Final Report Summary - CASPER (Child advanced safety project for European roads)

The CASPER project aims to improve the global protection of children in cars, using as a basis all the research results obtained both in previous European projects financed by the European Commission (EC, such as CREST and CHILD), and also the knowledge acquired through the collaboration with other European organisations such as EEVC WG 18, ISO/TC22/SC12/WG1 and NPACS. The activities have been mainly supported by research addressing many fields such as in depth road accidents data collection and analysis, the influence of the impact of societal behaviour of adults in transport situations and technological based solutions to improve the safety of children.

CASPER addresses two main aspects:
- the analysis of the reasons and consequences of misuse of cars and restraint systems (CRS) and of the influence of the conditions of transportation of children, as compared to the certification test procedures;
- the improvement of the efficiency of child protection through the development of innovative tools in order to provide to CRS manufacturers the possibility to develop and test their products at a lower cost, with new methods, and at a same guarantee of efficiency.

The first point has been treated in reports on the conditions of use of CRS and related consequences in accidents. They include messages to be forwarded through campaigns of information. Positive effects on the protection of children derived from these reports could be seen in a short time. This would solve a large part of the issue of children involved in traffic accidents. The improvement of the behaviour of dummies, associated to new sensors, as well as dummies and child human numerical models are necessary to propose improved test procedures, based on road reality issues. The effect on the protection of children is therefore at longer stage but complementary to the improvement of rate of correct use of children.

The project is mobilising a large part of the European scientific and business expertise in the field of passive safety related to children: 7 European countries are involved, with 15 partners. The proposed consortium of CASPER does not involve any CRS manufacturer. The preferred solution was to disseminate results in existing working groups in which a large number of CRS suppliers are involved, to organise regular workshops and to disseminate results in international conferences.

The work plan of the CASPER project is made to use as much as possible existing data related to injuries of children and to collect the missing ones, which can help to find reliable solutions for an improved protection of children in road accidents. Dummy modifications and modelling, creation of tools of new generation such as human models, analyse the possible solutions both on the side of vehicles and CRS.

Work has been organised around five technical work packages (WPs):

- WP1 has been considering the protection of children based on the use of crash test dummies;
- WP2 has defined, developed and validated children human body segments corresponding to children of five different sizes (ages);
- WP3 aimed to understand the travelling conditions of children in cars and the main issues in terms of lack of protection in accidents;
- WP4 has evaluated possible solutions based on the real travelling conditions of children, the previous information and enforcement campaigns;
- WP5 has been organising the dissemination and the exploitation of the project results as well as for networking with other organisations involved in the field of child protection in road transport.

Project results:

Initial investigations

Prior to any new development or improvement of the tools used for the evaluation of the performance of CRS, it was necessary to define the state of the art based on the knowledge from previous EC projects and to determine what were the priorities in terms of protection for children of different ages.
The objective of this action was to identify the various child injury mechanisms in frontal and lateral collisions and to determine the associated physical parameters, in order to provide injury risk curves or at least to recommend limits. Priorities are given in terms of injury mechanisms necessary to be reproduced in accident reconstructions and simulations both by child dummies, child dummy models and child human models. They are given for each dummy corresponding age and for the following body regions: head, neck, thorax and abdomen. As result of this analysis, a focus has been defined in the CASPER project on limits to be found on the head-neck segments for youngest children and on the abdomen and thorax for older children (3 and 6 years). Consequently, injury criteria are needed on these areas and corresponding injury mechanisms are integrated in the specification of child models.

WP1: Tools for dummy approach

It was found necessary to identify the shortcomings of the dummies: One of them was about the lack of instrumentation of the Q series dummies in the abdominal region. It was necessary to have an indicator of the penetration of the seatbelt or of one part of the CRS into the abdomen. Based on the experience of the CHILD project, and literature reviews, two systems were candidates and directly usable on the Q dummies for research purposes and one was existing as a prototype for the Hybrid III - 6 year dummy. The selection of the abdominal sensor systems to be proposed by CASPER was mainly based on the potential to be used on a regulatory basis. That means that sufficient robustness and the delivery of an adequate injury risk curve was required. Q Dummy updates (including instrumentation) as proposed in CASPER will be discussed in GRSP Informal Group on Child Restraint Systems final decision-making and implementation.

- Abdomen sensor system for Q dummies developed and evaluated for industrial application

The objective was to progress on the development of an abdominal sensor system that could be used to assess the risk of abdominal injury for the Q dummies. On the three available solutions, one was selected by the project partners based on availability, forecasted acceptability and cost, and likelihood to be able to solve the identified shortcomings of these systems. The abdominal pressure twin sensors, originally developed and prototyped within the CHILD project were selected and further development work towards an industrialisation of the sensor was conducted. The new work includes the characterisation of the APTS in multiple loading scenarios, and the development of possible solutions to solve a number of shortcomings that were identified.

