IMPROVEMENT OF FRONTAL CRASH SENSOR CALIBRATION THROUGH MADYMO SIMULATIONS

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ABSTRACT

This paper describes the usage of MADYMO simulations in improving frontal crash sensor calibration. MADYMO simulations were conducted in the frontal impact program to improve the sensor calibration. In developing the advanced frontal impact restraint system using dual stage inflator, sensor calibration is very important. Late firing of the first stage inflator and large time delay between first and second stage time-to-fires increased occupant injuries. In the early version of sensor calibration, the initially given TTF's were not satisfied in some test speed conditions due to late first stage TTF and large time delay. Therefore, in order to determine the correct required TTF's, MADYMO simulations were used. First, the dual stage inflator was modeled as having two stages, which are primary and secondary stages. Then, MADYMO simulations were conducted by giving time delay between first and second stages of inflator model. Through simulations, the required TTF's were determined, which produced the injury values meeting the customer targets, and it was found that the relatively large time delay could be used in the low speeds. With the new required TTF's and the relatively large time delay in low speeds, sensor calibration was repeated. The recalibration was found to satisfy the required TTF's from the MADYMO simulations. A sled test was conducted in the worst-case condition and the injury results met the regulation limits.

INTRODUCTION

In developing the advanced frontal impact airbag restraint system using dual stage inflator, sensor calibration is very important. Late firing of the first stage inflator and large time delay between first and second stage TTF's increase occupant injuries due to large momentum changes. And, in sensor calibration, some trade-off can happen between different conditions. This kind of situation happened in one program. The initial sensor calibration did not satisfy the deployment logic in some conditions. In order to improve sensor calibration which meets the deployment logic, MADYMO simulations were conducted. As the first step, two MADYMO inflator models have been made. One is the primary stage inflator model and the other is the secondary stage inflator model. Therefore, two inflator models can be fired independently in the same way as the real dual stage inflator. By doing so, any time delay between the primary and secondary stages can be given. The next step was the droptower test and simulation. Through this process, the validated airbag model has been made. Then, MADYMO simulations were conducted according to the initial sensor calibration. Injury values from MADYMO simulations were reviewed to decide the new required TTF's and the direction for sensor calibration which meets the deployment logic. Based on the MADYMO simulation results, the new required TTF's and the direction for sensor calibration have been decided and the worst-case condition has been chosen to be tested, which guarantees the injury performance in other conditions. The sled test has been conducted with the worst-case condition and the injury performance has been confirmed to meet the sensor calibration direction and the deployment logic.

MADYMO Simulations for Frontal Crash Sensor Calibration Improvement

MADYMO was used to improve the frontal crash sensor calibration which initially did not meet the required TTF's and deployment logic. In this study, only the passenger side has been considered because the passenger side injuries were more critical to sensor calibration than the driver side injuries.

Deployment Logic

For 50th %ile-unbelted condition, the deployment logic required the low output at 18 mph and the high output at 22mph. The speed range between 18 mph and 22 mph was the gray zone which means that the low or high outputs can be allowed. The high output is required in 25mph-50th-unbelted-RH 30 deg Angular condition.

Initial Sensor Calibration

Initial sensor calibration was given to be reviewed. For the high output, the fixed time delay of 5msec was applied between the primary and secondary stages. However, the initial sensor calibration did not meet the requirements in 18mph-50th %ile-unbelted, 22mph-50th %ile-unbelted and 25mph-50th-unbelted-RH 30 deg Angular conditions as shown in Table 1.

Table 1.
Initial Sensor Calibration Results

	Unbelted Stage 1				Unbelted Stage 2			
Test Condition	Required TTF (msec)	Min TTF	Normal TTF	Max TTF	Required TTF (msec)	Min TTF	Normal TTF	Max TTF
18mph-50th-unbelted-0 deg.	23	17	19	26	23+120	29	35	35
22mph-50th-unbelted-0 deg.	18	16	18	18	18+5	24	29	31
25mph-50th-unbelted-RH 30deg.	27	23	24	25	27+5	25	28	145

(highlighted) Did not meet the RTTF.

As seen in Table 1, the max TTF of unbelted stage 1 in 18mph-50th-unbelted-0 deg condition did not meet the RTTF. In 22mph-50th-unbelted-0 deg condition, the low output is fired because the time delay exceeded 5msec. In 25mph-50th-unbelted-RH 30 deg condition, the max TTF in unbelted stage 2 did not meet the requirement which needs the high output. It was mentioned by the sensor calibration engineer that if the time delay of 15 msec in 22mph-50th-unbelted condition is allowed for high output, all conditions can be satisfied.

Inflator Modeling

In order to do MADYMO simulations with the various time delays, inflator modeling is needed which has two stages. Inflator modeling having two separate stages starts from the tank test pressure curves. Figure 1 shows the tank test pressure curves of high and low outputs considered. The tank volume was 60 liter. For the high output tank test pressure curve, the time delay of 5 msec was used. For the low output, the time delay of 120 msec was used for disposal purpose after firing the first stage. The primary stage inflator model is obtained from the low output tank test pressure curve through MTA analysis. The secondary stage inflator model is obtained by using both the high and low output tank test pressure curves and through MTA analysis.

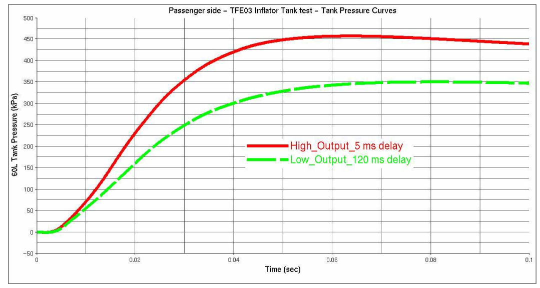

Figure 1. Tank Test Pressure Curves.

Figure 2 shows the mass flow rate curves of the primary and secondary stage inflator models obtained through MTA analysis.

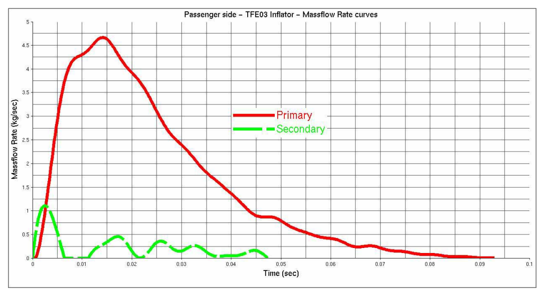

Figure 2. Mass Flow Rates For High and Low Outputs.

In order to prove that the mass flow rates are correct, the MADYMO tank simulations are conducted using the mass flow rates obtained through MTA analyses. For the MADYMO tank simulations, a 60 liter tank model was used. Figure 3 shows the comparison between tank test pressure curves and tank simulation pressure curves. From Figure 3, it is proved that the mass flow rates obtained through MTA analyses are valid.

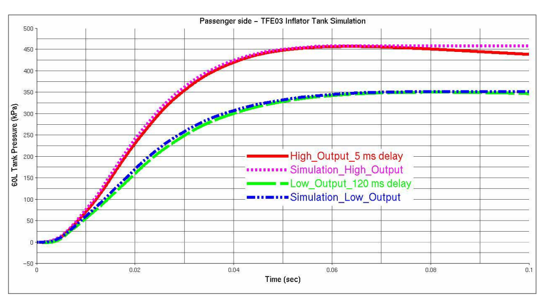

Figure 3. Comparison Between Tank Test And Tank Simulation Pressure Curves.

Droptower Tests and Simulations

To obtain the validated airbag models, droptower tests and simulations are conducted. Figure 4 shows the droptower testing picture.

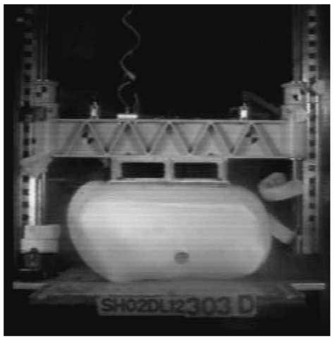

Figure 4. Passenger Airbag Droptower Testing.

From the droptower tests, the acceleration, velocity and displacement of the drop mass are measured. To obtain the validated airbag models, droptower simulations are conducted using a droptower model as seen in Figure 5.

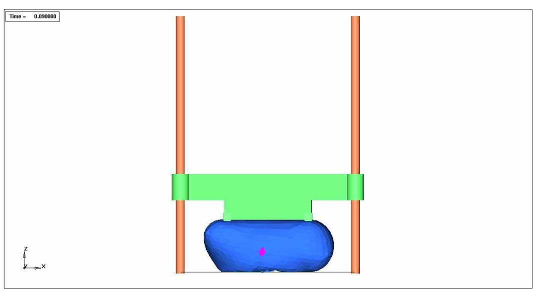

Figure 5. Passenger Airbag Droptower Simulation Model.

During droptower simulation, the acceleration, velocity and displacement of drop mass in the droptower model are correlated to the ones from the droptower test by changing the parameters in the model. The parameters adjusted were the effective area of vent hole according to bag pressure change and gas leakage amount through connection parts according to bag pressure change. Therefore, the airbag models are dependent on the bag pressure and independent of time. Figure 6 shows the correlated acceleration, velocity and displacement curves for high output. For the high output airbag model, the primary stage inflator model is fired first and then the secondary inflator model is fired with the time delay of 5 msec. For the low output airbag model, the primary stage inflator model is fired first and then the secondary inflator model is fired with the time delay of 120 msec.

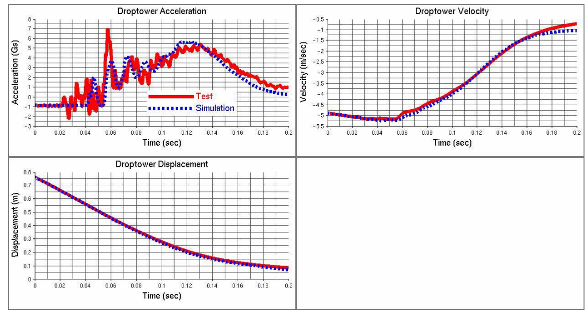

Figure 6. Droptower Correlation For High Output.

The validation levels of airbag models are checked by the validation statistics S/W which is internally developed by Key Safety Systems. The validation static number of “0” means the perfect matching of the simulation curve against the test curve. The large validation static number means poor matching between curves. If the average validation statistic number is below 0.15, the validation level is considered acceptable. In the passenger airbag models considered here, the average validation statistic number of low output airbag model was below 0.15 and the average validation statistic number of high output airbag model was also below 0.15. Both were considered acceptable. Since the airbag models from droptower simulations are independent of time and dependent on airbag pressure, the airbag models can be incorporated into MADYMO sled models without concerning TTF’s.

MADYMO Sled Model Simulations

In the initial sensor calibration, there were issues in 18mph-50th-unbelted-0 deg, 22mph-50th-unbelted-0 deg and 25mph-50th-unbelted-RH 30deg Angular conditions. In 18mph-50th-unbelted condition, the max TTF of 26 msec in the unbelted stage 1 needs to be investigated through MADYMO simulation. In 22mph-50th-unbelted condition, all TTF’s in unbelted stage 2 need to be investigated through MADYMO simulation. For the 25mph-50th-unbelted-RH 30 deg Angular condition, the high output is required. Therefore, MADYMO simulations are not needed and the sensor calibration needs to be improved to change the max TTF of 145 msec to within 30 msec which guarantees the high output with the fixed time delay of 5 msec. Considering the above, the MADYMO simulation matrix has been made as shown in Table 2.

Table 2.
MADYMO Simulation Matrix

	1st TTF (msec)	2nd TTF (msec)
18mph-50th-unbelted	26	146
22mph-50th-unbelted	16	24
22mph-50th-unbelted	18	28
22mph-50th-unbelted	18	29
22mph-50th-unbelted	18	31
22mph-50th-unbelted	18	33

Madymo simulation was conducted for the 18mph-50th-unbelted-26msec-146msec condition. The injury bar chart is shown in Figure 7. As seen in Figure 7, all injuries were below 80% of the FMVSS 208 FRM limits.

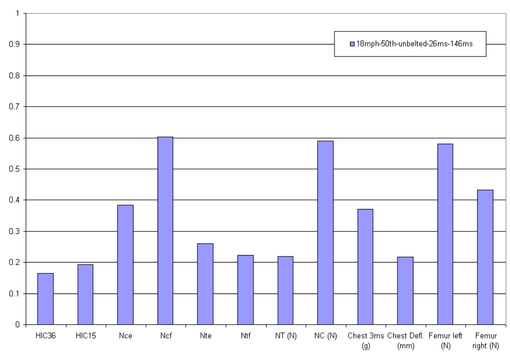

Figure 7. Injury Plot for 18mph-50th-unbelted-26ms-146ms

For the Madymo simulations of 22mph-50th-unbelted conditions, two more cases were added to Table 2 to investigate the wide range of time delay. Two added items to Table 2 were the "22mph-50th-unbelted-18ms-36ms" and "22mph-50th-unbelted-18ms-38ms" conditions. Therefore, seven conditions were simulated for the "22mph-50th-unbelted" condition. For Madymo simulations, the validated Madymo sled model of "22mph-50th-unbelted-15ms-135ms" was used. Table 3 shows the injury differences between the validated Madymo model simulation, sled test and barrier test in the "22mph-50th-unbelted-15ms-135ms" condition. From Table 3, it is noticed that the N_{cf} and neck compression were the concerns in 22mph-50th-unbelted condition. In the N_{cf} and neck compression, the validated Madymo model over-predicted against the sled test results and the sled test results over-predicted against the barrier test results.

Table 3.
Comparison Between Validated Madymo Simulation, Sled And Barrier Test Results In 22mph-50th-unbelted-15ms-135ms Condition

	Madymo	Sled	Barrier
HIC36	451	403	264
HIC15	451	403	241
Nce	0.754	0.609	0.494
Ncf	1.041	0.877	0.775
Nte	0.293	0.457	0.279
Ntf	0.367	0.269	0.392
NT (N)	423	819	1517
NC (N)	4646	3751	3044
Chest 3ms (g)	29.3	38	32.3
Chest Defl. (mm)	17.4	7.5	6.5
Femur left (N)	5456	4340	5062
Femur right (N)	4979	4369	3728

(red) Exceeded FRM limits.
(yellow) Exceeded 80% of FRM limits.

The reason why the sled test results over-predicted against the barrier test results is that the Lexan windshield is used in the sled test and there is pitching motion in the barrier test. The Lexan windshield is much stiffer than the glass windshield of the vehicle. Also, the vehicle pitching motion in the barrier test minimizes the head contact with the windshield. Considering these facts, MADYMO simulations were conducted using the validated MADYMO model to investigate the maximum allowable time delay in 22mph-50th-unbelted condition. As pointed out before, seven conditions were simulated. In determining the maximum time delay, the N_{cf}, neck compression and HIC_{15} were the critical injuries which were considered here and may be produced from head contact with the windshield. Table 4 shows the Madymo sled model simulation results. As seen in Table 4, HIC_{15}, N_{cf} and neck tension were the responses which need to be investigated. Figure 8 shows the variation in HIC_{15}, N_{cf} and neck compression according to TTF's variation. Considering Figure 8, Madymo simulation with "18ms-33ms" produces HIC_{15}, N_{cf} and neck tension which are below 100% of the FMVSS 208 FRM limits. However, considering over-prediction in Table 3, the TTF condition of "18ms-36ms" is considered to produce HIC_{15}, N_{cf} and neck tension which are below 100% of the FMVSS 208 FRM limits, in sled and barrier tests. Therefore, the TTF condition of "18ms-36ms" was chosen for the sled test to confirm the injuries.

Table 4.
MADYMO Simulation Results With Different Time Delays In 22mph-50th-unbelted Condition

Speed	22mph	22mph	22mph	22mph	22mph	22mph	22mph
Dummy	50th	50th	50th	50th	50th	50th	50th
Belt	unbelted	unbelted	unbelted	unbelted	unbelted	unbelted	unbelted
Primary	16 ms	18 ms	18 ms	18 ms	18 ms	18 ms	18 ms
Secondary	24 ms	28 ms	29 ms	31 ms	33 ms	36 ms	38 ms
HIC36	178	259	267	272	405	389	654
HIC15	125	213	221	216	405	389	654
Nce	0.244	0.547	0.496	0.568	0.62	0.689	**0.908**
Ncf	0.249	**0.85**	0.695	**0.84**	**0.886**	**0.893**	**1.284**
Nte	0.178	0.168	0.188	0.172	0.352	0.22	0.309
Ntf	0.273	0.333	0.336	0.327	0.331	0.362	0.452
Neck Tension (N)	346	93	381	193	336	637	484
Neck Comp. (N)	990	**3369**	3056	**3497**	**3820**	**4244**	**5593**
Chest 3ms (g)	32	29.7	30.9	31.2	32.6	31.2	33.5
Chest Def. (mm)	17	18.5	18.4	18.5	19.3	19.1	19.7
Femur left (N)	5519	5418	5471	5453	5484	5486	5511
Femur right (N)	4944	5020	5030	5019	5014	5043	5033

Exceeded 80% of FMVSS 208 FRM limits.
Exceeded 100% of FMVSS 208 FRM limits.

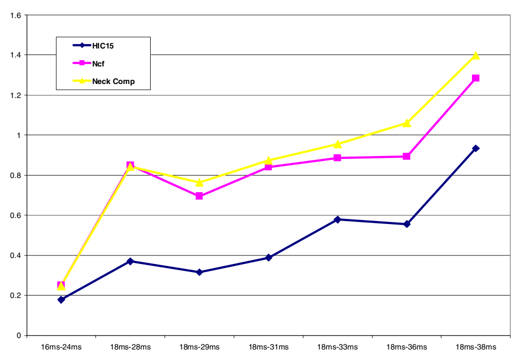

Figure 8. Comparison In HIC_{15}, N_{cf} And Neck Compression.

Confirmation Sled Testing

The confirmation sled testing has been conducted with the "22mph-50th-unbelted-18ms-36ms" condition to identify the injuries. Table 5 shows the sled test and Madymo simulation results. It is seen from Table 5 that Madymo simulation under-predicted N_{cf} by 13% and over-predicted neck compression by 9% against the sled test. When considering Table 3, the TTF condition of "18ms-36ms" may be OK to meet the FMVSS 208 FRM in the barrier test. However, the TTF condition of "18ms-33ms" was chosen for safety which shall guarantee all injuries in the barrier test below 80% of the FMVSS 208 FRM limits. Therefore, the worst case in 22mph-50th-unbelted condition which the sensor calibration should satisfy was the "18ms-33ms" which gives the time delay of 15 msec in the speeds below or equal to 22mph. Initially the fixed time delay of 5msec had to be met by the sensor calibration.

Table 5.
Madymo Simulation Vs. Sled Test Results In 22mph-50th-unbelted-18ms-36ms

	Madymo	Sled
HIC36	389	279
HIC15	389	279
Nce	0.689	0.626
Ncf	0.893	**1.009**
Nte	0.22	0.19
Ntf	0.362	0.408
Neck Tension (N)	637	311
Neck Comp. (N)	**4244**	3864
Chest 3ms (g)	31.2	38.4
Chest Def. (mm)	19.1	20.8
Femur left (N)	5486	4225
Femur right (N)	5043	3470

Exceeded 100% of FMVSS208 FRM limits.
Exceeded 80% of FMVSS208 FRM limits.

Renewed Sensor Calibration

As mentioned before, the fixed time delay of 5msec caused the issues in 22mph and 25mph-RH 30 deg angular conditions and the late TTF caused issue in 18mph. After Madymo simulations and confirmation sled test, the maximum time delay of 15 msec could be given in 22mph-50th-unbelted condition. Also the 1st stage TTF of 26ms could be confirmed in 18mph-50th-unbelted condition. Therefore, the RTTF of 18mph became 26ms and the time delay of 15ms could be allowed in the speeds below or equal to 22mph. However, the fixed time delay of 5ms was kept in the speeds above or equal to 22mph. With these new conditions, the sensor calibration was repeated. Table 6 shows the new calibration results in 18mph-50th-unbelted, 22mph-50th-unbelted and 25mph-50th-unbelted-RH 30 deg angular conditions.

Table 6.
2nd Sensor Calibration

	Unbelted Stage 1				Unbelted Stage 2			
Test Condition	Required TTF (msec)	Min TTF	Normal TTF	Max TTF	Required TTF (msec)	Min TTF	Normal TTF	Max TTF
18mph-50th-unbelted-0 deg.	26	19	25	26	26+120	139	145	146
22mph-50th-unbelted-0 deg.	18	18	20	20	18+15	22	24	29
25mph-50th-unbelted-RH 30deg.	27	16	16	18	27+5	18	18	20

Did not meet the RTTF.

In Table 6, it is noticed that the normal TTF and maximum TTF of 1st stage in 22mph did not meet the RTTF. Therefore, MADYMO sled simulations were conducted to confirm the injury values in 22mph-50th-unbelted-20ms-24ms and 22mph-50th-unbelted-20ms-29ms conditions.

2nd Madymo Sled Model Simulations

As mentioned above, Madymo sled model simulations were conducted in the above two conditions. The injury results are shown in Table 7. As seen in Table 7, all injuries were below 80% of the FMVSS 208 FRM limits. Therefore, the RTTF of 1st stage in 22mph can be changed from 18 msec to 20 msec. In that case, the yellow colored cells in Table 6 can be removed. With the 2nd sensor calibration , there were no issues in other speed conditions. Therefore, the 2nd sensor calibration could be finalized, producing acceptable injury values in all speed conditions.

Table 7.
2nd Madymo Simulation Results In 22mph-50th-unbelted Conditions

Speed	22mph	22mph
Dummy	50th	50th
Belt	unbelted	unbelted
Primary	20 ms	20 ms
Secondary	24 ms	29 ms
HIC36	267	273
HIC15	222	270
Nce	0.341	0.647
Ncf	0.537	0.79
Nte	0.159	0.236
Ntf	0.278	0.316
Neck Tension (N)	414	28
Neck Comp. (N)	2103	1599
Chest 3ms (g)	29.8	31.82
Chest Def. (mm)	17.9	19.2
Femur left (N)	5431	5455
Femur right (N)	5006	4591

CONCLUSIONS

In this work, dual stage inflator modeling was very important to give time delays between the 1st and 2nd stages of inflator. Even if the validated Madymo sled model is used, the Madymo sled model simulation results should be carefully analyzed with sled and barrier test results to judge over-predicted or under-predicted injury numbers. Through Madymo sled model simulations, the RTTF of 1st stage could be changed from 23 msec into 26 msec in 18mph-50th-unbelted condition. In the 22mph-50th-unbelted condition, Madymo sled model simulations allowed the time delay of 18 msec between 1st and 2nd stages and the sled test result confirmed it. However, the time delay of 15 msec was chosen for safety. With the maximum time delay of 15 msec allowed in the speeds below or equal to 22mph, the 2nd sensor calibration was successful in all conditions except the 1st stage RTTF confliction in 22mph. Through the Madymo sled model simulations, the original RTTF of 18 msec could be changed to 20 msec without any injury issues. Therefore, Madymo sled model simulations could guide the sensor calibration successfully in all conditions.

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PRE-CRASH SENSING COUNTERMEASURES AND BENEFITS

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ABSTRACT

This paper introduces a research plan by the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation to be used for developing objective test procedures and estimating safety benefits of pre-crash sensing countermeasures. The main objective of pre-crash sensing applications is to sense a collision earlier than the current accelerometer-based approaches with anticipatory and more descriptive sensors, communicate this information to the vehicle and its occupant protection systems, and take appropriate actions to reduce the severity of crash injury. In addition, this paper provides preliminary results from a preparatory analysis to review state-of-the-art pre-crash sensing technology and applications, proposes a methodology to estimate their safety benefits, and defines relevant crash problems. The technology review is based on literature available in the public domain. The benefits estimation methodology is founded on the reduction of total harm by comparative assessment of crash injury with and without the assistance of pre-crash sensing systems. The crash problem is defined using the Crashworthiness Data System to identify relevant crashworthiness scenarios and their respective harm.

INTRODUCTION

Quicker crash sensing times and more robust information are required to upgrade vehicle safety involving deployment of occupant protection components. The main objective of pre-crash sensing applications is to sense a collision earlier than the current accelerometer-based approaches with anticipatory and more descriptive sensors, communicate this information to the vehicle and its occupant protection systems, and take appropriate actions to reduce the severity of crash injury. This type of crash countermeasure is aimed at reducing injuries once the crash is deemed unavoidable; as opposed to crash warning systems that help drivers avoid the crash.

Pre-crash sensing countermeasures fall under two categories. The first category encompasses reversible features that are activated just before a potential crash, but usually with the capability of being reset in case the crash does not occur. Examples include air bag pre-arming, non-pyrotechnic seat belt pre-tensioning, bumper extension or lowering, and emergency brake assist. The second category consists of non-reversible features that are initiated just before a crash, but usually with the drawback of not being re-settable, such as pyrotechnic seat belt pretensioning. System reliability is paramount for pre-crash sensing countermeasures, as is fast decision-making time, given the short time available to deploy such countermeasures. The potential benefits of pre-crash sensing applications span a number of vehicle-to-vehicle and vehicle-to-obstacle crash types.

This paper introduces a research plan by the NHTSA to be used for developing objective test procedures and projecting safety benefits for pre-crash sensing occupant protection technologies. NHTSA's goal is to use pre-crash sensing technology to automatically mitigate occupant injury severity once a crash has been determined inevitable. Preparatory analyses are currently underway to assess the state-of-the-art technology of pre-crash sensing countermeasures, define relevant crash problems, and devise a methodology to estimate their potential safety benefits.

The assessment of pre-crash countermeasure technologies is based on a literature review of widely available information from technical conferences and manufacturer's product development publications, both online and in print. A preliminary methodology is proposed to estimate the safety benefits of pre-crash countermeasures, which correlates pre-crash scenarios of vehicle movements and driver actions prior to the crash to crashworthiness scenarios based on vehicle damage area, vehicle type, driver type, air bag deployment, seat belt use, and driver seat track position. This methodology estimates total harm reduction by comparing crash injury severity between non-equipped vehicles and vehicles equipped with pre-crash sensing countermeasures. Relevant crash problems are defined using NHTSA's Crashworthiness Data System (CDS) crash databases from 1999 through 2003. This paper describes the CDS variables that were selected to identify the crashworthiness scenarios.

Next, this paper introduces NHTSA's research plan to address pre-crash sensing countermeasures. Preliminary results from a technology review of current pre-crash sensing systems follow. This paper then presents a methodology that estimates potential safety benefits of these countermeasures including the introduction of the term "harm units" for crashworthiness scenarios. This is followed by preliminary results from CDS crash analysis. Finally, this paper concludes with a discussion of preliminary analysis results and future research steps.

RESEARCH PLAN

The primary goal of NHTSA's research plan is to develop objective test procedures and estimate safety benefits for the most promising pre-crash sensing occupant protection technologies. The approach consists of the following steps:

- Define relevant crash problems.
- Determine performance specifications of pre-crash sensing countermeasures addressing the crash problems.
- Estimate preliminary safety benefits of potential countermeasures.
- Select safety-effective countermeasures for advanced development.
- Develop objective test procedures for selected countermeasures.
- Estimate fleet benefits.

The program plan proposed here allows for the motor vehicle industry to be involved from the beginning of the research. This early involvement aids in the research and development of pre-crash sensing systems while formulating objective test procedures to validate these systems.

The potential benefits of pre-crash sensing applications span a number of vehicle-to-vehicle and vehicle-to-obstacle crash types. The main safety objective of these systems is to minimize head and chest decelerations, upper neck forces and moments, and chest deflection. It should be noted, however, that research is needed to translate earlier deployment of occupant protection systems into significant improvements in injury mitigation. Studies are required to correlate the improvement in time-to-deploy and occupant protection for specific crash types, vehicle structures, and occupant characteristics. Such research must be founded on a better understanding of the crash problem and resulting injuries, countermeasure functional requirements, and capability of potential system technologies.

NHTSA is currently managing a cooperative research agreement with four consortia of automakers, known as the Crash Avoidance Metrics Partnership (CAMP), funded through the Federal Highway Administration (FHWA) Intelligent Transportation Systems (ITS) Program (#DTFH61-01-X-00014). This agreement is funded 65% by the U.S. government and 35% by the auto industry. This agreement includes collaborative work on performance metrics and objective tests for forward crash warning, performance requirements for enhanced digital maps for safety, performance requirements for vehicle safety communications, and identifying and analyzing driver workload metrics. The nature of this cooperative research provides a paradigm for the type of dialogue sought for pre-crash system development.

NHTSA's research path for pre-crash sensing countermeasures will involve the development of the necessary scientific basis in terms of test procedures through the CAMP cooperative agreement, with emphasis on reaching industry consensus on the test conditions and procedures for objectively evaluating pre-crash sensing systems. Figure 1 shows a proposed Gantt chart of this research plan that was initiated in 2004 with preparatory analyses to review technology and estimate preliminary safety benefits. A 3-year cooperative project between NHTSA and the automakers will develop objective test procedures, based on the results of the preparatory analyses. A parallel analytical effort will be undertaken to develop analytical results in support of NHTSA's inputs to the cooperative research as it proceeds. At the end of this research program, an understanding of the technology available and estimated safety benefits through objective testing will be available to NHTSA. This preparation will support NHTSA's adoption of a research path on pre-crash sensing technology.

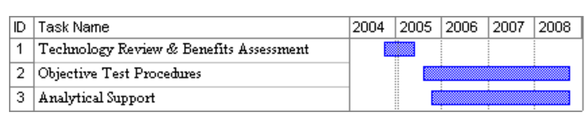

Figure 1 Major Tasks of NHTSA's Research Plan for Pre-Crash Sensing Countermeasures

TECHNOLOGY REVIEW

The technology review of pre-crash sensing countermeasures covered systems that are in any of the following developmental stages: concept, test-bed, prototype, or in production. This literature review was based on published information collected from technical conference proceedings, manufacturer's product or development Internet websites, and several other sources [1-13]. Preliminary results from the technology review are presented below, including a summary of R&D efforts among international manufacturers and research organizations. Moreover, the technology review describes the applications of pre-crash sensing technologies, their components, functionalities, available test results, and reported system effectiveness. In addition, the technology review helped to identify relevant crash scenarios for the crash problem definition, and to obtain technical data for modeling, such as pre-tensioning belt forces.

Worldwide R&D

The applications of pre-crash sensing technologies are classified into the following four groups:

- Seat belt pre-tensioning
- Emergency brake assist
- Seat adjustment
- Pedestrian protection

Table 1 summarizes international efforts in these applications by automakers and first tier suppliers. It should be mentioned that this tabular list was based on a limited literature review thus it may not be all-inclusive and might include redundant information between automakers and suppliers. While some applications have received greater attention (e.g., seat belt pre-tensioning), other applications have been studied less (e.g., seat adjustment). The following discusses details of the individual applications found so far.

