GLOBAL HARMONISATION OF TEST PROCEDURES FOR DRIVER ASSISTANCE SYSTEMS

Frank Leimbach
DEKRA Automobil GmbH
Germany
Uwe Schmortte
Helge Kiebach
KTI GmbH & Co. KG
Germany
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ABSTRACT

INTRODUCTION

In the past, the vehicle brake developed in leaps and bounds. The initial two-wheel brake was upgraded to the four-wheel brake, which was followed by the brake force booster. The introduction of the ABS was a significant step in the further development of the wheel. For the first time it was possible to control the braking power at each individual wheel. The new, advanced driver assistance systems (ADAS) enabled the vehicle brake to go into action without the driver having to do anything. These advanced driver assistance systems can analyse individual traffic situations and, in an emergency, apply the brakes automatically if the driver is not paying attention. This action can reduce speed and therefore mitigate the consequences of accidents. Ideally, there will not even be a collision, because the ADAS slows the speed of the vehicle down to zero.

PRINCIPLES

Advanced driver assistance systems (ADAS) not only prevent accidents, they also make it possible to reduce the effects of accidents, for example by reducing the collision speed. There are various approaches which are able not only to warn the inattentive driver but also to apply the brakes automatically. The action of the ADAS depends on the traffic situation and the philosophy implemented in the design of the ADAS. In particular, the underlying philosophy is an important aspect.
If the system reacts very quickly with a warning, the driver is warned in good time. This warning is always based on a prediction of the behaviour of current road users and their movement parameters. These parameters can change and therefore the traffic situation can ease, so the driver does not get into any trouble.

If the system reacts very quickly by applying the brakes, a predicted collision is completely avoidable. In this case, too, the situation can ease, because the driver, instead of braking, initiates a steering manoeuvre. This steering manoeuvre may correspond to the normal traffic situation.

The earlier the warning or braking, the more uncertain the reliability of the underlying prediction. Warnings or automatic actions on the part of the system in situations which the driver regards as non-critical or in which the driver intends to take a different action can lead to problems of acceptance. It makes sense to gear the design of an ADAS towards actual occurrences of accidents which demonstrate situations in which drivers do not deal correctly with the traffic situation.

There are a number of activities currently underway to develop procedures to test ADASs. The purpose of these testing procedures is to demonstrate the functionality or effectiveness of the ADAS. A test standard is therefore needed which depicts the actual occurrence of an accident but which does not ignore the normal traffic situation in which the accident occurs.

Various companies and institutions have decided to work together to develop proposals for procedures to test selected ADASs. Allianz Zentrum für Technik, Audi, Bundesanstalt für Straßenwesen (The Federal Highway Research Institute – BASt), BMW, Daimler, DEKRA, Ford, GDV, Honda, KTI, Opel, Porsche, Toyota and Volkswagen make up the Advanced Forward-Looking Safety Systems Working Group (vorausschauende Front Schutz Systeme – vFSS). The aim of the Working Group is to develop proposals for forward-looking driver assistance systems which are based on real world accidents. The testing procedure is intended to be independent of sensor technology. The vFSS Working Group is currently focusing on systems for forward-looking pedestrian safety and longitudinal traffic safety when cars are involved in a frontal impact. In the future, other ADASs (lane departure warning, intersection assistance, etc.) will be included.

The vFSS Working Group used both published reports of EU projects and publicly available accident statistics from Germany, [1] [2] [3]. These were supplemented by analyses from the in-depth accident databases of GIDAS (German In-Depth Accident Survey), UDV (Accident research carried out by the insurer), AZT (Allianz Zentrum für Technik) and DEKRA.

FORWARD-LOOKING LONGITUDINAL TRAFFIC SAFETY

Traffic situations involving a conflict with the vehicle in front are normal in traffic. Only a tiny minority of these situations is critical and only a minority of critical situations ends in a collision.

Longitudinal traffic safety – accident analyses

The accident analysis findings given below are just some of a series of findings and describe the scale of the problem and the most important factors in rear-end collisions.

