NPACS (New Programme for the Assessment of Child restraint Systems) Phase 1 Final Report

by G Cheung and M Le Claire (TRL)

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PROJECT REPORT

TRL Limited

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1 Executive Summary

The Department for Transport's plan for reducing casualties in road accidents (Tomorrow's roads: safer for everyone; the Government's road Safety strategy and casualty reduction targets for 2010) emphasises their aim to improve child safety. The action plan identifies a need to improve the protection levels offered by child restraint systems, including their ease of use and fitment into cars. Approximately 1,000 children are killed and 80,000 are injured annually on European roads. This produces an unacceptably high burden on Europe's society and economy and it could prove valuable to explore new methods for improving the protection of child car occupants.

The NPACS programme intends to accomplish benefits for the enhanced safety of child restraint systems, leading to their improved performance and ease of use and fitment into a range of vehicles. Consumer information schemes, such as vehicle safety performance schemes, have been shown to be effective in creating a market for safety improvements. This has been achieved through equipping consumers with accurate information to enable them to make decisions to purchase and also for manufacturers to improve the safety levels of their products.

The intention of this international collaborative research programme was to develop a single harmonised European, scientifically based assessment procedure for the dynamic safety and usability rating of Universal child restraint systems in cars. In addition to rating child restraint systems, NPACS intends to encourage innovative design solutions from child restraint manufacturers to bring safety to another level. This would be achieved by creating a set of testing protocols and associated rating schemes. The NPACS assessment protocols cover three areas: Usability, Dynamic Performance (front and side impact), and Rating. A website was to be created to provide a means of communication for the project in the first phase and possibly a source of the test results database for NPACS in phase 2.

In Europe child restraint systems (CRSs) are evaluated for crash safety in front and rear impacts by testing them to the UN-ECE Regulation 44. This is a Universal minimum safety level and all products sold must comply with these requirements. Regulation 44 provides very little assessment of the ease of use, which is seen as a role for consumer groups and makes minimum provisions to prevent the potential for misuse of CRS. Consequently, the tests included within the Regulation cannot be used to provide guidance to parents on the relative crash performance and ease of use of child restraints. The current regulatory requirements provide no minimum requirements for side impact.

Currently, Euro NCAP includes an element of CRS assessment. It looks at the usability and safety aspects of the child restraints recommended by the vehicle manufacturer for use by 18 month old and 3-year-old children in a specific vehicle under test. The high dependency of the performance of a CRS on the vehicle design and performance (crash pulse, seat geometry, interior space etc) means that this assessment is not useful for selecting a child restraint for use in other vehicle models. Neither does it provide any guidance on the comparative performance of alternative child restraints for use in that specific vehicle.

Child restraints can essentially be of three types; those intended for use in a specific vehicle or vehicles, those that can be used in a range of identified vehicle models and those intended for 'Universal' use. The Universal category child restraint is almost unique as a safety device. It's fit and safety performance is dependent on the local environment into which it is fitted, i.e. the car. However, for practical day to day use, the ability to transfer this safety device from vehicle to vehicle is an essential characteristic. Thus it is crucial to be able to assess how well these CRSs are likely to perform over a range of vehicle environments.

Before the NPACS project began there were at least three different consumer assessment methods being used within Europe providing advice to consumers on their selection of CRSs. They produced different results for the same restraint models and hence conflicting advice. This led to confusion, highlighting a need for a single well-founded assessment method.

The New Programme for the Assessment of Child restraint Systems research project, known as NPACS, was initiated by TRL. The research programme has been undertaken by a European consortium and funded by national governments of the United Kingdom, Germany, The Netherlands and Catalunya, Motoring clubs (ADAC, ÖAMTC), the insurance industry (GdV), consumer groups, the FIA Foundation and the European Commission.

The NPACS project was conceived to be completed in two distinct phases. This document reports on the first phase, which had as its aim the establishment of appropriate, scientifically based, objective test and assessment methods, with complementary rating schemes. The second phase vision is the implementation of the agreed test protocols and rating scheme and dissemination of consumer information. The two phases are seen as separate and participants in the first phase may not necessarily participate in the second phase.

NPACS has been administered via two committees; the Foundation Committee (FC), formed from organisations or groups of organisations who have funded the programme and provided governance, and a Technical Working Group (TWG), who have been responsible for planning and undertaking the research programme. The TWG have been responsible to the FC.

While this research has been directed at the development of assessment techniques to provide consumers with reliable rating of child restraints, where appropriate the research results have fed into EEVC WG18 (www.eevc.org) on child restraints and the EC CHILD (www.childincarsafety.org) project.