- Evaluation of the lumbar spine stiffness

The stiffness of the lumbar spine is one of the parameters influencing the rotation of the pelvis under the lap strap and its subsequent penetration into the abdominal cavity. Physicians and physiotherapists think that the lumbar stiffness is too high. Tests were performed on the Q3 dummy to evaluate its lumbar spine stiffness in flexion. The stiffness was found to be similar to the stiffness of the HIII 3 Y.O. dummy. In the absence of better biomechanical reference, it was decided to take no further action on this issue and focus on the gap at the groin.
Auxiliary equipment for Q3 and Q6 to improve belt interaction response

Several proposals were made to reduce the risk for the belt to lock itself into the gap at the groin. Two proposals were selected for the current task: creation of a soft abdominal insert to fill the gap made of silicon and reinforcement of the dummy suit realised with additional patches to be positioned as a prototype solution.

LS-DYNA dummy models

In order to complete the Q-dummy finite element (FE) model family Q, Q1.5 and Q6 dummy models were generated on the basis of the Q series physical dummies using information from the existing Q3 dummy model. Component level and full dummy level's validations were performed to evaluate the FE model performance. The test conditions assumed are standard dummy certification tests. Compared with these physical test data generated, the model responses are satisfactory. For future model updates it is suggested to validate the performance in conditions that are closer to real crash configurations.

i. Q1 and Q1.5
The Q1 and Q1.5 models were created on the basis of the physical Q1 Dummy Rev B Dec 2008 and the physical Q1.5 dummy Rev B July 2009. The Q1 model was developed first and the Q1.5 was obtained by scaling and local remeshing from Q1. For both sizes a Beta V1.0 release model has been prepared. The model has been used by project partners in virtual testing procedures. More validation works are needed to improve the performance of the models and bring them to a tool usable by the industry.

ii. Q6 dummy model
The Q6 model was created on the basis of the physical Q6 Dummy Rev A, December 2008. All the requirements were considered when developing the models as far as possible. On the simplified loading conditions it has to be remarked that no test data were available for the Q dummies. As CASPER did not have the budgets for generating such data this recommendation could not be fulfilled and validation is done only on the certification tests. It should be noted that they do include full scale dummy tests, assuming impacts on the thorax. A Beta V1.0 release model has been prepared. The model has been used for the determination of accident reconstruction scenarios prior to perform a physical test with dummy. It has also been used in the validation of side impact test procedure in combination with models of generic CRS and using the virtual test environment developed in CASPER.

iii. Q10 (reported in second periodic report)
At the end of the CASPER project, Q10 prototypes were recently delivered by the EU EPOCh project and the first Q10 CAD data were made available. During the second month extension of the project, works was initiated in CASPER aim to complete the Q dummy family. The development of the model of the Q10 mesh and assembly was started.

Accident reconstruction database

Software: For appropriate injury criteria and corresponding load limits biomechanical knowledge is
crucial. As biomechanical tests (e.g. cadaver tests and volunteer tests) with children are extremely rare, the International Task Force Child Restraint Systems started in the early nineties to reconstruct well documented accidents involving children as car occupants in order to compare dummy readings with the actual injury severity levels sustained in the corresponding accident. This programme was continued in the EU-funded projects CREST and CHILD and then in the CASPER project. In order to make best use of the data gathered in the reconstruction programmes a suitable database is needed.

The accident reconstruction database was developed with the following requirements:

- use of a central web-based database;
- different users with different user rights;
- cases can be full-scale tests, sled tests, component tests and / or simulations;
- meta data are stored in the database directly, large datasets (channel data, photos, movies etc.) are linked from external data storage;
- user interface of the database is in English;
- data format for importing data is ISO 13499 (ISO MME);
- validation status of the data is included in the database;
- reports and other documents can be uploaded. To open them, the standard software of the computer will be used;
- the database content can be exported to client copies but re-import is not necessary. The central database is always the master version.

Initial tests with a simplified web based database showed that the majority of project partners would be unable to approach the database server due to internal IT security regulations of the individual partners. Therefore the database was developed as a desktop version. All the other requirements were met, this tool can be used for the storage of test data and offers the possibility to enter data from the accident, on vehicles and children seated at a position where a child dummy has been used in the reconstruction. There is not a link of this database with the CASPER accident database.

Content

Once the CASPER accident reconstruction database was developed, available data from previous accident reconstruction programmes was imported. Quality checks for the input data were performed and when necessary, corrections of the data took place.

Then, the new reconstructions performed in the CASPER project have been regularly uploaded. In total 36 full-scale reconstructions and 2 sled tests to repeat previous reconstructions with updated dummies were performed. Of these tests, 32 were judged to be valid with respect to overall accident reconstruction. 70 datasets of dummy readings are available for frontal impact, distributed across all dummy sizes, and 23 for lateral impact with very few cases for small dummies, as the focus was made on Q3 and Q6.

Based on accident reconstructions from the CREST, CHILD and CASPER projects, injury severity levels were paired with dummy reading results. For the head in frontal impact conditions, reliable numbers of data points are available to derive injury risk curve with a high confidence using the survival method. For
the neck in frontal impact conditions a trend for Q1 and Q1.5 dummies can be observed that scaled data from adult seems to describe the injury risk quite well. For the chest neither resultant acceleration nor the chest deflection seem to be injury risk predictive. For the chest compression this is likely caused by belt interaction problems of the Q dummies for 3-point belts and/or issues in the test with respect to the use of the chest compression sensor (e.g. wrong installation, wrong treatment of data). The further developed APTS abdominal sensor shows good prediction of injury risk although the number of cases is still low. For lateral impact only an injury risk curve for head a3ms was derived. For the other body regions the number of cases with injuries is too low.

