

EVALUATION OF THE EFFECTIVENESS OF VOLVO'S PEDESTRIAN DETECTION SYSTEM BASED ON SELECTED REAL-LIFE FATAL PEDESTRIAN ACCIDENTS

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ABSTRACT

The objective of this work is to test freely available system for active pedestrian protection. Tests are based on real fatal accidents that happened in the past with passenger cars that were not equipped with active safety systems. Tests have been conducted in order to evaluate what the real benefit of the active safety system is, and not to gain only a methodological prediction. The testing procedure was the first independent testing in the world which was based on real fatal pedestrian accidents. The aim of the tests is to evaluate the effectiveness of Volvo pedestrian detection system.

An in-depth accident database contains about 300 fatal pedestrian traffic accidents in urban areas. Eighteen cases of pedestrians hit by the front end of the passenger vehicle were extracted from this database. Cases covering an average traffic scenario have been reconstructed to obtain detailed model situations for testing. Simulations of accidents have been made in PC Crash 10.0 using a multibody object and a mesh model of vehicles. Active safety testing scenario was built on the basis of reconstructed accidents with Volvo V40 cc and a new dummy simulating a pedestrian. Before the tests the dummy was evaluated in anechoic room to gain required radar reflection properties which would be the same as those of a human body. The movement of the dummy was driven by the autonomous ultraflat overrunable robot (UFO) for experimental ADAS testing and synchronized with Volvo motion by D-GPS with high accuracy of motion.

INTRODUCTION

The study is based on the measurements made under the leadership of Peter Vertal' in 2014 in Linz, Austria, in cooperation Institute of Forensic Engineering Brno University of technology, Vehicle Safety Institute Technische Universität Graz, DSD Dr. Stefann Datentechnik and Institute of Forensic Engineering University of Zilina.

SOFT DUMMY

The most important element in the experimental measurement of the conditions for the activation of the pedestrian detection system is a dummy representing a pedestrian. For the purposes of this paper, a pedestrian's movement was simulated using a dummy placed on an autonomous platform. The platform called "UFO" had a built-in D-GPS module for orientation in space and it was powered by two servomotors. The pedestrian dummy placed on the UFO platform had to undergo an evaluation process. The evaluation process guaranteed the achievement of the required reflective properties of the dummy identical to the human body. The reflective properties of the dummy for the short-range 24 GHz radar had to correspond to the reflective properties of the human body in order to avoid confusion of the dummy for an object that does not correspond to the properties of the human body.

For the purposes of reconstruction and expert activities related to the analysis of accident events, it was necessary to evaluate and re-create an ideal dummy whose reflective properties correspond to those of the human body. For the purposes of this paper, three basic positions of the dummy were determined that had to be evaluated by measurement for the subsequent use. The position of a standing person facing the radar source, the sideways

position and the position of a standing person with the back to the source. The dummy's positions were compared with the reflective properties of a test subject. For the purposes of this paper, the simulation involved only dry-weather conditions without the presence of significant moisture on the clothing of the pedestrian/dummy. During the measurements, it was necessary to compare the properties of the dummy with a human who is undressed, partially dressed and dressed in several layers in order to take into account all possible conditions of the pedestrian-car system.

Figure 1 shows a comparison of an empty anechoic chamber, with a test subject, a dummy before adjustments and after adjustments. The graph shows that the dummy without adjustments has approx. 15 dB lower values of reflection properties. The adjustments of the dummy resulted in identical properties to those of the human body. The value approx. 50 dB matches the test subject's value.

