Assessment of the effectiveness of Intersection Assistance Systems at urban and rural accident sites

C Zauner*, E Tomasch**, W Sinz***, C Ellersdorfer* and H Steffan****

* Project-Assistant, Graz University of Technology, Vehicle Safety Institute, Inffeldgasse 23/I, Graz, Austria
** Project-Senior Scientist, Graz University of Technology, Vehicle Safety Institute, Inffeldgasse 23/I, Graz, Austria
*** Vice Head of Institute, Graz University of Technology, Vehicle Safety Institute, Inffeldgasse 23/I, Graz, Austria
**** Head of Institute, Graz University of Technology, Vehicle Safety Institute, Inffeldgasse 23/I, Graz, Austria

Abstract

An Intersection Collision Avoidance System is a promising safety system for accident avoidance or injury mitigation at junctions. However, there is still a lack of evidence of the effectiveness, due to the missing real accident data concerning Advanced Driver Assistance Systems. The objective of this study is the assessment of the effectiveness of an Intersection Collision Avoidance System based on real accidents. The method used is called virtual pre-crash simulation. Accidents at junctions were reconstructed by using the numerical simulation software PC-Crash™. This first simulation is called the baseline simulation. In a second step the vehicles of these accidents were equipped with an Intersection Collision Avoidance System and simulated again. The second simulation is called the system simulation. In the system simulation two different sensors and four different intervention strategies were used, based on a Time-To-Collision approach. The effectiveness of Intersection Collision Avoidance Systems has been evaluated by using an assessment function. On average 9% of the reviewed junction accidents could have been avoided within the system simulations. The other simulation results clearly showed a change in the Principal Direction of Force, delta-v and reduction of the injury severity.

NOTATION

ADAS	Advanced Driver Assistance Systems
AIS	Abbreviated Injury Scale
BP	Brake Power
C2C	Car-to-Car
C2I	Car-to-Infrastructure
Delta-v (Δv)	Change in velocity
EES	Energy Equivalent Speed
GoFAST	Generic Sensor Effectiveness Assessment of Advanced Driving Assistance Systems Tool
ICAS	Intersection Collision Avoidance System
LRR	Long Range Radar
MAIS	Maximum Abbreviated Injury Scale
MD	Median
PDoF	Principal Direction of Force
SD	Standard Deviation
SRR	Short Range Radar
TTC	Time-To-Collision
v_k	Collision velocity
ZEDATU	Zentrale Datenbank zur Tiefenanalyse von Verkehrsunfällen

INTRODUCTION

On average accidents at junctions make up 37% [13, 2010b, 18] of all road accidents with injuries. Various countermeasures for junction accidents have been developed. These countermeasures could be associated to the primary (collision avoidance), secondary (mitigation of injuries) or tertiary (post-crash treatment) safety. The main causes for the high density of accidents taking place at junction are misinterpretations and inattentiveness by the vehicle drivers at cross-over points. Misinterpretation means that the situation at junctions itself is perceived by the driver, but the individual interpretation is often ranked wrong. A typical example would be the misinterpretation of other vehicle's velocities. Furthermore the complexity of junctions tends to hinder the driver of visualizing potential threats. Exemplarily the driver's behaviour "looked" but "failed to see" is mentioned. Inattentiveness refers to the distraction of the driver from normal driving tasks, which often results in extended reaction times. Driving and the parallel use of a mobile phone is mentioned exemplarily. [11, 2012, 15, 2007b]

Reviewing the main causes for junction accidents allows formulating the basic requirements for an Intersection Assistant System. By approaching an intersection the information density a driver must process increases a lot. ADAS (Advanced Driver Assistance Systems) that use a variety of sensors to check surroundings support the driver in decision-making as well as taking counter measure for accident avoidance into effect. ADAS integrate semi- as well as fully autonomous intervention strategies to avoid collision or at least mitigate injury severity. Depending on a TTC (Time-To-Collision) approach different intervention strategies use characteristic threshold values for initiation. TTC refers to the time from the first opponent detection until collision. [11, 2012]

To evaluate the effectiveness of ADAS especially ICAS (Intersection Collision Avoidance Systems) several approaches in current literature exist. Each testing environment is distinguished itself by several advantages and disadvantages.

Possibilities to evaluate the effectiveness of ICAS

Statistical evaluation

In most countries statistical data of traffic accidents is collected at a regular basis by the police. If this data includes information of active safety systems e.g. ICAS conclusions can be drawn. Due to the very young history of ICAS, the density of accident data concerning these systems is still quite moderate. Therefore statistical data provides basic information, but a detailed evaluation of ICAS is often impossible. [5, 2010a]

Driving simulator

Driving simulators offer accurate adjustability and a high degree of repeatability to evaluate a diversity of possible accident scenarios. In addition they allow system tests in early stages of the developing process. The digital surrounding generation allows a variety of driving situations and system parameters to be tested and evaluated in detail. Limitations for the driving simulator refer to the drivability of the proband, because of the restricted threat awareness (Image and movement system). Furthermore the use of driving simulators requires a high amount of effort to prosecute Hard- and Software, scenario layout and illustration of vehicles and systems. [11, 2012, 12, 2006b, 19, 2010c]