1.1 Aim and Objectives

The aim of NPACS was to develop scientifically based, objective and harmonised test procedures and rating scheme suitable for use in a consumer information scheme. The NPACS test procedures and rating schemes would assess the dynamic safety and usability rating of Universal child restraint systems in cars. The NPACS assessment protocols cover three areas: Usability, Dynamic Performance (front and side impact), and Rating. A website was to be created to provide a means of communication for the project in the first phase and possibly a source of the test results database for NPACS in phase 2.

1.2 Technical Approach

1.2.1 Usability (A Tasks)

This topic began with the collation and review of all known current methods for the assessment of usability and misuse of child restraints. Comparisons of the various usability methods were drawn up, differences listed and the relative advantages and disadvantages of each method identified.

The results of existing Field studies and trials were analysed to explore misuse and usability aspects for modern designs of child restraint, and accident data bases were reviewed for evidence of misuse in accidents.

The misuse modes observed in these studies were evaluated for their relative significance through dynamic testing.

Using the results of these studies, testing methods were developed that would assess the use of CRS with dummies in cars. Dummies were assessed for their suitability in the assessment of usability across a range of vehicles. Car models were chosen based on the experience of the motor clubs and others regarding usability, fit and misuse.

A usability assessment method was developed and evaluated for effectiveness, repeatability and reproducibility.

1.2.2 Durability (B Tasks)

UN-ECE Regulation 44 includes tests for safety-critical durability issues. However, some durability aspects may only be cosmetic in nature. Nevertheless, if such durability problems result in the non-use of a CRS, it could lead to a safety concern. It was decided that an assessment method would be developed only if the need for an evaluation of this type was demonstrated during the first part of the project.

Initially, the existing regulations and anticipated future developments were reviewed to identify any perceived outstanding and potentially important durability issues.

In parallel, accident data and the misuse surveys undertaken under (1.2.1 Usability A Tasks) were reviewed for any evidence of durability problems.

Outstanding issues and durability problems, seen in accident data or user surveys, were assessed for their significance through dynamic testing.

1.2.3 Dynamic Performance (C Tasks)

The dynamic assessment of child restraints is not a straight forward task as there are many variables to consider. In order to have a successful, cost effective programme the number of tests per child restraint were kept to a minimum. All known methods for the assessment of the dynamic performance of child restraints were collected and reviewed. Comparisons were drawn up, differences listed and the relative advantages and disadvantages of each method identified.

In parallel, existing accident studies and databases were analysed to identify the important characteristics of accidents that should be incorporated into the assessment methods. The analysis ascertained the crash pulse, speed, principal direction of force in accidents on the roads where the majority of children were being injured and established aspects concerning seriously injured and fatally injured restrained children. This analysis was used as a basis for developing the test pulse. The frequencies and severities of front, angled front, side, rear and rollover accidents were examined and used to determine the numbers and types of dynamic tests to be included in the assessment. It was anticipated that at least front impact and side impact would be included in the test method.

In current test procedures seat configurations vary internationally. It was necessary to determine whether the NPACS assessment should use a single standardised test bench or a number of benches. Universally approved child restraints are designed to pass a dynamic test on a Regulation test bench. This may mean that they are optimised for this particular seat and that their performance may improve or deteriorate when used on a vehicle seat, where the dynamic seat stiffness, cushion thickness and seat understructure may be different. It was necessary to design a test bench that represented the extremes in vehicle seat design, whilst keeping the number of dynamic tests to a minimum. To this end the seat geometry and stiffness and the seat belt geometry and configuration in a range of modern cars were measured. A selection of cars was made (by the motor clubs and consumer groups) to provide a wide range of current vehicles including any with known problems.

1.2.3.1 Front Impact

A test bench was developed to cover the range of variables observed based on the measurements found in Section 1.2.3. The Regulation 44 assessment is a pure longitudinal test with fixed anchorage positions. It was possible that testing at an angle may be more discriminating and that vehicle pitch may be important. Therefore tests were performed using the developed bench and bodyshells to explore the influence of impact angle, seat belt anchorage position, and pitch, using input from the accident studies.

From these results, the test conditions and dummies for use in the assessment method were selected.

1.2.3.2 Side Impact

Full scale vehicle side impact tests were performed with dummies in child restraints on the struck side in both front and rear seating positions to provide baseline tests against which the sled tests were compared.

The candidate side impact test procedures (ISO, ADAC, Technische Universität Berlin (TUB) modified ISO, and TNO) were undertaken, using the same dummies and child restraints used in the baseline tests. These results were compared with the results in the equivalent baseline full scale tests and these comparisons used as a guide to the selection of the preferred side impact test procedure.

There was a further evaluation of potential child dummies for use in side impact testing.

