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"Analysis of Coaches Rows Seats Distance Influence on the Passengers Comfort and Safety". ESV 2009.

ANALYSIS OF COACHES ROWS SEATS DISTANCE INFLUENCE ON THE PASSENGERS COMFORT AND SAFETY

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ABSTRACT.

Rows seats distance is a key parameter for the comfort on coaches. This distance it is also important for the passenger safety and also for example to extend the use of rearward facing CRS in a safer way. This study analyses what could be the minimum distance (based on comfort from volunteer) and how this comfort distance is affecting the passengers level of protection in R80 frontal impact with respect the minimum distance requested in current Regulations R36/R107. Volunteer testing have been performed to obtain the comfort sitting positions for coach seats geometry. Also CAE software has been used to determine minimum row seats comfort distance for a wider sample of seats geometry. In later phase, R80 sleds tests with two and four Hybrid-III dummies and with two types of seats (2-point and 3-point safety belts) have been performed, to asses the level of protection of the passengers in frontal impact at the current R36/R107 row seats distance and with the proposed one.

This study present a recommendation for a minimum row seat distance to guarantee passengers comfort and how this distance is affecting the passengers safety in frontal impact with the injury assessment criteria of both R80 and R94 for the Hybrid-III dummy. With 3-point safety belts seats, the increment on the row seat distance is beneficial for the passengers safety, except when they are unbelted and if the design of the seat is maintained. With 2-point safety belts seats, the level of protection is similar for both distances. The R94 neck injury criteria and tibia displacement are over exceed even with the lower R80 impact speed (55 kph vs 30 kph). This study shows the status of coaches frontal impact protection levels after the 2003/20/CE Directive has been made compulsory the use of the safety belts in coaches even in the city and road travels.

INTRODUCTION - OBJECTIVES.

Nowadays, the coaches seat spacing is established in the UNECE regulations to a minimum of 680 mm for the class II and III vehicles. The tendency in the market is to maintain this distance at minimum level in order to increased the number of available passengers seats in the vehicles. Garcia and Quintana-Domeque (2007) have shows the secular growth of the height in the population of 10 European countries during last decades. This growth in the height has conducted to a situation that during last years largest number of passenger can feel uncomfortable in the coaches travels. When the seat spacing is compared with the train seat spacing the coaches are in worst situation. It could be important to maintain a high level of satisfaction in the coaches transportation in order to not start a decreasing tendency in the use of this transport method in the population.

The ergonomics study conducted have been oriented to obtain a reliable minimum seat spacing that could be evaluated as comfortable for a large sample of the population, including the tallest and shortest ones.

As seat spacing is influencing the passenger safety in frontal impact, the new proposed seat spacing distance has been evaluated in terms of passenger safety. This evaluation have been performed for the two seat spacing distances, the actual and the recommended one from the ergonomics study.

METHODS.

ERGONOMIC STUDY.

To analyze the position of comfort in coach seats, measurements were made with volunteers. The selection of volunteers is done with the aim of having the following percentiles of the population: 5^{th} female, 50^{th} male and 95^{th} male. To determine the comfort position of each percentile on a coach seat we follow the recommendations found in the literature and also through tests conducted with volunteers on a seat selected mounting on a platform. Output form these volunteers have been used to obtain the minimum distance between seats in the module test and the maximum angle of inclination of front back until volunteer leg contact. These parameters measured in the laboratory have been used to perform an analysis with the selected software ergonomics (CATIAv5).

In a latter process, different parameters have been considered to extend the evaluation of comfort to a wider sample of seats coaches using the CAD software, these are:

- Seat back dimensions and angle.
- Sitting angles.
- Armrest.
- Height, deep, wide and surface of the cushion.
- H point height (closely to popliteus muscle).
- Free space for lower legs.

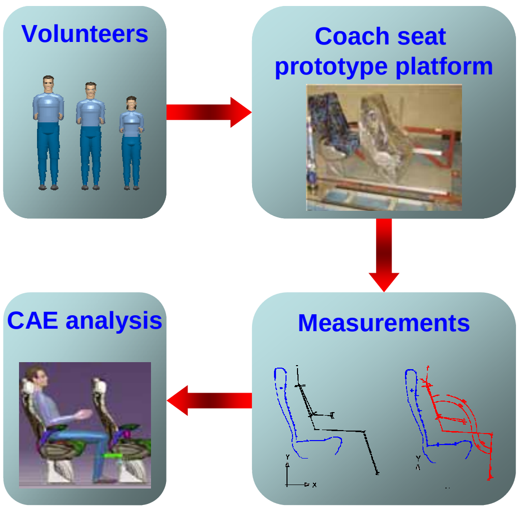


Figure 1. Ergonomic study methodology.

SAFETY STUDY.

For the safety study there were conducted a total of 12 sled tests. These tests have been performed as specified by the ECE R80 (i.e. 30-32 kph with a mean deceleration between 6.5 – 8.5 g). Six tests were performed at a short distance (the minimum distance required by the ECE R36 - 680 mm) and the others to a greater distance (obtained through the ergonomic study). It has also tested different configurations (restraint systems and seat occupancy). Both seat belts with 2 points and three points have been tested. Three scenarios-configurations have been identified to perform the tests (two of them taken from the ECE R80), these settings are:

- **Setup 1:** Safety belts fastened (two rows of seats with four dummies). *Objective:* asses rear passengers safety when forward seat if loaded/deformed by its own passengers. This is considered the most realistic configuration.
- **Setup 2:** No belts fastened (from ECE R80 – Test 1). *Objective:* asses form seat restraint performance.
- **Setup 3:** Safety belts fastened (from ECE R80 – Test 2). *Objective:* asses passengers impact against a free front seat.

As shown above, the latter two configurations correspond to regulatory tests (ECE R80), while the first configuration corresponds to a real situation.

		Setup 1	Setup 2	Setup 3
Seat Belt	Distance			
2P	680 mm	X	X	X
	Ergonomic	X	X	X
3P	680 mm	X	X	X
	Ergonomic	x	X	X

Figure 2. Sled tests setup configuration.

Each sled test was conducted with two high speed cameras (one on each side) with a sampling rate of 1000 fps. In addition, the contacts in the back of the seats have been checked (using the same colour code as in EuroNCAP frontal impact).

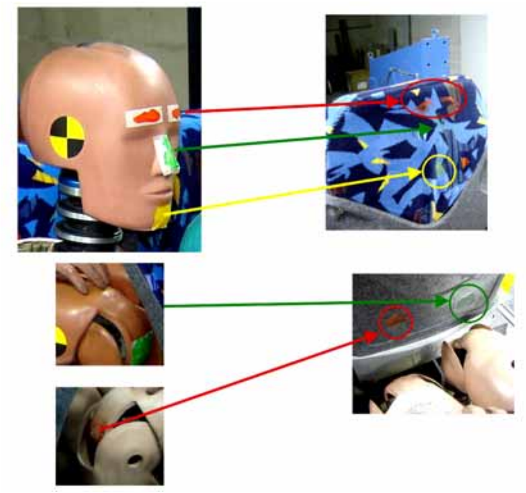


Figure 3. Colour codes for checking the contacts.

