

# PEDESTRIAN PROTECTION – AN EVALUATION OF AN AIRBAG SYSTEM THROUGH MODELLING AND TESTING

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## ABSTRACT

Pedestrian impacts currently account for over 900 deaths and over 40,000 casualties each year in Britain. The chance of death or serious long-term disability increases greatly with impact speed. At 20mile/h (32km/h) the probability of killing or seriously injuring a child is 20%, but this rises to 80% at 40mile/h (64 km/h).

Advanced Active Adaptive Secondary Safety systems were studied, which comprised sensors to identify a pedestrian within the vicinity of a vehicle and determine the likelihood of an impact and airbags fitted to various parts of the vehicle front to protect the pedestrian in an impact. The research comprised modelling in MADYMO followed by impact testing. Sensor systems were investigated in parallel.

Impacts between a 50<sup>th</sup> percentile adult dummy and a saloon car and a Sports Utility Vehicle (SUV) were simulated in MADYMO at two impact velocities; 25mile/h (40km/h) and 30mile/h (48km/h). The vehicle models were modified, where possible, to ensure likely compliance with the proposed EEVC pedestrian protection limits. These models and the resulting potential injuries were used as the basis for comparison with the active systems. The simulation results for active systems showed that the potential for injury reduction was substantial. For example HIC was reduced from 1062 to 113 in an impact of 25mile/h (40km/h) with the saloon car. These results were used to select the system for experimental tests.

Testing consisted of impacts to an instrumented adult OPAT dummy and a child OPAT dummy with vehicles and conditions similar to those modelled and at the same velocities. Injury potential from the impacts was assessed. Results were similar to the simulation predictions and showed that a substantial reduction in lower limb and head injury may be possible with airbags mounted on the bumper and the bonnet. The paper describes the research including a brief resume of the sensor development.

## INTRODUCTION

Pedestrian impacts account for over 900 deaths and over 40,000 casualties each year in Britain, RAGB (1998). The chance of death or serious long-term disability increases greatly with impact speed. At 20mile/h (32km/h) the probability of killing or seriously injuring a child is 20%, but this rises to 80% at 40mile/h (64km/h).

Certain improvements to vehicle design have already been proposed in earlier papers by TRL (Hobbs et al. 1985), and these were shown to produce injury reductions. Previous research has shown that the design of vehicle fronts to afford adequate protection to pedestrians is possible using soft bumpers and reactive re-settable systems for low speed impacts, but once the impact velocity is above 25 mile/h (40km/h), these systems can no longer withstand the energy management requirements. A child needs a softer bumper, front part of bonnet and bonnet leading edge, than an adult, in order to reduce the average acceleration, but may be more resistant to certain injuries. This has a consequential requirement that a recognition system is incorporated into the pedestrian detection system to determine the size of the person likely to be involved in a collision. There would be advantages in linking the active pedestrian system to the braking system to enable the brakes to be activated prior to impact, and it is recommended that this concept should be explored further. The evolution of electronically controlled safety systems has meant that this work has the potential to be taken much further by the inclusion of airbags on vehicle fronts.

The work reported here has involved the computer simulation of pedestrians being impacted by two sizes of car, a medium sized saloon car and an off road vehicle. Practical testing to verify the trends indicated from the modelling followed this work.

Autoliv Ltd. provided airbag models which were used with MADYMO software. The pedestrian model used was the 50<sup>th</sup> percentile standard part 572 dummy, revision 1.3, supplied by TNO, with a modification to the knee joint. The knee joint stiffness in lateral bending was changed to be the

same as the stiffness of the lower leg impactor used for the pedestrian sub-system impact tests. The MADYMO vehicle models were adjusted so that they complied, approximately, with EEVC proposals for pedestrian frontal impact protection. Airbag models were then added and injury reduction potential quantified.

