

# AN EVALUATION OF THE BENEFITS OF ACTIVE RESTRAINT SYSTEMS IN FRONTAL IMPACTS THROUGH COMPUTER MODELLING AND DYNAMIC TESTING

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## ABSTRACT

Frontal restraint systems are currently designed to optimise the protection afforded to 50<sup>th</sup> percentile car occupants in one particular impact type at one particular speed, largely because of regulatory testing. The purpose of this work was to investigate active adaptive systems for vehicle occupants of different sizes and to quantify the benefits. A variety of active adaptive systems were evaluated in computer simulation using discrete and scaleable dummies and in tests on a sled rig using 5<sup>th</sup>, 50<sup>th</sup> and 95<sup>th</sup> percentile discrete dummies. The restraint system characteristics studied parametrically included: seat belt anchor height, pre-tensioner stroke and load, load limiter maximum force, airbag size and vent area, out of position occupant and a moving seat concept. The results indicated that adaptive systems can provide substantial benefits but disadvantages can also be introduced if the system is not properly optimised and tested. A moving seat concept was shown to have the potential to reduce injury substantially to smaller occupants and in some out of position cases, especially when coupled with occupant sensing and collision prediction.

## INTRODUCTION

The main purpose of this work was to investigate the performance of potential active adaptive secondary safety systems in frontal impacts. This was part of a much larger project to investigate the active adaptive safety for a range of accident types and road users. These included side impact and the protection of cyclists and pedestrians by the use of active systems external to the vehicle. Cost benefit analysis was used to select three systems to investigate experimentally. See ESV 2001, Paper 330. People vary in size and seating position and accidents vary in severity and complexity. Current safety systems do not account for this and, therefore, they are not exploiting the full benefits that may be gained from the principles they embody. Indeed, cases are known where safety has been worsened rather than improved because a system could not adapt to the needs of the occupants.

Frontal restraint systems are currently designed to optimise the protection afforded to 50<sup>th</sup> percentile car

occupants in one particular impact type at one particular speed, largely because that is what is examined in regulatory testing. Thus, these systems may perform substantially less well for that occupant in other impact conditions and for small and large occupants in a variety of crash conditions. The purpose of this work was to investigate active adaptive systems for vehicle occupants and to quantify the benefits.

However, although it may be technically possible to provide a restraint system whose characteristics can be varied to suit the occupant, it is difficult to determine what those characteristics need to be. However, to this end and as part of the overall project, some 11,000 accident cases were analysed to correlate the injury outcome for a wide range of occupant characteristics such as height, weight, body mass index, gender and seating position. This research is reported in paper 314 submitted to this conference.

Various components were sought and systems thought likely to be beneficial were identified. The method used was to investigate a wide range of system characteristics using computer simulation and then to construct the most promising systems and evaluate them in tests using a car body on a dynamic sled rig. A range of dummy sizes was used in the computer simulation and 5<sup>th</sup>, 50<sup>th</sup> and 95<sup>th</sup> percentile dummies were used in the tests.

It should be noted that the simulation was in two parts. Initially a MADYMO model was used with a 50<sup>th</sup>, 5<sup>th</sup> and 95<sup>th</sup> percentile Hybrid III dummy set. This was used to determine the most promising systems for further investigation. These systems were then investigated, in parallel, using a sled rig and a MADYMO scaleable dummy simulation package.

A very important part of any adaptive system is the use of sensors to identify the occupant characteristics. A variety of sensors with the potential to provide active adaptive control systems with accurate and reliable information on occupants has been analysed and assessed. Details of all of these parts of the project are given below. However, the emphasis in this paper is on the simulation and the system tests.

## **COMPUTER SIMULATION USING DISCRETE DUMMY MODELS.**

A series of FE models was produced using the MADYMO software suite, in order to compare active adaptive frontal impact restraint systems with the non-adaptive restraint systems currently fitted to cars. In addition, some 11,000 Co-operative Crash Injury Study (CCIS) and fatal accident cases were analysed to identify the effect of human characteristics, such as body mass index (BMI), age, gender and seating position, on the injury severity.