This methodology allows for a comparative analysis between the different distances between seats tested (main objective of the study), different scenarios selected (for the same restraint system and distance) and the different safety belts configuration (for the same scenario and distance).

Below is the nomenclature used in the tests, in order to clarify the different images or graphs shown later.

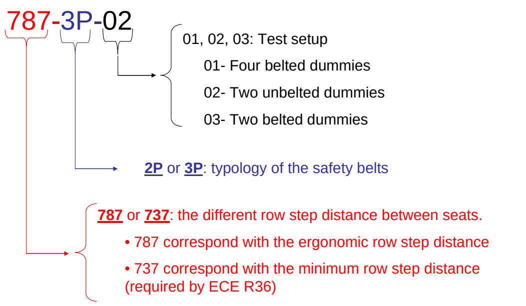


Figure 4. Nomenclature used in the sled tests.

To analyze the results, four Hybrid III 50^{th} male dummies have been used with the following instrumentation:

Dummy Hybrid III 50^{th}			
Dummy part	**Instrumentation**	**Direction**	**Dummy**
Head	3 axis accelerometer	Ax Ay Az	LD / RD
Neck	Upper neck load cell	Fx Fy Fz	- / RD
		Mx My Mz	- / RD
Thorax	3 axis accelerometer	Ax Ay Az	LD / RD
	Displacement	Dx	LD / RD
Pelvis	3 one axis accelerometer	Ax Ay Az	LD / RD
Right femur	Load cell	Fz	LD / RD
Left Femur	Load cell	Fz	LD / RD
Right tibia upper	Displacement	Dx	LD / RD
Left tibia upper	Displacement	Dx	LD / RD
LD = Right dummy. RD = Left dummy			

Figure 5. Instrumentation used in the sled tests.

The degree of safety of the seats has been checked after running the tests. This would have taken the criteria of ECE R80. Since the ECE R80 have a shorter injury criteria assessment than a more recent ones regulations, it was decided to increment the aim of the study introducing the criteria imposed by ECE R94. Below, there is a table with the analysed requirements:

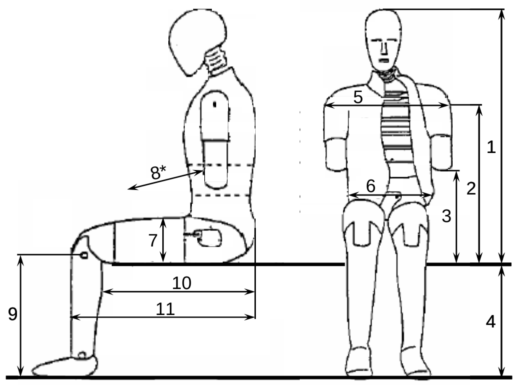
	Criterion		Reglamentation
Head	Head injury criterian (HIC_{36ms})		ECE R80
	Head resultant acceleration (3ms)		ECE R94
Neck	Neck injury criteria (NIC)	Axial force	ECE R94
		Shear force	ECE R94
		Extension moment	ECE R94
Thorax	Thorax compression criterion (ThCC)		ECE R94
	Thorax resultant acceleration		ECE R80
	Viscous criterion (V*C)		ECE R94
Leg	Femur compression force		ECE R80
	Movement of the sliding knee joints		ECE R94

Figure 6. Injury criteria analysed.

RESULTS.

ERGOMOMIC STUDY.

For the ergonomic study has been used a total of nine volunteers (three for each percentile). To check if the sample is representative, it have been taken some external measurements for each of the percentiles in a 90 degrees backrest chair. The following figure shows the dimensions taken of the volunteers:



	Group 1: 5^{th} Female			Group 2: 50^{th} Male			Group 3: 95^{th} Male		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	804	840	775	888	918	903	952	974	918
2	560	595	520	650	648	640	670	700	670
3	235	245	200	250	240	220	235	270	235
4	415	405	410	440	460	490	500	510	510
5	369	363	384	439	444	450	456	425	471
6	363	379	359	333	355	365	396	384	427
7	121	125	112	160	137	145	135	140	155
8	230	240	230	290	310	290	300	295	310
9	445	450	445	515	525	540	560	560	550
10	460	468	466	530	560	505	545	567	564
11	550	580	565	635	665	640	655	685	701
A	1530	1570	1500	1760	1800	1770	1840	1910	1850
B	48	55	50	80	88	80	80	83	95
	A: Total height. B: Total mass (kg). Dimenssions in "mm".								

Figure 7. Volunteer measurements.

Once the general measures for each volunteer is done, the volunteer was sited in a real seat coach (unaccompanied) and remains for at least 20 minutes. When the volunteer is comfortable enough, a number of representative points are taken in order to obtain a stickman of the volunteer. These points are taken from Appendix K of UMTRI report. Each measuring point was taken with a three-dimensional measuring machine (FARO-Arm®). Below there is an example of the measurement points taken as reference (Figure 8) and the measurement of a volunteer about his seat (Figure 9).

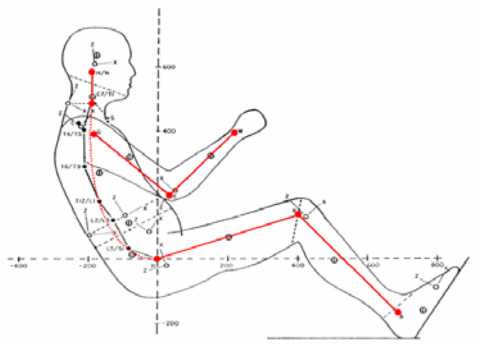


Figure 8. Reference points.

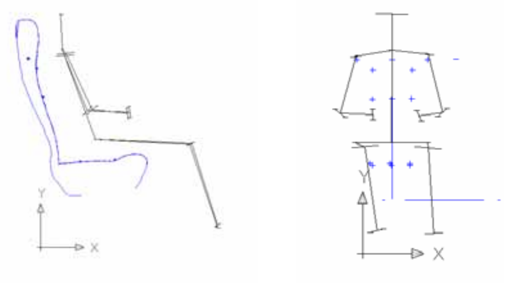


Figure 9. Example of the measurements taken.

Once the volunteers got their position of comfort and measurements made with the FARO-Arm®, the forward seat was moved until the volunteer ceases to be in a comfortable position (measurement the step between rows of seats). With this distance between seats, the backrest (of the front seat) was reclined until the volunteer got another uncomfortable position. The measures of the step between seats and the back tilt are shown below:

		Distance L (mm)	Distance H (mm)
Group 1 5th Female	Volunteer 1	780	723
	Volunteer 2	825	768
	Volunteer 3	770	713
Group 2 50th Male	Volunteer 4	680	623
	Volunteer 5	740	687
	Volunteer 6	785	728
Group 3 95th Male	Volunteer 7	670	613
	Volunteer 8	635	578
	Volunteer 9	605	548

Figure 10. ***Distance L:*** **step of rows.** ***Distance H:*** **internal distance between backseats.**

		Angle α (°)	Contact
Group 1 5th Female	Volunteer 1	60.5	Rear seatback tray
	Volunteer 2	55.5	Seatback
	Volunteer 3	57.0	Seatback
Group 2 50th Male	Volunteer 4	69.6	Seatback
	Volunteer 5	58.7	Seatback
	Volunteer 6	54.7*	Maximum reclined
Group 3 95th Male	Volunteer 7	54.7*	Maximum reclined
	Volunteer 8	68	Upright position
	Volunteer 9	58.1	Seatback

Figure 11. Seatback angles.