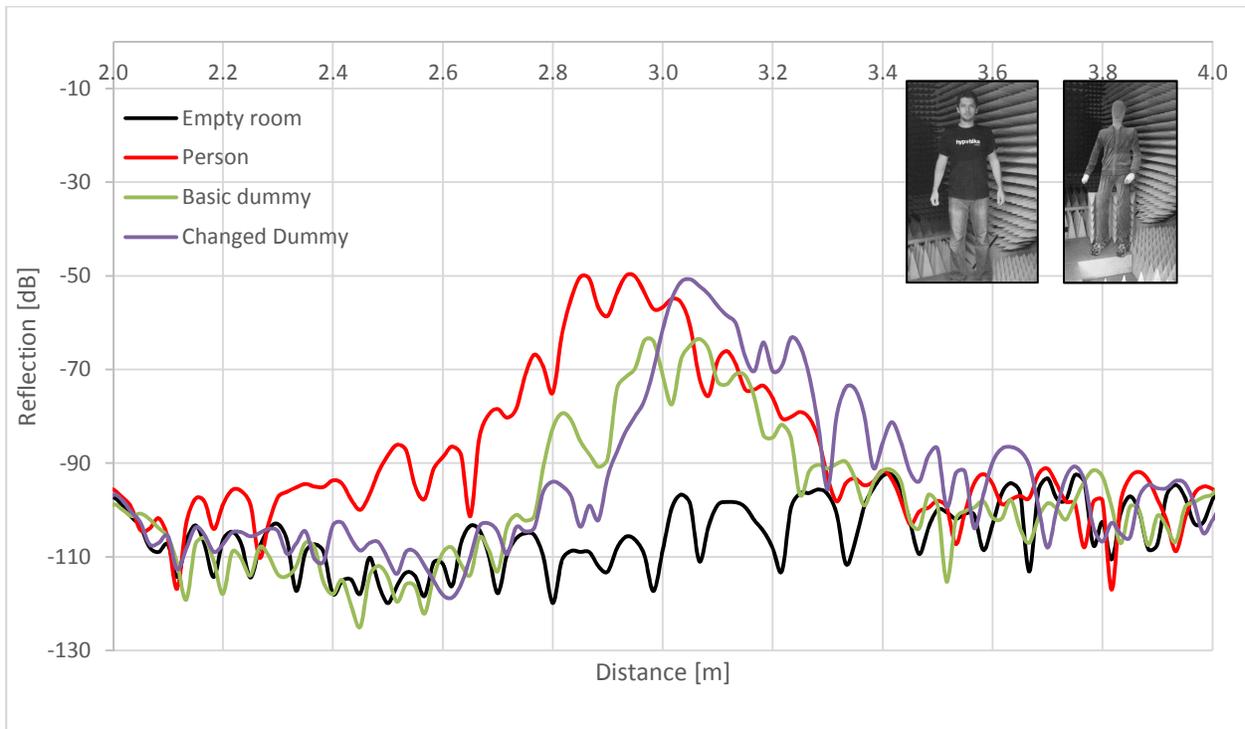


Figure 1 Reflection of the person, basic dummy and changed dummy in anechoic chamber.

After an in-depth analysis and measurements made in the anechoic chamber, it was possible to finalise the form of the dummy. During the experimental measurements, the dummy was adjusted using adhesive aluminium tape. The use of the aluminium tape increased and decreased the intensity of the reflected radar waves. After repeated measurements, tests and adjustments of the dummy, it was possible to create a dummy whose intensity of the reflected radar waves corresponded to the human body. This dummy was used for the experimental measurements with a Volvo vehicle.

PROCESSING OF THE RESULTS

The measurements consisted of a series of tests based on selected real traffic accidents. For a complete test of the active safety system, it was necessary to choose accidents where the movement of the vehicle and the pedestrians cover the entire range of traffic accident situations. A full overview of the case studies and vehicle speeds at the time of collision resulting from the analysis of the accident studies is shown in Tab.1. Tests were performed under the conditions corresponding to the five characteristic types of traffic accidents with pedestrians. During the measurements, the following traffic situations were simulated: a pedestrian crossing the road in the perpendicular direction, in the oblique direction and in the direction towards the vehicle, a pedestrian standing on the roadside, a pedestrian coming from behind an object, a lying person, day and night conditions and situations combining the above.

Table1. Overview of vehicles from traffic accidents and pedestrian motion

Case	Brand	Model	Registration year / Accident year	Impact velocity +/- 10% (km/h)	Direction of a pedestrian motion	Pedestrian age (years)
1	Opel	Astra	1999 / 2003	23 - straight	→	W 69
2	Citroen	AX	1990 / 2003	47 - straight	→	W 71
3	Opel	Corsa	1990 / 2003	12 – cornering L	←	W 78
4	Peugeot	306	1994 / 2003	50 - straight	→	M 96
5	Volvo	S70	1997 / 2004	32 - straight	→	W 89
6	VW	Multivan	1989 / 2004	19 - straight	←	W 84
7	BMW	3	1995 / 2004	41 – cornering L	←	M 91
8	Honda	Civic	1990 / 2005	55 – overtaking R	→	M 43
9	VW	Sharan	2006 / 2006	18 – cornering R	←	W69
10	VW	70D	1993 / 2007	39 - straight	standing	M 12
11	Mitshubishi	Pajero	1992 / 2008	32 - straight	←	M 61
12	Ford	Transit	1999 / 2004	36 – cornering L	→	W 45
13	Toyota	Avensis	2001 / 2003	45 - straight	lying	W 62
14	Mazda	Demio	1999 / 2004	42 - straight	↘ 30 °	M 81
15	Renault	Twingo	1993 / 2004	46 - straight	↘ 60 °	W 77
16	Opel	Corsa	2003 / 2004	39- straight	→	M 28
17	VW	Passat	1993 / 2005	30 - straight	→	W 92
18	VW	Transporter	2000 / 2005	47 - straight	↙ 15 °	M 84

