 1. The first concept called “Simple IVC” uses only inter-vehicle communication and in-vehicle sensors and does not rely on any infrastructure sensor. The second concept called “Sophisticated IVC” utilizes inter vehicle communication as well as road vehicle - communication. Besides the direct communication with other equipped vehicles a sensor (e.g. camera) is implemented at the intersection, which detects also the non-equipped vehicles in the intersection range and transmits this information to the equipped vehicles. In contrast to the concept “Simple IVC” an equipped vehicle would get information about the presence of all vehicles in this case and not only about the equipped vehicles independent from the equipment rate. But the non-equipped vehicles themselves would not have any advantage from this more sophisticated concept. The concept “Simple IVC” will have at low equipment rates nearly no effect, because the probability that two equipped vehicles come at the same time into the intersection area is too low. “Simple IVC” make only sense at high equipment rates.

For each of the concepts two different levels of utilized technologies are defined: Today’s available and future technologies and sensors.

These four concepts were simulated with the traffic flow simulation tool PELOPS, which has been developed by fka (Forschungsgesellschaft Kraftfahrwesen mbH Aachen, Germany) in cooperation with the BMW AG and is sold and maintained by the fka today. It represents a combination of models according to vehicle- and traffic technique, whose advantage is to be found in considering all interactions that take place between the driver, the vehicle and the traffic as shown in Fig. 2. Therewith PELOPS can simulate the traffic and driver assistance in a high resolution. The three elements - track/environment,

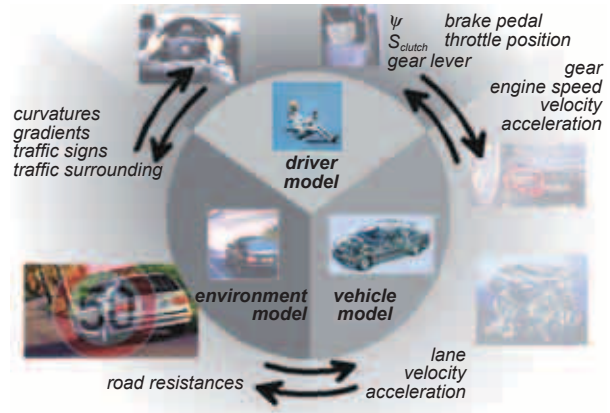


Fig. 2 The traffic flow simulation tool PELOPS

driver and vehicle - are modeled in a modular program structure and defined by interfaces<sup>5)-8)</sup>.

The traffic environment is adequately presented by the environment model. Necessary environmental parameters of the traffic environment, which depend on the track such as visibility and moisture, can be easily selected. By varying the parameters of the track topography, the signage, etc. driving situations can be specifically simulated and the effects on the single traffic- and vehicle component can be contemplated. The effects of an assistance system on the moving traffic can be regarded and thus assessment about the efficiency and safety of the traffic process can be made.

The vehicle dynamic characteristics are calculated by using the results of the driver action model (like pedal position, gear and steering wheel position) in the vehicle model. Since the vehicle model is presented very detailed, the parameters such as the overall efficiency and the fuel consumption can be also determined very precisely. The vehicle itself is modeled according to the cause-effect-principle and considers longitudinal as well as lateral dynamics. Thus the opportunity is provided to analyze and test driver assistance systems according to their capability,

	Low-tech “Simple IVC”	High-tech “Simple IVC”	Low-tech “Sophisticated IVC”	High-tech “Sophisticated IVC”
Communication technology	IVC	IVC	IVC+RVC	IVC+RVC
Sensor technology	today’s GPS+ digital maps	next generation system + advanced digital maps	today’s GPS+ digital maps	next generation system + advanced digital maps
GPS-Accuracy (m)	10	2	10	2
Communication range (m)	120	120	120	120
Signal accuracy (%)	5	5	5	5
Latency time (ms)	300	100	300	100
Update rate (Hz)	10	10	10	10
Equipment rates (%)	80 and 90	80 and 90	10 and 20	10, 20
RVC-detection range	-	-	50	50
Applicable assistance	informing/warning	informing/warning intervening	informing/warning	informing/warning intervening

Fig. 1 Parameters for the assessed technology layouts

which shortens the development time of such systems significantly.