Two types of ergonomic position were obtained for each group percentile representing by the volunteers selected. One more upright (back support on the backrest of the seat), while the other is lying stretching the legs. These measurements can be seen in Figure 9.

In the literature, there were no comfort parameters for coach passengers, perhaps the closest comfort position is the driving position in coaches. This ergonomic position is defined in Figure 12. The five angles defined along with anthropometric measurements taken (see Figure 7) uniquely define the volunteer.

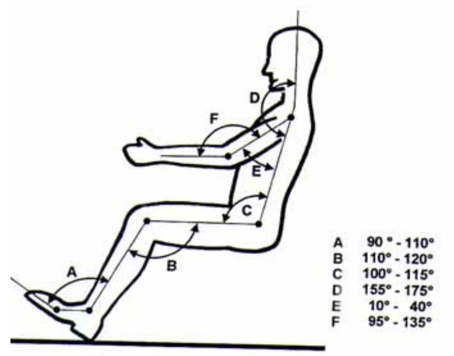


Figure 12. Position of comfort for coach drivers (Kraus - 2003)

In the case of the angles defined in the legs (back - femur / femur - tibia) the average of the two angles has been taken. These angles can be seen in the figure below.

		Tibia - Foot A	Femur - Tibia B	Back - Femur C	Back - Neck D	Back - Vertical D'
Group 1 5th Female	Volunteer 1	102	122	137	159	26
	Volunteer 2	70	84	122	167	18
	Volunteer 3	91	104	126	160	23
Group 2 50th Male	Volunteer 4	85	92	114	159	18
	Volunteer 5	83	85	115	170	25
	Volunteer 6	118	127	120	154	20
Group 3 95th Male	Volunteer 7	91	87	105	149	20
	Volunteer 8	109	111	113	162	20
	Volunteer 9	88	91	113	154	20

Figure 13. Angles of the comfortable position.

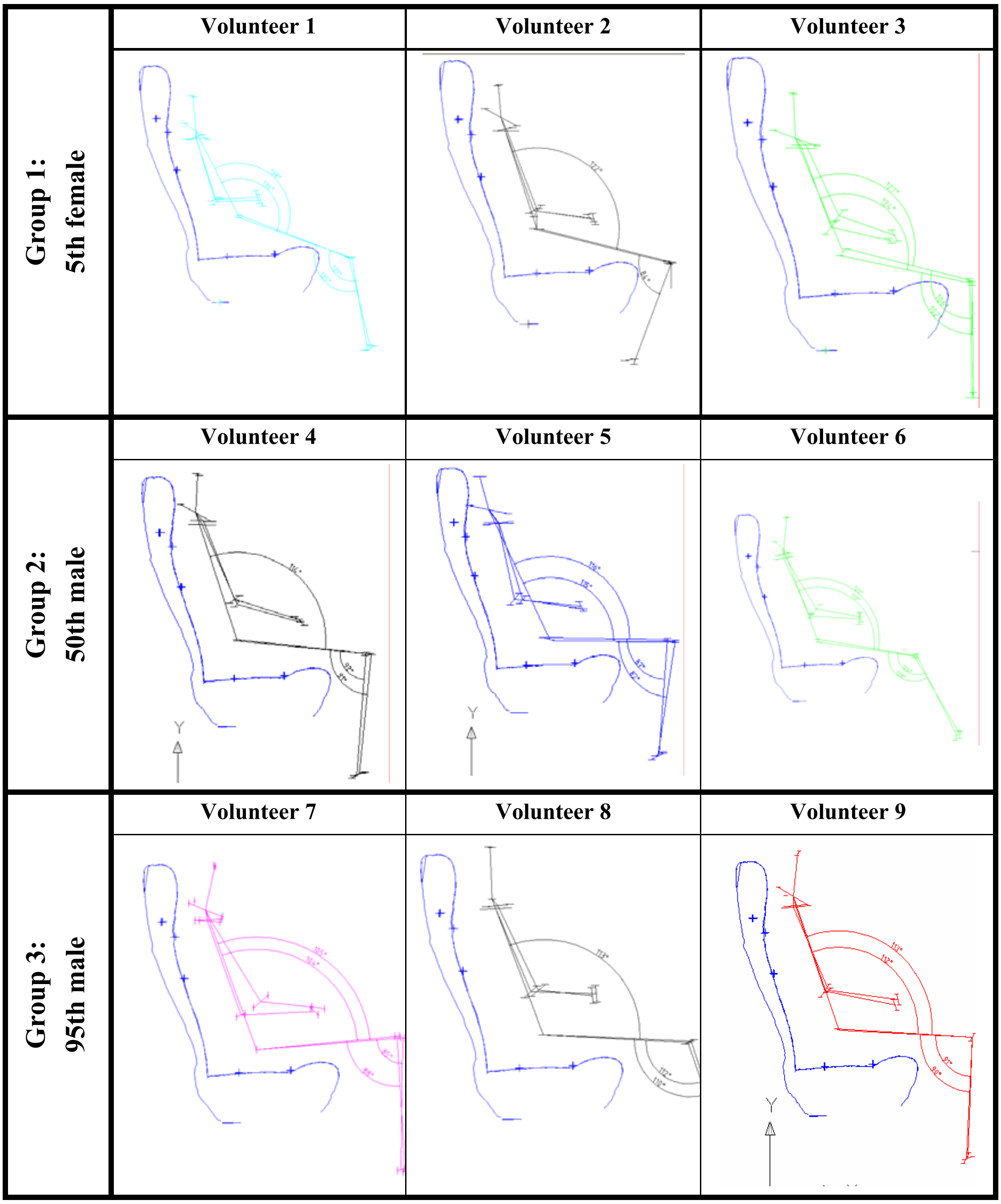


Figure 14. Measurements taken from the volunteers.

