Implementation of an active safety system for pedestrian detection in Volvo's cars and the real benefits of the system based on selected real-life fatal pedestrian accidents

Dipl. Ing. Peter Vertal
Institute of Forensic Engineering
University of Zilina
Zilina, Slovakia
e-mail: peter.vertal@usi.sk

Prof. Dr. Tech. Gustav Kasanicky
Institute of Forensic Engineering
University of Zilina
Zilina, Slovakia
e-mail: gustav.kasanicky@usi.sk

Prof. Dr. Tech. Hermann Steffan
Vehicle safety institute
University of Graz
Graz, Austria
e-mail: h.steffan@tugraz.at

***Abstract* - Experts that solves traffic accident involving a vehicle with a fully autonomous braking in a critical situation, encounter the problem of taking into account the impact of this system on the course of a traffic accident. Experts do not have enough information about the behavior of autonomous braking system. The implementation of such active safety systems has not yet been described and studied. Benefit of active safety systems to prevent road accidents can be achieved, for example, early warning driver of a potential collision situation sufficiently in advance to reaction and post-maneuver (braking, yaw, ..). Professional community of traffic accident experts have lack of information about the general behavior of autonomous braking systems. From the perspective of traffic accident experts on following problems is study focused:**

- ***How weather conditions affected to the operation of the system?***
- ***In what speeds the system can prevent or reduce the risk of an accident?***
- ***What type of pedestrian motion can system recognize?***
- ***What period of time prior to the collision situation the system is warning the driver?***
- ***How is the deceleration of the vehicle during autonomous braking?***

The objective of this work is to test the potential benefit of active pedestrian protection systems. The tests are based on real fatal accidents 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 would be, 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 the Volvo pedestrian detection system.

***Keywords* - active safety, autonomous braking, traffic accident, Volvo, pedestrian recognition**

I. INTRODUCTION

Increase the probability of prevent road accidents by installing autonomous systems in a vehicles is the current trend in the field of active safety with a focus on pedestrian safety. The work deals with the evaluation of intervention of active safety system for pedestrian detection assembled in series production. Benefit of active safety systems to prevent road accidents can be achieved, for example, early warning driver of a potential collision situation sufficiently in advance to reaction and post-maneuver (braking, yaw, etc.). The evaluation of the intervention of active safety systems, which aim to prevent an accident with a pedestrian is necessary to experimentally evaluate the behavior of these systems.

The main objective of this work is to test the selected system based on different types of real accidents. At the time of the measurements and present, are not for experts and specialists in the field of road traffic accidents publicly accessible data about the behavior of such a system. The work aims to evaluate the behavior of the Volvo system in inducing real traffic situations. For the evaluation of this system are precisely analyzed fatal traffic accidents with pedestrians in the urban area (speed of vehicles up to 60 km/h). Simulated traffic situations by their nature cover the most common critical situations in urban traffic. Expert community and the professionals who deal with the solution of traffic accidents receive this work valuable data to deal with such accidents. Based on these measurements give more expert input data to solve a collision with a pedestrian. The basis for understanding the behavior are created graphs of distance, speed and time at a key moment of the collision. These key moments include entry a pedestrians to driving corridor of the vehicle, system's response to conflict situations, warn the driver and then autonomously brake active safety system

The in-depth accident database ZEDATU contains 300 fatal pedestrian traffic accidents in urban areas. Eighteen cases of pedestrians hit by the front end of a 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. An active safety testing scenario was built on the basis of the reconstructed accidents with a 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 the Volvo's motion by D-GPS with high accuracy.

II. 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 servo motors. It was necessary to ensure that the dummy, placed on the UFO platform, had reflective properties which were 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 with 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 corresponded 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, the chamber with a test subject, and the chamber with 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. Chart showed, that is small differences in position of person approx. 2.9 m from radar source and dummy approx. 3.1 m. The reflection is the same only distance from radar of the figurant and dummy in anechoic room was little bit different. For paper and measurements purposes is important that reflection is similar. The car is evaluating object in front of a car base on radar if is an object made from paper, plastic, steel etc. base on different reflection. Then a camera continue in evaluation what object it is. Because of different reflection of objects the car try to predict if he object is from not dangerous material (paper box lying in road or from a rigid material).

