

# Specification and Assessment of Different Intersection Assistance Concepts Based on IVC (Inter-Vehicle-Communication) and RVC (Roadside-Vehicle-Communication)

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## ABSTRACT

An approach for intersection assistance, which is based on IVC (Inter-Vehicle-Communication) and RVC (Roadside-Vehicle-Communication), is described in this paper. Different technology scenarios, which cover a wide time horizon and a wide area of system complexity, are analyzed in a realistic traffic simulator and assessed concerning the expected user acceptance as well as the system's effect on traffic safety. The starting point of the technology concepts is the up-to-date communication technology. The simulation results show that the most important parameter regarding the specification of necessary communication technology is the communication range. The equipment rate of intersection assistant systems has the greatest contribution to reduction of intersection accidents. Based on the simulation study two technology concepts for IVC and RVC based intersection assistance are recommended.

## KEYWORDS

Intersection assistance, IVC, RVC, traffic safety, user acceptance

## INTRODUCTION

During the recent years the traffic volume has increased continuously. This tendency will presumably persist in the next years. New technologies shall ensure that despite of the increasing traffic volume the number of accidents and fatalities decreases. Many active as well as passive safety precautions were already invented in the past to enhance traffic safety and have shown their positive effects on traffic safety.

Today the number of killed persons in traffic accidents still counts about 7000 per year in Germany. The European Commission has set up a demand to reduce the number of casualties in Europe to a half up to the year 2010. In order to reach this aim it is necessary to use the

whole potential of possibilities to increase traffic safety. Therefore new active safety measures have to be considered.

Due to [1], [6] about 34.7 % of all accidents in Germany occur in the range of traffic nodes (intersections, junctions and gateways). 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 realisation of such an assistant makes high demands on the detection and determination of the traffic situation on crossings. Conventional environmental sensors 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 approaches an 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 main objective of this paper 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 and data exchange are analysed for different traffic situations and conditions using the advanced traffic simulator PELOPS. The result of this paper is the assessment of the potentials of different IVC/RVC-based intersection assistant concepts regarding to enhancement of traffic safety and the influence of the regarded parameters on the functionality of the corresponding assistant concepts.

## **REQUIREMENTS ON INTERSECTION ASSISTANT**

The high number of accidents at intersection (34.7 % of all accidents) shows the necessity to support the driver in intersection situations. An intersection assistant has huge potentials to improve traffic safety. The traffic situation at intersections is complex because of the different types of traffic participants (passenger cars, pedestrians, cyclists etc). But as the accident analysis showed that the most dangerous situations are car-to-car situations (90 % of all accidents are caused by passenger cars), the most accidents could be prevented by a communication based assistant. About 63 % of all node accidents occur at the four situations:

- left turn with oncoming traffic,
- traffic from right,
- straight forward with traffic from left and
- left turn with traffic from left,