1.2.3.3 Rear Impact

Originally, this task involved checking the necessity for rear impact testing and if appropriate, develop a rear impact test method. The need for these tests to be incorporated into the assessment method was dependent on the outcome of the accident review. This showed that no dynamic testing was needed for rear impact within the NPACS assessment.

1.2.4 Rating Scheme (D Tasks)

Initially, all known rating schemes for child restraints worldwide, including the Euro NCAP assessment scheme were reviewed. Comparisons were drawn up, differences listed and the relative advantages and disadvantages of each method identified.

The preferred elements of schemes were identified and were included in the finalised NPACS rating method.

1.2.5 Development of Protocols

Protocols for the assessment and test methods and also the rating schemes were produced.

1.2.6 Internet Website and Database (E Task)

A database was created to help manage the large amount of data that would be generated within NPACS testing. In addition to storing and managing test information, the database was designed to provide (approved NPACS users) with access to information regarding specific CRS, and to enable assessors from different laboratories to input test results. The database would also include the rating scheme such that a CRS rating could be generated upon entering the test results for any child restraint systems. A website was also created which could contain the database for NPACS test results in Phase II. This could potentially allow access to the database from virtually any location. This could be one method of releasing information to journalists and the general public. In Phase I, this would be used as a resource for information and documents for NPACS members only.

2 Research Output

NPACS Phase I consisted of a large consortium of partners, each of whom contributed various outputs to the overall project. The European Commission and the United Kingdom Department for Transport were the largest contributors to the NPACS project funding 27% and 23% of the total cost of the project respectively. The UK Department for Transport also provided an extra contribution to NPACS for the development and completion of the NPACS rating and protocols. This extra contribution was completed under UK Department for Transport contract S0447/V8 (PPRO 4/012/015). As both the scope of project tasks and project outputs vary considerably, the main outputs have been included in this report as Annexes. [For those reading this document electronically, click on the Annexe of interest in order to access the output. A hyperlink will direct the reader to the relevant document(s).]

2.1 Usability and Misuse

Usability is considered to be an important aspect of the assessment of CRS for consumer information. It is known that the rate of misuse is high and that misuse can impair the effectiveness of a CRS. It is also known from experience that design can influence the ease of use and the likelihood of misuse.

As a basis for the development of the NPACS usability procedure, a review was undertaken of all current known usability and misuse assessment methods. The review can be seen in Annexe 1, which provides details of each known method, according to several different classes of observations and assessment. The various methods were reviewed and compared, identifying the differences between them. The review determined which areas of assessment should be considered in the NPACS usability procedure. These areas of assessment would later be used as a guide for the general 'headings' and 'sub-headings' for the different sections of the Usability protocol. These headings and sub-headings can also be seen in Annexe 1. In parallel, several studies of usability and of misuse were assessed to help identify the main issues. A series of dynamic tests on the influence of misuse were performed. The findings revealed that tests involving misuse modes generally loaded the child dummy more than the reference tests. This demonstrated that the misuse of a CRS is an important factor to consider and therefore, should be included as part of the NPACS assessment. In addition, an observation study of misuse was conducted. This indicated the common misuse modes found when using various types of child restraint systems. Accident studies were reviewed for evidence of obvious misuse and the influence of this misuse on accidents. These can be found in Annexe 2.

One target for the development of usability testing was to make the results as quantitative and tester-independent as possible. The implementation of NPACS is expected to involve several laboratories and test personnel. It was therefore deemed necessary to ensure that the usability assessment method was as objective (i.e. non-subjective) as possible. To this end, it was seen as desirable to use dummies rather than child subjects in the assessment. Dummies currently available or under development were reviewed for their suitability for use in this assessment. No existing set of dummies was found that was suitable for the handling assessment. Therefore a new family of dummies is currently being developed for future use in the NPACS evaluations. This can be seen in Annexe 3. There was no provision for the development of dummies within the NPACS research programme; therefore these are being developed outside the programme, with consultation of the NPACS Technical Working Group.

There was considerable experience within the NPACS Technical Working Group regarding fitment issues. This experience was used to select a broad range of vehicle models exhibiting the main fitment issues observed in recent years. These were used as a basis for the development of the assessment methods. Modern vehicles were selected in order to ensure that the NPACS research reflected the current situation regarding vehicle fleets. The range of vehicle models identified can be found in Annexe 4. This selection of vehicles is also linked to the selection of vehicles in the NPACS dynamic testing research programme (Section 2.3.1), where thirty modern vehicles were selected for the purpose of obtaining car measurements relevant to CRS safety performance.

