Communication-based Intersection Assistance

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Abstract—**The approach of communication-based intersection assistance is described. Different technology scenarios were analyzed in a realistic traffic simulator to cover a wide time horizon and a wide area of system complexity. The results regarding the specification of the necessary communication technology are proposed. Additionally the different technology scenarios are assessed regarding to the expected user acceptance and their effect on traffic safety. The most important parameter for the reduction of intersection accidents is the equipment rate with communication-based intersection assistant systems. The starting point of the technology concepts is today's available communication technology. Based on the presented simulation study two technology concepts for communication based intersection assistance are recommended.**

Index Terms—**intersections, driver, assistance, inter-vehicle communication, traffic safety, user acceptance**

I. Introduction

ABOUT 34.7 % of all accidents in Germany occur in the range of traffic nodes (intersections, junctions and gateways) [1][6]. The rate has not changed significantly during the last three years. The potential of an intersection assistant, which supports the driver in such conditions, would be enormous. But on the other side the realization of such an assistant makes high demands on the detection and determination of the traffic situation on crossings. Conventional environmental sensors (Radar, Lidar or vision) cannot manage the detection of all vehicles in the range of a crossing, especially if the vehicles are out of sight, because of obstacles like houses, trees etc. But the driver needs support, especially in those situations, where he cannot see if there is a vehicle coming into the range of the intersection or not. Inter-vehicle communication offers the possibility to solve this problem and to provide the necessary information. Precondition for that is a positioning system, which provides location data and a digital map containing the road characteristics. Via communication the assistance system gets position and velocity information about all involved vehicles.

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 (inter-vehicle communication) and RVC (road-vehicle communication). For this purpose the main technology characteristics like communication range, equipment rate or data exchange 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.

II. 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:

- 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 digital maps
- 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 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 do not rely on any infrastructure sensor. The second concept

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called "Sophisticated IVC" utilizes inter-vehicle-communication as well road-vehicle-communication. Besides the direct communication with other equipped vehicles a sensor (e.g. camera) is implemented in the intersection range, 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.

	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.

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. The root of the program is built by the three significant elements of the traffic system – track/environment, driver and vehicle, as shown in Fig. 2. Therewith PELOPS can simulate the traffic and driver assistance in a high resolution. The three elements - track/environment, driver and vehicle - are modeled in a modular program structure and defined by interfaces [2], [3], [4], [5].

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. Thus assistance systems for example in the urban-, interurban- and in the motorway traffic can be analyzed and optimized (e.g. stability of the control, system safety, fuel consumption etc.). Furthermore the effects of an assistance system on the moving traffic can be regarded and thus statements about the efficiency and safety of the traffic process can be made.

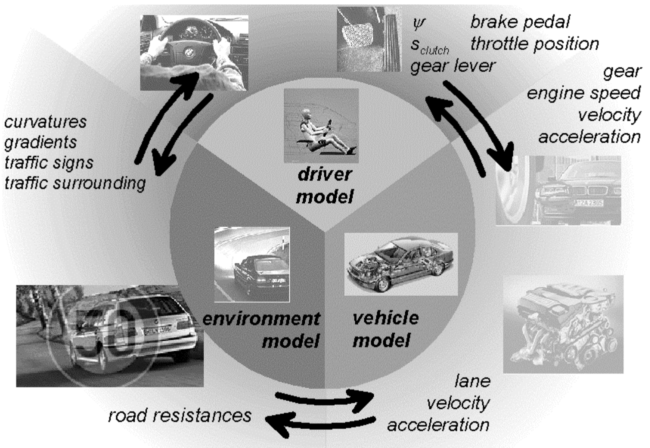

Fig. 2. The traffic flow simulation tool PELOPS.

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, 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 by means of the parameters of the driving strategy and the driver's reaction the position parameters of the vehicle, such as accelerator position, steering wheel and gearshift.

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, gearshift, acceleration, longitudinal and lateral position on the road, etc.), as the driver in reality does it. 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 signing, 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.

The driver model of PELOPS identifies the different situations in dependency of the information about the surrounding traffic and the vicinity. In case of an identified situation, the corresponding algorithms are used to determine the driver's reaction. In most cases not only one situation is identified but also several different situations, like following a leading vehicle and simultaneously react to a curve ahead. In such cases the situation is chosen, which leads to the more intensive reaction of the driver. The reaction in case of longitudinal situations is described by a desired acceleration, which is transformed by the action model into a pedal position and a gearshift. This means that the situation with the lowest resulting desired acceleration is chosen in case of several simultaneously identified situations. In this way the model driver always reacts to the most important (most dangerous) event in his surrounding.

For the specification the main technology characteristics like communication range, penetration rate and data exchange 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 communication 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 veh/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".

III. 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.

A. *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. 3.

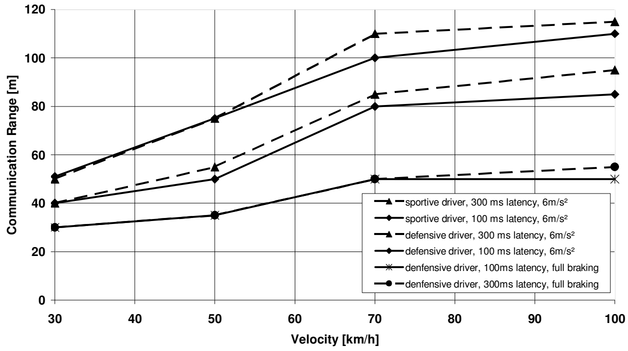

Fig. 3. Necessary minimum communication range for accident avoidance in worst-case situation at different speed levels

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 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 is higher. At 25 m the number of missed alarms rises due to the short detection range.