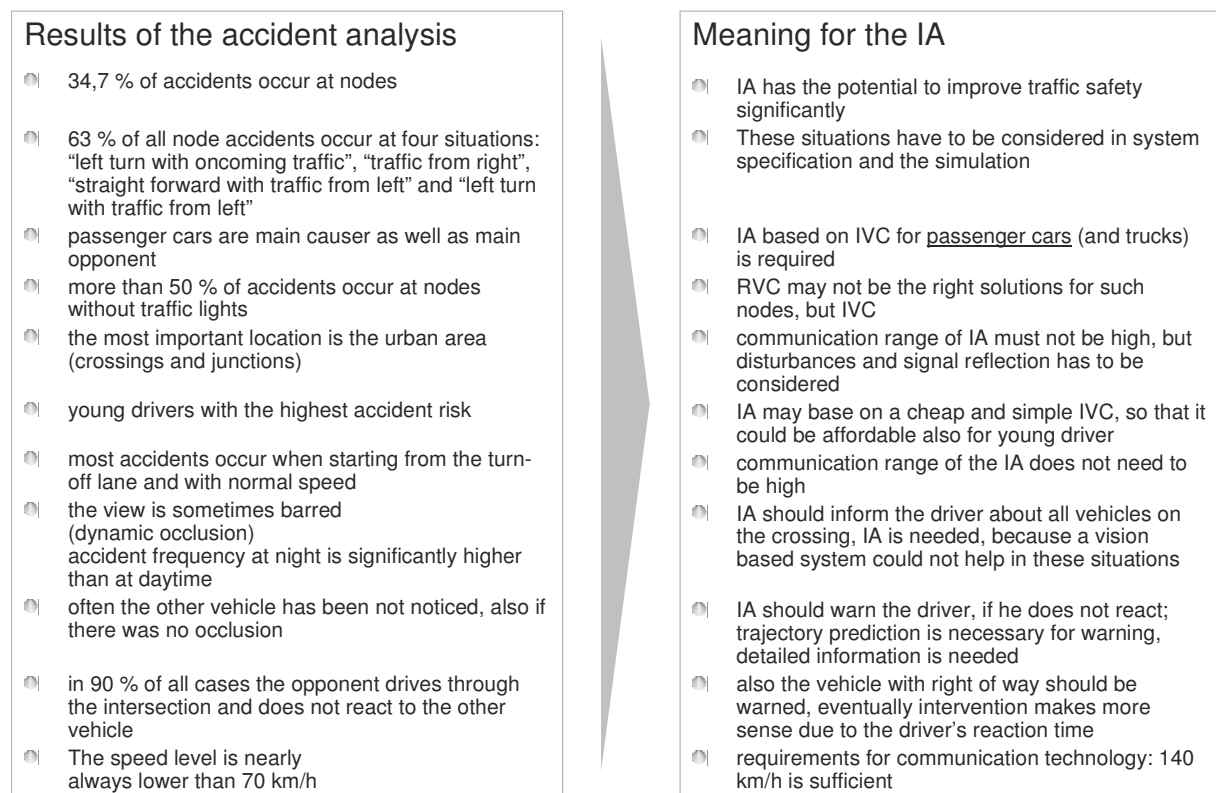
where pedestrians and cyclists are not involved.

The most intersection accidents occur in urban areas, so that this special operational area has to be considered for the development and laying of the intersection assistant. The velocity range and thus also the communication range does not have to be very huge. The speed range, in which more than 90 % of all intersection accidents happen is between 50 km /h and 70 km/h. But in urban areas other aspects have to be considered. The communication signal could be reflected by the buildings or disturbed. The traffic density is normally higher, so that the number of received messages could be also very high, which increases the computation demands and results in higher efforts to identify the relevant messages (also because the

intersections are close to each other). So a high communication range could have also negative consequences.

Considering the addressed age group for the intersection assistant the analysis showed that the most accidents are caused by the age group between 20 and 40 years, but the highest accidents risk is given for the group of young drivers. Because these groups are in general not wealthy and drive lower class and middle class vehicles, a cheap and simple system would be reasonable, if a significant reduction of accidents is aimed. Also considering the raising effect of such a communication-based system with increasing equipment rate a cheap and simple system comes into the foreground.

The interviews to the people, which had caused intersection accidents, showed that visibility is one of the important aspects at intersection situations. The number of accidents at night is super-proportional compared to the accident number at daytime regarding the higher traffic flow at day. Also at daytime the view on the other vehicles is often barred by other vehicles or by stationary objects like buildings and trees. For the requirements on the intersection assistant this means that the system itself should have a wider visibility range than the driver and should detect also occluded vehicles. In contrast to a vision-based intersection assistant this requirement is fulfilled by a communication-based assistant (IVC- as well as RVC-based).



**Figure 2 – Requirements on intersection assistance**

Another very important aspect regarding the reasons for intersection accidents is distraction or inattention. A lot of accidents occur despite of free view, because the drivers do not notice the other vehicles. The misjudgement of traffic situations is compared to the inattention situations seldom and probably only relevant for other types of traffic participants like motor-cyclists and pedestrians. Considering this aspect the meaning of a warning system raises, compared to that of an information system. In case of warning (e.g. acoustical beep) a distracted driver may pay attention again to the traffic situation, while the additional information e.g. in a display is probably overlooked.