The outputs from the aforementioned Usability tasks described in this Section thus far led to the development of the usability assessment method which can be seen in Annexe 5. The 'headings and sub-headings' described earlier in this section (which can be seen in Annexe 1), guided the structure of this procedure. The procedure addressed all aspects of a CRS' usability including:

- instructions both in the manual on the product
- assembly and set-up
- installation and removal of the CRS
- restraining and removal of the occupant

- ergonomics and comfort

for both conventionally restrained (3-point systems) and ISOFix restrained CRS. This procedure was then evaluated for repeatability and reproducibility by several organisations. TRL organised, hosted, and participated in a usability workshop in order to assess the repeatability and reproducibility of the assessment procedure. All assessors were familiar with child safety products and terminology. The assessment involved a number of different child restraint systems in three different vehicles (super-mini, small family car, and large MPV). Following an initial assessment to the procedure, the assessors made amendments to increase its repeatability and reproducibility. The revised procedure was then assessed a second time with assessors who were not involved in making the amendments. The second assessment confirmed an overall improvement in the procedure. The consumer groups and automobile clubs assessed the effectiveness of the usability procedure. They also assessed the issues surrounding the test environment for the Usability procedure. This involved the comparing of the advantages and disadvantages of using a test rig versus real vehicles for the usability assessment. The conclusion drawn was to use real vehicles in the interim. A test environment such as a test bench could still be desirable; however, it would require further research in order to consider the requirements needed to design an adequate test environment. These assessments can be found in Annexe 6. Finally, a comparison of the Usability procedure to field results was conducted. This compared the results of past misuse observation studies to the proposed NPACS Usability procedure for validation purposes (as can be observed in Annexe 7). The validation procedure examined if common misuse modes could be found in the NPACS Usability procedure. It was concluded that the NPACS Usability procedure was able to address and assess the majority of common misuse modes (approximately 85% of the modes found in the field studies). The remaining 15% were misuse modes that could not be considered in the procedure itself (e.g. routing the adult shoulder belt underneath the arm). The validation process concluded that the Usability procedure was suitable for use. The complete Usability protocol which was derived from these outputs is discussed in Section 2.3.5.

2.2 Durability

A review of durability was undertaken, based on accident analyses, field studies, some mechanical testing and also a study of modern CRS designs. The accident and survey data did not reveal any useful information regarding durability issues. However, several durability issues arose from the mechanical testing of CRS mechanical components. This can be seen in Annexe 8.

However, on consideration, most of these were deemed to be more appropriate to regulations than consumer testing. For instance, some CRS designs incorporate a base unit which remains attached to the car, while the CRS body is attached and detached from this base unit either so that the CRS can be used to carry the child or so that it could be reversed in direction. The attachment between base and CRS body is likened to the buckle and could be tested for durability in the same way within the regulation. These issues have been passed to the EEVC for their information.

The outstanding issue of durability is the lifetime expected for the CRS. Some research was undertaken on this aspect and it was considered that the lifetime was related to aging of the plastic shell and components. However, it was agreed that the method for assessing this required further research and could not be considered for the first stage of testing within NPACS. Therefore, NPACS is not proposing any durability assessment at this stage.

2.3 Dynamic Performance

As a basis for the development of the NPACS dynamic test procedures, a review was undertaken of all current known dynamic test methods. Existing test procedures, used for either regulatory or consumer testing, were reviewed as part of the initial study for this topic. Comparisons were made and examples of advantages and disadvantages of each were cited. The comparisons were grouped into front impact, side impact, and rear impact categories (if applicable). This comparison of dynamic test procedures can be seen in Annexe 9. In parallel, analyses of accident databases formed an important input into the development of suitable test procedures. National databases from the United Kingdom and Germany were queried to understand the circumstances surrounding how children are injured in cars and the injury mechanisms involved. Specifically, the accident studies queried were:

- On The Spot (OTS) – United Kingdom
- Co-operative Crash Injury Study (CCIS) – United Kingdom
- Great Britain National Road Accident database (STATS19) – United Kingdom
- Child Safety 90 (CS90) – Germany
- Traunstein 96/97 (TS97) – Germany

Characteristics of accidents involving children were studied to provide information on the occurrence of different injury severities on various road types. This helped to determine the cumulative speed distribution for different injury severity levels for restrained child occupants. Such aspects as impact direction, impact velocity change, injury causation and other factors including those relating to car-CRS interaction, were analysed and contributed to the development of the test conditions. A report was produced on this analysis and can be found in Annexe 10. The accident characteristics provided evidence to assist in the development of the NPACS dynamic test procedures. It was important to ensure that the test procedures provide protection for the majority of children and in addition to this, provide added protection to decrease the number of children killed or seriously injured. From this analyses it was determined that child restraint systems will need to be evaluated under frontal and side impact conditions.