Test phases on testing ground and real road traffic

Test phases on testing ground are compared to driving simulators closer to reality. Probands drive a vehicle without restrictions regarding sight and driving dynamics. Simple test scenarios need to be developed and proven to be repeatable and reliable. These tests require a high amount of effort to be illustrated in an effective non-threatening, but for the driver subjective critical situation. [11, 2012]

Virtual pre-crash simulation

Another approach to evaluate the effectiveness of ADAS is a virtual pre-crash simulation. The reconstructed accident using a trajectory based simulation software such as PC-Crash™ guides as the baseline simulation. All of these reconstructed accidents are calculated and simulated a second time but the vehicles are equipped with ADAS. Different sensors and intervention strategies can be applied separately. This simulation is called the system simulation. The evaluation of the effectiveness of ADAS uses an assessment function comparing the baseline with the system simulation. [4, 2008b]

METHODOLOGY

The method used in this study (see Figure 1) refers to the virtual pre-crash simulation. The baseline used to evaluate the effectiveness of ICAS emanates from real accidents at junctions taken from ZEDATU (Zentrale Datenbank zur Tiefenanalyse von Verkehrsunfällen) [6, 2007a] database. The numerical simulation software PC-Crash™ is used for the reconstruction of the real accidents from ZEDATU. ZEDATU uses a retrospective accident investigation approach [7, 2006a, 8, 2008c, 2, 2009].

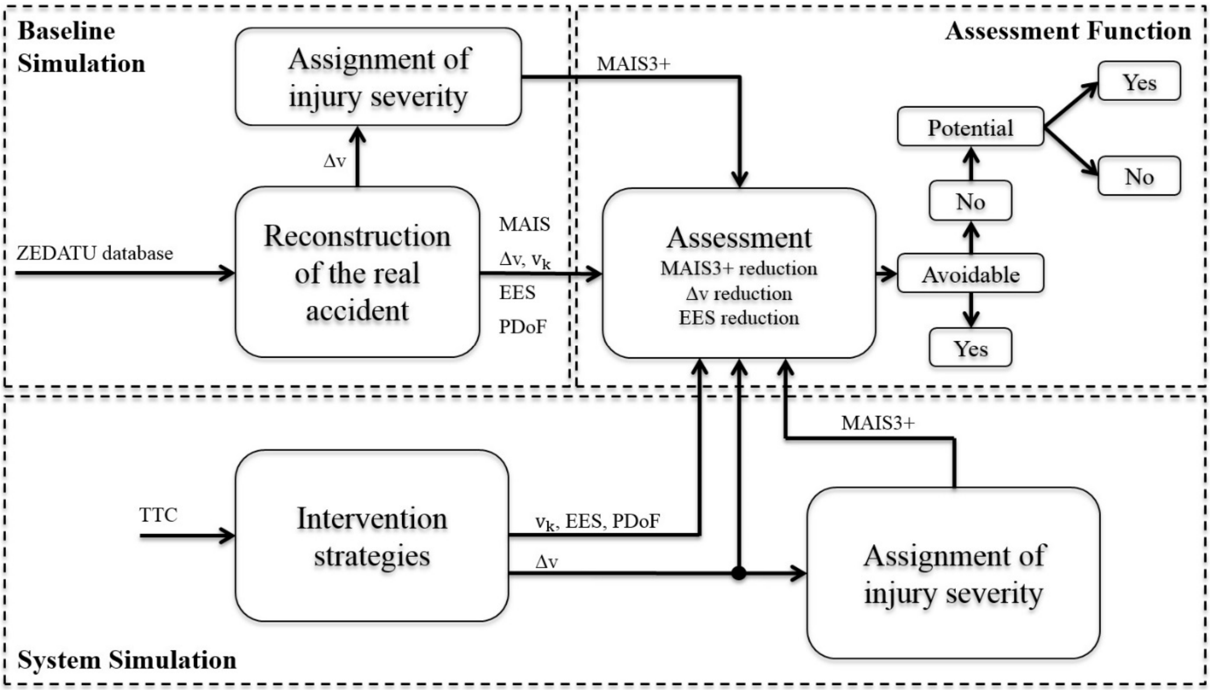

Figure 1. Virtual pre-crash simulation method

Baseline Simulation

The reconstruction includes the pre-crash phase for the involved vehicles using a forward and backward simulation. The forward simulation is used to calculate the delta-v, EES (Energy Equivalent Speed), etc. For the calculation of the crash phase the three dimensional momentum-based impact model [10, 1966b, 3, 1966a] has been chosen. This impact model allows a compromise between effort and accuracy. In the backward simulation the initial vehicle velocities and the trajectories of the participants are calculated to define the pre-crash phase. The reconstructed accidents in ZEDATU guide as the *"baseline simulation"*.

System Simulation

A backwards calculation from the impact point of approximately 5s or more is necessary to initiate a second simulation starting in the pre-crash phase. This simulation is called the *"system simulation"*. The system simulation builds up on the baseline simulation. An ICAS is now included in one of the involved vehicles. To evaluate the influence of ICAS on different vehicles, each vehicle gets equipped with ICAS in separate simulations.