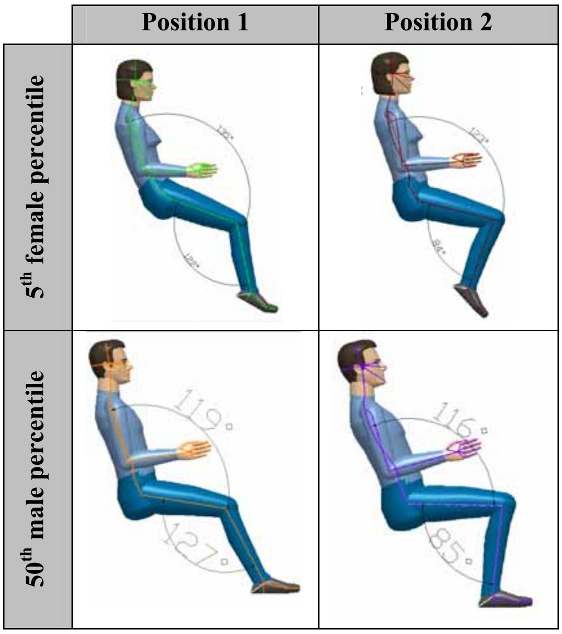
Comparing the angles measured in the volunteers with those defined as angles of comfort it is obtained that:

- The values of the ‘A’ angle (tibia to foot) is located between 70º and 118º, but the largest number of respondents is around the 85-90º. This range is higher than the reference, however, this is because the volunteers support the foot in a horizontal plane, while the reference is set for a driver that support their foot on a pedal.
- The ‘B’ (femur to tibia) values are between 84º and 127º. Here the two

trends mentioned above are shown. The more upright position obtained 'B' angle values of 84-92º, while the reclining position is at values around 105º to 125º (similar to the reference position).

- The 'C' (back to femur) values lie between 105 and 137º. It is noted that for the smallest volunteers (5th female) got angles much greater than in other volunteers. This is caused by the height of the chair, in which the small volunteers were able to recline their back in order to rest their foot on floor. For other volunteers, got values between 105º to 120º, close to the reference.
- The 'D' (back to neck) values are between 149º and 170º. Only one volunteer is outside the reference range (155º-175º), by 6º.

These data have been entered into the ergonomic module of CATIAv5. Since it has been proven that there are two tendencies in the positions for each percentile, these two positions were analysed through the ergonomics module. Finally a total of 6 models were necessary to study (two positions for each of the percentiles).



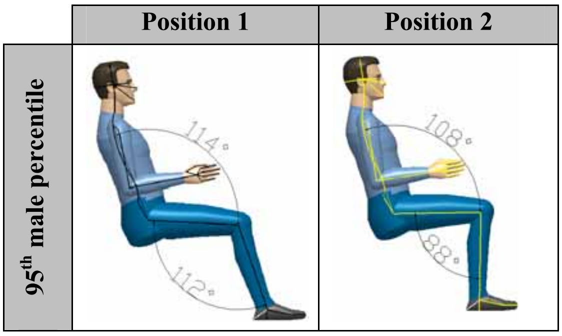


Figure 15. Different models analysed.

Once obtained the various percentiles, it is necessary to incorporate into the ergonomic model different seats for a larger and reliable study. First, the volunteers seat tested were taken as a reference and incorporate into the model, then through a market study (25 real seats were measurement), the maximum and minimum dimensions of the seats had been obtained. These measurements are shown bellow:

	Seat test	Maximum	Minimum
Total heigh (mm)	1128	1044	1153
Seatback angle (º)	22	18	25
H point (mm)	503	470	520
Length pad (mm)	468	430	490
Seat/pad heigh (mm)	465	425	495

Figure 16. Seat dimensions.

Once entered into the model the percentile, their comfort position and the seats, a simulation matrix is defined in order to perform different virtual checks. The distance between seats and backrest inclination were varied into the model. Figure 17 shows the matrix of the performed simulations.

		5th female	50th male	95th male
Upright position of seatbacks	Seat test	X	X	X
	Maximum	X	X	X
	Minimum	X	X	X
Reclined of the front seatback	Seat test	X	X	X
	Maximum	X	X	X
	Minimum	X	X	X
Reclined of both seatbacks		X	X	X

Figure 17. Simulation matrix.

SAFETY STUDY.

A total of 12 sled tests were being performed as described above. Six of these tests have been conducted with the minimum distance between seats required by regulation (680 mm) which corresponds with a passage between seats of 737 mm. The other six tests were performed with the ergonomic distance (mentioned later in this article), which corresponds to a distance between seats of 730 mm (for the tested seat it was a row step distance of 787 mm).

Each of the registered signals have been filtered according to the requirements imposed by regulation (ECE R80, ECE R94 or SAE J211, depending on the criterion to be evaluated). For the analysis of results, the most important data of each test have been taken into account, and the signs that do not coincide with the direction of impact were not taken into account. The following figure shows the signals that have been taken for analysis:

Body part	Signal
Head	Resultant head acceleration
Neck	Upper neck force X (+)
	Upper neck force Z (Tension)
	Upper neck moment Y (Extension)
Thorax	Resultant thorax acceleration
	Thorax deflection
Pelvis	Resultant pelvis acceleration
Femur	Right femur force Z (Compression)
	Left femur force Z (Compression)
Knee	Right knee slider
	Left knee slider

Figure 18. Signals used for the result analysis.

Below is shown a comparison of each of the scenarios tested (shown in Figure 2) with equal restraint system and varying the row step distance. A comparison of the kinematics of the tests (at 0, 50, 100 and 150 ms after the start of the test) and the maximum values of recorded signals were done.

Setup 1 – <u>3 point seat belt.</u>

The sequence of images shows that the rear ones dummies do not impact with the head against the back seat (regardless of distance). This fact is due to the deformation of the seat back caused by the front dummies through the third point of the safety belt. In both distances, the knees impact against the front seat, while the long distance contact is much lower (as it can be seen in the compression load of the femur - Figure 20).

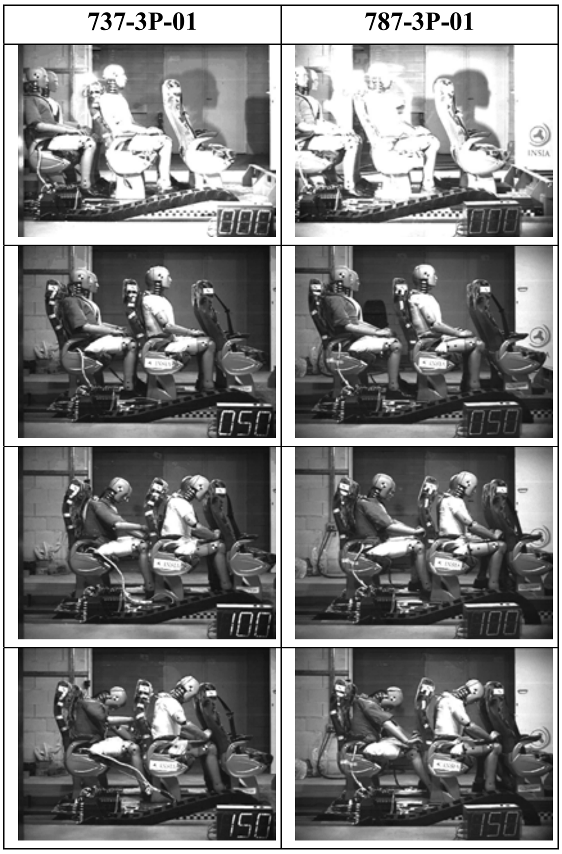


Figure 19. Sequence of images for setup 1 (3P seat belt).