The experience of the NPACS Technical Working Group on the interaction between child restraints and different cars was used to select a range of thirty to fifty vehicle models, which illustrated some of the interaction problems and also the range of seat and seatbelt configurations and seat stiffness with which the child restraint systems could interact. This list of vehicles can be observed in Annexe 11. From this range of vehicles, thirty modern vehicles were selected based on sales, child safety performance in Euro NCAP testing and known CRS interface problems. The seat and seat belt geometry were measured, as well as the dynamic stiffness of the front and rear seat cushions for the 30 vehicles selected. The measurements included seat squab and backrest angles, cushion dimensions, anchorage point locations, and ISOFix anchorage locations (if applicable). Vehicles of all sizes and classes were measured. These measurements were considered to be representative of the modern fleet of vehicles found on European roads today. The dimensional and stiffness data on vehicle seats from the range of modern vehicle models can be found in Annexe 12. The vehicle seat measurement data was then used to design and develop a test bench that was representative of modern vehicles in order to conduct dynamic assessments of 'universal' child restraint systems. The wide range of data that was obtained from these measurements guided the design of a fully adjustable test bench. Annexe 13 contains the engineering drawings for the test bench. This fully adjustable test bench was designed to have the capability to represent different extremes in seating environments to which a CRS may be exposed. The test bench parameters that could be varied include conventional 3-point belt anchorage locations (upper anchorage and both lower anchorages), ISOFix anchorage locations, seat squab and seat backrest angles, cushion thickness, cushion stiffness, and impact angle. This fully adjustable test bench was then used in the NPACS front impact research test programme described in Section 2.3.1, where the sensitivity of CRS to variance of in-vehicle conditions was assessed.

2.3.1 Frontal Impact

NPACS proposes to assess CRS for universal or semi universal use; i.e. CRS that can be used in a wide range of cars. The internal dimension, seat characteristics and seat belt or ISOFix anchorages will vary in this range of cars. As mentioned, these factors were measured in a sample of thirty representative modern cars. Currently, the European Regulation (ECE Regulation 44) tests CRS in pure frontal and rear impact conditions.

Based on the previously described tasks within NPACS such as the accident studies and measurement studies, a comprehensive frontal impact test programme was designed to assess the sensitivity of child restraint systems to various conditions. Several test bench parameters were selected as being important for consideration. The influence of seat stiffness, seat thickness, seat backrest angle, seat squab angle, anchorage locations and also angled impact were studied in a large series of sled tests, using the range of conditions measured in the thirty cars. The tests simulated both ends or 'extremes' in CRS environment, as well as the mid measurement value, for all of the test bench parameters. Ideally, CRSs that will be used in several different cars should be insensitive to the different car seat characteristics and anchorage locations and should also work well if the impact is not purely frontal. However, assessing the performance under all conditions could involve a large number of tests. Different conditions would include testing the CRS with dummies at the upper and lower mass range for the Group classification, and in reclining and upright positions if applicable. The test matrix of the frontal impact research test programme can be seen in Annexe 14.

The research programme did not indicate a large change in performance over the whole range of conditions used. Therefore the proposal is to test using the mid range of the characteristics measured in the sample of thirty modern cars but with a minimum of additional tests to assess CRS sensitivity to angle and upper seat belt anchorage location, where these are considered to be significant. Thus for forward facing CRSs held by the adult seat belt, an additional test will be performed with the largest dummy and with an upper anchorage at the 95th percentile forward position measured on the car sample and a second additional test with mid position anchorages but at 30° to pure frontal, angled to align the force towards the upper anchorage of the adult belt so that the maximum restraint force is generated. For rearward facing CRSs attached by the seat belt, the sensitivity to the fore-aft position of the upper anchorage location is far less so the two extra tests use the mid anchorage location and an impact of +30° and -30° to pure frontal to assess potential extra excursion and also extra asymmetric loading. ISOFix-attached CRS are not asymmetrically attached and they are clearly unaffected by adult belt upper anchorage location, so these have only one extra test at 30°. The full test matrix proposal is shown in the Front Impact Test Protocol.

If all accidents where a child was injured are taken into account then a test speed of 45 – 50km/h would be representative. If accidents where children are being seriously injured or killed are taken into account then a change in velocity of 65 km/h would be representative. It is important for child restraint systems to absorb the energy of the crash in both of these conditions. The NPACS Technical Working Group felt that CRSs should not be optimised to perform at only one of these conditions. However, in order to minimise the number of tests, and providing CRSs are assessed for approval by ECE Regulation 44 at a test speed of 50 km/h, NPACS need only assess CRSs at the more severe condition. This decision was made with the understanding that if the severity of the regulation changes then NPACS will need to adjust its test conditions accordingly. This impact can be performed both with deceleration sleds and acceleration sleds.