The practical test work sought to substantiate the potential benefits suggested by the mathematical modelling of these pedestrian safety systems, by testing two vehicles fitted with a variety of foam padding and airbag devices in impacts with adult and child OPAT dummies at two velocities. The first, 25mile/h (40km/h), was chosen because it is the proposed EC legislative test speed, whilst the second, 30mile/h (48km/h), was chosen because it represented a severe impact to an adult or child and imparts 44% more energy than the first, so is likely to produce much greater injuries. This work has included both computer simulation and practical testing, and demonstrated that a clear advantage can be achieved by the use of active pedestrian safety systems in the reduction of potential injury levels.

The format of this paper is arranged so that it follows the progression from mathematical modelling to practical testing, which leads to a discussion of the results. This is followed by a discussion of the possible sensing systems, which could be used for the practical implementation of such safety systems.

**COMPUTER SIMULATION**

The simulation involved the use of two different shaped vehicle fronts to impact a pedestrian dummy modified to have the same lateral knee joint stiffness as the lower leg impactor used in pedestrian subsystem tests. The MADYMO models were supplied in part by a motor manufacturer and represent the typical frontal structures of a saloon and an SUV (sports utility vehicle). Autoliv Ltd supplied the airbag models.

The main objective of this study was to determine the effectiveness of airbags at protecting pedestrians impacted by the two very different cars. Other types of protection were considered, such as pop-up bonnets and extended soft bumpers, but airbags were thought to offer the best potential for improved protection, and may be conveniently packaged to suit most vehicles.

The injury criteria studied were knee lateral bending angle, knee shear force, knee 3ms exceedence acceleration, upper leg contact and HIC36. The

modified baseline vehicle models just met the human tolerance requirements for these criteria. It should be noted that the models were not fully compliant as the windscreen stiffness was too high, which would affect pedestrian head injury levels if impacted during the collision.

Three airbag protection systems were evaluated for the saloon car. The first of these was a large passenger airbag mounted in the top of the bonnet / windscreen area, for the second the same airbag was mounted on the front of the car and the third a combination of the two. Figure 1 shows the combination airbag arrangement part way through a pedestrian impact. The injury criteria values predicted resulting from a 25mile/h (40km/h) pedestrian impact are tabulated for the three airbag protection systems in Table 1. Examination of this table shows that the model predicted a substantial reduction in the knee, upper leg and head injury criteria by fitting airbag protection systems. However, although the upper leg contact force was reduced by fitting the bumper/grill airbag system, a reduction of nearly this magnitude could be achieved by softening the bonnet leading edge.

**Table 1.**  
**Predicted injury levels for saloon car mathematical model**

Model Description	Knee Injury			Upper Leg Injury	Head Injury
	Knee Accln (g)	Knee lateral bending angle, (deg)	Knee shear (kN)	Upper leg contact force, (kN)	HIC 36
EEVC Compliant	1259	-13.8	-4.2	5.8	6450
Bonnet/Wind screen airbag	1263	-13.8	-4.2	5.8	32
Bumper/Grill airbag	312	3.6	-1.1	2.6	3096
Bonnet/Wind screen and Bumper/Grill airbag	312	-2.9	-1.1	2.5	113

At 30mile/h (48km/h), the injuries were reduced by a lesser amount, but still represented a worthwhile improvement. Knee acceleration was 54.5g, knee bend -8.6 degrees, knee shear force 1.2kN, upper leg contact force 4.3kN, and HIC36 247, which was still considered a very survivable impact.

One airbag protection system was evaluated for the SUV. This was an airbag mounted on the grill. The injury criteria values predicted resulting from a

25mile/h (40km/h) pedestrian impact are tabulated for the EEVC compliant model using the baseline model upper leg contact force and the airbag protection systems, Table 2.