Analyses of German accident data from 2005 to 2008 show the significance of rear-end collisions. Longitudinal traffic accidents account for 39% of accidents resulting in minor injuries (serious injuries and fatalities 27% and 35% respectively). Longitudinal traffic accidents are the most frequently cited type of accident resulting in mostly slightly injured persons and the second most frequently cited type of accident resulting in fatally injured persons. A further subdivision of longitudinal traffic accidents results in an accumulation of collisions involving oncoming traffic resulting in mostly serious injuries and fatalities. The sub-group of accidents involving oncoming traffic accounts for just 9% of longitudinal traffic accidents resulting in fatalities and 11% of longitudinal accidents resulting in serious injuries. However, they account for almost two thirds (65%) of longitudinal traffic accidents resulting in minor injuries.

Analyses of GIDAS accident data show that, in longitudinal traffic accidents, only a small minority of drivers initiate rapid deceleration. Deceleration of at least 6.0 m/s^2 is demonstrable in under 28% of approaching passenger cars, Figure 1. A further circa 24% demonstrably did not brake and 24% executed only partial braking. It can be speculated that the driver was not paying attention and/or incorrectly assessed the situation. There is potential here for an appropriate driver assistance system.

- Driver-related accidents
- Turning
- Turning into or crossing intersections
- Crossing the road
- Accident as a result of stationary traffic
- Longitudinal traffic

In stationary traffic

- Vehicle moving forwards or waiting (depending on the traffic)
- Travelling in the same direction in parallel traffic
- Oncoming
- Leaving the carriageway
- Other kinds of accidents

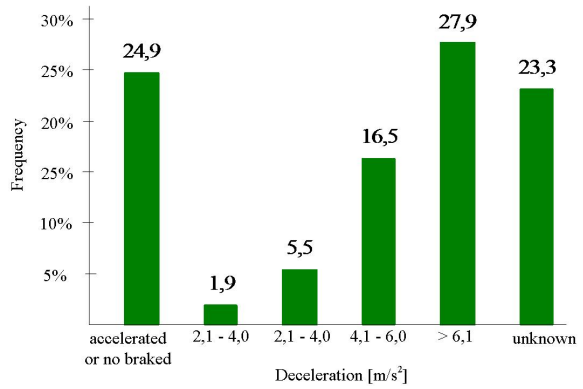

Figure 1. Distribution of brake retardation values of cars when approaching a two-track vehicle (data source: GIDAS).

An analysis of accident situations indicates three fundamental collision scenarios which, together, account for more than 80% of analysed collision situations. The scenarios are:

1. approaching a vehicle in front that is moving more slowly;
2. approaching a stationary vehicle;
3. approaching a braking vehicle.

The accident scenarios can be transposed directly into test scenarios. The proposal developed by vFSS contains these scenarios and suggests speeds for test conditions (Table 1). These test scenarios can essentially be identified in proposals put forward by other institutions working in this area.

Table 1.
Accident scenarios derived from GIDAS with proposed speeds for test scenarios

Scenario			Impacting (approaching) vehicle	Impacted vehicle
		100% = all rear impacts	Frontal impact	Rear-end collision
1	Approaching a stationary vehicle	46.6%	v0 = 50 km/h	v0 = vk = 0 km/h
2	Approaching a moving vehicle	14.1%	v0 = 90 km/h	v0 = vk = 45 km/h bv = 0 m/s²
3	Approaching a braking vehicle	22.4%	v0 = 50 km/h Distance to target D = 15 m	v0 = vk = 50 km/h bv = 4.5 m/s²

Longitudinal traffic safety – test constraints

Numerous constraints have always to be complied with when tests are carried out so that the results can be compared. An in-depth examination of the "standard constraints" is beyond the scope of this paper. Examples of standard constraints are ambient temperature, condition of the vehicle, appropriate choice of route, and others.