The analysis of the data was used to identify the moment prior to a vehicle's contact with a pedestrian of the initial acoustic and visual warning of the driver against a potential barrier in the direction of the vehicle's movement. The measurements identified that the acoustic signal is always activated together with the visual warning. The visual warning of the driver is accompanied by a flashing light alarm which is located between the speedometer and the windscreen. It is a place with very good visibility for the driver. The light strip is approx. 15 cm long and its size is sufficient to alert the driver.

During the initial measurements, the vehicle was tested for the detection of pedestrians in the setting sun, i.e. when the sun is low over the horizon and dazzles the driver and also the camera. The measurements showed that when the sun is low over the horizon (15° and less), the functionality of the system will not deteriorate when driving in the direction of the sunlight ± 30 degrees (measured range) from the direction of the vehicle's movement.

Night measurements with no light source other than the vehicle's lighting showed that the system is unable to detect and react to a pedestrian. The system is able to detect a pedestrian at night up to the speed of approx. 20 km/h and brake subsequently. The system activates and identifies this manoeuvre based on a barrier (vehicle) and not based on the detection of a human figure. This fact was supported by a message "City Safety was activated", which appears upon the system's activation based on a critical situation ahead of the vehicle due to the presence of another vehicle. This conclusion follows from the functionality of the City Safety system, which is designed for driving the vehicle in traffic jams at low speeds, where the system reacts to objects or vehicles in the vehicle's traffic corridor and not to pedestrians.

During the tests with a lying dummy, the system was not activated in any event. The technical manual of the vehicle states that the system reacts to figures taller than 80 cm.

An Example Case Study Analysis

The study includes the acceleration curve derived from the measured data. It was subsequently converted to a video sequence which simplified video evaluation. It involved a vehicle moving at the speed of approx. 47 km/h at the time of the real collision. A pedestrian moving at approx. 4 km/h entered the vehicle's corridor from the left. The vehicle and the pedestrian were synchronised based on the result of an exact simulation of the PC Crash 10.0 programme. The visual representation of the course of case study No. 2.

1. The simulation started at the moment of a vehicle's passage through the light gate 5 s and 70 m before the collision with a pedestrian. The dummy is still standing at this moment. At the moment of the vehicle's passage through the light gate, UFO's control unit evaluates the right moment for the activation of UFO (pedestrian) based on the current speed of the Volvo vehicle.
2. The vehicle moves on at a constant speed of 47 km/h and at the time 4.3 s before the collision with the dummy, UFO is activated with an acceleration of 1 m/s^2 . A fully automated and synchronised action reproduces a real accident.
3. At the time 2 s and 19 m ahead of the dummy movement corridor (Fig.2), the acoustic and visual warning of the driver is activated at the moment when the dummy is located at a distance approx. 0.7 m from the movement corridor of the Volvo vehicle driving at approx. 45 km/h. The Volvo does not brake autonomously at this moment.