To examine different ICAS with different intervention strategies the software tool GoFAST (Generic Sensor Effectiveness Assessment of Advanced Driving Assistance Systems Tool) was used. This tool allows to define specific system parameters (e.g. sight distance, angle of aperture, etc.) for the sensor as well as system manoeuvres and the TTC reaction point to initiate those manoeuvres. After defining the system parameters the system simulation can be calculated automatically within the PC-Crash™ simulation environment.

To allow a comparison of injury severity between baseline and system simulation the generic injury severity for the vehicle drivers is calculated on the basis of risk curves for the baseline as well as for the system simulation. Considering real accidents only, the injury severity for the vehicle passengers can be classified according to the AIS (Abbreviated Injury Scale) injury scale. The risk curves used for this study constitute a correlation between delta-v and the probability of a MAIS3+ injury severity for the vehicle drivers (see Figure 2). Exemplarily the results for the probability of a MAIS3+ injury severity for the vehicle driver are illustrated for a frontal collision in Figure 2. Comparing a delta-v of 60 km/h from a real accident (baseline simulation) with the delta-v of 32 km/h from a generic accident (system simulation) by using ICAS b) (see Figure 4), the probability of MAI3+ injury severity for the vehicle driver could be reduced from 98% to 24%.

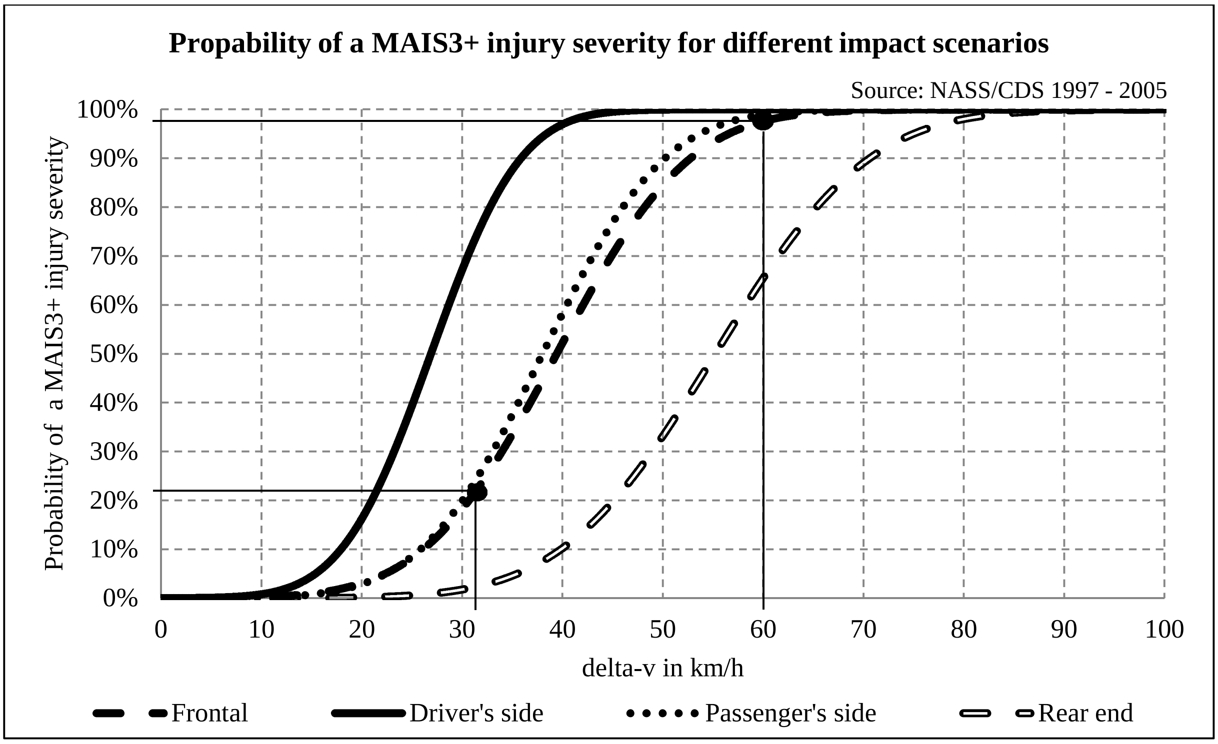

Figure 2. Relation between MAIS3+ and delta-v for the vehicle driver [14, 2011]

Sensor definition for surroundings detection

In the system simulations the vehicles have been equipped with a LRR (Long Range Radar) and three SRR (Sort Range Radar) sensors (see Figure 3). The sensors have only been implemented geometrically in the reviewed simulations. Detailed tracking and classification algorithms haven't been considered for this study. The detailed sensor parameters (sight distance and horizontal angle of aperture) are given in Table 1. Participants which enter the view cone of the sensors are identified. After a time frame of 100ms in the sensor view cone an intervention strategy is initiated in case of an appropriate value of TTC. If the detected vehicle has left the view cone at the intervention strategy initiation point, the system simulation has been aborted. It is assumed that the surroundings detection works ideal (e.g. no consideration of the material depending reflection of radar beams, no detection probabilities for different objects, etc.) and independent from external influences (e.g. weather, lightning conditions, etc.). [2, 2009, 1, 2008a]