A non-adaptive restraint MADYMO model was supplied by Autoliv Ltd, which included a correctly seated 50<sup>th</sup> percentile Hybrid III occupant, the vehicle interior intrusions profile and crash pulse from a 30mile/h (48km/h) barrier impact test. Ninety fifth percentile and a 5<sup>th</sup> percentile Hybrid III dummy models were added by TRL, so that the effect on injury potential of changing the restraint characteristics could be quantified and contrasted for all three dummy sizes.

The restraint system characteristics were studied parametrically to determine the injury potential for each dummy size. The factors studied included:

- seat belt anchor height
- pre-tensioner stroke and load
- load limiter maximum force
- airbag size and vent area
- combinations of the above
- out of position occupant
- a moving seat concept.

Results from this study indicated that dummy injury parameters could be reduced, for example by up to 41% for HIC<sub>36</sub>, 18% for chest acceleration and 23% for chest compression by using restraint systems with certain characteristics. A moving seat concept was examined by placing an occupant further rearwards in the model before running it. It was believed that a seat that moves rearward just prior to impact would reduce the potential for injury especially for small and out of position occupants. In practice the seat would be powered or moved rearwards using a stored energy system.

The accident analysis for frontal impacts showed that injury potential varied according to age, gender, and BMI; see McCarthy, ESV 2001, paper 314. This information and the modelling results were used in a cost benefit analysis and a more complex ranking analysis using weighted factors. This analysis showed

that active adaptive frontal impact restraint systems were likely to be of great benefit and the systems that were selected for experimental testing using TRL's sled test rig were as follows:

1. Adaptive airbag with adaptive seat belt pre-tension but without load limiting
2. Adaptive airbag with adaptive load limiting and standard pre-tensioning
3. Adaptive airbag, adaptive seat belt pre-tension, adaptive load limiting and a moving seat

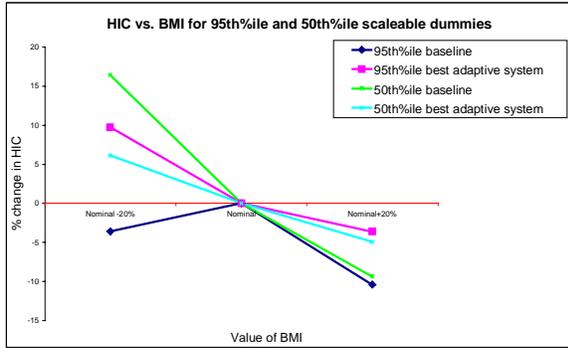
It was decided that these systems should also be evaluated using a newly acquired MADYMO scaleable dummy simulation package. Both types of evaluation are described below with the simulation being first reported and then followed by a description of the extensive experimental testing, which was based upon a typical saloon car.

## **COMPUTER SIMULATION USING A SCALEABLE DUMMY**

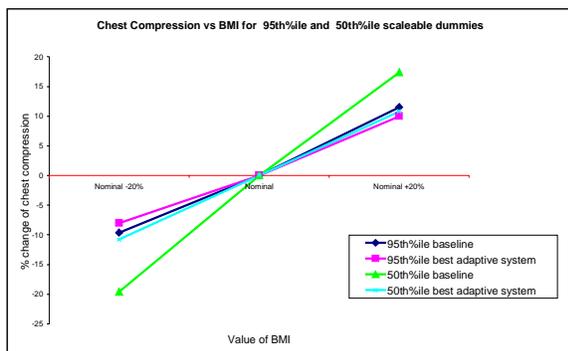
A MADYMO scaleable dummy simulation package was obtained from TNO and this was also used to investigate adaptive systems. The simulation was used to obtain results across a range of dummy sizes not available for impact testing. Body mass was varied for a given height of person. The results were used to augment the findings of the impact tests.