It is important to state that the developed injury risk limits are based on comparing Q dummy readings with injury severity and are therefore only applicable for Q dummies. However, the advantage of this approach is that no scaling between human and dummy is necessary because the curves were already derived using the tools they should be applied to.

Chest measurements remain an issue: biomechanically, a chest deflection based metrics is considered to deliver correlation with injury risks but the reconstruction results to date do not allow collecting usable deflection data with confidence. Except for the head in frontal impact conditions the risk curves still suffer from a lack data points. That means that further research is necessary to improve the confidence. This is in particular true for lateral impact.

- Q dummy behaviour report

During the first phase of the project, works were carried out to identify the possible shortcomings of the Q dummies, a prioritisation was made and an estimation of the necessary work on the different items. The number ones were the gap at the groin and the lack of measurement on the abdominal segment (which are related though the possible submarining behaviour of the dummy). Related works have been already presented in the beginning of this chapter. The other ones are presented hereafter in an anatomical order from top (shoulder) to down (pelvis-thigh).

Shoulder: The lack of flesh in the shoulder area, the negative strap-engaging slope, the strap-catching hollow and the hollow armpit can cause the slippage of the thoracic strap. After the slippage, the dummy is restrained by the neck and the clavicle. Such behaviour would be likely to affect the overall kinematics and the neck loads. The high stiffness of the thoracic cage (discussed later) and its geometry may exacerbate this tendency for slippage.

Thorax: The thoracic cage is made of two polyurethane sheets rolled together. Several sources of information suggest that the ribcages of the current dummies are too stiff. However, the dummy manufacturer stated that the initial versions of the Q dummies suffered from severe, early time, bottoming out in sled tests. As a consequence the stiffness was adjusted.

WP2: Human body modelling

The development of finite element models (FEM) of children was one of the aims of the CASPER project. Such models can be used as complementary tools to dummies in order to simulate the response of a child
subjected to impact loading. One possible application for such models is the development of model based injury criteria and tolerance values by simulating the child response in accident configurations. It is similar in principle to the work performed using dummies and accident reconstructions in the CASPER project, and before that in the CHILD and CREST projects.

Within the CASPER project it was decided to focus on the models of the head-neck for youngest children (6 weeks, and 6 months, 1 year and 3 years) and on the abdomen and thorax for older children (3 and 6 years). Partners from different institutes were developing models of body segments that have to be merged to have complete human body models of different sizes. It was necessary to proceed step by step in order to ensure that all parts would be compatible, that the interface between parts would allow them to be meshed and that in the end different full body models would be able to be run. The first step was to define the size of the mathematical models for each body segment in terms of the anatomical structures.

Report on child geometry for modelling purposes

This information is essential for the development of human models both on external and internal geometry. This task aims to provide essential information related to children for external data but also for data on the geometry of bones and internal organs. Data were collected both from literature and by collecting missing data.

- External

The external geometry of 71 children have been measured (33 three year-olds and 38 six year-olds) in the framework of an anthropometric measurement survey. 29 anthropometric dimensions were taken for each leading to a total of more than 2800 measurements. These ages match the transition from using a restraint system type (integral seat) to another (booster). This work is based on a measurement survey which allowed acquiring anthropometric data in two approaches: classical (sitting and standing measurements) and in a car, with different restraint systems.

- Internal

The aim of this work was to provide the internal data of a 1 and 3 year old child (YOC). To develop a FE model of the 1 and 3 YOC it was necessary to have the complete geometry of a 1 and 3 YOC. The model geometry is based on whole body CT scans. From anonym medical images of two subjects, the 3D geometry of the skin, bones, and the main soft organs has been reconstructed and transmitted to other CASPER partners in order to develop the corresponding numerical model. A similar process was followed for the 6 YOC.

- Scaling techniques

A report on this subject has been written. It includes a bibliographic summary regarding scaling techniques for modelling purposes. Scaling is a common used principle to create / build new systems, which are similar to its origin by many factors, but not similar by the size or mechanical properties.
This work allowed to highlight in particular the following:

- 3-year old is the lowest possible age for scaling down an adult model, except for the head and neck for which it is 6 years) below that age the child's morphology differs too much from adult's body.
- Some mechanical properties of bones, muscles and tendon tissue for different ages are available in the literature. It will be assumed that other bio-tissues will not significantly change their mechanical properties with the age.
- The response curve scaling is an efficient method to validate scaled FEMs, when only the geometrical properties are known and as long as no experimental data is available in the literature.
- Significant attention has to be paid to the actuality of the geometrical data.
- Several scaled models for the 6 YOC, mostly based on the HUMOS and THUMS models were already performed, however the models and validation data are not public.

- Report on child mechanical parameters

The general objective of this report is to provide data on the mechanical properties of children and validation data contributing to the development of specific human segments and whole body models per age. An in-depth literature review has been performed and reported. Even if it is obvious that lots of data are missing, no experimental work on this item has been conducted in the CASPER project. Scaling methods have been used as far as possible to fill the lack of data. Starting points for a mechanical definition as well as sources of experimental data for validation of the segment model and human body models were listed.