Applications

A pre-crash sensing system is generally composed of sensors, decision-making units, actuators, and driver interfaces. The sensors may include both remote sensors and in-vehicle sensors. Computers or electronic control units (ECU's) serve as the decision-making units. These units process the signals received from the sensors and determine if a crash is unavoidable. Once a crash is determined to be imminent, the actuators deploy the safety systems automatically or upon receiving a signal from the driver interface, such as a pressure pulse on the brake pedal. The specifications of individual systems according to the applications are described next.

<u>Seat Belt Pre-Tensioning and Emergency Brake Assist</u>

Figure 2 illustrates the configuration of Toyota's Pre-Crash Safety (PCS) system with seat belt pre-tensioning and emergency brake assist applications

Table 1 Preliminary Summary of Worldwide R&D in Pre-Crash Sensing Applications

	Seat belt pre-tensioning [1-4, 7-8, 12-13]	Emergency brake assist [1-2, 5, 7, 13]	Seat adjustment [3-4, 12-13]	Pedestrian protection [6, 9, 10-11, 13]
Toyota, Japan	√	√		
DaimlerChrysler AG, Germany	√		√	
Ford, USA		√		
TRL Ltd., UK	√		√	√
Honda, Japan	√	√		
Nissan, Japan	√			√
BMW AG, Germany	√		√	
Autoliv, Sweden				√
Continental Teves	√	√	√	√

[1-2]. The system utilizes millimeter-wave radar as its remote sensor to detect obstacles and oncoming vehicle conditions. The PCS' ECU is shared with the adaptive cruise control (ACC) unit. The remote sensor signals, combined with vehicle sensor signals indicating vehicle yaw rates and steering angles, are sent to the pre-crash seat belt (PSB) and pre-crash brake assist (PBA) ECU's. If the ECU's detect an imminent crash or emergency braking, an electric motor automatically pre-tensions the seat belts. Tension is removed from the seat belt once the threat has passed and the seat belt returns to its original state. The PBA ECU analyzes inputs from vehicle wheel speed sensors and a brake pedal sensor, and will not deploy the brake assist until the driver has already stepped on the brake pedal.

Honda's Collision Mitigation Brake System (CMS) and E-Pretensioner also apply both the brake assist and seat belt pre-tensioning technologies [7]. However, Honda's CMS does not require that the driver brake to activate the brake assist – it will activate automatically once the system determines a collision is imminent. Automatic braking, as well as seat belt retraction, intensifies as the driver fails to respond to system warnings.

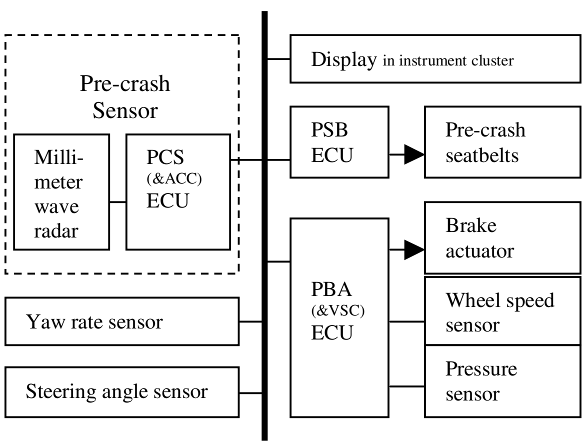

Figure 2. Configuration of Toyota's Pre-crash Safety System [1,2]

Seat Adjustment

DaimlerChrysler, BMW, and TRL studied a moving seat concept that involves moving an occupied seat from far forward to rearward positions just prior to a crash [3-4, 12]. While DaimlerChrysler and BMW provided only conceptual or descriptive information, TRL conducted a series of sled tests and described the results. These sled tests were conducted on 5th and 50th percentile dummies only, in conjunction with the use of pretensioners and variable air bag sizes/vent areas. A large occupant (such as a 95th percentile dummy) is assumed to sit already fairly rearward so moving the seat will not help as much as in the small and medium occupant cases. The tests did show additional protection provided by moving the seats rearward, in terms of reduced neck loads, chest accelerations and/or pelvic accelerations.

TRL did not describe any tests or results with out of position (OOP) occupants but was confident the moving seat concept can benefit this group of occupants as well. Presumably, the benefits will come from the potential of moving an OOP occupant out of the "danger zone".

DaimlerChrysler also explored the idea of seat back correction – a front passenger's seat back that is inclined far back can be moved into an upright position, in which the seat belts are expected to function more effectively.

Pedestrian Protection

This system uses sensors to detect an obstacle in front of a car. The sensors include frequency-modulated continuous-wave (FMCW) radar, laser, infrared imaging, contact sensor, accelerometers, etc. An algorithm is usually employed to discriminate a human from a non-human object. If a computer or an ECU determines that a collision with a pedestrian is impending, a number of technologies have been studied and can be deployed. These include a rear-lifting hood, air bags fitted to various parts of the vehicle front, and A-pillar air bag inflation [6, 9, 10-11, 13].

System Effectiveness

Evaluating system effectiveness is an important first step toward estimating the safety benefits introduced by pre-crash sensing countermeasures. Different types of technologies may contribute to different aspects of safety improvements. For example, the brake assist can reduce impact velocities; seat belt pre-tensioning can reduce occupant forward displacements and chest decelerations; pedestrian protection is aimed at reducing head impact velocities, head injuries, chest decelerations and lower extremity injuries; and moving seats can reduce injuries sustained by small or OOP occupants.

Based on the information gained from reviewing pre-crash sensing countermeasure technologies, this paper will next discuss estimation of their safety benefits. Estimated effectiveness values of pre-crash sensing systems in reducing relative speed or severity of impact due to seat belt tensioning, seat position movement or other measures found from the technology review will be factored into the analysis of system benefits and ultimately harm reduction. Additionally, sensor robustness and false alarm rates impact system benefits, and factor into how often a system responds correctly to a crash situation or incorrectly to a non-crash condition.

BENEFITS ESTIMATION METHODOLOGY

Figure 3 illustrates a general approach to estimate the safety benefits of pre-crash sensing countermeasures based on a concept of harm unit measurements. For a particular pre-crash sensing technology, target pre-crash scenarios addressed by the countermeasure as well as related driver response are examined. For scenarios resulting in an impact, detailed crashworthiness scenarios are analyzed to calculate harm units. Crashworthiness scenarios are based on factors that influence the crash characteristics such as change of speed at impact (ΔV), seat belt use, air bag deployment, seat track position, etc. Detailed description of variables used to define the crashworthiness scenarios is discussed in the sample data section of this paper. The CDS crash database is the source for the identification and harm computation for the crashworthiness scenarios.

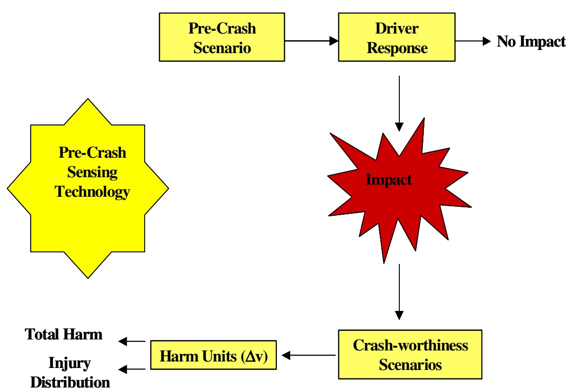

Figure 3. Benefits Estimation Approach

The CDS is a database that houses a collection of police reported crashes from the United States. Information is collected by twenty-four teams of crash researchers situated throughout the country, each investigating an appropriate probability sample of crashes involving passenger cars, light trucks, and vans, which were towed from the scene due to damage. The crash must involve a harmful event defined as resulting in either property damage or personal injury and the injury must be a result of the crash. Additionally, at least one vehicle involved in the crash must be in transport on a traffic-way. This excludes crashes that occur in private driveways and parking lots. Because the CDS only collects information for crashes where the vehicle is towed from the scene, damage must be significant enough to require assistance. It is difficult to speculate on the effect this may have on the comprehensiveness of the analysis of injury severity or crash magnitude, but it does affect the composition of the dataset explored by this preliminary crash analysis.

Harm Units Concept

Injury severity is the key measure to estimate the safety benefits of pre-crash sensing countermeasures. Equation (**1**) presents the calculation of harm units, which provides a cost (direct economic cost or functional years lost) for a particular combination of pre-crash scenario and crashworthiness scenario based on the distribution of injury severity. An example of this formula's application is given in the sample data section. Injury severity is measured on the Maximum Abbreviated Injury Scale (MAIS), whose values are shown in Table 2. Also shown in Table 2 are the direct economic costs, $w(i)$, associated with a particular MAIS level based on 2000 U.S. dollar amount [14]. The values of $I(i)$ are found from the CDS database query for injuries sustained by the driver (vehicle occupants). The parameter N_o represents the total number of drivers (occupants) involved. At this level of preliminary crash analysis and benefits estimation, only the driver injury was examined to keep cost comparisons between crashes of different pre-crash and crashworthiness scenarios the same regardless of varying factors such as the number of occupants.

$$\frac{\sum_{i=0}^{6} w(i) \times I(i)}{N_o} \qquad \textbf{(1)}$$

Once harm units are known for a particular combination of scenarios, the next step is to determine how much injury reduction, therefore harm reduction, results from the implementation of a pre-crash sensing system. Harm reduction, H_R, is calculated by subtracting total harm *with* the system, H_w, from total harm *without* the system, H_{wo}, as shown in Equation (**2**):

$$H_R = H_{wo} - H_w \qquad \textbf{(2)}$$

Table 2. MAIS Injury Description and Cost (Based on 2000 $ Amount)

MAIS	Cost
Uninjured	$ 1,962
Minor	$ 10,562
Moderate	$ 66,820
Serious	$ 186,097
Severe	$ 348,133
Critical	$ 1,096,161
Fatal	$ 977,208

Note: The costs shown in Table 2 reflect the dollar amount of economic costs. These include lost

productivity, medical costs, legal and court costs, emergency service costs, insurance administration costs, travel delay, property damage, and workplace losses.

The calculation of total harm *without* the system can be achieved with data from the CDS. On the other hand, calculating harm with a pre-crash sensing system will be based on information found in either the technology review or vehicle crash modeling in the first stages of benefits analyses, or through real-world testing in later stages. Modeling can be used to investigate how affecting seat position, movement, vehicle speed, or other factors prior to a crash may influence injury severity experienced by the driver. For example, a pre-crash brake system may identify that the host vehicle is rapidly approaching an object and a collision is imminent. If the system responded by applying the brakes to reduce speed, thus lessening ΔV, the injury severity of the driver would decrease. By reducing driver injury severity for any collision sensed by the pre-crash brake system, the distribution of injury severity levels should shift towards less severe injuries, decreasing overall harm.

Safety Benefits Calculation

$$H = N \sum_n C_n \times \sum_m R_m(C_n) \times \sum_i S_i(C_n,R_m) \times \sum_j P(\Delta V_j|S_i) \times \overline{H}(\Delta V_j|S_i) \quad \mathbf{(3)}$$

N = Number of drivers involved in the crash
C = Relative frequency of certain crash type
R = Relative frequency of certain driver attempted avoidance maneuver
S = Relative frequency of certain scenario
P = Probability of certain scenario for ΔV_i given S_i
$\overline{H}$ = Harm unit, average harm per driver for ΔV_i given S_i
= Parameters to change with pre-crash technology

Equation (**3**) breaks down the computation of total harm by a number of components that might be affected by various pre-crash sensing applications. The calculation of safety benefits in terms of total harm reduction is then based on computing H_{wo} and H_w according to Equation (**3**). The computation of H_{wo} requires two separate queries into the CDS. The first query examines pre-crash scenarios and driver response prior to the crash. The second query explores crash conditions such as location of damage, driver characteristics, restraint systems, and ΔV.

The first three factors of Equation (**3**) depend on information pertaining to pre-crash data, whereas the remaining factors rely on crashworthiness data. The harm units are represented by $\overline{H}(\Delta v_i \mid S_i)$. For the above example of a pre-crash brake system, only the ΔV factor is affected by the system, resulting in a different $P(\Delta v_i|S_i)$ *with* the system than *without*. This will affect the last summation of Equation (**3**). The third factor connects crashworthiness scenarios, S_i, with pre-crash scenarios C_n. For a pre-crash brake system, C_n values might include stationary objects or vehicles, and vehicles accelerating, decelerating, or traveling at constant speed. The equation specifies pre-crash scenarios by vehicle movements prior to the crash because some systems have sensing limitations that affect the number of scenarios they address. Also included is driver response to the pre-crash scenario because this will also limit the number of crashes a system may address. As discussed previously in the technology review, some pre-crash brake systems respond to potential collision situations automatically; others require driver braking before activation.

FRONTAL DAMAGE SCENARIO DESCRIPTION AND SAMPLE DATA

The CDS database contains crash files of all types and severities [15]. Some crashes result in multiple impact events. The preliminary crash analysis concentrated on crashes with frontal damage only as the first event, and filtered out crashes with multiple impact events since other factors might have influenced the injury severity sustained by the driver. In addition, the crash vehicle population was divided into four categories: automobile, light truck, sport utility vehicle (SUV), and van. This split was necessary due to different body structures and crash performance characteristics. Table 3 lists CDS variables that the preliminary crash analysis addressed to describe frontal damage crashes.

Table 3. CDS Variables Used in Frontal Damage Analysis

Pre-Crash Scenario Variables
Accident type
Attempted avoidance maneuver
Crashworthiness Scenario Variables
Δ V
Offset
Air bag deployment
Seat belt use
Seat track position
Driver weight

Pre-crash scenarios of interest can be identified from the Accident Type and the five pre-crash variables in the CDS. However, this preliminary crash analysis focused on the Accident Type variable and the Attempted Avoidance Maneuver pre-crash variable. The applicability of pre-crash sensing countermeasures depends on the dynamic characteristics of pre-crash scenarios. Most rear-end collisions incur damage to the front of the striking vehicle; however, some striking vehicles may end up with a damage area other than the front part of the vehicle due to driver evasive maneuver. For example, a driver may try to avoid hitting a vehicle stopped at an intersection by braking and steering. This maneuver may result in the vehicle skidding sideways and striking the vehicle at the intersection with the side of their vehicle. Other potential maneuvers include braking only, steering only, and no response.

Crashworthiness scenarios are built with variables that have bearing on crash characteristics and therefore driver injury severity. The most important factor is ΔV, which identifies the change in velocity experienced by the vehicle and its driver. Crash offset measures the location of the crash relative to the center of the vehicle, determining over what area the crash energy is absorbed. It is calculated taking into account several CDS factors including direction of force, general area of vehicle damage, vehicle deformation location, and horizontal location of vehicle damage. By combining all these factors into the offset variable, many details about crash specifics were found through one variable. The CDS codes of air bag deployment and seat belt use were consolidated into either yes, no, or unknown conditions. To operate as intended, pre-crash countermeasures utilizing seat belt pretensioning require seat belt use information. Driver seat track position was also considered. This variable measures longitudinal location, which may change if a pre-crash sensing application moves the seat back when an impending crash is detected. Finally, driver weight was selected to represent the driver factor, which cannot be influenced by any system but it may affect how a system modulates seat belt pre-tension or seat track location.

Next, sample results from the preliminary crash analysis based on the 1999-2003 CDS are presented to illustrate the definition of crashworthiness scenarios and the computation of concomitant harm units. Table 4 provides crash statistics in terms of the number of drivers and relative frequency, in a descending order, for crashworthiness scenarios of automobiles involved in frontal damage crashes. In addition to variations of crash offset, seat track position, and driver weight, these scenarios include air bag deployed and seat belt used conditions. Combinations of crash offset, driver seat track position, and driver weight amount to a total of 60 potential crashworthiness scenarios, S_i in Equation **(3)**. Table 4 only lists the scenarios with individual relative frequency of 1% and higher, comprising approximately 91% of total drivers for these scenario combinations. "Full Frontal" crash offset indicates minimal or no frontal offset, and crashes not fitting any other offset category are classified as "Frontal Other". Light drivers weigh less than 150 pounds, medium-weight drivers are greater than or equal to 150 but less than 190 pounds, and heavy driver weigh 190 pounds or more.

Table 4. Crashworthiness Scenario Frequency for Automobile, Frontal Damage, Belted Driver, and Air bag Deployed Crashes (Based on 1999-2003 CDS)

Crash Offset	Seat Track Position	Driver Weight	# of Vehicles	Relative Frequency
Right	Middle	Medium	42,090	7%
Left	Middle-Rear	Light	35,501	6%
Left	Forward	Light	33,938	6%
Full Frontal	Rear	Light	32,574	6%
Right	Rear	Medium	29,159	5%
Full Frontal	Rear	Heavy	29,134	5%
Left	Rear	Heavy	24,990	4%
Right	Forward	Light	19,113	3%
Full Frontal	Middle	Light	19,098	3%
Right	Middle	Light	18,082	3%
Front Other	Middle-Rear	Medium	17,808	3%
Right	Middle-Rear	Medium	17,666	3%
Left	Rear	Medium	17,457	3%
Full Frontal	Middle	Medium	16,812	3%
Full Frontal	Rear	Medium	16,487	3%
Left	Forward	Medium	16,247	3%
Left	Middle	Medium	16,141	3%
Right	Forward	Medium	15,581	3%
Left	Middle	Heavy	14,659	2%
Left	Middle	Light	14,503	2%
Right	Rear	Heavy	14,459	2%
Left	Middle-Rear	Medium	12,499	2%
Right	Rear	Light	11,393	2%
Full Frontal	Middle-Rear	Light	10,747	2%
Left	Rear	Light	10,369	2%
Full Frontal	Middle-Rear	Heavy	9,495	2%
Full Frontal	Forward	Medium	8,670	1%
Full Frontal	Middle-Rear	Medium	7,624	1%
TOTAL			532,297	91%

Further statistics on the most frequent scenario in Table 4 are provided to demonstrate harm calculations. Table 5 lists a breakdown of crash relative frequency for this scenario by ΔV, including both recalculated and estimated ΔV values from the CDS. These values are represented by the parameter P in Equation **(3)**.

Average harm unit value, found using Equation **(1)**, requires a distribution of crash injury severity from the MAIS, number of drivers, N_o, and cost of the injury $w(i)$ from Table 2. Using the two most frequent known ΔV values as an example, this paper now demonstrates how harm units are calculated.

Table 5. ΔV Distribution for Offset Right, Middle Seat Track, and Middle Weight Scenario

Δ V (kmph)	% of Total
Δ V<10	0%
10≤Δ V<25	41%
25≤Δ V<40	14%
40≤Δ V<55	2%
55≤Δ V	0%
Minor	0%
Moderate	1%
Severe	0%
Unknown	43%
TOTAL	100%

Table 6 shows the number of drivers by MAIS severity for the selected scenario and two ΔV ranges. Injury levels are likely on the lower end of the scale due to relatively low ΔV values, generally lower harm crash type and crashworthiness conditions of air bag deployed and seat belt used. The cost of crashes is calculated in the last two columns by multiplying harm cost with the number of drivers for each MAIS severity. To arrive at average harm per driver, total cost of crashes for each column is divided by the total number of drivers for that ΔV. This results in an average cost per driver for a specific scenario-ΔV combination, which completes the last term of Equation (**3**). These values illustrate that if a pre-crash sensing countermeasure reduced ΔV for a forward collision type, shifting the distribution of ΔV's to lower value ranges, the system would decrease average harm per driver. Thus, according to Equation (**2**), this would translate to a harm reduction due to system use.

Table 6. Injury Severity and Average Cost for Selected ΔV for Offset Right, Middle Seat Track, and Middle Weight Scenario

MAIS	Number of Crashes		Harm Cost	Cost of Crashes	
	$10 \leq \Delta V < 25$	$25 \leq \Delta V < 40$		$10 \leq \Delta V < 25$	$25 \leq \Delta V < 40$
Uninjured	406	1,245	$ 1,962	$ 796,380	$ 2,442,872
Minor	16,563	4,409	$ 10,562	$ 174,940,687	$ 46,567,668
Moderate	15	321	$ 66,820	$ 1,009,984	$ 21,442,204
Serious	-	36	$ 186,097	$ -	$ 6,759,974
Severe	-	-	$ 348,133	$ -	$ -
Critical	-	-	$ 1,096,161	$ -	$ -
Fatal	-	-	$ 977,208	$ -	$ -
TOTAL	16,984	6,011		$ 176,747,051	$ 77,212,718
		Average Harm per Driver		$ 10,407	$ 12,845

DISCUSSION

The following discusses issues related to a better understanding of the crash problems and crashworthiness scenarios that pre-crash sensing countermeasures address, and the use of computer modeling to determine system effectiveness in reducing the severity of crash injury.

Crash Analysis

As demonstrated by preliminary crash data in this paper, there are several limitations of the CDS database. After aggregating 5 years of data, several injury severity cells were empty for the most common crashworthiness scenarios. There are two potential solutions to this weakness. First, more years of CDS data could be used to increase the sample size; however, complexities might arise in data query if CDS variables and codes have changed over the years. CDS databases could be used dating back to 1992 when pre-crash variables were introduced into the CDS. A second approach to dealing with the lack of adequate cases in the CDS is to not have such finely defined crashworthiness scenarios. For example, a rear-end pre-crash sensing countermeasure may reduce ΔV and therefore injury severity and not have any interaction and effect on seat belt use, seat position etc. With less crashworthiness factors, each scenario would be represented by more cases, but this assumption will not work for countermeasures that affect multiple factors either directly or indirectly.

A second weakness of the CDS is the relatively high frequency of variables coded as "unknown". As seen in Table 5, certain scenarios resulted in high-unknown values, although typically unknown values are much lower. One way to compensate is to redistribute them proportionally based on relative frequency among known values.

Modeling

The harm units without pre-crash sensing countermeasures can be calculated from the injury probability data obtained from analyses of the CDS database. In some cases, database analyses can also yield an estimation of the harm units with the countermeasures. For example, such analyses readily yield the system effectiveness of emergency brake assists (in terms of reduced ΔV), or that of seat tracks positioned more rearward. In other cases, however, pre-crash sensing countermeasures need to be implemented in physical testing or mathematical simulations to give a direct evaluation of the system effectiveness. Between these two methods, mathematical modeling is often more cost-effective.

With a modeling approach, first the analysis methods will be determined and vehicle-occupant models will be identified. While either finite element or rigid body dynamics (RBD) models can be utilized, the large size of prospective simulations will most likely lead to RBD as the method of choice owing to its much lesser demand on computational resources. There is a family of occupant models available, but some vehicle models in RBD, especially those with major load bearing structures, may not actually exist. An occupant compartment model can be used instead, but a crash pulse to the occupant is needed in such cases.

The inputs to a model will be generated based on the information from the CDS database analyses. A crash pulse can be reconstructed from such information as crash type, general area of damage, ΔV, direction of force and offset. However, it should be noted that the available crash information is limited and a reconstructed crash pulse will not be unique. Driver weight data can be used to determine the type of occupant models. Pre-crash sensing countermeasures are realized in the simulations via proper setups of air bag deployment, seat belt forces, etc.

To satisfy the common requirement of validating a model (or models) before applying it in application simulations and gaining insights from its outputs, it is proposed that for each simulation with one type of countermeasure applied, a corresponding case without the countermeasure is also simulated and the outputs compared with the results from the database analyses. This practice can help to gain a level of confidence in the modeling approach. However, it can also double the total number of simulations to be conducted.

The outputs from the simulations include injury criteria in different body regions. Injury risk functions, available for head, neck, thorax and lower extremities, can translate these injury criteria into injury probabilities that are comparable to CDS MAIS data. However, simulated injury probabilities are available in four of the above mentioned body regions, and it remains to be determined whether the injury probabilities in one selected body region, or a certain combination of the four, are to be used in the harm unit calculations.

CONCLUSIONS

This paper introduced a research plan to be used by NHTSA to understand the preliminary safety benefits of pre-crash sensing countermeasures and develop objective test procedures for most promising systems. As part of this research effort, preliminary analyses have been conducted to review the technology and applications of current pre-crash sensing systems, define their crash problems, and devise a methodology to estimate their safety benefits. Preliminary results of technology review, high-level benefits estimation methodology, and crash analysis were presented.

The technology review identified 4 major pre-crash sensing countermeasure technologies: seat belt pretensioning, emergency brake assist, seat adjustment and pedestrian protection. A preliminary estimation of the benefits from an emergency brake assist countermeasure was conducted using the 1999-2003 CDS. For a certain combination of crashworthiness variables, reducing ΔV from the [25, 40) range to the [10,25) range resulted in an average harm reduction per driver of $2,438 (from $12,845 to $10,407).

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ENHANCED CHILD RESTRAINT DATA COLLECTION IN NASS CDS

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ABSTRACT

The National Highway Traffic Safety Administration's (NHTSA), National Automotive Sampling System (NASS), has conducted detailed field crash investigations through its Crashworthiness Data System (CDS) since 1988. Each year CDS collects detailed information on a nationally representative, random sample of minor, serious and fatal, police-reported, tow-away traffic crashes involving passenger cars, light trucks and vans. CDS data supports research into the crashworthiness of passenger vehicles and the biomechanics of trauma, development of test equipment procedures and criteria, and the development and support of motor vehicle safety standards for occupant protection and consumer information programs.

Data collection into these real-world crashes involving child occupants provides a unique data set useful to the agency as well as the whole child occupant protection community.

In 2002, new and updated data collection methodologies related to child occupant restraints were incorporated into the NASS, CDS, Electronic Data Collection System. This paper presents a summary of these improved data collection methodologies.

BACKGROUND

The primary impetus behind the CDS was a need for more detailed information on how a vehicle and occupant respond in a crash, and how the interior components of the vehicle injure and/or protect occupants. In 1988, the CDS was initiated with 36 trained field research teams across the country which studied about 7,000 crashes each year. In 2004, the CDS had 27 field research teams and 76 field researchers collecting data from about 5,500 crashes. The CDS currently collects and codes crash information involving over 600 data elements obtained during on-site crash scene inspection and exterior and interior vehicle inspections, interviews with crash victims, along with pertinent medical information. Interviews with crash victims may be done in person or over the telephone entailing questions dealing with pre and post-crash events involving all occupants of the vehicle. Details regarding the occupant, e.g., seating position, restraint type available, restraint use, along with any available medical/injury information, are collected and coded into each case.

Dating back to 1999, NHTSA has collected about 200 occupied child restraint cases per year involving approximately 250 child restraints each year, (allowing for more than one child restraint per crash). Overall cases involving child restraints make up about 5% of the total number of cases coded in CDS since 1999. The yearly totals dating back to 1999 are listed in Table 1 and shown graphically in Figure 1.

Table 1. Number of CDS Child Seat Cases and Number of Child Seats Coded Between 1999-2004

YEAR	TOTAL # OF CDS CASES	CHILD SEAT CASES	# OF CHILD SEATS CODED
1999	4,274	182	230
2000	4,307	210	248
2001	4,090	188	220
2002	4,589	225	279
2003	4,754	219	276

Source: NASS CDS, 1999-2003

Motor vehicle crashes remain a leading cause of death for children of all ages, and according to the Agency's Fatality Analysis Reporting System (FARS), there have been 2,519 passenger vehicle occupant fatalities among children under 5 years of age between 1999 and 2003. Of these 2,519 fatalities, an estimated 1,636 (65 percent) were restrained by either a child seat or a vehicle safety belt system. The FARS data file contains limited information, police accident report (PAR) only, and other official State records, documenting details from all fatal traffic crashes within the 50 states, DC and Puerto Rico. It is in part, due to this lack of detailed information, that the Agency is using its resources within other program areas to acquire and document restraint use data by children in all types of crashes.

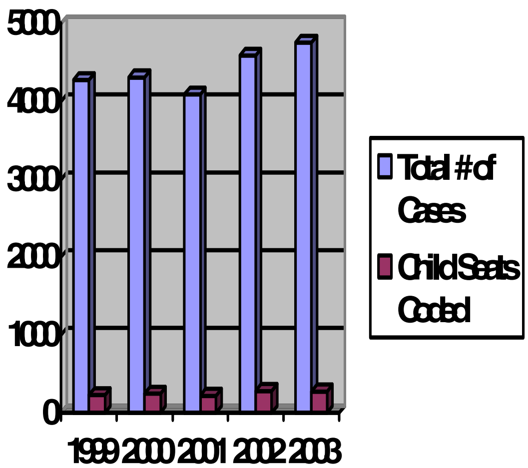


Figure 1. Child Seats Coded within CDS by Year

NHTSA is committed to understanding how child restraint systems perform in real-world crashes. This, coupled with the requirements initiated in the implementation of the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act, Section 14, created the need for improved and updated real-world crash data and collection methods related to child occupants. As a result of TREAD, in 2002 the Agency developed enhanced child restraint data collection variables and attributes in an effort to improve data collection regarding the specific types of restraints used by child occupants. Therefore, this paper highlights the efforts to enhance data collection in NASS CDS on child restraints.

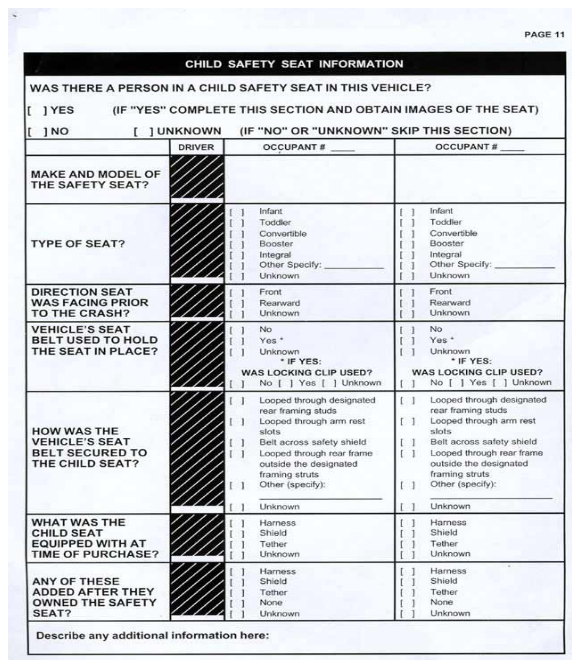
INTRODUCTION

Prior to 2002

The Agency's collection of child restraint information prior to 2002 lacked certain detail/specificity necessary to identify the various types of child restraints involved in crashes. The majority of the child restraint "Types" were being coded as "Unknown/Other" due in part to lack of information in the field (e.g., the child restraint had been destroyed and was no longer available for inspection coupled with the fact that the parent/care giver was unfamiliar with the restraint and unable to provide many identifying details).