When accident scenarios are converted into test scenarios there are a number of contradictory aspects which are to some extent categorised differently by the various institutions working in this area. One possible aspect is keeping the planned tests to a strict minimum so as to save time and costs. Another aspect is sampling the widest possible range of speeds so as to demonstrate the efficiency of the tests as comprehensively as possible.

Another important aspect during testing is that of the warning. Should the warning be tested and evaluated at the same time? Essentially, the system should attempt to make the driver aware of the problem, if there is enough time. The warning must not come so early that the driver feels uncomfortable, categorises the ADAS as annoying and possibly switches it off. This could happen if the predicted situation fails to arise, but the driver has already recognised it in advance. A warning given less than 1.2 seconds before the calculated time to collision is ineffective, because the reaction time of the normal driver is no longer sufficient.

A very early warning may give rise to an undesired vehicle reaction, causing a problem both for the driver and for other occupants. Such braking manoeuvres can generally be overridden by the driver, but they disturb the driver and they could, in an extreme case, create a dangerous road traffic situation.

The target conflict depicted in Figure 2 between steering and braking in a critical situation is something which only the driver can resolve. At the indicated speed of 60 km/h a moderate braking process (6 m/s^2) needs approximately 18 m, and a moderate swerving manoeuvre can be carried out up to 12 m before the obstacle. The graph in 3 shows, for a deceleration of 6.0 m/s^2 an intersection point at approximately 30 km/h. Below this speed, the braking process is more relevant than steering for the prevention of accidents. The influence of humans is also of relevance. A sporty driver can prevent an accident at a later point through steering.

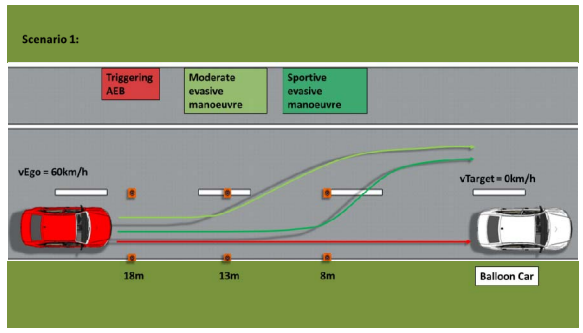

Figure 2. Presentation of the dilemma between braking and steering.

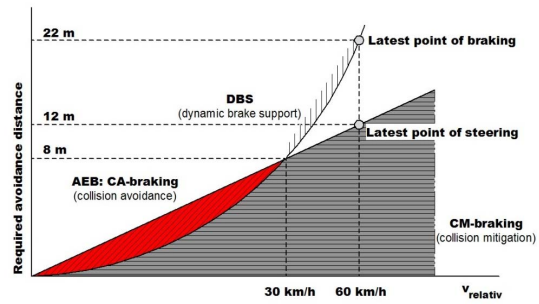

Figure 3. Theoretical resolution of the conflict between braking and steering (a = 6m/s^2).

Longitudinal traffic safety – development of suitable test targets

A defined target is required for a testing procedure. The target must be recognised by the driver assistance system regardless of the underlying physical principle. It should exhibit the physical properties monitored by the sensors.

The activities of vFSS also included actions to compare various targets. In comparative tests, the systems of vFSS members were supposed to react to various targets. Tests carried out by other institutions and those of vFSS showed that, in the implementation of a target for all sensor types, the properties of actual vehicles have to be reproduced exactly, so that all sensors have the same chances of recognising a target. Ultimately, a test is not intended to investigate how the vehicle reacts to the target but how the system in the vehicle behaves in real life. A target is also supposed to produce the radar reflectivity of an actual vehicle from slightly modified directions, while at the same time reproducing the optical properties (including the shadows cast). The properties should be reproduced in the target as accurately as possible. A radar echo that is too small is just as unfavourable as one that is too big. A reflector that is positioned too far inside

the target can lead to the ADAS assessing a situation incorrectly, thereby influencing the result of a comparison test. During target braking, the vehicle brakes too late or insufficiently.