- FEM child models

The objective was first to set child segment models based on the geometrical and mechanical properties for each child age under consideration. So partners have shared the work and body segments to be developed were head, neck, thorax, abdomen and lower legs. The coupling of the segment models has been organised as well by attributing to each institution a specific coupling issue. Finally the methodology for accident simulation has been set.

- 6 week old human model

For this child's age, it was proposed to limit the development of FEM to the meshing of the head neck system of the six week old child. Only one partner has been involved in the development of this body segments and in the meshing work. The model developed in this project includes the main anatomical features of a newborn head: the scalp, the cerebrospinal fluid (CSF) and the brain were modelled with brick elements. Coronal, sagittal, lambdoid and temporo-parietal sutures were modelled with shell elements as well as anterior, posterior and sphenoidal fontanels. Skull and membranes were modelled with shell elements.

- 6 month old human model

As for the 6 week old FEM, it was decided to focus on head and neck only for the development of a 6
A 1 year old child FEM. This work is also a single partner contribution, for the development and the meshing works. The new finite element head model simulates closely the main anatomical features: skull, sutures, fontanel, falx, tentorium, subarachnoid space, scalp, cerebrum, cerebellum and brainstem.

- 1 year old human model: head, neck, chest, abdomen, lower limbs, and complete meshed body

Body segments constituting this 1 year old child FEM have been developed separately by different partners and meshed after validation of the different parts. This 1 year old child FEM includes a detailed head-neck model and the whole skeleton and the ligaments and flesh attached to them of the other parts.

Head: Based on the report on relevant children injury in road accident and specification of children segment models as a function of age, it was decided to focus on skull fractures and head injuries. A deformable approach will be used and the following choices were made: Hexa elements and quads were used for all parts of the head. The new finite element head model simulates closely the main anatomical features: skull, falx, tentorium, subarachnoid space, scalp, cerebrum, cerebellum and brainstem. Globally, the 1 year old child head model developed for the current project consists of 21,707 elements. Due to the low number of reconstructed cases available for the 1 year old child, conclusions cannot be defined and results must be consolidated with the simulation of a larger number of accident.

Neck: Based on a scanner of a 1 year old child, this file was then imported and the surfaces of each of the cervical vertebrae were reconstructed, than the cervical vertebrae could be completely meshed. The cervical vertebrae were modelled using shell elements the intervertebral discs with brick elements and the ligaments with spring elements. The modelling option for vertebra is justified as shell elements offer the possibility to strictly respect the anatomical surface and to declare this part as a rigid body in order to respect the geometry of the articular surfaces and to correctly reproduce the inertias. The option to represent the intervertebral discs with bricks elements (5 layers) is justified by the need to reproduce the 3D shearing behaviour of this structure.

Chest, abdomen, limbs: The FE model of the 1 year old child upper and lower bodies was developed following the anatomical image as stated in the general description of this model. It includes a complete skeleton of the chest rib cage, the spine, and other bones such as humerus, ulna, radius, clavicle, pelvis, femurs, tibias, fibulas, foot bones. The main anatomical features of soft tissues and internal organs were represented with certain simplifications, especially for internal organs. The validity of the thorax model was evaluated by simulation of thorax frontal impact. Response of the thorax model is rather stiff, and there is needs for adjustments of soft tissue material properties.

Complete body: Meshing works have been conducted in order to obtain a complete body of 1YOC FEM. The developed model of the whole 1 year old child body is totalising 99,168 elements, and node number is 110,753. Mechanical properties have been implemented and complete body validations were initiated, to first check the robustness of the model. When possible, real world accident cases physically reconstructed were used as input for the model for further validation. This accident simulation task has been necessary to adjust parameters such as mechanical properties. After this phase of evaluation and adjustments, accidents cases (domestics and road) can be reconstructed with this model in the limit of virtual environment existing today for example to develop injury criteria.
- 3 year old human model: head, neck, chest, abdomen, lower limbs, and complete meshed body

Body segments constituting this 3 year old child FEM have been developed by different partners in the aim of merging them to obtain a complete body 3 year old child FEM after the validation of the different parts. The starting point of this model is the geometry coming from DICOM data of a 3,25 years old child with a height of 94cm and weight of 18kg. The complete model is composed about 170 000 elements.

Head: The new finite element head model simulates closely the main anatomical features: skull, falx, tentorium, subarachnoid space, scalp, cerebrum, cerebellum and brainstem.
Neck: The neck model integrates the first thoracic vertebra, the seven cervical vertebrae, intervertebral discs and the upper and lower ligament system.
Chest and abdomen: Development of a detailed thorax and the abdomen meshing including lungs, kidneys, spleen, heart, liver, abdominal area, combined muscle, inner soft tissue, ribcage and thoracic vertebrae.
Lower limbs: The lower limbs model includes, Femur, Tibia, Fibula, foot, pelvis, ligament system and flesh.

After the validation work, the model has been coupled to the head/neck and to the pelvis model. Simulation and validation work for the combined model were limited due to the late delivery of the body segments by the partners.

- 6 year old human model: head, neck, chest, abdomen, lower limbs, and complete meshed body

The objective was to develop a six years old child finite element model developed in this project in terms of meshing segment per segment. The boundaries of the model (near the neck and the lower extremity) were shared with the groups working on the neighbouring models. The same outer skin surface was used as a reference for the trunk and the lower extremities.