Only a limited number of variables regarding child seat characteristics and usage were coded prior to 2002, some of which were outdated and no longer reflective of current child restraint types and designs. For example, the attributes for Seat Type were Infant, Toddler, Convertible, Booster, Integral, Other and Unknown.

The predominant means of obtaining child safety seat information was through an interview consisting of seven questions, which could be conducted by telephone or in person. The interview form is shown in Figure 2.



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CHILD SAFETY SEAT INFORMATION

WAS THERE A PERSON IN A CHILD SAFETY SEAT IN THIS VEHICLE?

[ ] YES (IF "YES" COMPLETE THIS SECTION AND OBTAIN IMAGES OF THE SEAT)

[ ] NO [ ] UNKNOWN (IF "NO" OR "UNKNOWN" SKIP THIS SECTION)

	DRIVER	OCCUPANT # ____	OCCUPANT # ____
MAKE AND MODEL OF THE SAFETY SEAT?			
TYPE OF SEAT?		[ ] Infant [ ] Toddler [ ] Convertible [ ] Booster [ ] Integral [ ] Other Specify: ____ [ ] Unknown	[ ] Infant [ ] Toddler [ ] Convertible [ ] Booster [ ] Integral [ ] Other Specify: ____ [ ] Unknown
DIRECTION SEAT WAS FACING PRIOR TO THE CRASH?		[ ] Front [ ] Rearward [ ] Unknown	[ ] Front [ ] Rearward [ ] Unknown
VEHICLE'S SEAT BELT USED TO HOLD THE SEAT IN PLACE?		[ ] No [ ] Yes * [ ] Unknown * IF YES: WAS LOCKING CLIP USED? [ ] No [ ] Yes [ ] Unknown	[ ] No [ ] Yes * [ ] Unknown * IF YES: WAS LOCKING CLIP USED? [ ] No [ ] Yes [ ] Unknown
HOW WAS THE VEHICLE'S SEAT BELT SECURED TO THE CHILD SEAT?		[ ] Looped through designated rear framing studs [ ] Looped through arm rest slots [ ] Belt across safety shield [ ] Looped through rear frame outside the designated framing struts [ ] Other (specify): ____ [ ] Unknown	[ ] Looped through designated rear framing studs [ ] Looped through arm rest slots [ ] Belt across safety shield [ ] Looped through rear frame outside the designated framing struts [ ] Other (specify): ____ [ ] Unknown
WHAT WAS THE CHILD SEAT EQUIPPED WITH AT TIME OF PURCHASE?		[ ] Harness [ ] Shield [ ] Tether [ ] Unknown	[ ] Harness [ ] Shield [ ] Tether [ ] Unknown
ANY OF THESE ADDED AFTER THEY OWNED THE SAFETY SEAT?		[ ] Harness [ ] Shield [ ] Tether [ ] None [ ] Unknown	[ ] Harness [ ] Shield [ ] Tether [ ] None [ ] Unknown

Describe any additional information here:

Figure 2. Pre-2002 Child Restraint Interview Form

Information regarding the child restraint could be obtained by conducting interviews, both over the phone and in person, as well as from inspecting the child restraint, when available, during vehicle inspections. From these two sources the following information could be coded: Make, Model, Type, Orientation, Harness, Shield and Tether availability. Prior to 2002, a sample of this information is shown in Figure 3 of the "Child Seat Tab" from the NASS data entry program, NASSMain.

Child restraint Proper Use/Misuse information was coded using seat belt variables. There has never been a single variable or attribute, which gave the overall proper/improper use of the child restraint.

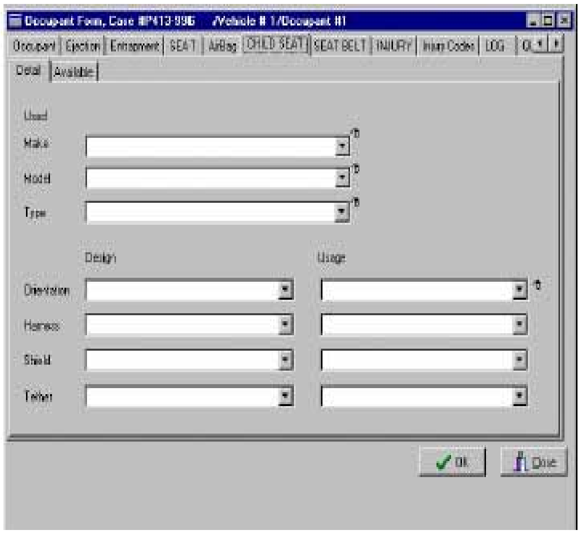

Figure 3. Occupant Form, Child Seat Tab Detail

The Proper Use/Misuse variables were defined as: Proper Use of Manual Belt (used properly with child safety seat – indicated when the manual belt was installed so as to comply with the manufacturers directions); and Proper Use of Automatic Belt (used properly with child safety seats – indicated when the automatic belt was installed so as to comply with the manufacturers directions). Proper/improper child seat installation is difficult to ascertain even when the child seat is available for inspection in the crash vehicle, while still installed with the vehicle safety belt system. It proves even more difficult to determine proper/improper use through information obtained by an in-person or over-the-telephone interview only. In addition proper/improper use information was not coded regarding the child seat's use, design type for child occupant, etc. So often times the proper/improper use information was misinterpreted. It was in part because of these "misinterpretations" that the proper use/misuse attribute was removed from the 2003 CDS file.

METHODOLOGY

Improved Data Collection Methodologies Incorporated in 2002

Improvements in the data collection and coding began with revamping methodologies, one of the first of which entailed developing a new, comprehensive Child Seat Interview Form. The new interview form consists of numerous questions pertaining to various child restraint types, (e.g., infant only, convertible, forward facing only, and belt-positioning booster seat) the parent/caregiver's knowledge of and familiarity with the child restraint, and its use and installation. There are also questions regarding information sources the parent/caregiver has used, (e.g., child seat checkpoints/clinics attended, vehicle and child restraint owner's manuals,) which aided them in the child restraint's use and installation. A reference sheet with various child restraint graphics is also part of the interview. It provides a visual of various seat types, which serves to help identify the type of child seat involved in the crash when the seat is no longer available and in-person interviews are conducted. Field researchers have always been encouraged to conduct in-person interviews rather than telephone interviews.

For those cases where the child seat is no longer available for inspection and/or an in-person interview is not possible, questions can be asked over the phone. Answers to several of these over-the-telephone interview only questions may still be able to help data analysts ascertain child seat type, harness system, orientation, proper/improper use, etc. Sample questions from the 2002 Child Restraint Interview Form are shown in Figures 4 and 5.

Another enhancement made in the CDS entailed updating the child seat make/model and type selection/pick list which now includes child restraints dating back to about 1985. Prior to 2002 this child seat "pick-list" was comprised of about 30 different makes of child seats covering about 120 different models, and five child seat types. Field researchers reference this list for selection of the respective child seat involved in a crash. The pick-list was expanded to include several older and newer models, and has been updated every year since 2002. This listing also includes the harness design for each model seat type along with the appropriate height and weight use recommendations according to each respective manufacturer.

The current list (up through 2004) identifies about 80 different makes, covering approximately 470 models, with 10 child seat types from which to choose. The current child restraint types are classified as: Infant Seat (ISS), Convertible Seat (CSS), Forward Facing Only (FSS), Booster Seat (BSS), Booster/Forward Facing Seat (BSS/FSS), Booster/Convertible Safety Seat (BSS/CSS), Integrated Seat (INT), Harness (HSS), Vest (VSS), and Special Needs (SNSS).

This listing also provides information regarding a restraint's harness system type and placement according to the occupant's weight and height in addition to providing a restraint's attachment/hardware system, e.g., Lower Anchorages and Tethers for Children (LATCH) features.

PSU Number: ____ Case Number Stratum: ____________ Vehicle Number: ______ Interviewee Role: __________

Occupant Information:	Occupant # ______ Height ___________ Weight___________ Age ___________	Occupant # ______ Height ___________ Weight___________ Age ___________	Occupant # ______ Height ___________ Weight___________ Age ___________
Seating Position of child restraint? [ ] Occupied [ ] Unoccupied [ ] Unknown	[ ] Front Mid [ ] Front Right [ ] 2nd Left [ ] 2ND Mid [ ] 2nd Right [ ] 3rd Left [ ] 3rd Mid [ ] 3rd Right [ ] Cargo area/trunk [ ] Other (specify) ___________	[ ] Front Mid [ ] Front Right [ ] 2nd Left [ ] 2nd Mid [ ] 2nd Right [ ] 3rd Left [ ] 3rd Mid [ ] 3rd Right [ ] Cargo area/trunk [ ] Other (specify) ___________	[ ] Front Mid [ ] Front Right [ ] 2nd Left [ ] 2nd Mid [ ] 2nd Right [ ] 3rd Left [ ] 3rd Mid [ ] 3rd Right [ ] Cargo area/trunk [ ] Other (specify) ___________
At the time of the crash how was the child restrained?	[ ] Child restraint with a harness/shield system [ ] Booster seat w/shield [ ] Booster seat w/seatbelt [ ] Veh Seatbelt w/Other (specify) ___________ [ ] Vehicle seatbelt only **(IF VEHICLE SEATBELT ONLY STOP, DO NOT CONTINUE)**	[ ] Child restraint with a harness/shield system [ ] Booster seat w/shield [ ] Booster seat w/seatbelt [ ] Veh seatbelt w/Other (specify) ___________ [ ] Vehicle seatbelt only **(IF VEHICLE SEATBELT ONLY STOP, DO NOT CONTINUE)**	[ ] Child restraint with a harness/shield system [ ] Booster seat w/shield [ ] Booster seat w/seatbelt [ ] Veh seatbelt w/Other (specify) ___________ [ ] Vehicle seatbelt only **(IF VEHICLE SEATBELT ONLY STOP, DO NOT CONTINUE)**
Was anything in the child's hand or lap at the time of the crash?	[ ] No [ ] Yes* *If Yes, What [ ] Bottle [ ] plastic or [ ] glass [ ] Toy [ ] Cup [ ] plastic or [ ] glass [ ] Other, specify ________ [ ] Unknown	[ ] No [ ] Yes* *If Yes, What [ ] Bottle [ ] plastic or [ ] glass [ ] Toy [ ] Cup [ ] plastic or [ ] glass [ ] Other, specify ________ [ ] Unknown	[ ] No [ ] Yes* *If Yes, What [ ] Bottle [ ] plastic or [ ] glass [ ] Toy [ ] Cup [ ] plastic or [ ] glass [ ] Other, specify ________ [ ] Unknown
Type of Restraint?	[ ] Infant [ ] Convertible [ ] Forward Facing Only [ ] Booster w/shield [ ] Belt-Positioning Booster w/seatbelt [ ] Integral [ ] Other (specify)________ [ ] Unknown	[ ] Infant [ ] Convertible [ ] Forward Facing Only [ ] Booster w/shield [ ] Belt-Positioning Booster w/seatbelt [ ] Integral [ ] Other (specify)________ [ ] Unknown	[ ] Infant [ ] Convertible [ ] Forward Facing Only [ ] Booster w/shield [ ] Belt-Positioning Booster w/seatbelt [ ] Integral [ ] Other (specify)________ [ ] Unknown
What weight child is the restraint recommended for?	[ ] 0-20 lbs. [ ] 0-22 lbs. [ ] 0-40 lbs. [ ] 5-40 lbs. [ ] 20-40lbs. [ ] 30-60 lbs. [ ] 30-80 lbs. [ ] 40-100lbs [ ] Other, specify________ [ ] Unknown	[ ] 0-20 lbs. [ ] 0-22 lbs. [ ] 0-40 lbs. [ ] 5-40 lbs. [ ] 20-40lbs. [ ] 30-60 lbs. [ ] 30-80 lbs. [ ] 40-100lbs [ ] Other, specify________ [ ] Unknown	[ ] 0-20 lbs. [ ] 0-22 lbs. [ ] 0-40 lbs. [ ] 5-40 lbs. [ ] 20-40lbs. [ ] 30-60 lbs. [ ] 30-80 lbs. [ ] 40-100lbs [ ] Other, specify________ [ ] Unknown
Do you still have the restraint involved in the crash?	[ ] Yes [ ] No [ ] Unknown	[ ] Yes [ ] No [ ] Unknown	[ ] Yes [ ] No [ ] Unknown

Figure 4. Sample of 2002 Child Restraint Interview

PSU Number: ____ Case Number Stratum: ____________ Vehicle Number: ______ Interviewee Role: __________

Does the seat have a high back (similar to a bucket seat)?	[ ] Yes [ ] No* [ ] Unknown ***If No, was the booster a sitting base only** [] Yes [] No [] Unknown	[ ] Yes [ ] No* [ ] Unknown ***If No, was the booster a sitting base only** [] Yes [] No [] Unknown	[ ] Yes [ ] No* [ ] Unknown ***If No, was the booster a sitting base only** [] Yes [] No [] Unknown
What restrained the child?	[ ] Lap/shoulder belt used [ ] Lap belt only [ ] No belt system [ ] Other, specify__________ [ ] Unknown	[ ] Lap/shoulder belt used [ ] Lap belt only [ ] No belt system [ ] Other, specify__________ [ ] Unknown	[ ] Lap/shoulder belt used [ ] Lap belt only [ ] No belt system [ ] Other, specify__________ [ ] Unknown
Continue if the seat was used as a belt-positioning booster with both the lap and shoulder belt			
At the time of the crash what was the child's posture? **[ ] Asleep** **[ ] Awake**	[ ] Upright [ ] Leaning [ ] forward [ ] left side [ ] right side [ ] forward and left [ ] forward and right [ ] Unknown	[ ] Upright [ ] Leaning [ ] forward [ ] left side [ ] right side [ ] forward and left [ ] forward and right [ ] Unknown	[ ] Upright [ ] Leaning [ ] forward [ ] left side [ ] right side [ ] forward and left [ ] forward and right [ ] Unknown
Where was the shoulder belt positioned on the child?	[ ] Over shoulder crossing chest [ ] Across the neck [ ] Across the face [ ] Under the Arm [ ] Across the child's arm (off shoulder) [ ] Behind the back [ ] Unknown [ ] Other specify________	[ ] Over shoulder crossing chest [ ] Across the neck [ ] Across the face [ ] Under the Arm [ ] Across the child's arm (off shoulder) [ ] Behind the back [ ] Unknown [ ] Other specify________	[ ] Over shoulder crossing chest [ ] Across the neck [ ] Across the face [ ] Under the Arm [ ] Across the child's arm (off shoulder) [ ] Behind the back [ ] Unknown [ ] Other specify________
How was the fit of the shoulder belt?	[ ] Snug [ ] Loose [ ] Unknown	[ ] Snug [ ] Loose [ ] Unknown	[ ] Snug [ ] Loose [ ] Unknown
Notes:			

Figure 5. Sample of 2002 Child Seat Interview Questions

Additional updating and restructuring was also made to the child seat and safety belt data collection variables and attributes. The attributes capture design features of the seat, e.g., harness/shield design, not designed with harness/shield, 3-pt harness, 5-pt harness, T-shield, Tray-shield, Shield and unknown. In addition, the improved attributes reflect how the features are used, e.g., harness used, harness in top, highest, middle or bottom slot, harness used, slots used unknown, shield used, etc. This has allowed for new information to be coded regarding a seat's harness/shield design and use, the LATCH features availability and use, and installation of the child seat in the vehicle by indicating the vehicle's belt routing and use.

Information regarding the child's position within the restraint is also collected. Through the interview process, the child's posture is noted as sitting upright, reclined, supine, slumped forward to the side, etc.

Specific information on the child restraint's design, installation features, (e.g., LATCH equipped, vehicle safety belt lock-offs, etc.), restraint use, harness strap(s) location, and LATCH features, are collected and documented for each child occupant. There are also questions, which may help determine the type of vehicle safety belt system used to install the child restraint and/or the child in instances where a vehicle inspection may have not been completed. For example safety belt types like lap/shoulder combination, lap belt only; locking features, latch plates, retractor types, (e.g., sliding, lightweight locking/cinching, locking, emergency and automatic locking, switchable retractor, etc.) and how the vehicle safety belt was used/locked to secure the child restraint.

Information is also collected pertaining to the use/installation of vehicle safety belt adaptations/add-ons, as well as use of aftermarket belt-positioning devices. All pertinent information regarding the child occupant, (e.g., interview, photos of crash scene, vehicles and child restraint) are collected and coded into the automated CDS file enabling researchers to reconstruct the pre and post crash environment of the child occupant. A sample of the Occupant Form, Child Seat Tab used for coding child seat information beginning in 2002 is shown in Figure 6.

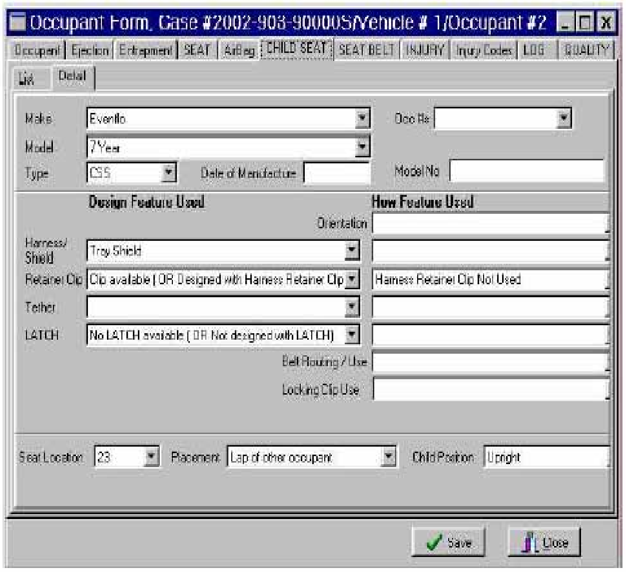

Figure 6. Sample of Child Seat Tab beginning with 2002

Once a child restraint make and model have been entered into the Child Seat Tab, the type of restraint along with certain other design features automatically pre-fill certain of the blanks extrapolating from previously entered data regarding each respective child restraint from the pick-list. The left-hand side of the Child Seat Tab, which specifies Design Feature Used defines how the child restraint is designed/equipped beginning with the type of harness system. A drop down list of harness options available for the particular seat allows selections such as 3-pt, 5-pt, T-shield, Tray-shield, and Shield. It can also be noted, via the drop down list, whether the child restraint was equipped with a harness retainer clip, top tether or lower anchorages. The How Feature Used side of the tab describes how the restraints features were used beginning with the orientation of the seat, orientation, e.g., rear, forward, supine; if harness was used which slots were used, e.g., harness straps in top/highest slot, harness straps in middle/bottom slot, slots used unknown; tether used or not used, LATCH used or not used, belt routing indicating which slots/channels on the child restraint were used for vehicle belt installation, and whether or not a locking clip was used on the vehicle belt system.

Updated photography requirements for child restraints were also incorporated into the 2002 CDS data collection year. In particular, field researchers were required to take photos of both the front and back of the child restraint, which could help clearly identify the type of seat, it's harness system and the harness system's position/location as it was likely used with the child. The new guidelines also request that all labels identifying the seat be photographed, especially the label which indicates the manufacturer make/model number and date of manufacture, which can help identify the seat's specific manufacturer and model.

Another very important data collection enhancement incorporated into the CDS has been providing additional child restraint and vehicle safety belt training for field researchers. An 8-hour child seat and vehicle safety belt update training was provided to all field researchers during NASS year-end training in November 2001, and field researchers have been provided with child occupant restraint update information at every year-end training since implementation of the new variables. Several of the field researchers have become certified Child Passenger Safety (CPS) Technicians through the Standardized Child Passenger Safety course, and it is planned to have at least 1 field researcher certified as a Technician at each of the 27 field research teams.

PROCEDURES

In-depth information relating to the case child occupant's environment, both pre- and post- crash, is gathered (e.g., restraint type used, how used, its installation, harness strap location, seating location, vehicle safety belt type utilized to anchor the child restraint, top tether and lower anchorage systems/LATCH, etc.). This information is collected from many sources, including a hands-on examination of the vehicle, and the child restraint, when available. When applicable, medical information regarding the child occupant is also sought. Once the information is obtained it is entered into the CDS using the Abbreviated Injury Scale, AIS-90 coding protocols.

Details regarding the child restraint crashes selected for CDS are collected and subsequently coded into each case by field researchers. The information coded is then reviewed and checked for accuracy by quality control staff, built-in edit check software, as well as receiving a second review by NHTSA headquarters staff prior to final data file release for child restraint cases coded since 2002.

DATA SUMMARIZATION

Data Parameters

Pursuant to the changes enjoyed by the Oracle NASS CDS files, the SAS data sets will be updated to an approximately 30-file data set, known internally as the oracle look-a-like file. This will occur retroactively to 2002, the year for which the child passenger safety modifications were made to the NASS CDS. Currently, the SAS data set available on the World Wide Web contains the traditional 11-file data set.

Years

NASS CDS was consulted for tow away crashes occurring in 2002 through 2003. These are the two most recent years available for the NASS System. These also mark the first two years of enhanced child seat collection.

Age Selection

Based upon a query reviewing all child seat cases in the NASS CDS for the years 1999 through 2003, it was determined that children through 9 years old were observed to be restrained by some child restraint system. This was not to say that some form of child safety seat and/or vehicle-equipped safety belt restrained all children from ages 0 through 9 years. Instead, there was incidence of some child safety seat usage among children up to 9 years of age.

Restraint Usage Aggregations

The restraint usage was categorized as: vehicle installed restraint, child restraint system secured with a vehicle installed restraint, none, or other. If the child was restrained with a lap, shoulder, lap and/shoulder belt, or an unknown type of manual restraint, the child was considered secured by a vehicle-installed restraint. If the manual restraint usage indicated that it secured a child safety seat and that a child safety seat was present in the seating position, then the child restraint system was secured with a vehicle installed restraint. Using the old definitions owing to their current availability in SAS, child seat was considered: infant seat, toddler seat, convertible, booster seat with shield, booster seat without shield, other seat, or unknown seat. In the case of an absent or inoperative manual restraint in a seating position, then a child was considered unrestrained. If the restraint usage did not fit the previous definitions, it was classified as other. These would include any child safety seat that was secured with one of the manual restraint usage options or the presence of an integrated seat. Until the advent of the new child safety seat variables, integrated seats were denoted through the child seat make variable as an aggregate of any make or model.

Seating Position

The seating positions were disaggregated in two ways. The first method of analysis contemplated any seating positions. The second method of analysis only considered child safety seat compatible seating positions.

First, any front seat, left, middle, right, on/in lap, or other, were aggregated. The second seat was comprised of any other seating position rear of the front seat but excluding other seats or unenclosed areas.

The second method only considered seating position in which a child seat could be installed. The front seat only considered the right front seating positions. Although, many vehicles are equipped with center seating positions, these generally avail themselves of a lap belt. It is not a comparable attribute amongst all vehicles. Further, the lap belt is not appropriate for use with belt positioning boosters. Since the present examination reports on an aggregate of child seat types, ages, and vehicle types, the front middle seating position was eliminated from consideration within the front row. The rear seats were any left, middle, or right seating position behind the front seat.

Child Seat Type

The child seat types were better defined, as of 2002. Using the SAS data set, the analyst was limited to the older formats. Upon the introduction of the Oracle look-a-like data set, SAS data users will have the enhanced child seat data. It should be noted that many of the child seat terms have been outdated and will be more completely defined with regard to orientation. The current formatting may have required the analyst to consult child seat orientation in concert with the child seat type.

Restraint Usage in Conjunction with Child Seat Type

When examining children transported in child safety seats, the manual restraint usage must also be considered. The safety of a child can be optimized only with the child secured in the child safety seat and the child safety seat secured to the vehicle/ vehicle seat. Although misuse of manual restraints and/or child safety seats was not directly contemplated, it may be considered a gross misuse to omit securing the child safety seat to the vehicle/vehicle seat.

As shown in Table 1, the frequency of child safety seats in a seating position occupied by a child was reported. Over the two-year period, 2002 through 2003, 555 children were reported. These 555 children need not have been secured to the child safety seat by virtue of harness or adult safety belt, nor would they have necessarily had the child seat secured to the vehicle. A more refined search considered whether the child seat was secured to the vehicle. The presence of the child seat, secured to the vehicle, did not indicate whether the harness, for pre-booster seat child, was fastened. It could, however, be surmised owing to the prevalence of low severity injuries among children transported in child safety seats that the children were fastened in the seat. The 30-file data was designed to reflect the child safety seat enhancement and provide complete information with regard to the child seat placement and the harness and/or safety belt usage of the child.

When studying those cases for which manual restraint usage indicated the presence of a child safety seat and that seat was present in an occupied seating position, the value from Table 1, 279 child seats for 2002 and 276 child seats for 2003, exceeded the number of child seats secured to the vehicle, 236 child seats for 2002 and 245 child seats for 2003. A difference of 74 cases was attributable to a combination of adult omissions in securing children in the safety seat or securing the harness, child behaviors, and early child safety data collection methods employed by CDS, as reflected in the 11-file SAS formats. For these two years, however, the new data set has been designed to allow the users to map from the older to the newer versions of the data set. With regard to this study, 19 cases were examined more carefully owing to a seemingly elevated number of child safety seats that were not secured to the vehicle.

The number of children transported in child safety seats differed when compared to children transported in a child safety seat that was secured to the vehicle, per Table 2. Nineteen cases were studied individually where the manual restraint usage was omitted and a child safety seat was reported. These cases were reviewed in their entirety using the CDS Electronic Case Access available on the NHTSA website. Five cases were found to be legitimately unrestrained occupants. Eight cases involved integrated seats; understandably, these were coded as unrestrained owing to a lack of evidence that must have accompanied the use of the vehicle belt system. Integrated seats do not require the manual restraint system for installation in the vehicle. One case indicated that the belt was routed unconventionally, as verified on the Electronic Case Access and to be resolved when using the forthcoming 30-file format. One LATCH installed child safety seat was identified, which would not have availed itself of the vehicle installed restraint system. A convertible seat was identified as secured by an automatic belt in the front passenger seat. This could not have been detected using the SAS data set owing to the formatting present for the automatic belt usage. Only the manual restraint use provided indication of the child seat presence. In practice, the automatic restraint was an uncommon way of securing the child safety seat. The unrestrained classification was made based upon the manual restraint use. Two other cases were determined to be restrained owing to more ample information contained in the forthcoming 30-file data set.

Table 2: Discrepancies to be Resolved with the Introduction of the Oracle look-a-like, 30-file Data Set

Restraint Use Status	Frequency
Unrestrained	5
Automatic Belt Use	1
Integrated Belt-positioning booster seat	8
Integrated Convertible Seat	1
Restrained, belt routed unconventionally	1
LATCH	1
Restrained	2
SAS-reported Unrestrained Occupants	**19**

Source: NASS CDS, 2002-2003 and NASS CDS Electronic Case Access

A more complicated query would have been needed when using the 11-file format to capture additional restraint use cases. Further, the integrated seat has been subsumed into the child safety seat types. In the previous query, the child safety seat, child safety orientation, and child safety seat make would have been queried to assess the child safety seat.

Injury Severity

Injury severity was determined using The Abbreviated Injury Scale (AIS) as devised by the Association for the Advancement of Automotive Medicine. Injuries are ranked with regard to risk of mortality from 0 through 7, as defined in Table 3. The highest injury severity, AIS score, sustained by an occupant became the Maximum AIS (MAIS) reported in CDS.

Data Composition

NASS CDS is a weighted sample estimating the yearly incidence of police-reported tow away crashes in the United States occurring on public roadways. Weighted estimates were based upon a sample of 21,020 occupants transported in vehicles that were towed. Of these occupants, 1,333 were children less than ten years old. Fifty-three percent of these children were involved in crashes in 2002 and 47 percent in 2003. The weights must be incorporated into any meaningful analysis. Without these weights, the cases become an interesting series of anecdotal accounts.

Table 3: Abbreviated Injury Scale Values	
MAIS Value	Description
7	Unknown
0	Uninjured
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum
Source: Injury Coding Manual, 2000	

Nearly ten million occupants were involved in tow away crashes during 2002 through 2003. Of these occupants, approximately 620,000 occupants were children under the age of ten years, with 55 percent occurring in 2002 and 45 percent occurring in 2003. This decrease is not statistically significant since CDS should not be used for yearly changes, instead it must be over several years to establish trends useful for analysis.

Since two years may not be used for a meaningful data analysis, owing to the small sample size, both weighted and raw numbers have been prepared. The raw numbers are illustrative and should not be used to interpret the data set.

Data Interpretation

Based upon the data parameters set forth, several questions were addressed. This section cannot be deemed an analysis owing to the small data set. Instead, it was meant to introduce the data set and describe its population while looking toward the 30-file data set. Issues considered included: the manner in which children were restrained, occupant seating location within the vehicle, types of child seats used, and injury severity.

How are children restrained?

Approximately 620,000 children were involved in tow away passenger vehicle crashes over the years 2002 through 2003, per Table 4a. Of these, 34 percent were transported in child restraint systems secured by a vehicle-installed restraint. Half the children were restrained by the vehicle installed restraint system. Less than 10 percent of these children were unrestrained.

Table 4a: Restraint Usage for Children from Birth through Nine Years Old, by Age, Weighted Data

Age	Vehicle Installed Restraint	CRS Secured with a Vehicle Installed Restraint	None	Other
0	475	29,160	4,001	2,646
1	2,781	67,141	3,044	6,157
2	4,626	39,852	4,739	6,747
3	6,536	32,619	1,668	1,032
4	15,135	20,575	10,699	2,299
5	28,720	12,551	9,899	6,022
6	67,293	6,546	3,082	1,427
7	41,071	3,647	8,753	8,253
8	92,272	14	3,825	2,756
9	48,253	1,552	6,388	5,323
Source: NASS CDS, 2002 - 2003				

Table 4b: Restraint Usage for Children from Birth through Nine Years Old, by Age, Raw Data

Age	Vehicle Installed Restraint	CRS Secured with a Vehicle Installed Restraint	None	Other
0	2	96	15	10
1	6	106	12	24
2	15	99	19	19
3	24	80	16	16
4	45	47	21	11
5	53	32	25	14
6	93	13	18	13
7	81	6	27	18
8	95	1	19	17
9	89	1	22	13
Source: NASS CDS, 2002 - 2003				

Where were these children seated?

Eighty-five percent of the children less than 10 years old were transported in the rear seating positions, per Table 5a. When limiting the seating positions to only those compatible with child restraint systems, a nearly identical percentage were transported in the rear seat, per Table 6a. This was understandable owing to child restraint system usage being predicated upon a seating position with vehicle-installed manual restraints. Those children using a child restraint system in conjunction with a vehicle-installed restraint in the front seat comprised 36 percent and an equivalent percentage in the rear seating equipped positions. These differences in restraint usage and seating position may be attributable to safety messages, dating to the mid-1990's, advocating rear seating positions for children 12 years old and under.

