A NEW CONCEPT FOR A THREE-POINT SEAT BELT AND CHILD RESTRAINT SYSTEM FOR BUSES

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ABSTRACT

Buses are one of the safest modes of transport available and one of the options that governments in Europe are especially trying to promote, in order to meet congestion and emission targets. When a bus accident occurs it often becomes the focus of media and public attention, especially because the people involved had confidence in the transport and sometimes it is their sole transport reliance. In particular, school bus accidents cause great public anxiety and often make the relative safety of buses be overlooked. While the incidence of bus occupant trauma is relatively low, there is concern on how best to improve bus safety.

Three-point seat belts are a good way of improving the level of protection for occupants and it is likely that future legislation worldwide will move towards compulsory installation and use in buses. One of the problems with conventional three-point seat belts is that they need to be compatible with child restraint systems to be effective for children; otherwise the shoulder belt adds a significant risk of injury. There is an availability problem of sufficient numbers of universal child restraint systems for different mass categories (G0/G0+, G1, G2 and G3 according to ECE R-44) that ensure an adequate level of protection for occupants of all age groups. If child restraint systems are vehicle specific or integrated there is still a problem with adjustments and there is evident risk of misuse.

This paper describes the development of a new concept of three-point seat belt for buses that is compatible with adults and children over 3 years, and self-adjustable. Applus+IDIADA designed, developed, tested and patented the system under contract to FITSA (Spanish Foundation Institute of Technological and Automotive Safety). This concept intends to provide an effective, inexpensive solution to the safety of children in buses.

INTRODUCTION

Various studies of accidents involving buses have proven that the main cause of severe and fatal injuries is partial or full ejection or projection from seats.[1] [2]. Any action taken in provision of restraint systems translates to improving the relative safety of buses by means of; in the first place, avoid full or partial body ejection, from seats and secondly, reduce the risk of the bodies contacting any rigid parts in the vehicles.

Restraining all occupants, in addition to the guarantee of a survival space in case of a rollover, prevents the majority of the injuries suffered in vehicles involved in accidents. The correct use of safety belts (the main restraint system in transport) prevents the ejection of occupants in collisions where the most important direction of deceleration is the longitudinal axis of the vehicle, and also in rollovers. This can substantially reduce the number of serious injuries in the event of an accident.

The inspiration of the project comes from a study based on the reconstruction of 8 severe accidents that occurred in Spain between 2000 and 2001 involving buses, which showed the reality of the protection offered to users. None of the passengers used a safety belt including the drivers. The majority of the serious injuries and fatalities were due to non-use of restraint systems, (resulting in impacts with rigid interior parts of the vehicle following occupant projection or partial/full ejection from seats). Ejection played a role in 86% of the fatalities, and 18% of the serious injury cases.

The most relevant conclusion of this study was a recommendation that adequate restraint systems for all occupants would reduce the severity of injuries, and the number of fatalities in accidents. Of course, this is true for adults and for children, as well. Therefore, a restraint system that is compatible with all users represents an increase of safety for all users. It is a big difficulty to approach the problem of child protection in buses and coaches with the same concept as for passenger cars. Most child restraint systems to be fitted in passenger cars have been designed for a particular group of age and need a complicated set of adjustments that are almost inapplicable to public transport.

Current safety belt design is meant for adult occupants and could cause injuries when applied to children. The design and homologation of a restraint system that is compatible for adults and children would mean a significant improvement in safety of public transport.

BACKGROUND

Standards and regulations

The standards and regulations that are currently applicable to buses and public transport fail to provide a sufficient guarantee of safety to all occupants. Applus+IDIADA recognises this project as a pre-legislative step; future trends in legislation are expected to move in the direction of making seat belts in buses and coaches compulsory.

The Spanish Royal Legislative Act 443/2001: Safety Conditions in School Transport. The retention of the occupants of buses is to be offered by the seat or structure immediately in front of each occupant, except in the case where there is no such structure, then a seat belt is required, and in the case that this position is to be occupied by children from 5 to 11 years then the seat belt shall be used in combination with a booster seat.

EC Directive 2003/20: In vehicles of categories M2 and M3, the use of seat belts is compulsory for all occupants over three years old, provided that their seats are equipped with safety belts.

EC Directives 2000/3, 96/37 (Seats and their anchorages) & 96/38 (Anchorages and safety belts): It is compulsory to install seat belts in vehicles of categories M2 and M3. Two-point seat belts are allowed. There is no exact date of this directive coming into force.

ECE Regulation 80 **(**Seats and their anchorages): There are static and dynamic requirements for the vehicle to restrain the occupants through the divisions in the vehicle (seats and structures).

ECE Regulation 44 (Child restraint devices): There are static and dynamic requirements for the child restraint systems to guarantee the protection of children in frontal and rear impacts.

The current legislation needs to be revised. Future legislation is expected to be a comprehensive system that makes the installation and use of restraint systems compulsory in all seating positions for all occupants of all vehicle categories, including buses and coaches.

Case studies

Applus+IDIADA carried out a study of 8 cases involving buses that occurred in Spain between 2000 and 2001. In order to relate the levels of injury to the kinematics of the occupants, a study was undertaken to analyse the case of the driver, the occupants of the first row on the right side, the occupants of the first row on the left side, the occupants of the seats in front of the stair case area, and the passengers of a central area on the right side and the left side of the vehicle.

Case 1 (2000-01): Frontal impact, Vehicles: Mercedes Benz / O 404, Touring; Truck Volvo / FH12 4X2; Trailer Lambert/ LVFS BAST. Following a an ill-fated overtaking manoeuvre by the truck, which ended in the total ejection of the driver, and the truck on lying across the road, broadside, the bus struck the rear half of the trailer at 105 km/h. The decelerations suffered are the most important consideration in frontal impacts. The lesser lateral component influenced the movements of the occupants in the bus, due to inertia; in this case, because the driver attempted to avoid the crash by steering left, the occupant inertia was to the right. There was no utilisation of seat belts by any of the occupants.