The accident analysis also showed that the opponent only reacts in some few situation. In about 90 % of all accident situations he does not expect the behaviour of the accident causer, so that he has no time to react on the changed situation. A warning in this case to driver with right-of-way could also prevent a lot of accident or at least lead to a reduction of the impact velocity and thus to the reduction of the accident severity. The main conclusions from the accident analysis are presented in figure 2.

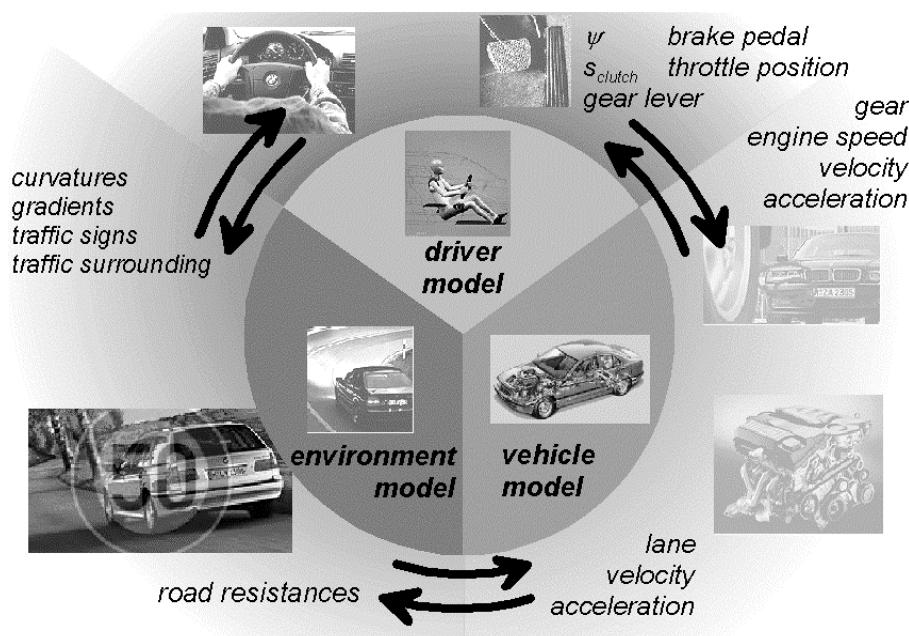
## SIMULATION CONCEPT

Based on the accident analysis different technology scenarios of a communication-based intersection assistant are modelled in PELOPS and simulated, in order to identify and specify the important parameters as well as to assess these technology concepts regarding user acceptance and their effects on traffic safety. In the following text the advanced traffic simulator PELOPS and the regarded technology concepts and are presented.

### PELOPS

The traffic simulator PELOPS has been developed by fka (Forschungsgesellschaft Kraftfahrwesen mbH Aachen) in cooperation with the BMW AG and is sold and maintained by the fka today.

PELOPS 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 (figure 3). Therewith PELOPS can simulate the traffic in a high resolution. The three elements - track/environment, driver and vehicle - are modelled in a modular program structure and defined by interfaces [2], [3], [4],[5].



**Figure 3 - The traffic flow simulation program PELOPS**

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 components can be contemplated. Thus assistance systems for example in the urban-, interurban- and in the motorway traffic can be analysed and optimised (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.

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 modelled according to the cause-effect-principle and considers longitudinal as well as lateral dynamics. Thus the opportunity is provided to analyse 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 behaviour- and an action model. The reactions of the driver according to the surrounding traffic situation are simulated in the behaviour 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.

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. By doing so the model driver always reacts to the most important (most dangerous) event in his surrounding.

Not only reactions to vehicles on the same lane are regarded but also realistic driver behaviour on multilane tracks is realised by a tactical model. This tactical behaviour model includes a situation dependant lane change model, which is based on the contented-ness of the drivers on the different lanes. Based on the assessment of the driver contented-ness at first it is proved if the driver has a lane change wish. In case of a lane change wish the realisability of the lane change regarding to the surrounding traffic and depending on driver-individual parameters (like gap width, in which to change) is determined. If the lane change is possible the driver begins to change his lane and accelerates or decelerates to reach the corresponding gap on the neighbour lanes.

## **Communication Technology Concepts**

For the realisation of an intersection assistance system, different technology layouts are modelled in PELOPS and assessed by the simulation results. These technology concepts should represent today's possibilities as well as future technologies and base on fully vehicle-autonomous technologies as well as a combination of vehicle and infrastructure sensors.