Table 5a: Restraint Usage for Children from Birth through Nine Years Old, by Seating Position, Weighted Data

Seating Position	Vehicle Installed Restraint	CRS Secured with a Vehicle Installed Restraint	None	Other
Front Row	29,205	26,647	24,559	9,415
Rear Rows	277,653	187,012	31,313	31,909
Other	303	0	226	1,336

Source: NASS CDS, 2002 - 2003

Table 5b: Restraint Usage for Children from Birth through Nine Years Old, by Seating Position, Raw Data

Seating Position	Vehicle Installed Restraint	CRS Secured with a Vehicle Installed Restraint	None	Other
Front Row	92	20	47	25
Rear Rows	410	461	146	118
Other	1	0	1	12

Source: NASS CDS, 2002 - 2003

What were the various types of child safety seats used?

Although 61 percent of children 0 through 9 years old used no child restraint system, the value was partially comprised of graduates to the vehicle-installed restraints, as well as unrestrained occupants,

Table 6a: Restraint Usage for Children from Birth through Nine Years Old, by CRS Compatible Seating Position, Weighted Data

CRS Compatible Seating Position	Vehicle Installed Restraint	CRS Secured with a Vehicle Installed Restraint	None	Other
Right Front Passenger Seat	28,546	26,647	12,878	5,478
Left, Right, and Middle Rear Rows	276,153	187,012	23,305	31,450
Other	2,462	0	19,916	5,733

Source: NASS CDS, 2002 – 2003

Table 6b: Restraint Usage for Children from Birth through Nine Years Old, by CRS Compatible Seating Position, Raw Data

CRS Compatible Seating Position	Vehicle Installed Restraint	CRS Secured with a Vehicle Installed Restraint	None	Other
Right Front Passenger Seat	82	20	27	23
Left, Right, and Middle Rear Rows	403	461	115	114
Other	18	0	52	18

Source: NASS CDS, 2002 – 2003

per Table 7a. From Table 8a, it should be recognized that children 0 through four years old comprise only 8 percent of the child safety seat omissions; 53 percent are 5 through 9 years old. As noted above, the majority of children were restrained, whether in age-appropriate child safety seats or, early graduations, by the vehicle installed restraint system. Of special concern were the five percent of children classified as booster-seat-with-shield users. As defined previously, these were formatting errors inherent to the SAS data set and will be corrected in the Oracle look-a-like file. When using the data, it should be noted that the reporting standards are appropriate and quality control has been performed to verify that these seats have been correctly classified. Each data user should label the SAS format booster seat with shield as aggregate booster seat. Table 7a was created using the format file provided with NASS CDS SAS data set for 2002 through 2003, which aggregated booster seats with and without shields under the booster-seat-with-shield attribute.

Table 7a: Restraint Usage for Children from Birth through Nine Years Old, by Child Safety Seat Type, Weighted Data				
Child Safety Seat	Vehicle Installed Restraint	CRS Secured with a Vehicle Installed Restraint	None	Other
None	307,161	0	48,527	25,244
Infant Seat	0	14,153	1,449	130
Toddler Seat	0	51,218	476	130
Convertible	0	83,033	3,862	0
*Booster Seat with Shield**	*0*	*29,465*	*429*	*0*
Other Seat	0	218	0	0
Unknown Type	0	35,570	1,357	17,156
Source: NASS CDS, 2002 - 2003				
***NOTE: Mislabeled Aggregation of booster seats.**				

Table 7b: Restraint Usage for Children from Birth through Nine Years Old, by Child Safety Seat Type, Raw Data				
Child Safety Seat	Vehicle Installed Restraint	CRS Secured with a Vehicle Installed Restraint	None	Other
None	503	0	175	108
Infant Seat	0	55	5	1
Toddler Seat	0	81	1	1
Convertible	0	155	3	0
*Booster Seat with Shield**	0	56	8	0
Other Seat	0	3	0	0
Unknown Type	0	131	2	45
Source: NASS CDS, 2002 - 2003				
**NOTE: Mislabeled Aggregation of booster seats.*				

As mentioned previously, the child seat type variable accounted for only those children transported in child safety seats, per Table 8a. The "none" category, comprising 61 percent of all occupants less than ten years of age, was not meant to be synonymous with unrestrained. Instead, it was the aggregate of not using a child safety seat. This group subsumed all vehicle installed safety belt users, as well as unrestrained occupants. Of the children using some form of child safety seat, the majority, 36 percent, were transported in a convertible seat and ranged in age from birth through 6 years of age. Without exposure numbers, with regard to vehicle, child age, and child seat type used for transporting children less than 10 years old, it was only possible to assess the restraint usage behavior of children involved in tow away crashes, not the generalized child restraint usage for children in this age group.

Table 8a: Child Safety Seat Usage for Children from Birth through Nine Years Old, by Age, Weighted Data						
Age	None	IS	TS	CS	BSS	Oth Unk
0	1,873	15,711	672	9,318	0	8,709
1	6,496	22	20,666	31,934	1,450	18,555
2	10,740	0	3,821	24,201	1,465	15,738
3	8,246	0	7,699	15,375	7,112	3,422
4	23,901	0	7,294	4,918	10,857	1,739
5	41,109	0	8,687	1,122	2,287	3,987
6	71,688	0	148	28	4,487	1,997
7	58,077	0	2,837	0	684	126
8	98,839	0	0	0	0	27
9	59,965	0	0	0	1,552	0
Source: NASS CDS, 2002 - 2003						
Key: None = no child safety seat present, IS = infant seat, toddler seat, TS = toddler seat, CS = convertible seat, BSS = booster seat with shield, and Oth Unk = other or unknown child restraint system present.						

Table 8b: Child Safety Seat Usage for Children from Birth through Nine Years Old, by Age, Raw Data						
Age	None	IS	TS	CS	BSS	Oth Unk
0	15	58	1	15	0	34
1	22	3	15	61	3	44
2	42	0	19	40	3	48
3	47	0	25	24	14	26
4	70	0	11	12	16	15
5	89	0	8	5	16	6
6	121	0	2	1	9	4
7	126	0	2	0	2	2
8	130	0	0	0	0	2
9	124	0	0	0	1	0
Source: NASS CDS, 2002 - 2003						
Key: None = no child safety seat present, IS = infant seat, toddler seat, TS = toddler seat, CS = convertible seat, BSS = booster seat with shield, and Oth Unk = other or unknown child restraint system present.						

How severe are the injuries sustained by children 0 through 9 years old?

Of the uninjured children, MAIS 0, 41 percent were transported in a child restraint system secured by a vehicle-installed manual restraint, per Table 9a. Another 50 percent were secured by the vehicle-installed manual restraint. As the injury severity declined, an increase in the restraint usage was noted. It must be noted that this cannot be asserted with any statistical confidence owing to the small sample size, however, an indication exists that must be tested over the coming years.

Table 9a: Restraint Usage for Children from Birth through Nine Years Old, by Maximum Abbreviated Injury Score, Weighted Data				
MAIS	Vehicle Installed Restraint	CRS Secured to a Vehicle Installed Restraint	None	Other
0	210,987	173,301	22,422	17,180
1	92,031	35,788	23,501	9,852
2	1,806	1,587	4,694	459
3	578	266	3,882	5
4	260	549	526	10
5	94	260	169	52
6	71	133	28	15
7	848	385	665	6,982
Source: NASS CDS, 2000 – 2003				

Table 9b: Restraint Usage for Children from Birth through Nine Years Old, by Maximum Abbreviated Injury Score, Raw Data				
MAIS	Vehicle Installed Restraint	CRS Secured to a Vehicle Installed Restraint	None	Other
0	236	293	54	69
1	208	143	69	41
2	17	14	20	7
3	15	6	12	1
4	4	3	7	1
5	3	6	6	2
6	2	2	1	1
7	16	9	22	29
Source: NASS CDS, 2000 - 2003				

Summary

Data shown in this section were meant to highlight changes to the NASS CDS data collection. Data analysis cannot be performed on two years of data, the period since the modifications were instituted. Approximately, five years of data must be compiled to perform meaningful analyses. In the case of child seat cases, more years may be needed owing to the low frequency of children reported in crashes each year.

CASE AVAILABILITY

Electronic case files may be accessed via the NHTSA website, Electronic Case Access Screen. The hyperlink is as follows: http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa

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CHILD SAFETY IN LIGHT VEHICLES

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ABSTRACT

In the last 30 years, our nation has achieved significant gains in child passenger safety. Child restraint systems (child safety seats and booster seats) have saved thousands of children. Even though child restraint systems have proven to be an excellent concept for injury mitigation, Congress directed the Secretary of Transportation to initiate a rulemaking for the purpose of improving the safety of child restraints. The National Highway Traffic Safety Administration (NHTSA) was able to conduct extensive research within the mandated timeframe. Many consumer information programs were developed, and some improved upon, to provide better consumer information on child safety restraints, usage, etc. Federal Motor Vehicle Safety Standards were upgraded and are currently being upgraded to continue improvements in child safety. This paper provides a status on recent analyses and proposed child safety research efforts.

INTRODUCTION

Motor vehicle crashes are the leading cause of death for children of every age from two to 14 years old. During 2003, 8,089 passenger vehicle occupants under 15 years of age were involved in fatal crashes. For those children, where restraint use was known, 30 percent were unrestrained; among those who were fatally injured, 53 percent were unrestrained. In 2003, 471 children under the age of five died as occupants in light passenger vehicle crashes. Of those 471 fatalities, an estimated 167 (35 percent) were totally unrestrained. Research shows that child restraint systems (CRS), when used correctly, can reduce fatalities among infants (children less than one year old) by 71 percent in passenger cars and among toddlers (one to four years old) by 54 percent.[1] That makes child safety seats one of the most effective safety innovations ever developed. Use of CRS is now required in all 50 states and the District of Columbia. Data indicate that the increased use of these restraints, as a result of mandatory usage laws, have significantly reduced the risk of child fatality in motor vehicle crashes.

In 2003, an estimated 446 children under age five were **saved** as a result of CRS use. That 2003 figure would have been 550 children saved if all motor vehicle occupants under 5 years old were protected by CRS. During that year, there were 185 fatalities among children in CRS. About 28 percent (52 fatalities) were in frontal non-rollover crashes, 28 percent (51 fatalities) were in non-rollover side impacts, and 26 percent (48 fatalities) were in rollover crashes.

The data show that the national injury problem remains an issue for children and requires further definition. Given the many crash types, crash severity levels, child occupant ages and child restraint categories, the child safety research area is very complex. Organization of the child safety research base is a major task itself, as is finding a vehicle-based countermeasure focus for maximum benefit across ages. Maximum benefits may not be realized by only focusing on the child restraint system improvements, but by possibly developing vehicle improvements. Further benefits may be realized through crash mitigation with advanced technologies.

BACKGROUND

Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act

On November 1, 2000, Congress enacted the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act (Pub. L. 106-414, 114 Stat. 1800) which, in part, requires the Secretary of Transportation to initiate a rulemaking for the purpose of improving the safety of child restraints.[1]

Section 14(a) of the TREAD Act mandated that the agency ''initiate a rulemaking for the purpose of improving the safety of child restraints, including minimizing head injuries from side impact collisions.'' Section 14(b) of the Act identified specific elements that the agency must consider in its rulemaking. The Act gave the agency substantial discretion over the decision whether to issue a final rule on the specific elements. Section 14(c) specified that if the agency does not incorporate any element described in 14(b) in a final rule, the agency shall explain in a report to Congress the reasons for not incorporating the element in a final rule.[2] Various Sections of the Act addressed consumer information improvements such as labeling, availability of compliance test data and CRS ratings. In response to Section 14, the agency examined possible ways of improving consumer information on child safety restraints, revising and updating its child restraint standard.

NHTSA published a final rule on June 24, 2003 (68 FR 37620), to address Section 14(b) of the TREAD Act. The rule incorporated five elements into FMVSS No. 213: (a) an amendment to make labels and instructions clearer and simpler; (b) an updated bench seat used to dynamically test add-on child restraint systems; (c) a sled pulse that provides a wider test corridor; (d) improved child test dummies; and (e) expanded applicability to child restraint systems recommended for use by children weighing up to 65 pounds. Child restraints will be tested using the most advanced test dummies available today and tested to conditions representing current model vehicles.[3] Although changes were made to the child safety standard, Congress further directed the Secretary of Transportation to make additional improvements to the Standard to address larger children.

Anton's Law

On December 4, 2002, the President signed "Anton's Law" (Public Law 107-318, 116 Stat. 2772) which in part calls for improvement of the safety of child restraints in passenger motor vehicles for larger, older children. Anton's Law mandated the Secretary of Transportation to 1) initiate a rulemaking proceeding to establish performance requirements for child restraints, including booster seats, for the restraint of children weighing more than 50 pounds; 2) develop and evaluate an anthropomorphic test device that simulates a 10-year old child for use in testing child restraints used in passenger motor vehicles; 3) require a lap and shoulder belt assembly for each rear designated seating position in a passenger motor vehicle with a gross vehicle weight rating of 10,000 pounds or less; and 4) initiate an evaluation of integrated or built-in child restraints and booster seats.

In response to Anton's Law, NHTSA published a report to Congress on built-in child safety restraints. The study found no additional benefits with built-in child restraints when compared to add-on child safety seats. More detailed results of the study can be found in the Report to Congress: Anton's Law Section 6 – Evaluation of Integrated Child Safety Systems.[4] In response to Anton's Law, on December 8, 2004, a final Rule was published requiring lap and shoulder belt assemblies for each rear designated seating position.[5] This rulemaking was instituted, in part, to offer comparable safety protection for larger, older rear center seated child occupants. The agency is continuing research efforts with the 10 year-old anthropometric test device which would be required in order to upgrade the child safety standard to evaluate restraint systems developed for use by children weighing more than 60 pounds.

RESEARCH APPROACH

During the last four years, extensive research efforts have been undertaken to revise Federal Motor Vehicle Safety Standard (FMVSS) No. 213, "Child Restraint Systems" (49 CFR §571.213) and improve consumer information on child safety restraints. Timely program, resource and funding decisions were required in order to address the mandates. In order to better focus the agency's resources and funding for research, a research approach needed to incorporate the concept of preliminary estimations of benefits based on engineering judgment. Preliminary estimate of benefits is used to help direct the agency on immediate and future activities in a more efficient manner. A 9-step research approach has been undertaken for the child safety research program.

[1] This followed an agency announcement in its November 2000 Draft Child Restraint Systems Safety Plan (Docket NHTSA–7938) that the agency would be undertaking rulemaking on these and other elements of Standard No. 213 (65 FR 70687; November 27, 2000).

The approach includes the following steps:

1. Select and define a crash problem
2. Set countermeasure functionality
3. Survey technology for functions
4. Create countermeasure concepts
5. Estimate preliminary costs and benefits
6. Select the most promising concept(s)
7. Develop and conduct objective tests
8. Refine costs and benefits
9. Agency decision on next steps

Step 9 is an agency decision-making step. In this phase of the process, the research results, along with cost and benefits, are then assessed by the agency to determine the next action to be undertaken. While research efforts are conducted within the framework of steps 1 – 8, agency involvement occurs throughout the entire process.

While the agency finalizes meeting the child safety Congressional mandates, a reassessment of the child safety data must be undertaken. As public knowledge has increased regarding child safety due to public programming, new state laws and joint partnerships, real-world requirements have changed/improved for children. For example, more children of appropriate ages and size are using booster seats and younger children are being appropriately restrained in child safety restraint systems.

Problem Definition

During the last four years, extensive data analyses have been conducted by the agency. To date, no compilations or summaries of these analyses have been completed. The intent of current analyses is to build, or expand, on previous analyses and to potentially develop new analytical approaches.

Multi-Dimensional Crash Assessment

The child safety problem has numerous relevant dimensions. The effects in an individual case can be measured by injury severity data (such as Maximum Abbreviated Injury Scale (MAIS) values as used in the Crashworthiness Data System (CDS) or fatality from the Fatality Analysis Reporting System (FARS)). The inputs that yield these results include crash type (e.g., front, rear, side, rollover), crash sub-type (e.g., offset frontal, far side impact), closing velocity, seating position, occupant age, restraint type, restraint appropriateness (e.g., premature graduation to seatbelts) and vehicle characteristics of all vehicles in the crash.

As no two crashes are the same and detailed analysis of large numbers of case studies is beyond the scope of this study, inferences must be made from large groups of similar crashes. Only after significant subgroups of crash parameters are identified can attempts be made to "drill down" to discover those for which countermeasures can provide effective benefits.

A case can be made for examining every recorded parameter, but the authors chose to limit the initial analysis to four major dimensions: crash type, occupant age, general restraint level (restrained/unrestrained/unknown), and injury severity. The years 1995-2003 (except 1997) were used. It should be noted that CDS provides data from tow-away crashes that can then be "weighted" to account for the overall prevalence of those crash conditions.

The total weighted or unweighted counts (normalized by year) provide useful insight into "hotspots" of child injury. An alternative is to estimate "fatality equivalents" associated with each age, crash type, and restraint level. A fatality equivalent factor is assigned to each Abbreviated Injury Scale (AIS) severity level. While the definition of fatality equivalents for children is beyond the scope of this study, the relative weight for each level can be approximated using the [injury-based] weightings in the Blincoe report.[6] When estimating fatality equivalents, it was decided to use FARS data for fatalities and to eliminate non-survivors from CDS data. That is, those data points that indicated an MAIS level of less than 6 but a finite survival period were removed from the CDS counts to avoid double counting. This technique has been used to analyze injury patterns on various crash types and sub-types.

Child Safety Research Inventory

A key aspect of the Child Safety Research Program is coordination and collaboration with other researchers. A specific effort has been made to avoid duplication of effort. The purpose of the newly created database is to provide a cross-reference for identified "hot spots" found in the initial data analysis. This allows analytical resources to be more efficiently allocated. Relevant research studies five years old or less have been entered into a relational database. Important characteristics of each study (e.g., the age groupings and crash types considered) were entered, as well as a summary of results. The database contains information regarding which child safety issues the study address (e.g., which specific age groups were considered, if any at all). A typical study is shown in Figures 1 and 2. The database will facilitate the identification of "holes" in the child safety problem that have been under-analyzed as well as current research and schools of thought for those that are being examined.

The prototype database includes recent governmental studies. Data regarding external studies will be added at a later date.

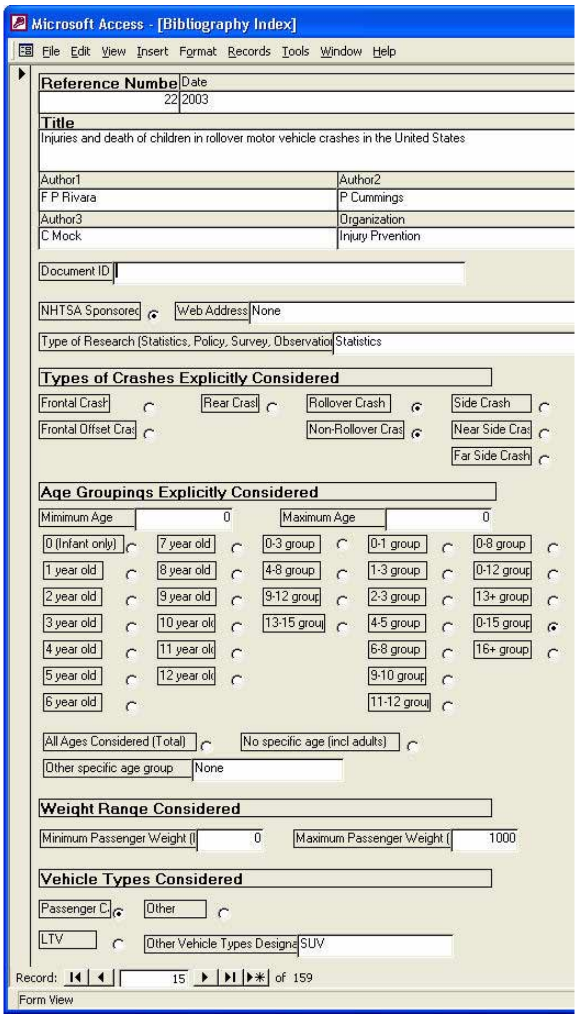

Figure 1 Screen Capture A of Inventory Database

Status of Injury to Children in Motor Vehicle Crashes - Exposure

Understanding the effectiveness of child safety initiatives requires data on both the number of child injuries as well as the number of opportunities or "exposure." One measure of exposure is the number of passenger miles traveled (PMT). Estimating exposure for children is difficult. An approximate method is proposed that relies on potentially questionable assumptions that injury rates and patterns of both drivers and occupants are independent of the age and total number of vehicle occupants. Nonetheless, it is hoped that the trends developed using this method can yield some insight into injury rates for important age groups.

It is tempting to estimate the relevant exposure of a certain age group by comparing the total count of injured and uninjured passengers (the sum of Maximum AIS value of 0 to 6) of an age group in a

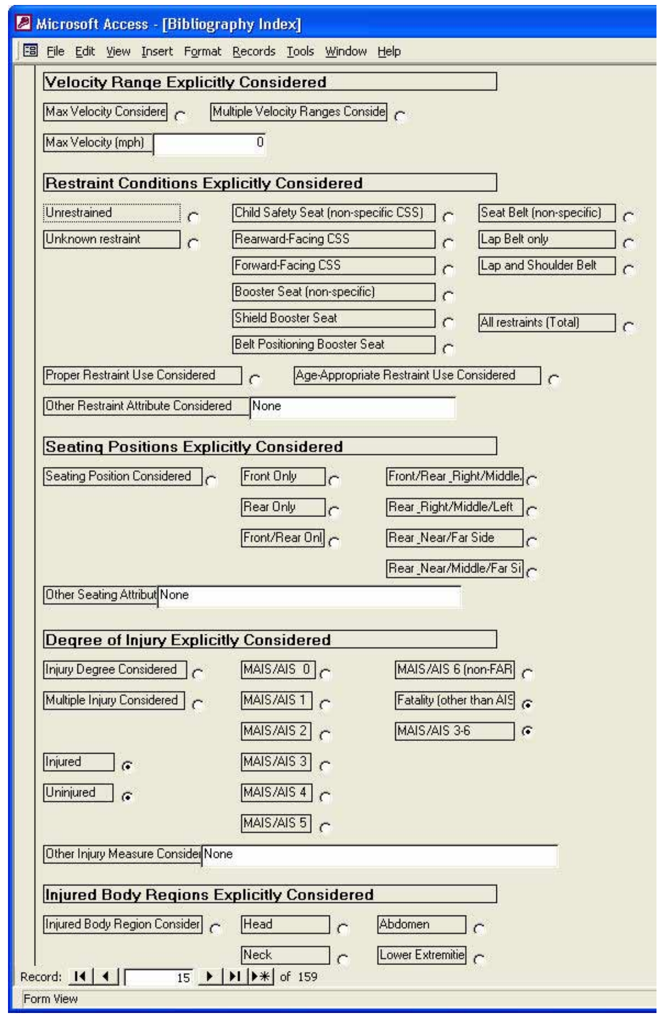

Figure 2 Screen Capture B of Inventory Database

large database (e.g., CDS of the National Automotive Sampling System [NASS]) to the total number of injured and uninjured drivers. Assuming the database contains information on every driver and passenger in every crash considered, the ratio of child occupants in the database to drivers in the database should be the ratio of passenger (child occupant) miles traveled to vehicle (driver) miles traveled. For the purposes of this paper, a "load factor" for a particular age group is defined as this ratio of passenger miles traveled (PMT) to vehicle miles traveled (VMT). The inherent assumption with this definition is that drivers' propensity for being involved in a crash is independent of the presence or the number and age of passengers.

A similar approach which yields some insight into the relative injury profiles of children and drivers involves determining the relative number of injuries of each severity level (e.g., the police injury severity rating where injury is classified from killed [K] to uninjured [O]) for crashes in the NASS General Estimates System (GES)) in which there is one driver and exactly one child passenger. For each severity level, there is a particular ratio of total children to total drivers. It is unlikely that this ratio will be exact unity. When there are more children than drivers at lower injury levels, one might infer that children are safer than drivers. At any given injury level, one can use this ratio and the ratio of total driver injuries to total child injuries to estimate a load factor. A sample calculation is given below:

In the years 1994-2003, GES estimates that there were 179,000 crash vehicles involving only a driver and a single infant (child occupant less than one year old). In those crashes, 154,100 children and 133,600 drivers were uninjured (severity level O). The ratio of these tow numbers is 1.15. Thus, infants were 15% more likely to be uninjured (i.e., have a severity level of O) than drivers. For these same years, the estimated total number of uninjured drivers in all crashes was 88,063,000 and the estimated total number of uninjured infants was 570,000. Since infants are 15% more likely to appear in this injury category, the estimated load factor is given by:

$$LF \cong (570{,}000/1.15)/88{,}063{,}000 = 0.56\%$$

This load factor analysis requires the assumption that injury distribution for children and for drivers in NASS crashes are completely independent of the presence of other occupants. This is unlikely to be the case. At the very least, seating location will be a function of the number of adult and child occupants. Hence, for infants, it is not surprising to find that the calculated load factors range from 0.52% to 0.91%, depending on the injury severity used. When all involved infants (levels K, A, B, C, and O combined) were considered, the computed load factor was 0.61%. The load factors calculated for level K (killed) varied most widely, given the relatively few occurrences compared with other injury levels. When the geometric mean was computed for levels A, B, C, and O, it was found to be 0.67%. Although no rigorous estimate of confidence level was made, it is likely that the actual load factor for infants is between 0.6% and 0.7%. That is, for every 100 vehicle miles traveled, there are approximately 0.6 to 0.7 passenger miles traveled for infants. While some uncertainty exists for each estimate, a consistent calculation method can be used to expose certain trends.

Figure 3 shows the calculated load factors for important age groups and subgroups using all the GES data. Some interesting patterns do emerge. First, infants have a relatively low load factor. One might presume that mothers of newborns avoid taking them on routine errands for several months. Second, load factors drop off as children enter school. Finally, load factors rise again as children enter their early teens.

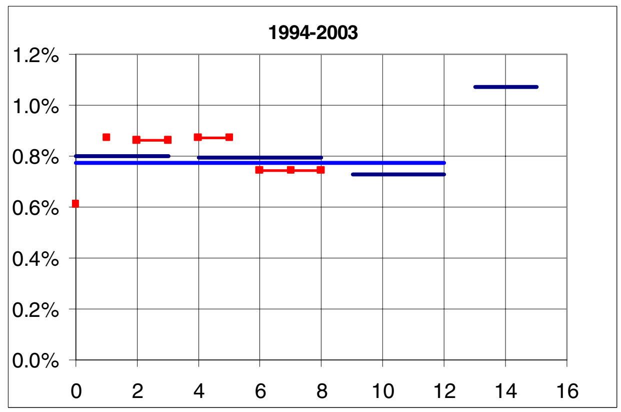

Figure 3 Load Factor vs. Age

These estimated load factors can be used to calculate estimated injury rates relative to PMT. The injury count for the years in question was estimated from MAIS data in CDS. The PMT for each age group was estimated by multiplying the load factor by the VMT reported by the Bureau of Transportation Statistics. Once again, the statistical sensitivity to low incident counts was higher for the more extreme injury levels. The estimated incidence rate is shown for various age groups in Figure 4.

This figure also shows some interesting trends. First, children over 8 years old seem to be far more vulnerable to injuries at all severity levels. This might be a result of diminished parental insistence on proper restraint at these ages. Second, infants and one-year-olds show lower injury rates at the middle severities. The implication is that young children are either well protected in a particular crash or susceptible to severe injury. How well this susceptibility correlates with proper restraint use is a subject for further research. Finally, the trends identified at the MAIS 6 level should be verified by applying FARS fatality data.

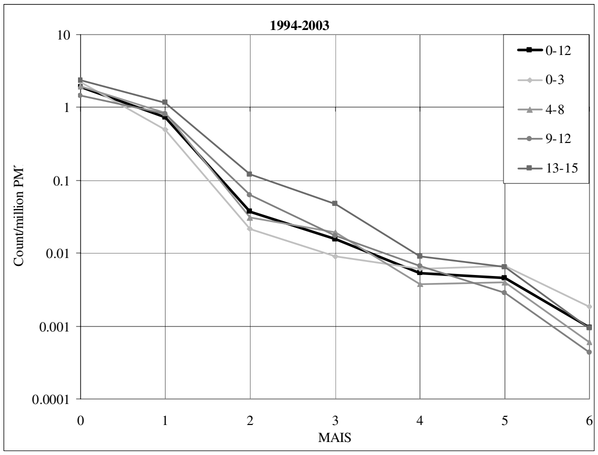

Figure 4 Incidence of MAIS level per Million Passenger Miles Traveled (by age group)

Next Steps

Once the data have been completely reviewed and analyzed, an assessment of countermeasures will be made. Countermeasure candidates will possibly be considered by age and restraint type. Based on each restraint type for the various child age populations, some countermeasure candidates may be vehicle-based. The countermeasure selection approach will then be determined by the applicable parameters. The estimated cost benefits approach will be based on the countermeasure(s) selection. Once the estimated benefits are determined, objective tests will be developed and conducted. These efforts will be undertaken within the framework of steps 1 - 8.

SUMMARY

This paper sought to describe the status of child safety in light passenger vehicles. Child safety in light vehicles is a complex problem area. The data show that child restraint systems are very effective when used. However, continued efforts are warranted to get the unrestrained children into the appropriate restraint systems. Although child restraint systems generally are performing well in real-world crashes, children are still sustaining injuries. Considerations may need to be given to improving the vehicle for occupant protection for children. Benefits may be realized not just for smaller children but older children as well. Nonetheless, further research is warranted. The authors will continue their work to identify opportunities for increased safety.

ACKNOWLEDGEMENTS

The authors express their sincere appreciation to Tewabe Aswebe, Lawrence Blincoe, Ana Eigen, Michael Huntley, Kenneth Paciulan, Susan Partyka, James Simons, Lisa Sullivan and a host of other staff for their technical support, guidance, endless input, and recommendations for this project. Your support has been instrumental in directing the child safety light passenger vehicle research efforts.

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METHOD OF EVALUATING ABDOMINAL INJURY IN JAPAN'S CHILD-RESTRAINT-SYSTEM ASSESSMENT PROGRAM

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ABSTRACT

This paper describes the electric pressure sensor-based abdominal injury measuring method employed in the Japan's CRS assessment program.

The CRS assessment program was launched in 2001 in Japan[1]. The objective of this program is to assess usability of CRSs for infants and toddlers and the systems' safety in frontal collision.

This assessment has started due to recent increase of casualties among minor passengers and to introduction of the mandatry use of CRSs for six-year-old or younger passengers.