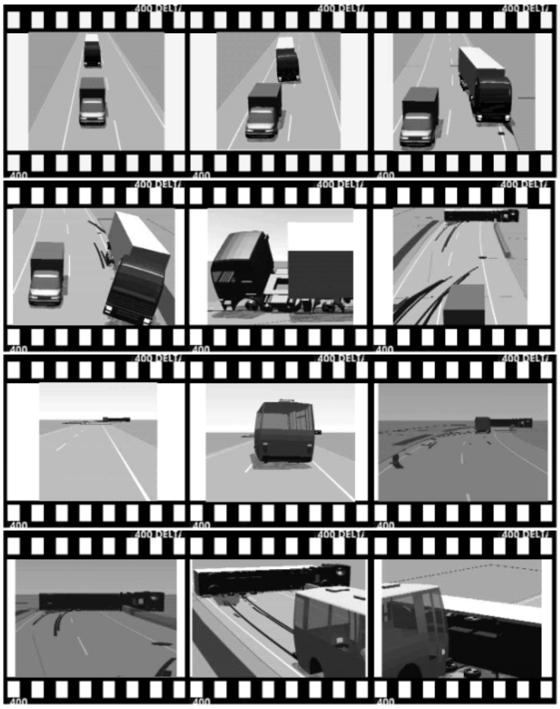


Figure 1. Reconstruction of vehicle kinematics (Case 2000-01)

The impact speed of the bus was 70 km/h and its post-impact velocity was 47,74 km/h. The difference of 22,7 km/h translates to 36 km/h EES (*Equivalent Energy Speed*) which is a measure of the deceleration pulse that the bus experienced and the value used in the simulations. For simulations, the first phase of the crash was simplified to an angled full frontal crash with the rear half of the trailer. The duration of the crash is limited to equal the duration of the deformation. If the deformation of the coach and the trailer is simplified by a uniform model, the coach and trailer suffered deformations of 0,6 m and 0,15 m respectively. The estimated deceleration pulse through the coach structure in the initial phase of the crash was 13,7 g for 46 ms. There were 3 fatalities, 18 serious injury cases and 27 minor injury cases; 48 occupants all in all.

Case 2 (2000-02): Coach careers off-course; Mercedes Benz O-303. There was 1 fatality, 10 serious injuries and 29 minor injuries – 54 occupants all-in-all. The coach careered off the road at 86 km/h and into what the driver thought was a slip road. He realised and tried to correct the error, but the drainage gutter was too deep to cross. The left side made contact with the ground at 50 km/h. This velocity was down to 18 km/h after the impact with a boulder in the gutter (ΔV= 9 km/h and EES 5 km/h). Maximum inclination 45°, rest inclination 37°. There were lateral and frontal intrusions of 0,19 m and 0,45 m respectively.

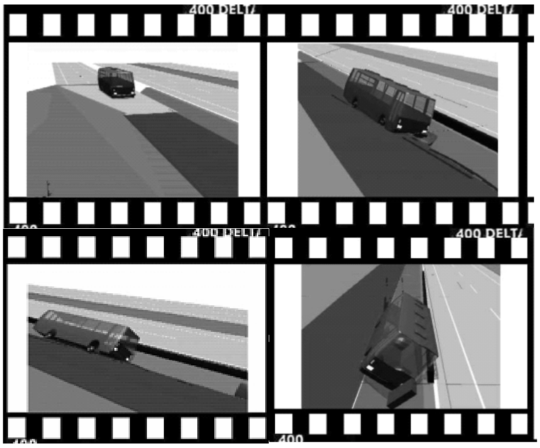


Figure 2. Reconstruction of vehicle kinematics (Case 2000-02)

Case 3: Careered off-course on a curve followed by multiple impacts; Mercedes Benz O-404. There were 24 occupants, 15 had minor injuries, 6 were seriously injured and there were 3 fatalities.

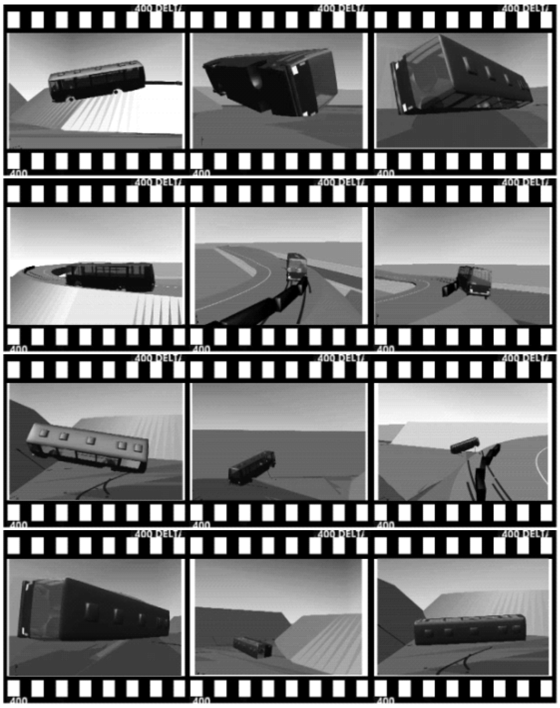


Figure 3. Reconstruction of vehicle kinematics (Case 2001-03)

According to the curvature and the coefficient of friction for asphalt, the vehicle was over the critical velocity. The coach failed to negotiate the curve at 80 km/h, went into the hard shoulder, took out the safety barrier at 74 km/h and went down an embankment finally coming to rest on a dry riverbed after impact with a wall on the edge of the bed. All the seats had safety belts; three point seat belts for the driver and the guide, and two point seat belts for the rest of the seats, but none of them were utilised.

Case 4: Careered off-course and over steered back in; Iveco Eurorider.