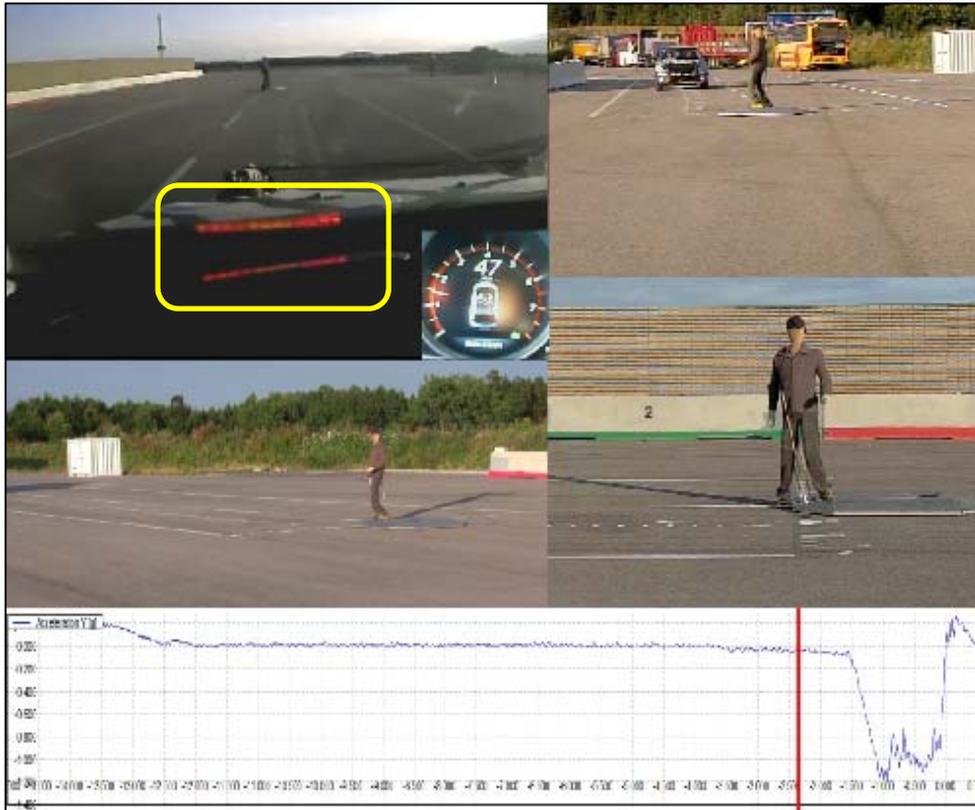


Figure 2 Activation of the visual and acoustic alarm

4. After less than 0.8 s from the activation of the alarm, the autonomous braking of the vehicle is activated at a distance of approx. 13 meters from the pedestrian movement corridor (Fig. 3). The vehicle brakes with an average deceleration of approx. 10 m/s^2 . The driver did not interfere in the vehicle's driving when the autonomous braking was activated. During the autonomous braking, the brake pedal goes down to the floor as with normal braking.

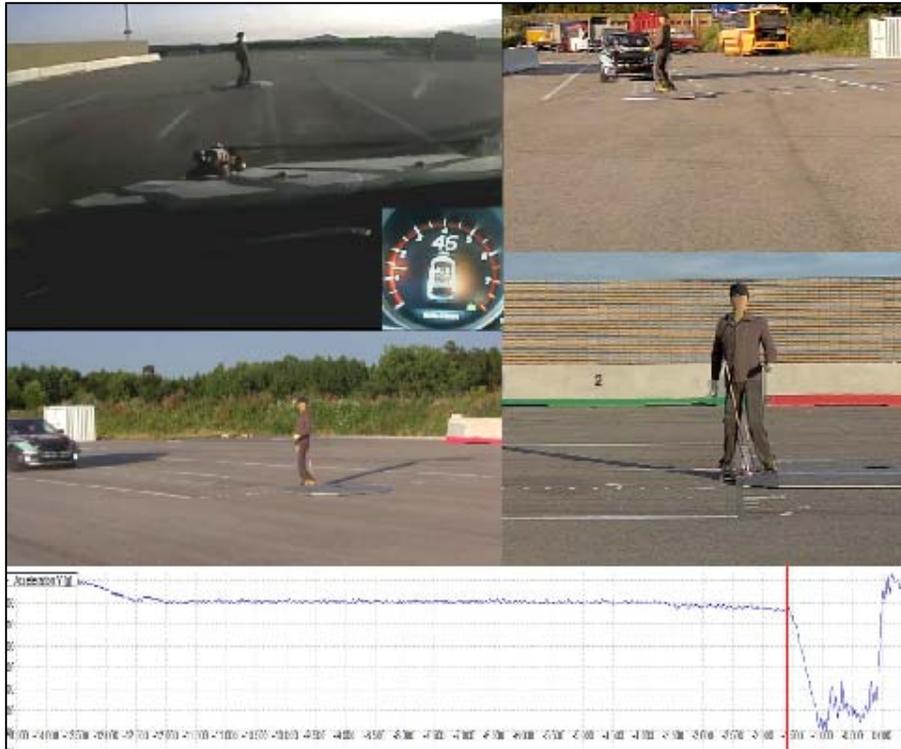


Figure 3 Beginning of the autonomous braking

5. After approx. 2 seconds from the initial acoustic signal, the vehicle collides with the dummy. The speed at the time of collision (Fig. 4) was approx. 12 km/h (base on acc and GPS) compared to 48 km/h in the real accident where the driver fails to react to a pedestrian.