The safety assessment test determines performance of CRSs by evaluating behavior of dummies and the target CRSs as well as damage caused by the CRS. It also investigates whether or not the CRS is constraining vulnerable parts of the child's body. In the initial plan, high-speed photography was to be used for determining the scale of the injury caused by restraining gear such as a harness on a child's body. It was found, however, that images from high-speed photography are not suited for determining degrees of compression on the abdomen, the most vulnerable part of the body. In order to solve this problem, we have started an investigation for an alternative method capable of quantitatively measuring abdominal compression.

Throughout the study, the electric pressure sensor-based method was employed for determining abdominal compression from the CRS assessment in 2003. This method allows for quantitatively observing the ever-changing pressure distribution on the abdomen. This approach first calculates abdominal loads from the pressure data collected from the area corresponding to the child's abdomen, and then selects the maximum load among them for use in the actual assessment. We have derived children's resistibility to abdominal load by scaling the relation between the waist belt and Abbreviated Injury Scale (AIS) among adults to the children's physique.

1. INTRODUCTION

In Japan, evaluation of usability of CRSs for infants and toddlers as well as safety of these systems in frontal collision has been conducted as part of the CRS assessment program since 2001.

In the frontal collision test, a cut body of Toyota's family wagon type Estima secured to the sled testing machine is caused to collide at a testing speed of 55km for an hour (see Figure 1). Safety of the CRS under test is evaluated based on behaviors of the dummies, degrees of damage on the dummies, scale of injury caused by the restraint and degrees of damage on the CRS body (see Tables 1, 2, 3 and 4).

In the usability evaluation test, five specialists is to assess ease of use of CRSs in the light of how they are protected from inappropriate usage. Usability of a system is rated for each of the evaluation items on a five-point scale from 1 to 5. Average of the scores on the five evaluation areas is then computed and published (see Table 5).

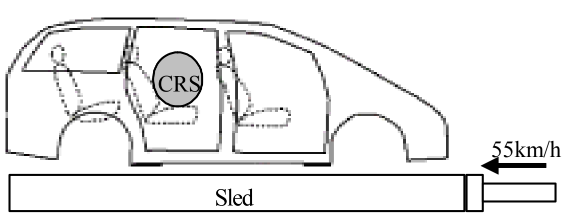


Figure 1 Test configuration

Table 1 Individual rating for rear-facing infant CRS

Rating items	Criteria	Rating
Damage of such as fixtures	No	◎
	Slight	○
	Terrible	×
Inclination angle of seat back **(A)**	60deg. ≧ angle	◎
	60deg. ＜ angle ≦ 70deg.	○
	70deg. ＜ angle	×
Projection of the head from CRS **(B)**	No projection	◎
	73mm ≧ projection	○
	73mm ＜ projection	×
Chest resultant 3ms acceleration **(C)**	539m/s^2(55G) ≧ acc.	◎
	539m/s^2(55G) ＜ acc.	○
Release of buckle		×
Released from seatbelt		×

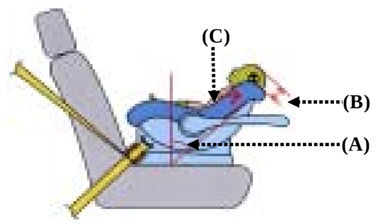


Table 2 Individual rating for bed-type infant CRS

Rating items	Criteria	Rating
Damage of such as fixtures	No	◎
	Slight	○
	Terrible	×
Restraining condition (Projection of the head from CRS, bottom angle of bed **(A)**)	Rotating rearward (No projection of the head)	◎
	No rotation (No projection of the head)	○
	Rotating forward or projection of the head	×
Head excursion in forward direction **(B)**	600mm ≧ excursion	◎
	600mm ＜ excursion ≦ 750mm	○
	750mm ＜ excursion	×
Chest resultant 3ms acceleration **(C)**	539m/s^2(55G) ≧ acc.	◎
	539m/s^2(55G) ＜ acc.	○
Release of buckle		×
Released from seatbelt		×

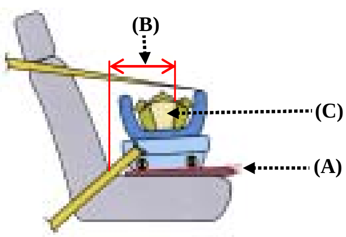


Table 3 Individual rating for forward-facing toddler CRS

Rating items	Criteria	Rating
Damages of such as fixtures	No	◎
	Slight	○
	Terrible	×
Head excursion in forward direction **(A)**	550mm ≧ excursion	◎
	550mm ＜ excursion ≦ 700mm	○
	700mm ＜ excursion	×
Head resultant 3ms acceleration **(B)**	785m/s^2(80G) ≧ acc.	◎
	785m/s^2(80G) ＜ acc.	○
Chest resultant 3ms acceleration **(C)**	588m/s^2(60G) ≧ acc.	◎
	588m/s^2(60G) ＜ acc.	○
Release of buckle		×
Released from seatbelt		×
Possibility of injury, such as that a harness press weak parts of the child's body (abdomen etc.).		×
Dropped from vehicle seat		×

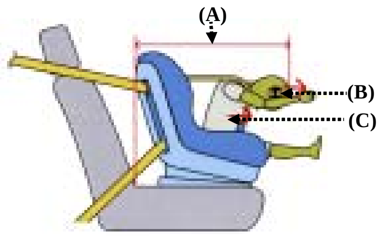


Table 4 Overall evaluations for frontal collision test

Excellent	No "× " and the results of all 4 rating items are "◎ ".
Good	No "× ", the results of any 3 rating items are "◎ "and the result of the rest of rating item is "○ ".
Normal	No "× " and the number of "◎ " is two or less.
Not recommended	If there is any "× " as the result of the test.

Table 5 Evaluation items used in usability test

Area	Target
Instruction manual, etc.	Instruction manual
	Package
Information on CRS	Information content
	Belt guide
Structural design	Movable structures (usability of reclining, rotation structures)
	Seat cover (ease of maintenance)
	Internal storage (for instruction manual, accessories)
Ease of installation (installation to vehicle seat)	Belt routing
	Installation
Ease of fitting	Harness
	Buckle
	Fitting

Each survey area is scored on a scale of 1 to 5, with a standard score of 3.

2. STUDY OF ABDOMINAL COMPRESSION EVALUATION METHODS

As to the vest-type CRSs, high-speed video was found to be incapable of determining the degree of abdominal compression caused by the worn harness because of complex behavior of the dummies during the test. We have therefore launched an investigation to find another abdominal compression measuring method and also to develop a well-defined evaluation method usable for this method.

2.1 Measuring Methods usable for Evaluating Abdominal Compression

Six measuring methods were examined for the above purpose, and usefulness of five of them has been verified in the tests similar to the frontal collision test used in the assessment program.

(1) High-speed photography

We have observed the state of the restraint applied to the dummies as well as their behavior using high-speed cameras. Two cameras were provided in the dynamic test; one was installed on the side position of the cut body to measure the amount of motion of the head and the other was placed on the front side of the cut body to observe the state of the restraint (see Figure 2). The front side camera was first set on the ground but then affixed to the cut body so that the relative distance between them will not be changed by movement of the cut body.

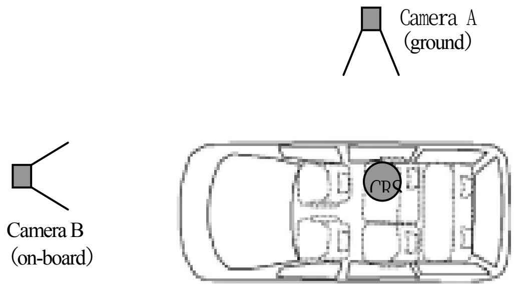


Figure 2 Layout of High-speed Camera

(2) Iliac bone load meter

We measured the load to the iliac bone after changing the original iliac bone of Hybrid III-3YO to Anterior Superior Iliac Spine (ASIS) load cell DENTON 3079. ASIS responses to the load in four separate areas of the right, left, top and bottom, allowing measurement for four channels of data for a single body of Hybrid III-3YO (see Figure 3).

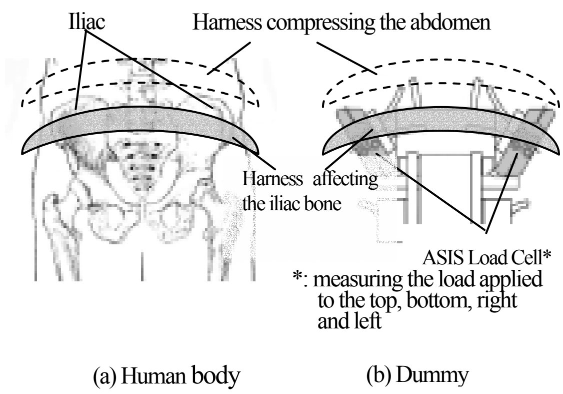


Figure 3 Image of ASIS Load Cell installed on Hybrid III-3YO

(3) Strain type manometer

Strain type manometers having a recipient pressure surface of 6 mm in diameter (KYOWA PS 1 MPa) were set at five positions along the centerline extending from the lumbar to the abdomen of the dummy (see Figure 4). With this arrangement, referencing outputs from the manometer allows us to observe where the harness is applied - lumbar or abdomen.

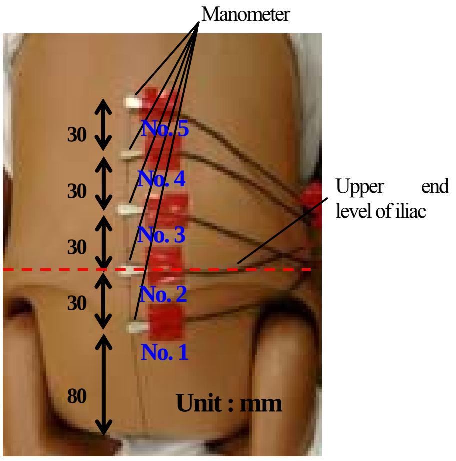


Figure 4 Strain Type Pressure Manometer installed on Hybrid III-3YO

(4) Pressure-sensitive sheet

The dummy's torso was wrapped with FUJIFILM Prescale LW, the surface of which turns red depending on the magnitude of given pressure (see Figure 5). Measuring range of the pressure-sensitive sheet is from 2.5 to 10MPa. This was used to measure distribution of the stresses generated by the restraint on the dummy's torso.

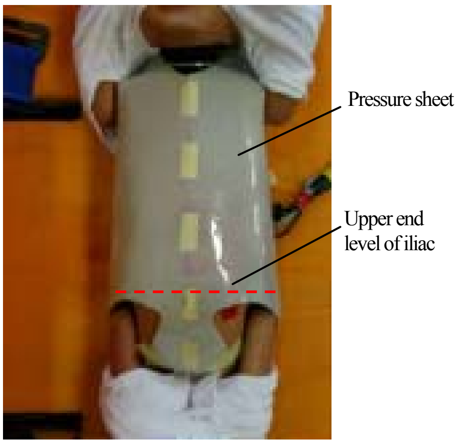


Figure 5 Pressure-sensitive Sheet installed on Hybrid III-3YO

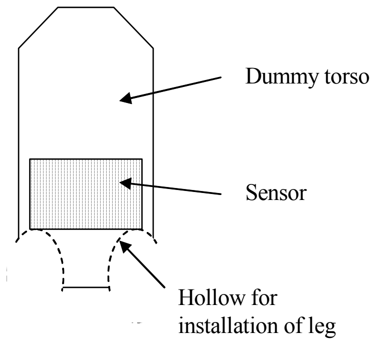
(5) Electric pressure sensor

A sheet-type, electric pressure sensor having approximately 0.1 mm in thickness, was installed on the dummy's abdomen to measure the applied pressure there (see Figure 6).

The electric pressure sensor was placed so that the lower end of the sensor coincides with the upper end of the hollow for installation of the Hybrid III-3YO legs. The measurement area was set to cover the spaces beyond the abdomen (see Figure 7).

The TEKSCAN Tactile Sensor High Speed System complied with the following specifications was selected as the sensor. Major specifications are described as follows.

- Measuring range was from 0 to 1.96 MPa.
- Measuring area was 120 mm in the vertical direction and 250 mm in the horizontal direction.
- Measuring cells were arranged in 12 lines in the vertical direction and 25 columns in the horizontal direction, enabling measurement of the pressure in 300 divisions.
- Resolution of the analog-to-digital converter used was 8 bits or more.
- The sampling frequency was 500 Hz or more.



(a) Installation position

(b) Actual situation

Figure 6 Electric Pressure Sensor installed on Hybrid III-3PO

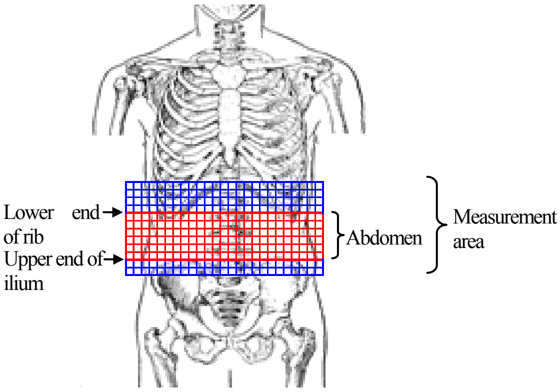


Figure 7 Image of Electric Pressure Sensor's Measurement Areas

(6) Styrofoam

Inserting Styrofoam in the dummy's abdomen is used as a method of determining scale of injury caused to the abdomen by the submarine phenomenon (see Figure 8). This approach is intended to measure scale of abdominal injury by referencing the deformation caused on Styrofoam during the test. However, since this approach requires use of Styrofoam and retrofitting the dummy to accommodate Styrofoam, we gave up using it for the CRS assessment before conducting its the dynamic test.

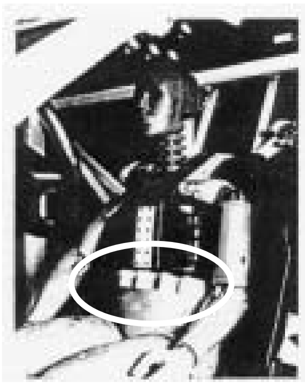


Figure 8 Styrofoam Installed in Hybrid III-3YO (Reference [2])

2.2 Study on Effectiveness in Frontal Collision Test

(1) High-speed photography

Figure 9 shows high-speed photos of the time when forward movement of the dummy's knees reached the maximum. We can recognize on the vest type test product that the waist harness that had originally been applied around the pelvis was pushed up due to the impact. It is, however, difficult to determine the degree of abdominal compression from the high-speed photos alone.

Figure 9 Check of Abdominal Compression by use of High-speed Photos

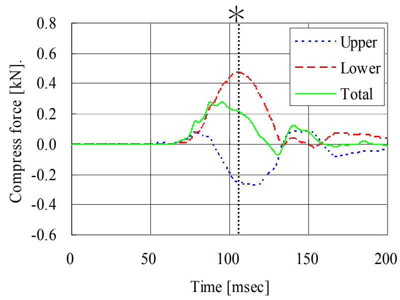
(2) Iliac load meter

Figure 10 shows the time series data obtained from the iliac load meter. Loads to the right and left side are summed up as shown in the figure. The time when the combined load to the upper and lower part of the iliac becomes the maximum roughly coincides with the time when the forward movement of the dummy's knees reaches its maximum. The above finding indicates that the tensile force of the harness has a relationship with the load on the iliac.

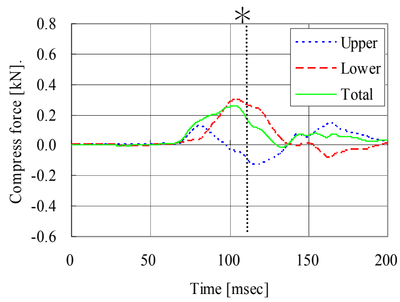
With the vest type systems as well as the systems on which shell's shield is used for constraint, our measurement detected existence of the load in the pulling direction rather than the compressive load in the load applied to the upper part of the iliac. Such pulling load was essentially not observed on the harness type shell. It comes from the structural features of the iliac load meter - the meter measures pulling load in the upper iliac load as the dummy's abdomen is compressed.

The above findings seem to suggest that the upper and lower iliac loads increase even when the pelvis is securely constrained, and looser constraint generates a larger difference between them.

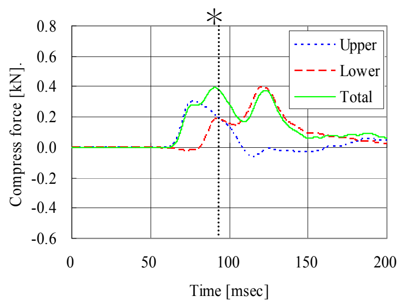
Since the iliac load meter reacts to external force not in the sensing direction, we must determine the meter's response patterns to various external forces before using it for the evaluation.



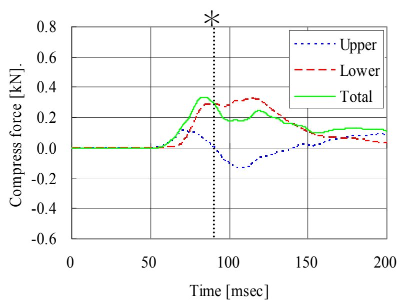
Sample A (vest type)



Sample B (vest type)



Sample C (shell +harness type)



Sample D (shell + harness + pad type)

＊:Time when forward movement of the knees reaches the maximum.

Figure 10 Iliac Loads Measured by ASIS Load Cell

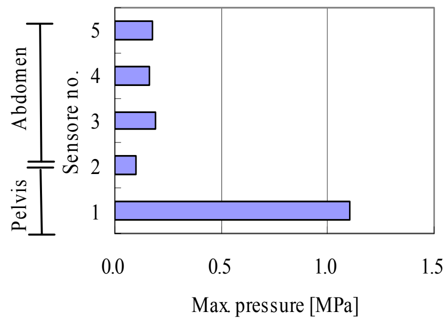
(3) Lumbar and abdominal manometer

Figure 11 shows the maximum pressure obtained from the measurements done at five points in the lumbar and abdomen. The sensor number is sequentially assigned in ascending order from the bottom. No. 2 sensor was placed at the boundary of the lumbar and abdomen.

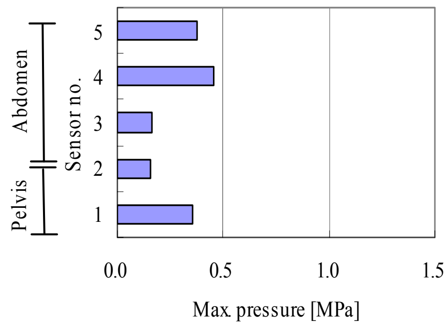
On Sample C and Sample D of the shell type, pressure measured by No. 1 sensor was greater than that obtained from other measuring points possibly because of the compression applied to the manometer from the crotch harness routed right above No. 1 sensor.

On Sample C where the harness type shell was used, pressure measured by No. 4 and 5 sensors was greater than that obtained from other measuring points possibly because the buckle on the measuring point compressed the manometer.

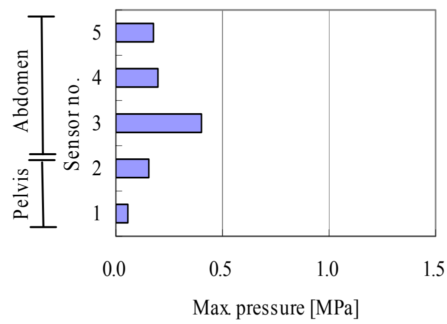
Measurement by use of the lumbar/abdominal manometer is available in limited areas only and pressure measurement beyond the measuring points is unavailable. The manometer protruding from the dummy's surface can interfere with the intended constraining behavior.



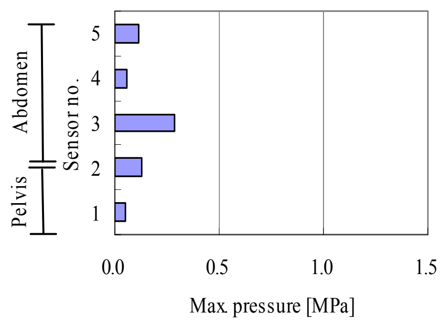
Sample D (shell + harness + pad type)



Sample C (shell + harness type)



Sample B (vest type)



Sample A (vest type)

Figure 11 Pressures Measured by Lumbar/Abdominal Manometer

(4) Pressure-sensitive sheet

Figure 12 shows the pressure distribution obtained by use of the pressure-sensitive sheet. The color becomes darker as the pressure goes higher. With the vest type products tested, traces of relatively high pressure applied to the abdomen were noticed. While on Sample D where the shell type pad is used, relatively high pressure is generated in the abdomen by the pad as well as the lumbar harness situated at a higher position.

However, change in the color was also noticeable on the pressure-sensitive sheets that had been set in the areas completely free from constraint. In this case, change in the color must have resulted from friction on the sheet surface.

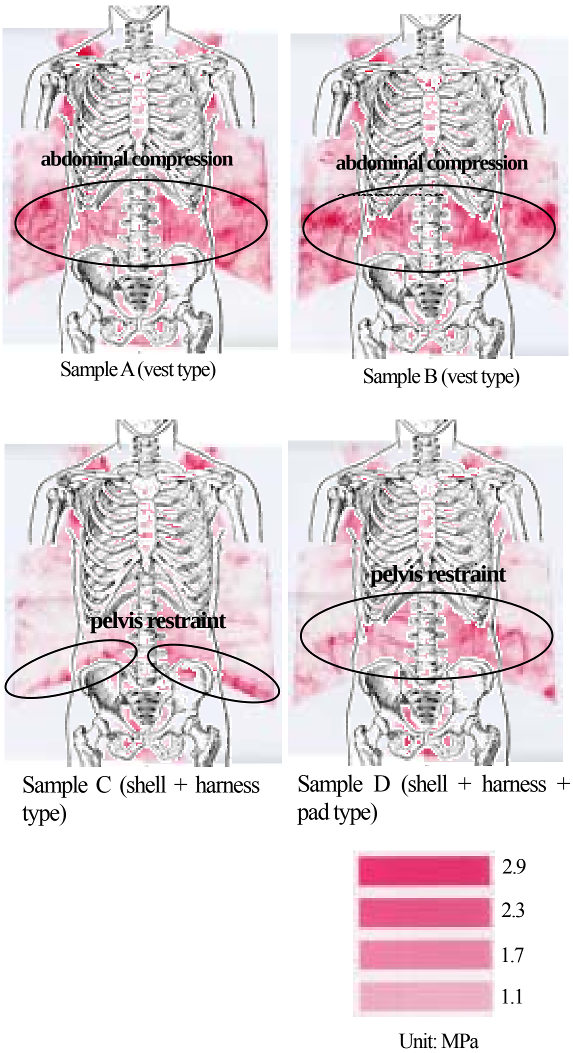


Figure 12 Pressure Distribution measured by Pressure-sensitive Sheet

(5) Electric pressure sensor

In order to determine effectiveness of this sensor in measuring pressure to the abdomen (the most vulnerable part of the torso), measurements on abdominal pressure obtained from various systems were compared after removing pressure to the chest and lumbar. For the comparison, pressure to the abdomen was first converted to load on the measuring cell basis and the loads were added together. In the following, the added load is referred to as the abdominal load.

Figure 13 shows the pressure distribution at the time when the abdominal load grows to the maximum. With Sample A of the vest type, pressure is distributed over almost the entire abdomen. With Sample B also of the vest type, pressure distribution is noticeable in the center part of the abdomen where the lumbar harness is applied.

Figure 14 shows change in the abdominal load over time. The load data fairly coincides with the dummy's behavior.

On various types of CRSs each using a different restraining method, we measured the pressure applied to the dummy's abdomen by use of the electric pressure sensor in the frontal collision test conducted under the same conditions as those used for the CRS assessment.

The sensor was capable of measuring the change in pressure distribution over time that is possibly caused by the harness and buckle of the respective CRSs. The above findings seem to well depict the features of the constraining method and behavior of respective CRSs.

These results prove that the electric pressure sensor is capable of measuring the pressure distribution overcoming the differences in the constraining methods or equipment shapes of the CRSs. This allows us to implement quantitative comparisons relating to the pressure applied to the abdomen. We have therefore decided to employ this approach for the evaluation of abdominal compression.

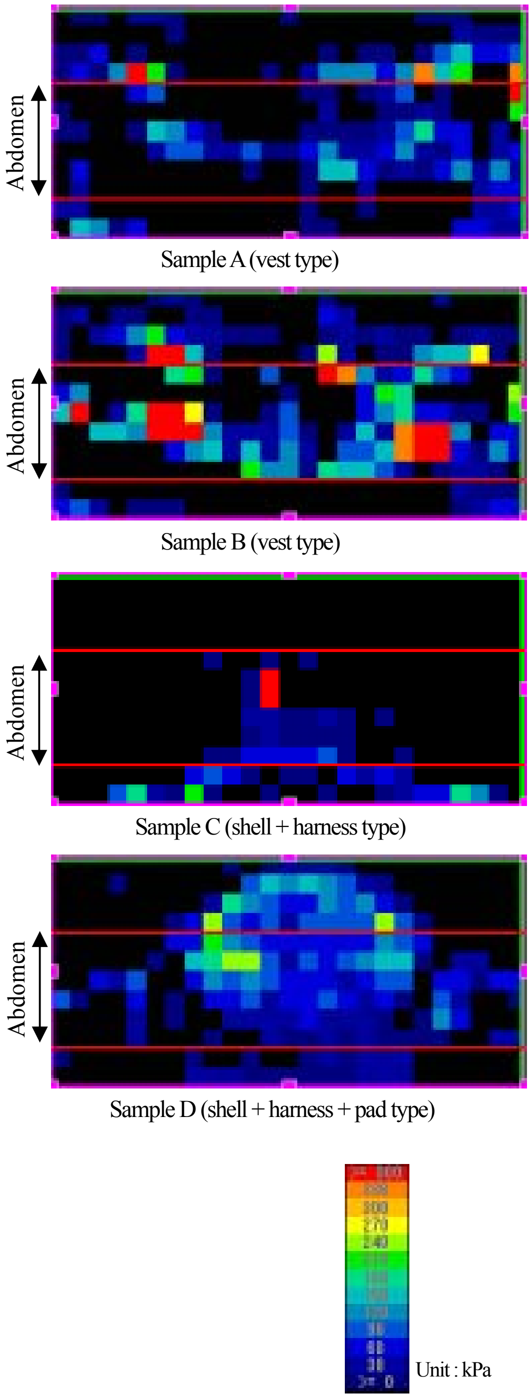


Figure 13 Pressure Distribution as Abdominal Load reaches Maximum

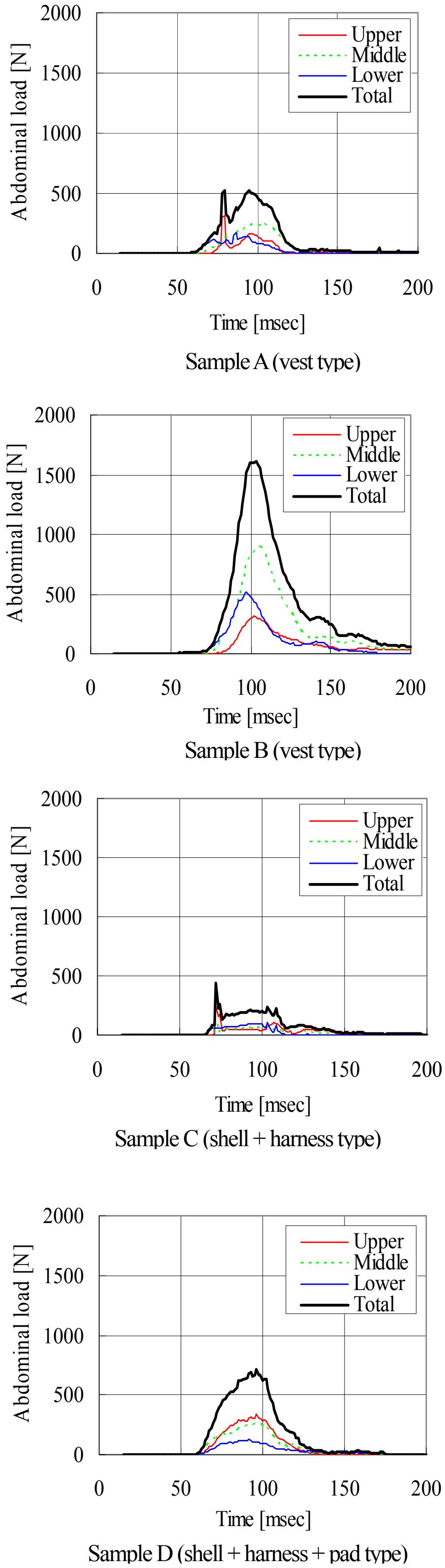


Figure 14 Changes in Abdominal Load over

2.3 Abdominal Compression Evaluation Methods

Abdominal compression comprises two types of load - one is the load that is applied to broader areas in the abdomen and the other is the load that is applied locally by the harness or buckle. As to the local compression, there are no studies available today on characteristic response to or resistance of the human body to such loads. Therefore, this subject was removed from our current study.

As for the load applied to broader areas, there is a reference document describing the relation between the waist belt and Abbreviated Injury Scale (AIS) [3] among adult males. We converted the adult males' resistance data to that of a 3-year-old child using scaling technique being employed by the Federal Motor Vehicle Safety Standards (FMVSS) [4, 5].

It is difficult in the frontal collision test to directly measure tensile force of the lumbar harness on a CRS. Thus we measured the pressure on the abdomen instead of measuring tensile force of the lumbar harness on the above with pressure measurement in the abdomen. The abdominal load was used to relate the pressure data to the lumbar belt's tensile force. Our research results on the relation between the waist belt and abdominal load were used in the conversion of the waist belt tension to the abdominal load. Conversion of the pressure data to the abdominal load was done by first converting pressure at each cell to load and then summing up the respective loads in the abdominal part.

We gave up using the concept of impulse (the value derived by integrating load with time) as an index in evaluation of the abdominal load since its relation with injury currently remains uncertain.