The driver model is subdivided into a behavior- and an action model. The reactions of the driver according to the surrounding traffic situation are simulated in the behavior model. Thereby the parameters of the local driving strategy such as speed- and lane choice are also determined. The action model determines the accelerator, steering wheel position and gearshift by means of the parameters of the driving strategy and the driver's reaction.

To fulfill the driving task in a realistic way the driver model needs information about the own vehicle, the surrounding traffic and the environment. In case of the own vehicle the PELOPS-driver needs response about the reaction of the vehicle to his control task (current velocity, gear, acceleration, longitudinal and lateral position on the road, etc.), as the driver in reality does also. To adapt the driving style to the traffic situation, information about the surrounding vehicles is necessary (for every vehicle: relative speed and acceleration, lane, longitudinal and lateral position, state of turning indicators, etc). Information about the signposts, the road topography (curvature, inclination, number of lanes, etc) and the weather conditions are also provided to the driver model. This information is normally available for the driver in reality, so it has to be considered of course also by the driver model.

For the specification the main technology characteristics like communication range, equipment rate and data contents are analyzed for different traffic situations and conditions. Besides the technology specification also the different regarded technology concepts and layouts are proofed and assessed. Especially their effect on traffic safety and the expected user acceptance of the intersection assistant system is analyzed.

For the simulation of the intersection assistant a model of the communication technology is implemented in PELOPS allowing to vary the communication parameters like range, update rate, etc.

Besides the different technology concepts also different kinds of assistance are regarded and modeled in PELOPS:

- Informing assistance: The system provides the received information to the driver. The situation assessment and the reaction stay as the driver's task.
- Warning assistance: The system receives information about the surrounding and assesses the traffic situation. Only in case of danger the driver is warned. The reaction stays as the driver's task.
- Intervening assistance: The system takes over the assessment task as well as the reaction task. Based on the received information the system brakes autonomously in dangerous situations to avoid accidents.

For the simulation of intersection assistance a scenario with one intersection is chosen, where the vehicles enter the simulation scenario randomly on each intersection arm, so that a traffic flow of about 200 vehicles/h for each arm is realized. Pre-simulations with higher traffic flows show that at higher traffic flows queues are formed on the arms without right of way, so that every vehicle on the lanes with

lower priority has to stop. In this case intersection assistance is not needed. Therefore the traffic flow is chosen lower.

An additional scenario without any kind of intersection assistance is also simulated for the comparison of the effect of the assistance systems. This scenario is called in the following as "basic scenario".

### 3. THE DRIVING SIMULATOR

For the purpose of applying PELOPS in a driving simulator, the driver module of the ego vehicle is replaced by the human driver (subject). Therefore the human driver is included in the control loop. With this kind of driving simulator a driver assistance system can be assessed by subjects even through it is still in developing phase. It also enables the analysis of user acceptance and the design of proper HMI<sup>9)</sup>.

Figure 3 illustrates the driving simulator, which is developed by the Institut für Kraftfahrwesen Aachen (ika) together with the Zentrum für Lern- und Wissensmanagement / Informatik im Maschinenbau (ZLW/IMA). During the simulation one of the vehicles, which are equipped with a driver assistance system, is not driven by the virtual PELOPS driver but by the subject. The subject sits in a mock-up (Mercedes S-class W140) and controls the vehicle by throttle, brake and steering wheel like he is used to in daily driving. These control elements are measured by proper sensors and converted into analogue signals.

These analogue signals are transferred to a C167-based controller and converted into digital signals. Via the CAN-bus they are available to the PELOPS computer in real time by using the Hardware-in-the-Loop Interface. With these values PELOPS is able to calculate the dynamics of the ego vehicle in the simulated traffic.