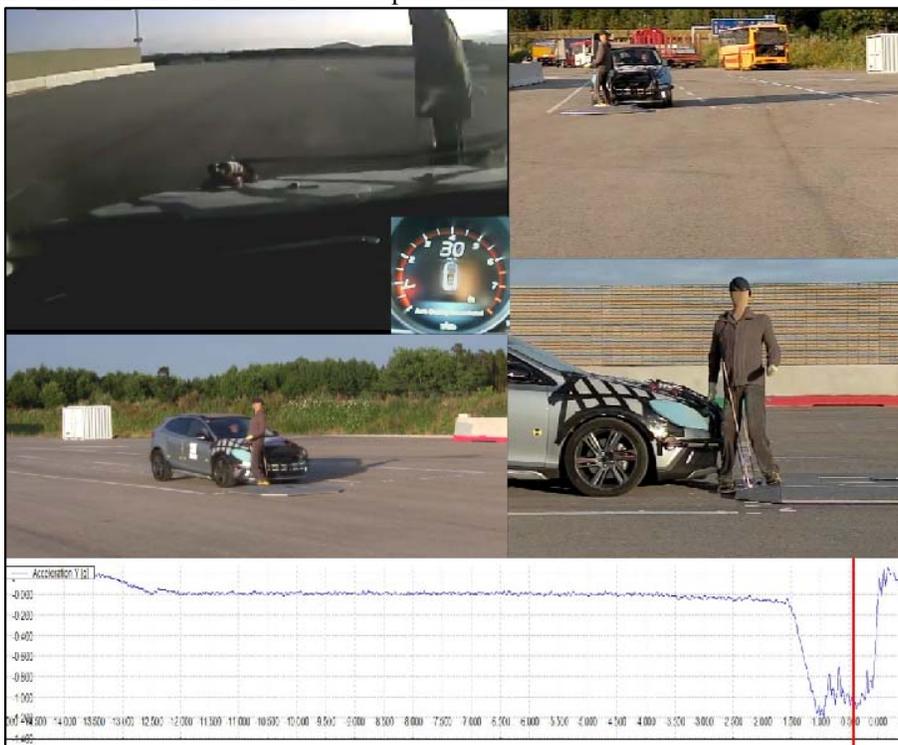


Figure 4 Time of the first contact with dummy

The course of the tested study allows us to clearly describe the entire accident depending on the time and distance of the vehicle from the dummy. If there was a collision with a pedestrian (a person weighing more than 15 kg), it is quite possible that the contact with the person would activate the active bonnet. This action would expand the clear space between the components in the engine compartment and the bonnet, which would contribute to a reduction in the pedestrian's injuries caused by solid parts. It is unlikely and questionable that the pedestrian airbag would be activated because the vehicle's speed at the moment of collision with the pedestrian was only approx. 12 km/h. These hypotheses are potential objectives for future research steps of the author of this paper.

Acoustic and Visual Signalization of the System

The analysis of the recorded data showed that in 69% of cases where the vehicle detected a pedestrian and evaluated it as an obstacle – “pedestrian”, the driver was warned in time intervals before the collision with the pedestrian. The driver was warned more than **1 second (1-2,0s)** before the collision in nine case studies from the total number of measurements. It is a matter of further research to determine what is the time required for the driver's reaction to this alarm and the subsequent driver's action (dodging, braking etc.).

From the forensic point of view, it is important to identify the dependence of speed, distance and time of activation of the acoustic and visual alarm. In some case studies, the alarm was activated nevertheless a vehicle collided with a dummy. For a more accurate representation of the dependence, Figure 5 distinguishes the conditions for the activation of the alarm depending on the dummy's crash into a vehicle's outside corner, the middle or the inside corner. Except for one case, the points shown in the graph represent a vehicle driving straight. It is technically feasible that when driving in a curve the system's behaviour depends on the turn radius; hence, it may react to a dummy earlier.