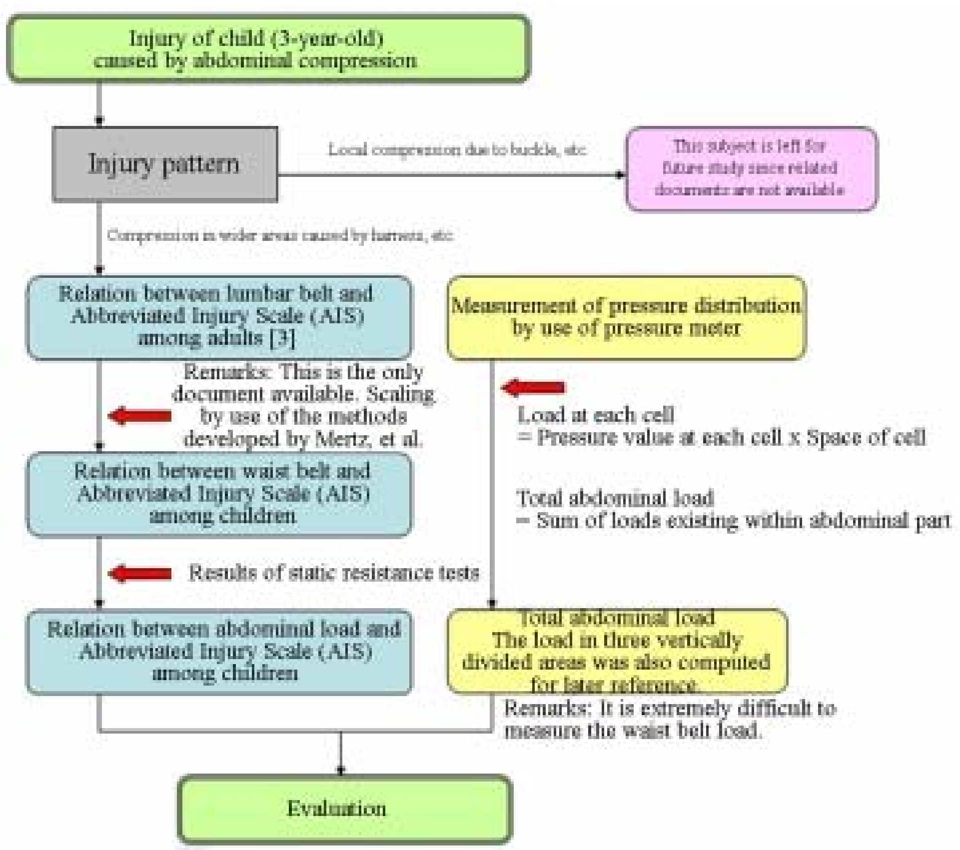


Figure 15 Concept of Abdominal Compression Evaluation Method

2.4 Resistance Value

(1) Resistance value of abdominal load in adult

Figure 16 shows the relation between the lumbar belt and abdominal injury among adult males. The findings were derived from the experiments conducted by using cadavers. If the waist belt's tensile force was used to represent the intersections of the approximate logarithmic curve and respective AIS level, AIS 0 (No injury) becomes 2.38 kN, and AIS 1（Minor）and AIS 2 (Moderate) become 3.20 kN and 4.31 kN, respectively. This is the only document that refers to the relation between the abdominal compression and injury scale.

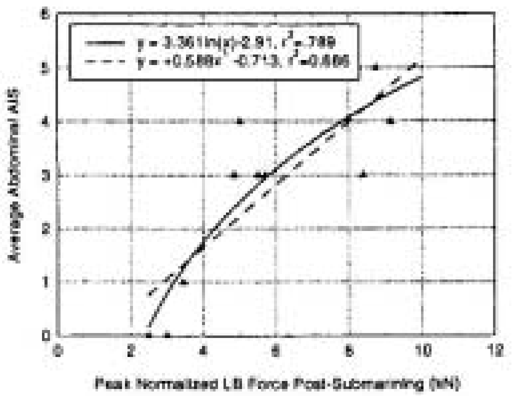


Figure 16 Relation between Waist Belt Tensile Force and AIS among Adult Males [3]

(2) Scaling of resistance values

We attempted to calculate the coefficient R_f that can be used in scaling the adult males' resistance value to that of three-year-old children. Since the coefficient for soft tissues such as the abdomen is not available, we employed the intensity coefficient of sinew $\lambda_{\sigma f}$. Dimensional coefficient of the torso λ_Y and λ_Z were employed as the size-related coefficient [4, 5].

$$R_f = \lambda_{\sigma f} \lambda_Y \lambda_Z$$
$$= 1.0/1.18 * 0.556 * 0.602$$
$$= 0.284$$

As a result, AIS 0 became 0.68 kN, and AIS 1 and AIS 2 became 0.91 kN and 1.22 kN, respectively.

(3) Conversion from waist belt to abdominal load

A static test as shown in Figure 17 was conducted to determine the relation between the waist belt's tensile force and abdominal load measured by the pressure sensor. An electric pressure sensor was attached to the abdomen of Hybrid III-3YO with laid on a sturdy table with its face up. Then a weight was hung by use of webbing. With this arrangement, the relation between the weight and abdominal load measured by the electric pressure was investigated. Figure 18 shows the results.

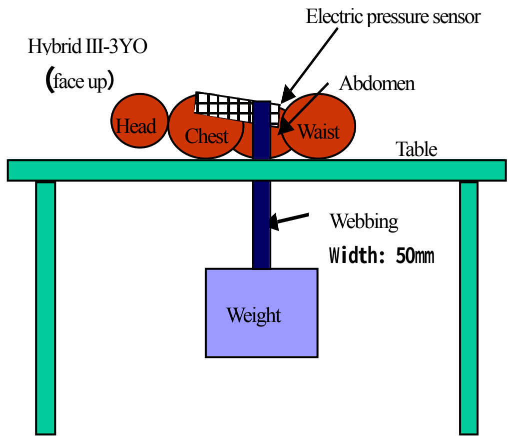


Figure 17 Electric Pressure Sensor used in Static Test

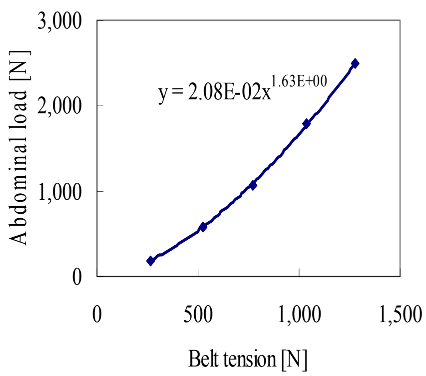


Figure 18 Abdominal Loads measured by Electric Pressure Sensor in Static Test

From Figure 18, we can convert each AIS level to equivalent waist belt tension from the electric pressure sensor as follows - AIS 0 to 0.85kN, AIS 1 to 1.38kN and AIS 2 to 2.24kN.

(4) Study on resistance values

We can determine the relation between the degrees of injury and abdominal loads in children measured by the electric pressure sensor first by scaling the relation between the waist belt tension and injury among a body size of adult males and children, then by determining the relation between the waist belt tension and abdominal loads obtained from the electric pressure sensor. No injury results were found from the above study then the abdominal load measured by the electric pressure sensor was 0.85 kN or less. Injuries of AIS 1 level and AIS 2 level resulted from loads of 1.38 kN and 2.24 kN, respectively.

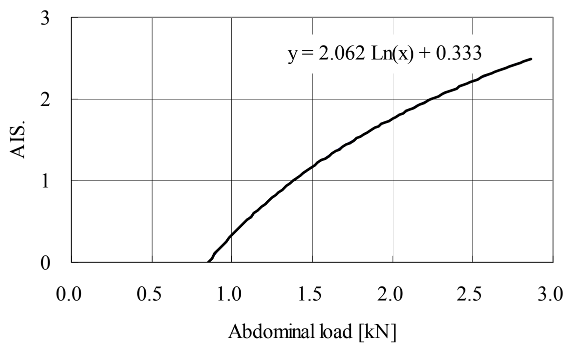


Figure 19 Relation between Abdominal Loads and AIS

2.5 Evaluation Method

Using the findings on abdominal loads corresponding to the injury level from AIS 0 to AIS 2, we have developed a tentative evaluation method. It is tentative because we could not find technical data or documents on characteristics of a baby's abdomen. In this approach, a four-level scale was set up for the evaluation as described below. Abdominal load equivalent to AIS 0 - "Abdominal compression is less likely", above AIS 0 up to AIS 1 - "Injury due to abdominal compression is likely", above AIS 1 up to AIS 2 - "Injury results from abdominal compression", and above AIS 2 - "Serious injury results from severe abdominal compression".

Table 6 Tentative evaluation criteria developed for this study

Abdominal load (AL)	Tentative evaluation criteria
AL ≤ 0.85 kN	Abdominal compression is less likely
0.85 kN < AL ≤ 1.38 kN	Injury due to abdominal compression is likely
1.38 kN < AL ≤ 2.24 kN	Injury results from abdominal compression
2.24 kN < AL	Serious injury results from severe abdominal compression

We attempted tentative evaluations using the above tentative evaluation criteria. We sorted the data by the pressure measurement data provided from CRS assessment 2002 (done by tentatively using the electric pressure sensor) and other research data by the constraint type (vest type, harness type, pad type and shield type). Load value of the harness type products is measured as "Abdominal compression is less likely" when constraint of pelvis is available in a static condition (see Table 7). Load value of one of the pad type as well as shield type products was rated as "Injury due to abdominal compression is likely".

There were substantial variations in the measured load values among the vest type products without the seat surface and backrest. The values ranged from "Abdominal compression is less likely" to "Injury due to abdominal compression is likely" and "Injury results from abdominal compression".

Table 7 Maximum abdominal loads measured

Main structure etc.	Abdominal load [N]
vest type A	529
	920
vest type B	1615
	1160
vest type C	647
	365
shell + harness type A	234
	153
shell + harness type B	155
shell + harness type C	134
shell + harness type D	110
shell + harness type E	469
shell + harness type F	693
shell + harness + pad type A	716
	748
shell + harness + pad type B	568
	564
shell + harness + pad type C	890
shell + harness + pad type D	694
shell + shield type A	829
	860
shell + shield type B	395
shell + shield type C	724

The threshold 0.85 kN between "Abdominal compression is less likely" and "Injury due to abdominal compression is likely" may appear to be a large load, but this load is the maximum value of the dynamically applied loads and not a constantly applied static load. If you drop a basketball from 5.9 m, resulting impact load on the floor surface is 1.02 kN, namely greater than the threshold (see Figure 20). Unlike the results in the frontal collision test, load values of every product of the traditional harness, and almost all pad type and shield products were the threshold. These CRSs are used over a long time and there is no report that claims of abdominal injury are remarkable among the children using these products. It seems therefore reasonable to set the pass or fail threshold at 0.85 kN. We are considering employing this evaluation of abdominal compression as one of the items in the frontal collision test for children, "Possibility of injury, such as from a harness pressing weak parts of the child's body."

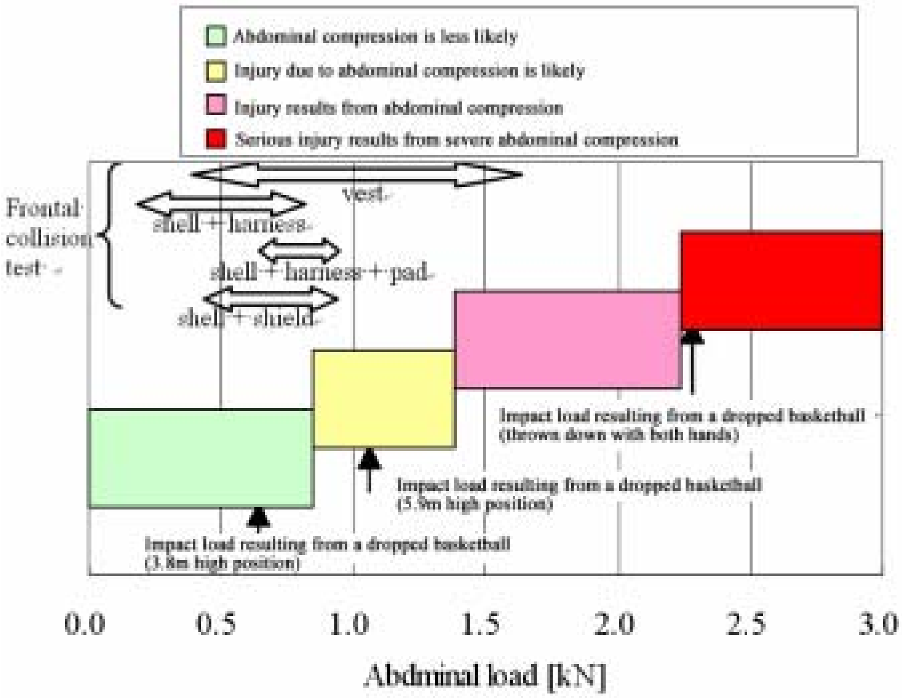


Figure 20 Impact Loads resulting from various Tests

3. SUMMARY

The above findings suggest that measurement of abdominal compression by a pressure sensor is effective and the measurement-based evaluation method is useful in comparing the degree of compression to abdomen. This approach therefore has been employed as a means for evaluation in the assessment program.

It would be effective in preventing injury due to the so-called bite from the harness to compare abdominal loads in the three vertically divided areas in the abdomen by use of the pressure sensor. If significant differences were detected among them, it would be useful to warn the users of the potential danger of bite from the harness.

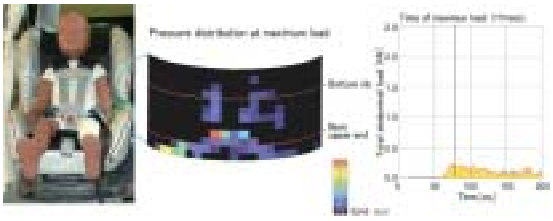
It is difficult to quantitatively evaluate the influences of abdominal compression being locally applied by the harness or buckle since there is no available report on their resistance values or characteristics. Thus, evaluation of injury due to local compression is left as a subject for future study.

4. RESULTS OF EVALUATION OF ABDOMINAL COMPRESSION IN CRS ASSESSMENT 2003

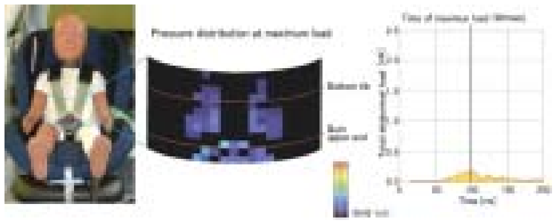
Evaluation of abdominal compression by use of the electric pressure sensor was officially started from the 2003 CRS assessment. In the CRS assessment of 2003, seven products were selected as the target of evaluation [6]. Among them, abdominal compression was tested on six products - three seats for toddlers and three other seats for both infants and toddlers. One of the toddler's seats was a vest type CRS.

Figure 21 shows results of the test. Abdominal loads beyond the threshold 1.38kN were measured on the vest type product alone. However, we could not install the waist belt of this product in a position to sufficiently cover the pelvis despite the instructions provided in the manual. Thus only the result of each category is given here instead of providing a holistic evaluation of the product.

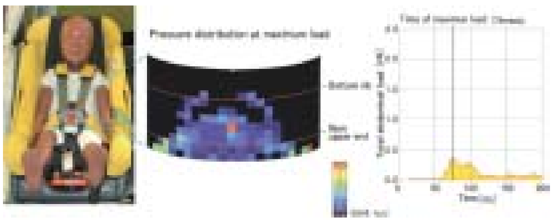
No other products produced abdominal loads beyond the threshold.



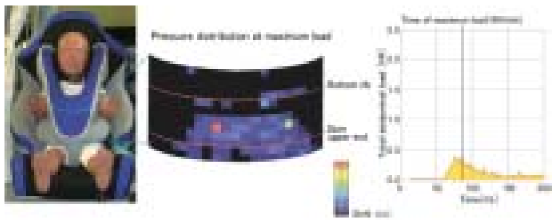
shell + harness type



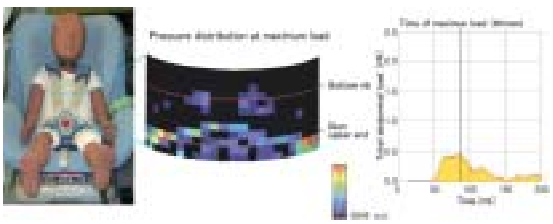
shell + harness type



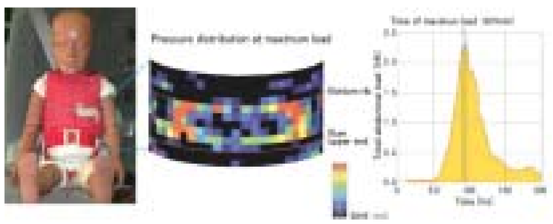
shell + harness type



shell + shield type



shell + harness type



vest type

Figure 21 Results of Evaluation of Abdominal Compression in CRS Assessment 2003

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DETERMINATION OF REAL WORLD OCCUPANT POSTURES BY PHOTO STUDIES TO AID SMART RESTRAINT DEVELOPMENT.

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UK

Paper number 05-0319

ABSTRACT

The "**P**roposed **R**eduction of car crash **I**njuries through improved **SM**art restraint development technologies" (PRISM) project is a European Commission funded 5th Framework project that is intending to determine appropriate smart restraint technologies for Europe.

This photographic study was undertaken as part of the PRISM project. The purpose of the study was to obtain statistical information regarding driver and passenger postures under normal driving conditions. The results gave a clear indication of real world postures at impact that should be considered for smart restraint systems.

Rural and urban sites were selected in Spain, Austria and the United Kingdom, representing southern, central and northern Europe. Sites were scrutinised for their suitability to film. Film analysis was undertaken on each vehicle filmed.

The primary measurements taken were: Driver nose to steering wheel, Driver head centreline to vehicle centreline and Passenger head centreline to vehicle centreline. Other parameters noted included use of seatbelts, hand positions, luggage locations etc. In all, 12 vehicle parameters and 15 driver parameters were noted per vehicle with additional parameters for each passenger, where appropriate. In total, over 4800 vehicles were filmed and analysed.

The site selection and survey methodology are described. Various issues, such as time-of-day and location influences, together with the limitations associated with the methodology are also presented.

Following a discussion of the results, a number of conclusions have been drawn, regarding statistical distributions of various parameters and their importance in occupant protection and for smart restraint design.

Although similar previous studies have been undertaken (MacKay, Hassan, Hill, 16th ESV, Windsor also Parkin, MacKay, Cooper, Proceedings, AAAM, Nov 93), this study utilises a wider range of sites, a larger sample size, and due to technology improvements better image quality, leading to an improved quality of data collection. Societal trends, such as the use of mobile phones, etc are also noted.

INTRODUCTION

It is widely accepted that vehicle occupants do not maintain exactly the same postures as crash ATDs (Anthropomorphic Test Devices) during normal driving, nor under the stressful conditions of vehicle pre-impact manoeuvres such as emergency braking. Consequently, their posture at the point of impact may be quite different from the ATD postures used for restraint system development and evaluation. "Out of Position" tests are undertaken as static or dynamic tests. However, the relevance and importance of specific tests are not widely agreed and are unlikely to be of the same priority in different parts of the world where many environmental conditions vary and legislation differs.

As the implementation of "smart" restraint systems increases it is important to specify the true priority posture cases that such systems must handle successfully. This paper discusses work package 1.4 "Investigate occupant position by photographic studies" undertaken within the project "PRISM" to determine the priority cases for the European market. The results of this work package are included in this report, although as the results will be used to feed in to other work packages such as *"Improved Understanding Of Passenger Behaviour During Pre-Impact Events To Aid Smart Restraint Development"* and *"The Effect Of Driver Positioning On The Dynamic Response To A Potential Accident Event"*, final conclusions cannot be drawn from this work, but are expected at the end of this project in 2005. This paper reports the simple results and conclusions from this work packages alone.

“Investigate Occupant Position by Photographic Studies”, was undertaken to determine how occupants sit in vehicles on the roads of Europe. Over 5000 vehicle samples were taken from six test sites, two in the UK, two in Austria and two in Spain. These samples were analysed to determine occupant longitudinal, lateral and upper limb locations. The practical result of this task was to provide realistic real world postures that could be considered as “pre-event” start positions for the second phase mentioned above known as *“Improved Understanding Of Passenger Behaviour During Pre-Impact Events To Aid Smart Restraint Development”* which determined how occupants behave within the vehicle in the pre-impact phase, such as emergency braking, swerving etc. This paper covers the work, lead by MIRA Ltd. A range of pre-impact manoeuvre events were undertaken and the human occupants were encouraged to adopt various postures based on those found in this study before the events took place. A similar study within the project "*The Effect Of Driver Positioning On The Dynamic Response To A Potential Accident Event”,* was undertaken by TRL Ltd., which studied the driver behaviour using a static driving simulator (Couper, 2004). This also used the “pre event” start positions.

A database was built in Microsoft Access© and was used to analyse all the vehicle samples. Whilst similar studies have been undertaken before (Parkin, 1993 and Mackay, 1998) this new study considers a larger sample, from a wider range of sites. Many aspects measured in this study are more detailed, especially the passenger measurements, other aspects are less detailed than previous studies in particular more generalised driver hand positions. It is also possible that the behavioural changes of the population may have changed since the previous studies so this study is likely to be more relevant to today’s conditions.

METHODOLOGY

The photographic installations were selected based on a number of specific requirements. These include the ability to film from the front of the vehicle at high level and downwards (from a bridge, high building etc.) and the ability to hide the cameras to some degree (to limit reactions to the cameras). The highway and motorway installations used a long duration high-speed camera (H) at 125fps (frames per second) to ensure good framing of the driver window and to minimise blur. The frontal cameras were conventional video cameras (V) at 25 fps since rate of vehicle progression through the frame was much lower (Figure 1.). The single carriageway sites did not require such rapid frame rates for the side camera, so a conventional video camera was used (Figure 2.).

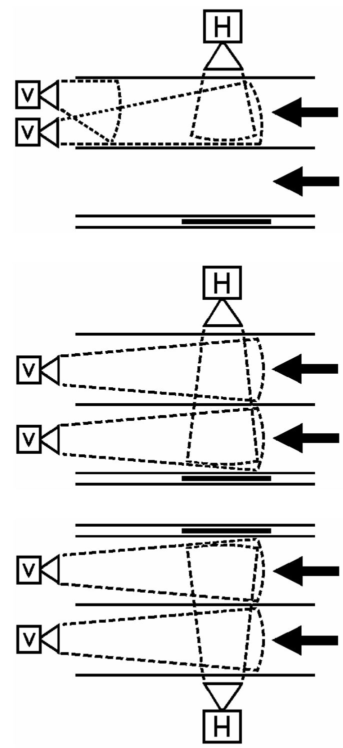

Figure 1. Highway and motorway camera configurations.

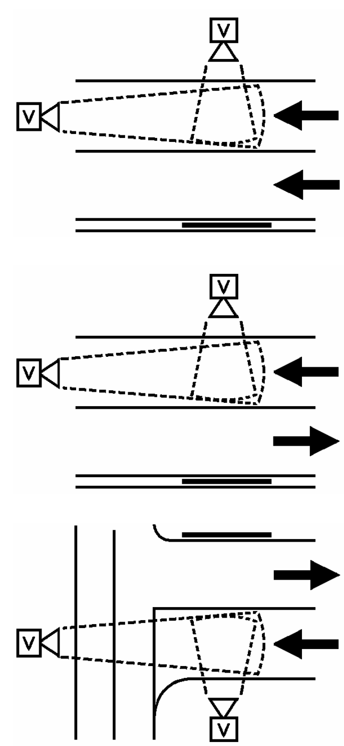

Figure 2. Urban and rural minor road camera configurations.

Rural high speed roads and urban low speed sites were selected in Spain, Austria and the United Kingdom. All sites bar one in the UK were chosen with bridges to position the cameras. Examples of high speed and low speed locations are given below. One of the high speed location in Spain was on a motorway heading out of Madrid (Figure 3.) the cameras are situated laterally and above on the bridge to give frontal images.

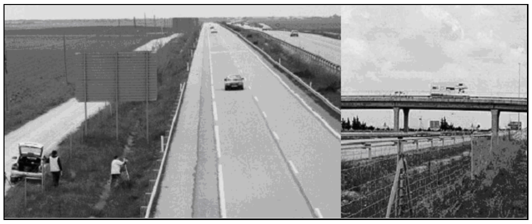

Figure 3. Site 1 Spanish Motorway

Austria's low speed site (Figure 4.) was in the city centre in Linz with the lateral camera hidden behind a sign and frontal cameras on the bridge.

Figure 4. Site 3 Austrian City

A chequered board was placed behind the sample vehicle in the centre reservation, or on the other side of the road, so that it could be seen in the background. (Figure 5.) The frontal camera images were firstly used to record the virtual lateral head positions of the front seat occupants and make observations. The occupant head positions were also measured virtually from the nose to the vehicle centre line (Figure 6.). The virtual measurements were quantified by a physical parameter study. The frontal camera(s) also provided lateral location information relative to tape marks on the road, which were a known distance from the side camera and the chequer board.

By trigonometry the depth / parallax error in the driver posture measurements could be reduced. These errors were monitored on a number of samples by taking the measurements of the side windows on the sample images and then by checking on a similar static vehicle by direct measurement. Of the samples that were checked, the typical accuracy was +/- 3% with the worst case being just over 5%.

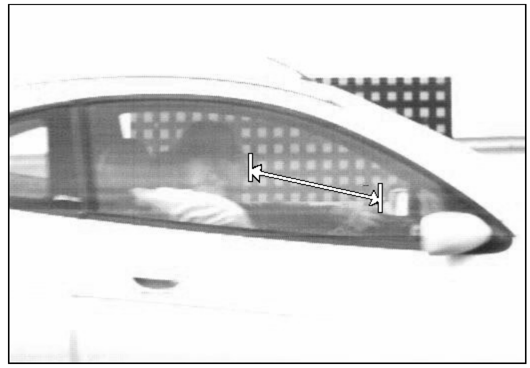

Figure 5. Side camera measurements.

Figure 6. Frontal camera measurements.

One important requirement for each site was to have sufficient traffic samples when the sun was in the correct position to minimise glass reflections. By experimentation with angles and polarising filters, it was normally possible to obtain a run time of 2 hours with the sun in a suitable position and with sufficient traffic flow. (Figure 7.) It was necessary that the reflection criteria were met for both the frontal and side cameras simultaneously. There was an initial target of 2000 vehicle samples per site.

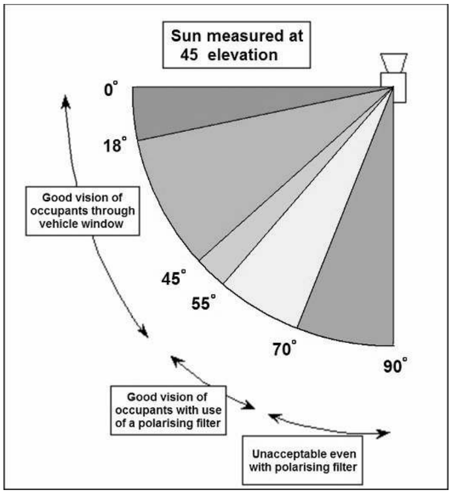

Figure 7. Acceptable sun angle.

The observed data werexc entered into a custom made database designed for ease of data entry and for clear parameter option selection. (Figure 8.) The database allowed all the information derived from the images to be input quickly and efficiently.

The database had a viewing pane where all the available image thumbnails could be selected to show full resolution versions for each vehicle. It enabled the vehicle data to be input such as model, manufacturer, hand of drive, and seating configuration. Driver details included such items as age, gender, build and hand and arm positions. The database was also able to calculate in millimetres the distance from the nose of the driver to the steering wheel, the driver head centre line and the passenger head centre line to the centre of the vehicle by entering in the pixel positions. Passenger information was extensive, front passenger age, gender build etc was entered along with hand and arm positions and similarly for each further occupant. Options for child seat and child position were also available.

Extra details such as type of vehicle ie was it a sports car or MPV, whether the windows or sunroof were open, whether occupants wore glasses or not etc were also input at this stage.

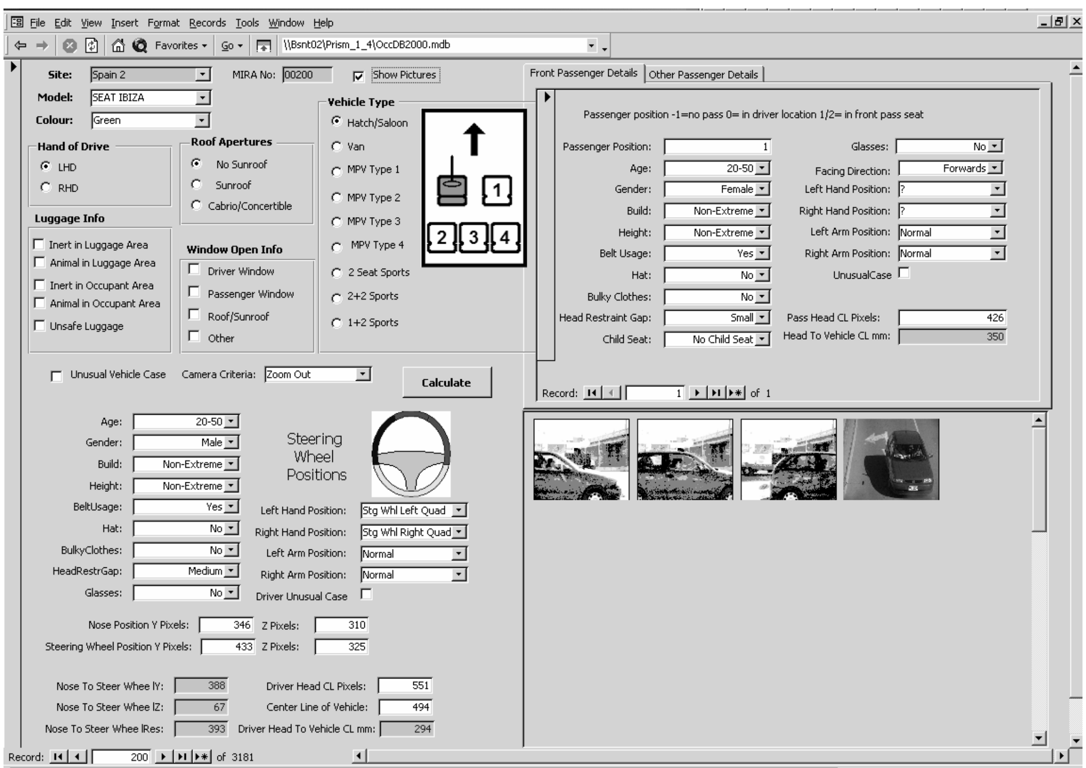

Figure 8. Database main input screen.

DATA AND RESULTS

The study covered vehicles in 3 countries. The 5106 vehicle samples were obtained from: Austria (approximately 40%), Spain (approximately 18%) and UK (approximately 42%). Although Spain had a low vehicle count it had one of the highest numbers of rear passengers in the study. Whilst the sites were selected to give approximately the same volumes of vehicles and each site had a 2 hour filming period, the final distribution was unbalanced. Poor weather and light meant that the Spanish motorway study had a shorter time span.

The results are split into several sections in order to give an example of the data obtained. It should be stated that with the use of the database any of the information available can be compared and contrasted with each other. The following results are identified as most relevant to the later stages of the PRISM Project. Results are also listed in Appendix 1.