Head: The development of a six years old child has been done by scaling down existing adult FE head-neck model. The six years old child FE head model simulates closely the main anatomical features: skull, falx, tentorium, subarachnoid space, scalp, cerebrum, cerebellum and brainstem.

Due to the low number of accident cases available for the six years old child, injury criteria cannot be provided. More results are needed and proposals must be consolidate with more accident cases reconstructed. However concerning the HIC value same trend as for the six years old child can be observed for the six years old child. With the six years old child head-neck FEM 15 accident cases have been reconstructed, 3 domestic accidents and 12 road accidents. Concerning DAI injury mechanism (loss of consciousness) the best candidate parameter found is the brain von mises stress.

Neck: The neck model integrates the first thoracic vertebra, the seven cervical vertebrae, intervertebral discs and the upper and lower ligament system and has been established by scaling down the adult neck model developed previously.
Thorax and abdomen: A finite element model of the abdomen and thorax of the six years old child was developed for the current project.
Lower limbs: A finite element model of the lower limbs of a six years old child was developed.

- Multi-body full body human model (MBM) are simpler to create and to use than the FEM. Their robustness is easier to achieve and the time needed to run a simulation is far lower than with FEM. For this reason it seemed interesting to develop child human MBM. The automotive industry can use such tools for a first validation of scenarios. Then FEM and physical tests can be useful to validate a chosen option, but the number of these tests can significantly be reduced by the use of MBM.

- 6W - complete body: As base model for the baby model (6 week old), the TNO’s facet 50th percentile human occupant model was used and scaled down towards baby dimensions using the Madymo / Scaler. The baby model geometry was based on Candat database geometry.

The model was developed using the software package Madymo, version 7.2. Madymo is a multi-body software package that is widely used for automotive applications for fast and accurate calculations of injury risks and safety performance.

- 6M - complete body: The method and tools used are similar than the ones used for the 6 week old MBM. The geometry of the model was also based on Candat database geometry. The model was developed using the software package Madymo, version 7.2. A literature review was performed to input the best possible mechanical properties (stiffness or force-displacement curves) and injury criteria for the body parts that are most vulnerable for babies in a car crash. Validation data were sought in order to validate the 6 month old baby model's responses to impact.

- Report on road accidents and domestic accident simulation methodology

Two kinds of methodology to define head-neck criteria for all ages have been proposed, one for road accident case replications and the second one for domestic accidents.

- For road accident cases, experimental T1 kinematics measured on Q-dummies is needed in order to assess the FEM of the head-neck system and to investigate some tolerance limits. Special attention will be paid on car environment interaction with the head.
- For domestic accidents, corresponding to fall cases, simpler in terms of loadings even if neck influence is not taken into account, everything is available in order to reproduce numerically per age these accidents which involved especially head segment.

- Synthesis on numerical and experimental injury criteria

The report ‘Synthesis on numerical and experimental injury criteria’ aims to expose mechanical properties used and validations elements per segment and per age as well used to determine as first attempt injury criteria by reconstructing numerically with the developed FEM some accidents (domestic and road accident cases).

Three focused analyses are proposed. The first concerns the one year old child FE model. It presents mechanical properties implemented under LS-Dyna code as well as road and domestic accident
reconstructions results in order to establish some tolerance limits to specific head injury criteria. Then validation of the thorax, abdomen and lower limb are presented separately. Works done with the complete meshed model are also presented in this report. The second part of this document aims to describe three year old child FEM. It shows the validation performed on isolated body segments by partners. The last part focuses on the six year old child FEM mechanical properties, validations and first attempt to tolerance limits. It ends with the presentation of the coupling of all segments that should lead to a whole six year old child FEM.

In the future, the evaluation of FE model based injury prediction capability and the determination of tolerance values could be derived from accident reconstructions by using the approach that has been used for the Q dummies. For the six year old child thorax and abdomen region, the work was initiated by performing the first simulations corresponding to a severe accident where both thoracic and abdominal injuries were observed. This was only a preliminary step towards accident reconstructions. Several methodological improvements could be needed prior to being able to perform enough reconstruction and build a reliable model based tolerance curve. These could include:

- improving of the coupled children model stability and robustness (e.g. by improving element quality if needed, material models, and performing sensitivity analyses);
- defining methodologies to develop simplified environments for the reconstruction, including simplified or generic CRS;
- developing or adapting positioning methods to include the human model (possibly scaled to the actual child size) in this environment;
- defining methodologies to take into account the variation of undocumented variables. This could lead to an evaluation of the robustness of the approach or the use of statistical methods to determine the most probable result.

WP3 'Diagnostic of child safety issues'

Field data collection, analysis and related test programme

Works done in this area are all based on a common subject: the use of CRS by children. Two aspects were considered in the CASPER project, the first one focusing on sociological aspects of CRS use in order to have a better understanding of parameters leading to situations not being the optimum in terms of protection of children, the second one on technical aspects of the restraint system use and misuse to see how could solutions be applied to enhance the situation.