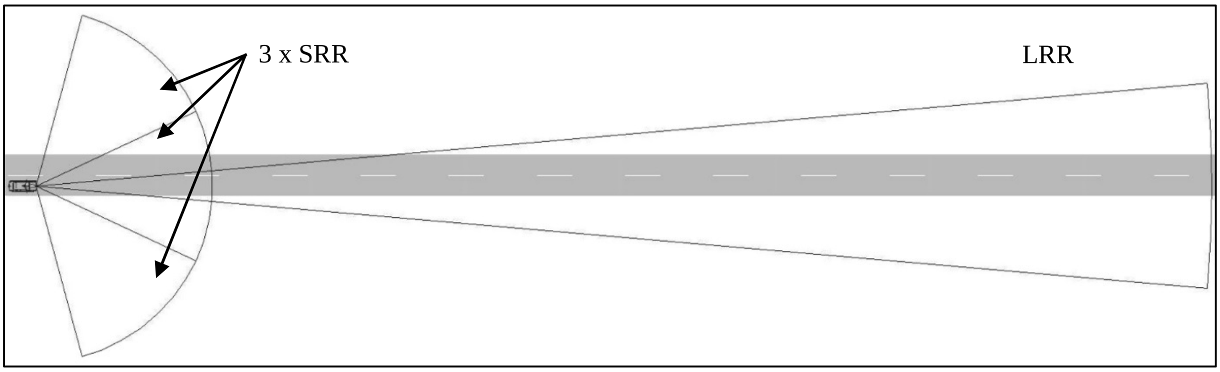

Figure 3. Sensors for surroundings detection

Table 1. Sensor parameters [16, 2006c, 9, 2008d]

Sensor	Sight distance	Horizontal angle of aperture
SRR	30m	50°
LRR	200m	10°

Examined intervention strategies for ICAS

Four different intervention strategies for an ICAS have been used and evaluated within the numeric simulation environment. For initiation, all four strategies refer to specific levels of TTC (see Figure 4).

a) **TTC = 2.6s:** It is assumed that the driver reacts with 0.8s reaction time on a warning signal (optical and haptic). After the reaction time the vehicle was decelerated with the maximum braking power without brake lag time.

b) **TTC = 1.6s:** The system starts to decelerate the vehicle with 50% of the maximum brake power to alert the driver. Again after the reaction time (0.8s) the vehicle was decelerated with the maximum brake force for the remaining 0.8s before stop or collision.

c) **TTC = 1.6s:** Again the system initiates a deceleration with 50% of the maximum brake power. In this strategy no reaction from the driver is simulated and the system keeps on braking with 50% brake force until stop or collision.

d) **TTC < 1.6s:** No reaction from the driver is assumed! When the vehicle reaches the TTC=0.8s limitation the system autonomously initiates an emergency braking manoeuvre until stop or collision.