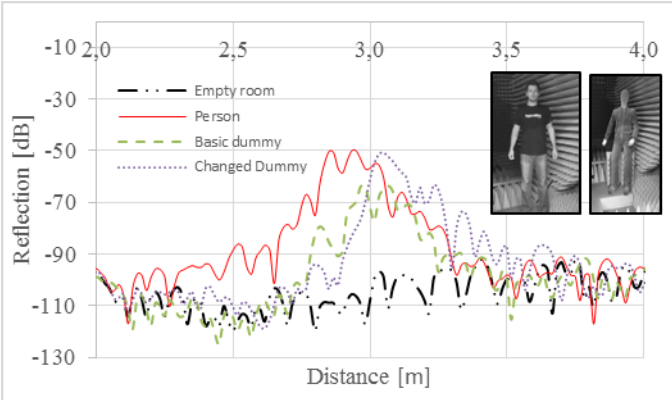

Fig. 1. Reflection of the person, basic dummy and changed dummy in the anechoic chamber.

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

III. 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 over the entire range of traffic accident situations. A full overview of the case studies, pedestrian information and vehicle speeds at the time of collision resulting from the analysis of the accident studies is shown in Table I and II.

TABLE I. OVERVIEW OF PEDESTRIANS INVOLVED IN ACCIDENTS

Case	Ped. sex	Medi-cal report	Ped. age	Job	High [m]	Weigh [kg]	Alc. Level ‰	Death after an accident
1	F	1	69	pensioner	1,6	x	0	12Days
2	F	1	71	pensioner	x	x	x	3Days
3	F	0	78	pensioner	x	x	0	x
4	M	1	96	pensioner	1.75	77	x	10Days
5	F	1	89	pensioner	x	x	0	10Days
6	F	1	84	pensioner	x	x	x	3Hrs
7	M	1	91	pensioner	x	x	0	1Hrs
8	M	1	43	secretary	1,61	71	x	8Days
9	F	1	69	pensioner	1,73	86	x	0Hrs
10	M	1	12	student	1,48	45	0	2Days
11	M	1	61	pensioner	1,53	x	0	x
12	F	1	45	not know	x	x	x	x
13	F	1	62	Not know	x	x	2,3	0Hrs
14	M	1	81	pensioner	1,83	x	0,95	x
15	F	1	77	pensioner	1,76	80	0	x
16	M	1	28	jobless	x	x	x	1Hrs
17	F	1	92	pensioner	1,46	58	x	3Hrs
18	M	1	84	pensioner	1,74	79	0,02	0Hrs

TABLE II. OVERVIEW OF VEHICLES INVOLVED IN TRAFFIC ACCIDENTS AND PEDESTRIANS MOTION

Case	OEM	Model	Registration year / Accident year	Impact velocity +/- 10% (km/h)	Direction of pedestrian motion	Ped. sex and age (years)
1	Opel	Astra	1999 / 2003	23 - straight	→	F 69
2	Citroen	AX	1990 / 2003	47 - straight	→	F 71
3	Opel	Corsa	1990 / 2003	12 - cornering L	←	F 78
4	Peugeot	306	1994 / 2003	50 - straight	→	M 96
5	Volvo	S70	1997 / 2004	32 - straight	→	F 89
6	VW	Multivan	1989 / 2004	19 - straight	←	F 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	←	F 69
10	VW	70D	1993 / 2007	39 - straight	standing	M 12
11	Mitsubishi	Pajero	1992 / 2008	32 - straight	←	M 61
12	Ford	Transit	1999 / 2004	36 - cornering L	→	F 45
13	Toyota	Avensis	2001 / 2003	45 - straight	lying	F 62
14	Mazda	Demio	1999 / 2004	42 - straight	↘ 30 °	M 81
15	Renault	Twingo	1993 / 2004	46 - straight	↘ 60 °	F 77
16	Opel	Corsa	2003 / 2004	39- straight	→	M 28
17	VW	Passat	1993 / 2005	30 - straight	→	F 92
18	VW	Transp.	2000 / 2005	47 - straight	↙ 15 °	M 84

Tests were performed under the conditions corresponding to the six characteristic types of traffic accidents with pedestrians. During the measurements, the following traffic situations were simulated: a pedestrian crossing the road in a perpendicular direction, in an oblique direction and in the direction towards the vehicle; a pedestrian standing on the roadside, a pedestrian coming from behind an object, a person lying down, day and night conditions, and situations combining the above.