	737-3P-01		787-3P-01	
Signal	Rear left	Rear right	Rear left	Rear right
Head AcRes (g)	34.38	33.57	27.11	26.53
UpNeck Fx (N)	-	99.12	-	73.89
UpNeck Fz (N)	-	1177.82	-	897.06
UpNeck My (N·m)	-	-12.24	-	-13.15
Thorax AcRes (g)	18.24	17.84	18.31	17.61
Thorax Def (mm)	-5.85	-10.99	-9.91	-17.66
Pelvis AcRes (g)	27.22	27.88	19.35	19.41
Right Femur Fz (N)	-1348.13	-1251.8	-890.82	-169.37
Left Femur Fz (N)	-1016.16	-1303.12	-154.28	-1040.62
Right Knee Slider (mm)	8.88	3.53	4.7	0.33
Left Knee Slider (mm)	4.28	7.9	0.1	5.36

Figure 20. Signals comparison (Setup 1 – 3P).

Setup 2 – <u>3 point seat belt.</u>

In this configuration, the occupants were not using the restraint system. In the first moments there was a free movement of occupants until impact with the knees (Figure 21). After this, there was a rotation of the body head, neck and shoulders contact with the front seat back. In long distance configuration, the relative velocity of impact is greater, so the values recorded in the head, neck and femur are greater, with increased values at around 15-20%, sometimes reaching 30% (Figure 22).

737-3P-02	787-3P-02

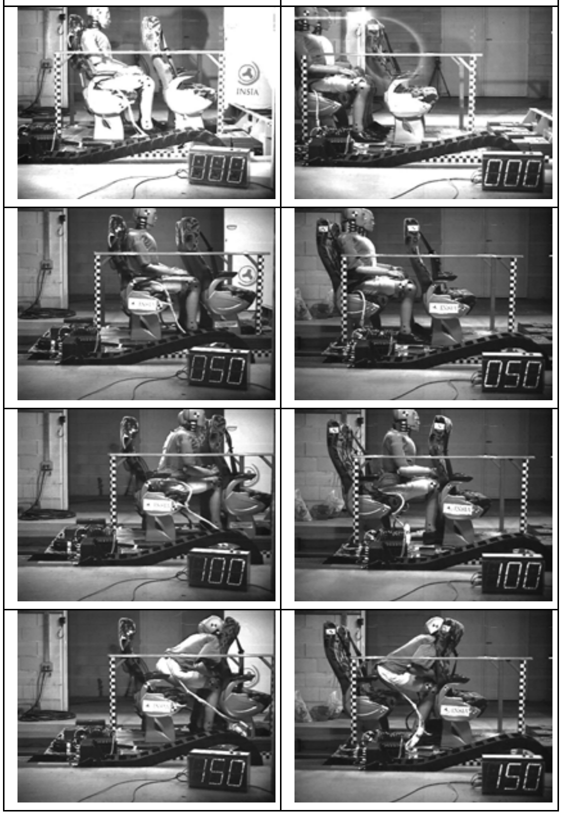


Figure 21. Sequence of images for setup 2 (3P seat belt).

	737-3P-02		787-3P-02	
Signal	**Rear left**	**Rear right**	**Rear left**	**Rear right**
Head AcRes (g)	89.57	87.2	102.45	107.14
UpNeck Fx (N)	-	1824.4	-	1456.26
UpNeck Fz (N)	-	1791.15	-	2118.25
UpNeck My (N·m)	-	-29.13	-	-46.53
Thorax AcRes (g)	18.41	19.19	21.61	21.74
Thorax Def (mm)	-2.48	-2.25	-0.08	-0.94
Pelvis AcRes (g)	25.44	25.77	32.88	34.66
Right Femur Fz (N)	-3165.13	-3872.17	-3615.07	-4209.79
Left Femur Fz (N)	-3790.15	-3306.67	-5249.11	-4529.61
Right Knee Slider (mm)	14.05	10.81	13.54	14.13
Left Knee Slider (mm)	11.72	13.62	13.31	15.09

Figure 22. Signals comparison (Setup 2 – 3P).

Setup 3 – 3 point seat belt.

In this configuration, two occupants used the restraint system (in this case the 3-point belt). It is noted that in both distances the knees impacted against the front seat back. Also occurs with the head (because the front seat did not have an occupant and it was not deformed through the 3-point belt). In long distance, both contacts the head and the knee are much lower than in the short distance (with values 50% lower in the head acceleration or femur force).

Figure 24 shows that the signals of the left side dummy on the left (in the long distance test) are crossed out, this is because during the test its safety belt did not work properly and the retractor did not locked. This fact is evident in the kinematics secuence.

737-3P-03	787-3P-03

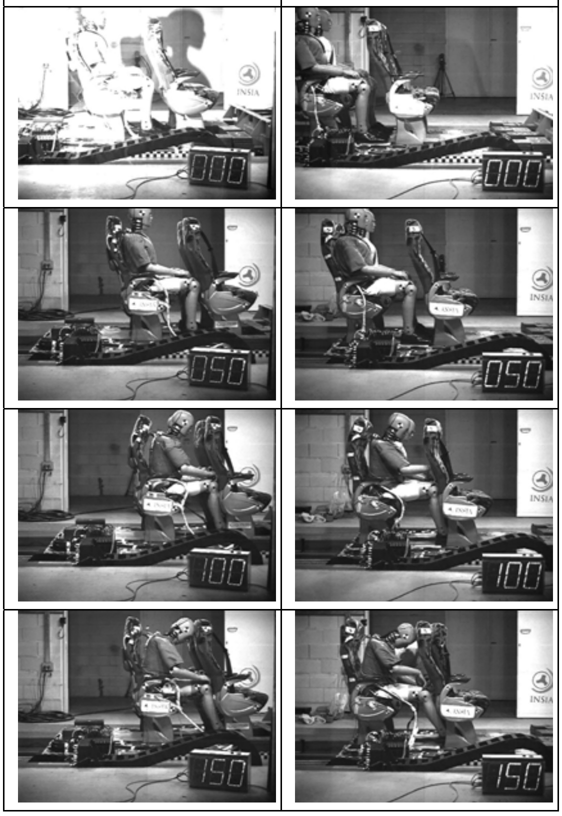


Figure 23. Sequence of images for setup 3 (3P seat belt).