**Table 2.**  
**Injury values predicted for a 25mile/h (40km/h) pedestrian impact for SUV with airbag protection system compared with EEVC compliant SUV**

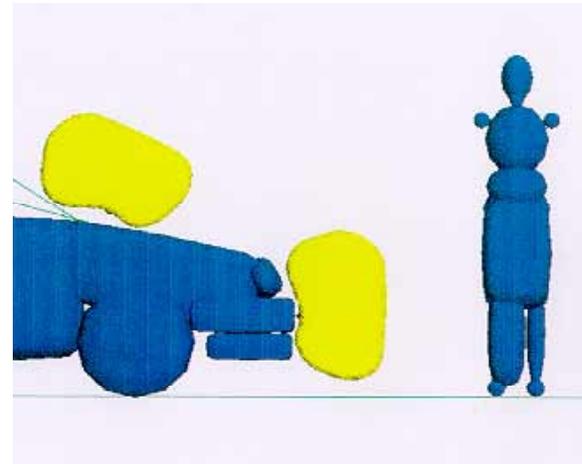
Model Description	Knee Injury			Upper Leg Injury	Head Injury
	Knee Accln (g)	Knee lateral bending angle (deg)	Knee shear (kN)	Upper leg contact force, (kN)	HIC <sub>36</sub>
EEVC Compliant	63	-11	-2.7	**12.5	989
Bumper/Grill airbag	22	-2.0	1.1	6.4	277

\*\* Note. Upper leg contact force value from baseline SUV model.

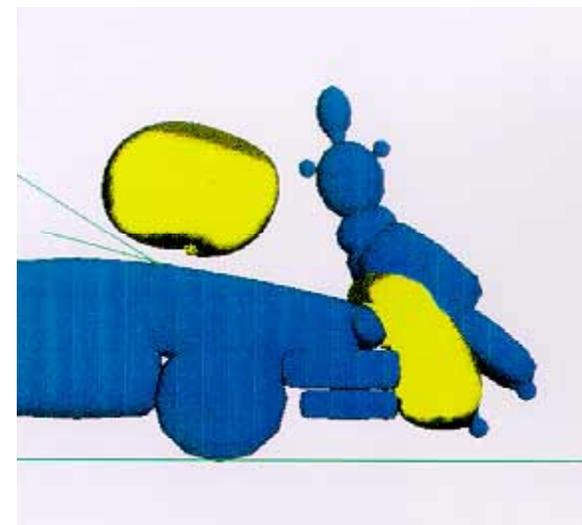
Examination of Table 2 shows that a substantial reduction in the knee, upper leg and head injury criteria is predicted by fitting the airbag protection system. The large reduction in upper leg injury that can be achieved with an airbag protection system is probably the only way to reduce injury substantially, in this body region, for vehicles with a high bonnet leading edge.

At 30mile/h (48km/h) the injuries were still potentially survivable. Knee acceleration was 36g, knee bend 15.7 degrees, knee shear force 1.5kN, upper leg contact force 9.6kN, and HIC<sub>36</sub> 663. Only the upper leg contact force was higher than the tolerance.

The overall conclusion from the modelling was that airbag systems fitted to the front of vehicles drastically reduce pedestrian injury risk. The dummy used in the modelling was not scaleable, so consideration could not be given to other sizes of pedestrian, and other people likely to be hit such as cyclists and babies in perambulators. Nevertheless, a cyclist or perambulator impacted by vehicles meeting current legislation is almost certainly likely to suffer serious injury even at relatively low speeds such as 30mile/h (48km/h). With the front of the vehicle completely protected by vented airbags, this is likely to reduce the injury sustained, and cushion the subject, rather than propel them onto the road or pavement.



**Before impact**



**During impact**

**Figure 1. Saloon car fitted with a combination frontal airbag system part way through a pedestrian impact.**

## EXPERIMENTAL TESTS

### Method and construction

Various vehicle shapes were considered for pedestrian impact testing, but the mathematical simulation concentrated on a saloon and a SUV, since they represent two common types of car front. In reality there are a great number of different vehicle shapes, each with attendant concerns, varying from almost vertical to severely raked. However, these two basic shapes were used for impact testing, namely a typical saloon car and a SUV.

A steel-skinned structure replaced the vehicle front to permit repeat testing without the need to replace damaged parts, see Figure 2.