Impacts from 30mile/h (48km/h) were simulated, for a variety of dummy and restraint system characteristics. Two principal models were created, 95<sup>th</sup> percentile and 50<sup>th</sup> percentile for which the mass was varied by  $\pm 20\%$  to create three 95<sup>th</sup> percentile and three 50<sup>th</sup> percentile height dummy models, six in total. In order to alter the BMI, which is mass divided by height squared, it was necessary to change either the mass or height in the dummy model; the height was kept constant to isolate the variable of head trajectory, which was separately investigated.

These six dummy models were used with the MADYMO standard restraints and vehicle model using appropriate acceleration pulses and repeated with system 3 (as given above), but without the moving seat, providing 12 sets of results.



**Figure 1. Chest compression vs BMI for 95<sup>th</sup> and 50<sup>th</sup> percentile scaleable dummy models.**



**Figure 2. HIC<sub>36</sub> vs BMI for 95<sup>th</sup> and 50<sup>th</sup> percentile scaleable dummy models.**

A strong link between head injury criterion and chest compression can be seen, in Figures 1 and 2, however there were some exceptions. One such exception was the 95<sup>th</sup> percentile, minus 20% BMI HIC<sub>36</sub> value for the standard restraint system. This mismatch could be due to a number of factors, such as the interactive timing of the seat belt and airbag restraint system on the dummy. A lighter person would experience a higher acceleration than a heavier person, and it would affect all parts of the body and probably the dummy motion. In addition, HIC<sub>36</sub> is calculated over a window of 36ms and can be affected by coupled accelerations in other parts of the dummy model, which in a real occupant would be damped out by connective tissues.

An inverse relationship between HIC<sub>36</sub> and chest compression was very evident, see Figures 1 and 2. This indicates that the lighter the person (for a given height) the higher would be the HIC<sub>36</sub> value and the lower the chest compression sustained. The study included two different occupant sizes, two different occupant restraint systems, non-adaptive and adaptive and a large range of occupant masses. Thus, these results are from a wide range of cases.

## EXPERIMENTAL TESTS

### Construction and assembly

The test rig, developed by TRL, comprised a saloon car body shell with the front and rear sections removed from the 'A' and 'C' pillars rearwards to allow access for dummy placement. In addition, the removal of doors and windows permitted clear filming from the front and both sides.

A left hand and right hand drive fascia from a saloon car were cut in half and the driver halves joined to provide a twin driver set up, along with two steering columns welded in appropriate positions. This permitted two driver occupants to be tested simultaneously in each test. This was necessary to quantify test to test variation and to obtain a second set of injury data for repeat tests. The steering wheel would be replaced in the event of damage to it during a test.

The rig was further modified to incorporate the moving seat. This replaced the rigid seat with a sliding seat, which was fired rearwards at low velocity just before impact of the crush tubes. This was to simulate a medium or short occupant being moved away from the steering wheel just before the impact. This modification used a plate mounted on guides, to which the car seat was attached. During the first part of the test the seat position was at its standard setting, then a hydraulic ram moved the seat rearwards at an appropriate time. The ram pressure could be varied to provide an acceleration of approximately 3g; an accelerometer was mounted on the seat to measure these acceleration levels.

The introduction of a moveable seat required the seat belt system to be mounted on the seat. The seat was modified so that a pre-tensioner could also be fitted and could be activated prior to the seat movement, thus pulling the occupant tighter into the seat immediately before impact. A consequence of this change is that some space under the seat would be needed, but such space could be readily available on many cars.

The rig was also designed to incorporate the frontal impact model intrusions reported in the simulation data obtained with discrete dummies and which corresponded to the actual intrusions the vehicle would have suffered in a frontal impact crash. This corresponded to less than 40mm in both horizontal and vertical directions, whereas no movement was recorded for the instrument panel. This provided a platform to investigate the effect of adaptive restraint

technology on different sizes of occupant in different positions and to compare the performance with that of standard systems and the results from the FE models. Figure 3 shows the body shell mounted on the sled trolley.