The first concept called "Simple IVC" uses only inter-vehicle communication and in-vehicle sensors and do not rely on any infrastructure sensors. The second concept called "Sophisticated IVC" utilises inter-vehicle-communication as well road-vehicle-com-

munication. Besides the direct communication with other equipped vehicles a sensor (e.g. camera) is implemented at the intersection area, 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 utilised technologies are defined: Today’s available and future technologies and sensors. Based on this consideration four technology layouts result:

- Low-tech “Simple IVC”, IVC-based system with today’s available technology
- High-tech “Simple IVC”, IVC-based system with future technology
- Low-tech “Sophisticated IVC”, IVC/RVC-based system with today’s available technology
- High-tech “Sophisticated IVC”, IVC/RVC-based system with future technology

The parameters for each technology layout are shown in table 1. The position accuracy of the low-tech layout is about 10 m (today’s possible GPS-accuracy without enhancement systems like DGPS). For the high-tech layout an accuracy of about 2 m is chosen, as it will be theoretically possible with the European Galileo positioning system. The latency time is in case of the low-tech layout 300 ms (today’s WLAN) whereas for the high-tech layout 100 ms is estimated. The signal accuracy for other sensor like velocity, acceleration and yaw rate is set for all layouts to 5 % according to today’s sensors.

The equipment rate for “Simple IVC” has to be high to achieve an effect with the intersection assistance as described above. Therefore an equipment rate between 80 and 90 % is aimed. For “Sophisticated IVC” such a high equipment rate is not necessary. An equipment rate between 10% and 20% of all vehicles is regarded. In case of “Sophisticated IVC” the detection of non-equipped vehicles in the area of the intersection is realised by an infrastructure-based sensor. The detection range of this sensor, which is chosen as 50 m, is very important for the system performance. The communication range (for IVC and RVC) is chosen due to the simulation of the minimum necessary communication range for the worst-case situation to 120 m.

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

**Table 1 - Parameters for the assessed technology layouts**

In table 2 the available information for the different technology layouts is summarised.

	Low-tech "simple IVC"	High-tech "simple IVC"	Low-tech "sophisticated IVC"	High-tech "sophisticated IVC"
<b>Own vehicle (dynamics)</b>	velocity, acceleration, yaw rate	velocity, acceleration, yaw rate	velocity, acceleration, yaw rate	velocity, acceleration, yaw rate
<b>Own vehicle (position)</b>	own position, heading direction, intersection arm	own position, heading direction, intersection arm	own position, heading direction, intersection arm	own position, heading direction, intersection arm
<b>Other equipped vehicles (dynamics)</b>	velocity, acceleration, yaw rate	velocity, acceleration, yaw rate	velocity, acceleration, yaw rate	velocity, acceleration, yaw rate
<b>Other equipped vehicles (position)</b>	position, heading direction, intersection arm	position, heading direction, intersection arm	position, heading direction, intersection arm	position, heading direction, intersection arm
<b>Other non-equipped vehicles (dynamics)</b>	--	--	--	velocity
<b>Other non-equipped vehicles (position)</b>	--	--	presence, intersection arm	position, heading direction, intersection arm
<b>Intersection</b>	position of the intersection	position of the intersection and its detailed layout	position of the intersection and its detailed layout	position of the intersection and its detailed layout
<b>Right-of-way regulation</b>	no	yes	yes	yes

**Table 2 - Available information for the different technology layouts**

## Level of Assistance

The intersection assistant is designed to assist the driver passing the intersection without any risky or dangerous manoeuvre by using the acquired data provided by the described technology concepts. How the benefit of the system is conveyed to the driver is depending on the Human-Machine-Interface. All possible levels of assistance are implemented in PELOPS to analyse the performance of those assistance system [7]:

- **Informing assistance:** The driver is informed about all detected vehicles in the intersection range and their position. The situation assessment has to be done by the driver himself.
- **Warning assistance:** The system assesses the intersection situation based on the available data and warns the driver in case of possible danger.
- **Intervening assistance:** The system assesses the intersection situation based on the available data and intervenes by braking the vehicle in case of a dangerous situation and a lacking of corresponding reaction of the driver.