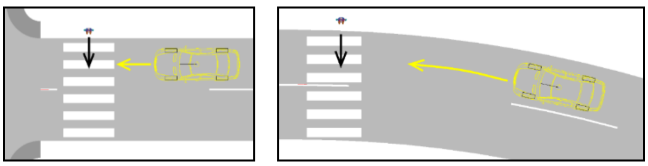

Fig. 2. Pedestrian crossing a road from right side

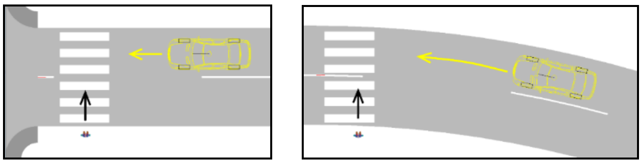

Fig. 3. Pedestrian crossing a road from left side

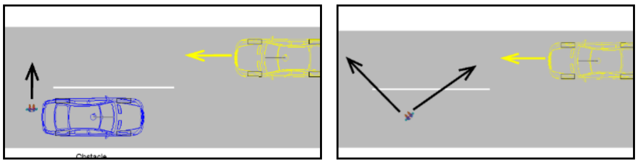

Fig. 4. Pedestrian crossing a road behind an obstacle or diagonally

The analysis of the data was used to identify the moment prior to the vehicle's contact with the pedestrian of initial acoustic and visual warnings to the driver from a pedestrian detection system against a potential barrier in the direction of the vehicle's movement. The measurements identified that the Volvo acoustic signal is always activated together with the visual warning. The visual warning of the driver is accompanied by a flashing light which is located between the speedometer and the windscreen. It is a place with very good visibility for the driver. The light strip is approximately 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 close to 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 travel.

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, however, able to detect a pedestrian at night up to a speed of approximately 20 km/h and brake subsequently because it simply identifies him as a barrier (i.e. another vehicle) and not through the detection of a human figure. This fact is supported by the 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 lane and not to pedestrians. During the tests with a lying dummy, the system was not activated in any event. The technical manual of the Volvo states that the system only reacts to figures taller than 80 cm.

IV. DESCRIPTION OF PEDESTRIAN MODEL IN PC CRASH

The pedestrian model in PC-Crash uses a multi-body system consisting of several rigid bodies to simulate the movement of the pedestrian. The different bodies, which represent the different parts of the pedestrian like head, torso, pelvis etc., are interconnected by joints. For each body different properties like geometry, mass, contact stiffness and coefficients of friction can be specified. The geometry for each body can be specified by defining a general ellipsoid of degree n. The number of bodies and joints used influences the calculation time needed. Therefore a compromise has to be found between calculation time and model detail.

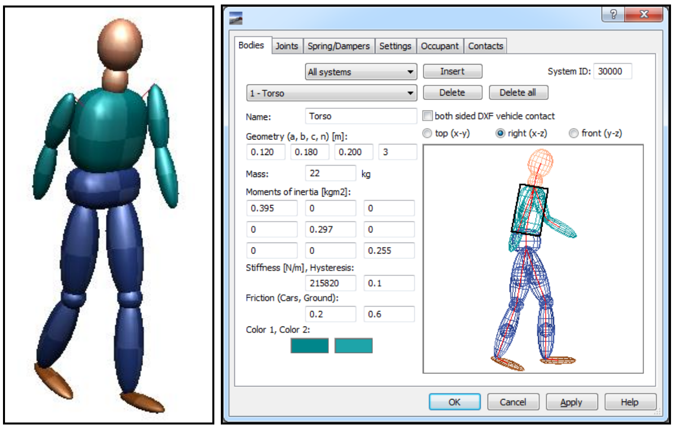

Fig. 5. Multibody settings [4]

At the moment for the pedestrian model 24 bodies interconnected by 15 joints are used. However, the multi-body module in PC-Crash can deal with an unlimited number of bodies and joints. Besides the definition of several properties for each body, the size and the weight for the whole pedestrian can be specified in the program. The initial conditions like position and orientation for each body as well as the velocities can be entered by the user to define the parameters of motion before the impact. However, the relative position of two bodies connected by a joint is defined by the joint location.