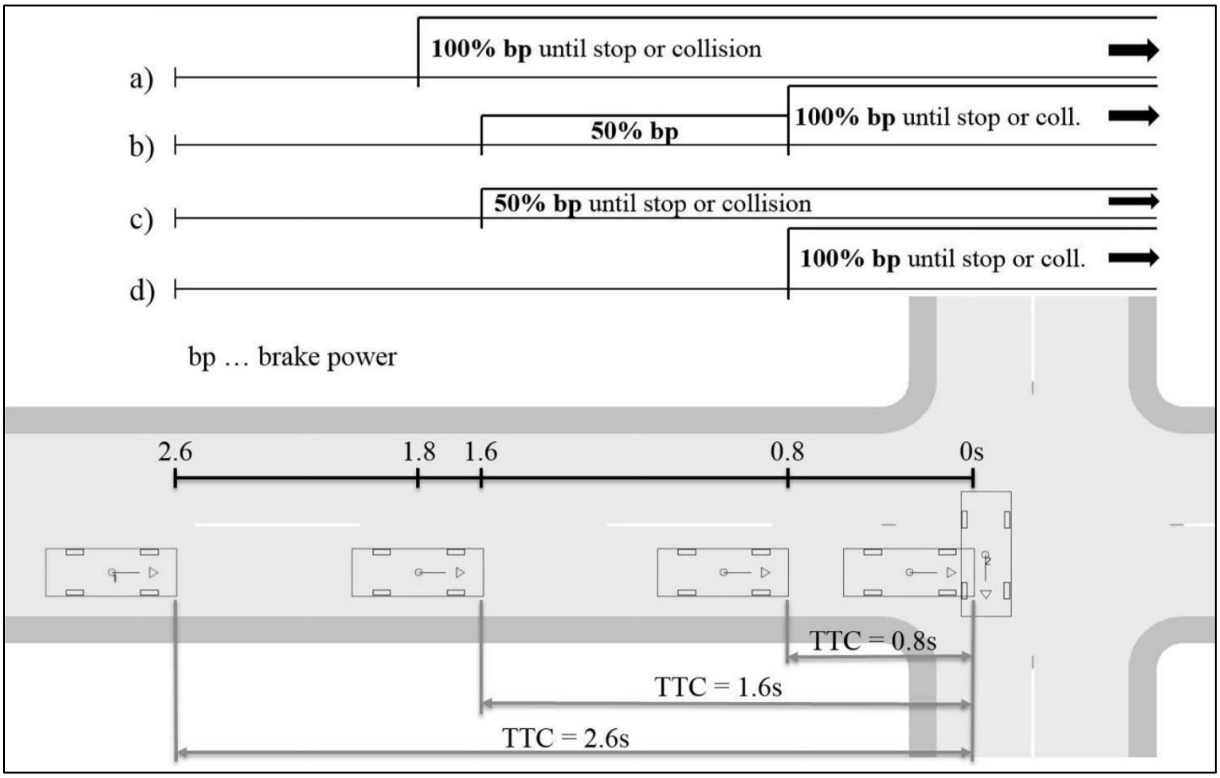

Figure 4. Examined intervention strategies for ICAS

Assessment Function

Basically the evaluation of the system effectiveness is based on a pre- post comparison between the baseline and the system simulation. If the ICAS included in the system simulation didn't contribute to avoid the collision between both vehicles, a potential of the examined system is calculated. The potential builds up on three parameters (delta-v, EES and MAIS3+). For each parameter the difference between baseline and system simulation is calculated. This comparison of delta-v, EES and MAIS3+ between baseline and system simulation indicates a positive or negative influence of ICAS on the circumstance of the accident.

LIMITATIONS

Currently ZEDATU only provides real accidents with at least one fatal injured road user. More precisely at least one road user either died because of the direct consequences of the accident or because of non-accident causal conditions (e.g. advanced age, heart attack, etc.). Therefore this study builds up on fatal road traffic accidents, while slight or severe road traffic accidents haven't been considered yet.

Moreover only traffic accidents at junctions between two cars, vans, small busses or lorries were taken from ZEDATU for evaluations concerning this study.

The risk curves for the assignment of injury severity (see Figure 2) origin from a finite amount of real accidents in different impact scenarios. Therefore slight variances between the actual AIS classification according to the real accident data and the generic probability of a MAI3+ injury severity are possible. Moreover it is mentioned that accident impacts have only been evaluated for the vehicle drivers.

View restrictions have been considered within the system simulations as far as possible. The transparency for radar waves of special objects (e.g. hedges, etc.) hasn't been included yet into the geometrical detection algorithm.

RESULTS

The following results build up on 44 reconstructed real junction accidents. At most each accident could include eight system simulations with results for both vehicles (theoretically 352 system simulation and 704 individual results at most). Depending on the individual calculated TTC for each real accident, ICAS strategies a), b), c) and d) have been integrated in separate system simulations. If TTC was calculated to a value of 1.7s, strategies b), c) and d) could be investigated in separate simulations exemplarily. Therefore ICAS a) couldn't be evaluated in this example, because ICAS a) requires a TTC of at least 2.6s or higher.

Figure 5 illustrates the absolute and cumulative frequency of TTC. Only accident cases with exact opponent detection were considered in this diagram. Theoretically each accident case results in two TTC values (system integration and evaluation for both vehicles separately). Therefore 88 results for TTC at most would be possible. Nevertheless in 10.2% of all reviewed cases the ICAS couldn't detect the opponent properly. The consideration of the absolute frequency reveals that about 50% of all examined cases took place within a TTC time frame of approximately 0.8 to 1.2s. In 92% of all examined junction accidents the TTC time frame was smaller than 1.8s according to the cumulative frequency. This result clarifies the comparatively small potential of Intersection Assistance Systems whose intervention strategies need TTC time frames bigger than 2s. The biggest TTC of all considered system simulations was calculated to 2.9s at a left turning scenario.