Forward-looking pedestrian safety

Pedestrian safety has become increasingly important in recent years in vehicle safety in particular during the development of new vehicles. Initially, activities focussed on passive safety, the main impact of which was on improved vehicle front-end design in relation to accidents involving pedestrians. In recent years there have been clear evolutionary steps in the development of driver assistance systems. These were made possible as a result of, among other things, the new capabilities of sensor systems and the improved performance of processors in conjunction with advances in knowledge about the real-life occurrence of accidents involving pedestrians.

Pedestrian safety – accident analyses

Accident analyses are primarily based on German accident data. The results of the analyses are supplemented by available results from Japan and European projects [4][2]. Further results are available for the United Kingdom out of the EU APROSYS project [3].

In Germany, a total of 320,614 accidents involving pedestrians were recorded by the police in 2008. These accidents led to 413,524 injured people (4,477 fatally injured + 70,644 seriously injured + 338,403 slightly injured people). The majority of these people were injured during the day (n = 299,526), which is almost three in four. The share of people injured during the night is less than one third of the total number of injured people (n = 11,237). A detailed analysis reveals that almost twice as many pedestrians were injured during the day than during the night (22,272 during the day compared with 11,151 during the night)). The same analysis reveals an almost opposite result in the case of fatally injured pedestrians. While 256 pedestrians were killed during the day, 397 pedestrians were killed during the night.

The high share of pedestrians fatally injured during the night is not unique to Germany. According to European accident statistics a similar picture emerges throughout the EU [2]. In the 18 EU countries investigated, in 2007 more than half (52.6%) of fatally injured pedestrians were killed during the night. A specially developed analysis of accident figures from Japan reveals that a very high share (68.6%) of accidents in which pedestrians were killed occurred during the night. Overall, Italy, France, Spain, Germany, the United Kingdom and Poland are the nations with the highest number of fatalities in accidents involving pedestrians on European roads. Essentially, accidents that take place when pedestrians are crossing the road represent the most common accident situations. This is the case in Germany and in the United Kingdom in at least 75% of accidents involving passenger cars and pedestrians. Japanese analyses indicate a similar significance, albeit not quite the same significance as in Europe.

The results of the analyses carried out by GIDAS, UDB, AZT and DEKRA deepen the insights gained from the general statistics. The databases show virtually the same typical scenarios for accidents involving pedestrians and passenger cars. These scenarios include crossing the road with and without sight obscuration, turning-off situations (to the right or left) and pedestrians moving onto the carriageway in the same or opposite direction to the movement of the car (accident in a linear flow of traffic). All the analyses show that crossing the road without sight obscuration was involved in at least 60% of accidents. At least a further 10% was accounted for by pedestrians crossing the road with sight obscuration.

Table 2.
Absolute frequency of pedestrians injured and killed depending on the light conditions in Germany 2008 (source: StBA)

Germany 2008	Day	Night	Night : Day
Injured	22,272	11,151	circa 1:2
Fatalities	256	397	circa 8:5

Table 3.
Distribution of typical accident situations involving passenger cars and pedestrians, various sources

	Germany			United Kingdom		Japan
	GIDAS	UDV	AZT	STATS 19		?
crossing without obstruction	59.0	65.0	71	58.6	At least 75% of all accidents	36.5%
crossing with obstruction	27.4	12.0	13.2	17.9		0.4%
turning accident	6.9	23.0	15.8			(11.7%)
along carriageway in/against direction	2.1	8.0		11.1		11.9%

In 60% of accidents between passenger cars and pedestrians the front of the vehicle is the area of impact. An analysis of GIDAS data reveals, like the official statistics, a higher number of accidents occurring during the day and a higher share of fatal accidents occurring during the night. The consequences of accidents for pedestrians are generally more serious during the night. The accident analyses distinguish six typical scenarios. The first scenario describes a pedestrian approaching from the right who crosses the carriageway (adult, 1.72 m tall, v = 5 km/h). The speed of the passenger car is between 45 and 50 km/h. The driver reacts by initiating a braking manoeuvre.