- Report on social approach of child safety

The CASPER approach was to use different sociological methodologies in order to rapidly get information. First a questionnaire was developed to gather data on demographics, travel patterns, CRS use, child position in the car, but also information regarding how parents perceive the way they secure their children, the way they drive, how they choose the systems and what kind of improvement they expect. This questionnaire, distributed online, collected 998 answers throughout Europe. The survey gives trends about parents' behaviour and beliefs concerning road child safety.
Methodologies for data collection have been developed, and been used, so the partners in the second part of the project have started to analyse the data and to disseminate results. In addition to the classical methods used an electronic survey on a larger scale has been done. For this, the form used for the field data collection was modified and translated in five languages to be used for an electronic survey at a large scale in Europe. As summary of results it can be said that people generally over-estimate their driving capacities, and their ability to correctly use restraint systems.

Although the study has highlighted insufficient knowledge of parents, the later could be offset during the purchase of the CRS by buying the CRS in specialised shops, where they got advice. But for the parents purchasing the CRS in supermarkets or on the Internet, parents claimed a lack of information. Despite this need of information, less than half of them were aware of campaigns on child safety in cars. This leaves an important field of action knowing that the communication media should mostly be television / radio, Internet and the press. CASPER has established a methodology to effectively conduct such focus groups regarding travelling with children. This approach could also be very efficiently completed by the observation of the real behaviour of parents in the everyday life through naturalistic studies.

- Child safety culture workshop event:

It was proposed to organise an event that allowed exchanging experiences and sharing methods also with organisations not belonging to the CASPER consortium, on cultural and sociological aspects. It was proposed to create a workshop dedicated to this approach of child safety and on how situations are different for children transported in cars across the world. The first workshop took place in 2009 and since then the scientific committee of the conference decided to integrate this in the annual process. It is constructed around a set of three or four presentations with a large degree of interaction between presenters and the audience.

- Misuse

The performance of a CRS is strictly influenced by the quality of its use. During the CASPER project misuses of CRS have been observed in the field and tested dynamically, in order to evaluate the effect of these misuses on the protection of children. Special efforts have been made to enhance the knowledge of safety experts by testing misuse linked to ISOFIX systems.

- Field studies

Misuse of child seats is still a widespread and serious problem. The main problem with the use of CRS is the correct belt path of the vehicle belt and the general installation of the child seat in the vehicle. Both problems could be prevented by the use of ISOFIX. Field studies have shown that less than 4 % of the CRS were fixed with ISOFIX in the vehicle. The market penetration of this system is extremely low considering that the vehicle fleet equipment of ISOFIX anchorages was around 50 % in 2011.

Results collected in Lyon during the CHILD and CASPER surveys were compared with the aim to estimate
the evolution in CRS usage and misuse: no significant difference was found in terms of appropriate use:
more than 80% of appropriate use according to the weight of the children, the rate of inappropriate use
being mainly due to a change of CRS too early for the child with similar patterns in 2003 and 2011.

A collaboration between CASPER and the Safety Road Institute of Belgium (IBSR) has resulted in an
additional data collection conducted in different areas of Belgium. Results at a global level show the same
tendencies as in the other studies: a lot of children are not correctly restrained, the use of CRS decrease a
lot for children older than 6 years, too many parents are not aware that the situation is not correct. For the
first time the number of ISOFIX systems was large enough to compare ‘classical attachment CRS’ and
‘ISOFIX systems’. The use of ISOFIX is more common in big cities than in the countryside.

- Test programme:

It has to be remembered that results are only applicable to the tested configurations (CRS, dummy, type
and severity of impact), but global tendencies can be outlined:

- Dummy behaviour: dummies are not able to measure the full range of injury risks (e.g. effect of having the
seatbelt twisted for children using a booster seat, excessive slack in harness).
- Dummy instrumentation: in a lot of cases, differentiating events using standard dummy readings is not an
easy task. Films are helpful to see differences in global kinematics. Abdominal sensors are also good
predictors to prevent injuries in this area. For the moment these sensors are not part of the standard
equipment of Q series dummies but are at an advanced stage of prototypes.
- Inappropriate use: The use of the inappropriate CRS for children too young can lead to the ejection of the
upper part or of the complete body from the CRS (escape at the level of shoulders) that can also lead to
serious injuries. This statement is mainly based on films combined with the knowledge that children and
child dummies behave differently in these conditions due to a difference of rigidity at the level of the
shoulders.
- Wrong use of practical functionalities: can lead to misuse for which the effect varies from no visible effect
to the total destruction of the CRS.
The non use of ISOFIX connectors on a booster seat does not decrease the level of protection considering
dummy readings.
- Postural effect: when the child dummies are positioned in more relaxed (and more realistic) postures, the
risk of sustaining serious injuries is higher for the head and for the abdomen: some head impacts and
some seatbelt penetrations into the abdominal areas have been observed on films and dummy readings.
- Wrong seatbelt route on boosters: is a critical misuse that leads to not restraining the upper part of the
child dummy or to strong forces applied onto the lower rib cage and abdominal areas.
- Add-on: The seatbelt adjuster device tested amplifies the risk of submarining through a poor positioning
of the belt on the abdomen even if used in combination with an approved CRS. Dummy readings are not
able to translate this additional risk except when the abdominal sensor is used.
- Communication: It is very important to communicate to children that the correct use of the seatbelt is
crucial for their safety and that it has to be combined with the use of a booster seat until their size is close
to the one of adults.