As input the driver needs information about the driving status, the vehicle environment and surrounding traffic to conduct the driving task. After the computation of vehicle dynamics in the PELOPS vehicle model, the vehicle speed and the engine speed are sent by CAN-message back to the C167-controller, which converts them into PWM signals and transfers them further to the dashboard, where this information is presented to the driver in the speedometer

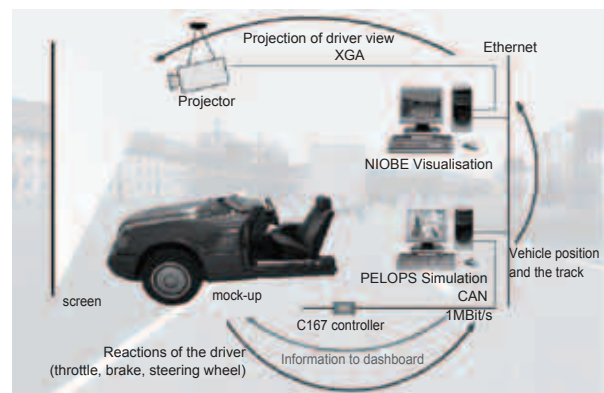


Fig. 3 The driving simulator of the Aachen University



Fig. 4 The simulated HUD in the driving simulator

and tachometer.

At the same time, the environment and the surrounding traffic are simulated in PELOPS and transferred via a SIL-interface (Ethernet) to a visualization computer. The environment includes the whole track (curves, inclination, visibility, number of lanes, lane markings etc.), signposting and intersections. Surrounding vehicles are visualized by the three-dimensional positions of the foreign vehicles.

The visualization computer projects the environment and surrounding traffic onto a screen (4x10 meters) in front of the mock-up by two video projectors. Figure 4 shows a scene with the simulated Head Up Display (HUD) as an example. The driver uses this video as input to orient in the simulated world and adapts his driving strategy. By doing so a closed control loop for the whole driving simulator is realized.

#### 4. TEST VEHICLES AND SYSTEM ARCHITECTURE

For the practical evaluation of the intersection assistant in real world tests, the system, which consists of the algorithms as well as the Human Machine Interface (HMI), has been integrated in a test vehicle.

Figure 5 gives an overview of the IA system architecture and the data communication of two test vehicles.<sup>10)</sup> In the test, the BMW 728iA is used as the main test vehicle (so-called host vehicle), which is equipped with IA system (controller and HMIs), GPS receiver and communication device. The MB A170 is used as the foreign vehicle in the test. It is equipped only with GPS receiver and communication device.

In the MB A170, driving speed and turning signal are measured by the onboard sensors and are available for a Infineon C167cs based micro-controller in analogue format. This controller also collects the GPS signals from a GPS device and converts all necessary information into CAN messages. These CAN messages are sent to a WLAN CANbox and further transmitted to the WLAN CANbox in the BMW 728iA.

In the BMW 728iA driving speed and turning signal are already available on the vehicle CAN bus. Through an

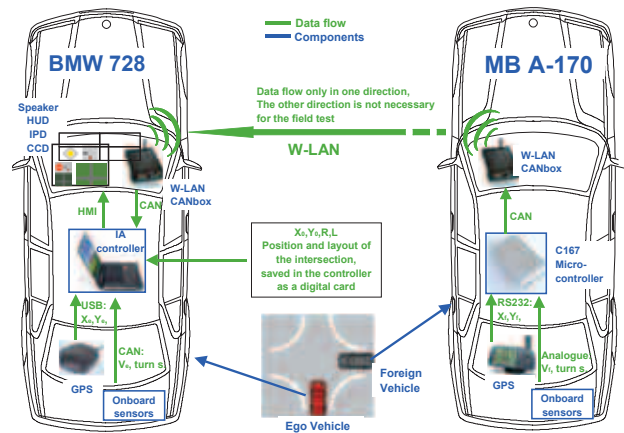


Fig. 5 IA system architecture

USB-serial adaptor GPS signals are delivered to the USB port of the IA controller, which is in this case a notebook-PC. In this way, all necessary input data of the IA system are available for the controller. After the calculation, diverse HMIs are activated according to the test layout.