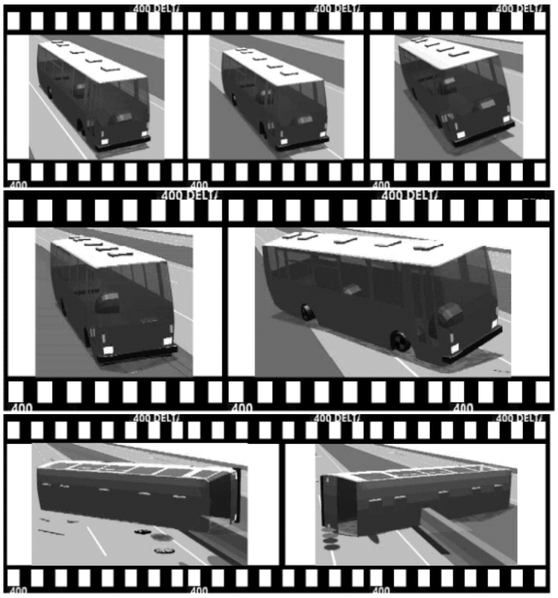
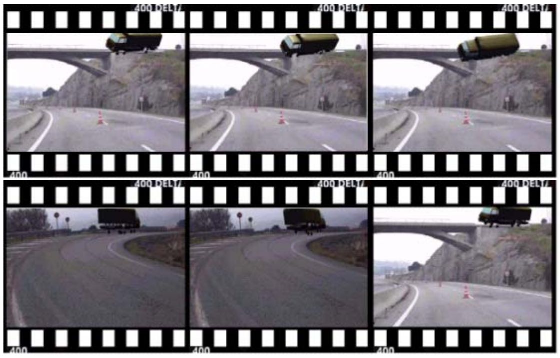


Figure 4. Reconstruction of vehicle kinematics (Case 2001-04)

Because of the rolling, the shell of the coach rather than the chassis took the brunt of the impact force. There were 7 fatalities, 10 serious injury cases, 2 minor injury cases, all in all 19 occupants. The coach careered off-course at 100 km/h. The correction attempt over steered and the result was that the coach turned over and skidded broadside into a safety barrier (motorway division). The impact velocity with the barrier was 30,28 km/h translating to EES of 16,15 km/h.

Case 5: Frontal Impact, Volvo B7R. There was one fatality, 8 seriously injured occupants and thirty seven minor injury cases; 46 occupants. A speeding truck failed to negotiate a curve approaching a fly-over. The truck went off the fly-over bridge coming to rest on the carriageway below, lying across two lanes on the left side. The coach and a passenger car were unable to avoid the truck; frontal crash for both vehicles.



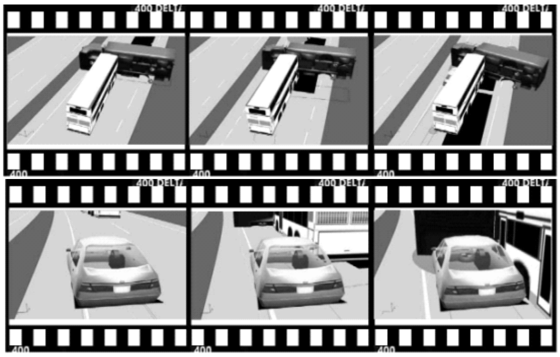


Figure 5. Reconstruction of vehicle kinematics (Case 2001-05)

The coach was travelling at 90 km/h and the calculated ΔV of the coach was 53 km/h, about 46 km/h EES. The calculated deceleration pulse of 20,3 g for 74 ms was used in simulation. There were three-point seat belts in the coach, none of which was used.

Case 6: Frontal impact, Pegaso 5036; Skoda Felicia

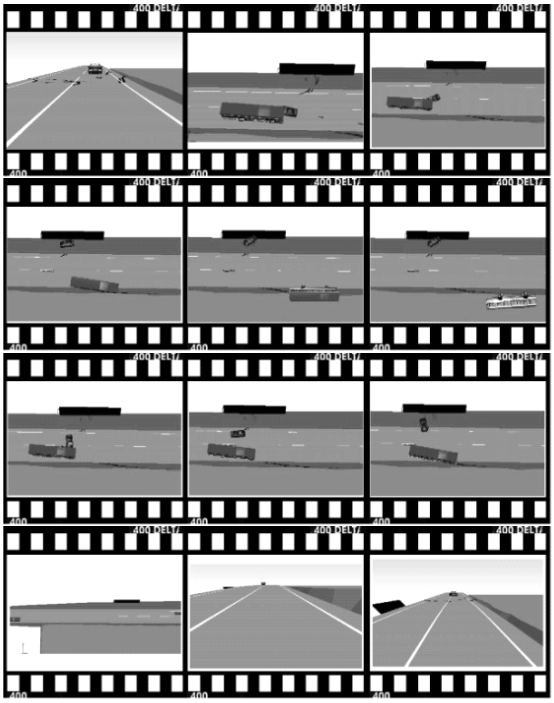


Figure 6. Reconstruction of vehicle kinematics (Case 2001-06)

There was a 30% overlap frontal crash when the Skoda failed to clear the lane during an overtaking manoeuvre. The coach left the road on the right, and went on to rollover. The impact velocity of the coach was 60 km/h and the post impact velocity was 54,5 km/h. ΔV= 5,7 km/h, EES 13,3 km/h. The calculated longitudinal average deceleration pulse was 1,7 g for 90 ms at the moment of the impact with the car. A more significant pulse of 6,5 g was produced by the impact in the gutter after the roll. Maximum intrusion: 1,80 m (front longitudinal).

There were 56 occupants in total. 16 of them suffered minor injuries and there were no other casualties.

Case 7: Career off-course and rollover; Mercedes Benz O-404. The coach careered off the road to the right, on an approach to a steep embankment (11,3 m below level road). The vehicle came to rest on its roof.

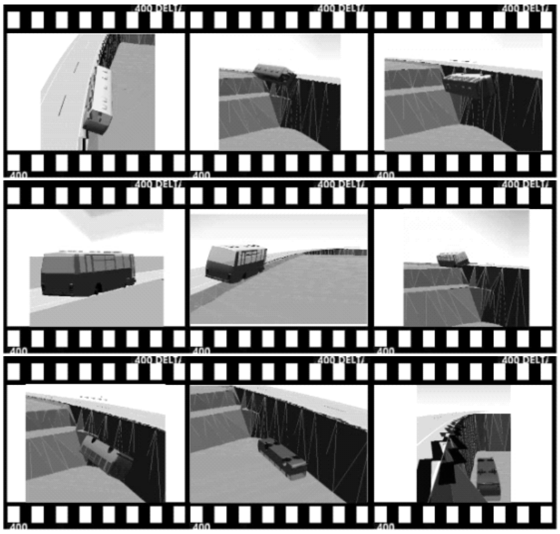


Figure 7. Reconstruction of vehicle kinematics (Case 2001-07)

There were 5 fatalities, 5 seriously injured occupants and 2 minor injury cases; 12 occupants all in all. The coach – Mercedes Benz O-404 – was travelling at 58 km/h at the moment of roll. The final resting position determined the pulse that the vehicle structure was put through, as it landed on the roof. The static deformation of the vehicle was 100 cm longitudinally in a simplified uniform model. The change of velocity ΔV was 37 km/h horizontally and the vertical velocity was 6 km/h. The calculated pulse, used in simulation, was 8 g for 140 ms.