	737-3P-03		787-3P-03	
Signal	Rear left	Rear right	Rear left	Rear right
Head AcRes (g)	75.64	80.95	~~101.35~~	46.3
UpNeck Fx (N)	-	90.82	-	98.24
UpNeck Fz (N)	-	1036.01	-	929.19
UpNeck My (N·m)	-	-18.13	-	-14.16
Thorax AcRes (g)	22.91	22.23	~~15.34~~	19.13
Thorax Def (mm)	-8.03	-9.42	~~-6.14~~	-9.71
Pelvis AcRes (g)	30.1	27.26	~~24.41~~	25.01
Right Femur Fz (N)	-1337.09	-1442.16	~~-1719.09~~	-577.68
Left Femur Fz (N)	-1856.47	-1488.09	~~-931.21~~	-1027.09
Right Knee Slider (mm)	9.25	5.81	~~9.8~~	3.57
Left Knee Slider (mm)	8.16	9.35	~~4.62~~	6.84

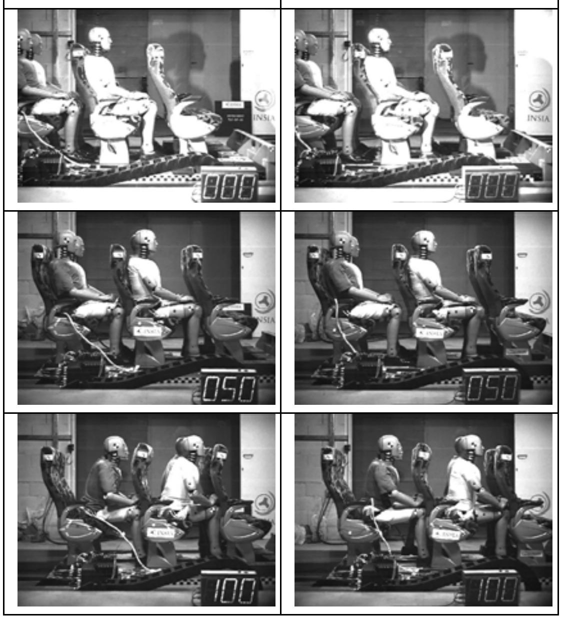
Figure 24. Signals comparison (Setup 3 – 3P).

Setup 1 – 2 point seat belt.

This test was performed with four adult Hybrid III 50th male, using the 2-point safety belt. There were no significant differences in the kinematics of the test, at the beginning a contact with the knees were occurred and then hit the head (no elevation of the pelvis due to the two-point safety belt). The values were similar in the head deceleration. The femur force registered was lower for long distance (approximately 30%).

The Figure 26 shows a knee slider displacement of one dummy was crossed out, this is because the data offered by the sensor were not reliable.

737-2P-01	787-2P-01



737-2P-01	787-2P-01

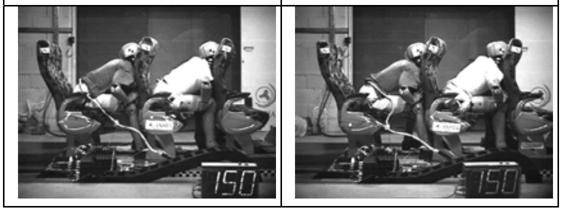


Figure 25. Sequence of images for setup 1 (2P seat belt).

	737-2P-01		787-2P-01	
Signal	Rear left	Rear right	Rear left	Rear right
Head AcRes (g)	106.15	119.04	104.79	105.92
UpNeck Fx (N)	-	893.1	-	1177.23
UpNeck Fz (N)	-	1612.26	-	1524.91
UpNeck My (N·m)	-	-98.88	-	-79.73
Thorax AcRes (g)	16.35	16.97	17.42	16.61
Thorax Def (mm)	-0.15	-0.06	-0.07	-0.09
Pelvis AcRes (g)	32.11	30.8	27.11	29.64
Right Femur Fz (N)	-1790.55	-2810.48	-1204	-1725.53
Left Femur Fz (N)	-2152.08	-1680.27	-1655.97	-1273.6
Right Knee Slider (mm)	9.74	10.26	5.65	7.9
Left Knee Slider (mm)	8.5	9.63	~~0.12~~	6.98

Figure 26. Signals comparison (Setup 1 – 2P).

Setup 2 – 2 point seat belt.

This configuration is similar to the tested seats with three points (Setup 2 – 3 point set belt). The behaviour of the seats with 2 or 3 points seat belt are different (although the same model of chair were used), this fact is due to the 3-point seat is more resistant than the 2-point seat belt. As in the configuration of three points seat belt, the highest relative speed on the dummies tested with the long distance with respect to the front seat, caused higher values in the short distance (15 to 30% higher).

The Figure 28 shows a knee slider displacement of one dummy was crossed out, this is because the data offered by the sensor were not reliable.

737-2P-02	787-2P-02

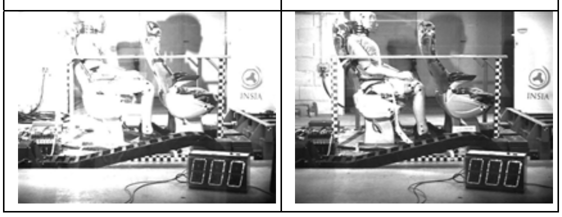


Figure 27. Sequence of images for setup 2 (2P seat belt).

	737-2P-02		787-2P-02	
Signal	Rear left	Rear right	Rear left	Rear right
Head AcRes (g)	74.55	78.82	75.33	88.23
UpNeck Fx (N)	-	1010.12	-	1197.57
UpNeck Fz (N)	-	1765.23	-	1612.48
UpNeck My (N·m)	-	-70.18	-	-78.2
Thorax AcRes (g)	16.45	15.69	15.37	16.58
Thorax Def (mm)	-2.56	-2.23	-2.31	-2.53
Pelvis AcRes (g)	26.5	25.2	26.43	29.25
Right Femur Fz (N)	-3370.93	-3327.98	-3651.98	-4624.57
Left Femur Fz (N)	-3675.63	-4016.71	-3790.17	-3856.51
Right Knee Slider (mm)	13.75	6.88	12.65	14.31
Left Knee Slider (mm)	~~19.91~~	14.35	13.72	13.83

Figure 28. Signals comparison (Setup 2 – 2P).

<u>**Setup 3** – 2 point seat belt.</u>

Finally, the configuration with two dummies fastened with two-point belt. The behaviour was similar to that of the four dummies belted with two-point safety belt. First there was a contact of the knees and finally the head impacted against the seat back. Increasing the row step distance caused a higher relative velocity of head impact and this caused higher head decelerations. Furthermore, the contacts of the knees were lowering severe in the long distance obtained smaller compression force.

Figure 29. Sequence of images for setup 3 (2P seat belt).

	737-2P-03		787-2P-03	
Signal	Rear left	Rear right	Rear left	Rear right
Head AcRes (g)	86.71	82.96	87.59	106.62
UpNeck Fx (N)	-	456.05	-	627.35
UpNeck Fz (N)	-	1707.19	-	1608.94
UpNeck My (N·m)	-	-94.07	-	-99.14
Thorax AcRes (g)	18.85	18.66	17.5	16.44
Thorax Def (mm)	-3.09	-4	-1.7	-2.2
Pelvis AcRes (g)	29.18	30	34.32	36.23
Right Femur Fz (N)	-1832.24	-3006.83	-1145.52	-2619.81
Left Femur Fz (N)	-2848.49	-2299.13	-2418.12	-2232.04
Right Knee Slider (mm)	10.04	11.68	7.69	10.97
Left Knee Slider (mm)	11.11	11	11.26	10.12

Figure 30. Signals comparison (Setup 3 – 2P).