In the second situation, the passenger car is travelling at between 55 and 60 km/h and the pedestrian approaches from the left and crosses the carriageway. The driver of the passenger car brakes before the collision. There are two variants of the scenario. Some of the accidents take place during the day and involve children running (height 1.2 m, v = 10 km/h), while some of the accidents take place during the night and involve adults walking (v = 5 km/h).
The third scenario is a left turn involving a pedestrian coming from the right in the side street. The passenger car is travelling at between 20 and 25 km/h. The adult pedestrian is walking. The driver of the passenger car brakes before the collision. The fourth scenario is a right turn. The passenger car is travelling round the bend at between 10 and 15 km/h. The walking pedestrian comes from the right. The driver reacts by initiating a braking manoeuvre.
The fifth scenario is similar to the first scenario. A running child (v = 10 km/h) comes out from behind a sight obstacle, while the car is travelling at between 45 and 50 km/h. The driver brakes before the collision. The sixth scenario replicates an accident on a secondary road. The pedestrian is walking along the edge of the road in the same or opposite direction to the passenger car (speed >70 km/h). The accident typically occurs when it is dark and very often ends with the pedestrian being very seriously injured.

An important aspect is the type of obscuration. An analysis of GIDAS data shows that sight was obscured in 42.7% of accidents between passenger cars and pedestrians, 30.5% of which were caused by a stationary vehicle.

Another important aspect is whether and how strongly the brakes were applied. The accident reconstructions in GIDAS were able to answer these questions in a good 80% of cases. Approximately 30% of all car drivers did not brake. A total of 34.9% (26.2%) of passenger cars involved in accidents during the day (during the night) braked at more than 6.0 m/s^2. Approximately 20% braked at up to 6 m/s^2. The generally somewhat weaker braking during the night, together with the higher start speeds, lead to higher collision speeds.

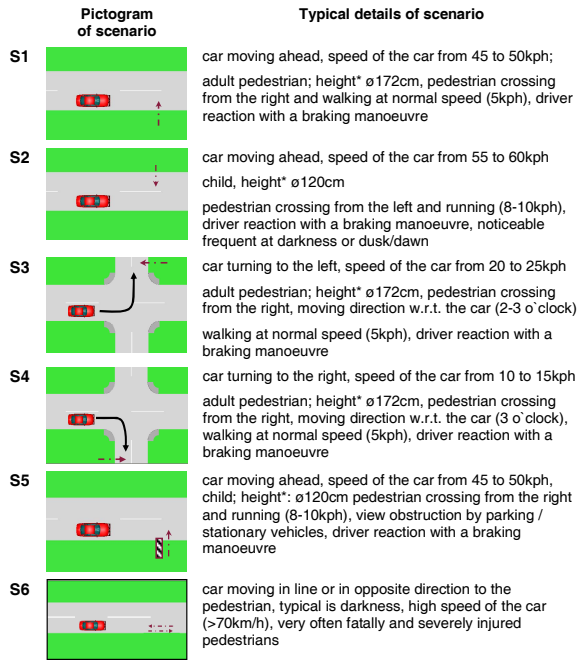

Figure 4. Typical scenarios of accidents involving passenger cars and pedestrians (source: UDV).

The analysis of the events leading up to an accident contains a time-to-collision (TTC) value, which reveals the time to collision under constant current constraints. When an object can first be recognised is important for driver assistance systems. In the case of accidents that take place when pedestrians are crossing the road, an analysis of these values shows that half of the objects (pedestrians) would have been visible and hence detectable as much as 3 seconds before the collision (Figure 5). Pedestrians that are clearly visible (without sight obscuration) would have been detectable 3 seconds before the collision in as many as 70% of cases. Obscured objects cannot be detected until the TTC = 0.9 seconds in 70% of cases. This is the limit value for the detection of pedestrians. At this point there does not need to be a call for reaction on the part of the driver and/or the assistance system. Not until there is a call for reaction, which there would be, for example, as soon as the kerb is crossed, should there be a reaction.
A particular feature of pedestrians who cross the carriageway is temporal avoidability, which is present under certain circumstances. In contrast to rear-end collisions, before the collision the pedestrian

is not always in the path of the passenger car. If the pedestrian arrives before the passenger car at the crossing point of the trajectories of both parties, he may have left it before the passenger car reaches it (Figure 6). If the passenger car arrives before the pedestrian it may have continued its journey before the pedestrian reaches the possible collision point.