Case 8: Mercedes Benz O-404; there was a judgement error in clearing distance during an attempt to overtake.

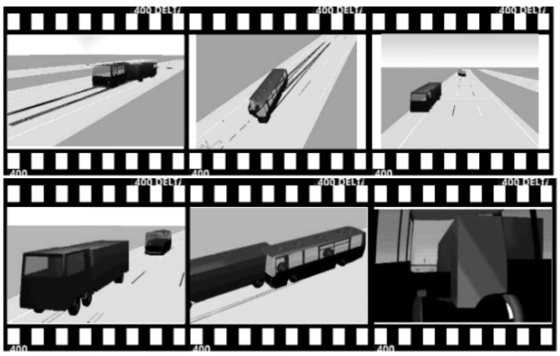


Figure 8. Reconstruction of vehicle kinematics (Case 2001-08)

There were 29 minor injury cases, 3 seriously injured people and one fatality, following an impact on the left side.

Recommendations

The study showed that in frontal impacts, the survival space of the driver and the guide is substantially reduced. The existing screens of separation between the first row and the driver or the guide, as well as between the central access and the row located in front of it, collapsed because of the load exerted by the occupants of the mentioned rows and they did not retain the occupants in these compartments as proposed by the principle of the regulation that the structure in front of the occupant should provide restraint capacity.

The general area-by-area injury characteristics show that the driver suffered fatal injuries to the head, as a direct result of impact with part of the trailer chassis, and rib-cage, due to partial ejection and impact with the steering wheel.

Occupants in the first row left suffered serious injuries due to impact with the separation screen between them and the driver. In the first row right, occupants suffered fatal injuries after ejection and impact with the trailer chassis and the other suffered lethal internal injuries due to full ejection followed by violent impact with the driver's separation screen. In the stair case area, the injuries suffered were a result of impact with the separation screen; vertebrae injuries, and head impacts following full or partial ejection. In the central areas, the occupants suffered dislocations and concussions as a result of impacts with the backs of the seats in front of them. The actual injuries depended on the seating orientation of the passengers just before the crash.

The figure below illustrates the general casualty summary for the seating positions (frontal crash); serious and/or fatal injuries in black, and minor injuries in white/grey.

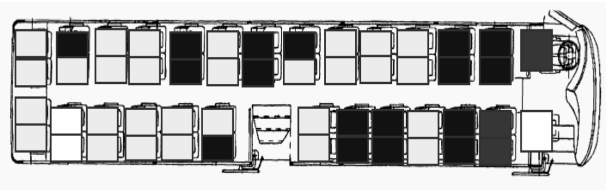


Figure 9. Area by area injury summary

In the cases of rollover there is a more even distribution of the risk of injury, due to the nature of the accident. This is due to the fact that the simplified model of a rollover can have multiple loading directions – a function of the number of turns and other cinematic properties of the vehicle. In these cases, such as the case 2001-4, the rollover that produced the most fatalities, the restraint of occupants could indeed have saved lives or at least prevented some of the severe and fatal injuries.

INTEGRATION OF CHILD RESTRAINT SYSTEM IN SEATS

The full or partial ejection or projection of the occupants was found to be the main event preceding the impacts that resulted in serious or minor injuries in all the cases that were studied. Applus+IDIADA carried out accident reconstructions, and with simulation techniques, the mechanism of the injuries sustained was illustrated – the results of one simulation are shown below.

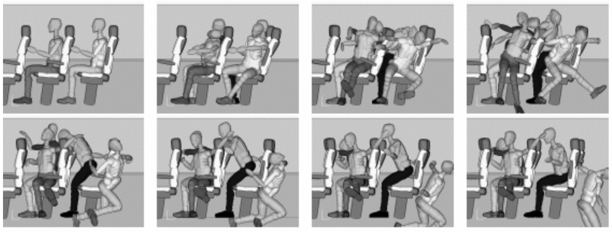


Figure 10. Without seat belts

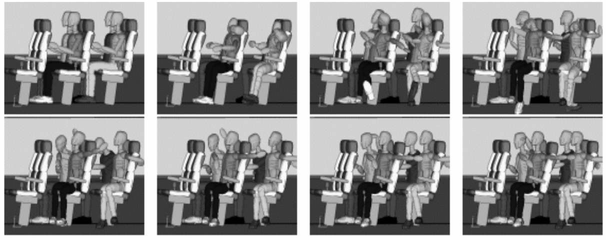


Figure 11. With seat belts (animation in MADYMO® for occupants on the right-isle seats, case 2000-1)

It is reasonable to conclude that the correct use of seat belts could have saved lives, as well as prevent some of the serious and minor injuries that occurred, simply through restraining the occupants which would have reduced the probability of impacts. In all of the cases studied, there were no restraint systems in use, either for the reason that there were not provided for all seating positions, or there were none at all. In the cases where restraint systems were provided, none of them was in use. This fact points to a fault in legislation and user awareness.

In tackling this problem it is necessary to make sure that any proposed design is compatible for use by adults as well as by children, without conceding to misuse problems, especially for children. The guarantee of restraint should cover all age-groups, and physical make-ups in order to sufficiently provide an increase in the overall safety for occupants.

In our consideration for school buses, the use of child restraint systems, integrated or accessories, is becoming a general practice. Nevertheless, technical solutions do not exist that make their incorporation in the vehicles viable.