**Figure 3. Frontal Impact Test Rig.**

The two pulses used for these experimental tests were derived from a saloon car full width 30mile/h (48km/h) barrier impact test and a less severe 19mile/h (30km/h) full width barrier impact test. Both of these impacts represent an accident of sufficient severity that the airbags would have needed to be deployed.

Three dummies were used during the testing, a 5<sup>th</sup> percentile female, a 50<sup>th</sup> percentile male and a 95<sup>th</sup> percentile male. These represented a range of the population of adult sizes and were used to assess the injury potential in the two impact pulses, which represented a high and low severity impact. Each test used a system with particular components and activation times predicted by the simulation to give a beneficial injury reduction. A standard non-adaptive system was tested to provide the reference for this assessment. A range of adaptive restraint systems was then evaluated and the results were compared with the simulation results. Thereafter, the results were used to determine the likely advantages that an adaptive system may provide and also to indicate possible disadvantages that need to be avoided.

### Tests

A full list of the tests to assess frontal impact protection systems is given in Table 1.

**Table 1.**  
**Impact test series**

Test No. and Velocity	Hybrid III dummy	Airbag description	Restraint system description
01 19mile/h	50 <sup>th</sup>	30 litre, 2mm,	Fixed buckle seat belt with web-locker retractor.
	5 <sup>th</sup>	32ms	
02 30mile/h	50 <sup>th</sup>	30 litre, 2mm,	
	5 <sup>th</sup>	18ms	
03 19mile/h	95 <sup>th</sup>	30 litre, 2mm,	2kN pyrotechnic pre-tensioner fired at 32ms, 4kN load limiting seat belt retractor
	50 <sup>th</sup>	32ms	
04 30mile/h	95 <sup>th</sup>	30 litre, 2mm,	
	50 <sup>th</sup>	18ms	
05 19mile/h	95 <sup>th</sup>	30 litre, 2mm,	2kN pyrotechnic pre-tensioner fired at 18ms, 4kN load limiting seat belt retractor
	50 <sup>th</sup>	32ms	
06 30mile/h	95 <sup>th</sup>	30 litre, ~42mm,	
	50 <sup>th</sup>	18ms	
07 30mile/h	95 <sup>th</sup>	30 litre, 26mm,	2kN pyrotechnic pre-tensioner fired at 18ms, 4kN load limiting seat belt retractor
	50 <sup>th</sup>	18ms	
		30 litre, 27mm,	
		18ms	
08 30mile/h	50 <sup>th</sup>	30 litre, 24mm,	
	5 <sup>th</sup>	30 litre, 28mm,	
		18ms	2kN -273ms, 4kN -248ms.
		18ms	
09 30mile/h	50 <sup>th</sup>	45 litre, ~42mm,	2kN -273ms, 4kN -248ms.
	5 <sup>th</sup>	22ms.	
		45 litre, ~59mm,	2kN -273ms, 2kN -248ms.
		22ms.	
10 30mile/h	50 <sup>th</sup>	45 litre, 23mm,	2kN -273ms, 4kN -248ms.
	5 <sup>th</sup>	22ms.	
		45 litre, 28mm,	2kN -273ms, 2kN -248ms.
		22ms.	
11 30mile/h	50 <sup>th</sup>	45 litre, 16mm,	2kN -273ms, 4kN -248ms.
	5 <sup>th</sup>	22ms.	
		45 litre, 20mm,	2kN -273ms, 2kN -248ms.
		22ms.	
Key		Size, vent dia., Fire time	Pretensioner and fire time, Load limiting seat belt retractor and rearward fire time

Note the fire times for tests 9, 10 and 11 were relative to crush tube contact. Pre-tensioners and moving seat were fired before contact to simulate pre-crash sensing.