Body properties: For each body of the multi-body system the following properties can be specified independently.

- Geometry: Each body is represented by a general ellipsoid, the length of the semi-axes a, b, c and the degree of the ellipsoid can be specified.
- Mass and Moments of Inertia: For each body of the multi-body system the mass and the moments of inertia have to be specified.
- Stiffness coefficients: A body stiffness coefficient has to be specified, which is used when calculating contacts. The stiffness coefficients for different body parts can be determined experimentally.
- Coefficients of friction: Two coefficients of friction can be specified. One is used for ellipsoid to vehicle contacts, the other one is used for ellipsoid to ellipsoid or for ellipsoid to ground contacts. These coefficients of friction are assumed to be independent of the amount of penetration.

The multi-body system used for the pedestrian model uses two different coordinate systems. One coordinate system is the inertial system and the second coordinate system is the body fixed coordinate system. The body fixed coordinate system is defined by the semi-axis of the ellipsoids. Both coordinate systems are right hand coordinate systems. However, the axis of the body fixed coordinate system coincide. For the simulation of the multi-body system during each time-step the external forces (gravity, contact forces, frictions forces and joint forces) on each body are calculated. Once the external forces are estimated the movement of each body is calculated independently by solving the equations of motion numerically.

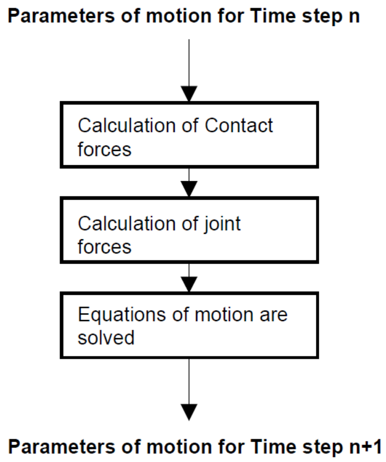

Fig. 6. Steps during the simulation of the multi-body system [5]

Vehicle geometry has a significant impact on the dynamics of pedestrians and therefore this model allows the use of various forms of vehicles. Body shape can be adjusted by choosing the right vehicle model DXF. In the wire contact model, vehicle models as wire structure made up of nodes (nodes) and area (faces). Wire structure can be connected as a three-dimensional drawing or be derived from the standard body shape in PC-Crash, and the foundation will be inserted dimensions (see). Wire model used to calculate the impact forces for each individual node model based on impact pressure deformation node. At the same time they take into account the friction forces. Contact wire model nodes are the points on which it is possible due to impact deformation, and surface defining a contact surface for the model.

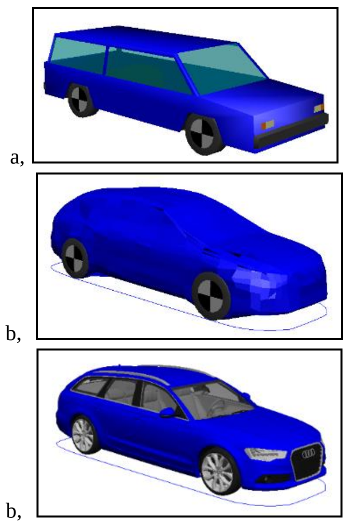

Fig. 7. a, The basic model of the Audi A6 b, mesh model of the Audi A6 c, mesh car model by the visual appearance of the vehicle. [4]

A. Short example of PC Crash simulation of case no. 07

For reconstruction of traffic accidents were used data from ZEDATU database. For each case these document were available: precise accident plan, photographs, medical reports on injuries, testimony of the parties, vehicle registration document, police reports. The analysis of study No.7 showed, that vehicle BMW 3 was drive before the accident in left cornering at speed about 41 km/h. Pedestrian walked straight into the car lane corridor from the right side with speed about 4 km/h. The pedestrian speed have been estimated base on statements of driver, kinematics criteria, accident simulation and literature [5]. The driver of the vehicle did not respond before the crash on the movement of pedestrians.