Pedestrian impact protection systems can be passive or active. The first series of tests were designed to establish the passive performance and show that it was similar to the simulation and close to the proposed EC vehicle legislative requirements. This was achieved through the use of open cell foam padding of a specific thickness glued on to the steel skin to replicate the vehicle structure during impact with an OPAT adult pedestrian dummy.

The same specification foam padding was then used for the OPAT child dummy impact tests, because a current vehicle would behave in a similar manner irrespective of the size of pedestrian impacted. The only region where this was potentially not true on the saloon car was from the bonnet leading edge to part of the way back towards the windscreen. This could be tuned to be softer for a child head impact on a real vehicle. The EuroNCAP protocol demonstrates this, with several different impact sites chosen for adult and child head forms.

When the foam testing had been completed, another test series was designed with airbags inflated by pressurised air gas bottles to provide the requisite airflow and pressure to keep the airbags inflated prior to impact. This was thought necessary because the trajectory resulting from contact would be different from that produced by padding and it was critical to obtain the correct timing before a pyrotechnic airbag test could be contemplated. This was to emulate an active system with pedestrian sensing capability and demonstrate that air bag technology may be suitable for pedestrian impact protection.

The test programme consisted of these two vehicles fitted with a variety of foam padding and airbag devices in impacts with an adult and child OPAT dummies at two velocities, 25mile/h (40km/h) and 30mile/h (48km/h). Twenty-five mile/h (40km/h) was chosen because it is the proposed EC legislative test speed and 30mile/h (48km/h) was chosen because it represented a severe impact of an adult or child. These two velocities were those used in the simulation.

Three series of tests were planned. The first to establish the relative performances of the two vehicles and to compare the results with the mathematical model outputs. In addition, it was necessary to ensure that the vehicles were modified

to comply as much as possible with the proposed EC vehicle legislative requirements.

The second series of tests was performed with airbags inflated by pressurised air from gas bottles which provided the requisite airflow and pressure to keep the airbags inflated prior to impact. This allowed a variation in bag pressure between tests which was achieved by an adjustment of a constant velocity pressure valve.

The third series of tests was with pyrotechnically inflated airbags.

Sixty litre passenger airbags and 9 litre head protection airbags were purchased from Autoliv Ltd. The latter had linked air pockets to provide a damped venturi effect. The bags were modified by TRL to permit inflation by a remote compressed air source or by a suitable pyrotechnic inflator. The airbag vents were blocked for all the tests.

The windscreens were protected by a similar steel structure supporting a plywood cover, thus permitting repeat tests without the need to replace any vehicle parts between tests. The bumper was simplified to a flat vertical surface in order to achieve more repeatable impacts. Further modifications to the vehicles were the inclusion of an emergency brake system to ensure more repeatable results and to stop the test vehicle inside the test area.

The principle of the test was to propel the vehicle toward the dummy, which was held in position by an electromagnetic quick release mechanism attached to a cable leading from its head. This was released just before the vehicle impacted the dummy. The test vehicle was attached to a winch system to provide propulsion and was also released prior to impact, thus ensuring free running at a constant velocity at the point of impact.

The dummy was orientated so that it represented a person crossing in front of the vehicle, with fifteen degrees of twist towards the vehicle to prevent the arms affecting head and torso trajectory, see Figure 2. This proved a very satisfactory initial position, and was used for all tests. The pelvis, chest and head injury values were resultant accelerations, hence were unaffected by this twist. Leg injury values, which may have been slightly influenced, were not corrected.



**Figure 2. Saloon car modified. Side view with 100mm layer of foam pre-test.**

The dummies used were an OPAT adult and an OPAT child especially modified to record injury potential specific to pedestrian accidents. In particular, the adult OPAT dummy was fitted with a lateral knee force transducer, a lateral knee clutch and a goniometer to measure lateral knee angle both to be used to indicate knee injury potential and to provide data for comparison with the modelling results. However, the goniometer was found to be impracticable and the dummy lateral knee angles were estimated from film data.