The position and the design of the intersection (like the radius of the corners, the length, the width of the road and right of way information) are saved in the controller as a digital map. This data is also used for map matching to improve the GPS accuracy.

#### 5. DESIGN OF HUMAN MACHINE INTERFACES

A suitable Human Machine Interface (HMI) is the precondition for the assessment of user acceptance by subjects. The HMI for driver assistance systems can be realized by visual, acoustical and haptical means. Within this paper the focus is set on visual and acoustical HMI. For intersection assistance a haptical interface seems to be not suitable, because the information, which can be provided by a haptical HMI is ambiguous. Besides that the information content provided by a haptical HMI is very limited.

##### 5.1 Visual HMI

According to 11), three visual HMIs namely a Head-Up Display (HUD), a Center Console Display(CCD) and an Instrument Panel Display (IPD) are selected and mounted at the respective positions (see Fig. 6).

The HUD is mounted in the dashboard and it projects an image by means of mirrors on the windscreen. Because the image of the HUD is within the optimum field of view, only eye movement is necessary to watch it. The disadvantage of this position is the occlusion of the real scenery by the display. Therefore the image, which is projected on the windscreen, has to be half-transparent, which of course also reduces the quality of the image. In this application HUD has the task to show a warning sign and a schematic description of the traffic situation at the intersection.

The Center Console Display (CCD) is mounted on top of

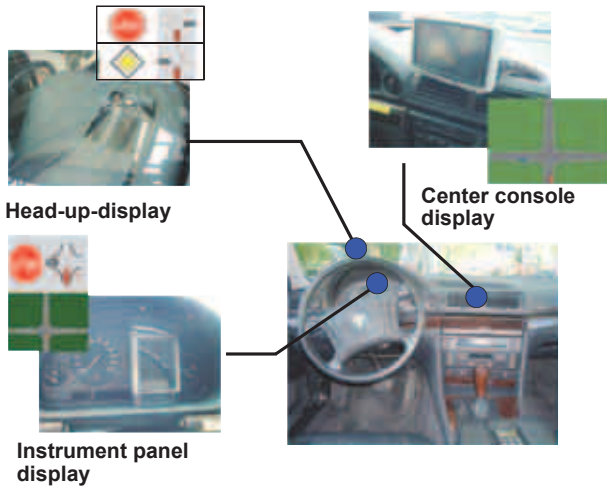


Fig. 6 The displays in the IA

the center console. At this position normally a display for navigation or for the infotainment system is installed in modern vehicles. In the test vehicle, a 7" TFT display is used as CCD.

CCD serves in this intersection assistant only as a source of information to show the scenery of the intersection. When the host vehicle approaches an intersection, the display is activated and shows a top view of the corresponding intersection by animation.

The Instrument Panel Display (IPD) is integrated in the instrument panel next to the speedometer. At this place usually small displays are integrated in modern vehicles. They are used for driver information systems like navigation and driver assistance systems like ACC to inform the driver about the current status of the system.

The image displayed on the IPD is divided into two parts. The upper part consists of a warning message and a description of the traffic situation by icons, which are also used for the HUD. The lower part shows the top view as it also used on the CCD. That means it integrates both functionalities of the CCD and the HUD.

### 5.2 Acoustical HMI

In addition to the above described visual HMI two types of sound are used as acoustical HMI: Single beep tone and verbal message in forms of human voice.

The single beep tone is used as a notification sound to arouse driver's attention at the activation of the HMI or when the situation changes.

Differing from the single beep tone the Human Voice (HV) includes more information and takes more time, e.g. "Beware, vehicle enters intersection, brake!". The human voice is not used as notification sound but as a warning message.