- Report on fatality studies
- **Literature review**

The database screening and literature review shows clear limitations referring to the focus on children fatalities as car passengers. No current numbers on child fatalities as car passengers for the whole world can be found in published data from WHO or the IRTAD database. Many figures are found, e.g. for road traffic accident fatalities only, but without separating to car passengers, or without separating to younger age groups. If available at all, age groups are not harmonised making comparisons difficult. The interactions between socio-economic status, affordability and availability of safety devices, ownership of a car, place of living, and exposure time in traffic by different participation modes, are not captured in child road traffic fatality studies up to now.

- **Detailed French child occupant fatality study**

For frontal impact fatalities in France, the priority is to improve the quality of use of restraint systems. When the child is correctly restrained, very few fatal cases are observed in conditions similar to the frontal test of the current regulation. In side impact, the current level of protection does not seem sufficient, the level of intrusion and the direct impacts with intruding objects are important for children on the struck side.

For roll-overs the priority is to protect children from being ejected from the car and from projection inside of the car. The rate of correctly restrained children in this type of fatal accident is very low in France, which indicates that existing systems when correctly used could be preventing these fatalities. Rear impact remains rare in the French fatality study.

It has been noticed that drivers report of safety influencing parameters such as distraction due to the presence of one or more children in the vehicle. Such data regarding driver behaviour are not often integrated in research works on child safety but it seems to be a potentially interesting and challenging in addition to child safety research. As for other occupants, primary safety systems that avoid the crash altogether or limit crash severity will have a role to play in the future protection of child occupants. Intrusion remains a major issue in side impact protection for children, even for correctly restrained occupants. Additionally, new designs of CRS are considering side impact protection even if it has not yet been integrated in the current European regulation.

- **Child passenger fatality figures for Europe**

Focusing on children from 0 to 13 years old, there are 392 fatalities recorded as car or taxi passengers in EU-23 for 2008, involved in 337 accidents. Just under one third were killed in single vehicle accidents, half in 2 vehicle accidents and one fifth in 3 or more vehicle accidents. Of the two vehicle accidents, 55 % of fatalities are in accidents involving two cars, followed by 23 % in accidents involving a heavy goods vehicle (HGV). Car passengers account for 44 % of all child fatalities, closely followed by 37 % for pedestrians. Child car passenger fatalities (0 to 13 years old) account for 1.1 % of all road accident fatalities (37 265) in EU-23 for 2008 and 7 % of all car passenger fatalities. Over a 10 year period the reduction in child car passenger fatalities is estimated to be 50 % for the EU-19 countries, higher than the improvement of 32 % for all fatalities. The number of child car passenger victims (fatal, serious and slight
casualties) for the EU-23 countries in 2008 is estimated to be 40,951. For the 20 countries with separate figures for fatal, serious and slight casualties the ratio is 1.1 per cent, 9.6 % and 89.3 %, respectively. For fatality rates by population, the EU-23 rate is 0.55 per 100,000.

- Software for the storage of data dedicated to the in depth study of child safety topic

Injury mechanisms for restrained children are studied and reported. To be able to run studies, it has been necessary to provide an appropriate database that holds the collected data. Each case must have appropriate photographs, vehicle damage information, estimate of crash severity, injury information (coded to the abbreviated injury scale) age and gender, position in vehicle and restraint situation data. The storage and viewing of accident simulations is also possible.

- Database for focused car accidents containing all accepted road accidents in this task

The database does give an indication of which body regions are being injured in different CRS types or for different ages of children and gives insights into restraint conditions that lead to injury. The combined data set, including the number of data available from the three EC child occupant safety projects (CREST, CHILD and CASPER) is one of the largest collections of in-depth road accident data focused on restrained child occupants.

- Database containing other types of accidents

To validate the FEM Q-Dummy series and to further develop injury risk functions, the method chosen is the reproduction through physical or virtual reconstructions of loads sustained by children during real car accidents. It is therefore necessary to collect accident data and to develop a tool adapted to the storage of specific data necessary for a good quality of reconstruction.

- Preliminary analysis of child injury mechanisms in other types of accidents

The new database is subdivided into domestic, pedestrian and cyclist accidents. Selected cases involved children of three years old approximately which is the age that corresponds at that time of the project to the only validated LS-Dyna FE Q dummy model. Because the children had isolated head injuries in all of the three cases it was assumed that the children hit the ground with the head first. The simulation results show that the head a3ms and HIC values do not correlate in the same way as observed from car occupant tests. The data points from the simulation do not help for the development of injury risk functions for the head because the HIC is far higher than known from previous tests and the a3ms values is slightly lower compared to the head injury severity as known from previous tests.

WP4 'Demands and application'

- Report on test procedures - frontal and side impact

For frontal impact it was concluded that the test set-up as defined for the new European Regulation UN-ECE R129 sufficiently reflects the passive safety needs to maintain high levels of occupant protection.
However, future activities should analyse modification of the seat cushion angle for booster type CRS. While the chosen seat cushion angle reflects average car conditions it might be worthwhile for booster type CRS to take into account worst case conditions which is expected to be more flat.