Seatbelt Usage

Overall driver seat belt wearing was 93% with 5% clearly not wearing belts and 2% unclear. Female drivers and passengers had a higher seat belt usage rate than males. Spanish drivers were least likely to wear seat belts around town (26% non-use) but the sample sizes of Spanish motorway and UK village were too small to give reliable belt wearing rate indication.

Passenger overall seat belt wearing was 90% with 7% clearly not wearing belts and 3% unclear. It would appear that from the study that drivers were more likely to wear belts than passengers, except in Spain around town, where unbelted male drivers with belted female passengers were very noticeable.

Vehicle Occupants

Overall, 78% of the vehicles were driver only and 20% had only one passenger. The day of week, time of day and local geographical location are all considered to have had an influence on the numbers of passengers observed. These varied considerably. Significant trends between rush hour, workday and weekends were observed. Children were most frequently observed on weekend days, despite the UK village site and time being selected to capture children going to school.

Age

The age of each occupant was estimated from appearance with the intention of identifying numbers of young and old occupants. Overall, 8% of drivers were judged to be over 50 years of age, 91% of drivers were between 20-50 years of age and the final 1% being judged under 20 years of age. Of the front seat passengers, 12% were estimated to be over 50 years, 10% adults under 20 years, and approximately 8% were estimated to be children. Based on these estimations it is suggested that only 32% of rear passengers were between 20-50 years of age and approximately 45% were children.

Gender

Overall quantities for drivers were 76% male, 24% female, for front passengers were 31% male 69% female. Rear occupants were very difficult to determine as side camera shots often only showed occupants from the neck upwards.

Head Position

The resultant distance from driver's nose to steering wheel top varied from a mean of 430 mm for females to a mean of 470mm for males (Figure 9.). A total of 17 drivers (10 male, 7 female) were measured as less than 200mm. The most extreme cases were one female at under 50mm and another between 50 and 100mm.

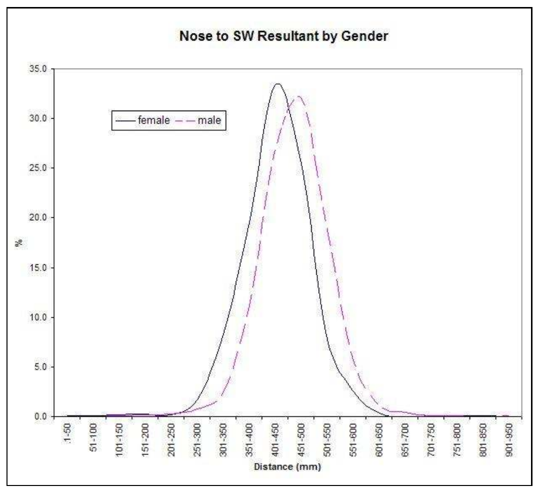

Figure 9. Nose to Steering Wheel by Gender

The gap between the driver head and the head restraint proved difficult to estimate because it was screened by the B-post for many vehicles. Bulky hair was also a problem in some cases. Where it was reasonable to estimate the gap three choices were possible: large gap (occupant visibly leaning forward) of which there were 11%, medium gap (relatively normal in appearance) of which there were 78% and small gap (touching or up to approx 50mm), of which there were 9%.

Hand & Arm Positions

The driver's hand position has been examined in 2 ways the first looking at results for each hand separately confirms expectations that most drivers hold the steering wheel in the upper left and right hand quadrants of the steering wheel (48%). After this the next most popular position is the bottom quadrant, (17%) the top quadrant, (12%) then the gearshift (10%). The driver's arms tended to follow the obvious natural route to the hand position (94%) but sometimes rested on the armrest (3%) or out of the window (0.5%).

Secondly, the left and right hand positions are compared to each other, i.e. both hand positions are examined together. (Table 1.) It can be seen that the most popular position is placing the hands at the "ten-to-two" or "quarter–to-three" positions (33%).

The most common position for the passengers was to have their hands on their laps. (45% had both hands in their lap). It was often difficult to see the passenger's hands as this depended greatly on the height of the camera. This meant that a high proportion of the passengers' hands could not be seen (27% where one or both hands could not be seen). The most common position for a passengers arm was in its natural position derived from the position of the hand. The next most common position for the passenger arms was crossed. Approximately 6% were involved in some activity using one or more hands (reading, drinking, on telephone, etc.) and 2 to 3% were holding a grab handle.

Unusual Cases

As data was input into the database it was possible to select it as an unusual case. A number of samples were recorded as unusual cases where some aspect of posture or other safety issue was noted that had not been considered before analysis. These are summarised here:

- Driver unusual cases: From 19 unusual cases the most common for drivers was smoking (total 7) followed by no hands on the steering wheel (5) and having arms across the body (2). Other unusual cases were driver leaning into the footwell show in Figure 10.

- Front passenger unusual cases: From 31 unusual cases, animals in the passenger area are most common for front passengers (total 5, mostly dogs on passengers laps). Next was holding or adjusting the seat belt (4). Luggage on the facia, sleeping and bending into the footwell were also highlighted (3 each). Including child standing in the footwell area (Figure 11.).

- Rear passenger unusual cases: From 33 unusual cases, a child standing on the seat or on the floor was most common for rear passengers (total 10). Next is the occupant leaning forward, often between the front seats (7)

Figure 10. Example of driver leaning into footwell

Table 1. Driver hand position related to left and right hand.

Right hand across / Left Hand down	?	Centre of Wheel	Distant Control	Drink / Food	Gear Shift	Gesture at Camera	Grab Handle	Map / Book / Papers	Nose / Mouth	Other	Out of Window	Phone / Head Side	Stg Whl Bot Quad	Stg Whl Left Quad	Stg Whl Right Quad	Stg Whl Top Quad	Grand Total
?	1.30%	0.08%			0.08%	0.04%				0.02%		0.02%	0.44%	0.02%	2.28%	1.38%	5.68%
Centre of Wheel	0.08%	0.13%			0.08%					0.02%		0.02%	0.04%	0.00%	0.10%	0.02%	0.50%
Distant Control												0.02%	0.08%	0.00%	0.29%	0.04%	0.44%
Drink / Food				0.02%									0.02%	0.00%	0.04%		0.08%
Gear Shift	0.02%	0.06%								0.02%			0.36%	0.04%	3.25%	1.17%	4.93%
Gesture at Camera													0.02%		0.10%	0.02%	0.15%
Grab Handle															0.10%	0.02%	0.13%
Left Quad		0.02%															0.02%
Map / Book / Papers								0.02%							0.02%		0.04%
Nose / Mouth	0.08%				0.02%				0.02%	0.02%			0.27%		1.05%	0.40%	1.87%
Other	0.02%									0.00%			0.19%	0.02%	1.36%	0.63%	2.22%
Out of Window					0.02%					0.00%			0.04%		0.13%	0.10%	0.29%
Phone / Head Side					0.06%					0.02%		0.04%	0.52%		0.75%	0.19%	1.59%
Stg Whl Bot Quad	0.06%		0.02%	0.06%	2.39%	0.06%			0.21%	0.38%	0.04%	0.25%	11.76%	0.13%	1.87%	1.11%	18.34%
Stg Whl Left Quad	1.26%	0.06%	0.10%	0.08%	6.71%	0.15%	0.02%	0.04%	0.96%	0.78%	0.02%	0.80%	1.68%		32.93%	2.72%	48.31%
Stg Whl Right Quad	0.10%		0.04%	0.02%	0.65%			0.02%	0.06%	0.06%		0.06%	0.02%		0.19%	0.02%	1.26%
Stg Whl Top Quad	0.80%		0.10%	0.04%	5.97%	0.02%	0.06%	0.04%	0.31%	0.48%		0.31%	0.67%		2.62%	2.70%	14.15%
Grand Total	3.73%	0.36%	0.27%	0.23%	15.99%	0.27%	0.08%	0.13%	1.57%	1.80%	0.06%	1.53%	16.12%	0.21%	47.10%	10.54%	100.0%

Figure 11. Example of front seat passenger – child standing in footwell

Manufacturer

Vehicle manufacturer simply shows the most common vehicle in that region. The UK shows Ford and Peugeot as being most popular. Spain shows Renault and Seat and Austria shows Volkswagen and Opel.

Miscellaneous

Other aspects that may be of interest were noted when it was reasonably easy to do so. Some of these were:

- Glasses: Over 29% of drivers and over 28% of passengers wore glasses. Spain showed the highest use with 48% of drivers wearing glasses (Figure 12.). This could be attributed to the bright sunshine meaning a high use of sunglasses rather than clear prescription lenses (not a distinction drawn in this study). Spain also had the highest number of front passengers wearing glasses.

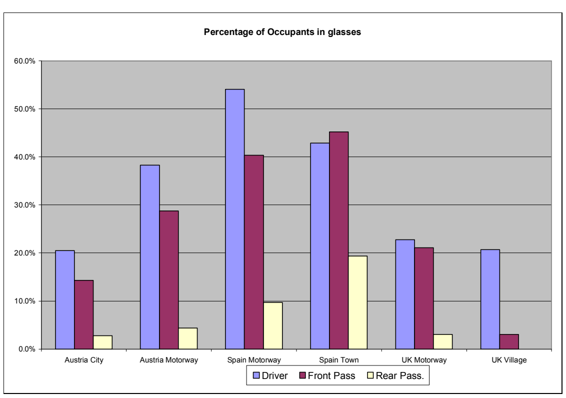

Figure 12 Percentages of Occupants in Glasses

- Luggage: Generally, visible luggage consisted of home improvement materials, such as wood planks etc. or travel luggage, such as suitcases, in estate vehicles.

- Child seat use: Most children appeared not to be seated in a child seat, although this was very difficult to see in the rear of the car as it was below the side camera view. It appeared that the use of child seats was only 5% in the front seat and 14% in the rear seat, However, this is likely to be an underestimate as some child seats, especially "booster" cushion types and dark coloured child seats may have been present but not discernable.

- Facing direction: In most cases (95%) front passengers are facing forward. Side facing occupant data could be anomalous as at most sites the chequer board was visible and may have attracted their attention.

CONCLUSIONS

The collected data was highly dependent on certain factors, such as weather, time of day, proximity to public amenities etc. Whilst some efforts were made to minimise these factors, the practicalities of obtaining the data (such as having good daylight for filming, etc.) meant that these effects could not be eliminated. Therefore these conclusions are MIRA Ltd's interpretation of the results. The results are a statistical statement of the facts. Although statistics can be altered, we have tried to be factual and simplistic in all statements. It must be taken into consideration that the conclusions are the opinion of the author.

The following statements summarise the results gathered;

It seemed more popular to wear a seat belt on longer journeys on the fast moving roads. A higher percentage of seatbelt wearers are female. It also seems that Spain had the highest proportion of non seat belt wearers.

The number of vehicle occupants varied from site to site dependant on the time of day or the day of the week. These variables have to be considered at all times. Improvements could be made to this process such as if the system of collation could be automated to film the vehicles at any time of day and to analyse each vehicle to show occupant position automatically then this would prove to be an invaluable resource. Results could be taken at different times of day and on different days of the week showing demographics of all the regions. The only limiting effect of this would be the lighting, as bright sun light and darkness would mean poor results.

The age groups were chosen to show extremes of ages. Most drivers were estimated to be in the 20–50 years of age category, which was expected. It was possible to see that males dominated this group for drivers and females dominated the group for passengers. The results showed that 20-50 years of age was the most common age group site wide. Rear passengers were estimated to be considerably younger with only 30% being in the 20-50 year old group and over 40% either large or small children or baby's under 1 year old.

Driver gender showed that most drivers were male and most passengers were female site wide.

Although it was difficult to see the head restraint gap the majority of drivers and passengers sat with a medium head restraint gap - HRG. This could be explained by the fact that large HRG was recorded when the gap looked to be extreme, and a small HRG was recorded when no gap could be seen. The results show that by a marginal difference more female drivers had a larger HRG than males, although female drivers also exceeded male drivers with a small HRG.
Female passengers had a higher amount of small HRG than male passengers. Male passengers had a higher amount of large HRG.

Nose to steering wheel resultant shows us that drivers have an average nose to steering wheel measurement of 475mm, comparing the results for male and female it can be seen that females sit approximately 50mm closer to the steering wheel than the males.

The hand and arm position of the drivers was examined to show that the most common position for a driver is to hold the steering wheel in the top left and right quadrants. The quadrant of the steering wheel that the driver holds does vary and is related to the use of the gearshift. The filming location may also have affected the gearshift result, such as approaching a junction compared to a high speed road.

This study showed that around a third of drivers and passengers wear glasses. This must show that the effect of wearing glasses must be considered in future testing. It also highlighted luggage dispersal, child seat use and occupant facing direction. Details are listed in appendix 1. All of this information can be used in further projects.

The unusual cases highlighted in this study were only a small proportion of the total vehicles analysed but it highlighted the possible extreme scenarios of how occupants position themselves within vehicles. Whilst the observations above may be of interest for those developing restraint systems, the primary purpose was to identify the postures that the volunteers should adopt in the occupant behaviour tests. After discussions with various members of the project consortium it was decided that various postures would be used based on incidence and potential severity.

These positions have been used to help determine scenario positions for Task 1.5 'Occupant Behaviour During Pre-Impact Braking'. These are summarised in Table 2.

Table 2. Passenger postures identified for further dynamic study.

Stable Postures
Normal position, hands on lap
Arm on door armrest
Arm on waist rail
Arm out of window
Arms crossed
Holding roof grab handle
Legs crossed at ankle
Feet forward (braced)
Feet rearward (unbraced)
Activity Postures
Looking in vanity mirror
Adjusting seat belt
Adjusting radio / vehicle controls
Using mobile phone
Reading
Higher Risk Postures
Sitting on foot / feet
Facing rear direction
Drinking / eating
Reaching into foot well
Unbelted

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APPENDIX 1

Total Vehicles Involved in Study by Site.

- Austria City 17.20% (821 vehicles)
- Austria Motorway 23.04% (1100 vehicles)
- Spain Motorway 3.06% (146 vehicles)
- Spain Town 14.66% (700 vehicles)
- UK Motorway 38.29% (1828 vehicles)
- UK Village 3.75% (179 vehicles)

Seatbelt Usage

Drivers Belt Usage:

Results from a total number of 4774 drivers

- 5% of Drivers at all sites do not wear seat belts

Site based results for not wearing a seat belt:

- Spain Motorway less than 1%
- UK Motorway 1%
- UK Village 1%
- Austria Motorway 1%
- In Austria City 4%
- Spain Town 26%

Driver Belt Usage by Gender:

- 6% of all Male Drivers
- 2% of all female drivers did not wear seat belts.

Country based results for occupants not wearing seatbelts:

- Spain
  - 22% male
  - 17% female
- UK
  - 2% males
  - 0.2% females.
- Austria
  - 3% of males
  - 1% of females

Front Passenger Belt Usage:

Results from a total of 2130 front passenger occupants.

7% of Passengers from all sites do not wear seat belts

Site based results for not wearing a seat belt:

- Spain Motorway 0.96%
- Spain Town 19.43%
- UK Motorway 2.2%
- UK Village 16.13%
- Austria City 4.76%
- Austria Motorway 4.76%

Front Passenger Spread by site:

- Spain Motorway 4.9%
- Spain Town 21.5%
- UK Motorway 40.5%
- UK Village 1.5%
- Austria City 7.9%
- Austria Motorway 23.8%

Front Passenger Belt Usage by Gender:

- 9% of all Male Passengers did not wear seat belts.
- 6% of all female passengers did not wear seat belts.

Country based results for front passengers not wearing seatbelts;

- Spain
  - 18% male
  - 15% female
- UK
  - 5% males
  - 2% females
- Austria
  - 8% males
  - 2% females

Vehicle Occupants

Number of Passengers in Vehicle; (The results have been split down to show the percentage of vehicles that have 1, 2 and 3 passengers in them)

Austria City

- Driver only 77.5%
- 1 passenger 20.5%
- 2 passengers 1.7%
- 3 passengers 0.4%

Austria Motorway

- Driver only 51.0%
- 1 passenger 41.0%
- 2 passengers 7.2%
- 3 passengers 0.8%

Spain Motorway

- Driver only 19.9%
- 1 passenger 51.4%
- 2 passengers 21.2%
- 3 passengers 6.8%
- 4 passengers 0.7%

Spain Town

- Driver only 28.7%
- 1 passenger 46.7%
- 2 passengers 15.0%
- 3 passengers 8.7%
- 4 passengers 0.7%
- 5 passengers 0.1%

UK Motorway

- Driver only 48.9%
- 1 passenger 38.8%
- 2 passengers 8.6%
- 3 passengers 3.1%
- 4 passengers 0.5%
- 5 passengers 0.1%

UK Village

- Driver only 82.1%
- 1 Passenger 15.1%
- 2 Passenger 2.8%
-

Age

Driver Age

- 8% of drivers were over 50 years of age
- 91% of all drivers were between 20-50 years of age
- 1.2% of drivers were under the age of 20

Site Based Results;

- Spain Town
  - 1.1% under 20 years of age
  - 91% 20-50 years of age
  - 8% over 50 years of age
- Spain Motorway
  - 90% 20-50 years of age
  - 10.3% over 50 years of age
- UK Motorway
  - 1.9 % under 20 years of age
  - 91% 20-50 years of age
  - 7.1% over 50 years of age
- UK Village
  - 0% under 20 years of age
  - 95% 20-50 years of age
  - 4.5% over 50 years of age
  - 0.6% indeterminable
- Austria City
  - 0.9% under 20 years of age
  - 89% 20-50 years of age
  - 10.1% over 50 years of age
- Austria Motorway
  - 0.9% under 20 years of age
  - 92% 20-50 years of age
  - 6.7% over 50 years of age

Driver age by Gender.

- Under 20 years of age
  - 53% female
  - 47% male
- 20-50 years of age
  - 24% female
  - 76% male
- Over 50 years of age
  - 15% female
  - 85% male

Front Passenger Age

- 12.1% of front passengers were over 50 years of age
- 70.4% of front passengers were between 20-50 years of age
- 9.7% of front passengers were under the age of 20
- 4.2% of front passengers were large child
- 2.7% of front passengers were small child
- 0.3% of front passengers were baby to 1 year
- 0.7% were indeterminable

Site Based Results: (if not listed count is zero)

- Spain Town
  - 12% over 50 years of age
  - 75% 20-50 years of age
  - 9% under 20 years of age
  - 2% large child
  - 0.2% small child
  - 0.4% baby to 1 year
  - 1.5% indeterminable
- Spain Motorway
  - 12.8% over 50 years of age
  - 83.5% 20-50 years of age
  - 1.8% under 20 years of age
  - 1% baby to 1 year
- UK Motorway
  - 14% over 50 years of age
  - 62% 20-50 years of age
  - 12% under 20 years of age
  - 7% large child
  - 4.5% small child
  - 0.3% baby to 1 year
  - 0.6% indeterminable
- UK Village
  - 9% over 50 years of age
  - 45% 20-50 years of age
  - 27% under 20 years of age
  - 15% small child
- Austria City
  - 21% over 50 years of age
  - 69% 20-50 years of age
  - 8% under 20 years of age
  - 1.2% large child
  - 1.2% small child
- Austria Motorway
  - 7% over 50 years of age
  - 78% 20-50 years of age
  - 8% under 20 years of age
  - 4% large child
  - 2% small child

Front Passenger Age by Gender.

- Over 50 years of age
  - 76% female
  - 23% male
- 20-50 years of age
  - 71% female
  - 27% male
- Under 20 years of age
  - 51% female
  - 47% male
- Large child
  - 53% female
  - 37% male
- Small child
  - 24% female
  - 60% male
- Baby to 1 year
  - 17% female
  - 17% male
  - 66% indeterminable

Rear Passenger Age

- 4.3% of rear passengers were over 50 years of age
- 31.7% of rear passengers were between 20-50 years of age
- 15.6% of rear passengers were under the age of 20
- 13.9% of rear passengers were large child
- 25.9% of rear passengers were small child
- 3.5% of rear passengers were baby to 1 year
- 5.1% were indeterminable

Rear passenger age by Site: (if not listed count is zero)

- Spain Town
  - 4% over 50 years of age
  - 37.2% 20-50 years of age
  - 17.2% under 20 years of age
  - 11.7% large child
  - 19% small child
  - 1.8% baby to 1 year
  - 9.1% indeterminable
- Spain Motorway
  - 1.6% over 50 years of age
  - 46.8% 20-50 years of age
  - 8.1% under 20 years of age
  - 19.4% large child
  - 8.1% small child
  - 3.2% baby to 1 year
  - 12.9% indeterminable
- UK Motorway
  - 5.3% over 50 years of age
  - 23.5% 20-50 years of age
  - 13% under 20 years of age
  - 14.4% large child
  - 36.8% small child
  - 4.7% baby to 1 year
  - 2.2% indeterminable
- UK Village
  - 25% 20-50 years of age
  - 50% under 20 years of age
  - 25% small child
- Austria City
  - 2.8% over 50 years of age
  - 41.7% 20-50 years of age
  - 30.6% under 20 years of age
  - 8.3% large child
  - 11.1% small child
  - 5.6% baby to 1 year
- Austria Motorway
  - 4.4% over 50 years of age
  - 33.3% 20-50 years of age
  - 18.4% under 20 years of age
  - 16.7% large child
  - 21.9% small child
  - 3.5% baby to 1 year
  - 1.8% indeterminable

Rear Passenger Age by Gender:

- Over 50 years of age
  - 56.8% female
  - 35.1% male
  - 8.1% indeterminable
- 20-50 years of age
  - 48.9% female
  - 39.6% male
  - 11.5% indeterminable
- Under 20 years of age
  - 36.8% female
  - 54.9% male
  - 8.3% indeterminable
- Large child
  - 34.7% female
  - 48.3% male
  - 16.9% indeterminable
- Small child
  - 22.3% female
  - 35% male
  - 42.7% indeterminable
- Baby to 1 year
  - 6.7% female
  - 20% male
  - 73.3% indeterminable

Manufacturer

Vehicle Manufacturer Shown by Site

- Spain Town
  - Renault
  - Seat
- UK MW
  - Ford
  - Peugeot
  - Vauxhall
- Austria City
  - Volkswagen
  - Opel
  - Ford
- Spain Motorway
  - Seat
  - Renault
- UK Village
  - Ford
  - Peugeot
  - Vauxhall
- Austria MW
  - Volkswagen
  - Opel
  - Ford

Gender

Driver Gender

- 76.1% of all sites were male drivers
- 23.9% of all sites were female drivers

Driver Gender by site

- Spain Town
  - 87.6% male
  - 12.4% female
- Spain Motorway
  - 92.5% male
  - 7.5% female
- UK MW
  - 78% male
  - 22% female
- UK Village
  - 68% male
  - 32% female
- Austria City
  - 69% male
  - 31% female
- Austria MW
  - 70% male
  - 30% female

Passenger Gender

- 56% were male drivers
- 24% were female drivers

Passenger gender by site

- Spain Town
  - 25.7% male
  - 71.5% female
  - 2.8% were indeterminable
- Spain Motorway
  - 30.3% male
  - 65.1% female
  - 4.6% were indeterminable
- UK MW
  - 32.8% male
  - 65% female
  - 2.3% were indeterminable
- UK Village
  - 57.6% male
  - 36.4% female
  - 6.1% were indeterminable
- Austria City
  - 38.5% male
  - 60.9% female
  - 0.6% were indeterminable
- Austria MW
  - 27.4% male
  - 69.7% female
  - 2.9% were indeterminable

Head Position

Driver Head Restraint Gap

- 8.9% of all drivers had a small head restraint gap
- 78.1% of all drivers had a medium head restraint gap
- 11.8% of all drivers had a large head restraint gap
- 0.4% of all had no head restraint
- 0.8% of all were indeterminable

Driver head restraint gap by gender

Female

- 10.7% of females small sized gap
- 73.86% of females medium sized gap
- 14.74% of females large sized gap
- 0.44% of females no head restraint
- 0.26% of females were indeterminable

Male

- 8.34% of males had small sized gap
- 79.47% of males had medium sized gap
- 10.90% of males had large sized gap
- 0.33% of males had no head restraint
- 0.96% of males were indeterminable

Passenger Head Restraint Gap

- 11.1% of all drivers had a small head restraint gap
- 82.3% of all drivers had a medium head restraint gap
- 5.2% of all drivers had a large head restraint gap
- 0.3% of all had no head restraint
- 1.0% of all were indeterminable

Passenger Head restraint gap by gender

Female

- 11.4% of females had small sized gap
- 84.1% of females medium sized gap
- 3.5% of females had large sized gap
- 0.3% of females had no head restraint
- 0.7% of females were indeterminable

Male

- 11% of males had small sized gap
- 79.3% of males had medium sized gap
- 8.7% of males had large sized gap
- 0.3% of males had no head restraint
- 0.7% of males were indeterminable

Indeterminable

- 3.6% of small head gap gender was indeterminable
- 73.2% of Medium head gap gender was indeterminable
- 8.9% of large head gap gender was indeterminable
- 1.8% indeterminable gender had no head restraint
- 12.5% gender or gap size was indeterminable

Driver Head to centre line distribution - Medium vehicles

- The normal distribution (x) was 400 to 450 mm
- Males highest distribution sat between 300-350 mm
- Females highest distribution sat between 300- 350 mm

Nose to Steering Wheel Resultant

- The highest distribution shows that drivers sit between 451mm to 500mm

Nose to Steering Wheel Result by gender

- Females sit between 401mm and 450mm.
- Males sit between 451mm and 500mm.

Nose to Steering Wheel Resultant by Site

- Site results show drivers on all sites sit between 401-500mm.
- Spain Town generally sit closer to the steering wheel than Austria City.

Hand and Arm Positions

Driver Hand Positions

- ? (Unknown)
  - Left Hand 5.70%
  - Right Hand 3.73%
- Centre of Wheel
  - Left Hand 0.50%
  - Right Hand 0.36%
- Distant Control
  - Left Hand 0.44%
  - Right Hand 0.27%
- Nose / Mouth
  - Left Hand 1.86%
  - Right Hand 1.57%
- Drink / Food
  - Left Hand 0.08%
  - Right Hand 0.23%
- Gear Shift
  - Left Hand 4.92%
  - Right Hand 15.98%
- Gesture at Camera
  - Left Hand 0.15%
  - Right Hand 0.27%
- Grab Handle
  - Left Hand 0.13%
  - Right Hand 0.08%
- Map / Book / Papers
  - Left Hand 0.04%
  - Right Hand 0.13%
- Other
  - Left Hand 2.24%
  - Right Hand 1.84%
- Out of Window
  - Left Hand 0.29%
  - Right Hand 0.06%
- Phone / Head Side
  - Left Hand 1.59%
  - Right Hand 1.53%
- Steering Wheel Bottom Quad
  - Left Hand 18.33%
  - Right Hand 16.11%
- Steering Wheel Left Quad
  - Left Hand 48.32%
  - Right Hand 0.21%
- Steering Wheel Right Quad
  - Left Hand 1.26%
  - Right Hand 47.09%
- Steering Wheel Top Quad
  - Left Hand 14.14%
  - Right Hand 10.54%

Driver Arm positions

- ? (Unknown)
  - Left Arm 0.7%
  - Right Arm 0.9%
- Across Body
  - Left Arm 0.7%
  - Right Arm 0.3%
- Arm Rest
  - Left Arm 4.1%
  - Right Arm 2.4%
- Crossed
  - Left Arm 0.1%
  - Right Arm 0.1%
- Normal
  - Left Arm 92.8%
  - Right Arm 95.3%
- Other
  - Left Arm 0.3%
  - Right Arm 0.6%
- Out of Window
  - Left Arm 1.1%
  - Right Arm 0.2%
- Waist Rail
  - Left Arm 0.2%
  - Right Arm 0.2%

Passenger Hand Positions

- ? (Couldn't tell)
  - Left Arm 26.8%
  - Right Arm 25.4%
- Drink / Food
  - Left Arm 0.4%
  - Right Arm 0.4%
- Gesture at Camera
  - Left Arm 0.3%
  - Right Arm 0.6%
- Grab Handle
  - Left Arm 1.9%
  - Right Arm 2.8%
- Lap
  - Left Arm 46.4%
  - Right Arm 45.9%
- Map / Book / Papers
  - Left Arm 1.1%
  - Right Arm 1.4%
- Normal
  - Left Arm 16.2%
  - Right Arm 15.8%
- Nose / Mouth
  - Left Arm 2.1%
  - Right Arm 2.2%
- Out of Window
  - Left Arm 0.1%
  - Right Arm 0.8%
- Phone / Head Side
  - Left Arm 1.2%
  - Right Arm 1.1%
- Other
  - Left Arm 3.3%
  - Right Arm 3.6%

Passenger Arm Positions

- ? (Unknown)
  - Left Arm 2.1%
  - Right Arm 2.0%
- Across Body
  - Left Arm 1.2%
  - Right Arm 1.5%
- Arm Rest
  - Left Arm 1.9%
  - Right Arm 2.5%
- Crossed
  - Left Arm 4.2%
  - Right Arm 4.1%
- Normal
  - Left Arm 88.9%
  - Right Arm 87.9%
- Other
  - Left Arm 1.1%
  - Right Arm 1.0%
- Out of Window
  - Left Arm 0.3%
  - Right Arm 0.7%
- Waist Rail
  - Left Arm 0.4%

Hand Positions in relation to each other

- 32.9% left hand on steering wheel left quadrant right hand on steering wheel right quadrant
- 11.7% have both hands on the bottom quadrant of the steering wheel
- 6.71% left hand on steering wheel left quadrant right hand on gear shift
- 5.97% left hand on steering wheel top quadrant right hand on gear shift
- 3.25% left hand on gear shift right hand on steering wheel right quadrant
- 2.72% left hand on steering wheel left quadrant right hand on steering wheel top quadrant
- 2.70% left hand on steering wheel top quadrant right hand on steering wheel top quadrant
- 2.62% left hand on steering wheel top quadrant right hand on steering wheel right quadrant
- 2.28% left hand can not tell right hand on steering wheel right quadrant

Miscellaneous

Glasses;

- 29.8% of all Drivers wear glasses
- 28.3% of all Front passengers wear glasses

Driver wearing glasses by site;

- Austria City
  - Male 11.3%
  - Female 9.1%
- Austria Motorway
  - Male 23.5%
  - Female 14.7%
- Spain Motorway
  - Male 50.7%
  - Female 3.4%
-
- Spain Town
  - Male 37.3%
  - Female 5.6%
- UK Motorway
  - Male 16.9%
  - Female 5.9%
- UK Village
  - Male 10.6%
  - Female 10.1%

Front passenger wearing glasses by site;

- Austria City
  - Male 2.4%
  - Female 11.9%
- Austria Motorway
  - Male 5.2%
  - Female 23.2%
- Spain Motorway
  - Male 12.8%
  - Female 26.6%
- Spain Town
  - Male 11.9%
  - Female 33.3%
- UK Motorway
  - Male 6.1%
  - Female 14.9%
- UK Village
  - No glasses wearers

Luggage

- 7.5% of vehicles in Spain Motorway had luggage in the occupant area.
- 7.5% of vehicles in Spain Motorway had luggage in the luggage area.
- 5.9% of vehicles in UK Motorway had luggage in the occupant area.
- 3.1% of vehicles in UK Motorway had luggage in the luggage area.
- 3% of vehicles in Spain Town had luggage in the occupant area.
- 2.7% of vehicles in Austria City had luggage in the occupant area.
- 2.7% of vehicles in Austria City had unsafe luggage.
- 2.5% of vehicles in Austria Motorway had luggage in the occupant area.
- 2.1% of vehicles in Austria City had unsafe luggage.