## RESULTS OF TESTS

### Systems compared

Tables 2,3,4,5 and 6 give examples of the results for three restraint systems tested: the standard system, an adaptive system and an adaptive system with the moving seat and the most important body regions, the

head and chest. The tables are separated by dummy type and impact velocity and the test numbers quoted correspond with the test list given in Table 1. It should be noted that no one test provided the best injury reduction potential for all body regions. Thus, those tests selected for the tables illustrate the maximum benefit for given body region, which is highlighted.

**Table 2.**  
**Comparison of frontal impact test injury results from three restraint systems for a 5<sup>th</sup> percentile dummy in a 30mile/h (48km/h) impact**

Criteria \ Restraint system	HIC 36	Chest accel. (g)	Chest compression (mm)
Standard (test 02)	566	44.8	22.2
Adaptive (test 08)	578	39.9	26.9
Moving seat (test 10)	772	36.4	22.2

**Table 3.**  
**Comparison of frontal impact test injury results from three restraint systems for a 5<sup>th</sup> percentile dummy in a 30mile/h (48km/h) impact**

Criteria \ Restraint system	HIC 36	Chest accel. (g)	Chest compression (mm)
Standard (test 04)	737	40.7	41.5
Adaptive (test 07)	483	36.8	27.6
Moving seat (test 10)	670	34.8	26.4

**Table 4.**  
**Comparison of frontal impact test injury results from two restraint systems for a 95<sup>th</sup> percentile dummy in a 30mile/h (48km/h) impact**

Criteria \ Restraint system	HIC 36	Chest accel. (g)	Chest compression (mm)
Standard (test 04)	356	41.1	44.4
Adaptive (test 06)	321	47.7	32.4
Moving seat	N/A	N/A	N/A

It should be noted that the moving seat was not applicable to a 95<sup>th</sup> percentile because for these tests the seat was placed in the rearmost position already.

**Table 5.**  
**Comparison of frontal impact test injury results from two restraint systems for a 50<sup>th</sup> percentile dummy in a 19mile/h (30km/h) impact**

Criteria \ Restraint system	HIC 36	Chest accel. (g)	Chest compression (mm)
Standard (test 01)	74	25.5	26.5
Adaptive (test 05)	68	21.0	20.5

**Table 6.**  
**Comparison of frontal impact test injury results from two restraint systems for a 95<sup>th</sup> percentile dummy in a 19mile/h (30km/h) impact**

Criteria \ Restraint system	HIC 36	Chest accel. (g)	Chest compression (mm)
Standard (test 03)	58	23.5	24.8
Adaptive (test 05)	39	17.7	16.6

In general, the adaptive systems showed a substantial benefit in that injury potential was reduced. However, it was not possible to optimise the systems within the remit of this research. Thus there are anomalies, especially with the 5<sup>th</sup> percentile dummy in the 30mile/h (48km/h) test for which no clear benefit could be found for the head and chest, although benefits for the neck and pelvis were measured as given below. Moreover, in one test (11) the HIC rose to over 1000. Reasons for this are given below in the analysis of the behaviour of the moving seat. Other body regions examined were the neck, pelvis and femur loads as follows:

**Neck moment:** the dummy neck moment for 5<sup>th</sup> percentile dummy in the test at 30mile/h (48km/h) with the moving seat was 30% less than for the standard test. However, the head protection was insufficient because the airbags available for the test were insufficiently deep, thus the head was not supported by the airbag. This was evident from film and data analysis. This system did offer better chest protection than a static seat however, and further research into the performance would undoubtedly produce further potential injury reductions. Neck moment was also reduced by 35% using adaptive restraints and a standard seat.