**RESULTS OF TESTS**

When assessed with an adult OPAT dummy, the potential injury reductions for the airbag system fitted to the saloon car were as follows:

- HIC<sub>36</sub> reduced by 93%
- Chest g reduced by 76%
- Pelvis g reduced by 24%
- Knee lateral angle reduced by 40%
- Lateral knee force reduced by 4%

The results from these impact tests when compared with the simulation results demonstrated consistency. The experimental tests also identified advantages and disadvantages that were not apparent in simulation.

The adult and child pedestrian impacts provided very different trajectories. The adult could be considered as a series of linked masses that progressively impacted the vehicle, whereas the child dummy was impacted almost as a complete body, which was especially the case for the high fronted vehicle. The only part of the child dummy not struck immediately was the head, which was then imparted a rapid

acceleration up to full vehicle speed and impacted on the bonnet. This resulted in a high neck moment and a severe acceleration to the head. It was not possible to test a child dummy in an airbag-equipped vehicle, within the resources available. The combined results are presented In Table 3, Table 4 and Table 5, and each test is described briefly thereafter. It should be noted that these tables include the simulation results.

**Table 3. Adult OPAT dummy impacted by a modified saloon car**

<b>Computer Simulation</b>						
Criteria	HIC 36	Chest res. (g)	Pelvis res. (g)	Knee lat (g)	Knee Fy (kN)	Knee angle (deg)
Std 25	1062	33.9	19.7	128	-4.2	-13.8
Std 30	1626	48.1	26.7	167.0	-4.6	-17.2
A/B 25	113	11.4	9.4	31.8	-1.1	-2.9
A/B 30	247	16.2	14.4	54.5	-1.2	-8.6

<b>Experimental Tests</b>							
Criteria	Run no.	HIC 36	Chest res. (g)	Pelvis res. (g)	Knee lat (g)	Knee Fy (kN)	Knee angle (deg)
Std 25	02	2777	41.1	33.0	218	-10.1	-25
Std 30	03	4179	50.2	50.0	323	-8.5	-40
A/B 25	07	N/A	21.0	29.0	63	-12.4	-5
	10	195	43.7	N/R	130	-11.1	-15

**Table 4. Adult OPAT dummy impacted by an SUV**

Criteria	Run No	HIC 36	Chest res. (g)	Pelvis res. (g)	Knee lat (g)	Knee Fy (kN)	Knee angle (deg)
<b>Computer simulation</b>							
Std 25		989	28.7	36.3	63.9	-2.7	-11
Std 30		2170	47.4	43.0	70.5	-3.2	-14
A/B25		277	24.7	18.2	22.0	1.1	-2
A/B30		663	30.2	29.5	36.4	1.5	-16
<b>Experimental tests</b>							
Std 25	11	1617	41.7	62.0	237	-9.3	-30
Std 30	12	3873	75.5	74.0	224	-10.2	-25

**Table 5.**  
**Child OPAT dummy impacted by an SUV and a modified saloon car**

<b>Experimental tests</b>				
<b>Criteria</b>	<b>Run no.</b>	<b>HIC 36</b>	<b>Chest res. (g)</b>	<b>Pelvis res. (g)</b>
<b>System</b>				
Std 25 saloon	04	1838	74.2	139
Std 30 saloon	05	2760	107.0	159
Std 25 SUV	13	1569	140	150
Std 30 SUV	14	2440	225	200

Key:

Std = EEVC-compliant modified vehicle FE model, or modified test vehicle which had a foam layer added to simulate component behaviour.

A/B = airbags on bumper and/or bonnet

25 = 25mile/h impact (11.1m/s)

30 = 30mile/h impact (13.4m/s)

Knee angles estimated from film

The child dummy would require active protection for pelvis, chest, neck and head for impacts with an off-road car (SUV), although the highest individual HIC<sub>36</sub> values were recorded during the adult tests at 30mile/h (48km/h) with both high and low fronted vehicles.