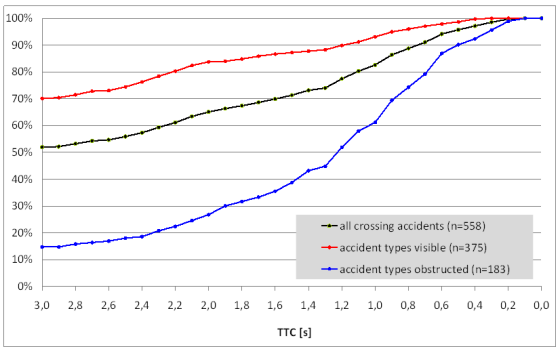

Figure 5. TTC values for the detection of pedestrians by the ADAS FAS (source: GIDAS).

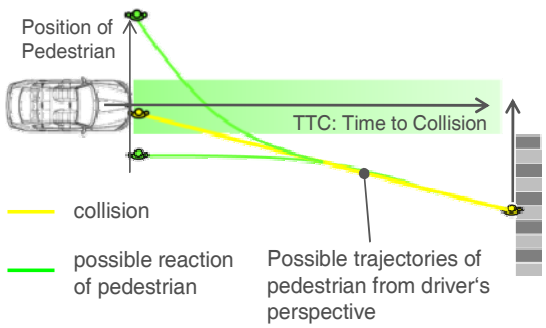

Figure 6. Possible trajectories of the pedestrian from the driver's perspective (source: Audi).

Pedestrian safety – derivation of test scenarios

The accident analysis contains a number of interesting findings. The task consists in implementing these findings in a testing procedure. One of the objectives of vFSS is to replicate the occurrence of an accident as comprehensively as possible with a limited number of tests. These tests should be designed independently of technology so that no system is disadvantaged. The accident scenarios shown above form the basis for this. Provided the ADAS to be investigated has a sensor arrangement that is symmetrical to the longitudinal axis of the vehicle, a test with a dummy coming from the right would be sufficient. Therefore, accident scenario S2 could be covered in a test that covers accident scenario S1.

Theoretical investigations of the turning scenarios S3 and S4 highlight the large number of parameters of the turning situation. These parameters include the speeds of the pedestrian and the passenger car, the cornering radius, the nature of the bend, the lateral displacement of the pedestrian at the starting position of the passenger car, the angle of opening and the position of the sensor (at the front of the vehicle or behind the interior mirror). In individual parameter combinations the pedestrian appears in the detection range of the sensor when the vehicle starts to turn, only to leave it, owing to unfavourable relative movements, before reappearing in the detection range shortly before the collision. In some cases, the pedestrian is not in the detection range of the sensor until shortly before the time of the collision (~0.1 s). At present no parameter combinations can be named which depict the event of the accident. No data is yet available on this. The parameter combinations of the theoretical considerations give different results depending on the combination. A slight change in parameter leads to significantly different results, which means that a system performance cannot be derived from it.

Accident scenarios S3 + S4 could also be seen as special cases of S5. When the vehicle is turning, the sensor can only recognise the pedestrian from a specific point. The effect of the turn would be that of a sight obscuration.

Scenario S6 does not pose a real challenge for the ADAS. A pedestrian who moves in the path of a vehicle without the relative transverse motion will be detected by the sensor. The system will react in a particular instance depending on the system design implemented.