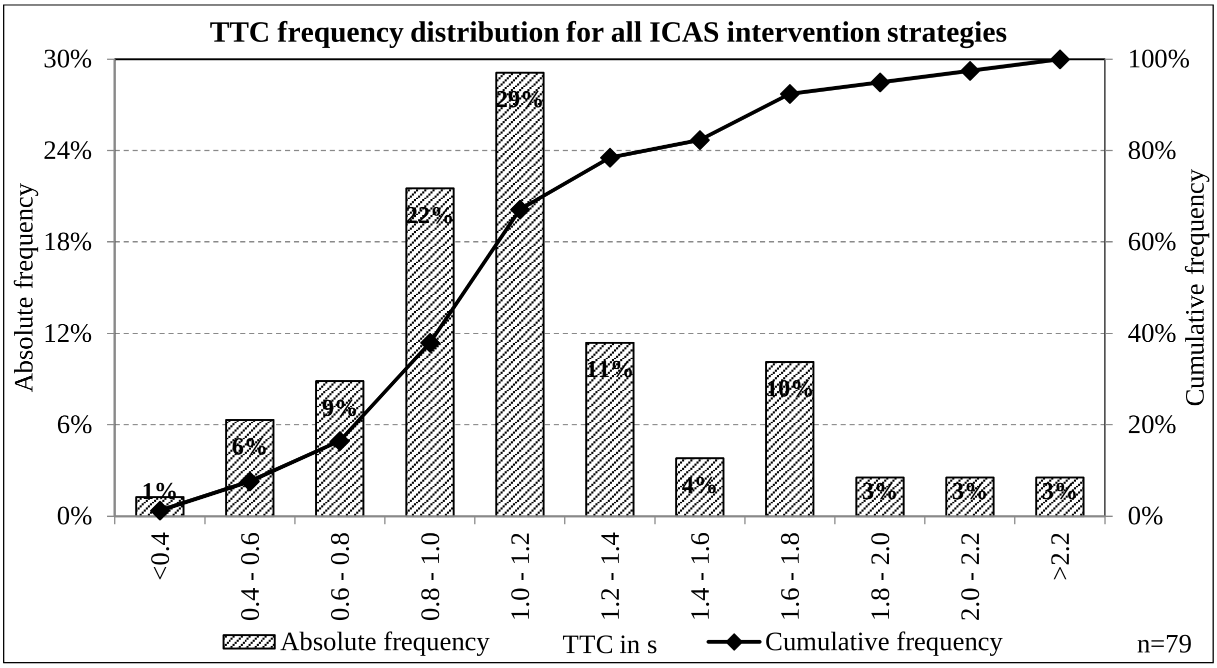

Figure 5. TTC frequency distribution for all ICAS intervention strategies

A comparison between the frequency distribution of baseline and system simulations for the Principal Direction of Force (PDoF) is shown in Figure 6 left. The PDoF classifies the direction of the impact force for the reviewed vehicle. The direction is defined according the clock face.

The evaluation of the system simulations revealed significant changes in PDoF. Through the integration of ICAS the impact force direction at 12 o'clock increased from 20% to 25% (see Figure 6). Furthermore the evaluation illustrates a distribution of the PDoF between 10 and 1 o'clock for approximately 80% of all examined junction accidents. Generally it was observed that the PDoF is moving towards more frontal impact forces i.e. PDoF of 12 o'clock. This change positively effects the probability of a MAIS3+ injury severity for the vehicle driver. The bigger crush zone of the vehicle front can absorb more deformation energy compared to the vehicle side and reduces therefore the probability of MAIS3+ injuries. The correlation between PDoF and the mean average delta-v for baseline and system simulations (see Figure 6 right) reveals a significant reduction of the mean average delta-v between 8 and 10 o'clock as well as between 1 and 4 o'clock. The highest reduction of mean average delta-v (23.2km/h) has been evaluated at 3 o'clock. In this study only junction accidents with frontal and side collisions have been considered. Therefore no correlation between baseline and system simulations concerning PDoF at 6 o'clock exists.

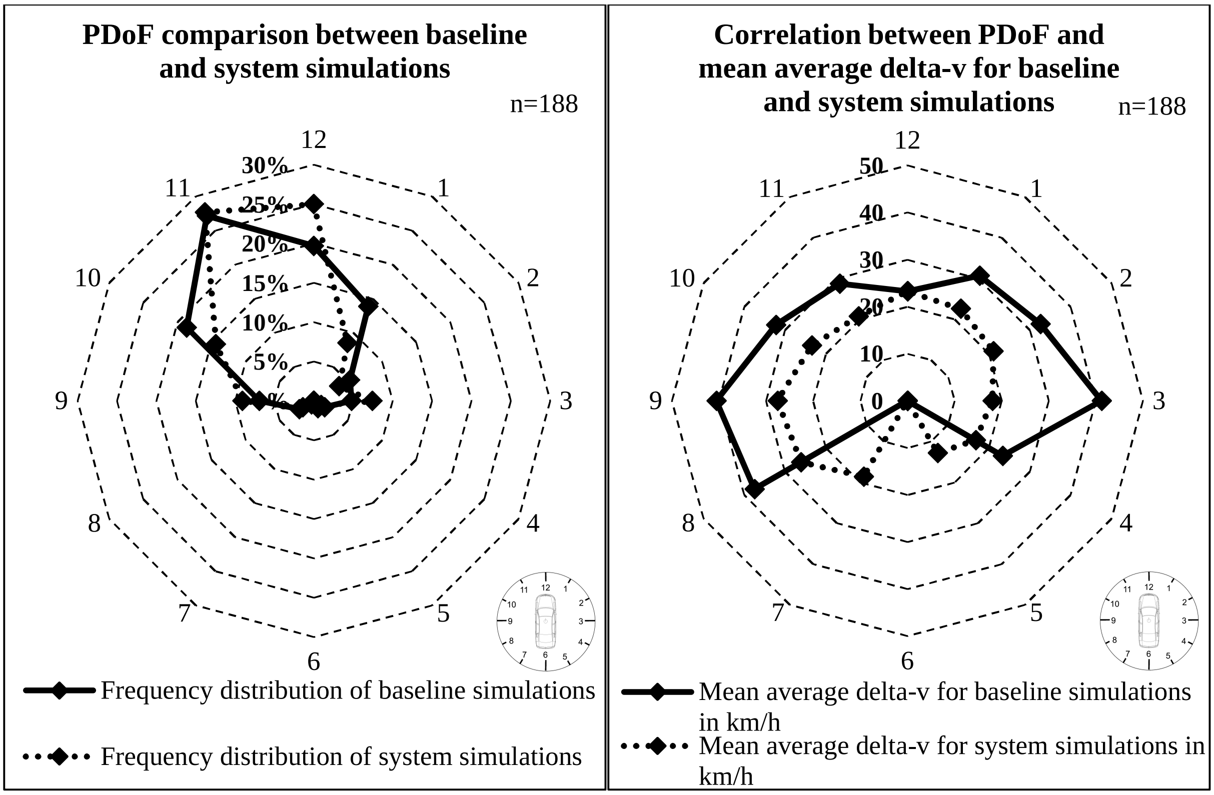

Figure 6. PDoF comparison between baseline and system simulations is shown in the left diagram. The correlation between PDoF and mean average delta-v for baseline and system simulations is illustrated in the right diagram.