In Spain the use of school buses is very widespread, especially for children over 3 years old – the age at which compulsory primary education starts. This raises the necessity to design a restraint system adapted to these users, but ensuring that its use is simple and foolproof.

Analysis of failure and error modes

An analysis of the different failure modes that occur related to the current restraint system was done, and there were three main categories of failure found; use of the locking system by children in adult configuration, use of the locking system in infant configuration by adults, and restraint system misuse in any configuration. In school buses, misuse is a serious issue, and in some cases it means that there is a need for guardians to check the proper use of these systems. In the cases where adult seat belts are used in combination with child restraint accessories, the process of making sure that the correct systems are anchored properly has inherent error due to the long list of criteria that need to be met. This translates to an overall risk for children even in the cases where a guardian is available, as they are also prone to errors.

The ideal solution needs to provide restraint capacity that is foolproof, and needs no preparation for any types of users, and as little supervision as possible to limit the possibility of misuse or failure in any of the modes described above.

In school buses the role of the guardian will be conveniently limited to verifying the 'use' rather than the 'proper use' of the locking system by all the travellers. This function could in the end be incorporated into the vehicle safety functions such as seat belt reminders.

Failure and related injury

Incorrect use of seat belts can result in injuries, and the risk is especially high for children. Different accident studies have found that in the cases of injuries caused by the belt, the majority of these are abdominal injuries. These injuries relate to the mechanism known as submarining, consisting of the sliding of the occupant below the lap belt. This is known to be the biggest threat posed by the lap belt when incorrectly installed or used.

Submarining takes place when the lap belt section does not retain the occupant by means of the pelvic crests, but rather by leaning into the soft weave of the abdomen, causing internal injuries in organs such as the liver or even spinal injuries. [3]

Child dummy tests

Applus+IDIADA carried out tests aimed at assessing the performance of the three-point seat belt, and the relative modes of failure; in the application of a restraint for children using a P3 dummy.

Following successful modification of the initial designs, the results of the fourth test were the following. Resulting acceleration of thorax during 3 ms: 48,61 g (below the limit of ECE R-44; 55 g), time with negative acceleration Z at thorax over 30 g: 0 ms (below the limit of ECE R-44; 3ms). No abdominal penetration was observed (in agreement with ECE R-44). The head of the dummy was contained (it did not cross planes BA and DA, in agreement with ECE R-44 vertical and horizontal displacement limits). In this test it was possible to find a configuration of a seat belt meeting the requirements described in ECE R-44.

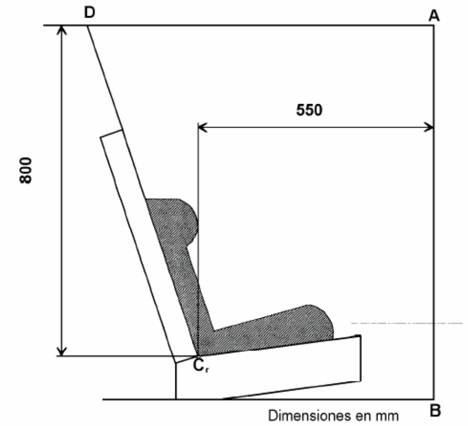


Figure 12. ECE Regulation 44 procedure

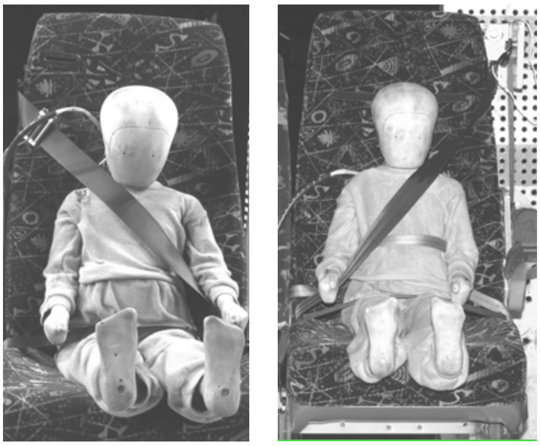


Figure 13. Dummy tests

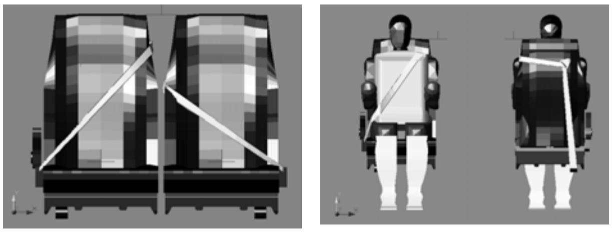
Although there are other smaller size dummies, it is considered that this restraint system design is inappropriate for the categories they represent.

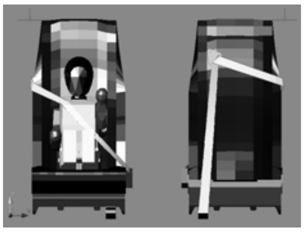
DESIGN AND DEVELOPMENT

The design by Applus+IDIADA was developed with the purpose of developing a locking system that guarantees the protection of the occupants, adults just as well as children, maintaining convenience for all type of statures, with no need of adjustments or preparation.

Applus+IDIADA raised a solution for the integration of child restraint systems in bus seats which consists of placing an extra guide of the belt at one side of the seat back.

Figure 14 shows (clockwise from left) the simulated model of the proposed system in child and adult configurations.





Integration of restraint system in seats

Figure 14.

By means of a fixed guide the belts' tendency to fall off the shoulder can be controlled to adapt to different heights according to the stature of the occupant. In the cases of adult passengers, the shoulder belt would be located at the height stipulated by ECE Regulation 14, whereas in the case of children, it would be located at the lower end. In either of the cases, the setting would not affect passing homologation since the consideration of child restraints as well as adult restraint system regulations would be addressed.

The pelvic points of anchorage will have to be placed within the vertical angle (30˚) of the P3 dummy by default. The belt will have to be equipped with a load limiter in the event that the rigidity of the seat is such that the tension produces too high decelerations of the thorax.

Figure 15. 3D model

CALCULATION OF ADULT OCCUPANT KINEMATICS WITH SIMULATION TECHNIQUES

Occupant Simulation

Prior to performing experimental tests using dummies, simulations in MADYMO® were carried out. These allowed the behaviour and performance of the system and the set-up to be evaluated through the virtual reproduction of the dummies and by simulating the true decelerations from live tests. Later, the correlation between the results of the simulation and the experimental tests was carried out in order to validate the simulation model.