It has been demonstrated that the requirements of the pedestrian protection systems are different for adult and child dummies. The adult requires different bumper characteristics, and must also be protected from a windscreen, scuttle or A-pillar, which in general are not struck by children although this depends upon the stature of the person struck, bonnet length, point of impact and relative velocity vector. It has been shown that both dummies would benefit from an increased time for acceleration to vehicle speed as provided by externally mounted airbags.

The pedestrian head local vertical acceleration contributed substantially to the resultant head acceleration and was the largest component of acceleration acting on the dummies' heads which, in most cases, contributed to the high HIC<sub>36</sub> levels observed. These were due to the torso being accelerated to car velocity rapidly, especially in the case of the 6 year old child dummy, where it reached 225g for a 30mile/h (48km/h) impact. This effect is also likely to occur in humans, but because the spine and neck of humans can stretch, the effect on head acceleration is likely to be less than with the dummy, which has very little compliance. Therefore, airbags are likely to be more effective than the dummy test results suggest, although there have been rare high-

speed accident cases where the severe head injuries caused were attributable to torso acceleration.

Injury reductions found during FE modelling were matched or exceeded in some cases by test results, although direct comparisons were not possible because the test vehicles were not directly comparable to the vehicle FE models.

OPAT adult and child dummies impacted by low and high fronted vehicles at two test speeds revealed the following:

- HIC<sub>36</sub> can be reduced substantially for an adult (and child by inference) by the use of bonnet/windscreen airbags. Values of less than 200 were achieved in test at 25mile/h (40km/h), whereas a comparable vehicle test by Mizuno and Kajzer (1999) revealed variable HIC values up to 1000 or more on the windscreen and up to 5000 or more on hard sites.
- Head vertical acceleration was adversely influenced by torso acceleration. Thus, the greater the torso peak values the greater the head peak values. Future accident data analysis may not reveal such a strong relationship, due to compliance of connective tissues in humans.
- Film analysis revealed that a damped bumper airbag could reduce neck bend and body rotation, and thus, in turn, improve the retention of the pedestrian on the bonnet. The bonnet/windscreen airbag must also be damped to prevent rebound.
- Chest acceleration resultant was reduced in an adult test at 25mile/h (40km/h) from 41g to 21g (49%) through the use of bumper and bonnet airbags. Pelvis acceleration resultant was reduced in an adult test at 25mile/h (40km/h) from 33g to 29g (12%) through the use of bumper and bonnet airbags. Lateral knee acceleration resultant was reduced in an adult test at 25mile/h (40km/h) from 218g to 63g (71%) through the use of a bumper airbag.
- Lateral knee force was not reduced in the tests but the load was more evenly distributed on impact with an airbag than it would be with the vehicle bumper. Knee lateral angle was reduced in a saloon impact at 25mile/h (40km/h) for the adult dummy from 25 to 15 degrees (40%).
- Average injury values rose by approximately 30-40% comparing a 30mile/h (48km/h) impact to a 25mile/h (40km/h) one. The increase in impact energy was 44%.

## EVALUATION OF SENSORS TO DETECT A PEDESTRIAN

Assessment of individual sensor types in a variety of conditions likely to be encountered in reality was undertaken using sensors mounted on a test vehicle. This was then driven around the TRL track and on public roads in different weather conditions and lighting. Sensors for external and internal applications were assessed for reliability and accuracy and their specifications discussed. A basic reliability study, failure mode and effect analysis (FMEA) and top level system fault tree analysis (FTA) of some possible control systems was performed.

A generic system for an internal, vehicle occupant, or external, pedestrian, protection system will comprise of a control system that includes:

- A sensor array.
- An electronic unit for processing the sensor signals (e.g. amplification).
- A programmable electronic unit to process the information (central processor, memory and input/output devices).
- An electronic interface between the sensor processing electronics and the programmable electronic unit (e.g. an analogue to digital converter).
- Output actuators with appropriate electronic signal conditioning.
- Appropriate software.