The most important examined sensor system for the detection of other road users or objects is the SRR. In 43% of all investigated system simulations equipped with ICAS b) or c) the detection happened by using the SRR. In 29% of those system simulations the detection was performed by using LRR in combination with SRR. Considering ICAS d) the percentage of the SRR detection even rises up to 86% and 9% combination between LRR and SRR.

The evaluation of ICAS a) within the system simulations (Figure 7 left) revealed a mean reduction of the probability of a MAIS3+ injury severity of approximately 66% (MD=67.00%, SD=38.43%). Due to the high required value of TTC (>2.6s) the intervention strategy ICAS a) could only be integrated in 5% of all investigated junction accidents. However, each system simulation with TTC>2.6s has been avoided by integrating ICAS a). In 95% of all cases the opponent detection either happened at TTC<2.6s or no opponent detection happened (opponent didn't enter the sensor view cone or opponent left the view cone before system initiation). The intervention strategy ICAS b) reached a mean average reduction of the MAIS3+ injury severity of approximately 44% (MD=44.00%, SD=33.04%) and ICAS c) of 42% (MD=50.00%, SD=30.86%) according to Figure 7 left. System simulation with ICAS b) as well as ICAS c) allowed to avoid collision of approximately 10% of all examined cases. In 14% of the reviewed cases the collision could not be avoided by using ICAS b) or ICAS c), but the values for MAIS3+ were reduced significantly. The lowest mean average reduction for MAIS3+ was calculated for the intervention strategy ICAS d) with 30% (MD=19.50%, SD=31.06%). Nevertheless the highest potential considering injury mitigation was calculated for ICAS d) with 77% of all investigated cases. In only 11% ICAS d) did not contribute to reduce passenger's loads. Additionally it is mentioned that in some cases the values for MAIS3+ did increase although ICAS d) was integrated. Therefore the minimum value for ICAS d) (lower whisker) in Figure 7 left is negative.

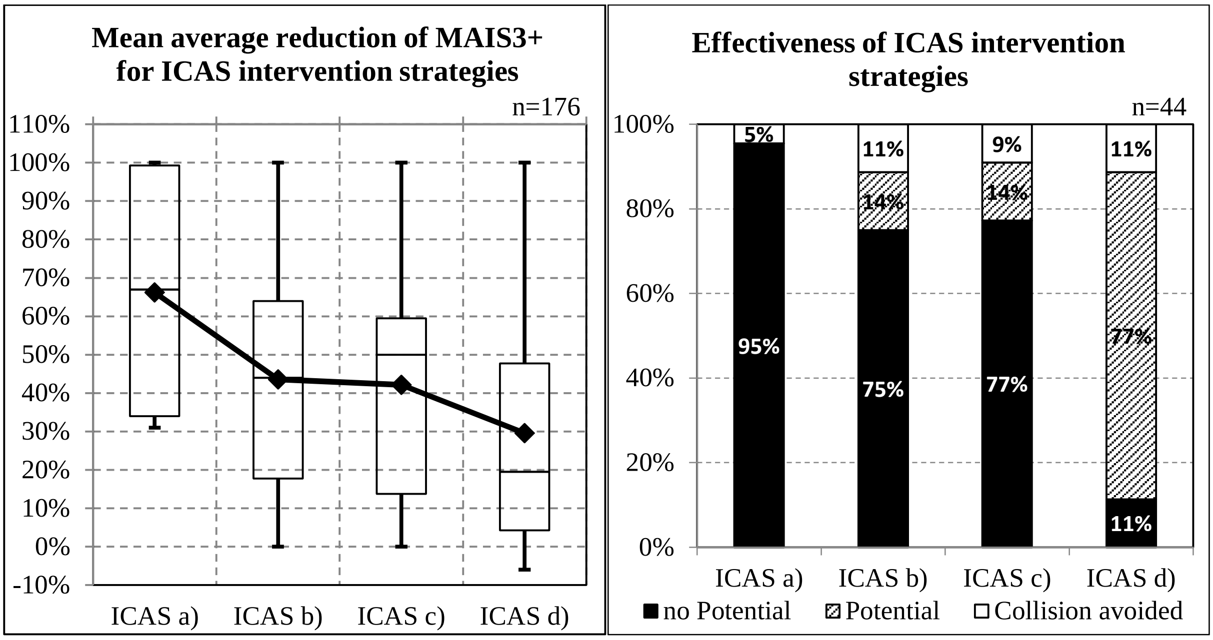

Figure 7. Mean average reduction of MAIS3+ and effectiveness for all investigated ICAS intervention strategies - The ranking of the effectiveness of ICAS intervention strategies in the left diagram refers to the height of the mean average reduction of MAIS3+ injury severity. The right diagram illustrates the effectiveness of ICAS intervention strategies concerning all reviewed junction accidents.

CONCLUSION & DISCUSSION

Intervention strategies that require a TTC>1.8s don't have a huge impact on the prevention of junction accidents or the mitigation of injury severity. About 90% of the evaluated cases had a TTC lower than 1.8s, because the opponent couldn't be detected earlier through the on-board sensor systems. To mention the short time frame before the collision, semi- as well as fully autonomous intervention strategies seem to be more appropriate than simple warning algorithms for intersection assistance.