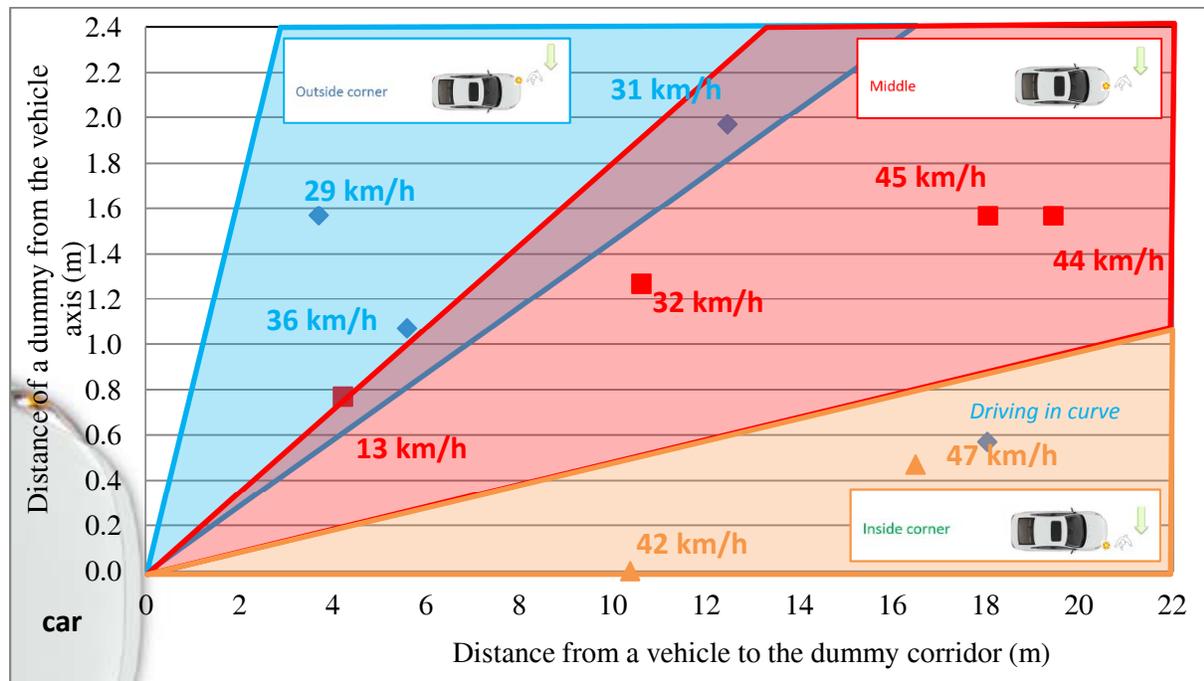


Figure 5 Activation of the alarm depending on the speed and distance of a vehicle from the dummy's movement corridor, distance of the dummy from the vehicle axis and the subsequent contact of the vehicle with the dummy (the inside corner, the middle of the vehicle or the outside corner)

Autonomous Braking of the System

Autonomous braking of the vehicle occurred in 63% case studies after the lapse of the acoustic warning of the driver. The time interval from the system's first acoustic and visual reaction until the initial moment of braking ranged from **0.1 to 0.8 seconds**. Braking was initiated without prior acoustic warning in one study case.

The measurements showed that the driver's sharp intervention with the vehicle's control at the time of warning or braking ends the process of warning and autonomous braking. It is the objective of further studies to determine what time interval after the initial warning is necessary for a distracted driver to react to objects in the driving corridor and, subsequently, to make the right manoeuvre to avoid collision with such object.

BENEFITS OF AUTONOMOUS BRAKING FOR THE COURSE OF AN ACCIDENT EVENT

The analysis of the test studies identified that Volvo's pedestrian detection system in Volvo V40 of the model year 2014 can stop the vehicle autonomously in front of a pedestrian at low speeds up to 30 km/h if the pedestrian's movement is sufficiently predictable and the system is able to monitor the pedestrian with no object impeding the camera's view of the pedestrian. It is necessary to note in such cases where the system can stop the vehicle from low speed that there is no jump or a sudden change in the direction of the pedestrian's movement towards the road. At speeds above 30 km/h, there is always a significant reduction in the vehicle's speed before the actual collision with a pedestrian, but by a maximum of approx. 30 km/h compared to the vehicle's speed at the time of the initial reaction of the system. The overall summary of the reduction in speed as a result of the vehicle's autonomous intervention is shown in Table 2.