In the simulation a detection range of 50 m shows the best performance, but it has to be considered that the moment of the warning (when the warning is given) is restricted due to the limited detection range. The user acceptance is definitely depending on the moment of warning, but its effect cannot be simulated in PELOPS. Further analysis with real drivers in a driving simulator or with test vehicles in real world scenarios are needed for the final specification of the 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 WLANcommunication, 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 - not at least because the driver himself cannot estimate the distances to other vehicles in a better way.

Intervening systems have the highest demands on the technology parameters apart from the communication range. Intervention is only feasible with the high-tech layouts (update rate: 10 Hz, latency time: 100ms, positioning accuracy: 2 m). A high communication range is not needed, because the system is activated only in the close range to the intersection, when the accident probability is very high. Note that the technology specification should be considered as the minimum requirements, because e.g. at congested traffic the communication bandwidth may not be sufficient, so that the update rate has to be enhanced.

B. System Assessment

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

- 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

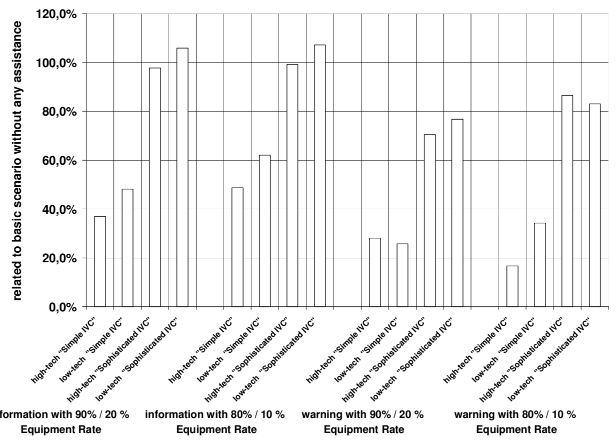

Fig. 4. Frequency of near-accident situations for the different technology concepts and layouts at 50 km/h speed limitation compared to the basic scenario without any assistance (90% / 80% equipment rate for "Simple IVC", 20 % / 10% equipment rate for "Sophisticated IVC")

Regarding the traffic safety the most important aspect is the equipment rate (compare to Fig. 4). 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 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, because those systems lead to a slower traffic in the close area of the intersection. This may influence the traffic efficiency negatively, but has a positive effect on the traffic safety in any case. The reason for this effect can be seen in the ideal parametrisation of the PELOPS-driver model, which always considers the warning. Further analysis with real drivers has to be done for the verification of this effect.

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 really missed alarms but only late alarms. Therefore the differences between the different informing systems, at which only the missed alarm

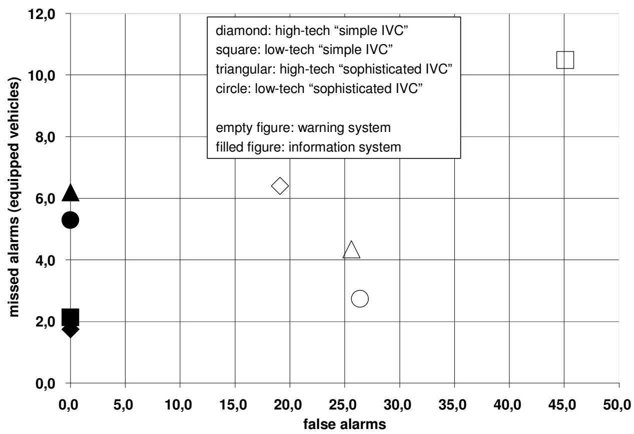

Fig. 5. False and missed alarm rate at 50 km/h speed limitation (per 100 equipped vehicles and 100 conflict situations)

rate can be assessed (no false alarms per definition), are low (compare to Fig. 5). 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 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.

C. Conclusions

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 next 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 accidents is probable based on the simulation results (see Fig. 4). The final assessment of the necessary detection range has to be done with real drivers.

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.

Further analysis especially regarding user acceptance, which is for example mainly influenced by the moment of warning, it is recommended to make further analysis with real drivers in a driving simulator respectively with test vehicles in real world scenarios, where such an intersection assistant is implemented.

REFERENCES

[1] R. Großpietch, PhD thesis at the Institut für Kraftfahrwesen der RWTH Aachen, Aachen, 2004, to be published (in German)

[2] R. Diekamp, “Entwicklung eines fahrzeugorientierten Verkehrssimulationsprogramms“, PhD thesis at the Institut für Kraftfahrwesen der RWTH Aachen Aachen, 1995 (in German)

[3] J. Ludmann, “Beeinflussung des Verkehrsablaufs auf Straßen - Analyse mit dem fahrzeugorientierten Verkehrssimulationsprogramm PELOPS“, PhD thesis at the Institut für Kraftfahrwesen der RWTH Aachen Aachen, 1998 (in German)

[4] M. Weilkes, “Auslegung und Analyse von Fahrerassistenzsystemen mittels Simulation“, PhD thesis at the Institut für Kraftfahrwesen der RWTH Aachen Aachen, 2000 (in German)

[5] P. Zahn, A. Hochstädter, K. Breuer, “A Universal Driver Model with the Applications Traffic Simulation and Driving Simulation”, 1st Human-Centered Transport Simulation Conference, Iowa, 2001

[6] U. Lages, „INTERSAFE – New European Approach for Intersection Safety, funded by the European Commission in 6th Framework Program“,11th World Congress on ITS, Nagoya, Japan, 2004