### 5.3 HMI designs

Three reasonable combinations of HMIs are chosen and implemented in the test vehicle to be evaluated by subjects:

HUD + CCD: In this combination the HUD is used to

show warning messages and a schematic traffic situation by icons, whereas the CCD provides a camera view of the intersection by animation, where the driver can see the intersection and the vehicles, which approach the intersection and are in the intersection area. Generally the activation of any HMI is introduced by a single beep tone to arouse the driver's attention to the displays. The single beep tone is also used, if the result of the situation assessment by the intersection assistant changes, while the HMI is activated (e.g. a new vehicle approaches the free intersection, so that driver has to stop, whereas earlier not).

IPD: In this case both icon messages (warning sign and traffic situation by icons) as well as the camera view of intersection are shown in this display. Again a single beep tone is applied, if the HMI is activated or the result of the situation assessment changes.

HV + CCD: The CCD is used as the single visual HMI in this case to show the top view of the intersection. A verbal warning message is given in addition to this visual information, if the driver has to consider the vehicles with higher priority (driver has to give right of way to other vehicles). A beep tone is not used in this HMI concept.

## 6. RESULTS

### 6.1 Simulation results

The simulation results aim the specification of the communication technology as well as the assessment of the defined technology concepts regarding traffic safety and expected user acceptance.

#### 6.1.1 Technology specification

The most important communication parameter for intersection assistance is the communication range. The simulation of the worst-case situation with different parameters (e.g. driver type, velocity, max. deceleration) in PELOPS shows that a communication range of 120 m is sufficient for the full velocity range up to 100 km/h as illustrated in Fig. 7.

Regarding RVC not only the communication range but also the detection range plays an important role. Due to the restricted detection range of imaginable systems like cameras only 25 m, 50 m and 75 m are regarded. The results show that a detection range of 50 m is sufficient and

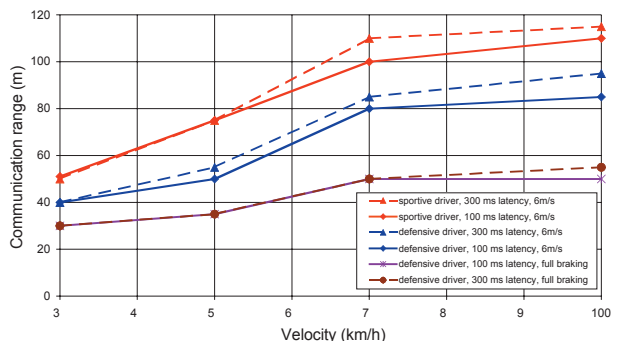


Fig. 7 Necessary minimum communication range for accident avoidance in worst-case situation at different speed levels

in some cases even advantageous. For low-tech “Sophisticated IVC” only the presence of other vehicles is known, but not their detailed position. With 50 m detection range nearly every detected vehicle is relevant and therefore the false alarm rate is minor. For higher detection ranges the false alarm rate increases. At 25 m the number of missed alarms rises due to the short detection range.

Regarding the IVC transmission update rate the simulations show that the requirements on this parameter are not high. An update rate of 10 Hz suffices in all cases. Also a latency time of 300 ms, which is state of the art e.g. for available WLAN-communication, is enough for warning and informing assistance.

The state of the art regarding the accuracy of positioning systems (10 m) is also sufficient for warning and informing systems, because the driver himself cannot estimate the distances to other vehicles in a better way.

**6.1.2 System assessment**

For the assessment of the different technology concepts and layouts two criteria are considered:

- Expected user acceptance, which is assessed by the number of false and missed alarms (considering only equipped vehicles)
- Traffic safety, which is assessed by the frequency of near-accidents and the number of total missed alarms (considering also non-equipped vehicles)

Regarding the traffic safety the most important aspect is the equipment rate (compare to Fig. 8). The technology concept and layout play only a secondary role.