DISCUSSION.

<u>ERGONOMIC STUDY.</u>

When the matrix of CAE simulations, shown in Figure 17, were done, a comfortable distance were obtained form an ergonomic point of view. An example of these simulations is shown in the figure below:

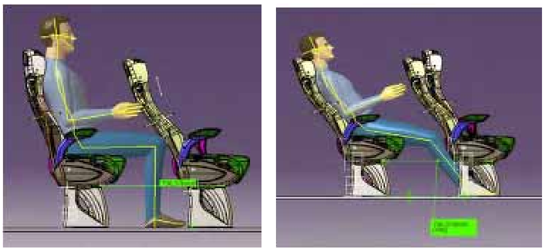


Figure 31. CAE análisis.

Authors define *"Distance L"* as the row step distance (measuring the same point between two adjacent rows of seats) and *"Distance H"* as the distance between seats (measured at the front of the rear seat and the back of the front seat - ECE R36 – *seat spacing*). For the seat included in the model, the difference between the *"Distance L"* and the *seat spacing* was 57 mm, therefore to obtain the distance between seats (*"Distance H"*) only need to subtract 57 mm from the values given in Figure 32 and Figure 33.

In configurations that did not recline the back (reasonable situation to not increase too much the row step distance between seats), the following results were obtained:

			Seat test	Maximum	Minimum
Distance L	Group 1 5th Female	Pos 1	592	605	584
		Pos 2	554	577	552
	Group 2 50th Male	Pos 1	735	722	762
		Pos 2	719	724	738
	Group 3 95th Male	Pos 1	772	766	787
		Pos 2	762	744	768

Figure 32. Ergonomic distance in upright positions of the seats.

With the 680 mm as marked as the current minimum distance ECE R36, the 50th percentile were in comfortable position without contact with the front seat (except one case: the lowest and "stretched" seat position for the passenger, but only 1 mm exceeded). The maximum distance required to ensure the comfort is found for the 95th percentile male and with the lower seat, the step distance found were 787 mm.

Although this was not the aim of this project, it should be noted that for the 5th percentile female, an excessive height of the seat could be quite harmful, found difficulty in supporting the foot on the floor.

In the case where the seats were reclined (Figure 33), the greater distanced were imposed by the larger percentile (95th male) seated in the lower height seat. Now, the distance was produced with the passenger in a vertical position (the contact occurs at the knee rather than in the lower leg). With the minimum distance defined in the ECE R36, the 50th percentile male were not covered if the front seats were reclined or its seat was reclined, except for the highest seat.

			Reclined of the front seatback			Reclined of both seatbacks
			Seat test	Maximum	Minimum	
Distance L	Group 1 5th Female	Pos 1	592	601	584	603
		Pos 2	570	593	569	
	Group 2 50th Male	Pos 1	738	725	768	750
		Pos 2	743	725	768	
	Group 3 95th Male	Pos 1	785	768	807	797
		Pos 2	797	760	820	

Figure 33 Ergonomic distance when reclining back seats were done.

<u>*SAFETY STUDY.*</u>

In the safety study, the influence of the distance between seats for each type of evaluated restraint system (2 and 3 points safety belt) was analyzed separately. This fact is due to because it is possible that increasing the distance between seats is beneficial in a particular restraint system and detrimental in another restraint system and vice versa.

To clarify the study, first a summary table was shown with the results of the injury criteria from each dummy (tested in the short distance – row step distance of 737 mm). Subsequently, another figure was shown which analyzes the trend of the results using the following coding:

- + : Beneficial trend.
- = : No significant changes.
- − : Not beneficial trend.

3 points safety belt.

In the case of three points belted dummies (with two to four occupants), the results show that increasing the separation between seats produces a slight reduction in all injury criteria, except for the chest. While in either of the two configurations distance, all the calculations are sufficient below the limits set by regulation:

- The parameters of the injury of the head, neck, femur and knee decreases slightly. However the parameters of the chest injury (acceleration and deformation), slightly increased its value in the case of a greater distance between seats.
- This behaviour was expected, since with increasing distance, both the head and knees of the occupants virtually no impact with the seat back before them, and therefore, there was a reduction of the criteria measured in head and femur. On the other hand, being the passengers retained only by the belt, the efforts to which they subjected the chest are larger,

as shown in the highest loads recorded in the safety belts load cells and the maximum deformation of the chest.

In the case of seats with three-point belts and unbelted passengers, the results shown that increasing the distance was counterproductive because it results in several of the injury criteria are higher.

This increase is due to the fact that by increasing the distance between seats, the relative speed with which the occupants impacted with the back of the seat were being increased, as it was increased the free flight.

In the configuration of unbelted dummies and greater distance between seats, the knee slider criterion was slightly higher than the ECE R94 limit. Also the 3ms head deceleration is close to the limit of injury.

		Criterion	3 Rows (Bealted)		2 Rows (Unbealted		2 Rows (Bealted)	
			LD	RD	LD	RD	LD	RD
3 Points seat belt	R 80	Head HIC_{36ms}	183.63	192.48	219.98	216.46	202.94	204.92
		Head AcRes 3ms	33.37	32.93	66.76	67.37	59.61	61.49
		Right Femur Fz	1220.48	741.93	2736.66	2604.8	896.56	846.71
		Left Femur Fz	595.97	1215.26	2650.09	2610.3	1196.55	1240.32
	R 94	Neck My	-	-12.24	-	-29.13	-	-18.13
		Thorax AcRes	17.92	17.55	18.07	18.59	17.96	17.62
		Thorax V * C	0.005	0.0103	0.004	0.003	0.0073	0.0072
		Thorax Def	-5.85	-10.99	-2.48	-2.25	-8.03	-9.42
		Right Knee slider	8.88	3.53	11.72	13.62	8.16	9.35
		Left Knee slider	4.28	7.9	14.05	10.81	9.25	5.81

Figure 34. Injury criteria summary.

		Criterion	3 Rows (Bealted)	2 Rows (Unbealted	2 Rows (Bealted)
3 Points seat belt	R 80	Head HIC_{36ms}	+	-	+
		Thorax AcRes	=	-	-
		Femur Fz	+	-	+
	R 94	Head AcRes 3ms	+	-	+
		Neck Fx	+	+	-
		Neck Fz	+	-	=
		Neck My	=	-	+
		Thorax V * C	-	+	=
		Thorax Def	-	+	=
		Knee slider	+	-	+
	Total		6+; 2=; 2-	3+; 0=; 7-	5+; 3=; 2-

Figure 35. Comparison of injury criteria (3P).

2 points safety belt.

In the case of two points seat belt and four occupants, increasing the separation was a slight improvement in some calculated criteria, but not enough to prevent more of the calculated criteria were beyond the limits. The 3ms head acceleration and the extension bending moment of the neck exceeded the thresholds of injury for the two distances tested (737mm and 787 mm).