On the basis of these arguments, what remains for a testing procedure is to replicate accident scenarios S1 and S5. In the new proposed procedure, the height of the pedestrian as well as the speed of the pedestrian and the passenger car are replicated in such a way that variations of these parameters are included. The vFSS Working Group proposes to use two sizes of pedestrians (child + adult) with two speeds (5 + 10 km/h) and a passenger car speed (40 km/h) for performance tests. These are supplemented by a preliminary test and a night test.

The actual performance tests consist of four test variants with TTC values of 1.3 and 2.7 s with two tests with and two tests without sight obscuration with a running child and a walking adult. A night test with defined lighting conditions shows whether the ADAS is able to act when light conditions are poor.

Should the ADAS react to the situation, this will open up the potential for this system to react in the case of accidents that happen at night, resulting in a higher potential benefit.

The preliminary test demonstrates, on the one hand, that the ADAS also functions at lower and higher speeds ($v_{passenger}$ car = 20 km/h and $v_{passenger}$ car = 50 km/h) than the speed specified for the performance test. There are also no-fire-tests to test the recognition of non-critical situations. They include a test with a group of pedestrians (adult + child) standing near the path of the vehicle and a test with a car passing a parked vehicle.

The tests replicate reality and the occurrence of the accident as far as possible. Dummies must exhibit the property or properties corresponding to the ADAS. In the case of an infrared sensor, the dummy that is used must have the body temperature that corresponds to that of a human. The test must not be limited to one or just a few physical properties of the dummy. If the ADAS uses the oscillating movement of the legs to recognise a pedestrian, the test must also be able to do so. The dummy used for the individual test does not have to exhibit all physical properties, just those that that correspond to the ADAS.
Two test variants are conceivable:

1. Test with contact between the dummy and the vehicle
2. Test without contact between the dummy and the vehicle.

vFSS favours the contactless variant. Shortly before the collision, the dummy is protected by means of a Dummy Rescue Manoeuvre (DRM). A DRM protects the vehicle and the dummy against damage. A repair costs time and money. The dummy does not have to be extremely light. The advantage of the variant involving the collision is that the test looks more realistic, which is also suitable for PR campaigns.

A further aim of the test is to ascertain the reduction in speed caused by the ADAS. This reduction in speed is synonymous with the benefit in the accident situation addressed by the ADAS. The injury-shift method that is already implemented continues to apply. The ascertained reduction in speed can be converted into a reduction in injury depending on the performance of the sensor (angle of opening, suitability for use during the night, etc). The conversion procedure is based on original accident data from GIDAS. The digital case files are calculated taking into account, amongst other things, the angle of opening of the sensor. Consideration is also given to the passive properties of the individual impact regions at the front of the vehicle [5]. The result is a set of curves which derives the reduction in the severity of the injury from the reduction in speed measured in the test depending on the parameters of the ADAS. The set of curves shown is only valid for one of several conceivable configurations. Each configuration has its own set of curves.