Table 2 Decreasing of velocity the Volvo car during simulated scenarios

Case no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Obstacle in driver view	yes			yes				yes									yes	
Motion of the car	streight	streight	cornering L	streight	streight	streight	cornering L	overtaking R	cornering R	streight	streight	cornering L	streight	streight	streight	streight	streight	streight
Impact velocity in crash accident (km/h)	23	47	12	50	32	19	41	55	18	39	32	36	45	42	40	39	30	30
Alarm		yes	yes	yes	yes	yes	yes			yes	yes			yes		yes		yes
Alarm before the crash (s)		2,0	1,0	1,7	1,5	0,5	1,6			1,9	1,5			1,1		0,6		1,5
Decreasing of the velocity (%)	0	74	100	48	0	0	59	0	0	64	34	0	0	57	0	0	0	30

All videos from measurements are available on youtube:

www.youtube.com – than write “Peter Vertal” to the search line

or

<https://www.youtube.com/channel/UCN6U-u4nQVjyCvSr8nm5eFg>

CONCLUSIONS

In the near future, our expert deeds will increasingly often involve vehicles that are equipped with modern and sophisticated systems. These systems are intended to facilitate and secure the movement of vehicles on roads, but they also cause complications when dealing with such accidents from professional or expert perspective.

The measurements made with a highly sophisticated vehicle model Volvo V40 CC identified the vehicle's behaviour in different traffic situations, whose range covers normal movement of pedestrians and vehicles in urban traffic. These measurements can be summarised in a few points.

- The system does not react to a lying pedestrian.

- The system does not react to a standing pedestrian shorter than 80 cm.
- The system does not react to a pedestrian in the dark if the pedestrian is only illuminated with the vehicle's dipped or main beam.
- In good light conditions (until dusk), the system detects a person regardless of whether the pedestrian is wearing a reflective vest or not.
- When driving the vehicle into the sun that is low above the horizon, the system reacts to such situation and can detect a pedestrian (the camera is not dazzled).
- In daytime conditions, the system reacts to a pedestrian moving from 3.6 to 7.5 km/h (the speed from real tested accidents). Higher speeds of a pedestrian's movement were not tested.
- The system reacts to a pedestrian who is standing in the driving corridor of the vehicle.
- The system reacts to a pedestrian who is moving perpendicular to the direction of the vehicle's movement.
- The system reacts to a pedestrian who is moving at an angle in the direction or in the opposite direction of the vehicle's movement, but only up to an angle of the pedestrian's movement of +/- 45° from the plane perpendicular to the plane of the vehicle's movement.
- The driver was warned more than **1 second (1-2,0s)** before the collision in nine case studies from the total number of measurements. It is a matter of further research to determine what is the time required for the driver's reaction to this alarm and the subsequent driver's action (dodging, braking etc.).
- The time interval from the system's first acoustic and visual reaction until the initial moment of braking ranged from **0.1 to 0.8 seconds**. Braking was initiated without prior acoustic warning in one study case.
- The brakes lag time takes about **0.5 seconds**. Standart brakes lag time during a driver braking is 0.2s
- The system does not react to a traffic situation where the vehicle is moving in a laevorotatory corner and a pedestrian is moving into the road from the left.
- The system does not react to a traffic situation where the vehicle is moving in a dextrorotatory corner and a pedestrian is moving into the road from the right.
- The system that has detected a pedestrian can stop the vehicle completely only if the vehicle is moving at a speed up to 30 km/h and the pedestrian's movement is smooth and predictable.
- The system that has detected a pedestrian can reduce the vehicle's speed if the vehicle moves at a speed over 30 km/h and the pedestrian's movement is smooth and predictable.
- The vehicle's speed at the detection of a pedestrian can be reduced by a maximum of 30 km/h.
- If the driver intervenes with the vehicle's control during its autonomous intervention, the system deactivates autonomous braking.

The measurements show that the benefits of the system are noticeable and it is a good step to reducing the severity of pedestrian injuries caused by a collision with a car. Although a Volvo driving over 30 km/h will not stop in front of a pedestrian, the time interval when the driver is warned of an obstacle in front of the vehicle ranges up to 2.0 seconds, which may have a positive impact on the course of an accident event.

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