The task of informing assistance is to provide all information, which is acquired by the applied technologies, to the driver. The most important information is the presence or the location of other vehicles in the intersection range. In the low-tech technology layouts the driver is informed about the position of foreign vehicles in case they are equipped with IVC. If they are detected by RVC, only their presence can be provided to driver. For the high-tech layouts and the concept with RVC also information about the intersection layout and the right-of-way are given to the driver.

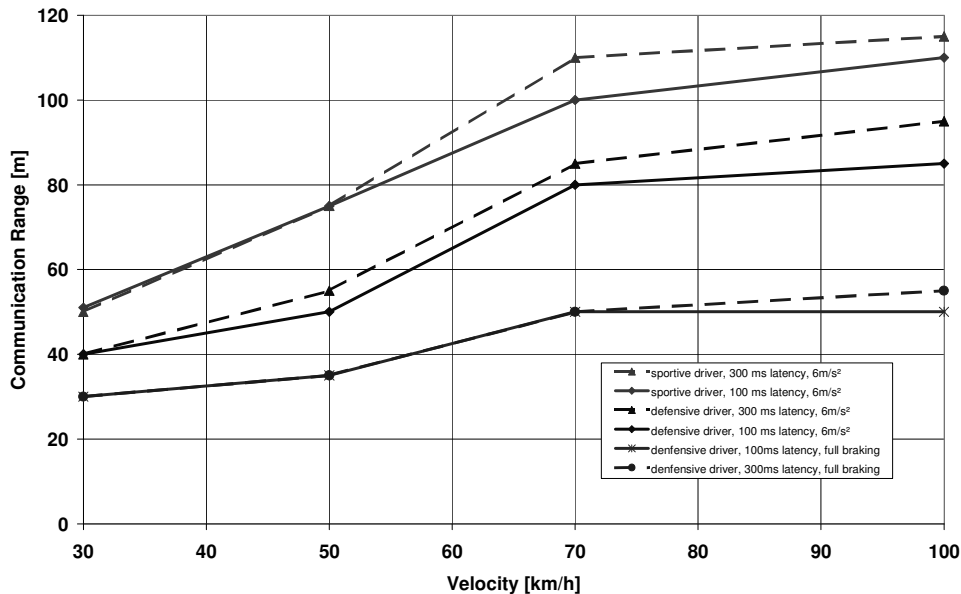
The warning assistance system does not provide any information to the driver, but give a kind of warning to the driver: acoustical, optical or haptical. The system assesses the current intersection situation considering all the available data, which is acquired by the utilised sensors and warns the driver in case of collision risk with another vehicle in the intersection range.

Intervening assistance works differently than the informing and warning assistance. The driver is at this kind of assistance outside the control loop and overruled by the system. The system itself does not influence the driver behaviour when the vehicle is still approaching the inter-section. It intervenes first and takes over the longitudinal control of the vehicle fully

automatically only in dangerous situations, where a collision can be predicted with a high probability. Very accurate and extensive data is necessary for the collision prediction, so that the intervention assistance is only recommended for the high-tech technology layouts.

## TECHNOLOGY SPECIFICATION

As mentioned already, that the most important parameter for the system specification 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 figure 4.



**Figure 4 - 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 timing of the warning (when the warning is given) is restricted due to the limited detection range. The user acceptance is definitely depending on the timing 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 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 - 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.