Since the system developed is to be used by children as well as adults, simulation of the behaviour of an ample margin of users was reasonable. The following family of dummies was used: P3, P6, P10, Hybrid III 5th percentile female, Hybrid III 50th percentile male and Hybrid III 95th percentile male. This assures the analysis for a complete array of possible users, from a three-year-old child weighting 15 kg to an adult of over 98 kg.

Deceleration pulse

For the purposes of simulations, average pulses were used, meeting the limits of the regulations. The average pulse is shown in the graph.

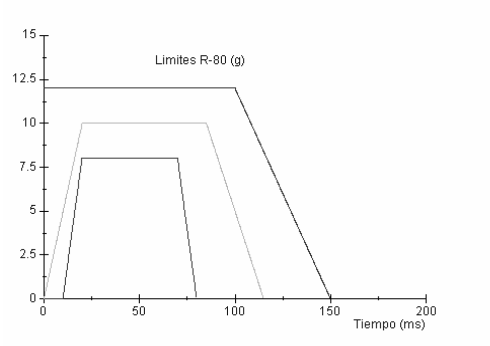


Figure 16. Limits of pulse in ECE Regulation 80 and average pulse used

The values associated with this graph are shown below.

Table 1
ECE R-80 Average pulse

Time	Acceleration
0 ms	0 g
20 ms	10g
85 ms	10g
115 ms	0 g

For the case of the child dummies (P3, P6 and P10) the same pulse was used – average within ECE Regulation 44 limits.

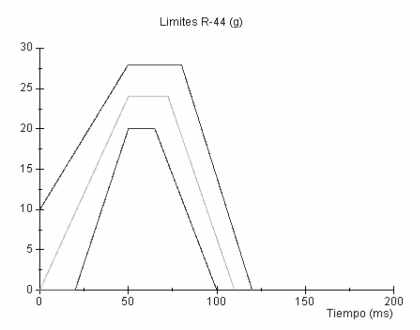


Figure 17. Average pulse used in Simulation – within limits of ECE Regulation 44

The values associated to this graph are in the table below:

Table 2
ECE R- 44 Average pulse

Time	Acceleration
0 ms	0 g
50 ms	24g
72,5 ms	24g
110 ms	0 g

Description of the simulation model

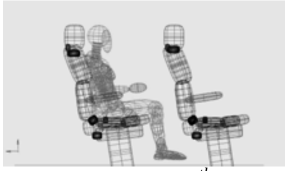
One of the objectives of the project was the development of the technology of computer numerical simulation of the behaviour of the seat belt system for trials in the laboratories of Applus+IDIADA.

A by-result of this project is that it created the possibility of making predictions on the behaviour of the restraint system for different dummies. For the accomplishment of this objective, the method of calculation by finite-element analysis techniques was used - through commercial software which is commonly used in the automotive industry.

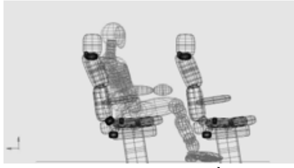
MADYMO® was used for the preparation of virtual models and calculations, Easy Crash® for the processes, Hyper View® for the post processing. The hardware used for all the simulation works was SGI Octane R12K/300 computers.

Laboratory data was obtained using Wincarat®, and the processing of data in the laboratory was made with Diadem®.

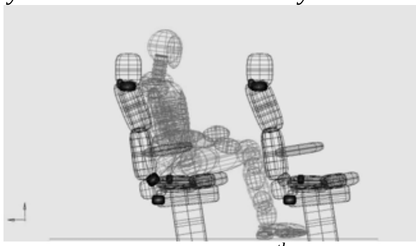
The model used the following characteristics, in the calculations by simulation: Row of two seats with anchored belt in each seat; dummy placed in the H-point, so that their position is natural.



Hybrid III 5th



Hybrid III 50th



Hybrid III 95th

Figure 18. Simulation Model

The seat belt was modelled as consisting of nine bar sections: 1st bar; from the reel placed and fixed in the rigid part of the seat (down left) and going up to a first guide slot fixed in the back. 2nd bar; from the first to the second guide slot (right part of the seat). 3rd bar; right to the way out guide slot (excluding the thickness of the back) to the dummy's shoulder. 4th bar: right to the shoulder (up to here it is considered that there is no pretension or looseness. 5th and 6th bars: cross the thorax of the dummy 7th bar: reach the buckle, rigidly fixed to the immobile part of the seat. 8th bar: from the buckle to dummy's pelvis 9th bar: finally reaches the anchorage placed between both seats which is considered fixed to the immobile part of the seat).

In the 5th and 9th bars part, a looseness of 20 mm was considered. In each step of guide slot and on the buckle a friction coefficient of 0,1 is considered. The rest of friction coefficients are considered as 0,02.

The position of guides 2 and 3 varies based on the height of the dummy but their position is considered fixed during the impact for each dummy. The material of the belt allows an elongation of 10% for a 10 kN tension.

The contacts of the seat foam with the dummy are set according to the characteristic functions of the seat model. The ground support of the feet has been placed to a natural distance of the seat. In figure 19, the modelled system is illustrated with a Hybrid III 5th percentile female, a Hybrid III 50th percentile male, and a Hybrid III 95th percentile male.

Simulation of Hybrid III 5th percentile female

This dummy has a weight of 46,3 kg and an equivalent height of 150 cm. The dummy is placed, belted-up in a natural seating position. The spacing of rows is 0,8 m and the interaction between the dummy and the back of the seats in front is monitored.

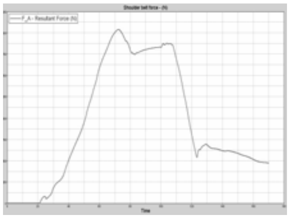
The model is put under a signal of deceleration generated from the limits in ECE R-80 (homologation of seats) as discussed in occupant simulation. The results of the biomechanics values (those of greater importance for the evaluation according to ECE R-80) are shown in the table below.