Because the most vehicles cannot be detected at low equipment rates, the system cannot react on those, so that dangerous situations cannot be avoided. Vehicles, which are equipped with “Sophisticated IVC”, indeed detect all vehicles in the intersection area and are therefore not involved in any accidents, but those few vehicles have no influence on the other non-equipped vehicles. Also the

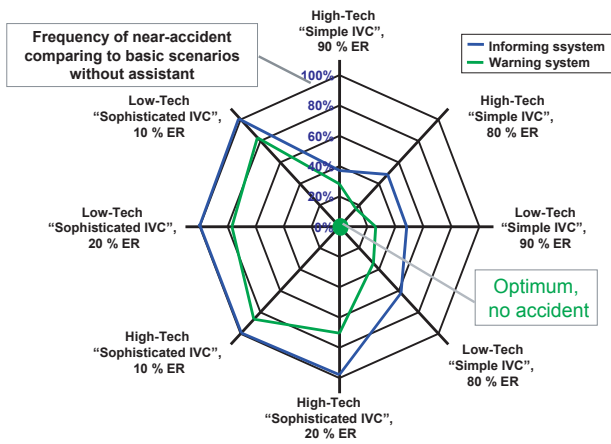


Fig. 8 Frequency of near-accident situations for different technology concepts and layouts compared to the basic scenario without any assistance (90% / 80% equipment rate for “Simple IVC”, 20% / 10% equipment rate for “Sophisticated IVC”)

probability that such an equipped vehicle passes the intersection at the moment, when there is a critical situation, is marginal, because such situations are seldom. For “Simple IVC” it has to be regarded additionally that the probability that two equipped vehicles meet each other at the intersection is square to the equipment rate. At an equipment rate of 20 % e.g. the probability amount to 4 % and is negligible low.

Warning systems are more effective than informing systems due to a more conservative warning threshold. This leads to a slower traffic in the close area of the intersection, which may influence the traffic efficiency negatively, but has a positive effect on the traffic safety in any case. It has to be mentioned that in the simulator study all drivers respect to the warnings.

To achieve a better effect on traffic safety with “Sophisticated IVC” a higher equipment rate is necessary. It can be expected that the safety effect is not linear depending on the equipment rate. But generally the simulation study shows that at “Sophisticated IVC” with the lower equipment rate (in the simulation 50 %) the same effect on traffic safety can be achieved as at the higher equipment rates of “Simple IVC” (in the simulation 80 %).

Regarding to user acceptance it can be said that the missed alarm rate for equipped vehicles is generally low for all technology concepts. Mostly there are not any missed alarms but only late alarms. Therefore the differences between the different informing systems, at which only the missed alarm rate can be assessed (no false alarms per definition), are low (compare to Fig. 9). The expected user acceptance is therefore well, but it has to be considered that the situation assessment has to be done by the driver himself. In contrast to PELOPS-drivers real drivers tend to be distracted and unwary, as the accident analysis has shown.

In case of warning systems only low-tech “Simple IVC” may not be accepted by the driver due to the high rate of false alarms caused by the unknown right of way at this technology stage. The best false alarm rate is achieved with

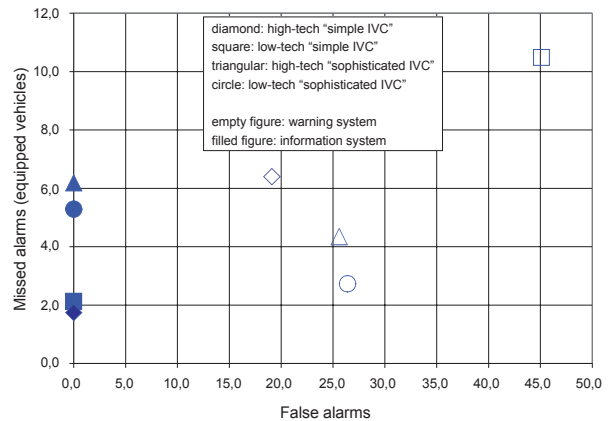


Fig. 9 False and missed alarm rate at 50 km/h speed limitation (per 100 equipped vehicles and 100 conflict situations)

high-tech “Simple IVC” at the cost of a higher missed alarm rate compared to “Sophisticated IVC”.