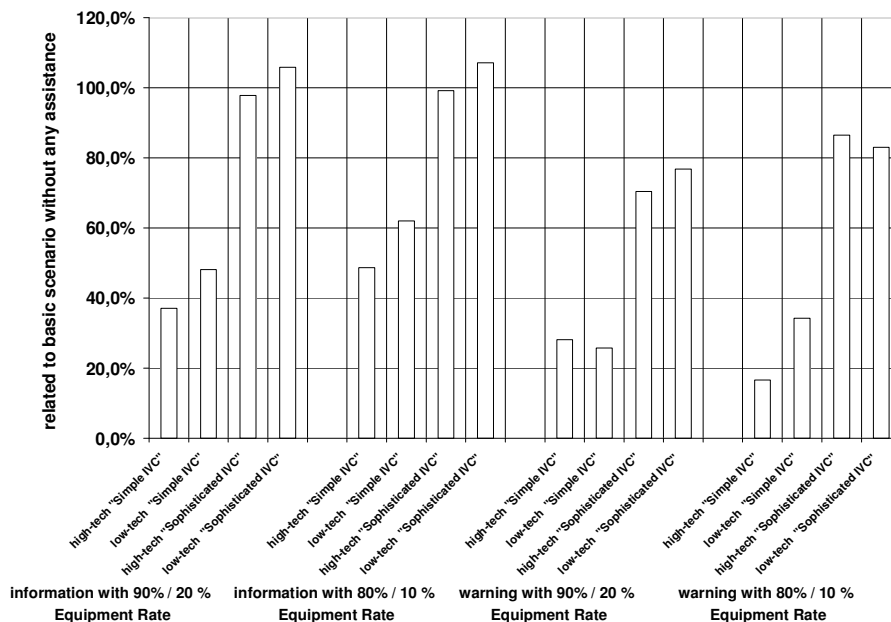
Note that the technology specification should be considered as the minimum requirements, because e.g. at congested traffic the communication bandwidth may not be sufficient, so that the update rate has to be enhanced.

## 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

Regarding the traffic safety the most important aspect is the equipment rate (compare to figure 5). The technology concept and layout play only a secondary role.



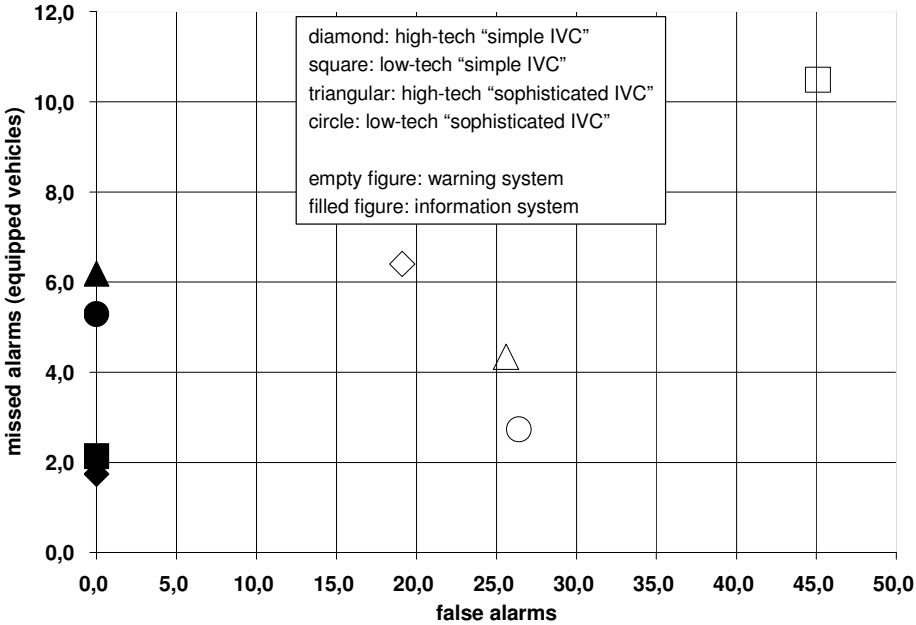
**Figure 5 - Frequency of near-accident situations for the different technology concepts and layouts at 50 km/h speed limitation compared to the basic scenario without any assistance (90% / 80% equipment rate for "Simple IVC", 20% / 10% equipment rate for "Sophisticated IVC")**

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 the warning algorithms are designed to be conservative to fulfil the requirements of all driver types. So the earning systems leads 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. 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 rate can be assessed (no false alarms per definition), are low (compare to figure 6). 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.



**Figure 6 - False and missed alarm rate at 50 km/h speed limitation (per 100 equipped vehicles and 100 conflict situations)**

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.

## CONCLUSION

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

- Low-tech “Simple IVC” with right-of-way information
- 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 a 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 this system concept, but a reduction of about 20 % of all car-to-car accidents is probable. 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 utilised digital maps.

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

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