Child seat use

- 86.1% had No Child Seat
- 12.2% had a forward facing seat
- 1.0% had a rear facing seat
- 0.8% had a child standing on the seat

Facing direction

- 95.9% of front passengers faced forwards
- 3.4% of front passengers faced sideways
- 0.5% of front passengers faced rearwards
- 0.2% of front passengers were on a lap facing forward
- 94.12% of rear passengers faced forwards
- 4.82% of rear passengers faced sideways
- 1.06% of rear passengers faced rearwards

Unusual Cases

Driver Unusual Case

- 36.8% smoking
- 21.1% no hands on wheel
- 10.5% arm across body
- 5.3% adjusting seatbelt
- 5.3% dog on lap
- 5.3% doing hair
- 5.3% large gap from steering wheel
- 5.3% head against steering wheel
- 5.3% radio adjustment

Front Passenger Unusual Cases

- 16.7% animal in passenger area
- 13.3% hand holding seat belt
- 10.0% luggage on facia
- 10.0% asleep
- 10.0% bent over looking in foot well
- 6.7% child on lap
- 6.7% arm under seatbelt
- 6.7% child stood in foot well
- 3.3% facing rearwards
- 3.3% feet on fascia
- 3.3% hand out of window
- 3.3% luggage on lap
- 3.3% no child seat
- 3.3% person holding baby

Rear Passenger Unusual Case

- 30.3% child stood up
- 21.2% leaning forward
- 9.1% unbelted not in place
- 9.1% child on lap
- 6.1% asleep
- 6.1% dog in rear
- 6.1% facing rearwards
- 3.0% hand out of window
- 3.0% dangerous luggage
- 3.0% looking rearwards
- 3.0% over crowded car

PERFORMANCE EVALUATION OF VARIOUS HIGH BACK BOOSTER SEATS TESTED AT 56 KPH USING A 6-YEAR-OLD HYBRID III DUMMY

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ABSTRACT

Recent increase in the use of child restraints, particularly belt-positioning booster seats, requires closer evaluation of their performance. Previous studies by Menon, et al. and Sherwood, et. al. have shown that the Hybrid III 6-year-old dummy produced unusual head-neck kinematics and neck injury measures that exceeded critical values while restrained in a high back booster seat. Both studies used similar high back booster seats for the tests but were done at different speeds and conditions. This study was undertaken to initiate a process to evaluate the performance of multiple high back booster seats by conducting a series of sled tests. These 56 kph sled tests were done using the Hybrid III 6-year-old child dummy in 4 different high back booster seats and their injury measures were compared.

Results of these tests have been summarized in this paper and provide an evidence for a differential performance among the various designs of high back booster seats compounded with the established lack of biofidelity of the Hybrid III 6-year-old dummy. Injury tolerances exceeded for the 6 year-old dummy in two of the high back booster seats for the Head Injury Criteria, in three of the seats for chest G's and in all the four seats for the Neck Injury Criteria. In two of the seats with similar design, the kinematics of the head was unusual, mainly due to the extreme hyper-flexing of the neck. This high neck injury measures obtained from the sled tests are in contrary to the field data, which show that children in belt-positioning booster seats suffered virtually no injuries to the abdomen, neck/spine/back. These test results and field data highlights the need for further research to be conducted to improve the biofidelity of the Hybrid III 6-year-old dummy neck and to understand the variation in the high back booster seat designs at higher speeds.

INTRODUCTION

Currently there are about 30 different types of belt positioning booster seats available to use for children who have outgrown child seats, but are yet not tall enough for adult seat belts [1]. The National Highway Traffic Safety Administration's (NHTSA) [2] and American Academy of Pediatrics (AAP) [3] currently recommend that children over 40 lbs and approximately between 4 and 8 years of age unless the child is 57 inches tall should be restrained using a belt positioning booster seat. Partners for Child Passenger Safety (PCPS) [4], a national data source of children in crashes, collected over a period of 5 years, provides an evidence of the increased uses of these belt positioning booster seats [5]. This data also shows that the belt-positioning booster seats provide added safety benefits over seat belts to children through age 7 years, including the reduction of injuries classically associated with improper seat belt fit in children. [6,7,8]

The study by Menon, et, al. [9] looked at the performance of the various child restraint systems by conducting sled tests with Hybrid III 3- and 6-year-old child dummies at a range of speeds. It was observed in the study that the 6-year-old dummy in the high back booster (HBB) seat at 56 kph experienced a significant neck flexion resulting in the chin and face contacting the chest of the dummy. Although this phenomenon of the dummy neck kinematics has been adequately explained by Sherwood et. al. [10] it must be noted that this extreme hyper-flexing of the Hybrid III 6-year-old dummy neck only occurred in the HBB at speeds above the standard test speed of 40 kph and not in other restraint types. Thus leading the authors to believe that the influence of the HBB design itself should not be ignored. Since there are many different high back booster seat designs that are available for use, therefore the primary purpose of this study was to conduct a series of sled tests at 56 kph with a Hybrid III 6-year-old dummy restrained in different belt-positioning HBB designs to assess the dummy's response and to evaluate the performance of the different HBB designs. This paper documents the Hybrid III 6-year-old dummy interaction with the HBB seats.

METHODS

Four HBB seats, Century Brevera, Evenflo Express, Cosco Highback and Britax Roadster, were selected for this study. Two of the seats, Evenflo Express and Cosco Highback, had some similarities in design. A total of eight sled tests were conducted for these 4 HBB seats. These tests were conducted on a HYGE accelerator sled at Calspan Corporation, formerly known as Veridian Engineering, Buffalo NY. Two sled tests were performed for each HBB seat. All the tests were performed at an impact speed of 56 kph with the sled acceleration pulse as shown in Figure 1. The maximum acceleration was above the standard value, but the duration of pulses was similar to the FMVSS 213[11] acceleration pulse. These tests were performed with a 6-year-old dummy positioned on one side of a standard FMVSS 213 bench seat. The guidelines provided in the standard were used for conducting the tests with the exception being the test speed, which was higher than the 49 kph standard test speed. Production seatbelts were attached to the bench seat assembly in the correct anchorage locations without using the pre-tensioners or the force limiting devices. When the dummies were placed in the HBB seats, the manufacturers instructions accompanying each HBB seat were followed carefully to properly restrain the dummies with optimum belt placement. Two tests were conducted for each HBB seat design to check for the repeatability of the results.

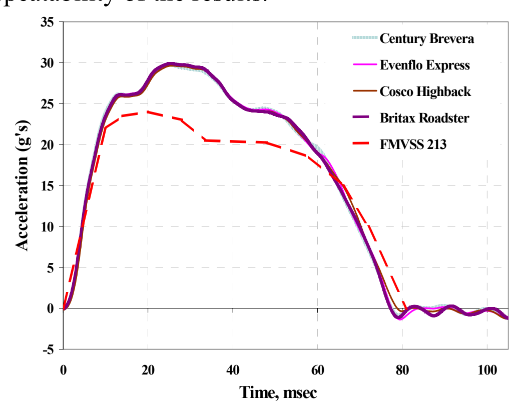

Figure 1. Sled acceleration pulse for 56 kph frontal sled tests.

The Hybrid III 6-year-old dummy was equipped with standard sensors for taking measurements, which included the head tri-axial accelerometers, upper neck load cells, chest accelerometer, chest potentiometer, pelvis accelerometer and a shoulder belt load cell. Electronic data was sampled at 10, 000 Hz and were filtered as per the Society of Automotive Engineers (SAE) recommended practice J211 [12]. Head and pelvis accelerations and upper neck loads were filtered at CFC 1000, whereas the cheat accelerations were filtered at CFC 180. Chest displacement and the upper neck moments were filtered at CFC 600. Finally the shoulder belt loads were filtered at CFC 60.

Since the current FMVSS 213 consists of only a test bench without any structure to represent the vehicle interiors, the injury measures, which may be specified as compliance requirement, are non-contact in nature. In order to assess the performance of the HBB designs tested, the injury measures obtained from these tests were compared to the published injury assessment reference values (IARVs) that are shown in Table 1. The injury measures that were obtained in these sled tests were Head Injury Criteria (HIC), neck forces, neck moments, chest acceleration, chest deflection, head excursions and the knee excursion.

The N_{ij} value was calculated for the upper neck as a predictor of neck injury potential and was based on the information provided by Eppinger et al. [13]. The critical values used for calculating Nij for the 6-year-old were F_{int} (tension) = 3096 N, F_{int} (Compression) = -2800 N, M_{int} (Flexion) = 93 Nm and M_{int} (extension) = -42 Nm.

Table 1.
Injury Assessment Reference Values

Injury Criteria	Hybrid III 6-year-old Dummy	Source
Head Criterion (HIC_{36ms})	1000	Title 49 CFR, Part 571, FMVSS 213
Neck Criterion (Nij)*	1	Eppinger et al., 2000
Chest Acceleration (G)	60	Title 49 CFR, Part 571, FMVSS 213
Chest Deflection (mm)*	40	Eppinger et al., 2000
Head Excursion Without Tether (mm)	813	Title 49 CFR, Part 571, FMVSS 213
Knee Excursion (mm)	915	Title 49 CFR, Part 571, FMVSS 213

Two cameras (Kodak Ektapro high speed video cameras) were placed on either side of the bench seat to provide sufficient film coverage of the dummy motion and to record the tests at 1000 frames/sec. The head and knee excursion values reported under results were obtained from the test video with the use of visualization software. The visualization software takes care of residual parallax error in head excursion measurements and also incorporates the necessary corrections for measuring the knee excursions.

INITIAL TEST SETUP

The initial test setup of the Hybrid III 6-year-old dummy in a Century Brevera HBB is shown in the Figures 2a and 2b. The vehicle belt was placed ideally over the pelvis and the chest. The belt guides provided for the shoulder belt in the HBB seat was not used because the belt path was ideally placed over the sternum without using the belt guide and this was in accordance to the manufacturer's guidelines. The seated angle of the lumbar with respect to a vertical plane was 18^0 and the angle of the thigh with respect to the horizontal plane was 13^0. The dummy seating posture is upright.

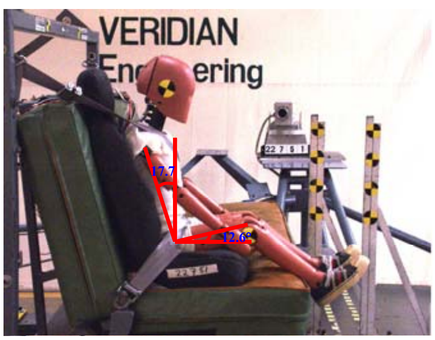

Figure 2a. Pre-test setup of the Hybrid III 6-year-old dummy in a Century Brevera HBB

Figure 2b. Shoulder belt routing of Hybrid III 6-year-old dummy in a Century Brevera HBB

Figures 3a and 3b shows the test setup of the Hybrid III 6-year-old dummy in an Evenflo Express HBB seat. The shoulder portion of the vehicle belt was routed through the top belt guide provided in the seat for proper belt routing over the dummy's sternum. The seated angle of the lumbar with respect to a vertical plane was 32^0 and the angle of the thigh with respect to the horizontal plane was 16^0. The dummy's initial seating posture has a slouch.

Pre-test setup of the Hybrid III 6-year-old dummy in a Cosco HBB seat is shown in the Figures 4a and 4b. The manufacturer's recommendations were used for restraining the dummy in the HBB and the vehicle shoulder belt was routed through the top portion of the belt guide for proper placement over the dummy's sternum. The seated angle of the lumbar with respect to a vertical plane was 31^0 and the angle of the thigh with respect to the horizontal plane was 16^0. It is observed that the Hybrid III 6-year-old dummy had similar seating posture in both Evenflo Express and the Cosco Highback HBB seats.

Figure 3a. Pre-test setup of a Hybrid III 6-year-old dummy in an Evenflo HBB

Figure 3b. Shoulder belt routing of Hybrid III 6-year-old dummy in an Evenflo HBB

Figure 4a. Pre-test setup of a Hybrid III 6-year-old dummy in a Cosco HBB

Figure 4b. Shoulder belt routing of Hybrid III 6-year-old dummy in a Cosco HBB

The Britax Roadster HBB seat is unique in design and its back can be adjusted in height to suit the child's height. The pre-test setup of the Hybrid III 6-year-old dummy in a Britax Roadster HBB seat is shown in Figures 5a and 5b. The vehicle shoulder belt routing was done based on the guidelines provided by the seat manufacturer. The height of the HBB seat back was adjusted such that the belt guide of the seat was at the shoulder level of the dummy. From Figure 5a the seated angle of the lumbar with respect to a vertical plane was measured to be 16^0 and the angle of the thigh with respect to the horizontal plane was measured to be 17^0 indicating that the dummy seating position is upright.

OBSERVATIONS AND RESULTS

Appendix A summarizes the results obtained from the sled tests for the Hybrid III 6-year-old in these four different HBB seats. The time histories of head and chest resultant acceleration, chest deflection and the shoulder belt loads along with HIC maximum head and knee excursion and the Nij obtained from the sled tests are provided.

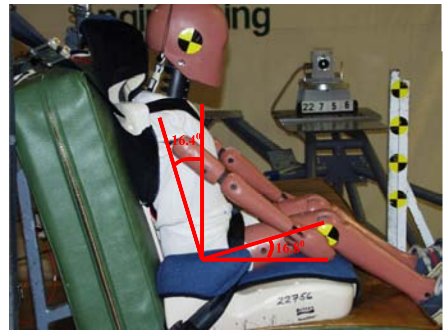

Figure 5a. Pre-test setup of a Hybrid III 6-year-old dummy in a Britax Roadster HBB

Figure 5b. Shoulder belt routing of Hybrid III 6-year-old dummy in a Britax Roadster HBB

The resultant head accelerations were measured with the help of a triaxial accelerometer mounted on the center of gravity of the dummy head. The time history of the head acceleration of the Hybrid III 6-year-old in the different HBB seats is shown in Figure 6. The head acceleration measured from the Evenflo Express and the Cosco Highback HBB seats were almost identical.

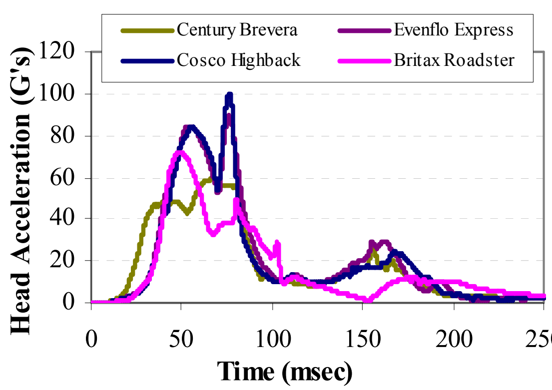

Figure 6. Resultant head acceleration with respect to time of a Hybrid III 6-year-old dummy

Head Injury Criteria (HIC), the predictor of head injury is calculated using the resultant head acceleration and the threshold limit of 1000 is considered as injurious. The HIC values are shown in Figure 7. The Evenflo Express and Cosco Highback HBB seated Hybrid III 6-year-old dummy experienced HIC values greater than 1000 whereas the Britax Roadster HBB seated dummy had the least.

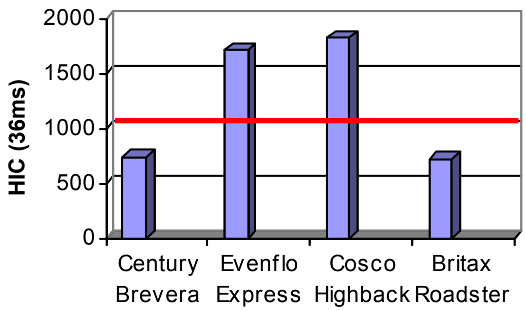

Figure 7. HIC (36ms) for the Hybrid III 6-year-old dummy

The resultant chest acceleration measured over a 3ms clip is shown in Figure 8. Of all the 4 types of HBB seats, the Century Brevera restrained Hybrid III 6-year-old dummy experienced the lowest chest accelerations.

Chest deflections of the Hybrid III 6-year-old dummy measured with respect to time is shown in Figure 9. The Century Brevera and the Britax Roadster restrained dummy experienced the highest chest deflections and their values exceeded the threshold limit of 40 mm. The other two HBB seats produced lower chest deflection measures.

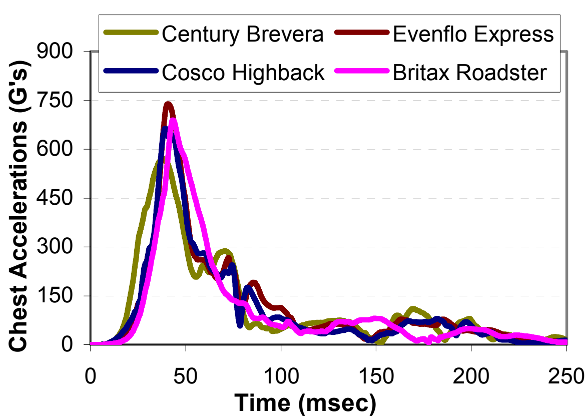

Figure 8. Resultant chest acceleration of a Hybrid III 6-year-old dummy

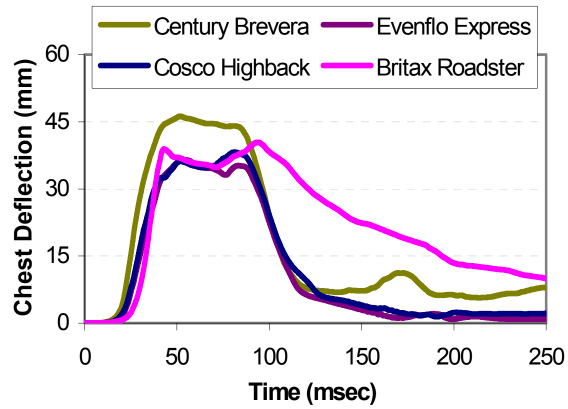

Figure 9. Chest deflections of a Hybrid III 6-year-old dummy in different HBB designs

The head and knee excursions for the 6-year-old dummy in all the different HBB seats were lower than their corresponding threshold limit and are shown in the Figures 10 and 11 respectively.

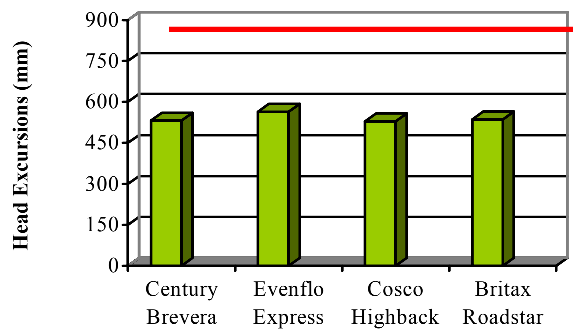

Figure 10. Head excursion of a Hybrid III 6-year-old dummy in different HBB designs

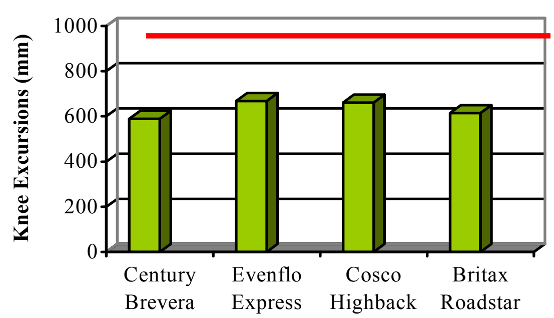

Figure 11. Knee excursion of a Hybrid III 6-year-old dummy in different HBB designs

The neck injury measure N_{ij} calculated based on the reading obtained from the neck load cell is shown in Figure 12. The Nij values exceeded the threshold limit of 1 for all the HBB seats. The failure of the neck can be observed mainly due to the higher tension values (both in flexion and extension). The Hybrid III 6-year-old dummy's neck experienced relatively low forces in compression.

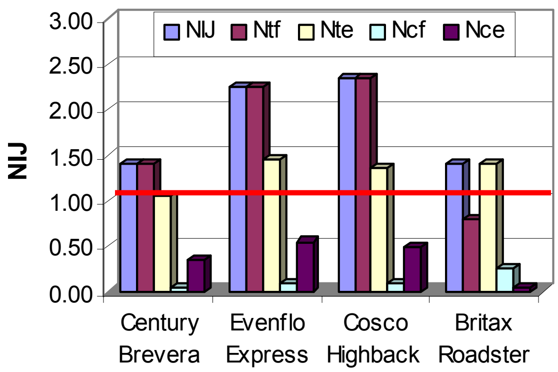

Figure 12. Neck injury measures of a Hybrid III 6-year-old dummy in different HBB designs

The shoulder belt loads experienced by the Hybrid III 6-year-old dummy during the sled tests is shown in Figure 13. It can be noted from the graph that the load distributions were almost identical in all HBB seats.

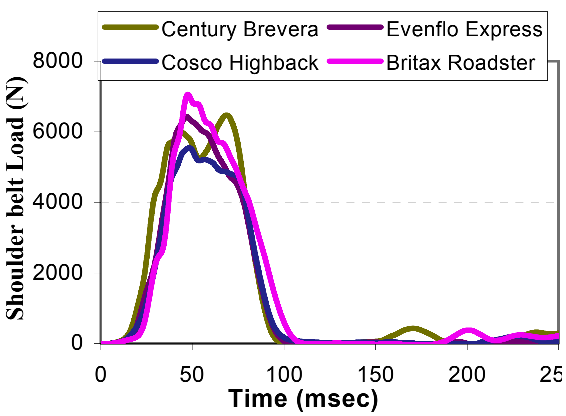

Figure 13. Shoulder belt loading of a Hybrid III 6-year-old dummy in different HBB designs

The HBB seats were examined post-test for damage. The Century Brevera was the only HBB seat with no visible damage to the seat structure. The visual inspection of the other three HBB seats reveled structural damage to all of them especially at the point of seat belt loading which varied from stress marks to breakage. The damage to the seats are shown in Figures 14a, 14b and 14c. The Evenflo Express had plastic deformation of the fins, the Cosco HBB seat broke at the lower belt guide and the Britax Roadster split at the seam.

Figure 14a. Post-test structural damage (stress marks and bending of material) of the Evenflo Express HBB seat

Figure 14b. Post-test structural damage of the Cosco Highback HBB seat

Figure 14c. Post-test structural damage of the Britax Roadster HBB seat

DISCUSSION

This study was undertaken to evaluate the performance of different high back booster seats by conducting a series of sled tests. These 56 kph sled tests were done using the Hybrid III 6-year-old child dummy in four different HBB seats and their injury measures were compared. These tests demonstrated that there is a difference in performance among the different designs of HBB seats compounded with the established lack of biofidelity of the Hybrid III 6-year-old dummy. Injury tolerances exceeded for the Hybrid III 6-year-old dummy in two of the HBB seats for the HIC, in three of the HBB seats for chest G's and in all the four HBB seats for the N_{ij}.

In two of the HBB seats, the Evenflo Express and the Cosco Highback, which were similar design, the kinematics of the head was unusual, mainly due to the extreme hyper-flexing of the neck causing the forehead to contact the chest. This phenomenon may be attributed to the stiff spine of the Hybrid III 6-year-old dummy as demonstrated by Sherwood et. al. [10]. A sequence of the sled tests with all the four HBB seats is provided in Appendix B, for comparison. Although the hyper-flexion of the Hybrid III 6-year-old dummy neck was also observed in the other two HBB seats (Century Brevera and Britax Roadster), the extent of the flexion was not as high and the forehead of the dummy did not make contact with its chest. This calls attention to the hypothesis by the authors that the design of HBB seat has an effect on the performance of the Hybrid III 6-year-old dummy.

This high neck injury measures obtained for all the HBB seats from the sled tests are in contrary to the field data, which show that children in belt-positioning booster seats suffered no injuries to the abdomen, neck/spine/back [8]. These test results and field data highlights the need for further research to be conducted to improve the biofidelity of the Hybrid III 6-year-old dummy neck and to understand the variation in the high back booster seat designs at higher speeds.

The kinematics of the tests show that the lap belt moved up on the pelvis of the Hybrid III 6-year-old dummy restrained in the Evenflo Express and the Cosco Highback HBB seats. Due to the lack of the abdominal measuring capability in the dummy any unwarranted forces on the Hybrid III 6-year-old dummy was not captured. This reiterates the need for the development for an abdominal measuring capability in the dummy.

Chest loading is directly dependent on the belt routing over the sternum. During these sled tests the shoulder belt slipped away from the sternum, when the Hybrid III 6-year-old dummy was restrained in the Evenflo Express and the Cosco Highback HBB seats thus giving lower chest deflection measures in these tests. Whereas the Century Brevera and the Britax roadster restrained dummy experienced higher chest deflections because of the proper routing of the shoulder belt and the correct loading of the sternum during the test. Therefore it is safe to assume that the design of the HBB seat induced belt slippage.

CONCLUSIONS

Overall the Hybrid III 6-year-old dummy responded differently while being restrained in the Evenflo Express and the Cosco Highback HBB seats when compared to the Century Brevera and the Britax Roadster HBB seats. The dummy had higher head accelerations, chest accelerations, knee excursions and higher neck tension loading in the Evenflo Express and Cosco Highback HBB seats. The higher head accelerations, chest accelerations and neck tension loads highlight the differential performance of the HBB seats due to their designs.

These tests confirm:

a) the differential performance of the HBB seats,
b) the need for a more biofidelic Hybrid III 6-year-old dummy, and
c) highlights the divergence between laboratory test performance of the dummy in the HBB seats with the data from the field.

ACKNOWLEDEGEMENTS

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APPENDIX A

Test results for Hybrid III 6-year-old dummy at 56 kph in different high back booster seats

Sled Velocity (kph)	Restraint Used	Test No.	HEAD			NECK					CHEST		KNEE
			Max Res. Accel. (G)	HIC-36	Excursion (mm)	Tension (N)	Compression (N)	Flexion (N-m)	Extension (N-m)	Nij	Max Res. Accel. (3MS) (G)	Deflection (mm)	Excursion (mm)
IARV				**1000**	**813**	**3096**	**2800**	**93**	**42**	**1.0**	**60**	**40**	**915**
56	Century Brevera	21050	64	802	523	**3526**	35	33	23	**1.6**	56	**46**	594
		21051	60	690	541	2765	100	31	23	**1.2**	**60**	**48**	584
	Evenflo Express	21052	90	**1674**	566	**5230**	81	44	24	**2.3**	**73**	36	673
		21053	90	**1748**	561	**4907**	71	52	34	**2.2**	**75**	38	663
	Cosco Highback	21054	101	**1815**	526	**5267**	72	43	28	**2.3**	**68**	38	658
		21055	113	**1829**	531	**5774**	99	38	24	**2.4**	**63**	38	663
	Britax Roadster	21056	70	693	533	2150	32	28	26	**1.3**	**67**	**41**	602
		21057	75	758	538	2234	126	38	33	**1.3**	**66**	**43**	625

APPENDIX B

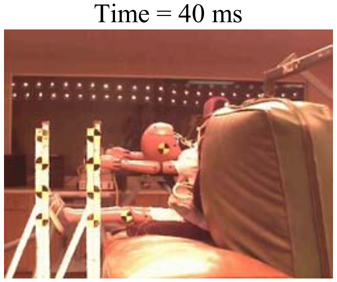
Test sequence of the Hybrid III 6-year-old dummy at 56 kph in different high back booster seats

Century Brevera

Time = 0 ms

Time = 20 ms

Time = 40 ms



Time = 60 ms

Evenflo Express

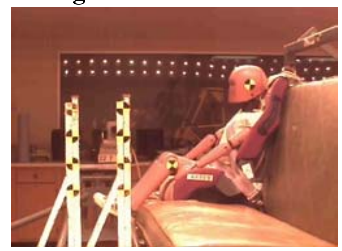
Time = 0 ms

Time = 20 ms

Time = 40 ms

Time = 60 ms

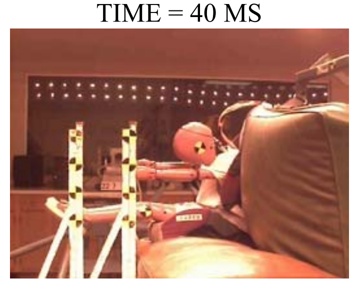
Cosco Highback



Time = 0 ms

TIME = 20 MS

TIME = 40 MS



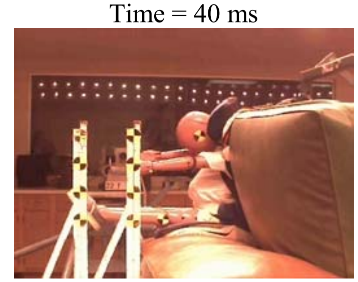
Time = 60 ms

Britax Roadster

Time = 0 ms

Time = 20 ms

Time = 40 ms



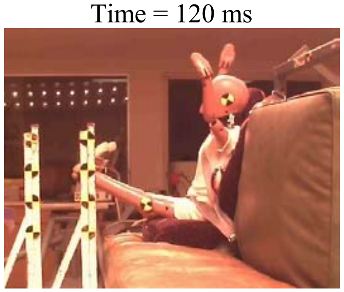
Time = 60 ms

Century Brevera

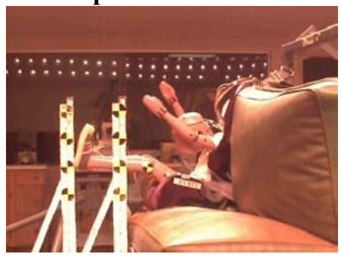

Time = 80 ms


Time = 100 ms


Time = 120 ms


Time = 135 ms

Evenflo Express


Time = 80 ms


Time = 100 ms


Time = 120 ms


Time = 135 ms

Cosco Highback


Time = 80 ms


TIME = 100 MS


TIME = 120 MS


Time = 135 ms

Britax Roadster


Time = 80 ms


Time = 100 ms


Time = 120 ms


Time = 135 ms