It can be expected that the best user acceptance will be obtained by “Sophisticated IVC” systems, because of a good false-missed-alarm ratio and because all vehicles (not only equipped ones) are detected. In case of “Simple IVC” the driver may be annoyed in a dangerous situation, at which he does not get a warning, independent from the matter of fact that the other vehicle is equipped with IVC or not.

**6.2 Subject tests with driving simulation and test vehicle**

The intersection assistant was assessed by sixteen subjects in the driving simulator and real world test respectively. The evaluation bases on questionnaires, which were filled out by them during the tests.

**6.2.1 HMI**

Figure 10 shows the preference among all three HMI combination concepts. HV + CCD is rated as most preferred in the real world test, whereas in the simulator HUD + CCD is rated best. Generally only small differences among these HMI can be seen. Compared to the driving simulator study, CCD + HUD and HV + CCD exchanged their roles. This could be explained by the modified subject groups (older subjects in the real world tests) on the one side and on the other side the more simpler intersection situations in the real world tests. The resulting requirements on the HMI are lower compared to the more complex situations in simulator.

**6.2.2 Technical layouts**

Various technical layouts are tested in the driving simulator study. Especially the user acceptance of the different technology layouts and equipment rates are the focus of these tests.

Figure 11 shows the subjects’ satisfaction with each technology layout. High-tech “Sophisticated IVC” has the best rate and is followed by low-tech “Sophisticated IVC”. High-tech “Simple IVC” with 90% ER (equipment rate) is rated better than high-tech “Simple IVC” with 50% ER, which is on the level of low-tech “Simple IVC” with 90%ER. From this it can be seen that for user acceptance

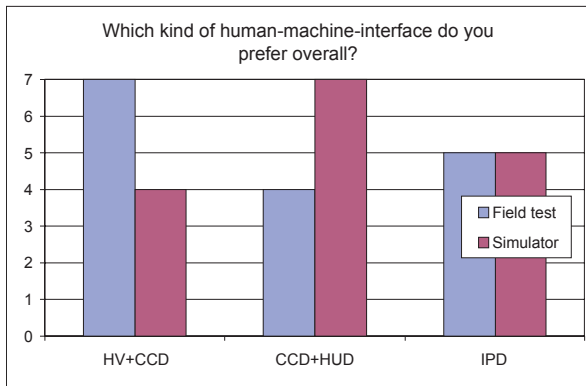


Fig. 10 The preference of HMI

the detection rate of other vehicles is the most important factor.

Low-tech “Simple IVC” has the worst rating. Due to the missing right of way information the subjects are warned also, if they have right of way. This is not accepted by the subjects. In general all layouts except low-tech “Simple IVC” are rated better than three (medium value).

**6.2.3 Influence of the IA on driving behavior**

The real world test enables the measurement of the influence of the IA on driving behavior. Three scenarios (S7, S8 and S9) as shown in Fig. 12 are applied in this test.

The average difference distance between the braking point with and without IA is given in Fig. 13. Negative values mean that the subject brakes earlier with IA.

As shown, with IA the subjects brake normally in all situations earlier (average values). This effect is more significant when the sight is occluded and the subjects have to give right of way (situation 8). Even in situation 9, where the driver has right of way, the impact of IA on the driver behavior can be seen.

Male subjects are influenced in all situations by IA, whereas female subjects only in situation 8. For experienced subjects the effect is higher than for inexperienced ones. Older subjects are influenced significantly, whereas the effect on younger subjects is lower. The older subjects react with IA in average up to 5 m earlier than without IA. Inexperienced and young subjects brake later in