However, to ensure comparable results, the pulse and total velocity change must be defined. A test pulse corridor has been proposed for this velocity change of 65km/h, based on typical Euro NCAP car accelerations for recent designs and also with reference to the accident reconstruction pulse used in the EC CREST programme. This can be observed in Annexe 14.

To aid the processing of the large amount of test data generated in the frontal impact research programme, TRL developed graphing software to shorten the time required to process and plot the data. The graphing software was able eliminate several days of tedious work by organising, plotting and comparing numerous channels of data from various different tests in a very short period of time. The graphing software enabled the comparison of any/all results relating to a specific measurement or 'channel'. For example, the software allowed for plotting and comparison of the resultant head acceleration time history for whichever tests were of interest. This could be achieved for any type of data recorded during the tests. This can be found in Annexe 15.

When two cars meet in a frontal impact, they tend to pitch because the centre of gravity is higher than the location of the centre of force between the cars. This pitch creates a vertical component of acceleration on the CRS in the car. Tests within the NPACS programme demonstrated that this can have a noticeable effect on the dummy responses. However, it was determined that the characteristics of the required pitch motion and the test equipment to generate this are insufficiently understood at this stage to propose this for the NPACS procedure. The initial research conducted in this area can be found in Annexe 16. Due to the marked influence noted in these tests, it was recommended that this be reconsidered in the future.

After reviewing all of the available crash test dummies such as the P Series dummies, Q Series dummies and Hybrid III Series dummies, the most recent version of the Q dummies, also known as the 'New Q' dummies, were selected for use in the NPACS frontal test programme. These child dummies were selected based on the following criteria: taking into account their availability in the masses required, their performances (regarding repeatability, reproducibility, and durability) and their measuring capabilities. A report on the Q series dummy was produced and can be referenced in Annexe 17. At the time of completion of NPACS Phase I, the Q Dummy family consisted of a Q0, Q1, Q1.5, Q3, and Q6. It has been proposed that each of these dummies will be utilised in NPACS consumer testing. The Q10 dummy will not be available for the first stages of NPACS assessment. Therefore it is proposed that the P10 is used until the Q10 becomes available. The accident analyses showed that the priorities for performance assessment should be based on measurements to the head, neck, chest and abdomen. It would be desirable to measure the responses of the dummy by internal instrumentation. However, for abdominal penetration, the instrumentation is insufficiently advanced to be able to do this and, in the interim, it is proposed that this important measure should be assessed photographically. The proposal is to cap the maximum score in the Frontal test if abdominal penetration is clear (scoring and rating will be discussed further in Section 2.3.4). This assessment should be scrutinised in the first test programme. In addition the structural integrity of the CRS after impact would be examined in frontal impacts.

2.3.2 Side Impact

The accident analyses conducted within NPACS and also by EEVC WG18 show that side impacts are the second highest cause of fatal and serious injuries to restrained child car occupants. Consequently, the performance in side impact is considered to be an important factor in the consumer rating of child restraints, particularly as there is no current side impact dynamic test in the European Regulation. A side impact test is included in at least one of the current European consumer testing schemes and also ISO had been developing a side impact dynamic test.

For the NPACS side impact research test programme, the existing consumer test method, the ISO draft side impact procedure ISO/DIS 14646 N_642, and two variants from the ISO draft procedure were compared to full scale side impact tests with three vehicle models (super-mini, small family car, and large family car) and six CRS models. These six CRS models included both forward facing and rearward facing CRS.

The baseline full scale tests were based on the test procedure used in ECE Regulation 95 and Euro NCAP. In these tests, a mobile deformable barrier (MDB) impacts a stationary target car with the centre of the MDB aimed at the R-point of the front seat of the target car. The car deforms such that the greatest deformation is in the region of the R-point and B-pillar. As the most serious consequence of this intrusion is impact to the region of the head of the child, rather than the feet, forward facing CRSs were placed in the front seat and rearward facing CRSs placed in the rear seat on the vehicle's struck side. This worst-case seating position was confirmed by conducting tests comparing the responses where the intrusion impacted the feet (i.e. forward facing CRS in the rear seat and rearward facing CRS in the front seat) with those where the intrusion impacted the head.

Comparisons were made between the baseline full scale car tests and the candidate sled test procedures. The analyses included a comparison of the child dummy loadings, head containment, sled and vehicle pulses, and time histories. In addition to using the side impact test data recorded in this programme, the following criteria were considered in the selection of the side impact test procedure; i) the recommendation should be from existing procedures, ii) the procedure must be available for use immediately, iii) the ideal for one side impact test procedure to be used for both forward facing and rearward facing child restraint systems, and iv) the results should compare with real world accidentology. In addition, input from the EC CHILD revealed there was a link between intrusion and real world injuries. This led to the selection of a 'hinged intrusion panel procedure'. Based on these criteria, comparisons between the baseline full scale car tests and the various candidate sled tests resulted in the selection of the TUB (Technische Universität Berlin) side impact test method, which was loosely based on the ISO draft side impact procedure. Annexe 18 contains the side impact research programme test matrix, summary of test results, and NPACS Technical Working Group recommendations.