Table 3
Results of H III 5th percentile female

Parameter	Simulation Result	R-80 limits
HIC_{36}	65,5	500
Thorax Acc_3.	13,5 g	30 g
Femur Force	0,65 kN	10 kN
Femur $Force_{20}$	0,4 kN	8 kN

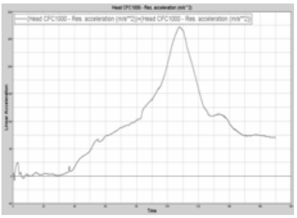
The graphs below show the main biomechanical results of the simulation.

Belt Force



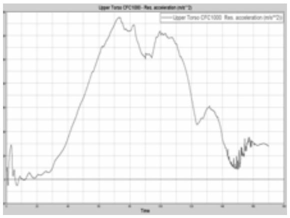
Max: 2,05 kN

Head acceleration



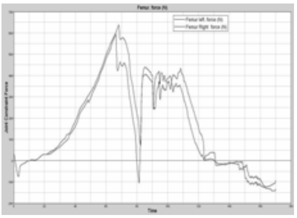
HIC_{36}: 65,5

Chest Acceleration



Max: 13,5 g

Force in femur



Max: 0,65 kN

Figure 19. Simulation biomechanical results

<u>Simulation of Hybrid III 50th percentile male</u>

This dummy weight 74,4 kg and its stature is 180 cm. The dummy is placed, belted-up in a natural seating position. The spacing of rows is 0,8 m and the interaction between the dummy and the back of the seats in front is monitored.

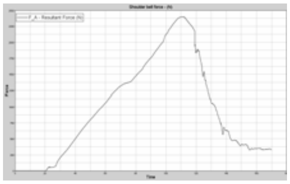
Table 4
Results of H III 50th percentile male

Parameter	Simulation Result	R-80 limits
HIC_{36}	106,4	500
Thorax Acc_3.	13,9 g	30 g
Femur Force	1,4 kN	10 kN
Femur $Force_{20}$	0,68 kN	8 kN

The model is put under a signal of deceleration generated from the limits in ECE R-80 (homologation of seats) as in the 5th percentile female simulation. The results of the biomechanics values (those of greater importance for the evaluation according to ECE R-80) are shown in the table above.

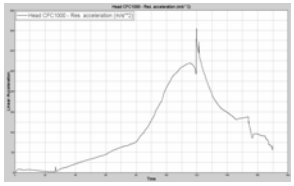
The graphs below show the main biomechanical results of the simulation.

Belt Force



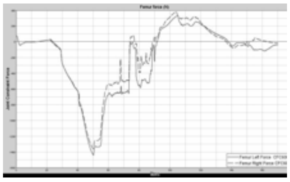
Max: 2,4 kN

Head Acceleration



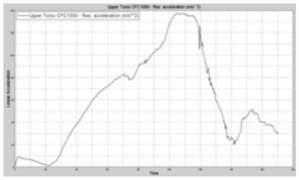
HIC_{36}: 106,4

Chest Acceleration



Max: 13,6 g

Femur force



Max: 1,4 kN

Figure 20 Simulation biomechanical results

<u>Simulation Hybrid III 95th percentile male</u>

This dummy has a stature of 185 cm and a weight of 97,5 kg.

The dummy is placed, belted-up in a natural seating position. The spacing of rows is 0,8 m and the interaction between the dummy and the back of the seats in front is monitored.

The model is put under a signal of deceleration generated from the limits in ECE R-80 (homologation of seats) as in the previous simulations.

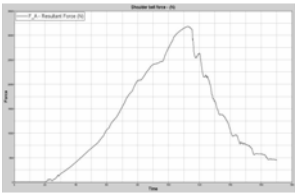
The results of the biomechanics values (those of greater importance for the evaluation according to ECE R-80) are shown in the table below.

Table 4
Results of H III 95th percentile male

Parameter	Simulation Results	R-80 Limits
HIC_{36}	115,0	500
Thorax Acc_3.	14,5 g	30 g
Femur Force	1,5 kN	10 kN
Femur $Force_{20}$	0,82 kN	8 kN

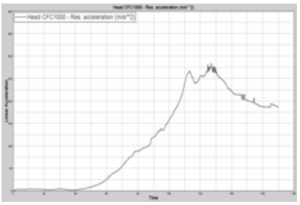
The graphs below show the main biomechanics results of the simulation.

Belt force



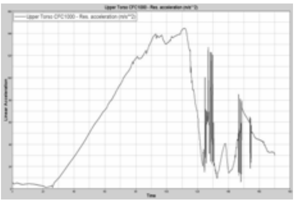
Max: 3,3 kN

Head Acceleration



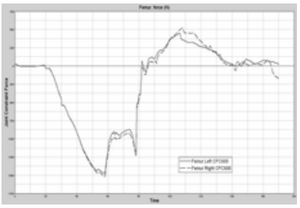
HIC_{36}: 115,0

Chest Acceleration



Max: 14,5 g

Femur force



Max: 1,5 kN

Figure 21. Simulation biomechanical results

The phase of simulation was validated by experimental tests in Applus+IDIADA facilities; technical centre in L'Albornar (Tarragona - Spain). These tests, known as sled tests, are carried out by means of a movable platform, on which the seats and the dummies are placed, simulating the deceleration caused by the impact.

The sled is stopped by means of calibrated deformable bars, and a deceleration curve is obtained under the requirements demanded in the regulations that relate to the respective tests. In the set of tests of the system as adult restraint, the settings of ECE R-80 were used, and for the tests with child dummies the settings of ECE R-44 were adopted. The series of experimental tests correspond to the simulated cases.

Therefore, a series of dynamic tests with the family of adult Hybrid III dummies discussed below was done. These tests represent head-on collisions and the human models used were that from the US standard regulations of NHTSA, Part 572. Its use is standard world-wide for frontal impact testing. Hybrid III 5th percentile female; dummy that simulates an adult of small stature, Hybrid III 50th percentile male; dummy that simulates an adult of average stature, and Hybrid III 95th percentile male; dummy that simulates an adult of big stature. The test procedure is defined in the regulation ECE R-80.