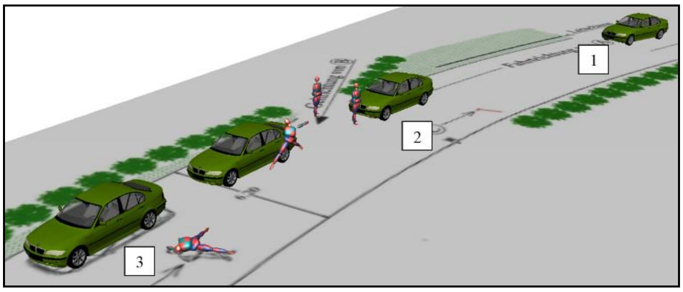

Fig. 8. Visualization of traffic accident - Location No. 1 shows driver reaction No.2 shows vehicle position at place of starting braking No. 3 final position of the vehicle and pedestrian.

V. An example case no. 02 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 approximately 47 km/h at the time of the real collision. A pedestrian moving at approximately 4 km/h entered the vehicle's path from the left. The vehicle and the pedestrian were synchronized based on the result of an exact simulation by the PC Crash 10.0 program. The visual representation of the course of case study No. 2 shows the following. Each case from study were performed 3 times to examine how repeatable the results are.

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 stationary 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 (the pedestrian) based on the speed of the Volvo vehicle.
2) The vehicle moves on at a constant speed of 47 km/h and at 4.3 s before the collision with the dummy, UFO is activated with an acceleration of 1 m/s2. This fully automated and synchronized action reproduces the real accident.
3) At 2 s and 19 m ahead of the dummy's path (Fig.9), the acoustic and visual warning of the driver is activated at the moment when the dummy is located at a distance of approximately 0.7 m from the path of the Volvo driving at approx. 45 km/h. The Volvo does not brake autonomously at this moment.

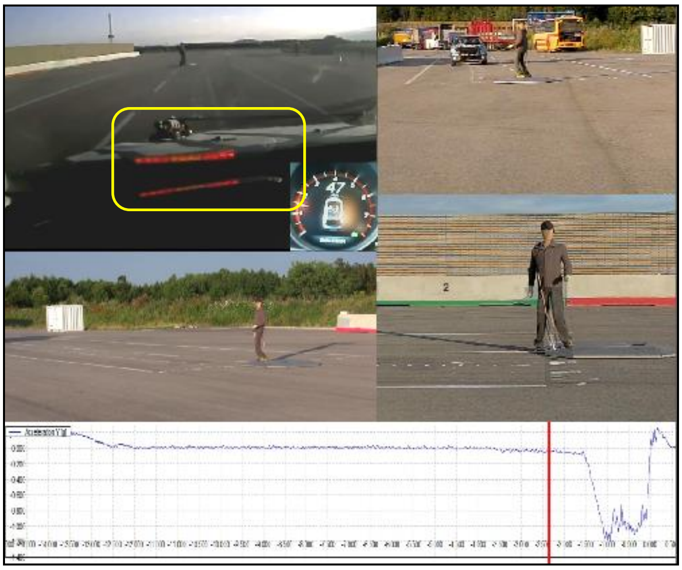

Figure 9. Activation of the visual and acoustic alarm

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 approximately 13 metres from the pedestrian's path (Fig. 10). The vehicle brakes with an average deceleration of approximately 10 m/s^2. The driver did not interfere with 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.

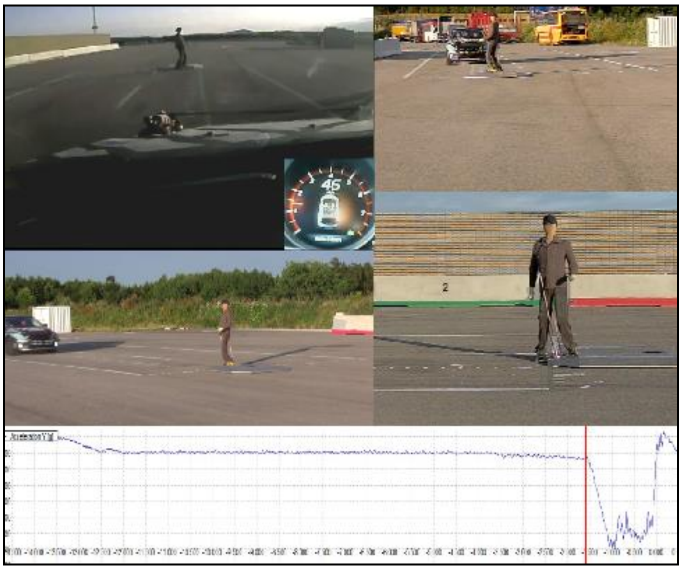

Fig. 10. Beginning of the autonomous braking

5) Approximately 2 seconds after the initial acoustic signal, the vehicle collides with the dummy. The speed at the time of collision (Fig. 11) was approximately 12 km/h (base on acceleration sensor and GPS) compared to 48 km/h in the

real accident where the driver failed to react to the pedestrian.