As part of the dummy selection process for side impact testing, TRL assessed the repeatability and reproducibility of several different child dummies. This included the comparison of the P3, 'Old' Q3, 'New' Q3, Hybrid III 3 Year Old, and the Q3s dummy. All dummies were subjected to a series of identical side impact sled tests based on the ISO draft side impact procedure for forward facing child restraint systems. The test results can be found in Annexe 19. It should be noted that during the NPACS time period allotted for this task, the Q3s was not available and therefore not included in their original comparison of child dummies for side impact. The comparison was based on the results of the P3, 'Old' Q3, 'New' Q3, and Hybrid III 3 Year Old only. Based on the research of these four dummies, TRL recommended the 'Old' Q3 as being the most suitable dummy for side impact testing.

Ultimately, as in the frontal impact test programme, after reviewing all of the available crash test dummies such as the P Series dummies, Q Series dummies and Hybrid III Series dummies, the most recent version of the Q dummies, also known as the 'New Q' dummies, were selected for use in the NPACS side impact test programme. These child dummies were selected based on the same criteria as in frontal impact: taking into account their availability in the masses required, their performances (regarding repeatability, reproducibility, and durability) and their measuring capabilities. The report on the Q series dummy can be referenced in Annexe 20. At the time of completion of NPACS Phase I, the Q Dummy family consisted of a Q0, Q1, Q1.5, Q3, and Q6. It has been proposed that each of these dummies will be utilised in NPACS consumer testing. The Q10 will not be available in the first stages of NPACS assessment. However, the side impact performance of the P10 is such that NPACS does not recommend its use in the interim. However, head containment is regarded as being so important in side impact, including that for the older age group, that NPACS does recommend the use of the P10 in testing in 2007 if the Q10 is still not available at that time.

The accident analyses showed that the most important body areas to be assessed were the head, neck and chest. It was felt to be very important to assess the ability if the CRS to 'contain' the head in side impacts and that this would be assessed photographically.

2.3.3 Rear Impact

Sled testing of child restraint systems under rear impact conditions were undertaken both purely rear impact and also at 30° to pure rear impact. These tests showed that there could be undesirable affects of pitch rotation of rearward facing CRSs in rear impacts and, in the angled tests, a risk of head contact to the B-pillar. This would be more serious for the larger child, as the child's head would be more exposed.

A review of the accident studies showed that rear impact accidents were a low priority for fatal and serious injuries to restrained children. Taking this into account, the NPACS Technical Working Group recommended that no rear impact test should be included in the NPACS assessment at this stage. It was suggested that this should be reconsidered in the future. Annexe 21 contains a report that summaries the research that assessed whether there was a necessity for rear impact testing in NPACS. This includes a review of accident data, current test procedures, and comparisons of rear impact crash pulses.

2.3.4 Rating Scheme

All current known rating procedures were reviewed. The various methods were compared to identify the differences between them. The final output can be seen in Annexe 22, which provides details of each known regulatory and consumer test rating procedure, according to several different classes of observations and assessment. The various methods were reviewed and compared, identifying the differences between them. The review helped to determine which areas of assessment should be considered in the NPACS usability procedure.

The next proposed task was to apply potential candidate rating methods to existing test results. From the review of rating procedures conducted in the previous task, it became clear that NPACS had clear understanding of the following rating methods; Euro NCAP, Auto motor und sport (AMS), and the procedure used by the European automobile clubs and consumer organisations (ICRT). The comparison of these rating procedures can be viewed in Annexe 23. This comparison showed that the European automobile club and ICRT ratings method provided the most desirable rating results for applying to universal child restraint systems. The experience of the automobile clubs and consumer groups in developing rating for test procedures was then incorporated into the development of NPACS ratings procedures.

The assessments made in the usability evaluation and the readings and observations in the front and side dynamic tests are converted into a rating for each of these components and then an overall rating for the product generated by a combination of the individual component ratings. The scores possible for each of the subcomponents in the individual assessments reflect the relative importance given to these subcomponents by the NPACS Technical Working Group, based on accident analyses, user and misuse surveys and on past experience.

NPACS proposed that the performance of the CRS should be grouped into five bands, both for the individual components and for the overall rating. For the dynamic tests and for the overall rating, the relationship between the responses and the points scored is not linear. The step from the lowest band to the next is greater than the step to the highest band from the one below. This reflects the increasing difficulty in achieving better responses as the product improves to the higher levels.