A very high reliability is required from any system used in active safety systems. An evaluation of possible sensor systems found that:

- Objects ahead of the vehicle could be sensed using frequency modulated continuous wave (FMCW) and phased array radar systems.
- Pedestrians could be sensed using a combination of systems, a transponder linked to image processing linked with a radar system for range and velocity.

Part of the research included an investigation of a prototype infrared image system. This device is made by IRISYS Ltd, who were commissioned to evaluate it at TRL to assess the potential for detecting and distinguishing a pedestrian from other heat radiating objects such as a car engine and objects, which reflect solar radiation. A car was driven around TRL's small road system with pedestrians, stationary and moving, in close proximity. A camcorder was used to

record the image that would be incident on the sensor. Thus both images could be contrasted and compared.

The infrared image system was tested and the results indicate that the system can differentiate between a pedestrian and other heat radiating objects such as a car engine and solar reflection from a tree. This system in combination with reliable radar has the potential to be used to fire an active pedestrian protection system such as airbags fitted to the front and bonnet of a car.

The tests performed clearly suggest that IRISYS thermal sensor technology is capable of detecting human targets in the vicinity of a vehicle. Figure 3 and Figure 4 summarise the results with a number of frames from the test sequences that illustrate the nature of the activity patterns generated by various signal sources.

As illustrated in Figure 3(a), the pedestrian was clearly visible as a well-defined region of thermal activity in all tests in which the field of view was appropriate. Scene clutter was substantially reduced due to the approximately isothermal background, and most static objects (such as roadside furniture) didn't create any significant thermal signals. Other non-human signal sources (in both the tests performed at IRISYS and the TRL test site) included other warm vehicles (illustrated in Figure 3(b)), the sky (illustrated in Figure 4(a)) and trees and ground heated by sunlight (illustrated in Figure 4(b)).





a

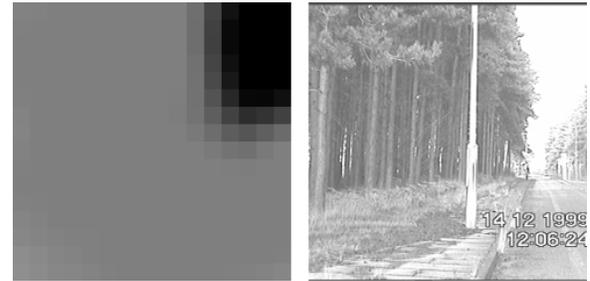


b

**Figure 3. Summary of test results: (a) typical pedestrian signature, and (b) typical vehicle signature**

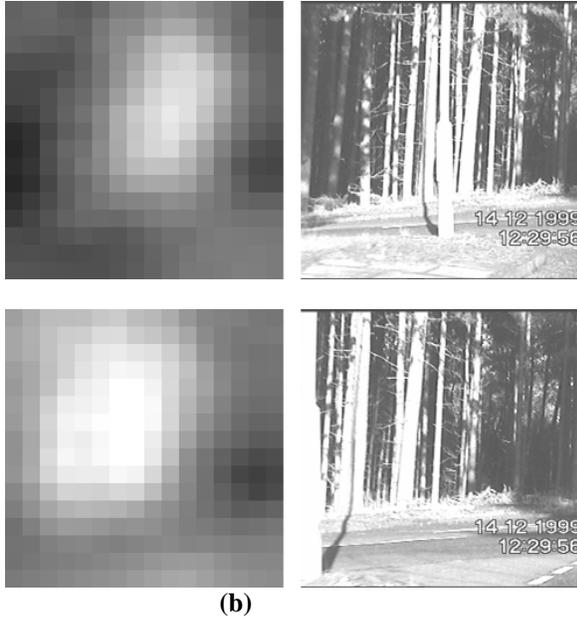
Although there were a number of non-human signal sources, the results suggest that it may be feasible to discriminate between humans and non-humans by considering the polarity, aspect ratio, size, and position of regions of activity, as illustrated in Figure 3 and Figure 4. Additionally, outlying signal sources may be excluded if their distance is known, perhaps via the use of an additional array or a different sensor technology.