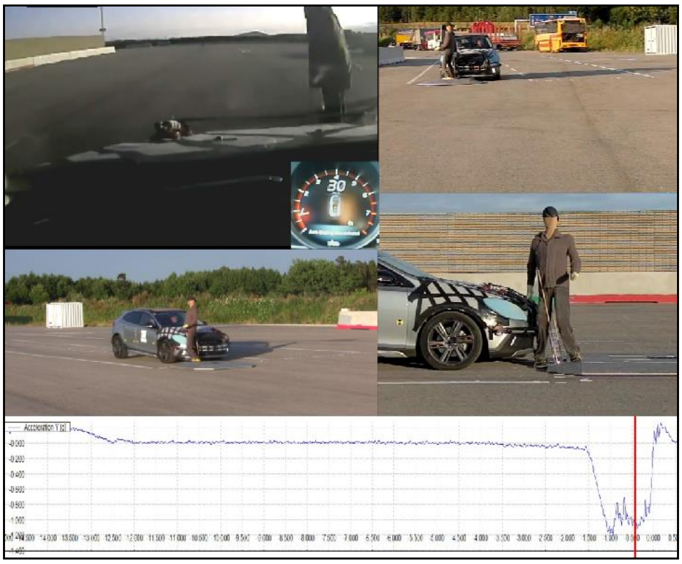

Fig. 11. Time of the first contact with dummy

The course of the 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 by the author of this paper.

A. *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 before the collision with the pedestrian. The driver was warned more than 1 second (1.0-2.0s) before the collision in nine case studies from the total number of measurements. It is a matter of further research to determine what the time required is for the driver's reaction to this alarm and the subsequent driver's action (swerving, 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 but the vehicle nevertheless collided with the dummy. For a more accurate representation of the dependence, Figure 12 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 behavior depends on the turn radius; hence, it may react to a dummy earlier.

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

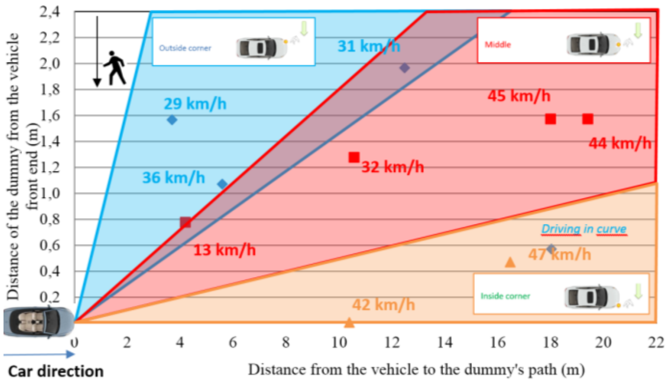

Fig. 12. Activation of the alarm depending on the speed and distance of a vehicle from the dummy's path, distance of the dummy from the vehicle axis and the subsequent contact of the vehicle with the dummy (the inside corner - blue, the middle of the vehicle - red or the outside corner - green).

B. *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 to the initial moment of braking ranged from 0.1 to 0.8 seconds. Braking was initiated without prior acoustic warning in one 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 his path and, subsequently, to make the right manoeuver to avoid a collision with them.

VI. 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 a 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 must be 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 the pedestrian, but by a maximum of approximately 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 III.