**Pelvis:** the pelvis resultant acceleration for 5<sup>th</sup> percentile dummy in the test at 30mile/h (48km/h) with the moving seat was 21% less than for the standard test although similar benefits were measured in the adaptive system with a static seat. The

50<sup>th</sup> percentile dummy pelvis resultant acceleration was reduced by 26% in the moving seat test at 30 mile/h (48 km/h), but only by 15% for a static seat with active adaptive restraints.

**Femur:** femur loads were so low in all tests compared with the injury tolerance value of 9.07 kN that the results are not relevant.

These results give 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 in the development of specifications and tests against which to judge the performance of active adaptive safety systems.

### Moving seat tests

The effect of the moving seat on the occupants was assessed by analysis of the front and side view high-speed films and this was correlated with the instrumentation outputs. The seat timing was arranged so that the dummy could return to its normal position before impact, thus, the side view camera recorded only the final motion.

The dummy seating position was largely unaffected by the seat motion, as illustrated by the frontal view film. Seat accelerations were deliberately low, less than 5g in all cases, which still enabled the seat to move 200mm in 100-150ms with a smooth acceleration relative to the body shell, see Figure 4. The deceleration of the seat relative to the vehicle body was achieved with a variable damper, which was set to minimise the peak acceleration during each test to a maximum of 12g.

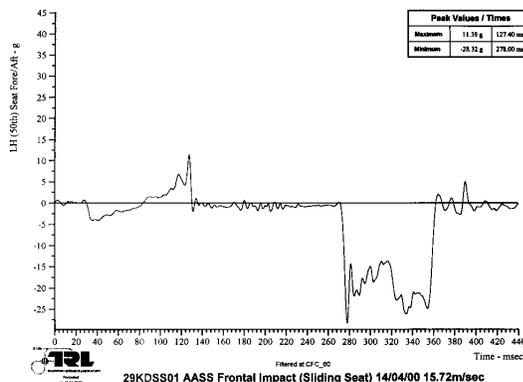


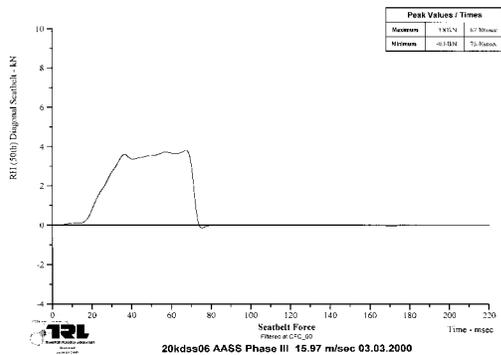
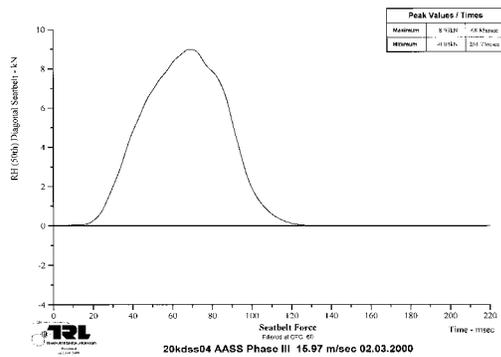
Figure 4. Moving seat fore/aft acceleration plot.

When the seat ceased to move rearward, there was a secondary rise in chest acceleration (and other criteria), which was up to twice the value recorded during the seat movement. This is because the seat was stopped by the damper, which may not have been tuned optimally for the occupant and seat combined mass. This could be optimised with further research and no doubt a vehicle manufacturer would design the mechanism to minimise this deceleration. However, these values were still only 20% of the maximum seen during the main impact and were of much shorter duration.

The variation in the seat acceleration was demonstrated by the rearward motion of the seat for the 50<sup>th</sup> percentile dummy, which was greater than that of the 5<sup>th</sup> percentile dummy, even though the total seat and dummy mass was almost 15kg more. This was because each seat was tuned individually using the bleed valves attached to the accumulator, and the damper system set to provide minimal rebound for each mass.