The slight improvement in safety seen in the four occupants configuration, was not confirmed in tests conducted with only two occupants. In this case, the long distance configuration, a slightly higher vales for the criteria for head and neck were registered, unlike in tests with dummies.

The criterion that produces a clear improvement for either configuration, it was in the femur load, although in both cases the values were sufficiently below of the limits established by ECE R80.

In the case of unbelted passengers, the results did not reflect a clear influence of distance on the safety offered to the occupants. The results obtained in tests in both configurations, were not very different, and only the neck extension moment was increased its values when the distance between seats is greater. In all cases, the neck extension values recorded were above the limit set by the ECE R94.

		Criterion	3 Rows (Bealted)		2 Rows (Unbealted		2 Rows (Bealted)	
			LD	RD	LD	RD	LD	RD
2 Points seat belt	R 80	Head HIC_{36ms}	392.43	413.44	205.98	189.13	326.33	298.37
		Head AcRes 3ms	**88.81**	**91.81**	70.18	67.77	75.84	76.04
		Right Femur Fz	1151.77	1601.83	2883.7	2634.07	1465.1	1809.76
		Left Femur Fz	1649.9	1519.59	2777.46	2862.69	1953.76	1838.85
	R 94	Neck My	-	**-98.88**	-	**-70.18**	-	**-94.07**
		Thorax AcRes	15.82	16.67	15.95	14.92	18.12	18.24
		Thorax V * C	0.0013	0.0013	0.0032	0.003	0.0039	0.004
		Thorax Def	-0.15	-0.06	-2.56	-2.23	-3.09	-4
		Right Knee slider	8.5	9.63	~~19.91~~	14.35	11.11	11
		Left Knee slider	9.74	10.26	13.75	6.88	10.04	11.68

Figure 36. Injury criteria summary.

		Criterion	3 Rows (Bealted)	2 Rows (Unbealted	2 Rows (Bealted)
2 Points seat belt	R 80	Head HIC_{36ms}	=	-	-
		Thorax AcRes	=	=	+
		Femur Fz	+	-	+
	R 94	Head AcRes 3ms	+	+	-
		Neck Fx	-	-	-
		Neck Fz	+	=	-
		Neck My	+	-	-
		Thorax V * C	=	=	+
		Thorax Def	=	=	+
		Knee slider	+	=	+
	Total		5+; 4=; 1-	1+; 5=; 4-	5+; 0=; 5-

Figure 37. Comparison of injury criteria (2P).

General discussion.

An increasing of the distance between seats was not an improvement of the security levels offered for all restraint systems analyzed. It has also reflected that the injury criteria established by the ECE R80 might be poor predicting injuries offered by the occupants. The ECE R94 (elaborately later) includes more injury criteria associated with impact dummy (this fact is independent of whether they are tested at 30 or 50 kph). It has been observed that the two points seat belts offered low protection in the neck. This fact is corroborated by Elias et al (2001 and 2003), which investigated the safety on school buses with similar conclusions. In addition, this study has verified that the levels of protection offered by unbelted occupants were limited. Through accidentological studies in Sweden, Albertsson et al (2003) concluded that a 2-point belt may have reduced injuries for two-third of all injured with MAIS 2–4 and a further injury reduction by 28% could be achieved by shifting 2-point belts into 3-point belts.

CONCLUSION.

To increase the comfort of coaches passengers authors recommended to establish a new seat spacing 50 mm higher that actual one, i. e 730 mm.

The effect of this new seat spacing in the passengers safety for the seats fitting 3 point belts is:

- If the safety belts are used the passenger protection is improved.
- If the safety belt is not used, the passenger protection will be lower, but nevertheless reaching the injury limits.

The effect of this new seat spacing in the passengers safety for the seats fitting 2 point belts remains unchanged.

To state of the results obtained in this study, it can be concluded that the requirements established by the regulation 80 to evaluate the passenger safety are not sufficient. It has been verified how in all the tests carried out with two point belts seats, they accomplish with all the requirements established by the Regulation ECE R80, but nevertheless, in some of the tests carried out in seats with two point belts, the injury criteria limits required by the ECE R94 have been overexceeded.

It seems logical to think that, if the R94 criteria are good to evaluate the security offered in frontal impact in a vehicle of the category M1, also they should be it for the case of the occupants from one of the category M3. Especially, when the injury criteria are associated to a specify dummy model and in a specific impact direction and not to the type of vehicle in which the tests are carried out.

For all it, it would be recommendable to revise the Regulation ECE R80 in order to incorporate the injury criteria defined in ECE R94. Doing this the passenger safety of coaches could be guaranteed in frontal impact accidents.

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REFERENCES.

[1] 1999 “Bus Crashworthiness Issues”. Highway Special Investigation Report. National Transportation Safety Board. Washington, DC 20594.

[2] Elias J. C. McCray L. Sullivan L. 2001 “Large school bus safety restraint evaluation”. 17th Enhanced Safety of Vehicles (ESV).

[3] Elias J. C. McCray L. Sullivan L. 2003 “Large school bus safety restraint evaluation – Phase II”. 18th Enhanced Safety of Vehicles (ESV).

[4] Walton A.C., Hashemi S.M.R, Anderson J.C. 2006 “Preventing Passenger Ejection from buses, coaches and minibuses” TTS Project Reference No: S0320/VE.

[5] Mitsuishi H. Sukegawa Y.Okano S. Nagase H. 2003 “Frontal Collision Safety of Bus Passengers in Japan” 18th Enhanced Safety of Vehicles (ESV).

[6] 2003 “Enhanced Coach and Bus Occupant Safety – ECBOS. Results and conclusions”

[7] Martínez L., Aparicio F., García A., Páez J., Ferichola G., 2003. “Improving occupant safety in coach rollover”. International Journal of Crashworthiness N8 Vol 2, pags 121–132.

[8] Regulation ECE 36R03. “Uniform provisions concerning the approval of large passenger vehicles with regard to their general construction”

[9] Regulation ECE 80R00 “Seats of large passenger vehicles”.

[10] Regulation ECE 94R01 “Protection of occupants against frontal collision”.

[11] Regulation ECE 107R02 “M2 and M3 vehicles”.

[12] SAE J211 1995 “Instrumentation for Impact Tests” SAE Recommended Practice.

[13] Schneider L.W., Robbins D.H., Pflüg M.A., Snyder R.G., 1983 “Development of anthropometrically based design specifications for an advanced adult anthropomorphic dummy family, Volume I”. DTNH22-80-C-07502

[14] Kraus W. 2003 “The driver workstation in commercial vehicles”. Vol 1768. pp. 271-287 [Note(s):[350 p.]] [Document: 17 p.] (4 ref.) ISBN 3-18-091768-7.

[15] Garcia J, Quintana-Domeque C. 2007. “The evolution of adult height in Europe: a brief note”. Economics & Human Biology. Volume 5, Issue 2, July 2007, Pages 340-349.

[16] Albertsson, P., Bj¨ornstig, U., Falkmer, T., 2003. “The Haddon Matrix, a tool for investigating severe bus and coach crashes”. International Journal Disaster Medicine 2, 109–122.