The overall rating is generated by addition of the weighted scores in the three component assessments. The weighting proposed, on consultation with the NPACS Foundation Committee, is 50 percent for Usability, 25 percent for Frontal Impact and 25 percent for Side Impact. This emphasis on usability reflects the majority view of the NPACS Foundation Committee that it is very important to encourage high usage rates for CRS and to reduce the rate of misuse seen in observation surveys and a high usability rating should help to achieve this. The rating scores and levels proposed allow a good differentiation between existing products to be demonstrated while allowing headroom for improvements anticipated being possible with current technology. NPACS proposed that the rating results be grouped into five bands and the results should be consistent between all participating parties regardless of the way the results are presented. The rating bands have been set to encourage new innovative solutions to increase the overall level of child safety in vehicles to be brought to the market now and to be incorporated into future designs. This has been achieved in such a way that it is envisaged that there will be very few four star, and no 5 star child restraint systems in the first assessment.

There are some measures that NPACS considers to be so important that a lowest level response in those subcomponents will cap the overall score for the product irrespective of the performance in other subcomponents and components. There are only two measures that NPACS currently proposes will have this effect: in the side impact test, a failure to provide any head containment will lead to total score capping to the lowest band and in the frontal impact test, the total structural failure of the product will have this effect. NPACS would have liked to include abdominal loading in this group, but the current methods for assessing abdominal loading are not considered reliable enough to apply capping in this case. The low weighting given to abdominal loading reflects the low confidence in the photographic assessment method for abdominal loading. However, this item is of such importance that the assessment is included albeit with a low weighting applied to the response. It is recommended that this be reviewed regularly. The resulting rating system should present the results to the consumer in a simple but meaningful way. The NPACS Rating Procedure can be found in Annexe 24.

2.3.5 Development of Protocols

The front impact, side impact, usability and rating protocols were developed based on research conducted in the NPACS research programme. In order to ensure that the protocols were completed and available on schedule, the United Kingdom Department for Transport, along with TRL, led the consortium in the development of the final NPACS protocols. Note: This was completed under United Kingdom Department for Transport contract: S0447/V8 (PPRO 4/012/015).

Annexe 25 contains the NPACS Front Impact Protocol, NPACS Side Impact Protocol, NPACS Usability Protocol, and NPACS Rating Protocol. The protocols culminate the NPACS Phase 1 research programme.

2.3.6 Internet Website and Database

A website has been registered for NPACS (http://www.npacs.com) and this provides a public page which currently describes NPACS and its functions. The intention is that this could provide one of the forms for publication of NPACS ratings.

There will also be a second and confidential section that will contain the database of all test results and a sophisticated program has been developed which will assist the testing laboratory and also generate the ratings. Once a CRS model and its Group and type have been entered, the laboratory is presented with the usability questions and dynamic tests that are appropriate for that CRS. The results can be entered and the rating generated.

The confidential side can assist with communication between members and has been used to good effect for this purpose both by the NPACS Foundation Committee and the NPACS Technical Working Group during Phase I.

At the time this report was written, access to the database and the database itself were not available from the NPACS consortium partner responsible for its production and release. When it becomes available, it can be found in Annexe 26 along with a description of the database and website.

3 Conclusions

A research programme has been undertaken which has resulted in a successful proposal for the assessment and rating of child restraints for consumer information. A complete set of test protocols have been developed. The assessment includes aspects of usability and the performance in frontal and side impacts. A rating scheme has been proposed which will convert the results of the separate assessments into a performance rating in five levels. A website has been created and a programme for the collection of and storage of test data and the calculation of the rating has been developed. At this stage, the NPACS Foundation Committee members will have to decide how to proceed to the next stage, where routine testing and publication will take place.

3.1 Summary

A child restraint is an unusual safety item; one that is often moved from one car to another and expected to fit and to provide a high level of protection in crashes. While there are child restraint systems that are designed and optimised for use in one car model, the normal practice is expected to remain as it is today where a ‘universal’ child restraint follows the child into different cars. Child restraints and cars have both changed considerably in the last ten years. Consequently it is highly desirable for the consumer to have a reliable rating system for ‘universal’ child restraints, incorporating an evaluation of the usability, misuse likelihood and crash performance of the available child restraints. It is also helpful to the consumer for there to be a single rating system used and publicised within a single market area. The NPACS research programme has been designed to provide the information needed to develop a modern rating scheme, based on the most recent data. It has resulted in a proposal for a rating scheme, complete with a set of test and assessment protocols and a methodology for presenting the results on the internet. Looking to the future, NPACS has been designed to encourage new innovative solutions from child seat manufacturers to increase the overall level of child safety in vehicles.

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