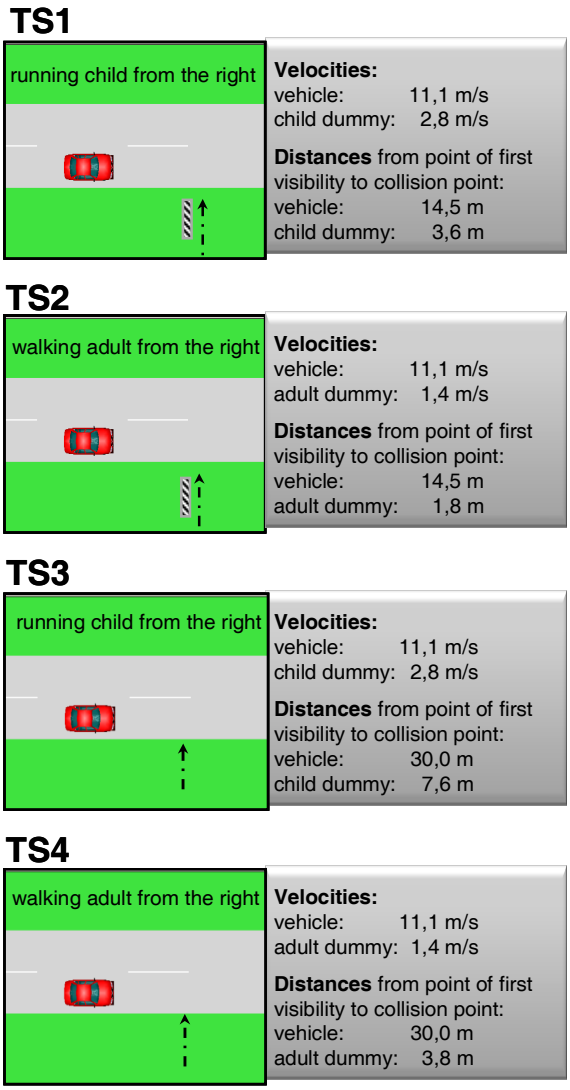

Figure 7. Test scenarios derived from an accident involving a passenger car and a pedestrian.

SUMMARY

The vFSS Working Group set itself the goal of developing proposals for procedures based on real world accidents that were independent of technology. The accident analyses reveal the importance of accidents in longitudinal traffic and of accidents involving passenger vehicles and pedestrians. Discussions were less about the basic accident scenarios than the different levels of importance attached to them internationally. The scenarios can, in principle, be played out anywhere.

There are six typical scenarios of accidents involving passenger cars and pedestrians and three scenarios for rear-end collisions.
In the three scenarios for rear-end collisions there are differences in speed of up to 40 km/h and a deceleration of 6 m/s^2. The three accident scenarios can also be replicated by means of test scenarios.

In the six scenarios of accidents involving passenger cars and pedestrians, the most common scenario is that of the pedestrian crossing the road. An important point to note is that considerably more accidents involving (injured) pedestrians occur during the day but the majority of fatal accidents take place during the night. Sight obscuration is implicated in a number of these accident situations. The six accident situations can be transferred to four test scenarios involving pedestrians of different heights (child and adult), pedestrians moving at different speeds (5 and 10 km/h), two TTC values (1.3 and 2.7 s), with sight obscuration included in some cases. The test speed of the passenger car is 40 km/h. In addition to the performance tests of the four test scenarios there are four preliminary tests with higher and lower passenger vehicle speeds (v = 20 and 50 km/h) and two no-fire tests. The test proposal also includes a night test to demonstrate the potential benefit of the ADAS. The test proposal is supplemented by a procedure based on the injury-shift method to convert the reduction in speed into a reduction in severity of injury.

The testing procedures must be geared towards actual occurrences of accidents, without neglecting the "normal accident situation". They must be system neutral so as not to disadvantage future developments. The targets applied must reflect reality so as to ensure that realistic results are achieved.

The international harmonisation of testing procedures is a major objective. In Europe a number of important institutions have exchanged ideas and information on harmonisation platforms on the topics of accident scenarios, target specifications and the evaluation of findings. The players are in general agreement with regard to scenarios and target specifications. Some questions remain unanswered, however, such as: Should the pedestrian be tested with or without contact? Should the TTC value, the speed, or both be varied? How is a warning function to be included in the evaluation?

OUTLOOK

A problem that has not yet been mentioned is the processing of the warning by the ADAS for the driver. No thought has been given here to the aspect of the optimal optical, acoustic or haptic signal. Hopefully, a driver will rarely encounter a situation where he receives a warning of an imminent rear-end collision or a pedestrian crossing the road. It is a moot point how appropriately the driver will react to this warning despite the rarity of the event if he has, at some point in the past, internalised the reaction as: "This signal is warning me of a rear-end collision or a pedestrian."

Another important aspect which will be certainly discussed more in the future is Periodic Vehicle Inspection (PTI). Driver assistance systems which are already on the market or will be put on the market in the future must be regularly checked in order to ensure that they are functioning properly and correctly. The aim must be to develop a standardised and harmonised procedure.

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