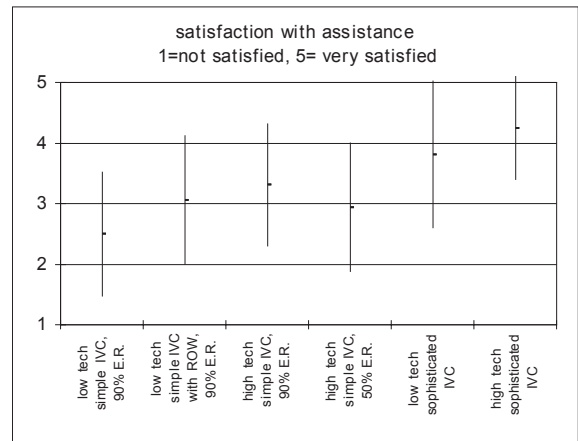


Fig. 11 Evaluation of the different technology layouts



Fig. 12 Scenarios to test the influence of IA

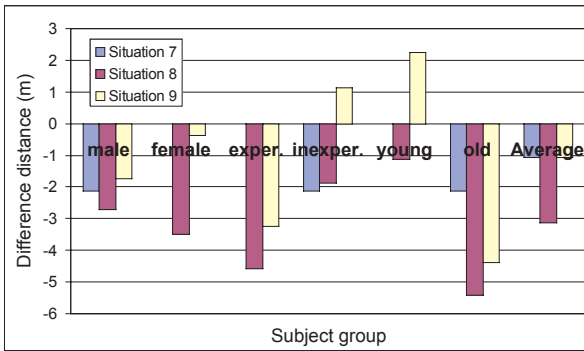


Fig. 13 Influence of IA on braking time

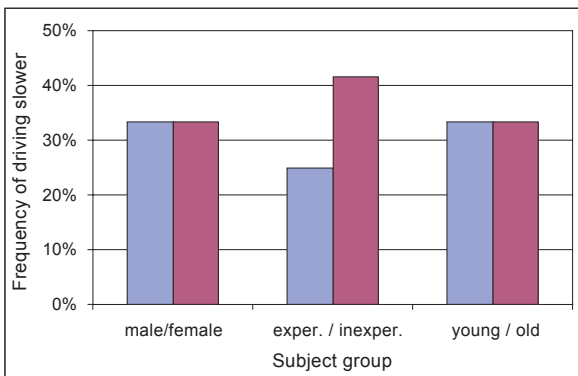


Fig. 14 Influence of IA on driving speed

situation 9 with IA. This could be a hint that those groups rely more on the IA than the other groups.

The influence of the IA on the driving speed through the intersection is also analyzed. Only speed differences higher than 1m/s are considered. There is no big difference in 30 cases. But in 16 cases subjects drive more slowly through the intersection with IA. Only in two cases subjects drive faster. The differences between the three situations are not significant.

Figure 14 illustrates the influence on the driving speed of each subject group in all three scenarios. Gender and age have no influence on this effect. Inexperienced subjects are influenced more than experienced ones. In around 40% cases the inexperienced subjects drive slower.

## 7. CONCLUSION AND OUTLOOK

In the scope of this paper, a communication based intersection assistant as well as suitable human machine interfaces have been designed and implemented in the traffic simulator PELOPS, a driving simulator and finally in a test vehicle.

Summarizing all simulation results two different technology concepts can be recommended:

- Low-tech “Simple IVC” with information about the right of way regulation
- Low-tech “Sophisticated IVC”

As it cannot be expected that the necessary equipment

rate for “Simple IVC” can be reached in near future, for the first introduction of communication-based intersection assistance a “Sophisticated IVC” solution should be chosen, even if RVC is only used at some accident-relevant intersections. Not all intersection accidents can be avoided by the RVC-based system concept, but a reduction of about 20 % of all car-to-car near-accidents is probable based on the simulation results.

To enhance traffic safety significantly the technology scenario “Simple IVC” is required. For a better user acceptance the right of way regulation at the intersection has to be implemented on the utilized digital maps.

The results of subject test show that HUD + CCD in the simulator and HV + CCD in test vehicle can provide most satisfying assistance, followed by IPD. Nearly all subjects agree, that this intersection assistant can improve the traffic safety and relieve the driver, but they are also worrying about that people could rely too much on the system.

Besides this warning intersection assistant, another possible design is an intervening system, which is activated very late and only in case of danger. The requirements on information acquisition and situation assessment are very high, since false alarms have to be avoided. It can be expected that the user will not accept the system, if the system stops the car in the middle of an intersection and causes another accident.

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