The specific effect of seat belt pre-tensioners was also investigated. The pre-tensioners fired 20ms before the seat was moved rearwards for all three moving seat tests, which resulted in a maximum head acceleration of 10g at 10ms, a chest acceleration of 8g max at 10ms and a chest compression of 4mm at 10ms. These values were at least as large as the values occurring as the seat moved rearwards before impact.

An important effect of seat belt load limiters was on head and neck trajectory in the reduction of neck bending, as measured by upper neck moment,  $M_y$ . Load limiting in combination with the moving seat ensured that the face approached the airbag squarely, instead of whipping down into it as happened in the tests with the standard system. This may potentially also reduce the occurrence of whiplash and facial scarring. A major benefit of diagonal seat belt webbing load limiting is the potential to limit chest loading to a specific value, see Figure 5. This will reduce chest loading, hence injuries in most cases. The load limit value can be adapted for different occupant sizes and impact conditions.



**Figure 5. Comparison of standard seat belt load with 4kN load limited seat belt for a 50<sup>th</sup> percentile Hybrid III during a 30 mile/h (48km/h) impact.**

**SENSORS**

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.

Some sensors and control systems were applicable to more than one system type, so that they were evaluated for a variety of applications. The potential to detect gender, age and physical or physiological condition of an occupant in addition to mass and position was investigated using some of the novel sensors researched. 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 very high reliability is required from any system used in active adaptive safety systems. An evaluation of possible sensor systems found that vehicle occupants could be best monitored by most of the systems. However, there would also be a requirement for an estimation of occupant mass with some sensors; the only exception would be the capacitance method as this has too low a range.

Normal design FMEA was not possible, because a detailed design would be required, but because two levels of block diagrams for the system were developed, an alternative method was employed. This consisted of assigning an impairment factor (IF) to each block, summing them and dividing by the number of potential faults to produce a normalised reliability factor (RF).

A summary of IF and RF values for four sensing systems is shown Table 7.

**Table 7. Summary of impairment factor and reliability factor for sensing systems**

Sensor	Impairment Factor	Reliability Factor
RADAR	88.6	0.36
Ultrasonic	28.4	0.86
Infra-Red	44.4	0.89
Laser	30.6	0.83

Another method of assessment used was fault tree analysis (FTA), which is a top down study that first identified the principal system failure modes and then identified less important failure modes.

An active adaptive secondary safety system will only function satisfactorily with a reliable control system. This is likely to be a central electronic module, which has inputs from external and/or internal sensors and then analyses the data produced from the sensors in real time. The characteristics needed for the restraint systems are determined by continuous monitoring of the sensors in real time and the output signals are used to implement changes and activate the system in the event of an accident. This occurs cyclically to increase the probability of a correct decision or series of decisions being made. Thus, this information gathering process is an iterative cycle.

System failures can be random or systematic. Random failures occur anywhere in the system at any time and cannot be eliminated entirely, whereas systematic failures occur because of software errors or design faults and happen at predictable times, hence can they be minimised through the implementation of the IEC 61508 for example. Techniques such as Failure Mode and Effects Analysis (FMEA), fault trees and a range of software techniques including structured languages, modular algorithms and testing routines need to be employed to analyse safety systems to reduce the chance of faults. Significant improvements in reliability could also be achieved by using diagnostic systems and fault tolerant software.

In conclusion, 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 and for functionality in adverse operating conditions. 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.

## CONCLUSIONS AND RECOMMENDATIONS

Impacts from 30 mile/h (48km/h) were simulated, for a variety of dummy and restraint system characteristics. A strong link was found between head injury criterion and chest compression and an inverse relationship between HIC<sub>36</sub> and chest compression was very evident.