The measured biomechanics values of the adult dummy family do not have to surpass the limits defined in the regulation: 500 in the case of HIC (Head Injury Criterion), 10 kN for the load in the femur, 8 kN with a duration greater than 20 ms for the load in femur and 30 g of acceleration in the chest with a minimum duration of 3 ms.

On the other hand, for the tests of the new design with child dummy family corresponding to ECE Regulation 44, there was clear intention of attempting to obtain results that ensure performance well below the regulatory limits.

The tests were performed with dummies belonging to the P family, defined in the regulation ECE R-44. Its use is standard in Europe for frontal impacts with child restraint systems. The following dummies are the ones with which the test was done: P3 - dummy that simulates a 50^{th} percentile three year old child, P6 - dummy simulating a 50^{th} percentile six year old child, P10 - dummy representing the average ten year old child.

Although there are dummies representing younger children, the concept is not designed for children under 3 years.

During the test the dummy tends to move forwards due to inertia. To ensure the seat makes an adequate retention, it must withstand 55 g acceleration for the chest for longer than 3 ms in impacts for the head occurring over 24 km/h, with a vertical acceleration in the lower abdomen below 30 g for no longer than 3 ms and without abdominal penetration of any kind. Finally, it must be verified by means of high-speed camera shooting that the centre of gravity of the head of the dummy does not have an excursion exceeding a certain displacement point predefined with respect to the seat.

First prototypes

After the completion of the first test series on a bench to test design concepts, the first prototype seats were manufactured. The following figures show these first constructed prototypes.

Figure 22. First prototypes

HOMOLOGATION TESTS ON PROTOTYPES

Following necessary modifications on the first prototypes, a series of seats with the proposed new design for the purposes of homologation testing was built.

Figure 23 P3 dummy

Figure 24 P6 dummy

The different dummies were positioned in the seats to determine the compatibility of the device for the different users.

Figure 25 P10 dummy

Figure 26 H III 5th

The dummies used were P3, P6, P10, Hybrid III 5th percentile female, Hybrid III 50th percentile male and Hybrid III 95th percentile male. All of them displayed a suitable retention in the tests that were carried out, under the respective regulation requirements.

Figure 27 H III 50th

Figure 28 H III 95th

With the purpose of improving the retention of the dummy P3 (the one of smaller stature) and 95th percentile male Hybrid III (the one of large build), it was proposed to increase the dimension of the guide by 1 cm above and 2-3 cm below the initial design length. These modifications were carried out on the prototypes used for the homologation tests.

Homologation tests

The homologation testing of the device was made following the procedures described in the following regulations. ECE Regulation 80: Seats and their anchorages (M2 and M3). EC Directive 96/37: Seats and their anchorages. EC Directive 96/38: Anchorages of lap belts EC Directive 2000/3: Lap belts and locking system. ECE Regulation 44: Child restraint systems.

After fulfilling all the acceptance criteria, it was verified that the integrated child restraint system developed for school bus transport seats in this project meets the requirements to be approved as a functional safety system. The following slides show the film of the homologation tests carried out with P dummies.

Figure 29. P3 and P6 Dummy homologation tests

PATENT

Applus+IDIADA successfully patented the following system;

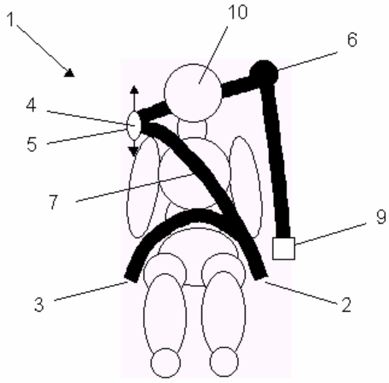


Figure 30. Patent

1.- System of guidance for lap belts (1), consisting of two lower points of anchorage (2, 3), located on both sides of the passenger, and a point of the guide (4) located at the height of the shoulder of the passenger, being the D-ring point (4) provided with a height adjuster (5), adapted to redirect the lap belt from one of the lower points of anchorage (2, 3) up to the locking system, adapted to fix the belt at the moment of the impact, positioning the strap (7) of the lap belt diagonally on the torso of the passenger, characterized because this height adjuster (5) of the D-ring (4) is automatic and consists of an element it guides fixed to the body or the seat of the vehicle, that it allows to freely move the D-ring (4) of the belt and to redirect the belt until a second fixed point of return (6), located at a height above that of the element it guides and arranged behind it, with which the height of the point of return (4) is regulated automatically, adapting to the height of the passenger. 2.- System of guidance for lap belts (1) according to vindication 1, characterized because the second fixed point of return (6) is shared in common with the seat and is located in the opposite side of the D-ring (4). 3.- System of guidance for lap belts (1) according to vindication 1, characterized because the second fixed point of return (6) is shared with the vehicle.

CONCLUSIONS

Buses and coaches are convenient modes of transport, and their safety is important especially in the cases of school buses which not only transport large groups of people, but large groups of young passengers, whose retention has specific requirements.

The standards and regulations that are currently applicable to buses and public transport fail to provide a sufficient guarantee of safety to all occupants. The current legislation needs to be revised. Future legislation is expected to be a comprehensive system that makes the installation and use of restraint systems compulsory in all seating positions for all occupants of all vehicle categories, including buses and coaches.

Studies of bus and coach accidents, including the cases covered in this project, have proven that the correct use of safety belts in these vehicles represents an increase in safety by preventing total or partial ejection and projection of occupants, which is the cause of most serious and fatal injuries.

The innovative design by Applus$^+$IDIADA is a contribution aimed at improving child safety in school buses. Applus$^+$IDIADA designed, developed, tested and patented the system of a self adjustable safety belt, integrated into bus seats, for use by adults as well as children. It has been verified that the integrated child restraint system developed for school bus transport seats meets the requirements to be approved as a functional safety system.

AKNOWLEDGEMENTS

This project was undertaken on behalf of FITSA (Spanish Foundation of the Technological Institute for Automotive Safety), who owns the rights of the patent.

The authors want to acknowledge that the collaboration of the Traffic Accident Research Unit and Passive Safety Departments of Applus$^+$IDIADA has also been essential to completing it.

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