In approximately 22% of all reviewed system simulations the probability of a MAIS3+ injury severity increased within the system simulations compared to the baseline simulations. In these simulations the opponent had more time to enter the danger zone, because of the system braking manoeuvres. Therefore collisions with more overlap and increased values for delta-v happened.

OUTLOOK

For further analysis of accident occurrence at junctions more detailed accident data is necessary. ZEDATU database was used to provide real accident data for accident simulations. Only accidents with at least one fatal injured vehicle passenger were considered for this study. Future evaluations should also consider real accidents at junctions with severely and slightly injured vehicle passengers. The effects of ICAS on road safety should also be investigated on trucks, coaches, motorcycles and pedestrians.

An interesting approach to increase road safety is C2C (Car-to-Car) and C2I (Car-to-Infrastructure). These systems could contribute to increase the functional range (on-board sensing systems) of existing ICAS to allow warnings on time or to enhance current intervention strategies. Today many unresolved issues (technical, standardisation, development, etc.) remain considering C2C and C2I. Nevertheless they will contribute to vehicle safety in future. [17, 2005] Therefore the assessment of potential in advance could support the further development of these systems. Further approaches for the assessment of the effectiveness of Intersection Assistance Systems could exemplarily consider traffic sign or traffic lights recognition and the consideration of transparent objects for radar waves (e.g. hedges, etc.).

ACKNOWLEDGMENT

This study is co-funded by the European Commission (7th RP Research Priorities) as part of the MATISSE (Modelling and Testing for Improved Safety of key composite Structures in alternatively powered vehicles) project.

REFERENCES

1. A Eichberger and E Tomasch: Retrospektive Bewertung der Effektivität unterschiedlicher Fahrassistenzsysteme bei tödlichen Verkehrsunfällen; Proceedings of VDI/VW-Gemeinschaftstagung; Wolfsburg, Germany, 2008a

2. A Eichberger, E Tomasch, R Rohm, W Hirschberg. Methodik zur Bewertung der Schutzpotentiale von Fahrerassistenzsystemen im realen Unfallgeschehen; Mechatronic Mobil, Volume: 1, Number 1, 2009

3. A Slibar. Die mechanischen Grundsätze des Stoßvorganges freier und geführter Körper und ihre Anwendung auf den Stoßvorgang von Fahrzeugen; Archiv für Unfallforschung, 2.Jg., H.1, 1966a

4. A Tapani: Traffic Simulation Modelling of Rural Roads and Driver Assistance Systems;Thesis/Dissertation 2008b

5. C Schmidt: Hardware-in-the-Loop gestützte Entwicklungsplattform für Fahrerassistenzsysteme;Thesis/Dissertation 27-8-2010a

6. E Tomasch: Entwicklung und systematische Verwertung einer In-depth Datenbank tödlicher Verkehrsunfälle; Graz University of Technology - Vehicle Safety Institute, Graz; Thesis/Dissertation 9-11-2007a

7. E Tomasch and H Steffan: ZEDATU – Zentrale Datenbank tödlicher Unfälle in Österreich – A Central Database of Fatalities in Austria; Proceedings of ESAR - Expert Symposium on Accident Research; Hannover, 2006a

8. E Tomasch, H Steffan, and M Darok: Retrospective accident investigation using information from court; Proceedings of TRA - Transport Research Arena; Ljubljana, 2008c

9. G Ma, D Müller, S-B Park, S Müller-Schneiders, A Kummert. Pedestrian detection using a single-monochrome camera; IET Intelligent Transport Systems, Volume: 3, Number 1, 2008d

10. H Kudlich: Beitrag zur Mechanik des Kraftfahrzeug-Verkehrsunfalls;Thesis/Dissertation 1966b

11. H Winner, S Hakuli, G Wolf. Handbuch Fahrerassistenzsysteme; Publisher: Vieweg+Teubner, GWV Fachverlage GmbH; 2012

12. J Breuer and W Käding: Contributions of Driving Simulators to Enhanced Real World Safety; Proceedings of Driving Simulation Conference; 2006b

13. J Broughton, J Knowles, and A Kirk: Traffic Safety Basic Facts 2010 - Junctions; 2010b, (Report)

14. K Digges: Research in Support of Enhanced Automatic Crash Notification. 8-3-2011

15. M Hoppe, R Zobel, and B Schlag: Identifikation von Einflussgrößen auf Verkehrsunfälle als Grundlage für die Beurteilung von Fahrerassistenzsystemen am Beispiel von Kreuzungsunfällen; 2007b, (Report)

16. S Luh: Untersuchung des Einflusses des horizontalen Sichtbereichs eines ACC-Sensors auf die Systemperformance;Thesis/Dissertation 2006c

17. S Tsugawa: Issues and recent trends in Vehicle Safety communication systems; 10-2-2005, (Report)

18. Statistics Austria: Accidents at junctions; http://www.statistik.at access to website: (2012)

19. W Käding and F Zeidler: 25 years driving simulator research for active safety; Proceedings of International Symposium on Advanced Vehicle Control (AVEC 2010); 2010c