The results from testing adaptive safety systems gave a clear indication that adaptive systems can be constructed that provide substantial benefit but disadvantages can also be introduced if the system is not properly optimised and tested. This should be borne in mind during the development of specifications and tests against which to judge the performance of active adaptive safety systems.



a





**Figure 4. Summary of test results:  
 (a) signature caused by sky, and  
 (b) signatures caused by solar heating.**

## CONCLUSIONS

A series of adult and child pedestrian OPAT dummy impact tests were conducted at two speeds with a medium sized saloon car or an off-road car (SUV), both of which were modified to include surface foam padding to emulate an equivalent vehicle that would satisfy the proposed pedestrian legislation. Bumper and bonnet airbags were then fitted to the saloon car for adult dummy impacts at 25mile/h (40km/h) only.

Conclusions from the pedestrian impact tests were:

- Injury criteria average values for adult and child rose by 30-40% for a 44% increase in impact energy (impact speeds were 25mile/h (40km/h) and 30mile/h (48km/h) for both types of cars).
- Head injuries could be reduced by a factor of five and chest decelerations could be halved by using pedestrian active safety systems comprising airbags on the bumper and bonnet. Lower injury potential could also be achieved for lower limbs .
- The dummy could be captured on the bonnet with a damped airbag system.
- The adult and child pedestrian impacts provided very different trajectories. The adult could be considered as a series of linked masses that progressively impacted the vehicle, whereas the child dummy was impacted almost as a complete

body, which was especially the case for the high fronted SUV, where only its head was free to rotate and impact the bonnet. The child dummy was contacted at approximately hip height by the saloon, which was close to the dummy centre of gravity.

- It has been shown in airbag tests with the saloon at 25mile/h (40km/h) that the adult dummy (and child dummy by inference) would benefit from suitably designed externally mounted airbags, as long as they are correctly damped. There would be advantages in linking the active pedestrian system to the braking system to enable the brakes to be activated prior to impact, and it is recommended that this concept should be explored further.

Sensor systems must be capable of determining the size of pedestrian and likely points of contact during trajectory, and the protection system employed must be correctly positioned and damped to be effective. This is more complicated than designing an energy-absorbing bumper. However, an airbag could be hidden and thus would not restrict styling to the same extent as body modifications and may thus be preferred by manufacturers.

An assessment of an infrared thermal sensing device and associated technology showed that such a system is capable of detecting human targets in the vicinity of a vehicle and was successful in differentiating a moving car from a moving pedestrian. Furthermore, the experiment was also able to show that a pedestrian could be differentiated from images generated by incident solar radiation and reflected solar radiation, from trees for example.

A pedestrian protection sensor needs to detect a pedestrian and examine the relative velocities to determine a likely impact. Different sensor types that may be used for pedestrian detection were assessed using failure mode and effects analysis (FMEA). The reliability factor for ultrasonic, infrared and laser sensors was between 0.8 and 0.9 but the factor was only 0.36 for radar. However, radar was otherwise technically superior particularly for the vector analysis of pedestrian movement. Current systems were used for the FMEA analysis to provide a guide and it is confidently believed that a radar device with a greatly improved factor could be designed specifically for use on a vehicle.

## **REFERENCES**

Hobbs, CA, Lawrence, GL and Clarke, CS (1985). PSC1 – a demonstration car with improvements for pedestrian protection. 10<sup>th</sup> International Technical Conference on Experimental Safety Vehicles, NHTSA, 1985 pp31-8.

Mizuno and Kajzer (1999) Head Injury Risk in Car-Pedestrian Impact. 5<sup>th</sup> IHRA Pedestrian, 1999.

RAGB: Road Accidents Great Britain: 1998: The Casualty Report.

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