Frontal impact dynamic testing at 30mile/h (48km/h) using three sizes of dummy produced the following results when adaptive restraints and moving seats were compared with a standard restraint systems:

- Chest g reduced for a 5<sup>th</sup> percentile Hybrid III from 44.8 to 36.4 (19%) with a moving seat and adaptive restraints.
- Chest compression reduced for a 5<sup>th</sup> percentile Hybrid III from 22.2mm to 20.7mm (7%) with a moving seat and adaptive restraints.
- HIC<sub>36</sub> reduced for a 50<sup>th</sup> percentile Hybrid III from 737 to 483 (34%) with adaptive restraints.
- Chest g reduced for a 50<sup>th</sup> percentile Hybrid III from 40.7 to 34.8 (14%) with a moving seat and adaptive restraints.
- Chest compression reduced for a 50<sup>th</sup> percentile Hybrid III from 41.5mm to 24.9mm (40%) with a moving seat and adaptive restraints.

- HIC<sub>36</sub> reduced for a 95<sup>th</sup> percentile Hybrid III from 356 to 321 (10%) with adaptive restraints.
- Chest compression reduced for a 95<sup>th</sup> percentile Hybrid III from 44.4mm to 32.4mm (27%) with adaptive restraints.
- Neck moment reduced for a 5<sup>th</sup> percentile Hybrid III from 33.8Nm to 21.9Nm (35%) with adaptive restraints, and to 23.5Nm (30%) with a moving seat plus adaptive restraints.
- Pelvis g reduced for a 5<sup>th</sup> percentile from 44.5 to 35 (21%) using a moving seat and/or adaptive restraints.
- Pelvis g reduced for a 50<sup>th</sup> percentile from 49 to 41.5 (15%) with adaptive restraints.
- Pelvis g reduced for a 50<sup>th</sup> percentile from 49 to 36.5 (26%) with a moving seat.

Frontal impact dynamic testing at 19mile/h (30km/h) using three sizes of dummy produced the following results when adaptive restraints and moving seats were compared with a standard restraint systems:

- HIC<sub>36</sub> reduced for a 50<sup>th</sup> percentile Hybrid III from 74 to 68 (8%).
- Chest g reduced for a 50<sup>th</sup> percentile Hybrid III from 25.5 to 21.0 (18%).
- Chest compression reduced for a 50<sup>th</sup> percentile Hybrid III from 26.5 to 20.5 (23%).
- HIC<sub>36</sub> reduced for a 95<sup>th</sup> percentile Hybrid III from 58 to 38.9 (33%).
- Chest g reduced for a 95<sup>th</sup> percentile Hybrid III from 23.5 to 17.7 (25%).
- Chest compression reduced for a 95<sup>th</sup> percentile Hybrid III from 24.8 to 16.6mm (33%).
- Neck moment reduced for a 50<sup>th</sup> percentile from 35.7 to 32.3Nm (10%).
- Neck moment reduced for a 95<sup>th</sup> percentile from 48.3 to 41.6Nm (14%).
- Pelvis g reduced for a 50<sup>th</sup> percentile from 26 to 24.7 (5%).

The results from testing frontal 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 in the development of specifications and tests against which to judge the performance of active adaptive safety systems. Mathematical modelling proved to be a reliable predictor.

In frontal impacts, the moving seat concept has the potential to reduce injury potential substantially to smaller occupants and in some out of position cases,

especially when coupled with occupant sensing and collision prediction.

Adaptive airbags can be adjusted to account for occupant mass, size and position when outputs from suitable sensors are correctly interpreted. This can improve protection in most cases.

Load limiting seat belts can reduce peak chest loading and the severity of whiplash if combined with a suitable airbag and sensing system.

Seat belt pre-tensioners can help reduce peak chest and head accelerations when force and displacement are correctly related to occupant size and body mass index.

## **REFERENCES**

Holding, P.N., Chinn, B.P. and Happian-Smith, J. (2001). Pedestrian protection – an evaluation of an airbag system through modelling and testing. ESV Paper 330.

McCarthy, M.G. and Chinn, B.P. (2001). The effect of occupant characteristics on injury risk and the development of active adaptive restraint systems. ESV Paper no. 314.

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