TABLE III. DECREASE 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’s view	yes			yes				yes									yes	
Motion of the car	straight	straight	cornering L	straight	straight	straight	cornering L	overtaking R	cornering R	straight	straight	cornering L	straight	straight	straight	straight	straight	straight
Impact velocity in real 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	1	1,7	1,5	0,5	1,6			1,9	1,5			1,1		0,6		1,5
Decrease of the velocity (%)	**0**	**-74**	**-100**	**-48**	**0**	**0**	**-59**	**0**	**0**	**-64**	**-34**	**0**	**0**	**-57**	**0**	**0**	**0**	**-30**

The kinematics of pedestrian and pedestrian injuries caused by collision with a vehicle are influenced by the impact speed, shape and stiffness of the front of the vehicle (bumper height, height of the bonnet and its length, windscreen frame), age, height and position of pedestrians and pedestrian and the vehicle. The main factor that is signed on the severity of injuries to pedestrians with the vehicle's speed.

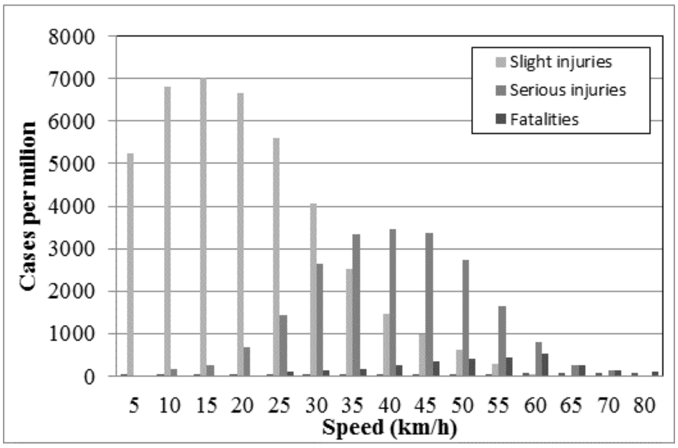

Fig. 13. The injury severity distribution and risk as a function of impact speed [2, 3].

The graph (Fig. 13) shows that, in over 90% cases of accidents the pedestrian with the vehicle have collided at a speed below 60 km/h. Colliding speed to 25 km/h were minor injuries. The frequency of serious injuries is most common in the range 25-55 km/h. At speeds above 55 km/h it is highly likely fatal injuries. Decreasing of velocity by the active safety system in Volvo car has positive impact on severity of injuries. With lower velocity is lower probability of serious or fatal injuries.

VII. CONCLUSIONS

In the near future, our expert investigations will increasingly often involve vehicles that are equipped with modern and sophisticated systems. These systems are intended to facilitate the safe 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 behavior in different traffic situations, whose range covers normal movement of pedestrians and vehicles in urban traffic. These measurements can be summarized in a few points:

- The system does not react to a pedestrian lying down.
- The system does not react to an upright pedestrian shorter than 80 cm.
- The system does not react to a pedestrian in the dark if the pedestrian is only illuminated by 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 into low sun, the system reacts to such situation and can detect a pedestrian (the camera is not dazzled).
- In daytime conditions, the system reacts to pedestrian’s moving from 3.6 to 7.5 km/h (the speeds from real tested accidents). Higher speeds of pedestrian movement were not tested.
- The system reacts to a pedestrian who is standing in the path 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 (1.0-2.0s) 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 (swerving, braking etc.).
- The time interval from the system’s first acoustic and visual warning 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. Standard brakes lag time during a driver braking is 0.2 s.
- Autonomous braking reached deceleration -10 m/s^2.
- Driver braking reached deceleration -10 m/s^2.
- The system does not react to a traffic situation where the vehicle turning to the left and a pedestrian is moving into the road from the left.
- The system does not react to a traffic situation where the vehicle is turning to the right and a pedestrian is moving into the road from the right.
- The system does not warning a pedestrian.
- There is no EDR and CDR data.
- 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 that it is a good step towards reducing the severity of pedestrian injuries caused by collisions with cars. Although a Volvo driving over 30 km/h will not stop before reaching 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.

Measurements show, that car could warning driver up to 2,5 seconds before the collision. The warning is not recognizable in the external environment of the vehicle. From forensic expert view, if the car will warn also pedestrian it could have positive impact on traffic accident scenario. If the focused (or spread) sound or focused (or spread) light beam signal will warning a pedestrian, the pedestrian could avoid an accident. Pedestrian could stop on very short distance, jump, change direction of the motion, etc. .. Focused sound or light beam will not disturb other user of traffic. With existing system pedestrian don't have any clue that car is warning driver or that accident will happen.

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