For rear impact no modifications are proposed as the current standard seems to offer appropriate safety performance. Regarding roll-over it is proposed to add an additional requirement for the head displacement. While the current criteria is just analysing the relative head displacement during roll it seems relevant to apply the same absolute limit as done for frontal impact regarding the head excursion limit in Z direction above CR point. It is proposed that a new threshold for maximum head excursion for all impact types should be negotiated between CRS and car manufacturers.

Finally, CASPER supported the GRSP informal group on CRS while developing and validating a new side impact test procedure. This test procedure consists of a flat intruding panel and an accelerated test bench. Within the CASPER consortium two deceleration sled facilities and one acceleration sled facility were used to implement the test procedure. The new test procedure is sufficiently repeatable and reproducible.

- Development of relevant parts for virtual test procedures

Virtual modelling and testing will become more and more important for child safety development. Therefore all relevant parts for virtual frontal and lateral test procedures were developed in the CASPER project. The sled test environment, numerical CRS development and first test results are presented exemplarily on a booster seat with a model of Q6 dummy.

- Virtual test procedure

The virtual test procedure consists of separate parts. Therefore the parts for the simulation are also included in separate files. The benefit of this handling is that the main simulation file is easier to be used. The specific included files are the test bench, the belt anchorage, the ISOFIX anchorage, the sled belt system, the sled pulse, the Q dummy models, the CRS models and the impactor shape used for side impact.

- Models of CRS

Three sizes of generic models of CRS have been created in order to validate the different sizes of dummy and human models developed in the CASPER project: group 0+, group 1 and group 2/3.

All of them went through a validation process in combination with virtual test environment models. For each CRS the separate parts were meshed and assembled together and defined with basic materials. The basic seat parts such as cushion, backrest, head rest and covers were defined as elastic material.

- Report on possible solutions for CRS in terms of use and car safety devices

Results from the sociological survey carried out as part of the CASPER project proved to be an extremely valuable resource as many of the proposed solutions are based on information gathered in the survey.
Recent statistics show that a large percentage of CRS are misused, this project aims to reduce this figure by implementing innovative designs and creating new legislation. To list some of the ways CRS are being misused: they are being incorrectly installed i.e. putting a rearward facing device in a forward facing position or incorrectly fastening the seatbelt to the device. Parents play a key role in child safety and this is researched in great depth within this project.

Research was carried out in two ways: preventing these types of CRS misuse as well as researching other problems with CRS such as the issue with transporting children with disabilities. The proposed solutions are presented alongside any issues that might occur.

- Report of the feasibility from physical testing to numerical criteria

Virtual development first requires virtual dummies and CRS and test setup models. In that particular case, injury criteria and limits can be the same for physical development. However, all the components of this approach have to be validated and have to demonstrate their ability to mimic reality.

Ethics

Creation of an ethical board

In accordance with clause 15 introduced into the CASPER Grant Agreement and in order to control the different ethical protocols used in the CASPER project:

1. The gathering of geometrical data to investigate biomechanical characteristics of children, based on external measurement - The responsible beneficiary is INRETS'.
2. The sociological study is a survey on the way how children are transported in cars, based on observations and interview series with adults who transport children. The responsible beneficiary is CEESAR.

It has been necessary to set up an internal ethical board that gave its agreement on the CASPER proposed protocols.

1. INRETS protocol

Regarding the gathering of geometrical data to investigate biomechanical characteristics of children, based on external measurement, the responsible beneficiary, INRETS, wrote his ethical procedure 'INRETS protocol for anthropometrical acquisition' (accompanied by the below explained-documents).

a/ The objective of the work in the subtask 2.2 'geometrical and mechanical properties' of the CASPER WP 2 was to provide geometrical data in order to perform the scaling of the meshes in task 2.3 and to confront the child passenger posture with the belt position in order to verify the adaptability of the belt position regarding the external morphology of children.

For each subject, anthropometric parameters have been recorded in two separate approaches:
- First, stomatology data recorded in two positions: standing and sitting on a chair. Dimensions will include heights, lengths, weight.
- Then, biometric data recorded on the same subject seated in a car with and without the restraint system (CRS).

b/ The acquisition of external geometrical data by INRETS, usable for the development of models, needed also the local and national ethic boards agreements. These boards have been consulted to approve the planned tests before the conduction of any measurements campaigns:

- neither the identity, nor the date of birth, nor the origins of the individual were indicated;
- a mere formality has been made: an on-line CNIL declaration by a basic procedure for this type of research.

Towards the CCIERBC and the CCPs: The INRETS committee of ethics on the biomedical and behavioural research (CCIERBC) has been consulted. One of its roles is to indicate if the envisaged researches fall within the said Huriet-Serusclat law. If it is the case, it is necessary to deposit a file with CPPs, the committees for the protection of persons.

- Concerning the INRETS measurement protocol, the advanced arguments were that the measures were in no way at all invasive; did not need medical attention or covering of the subjects. Indeed, the measurements concerning children were only external dimensions and did not concern biomedical research works.
- The CCIERBC answer was negative. The French Huriet law on the protection of persons participating in biomedical research didn't apply here.
- There was thus no necessity of submitting a file to the CPPs.

c/ The measurements were done by anthropological laboratory specialists in the field of geometrical data acquisition on children and with whom INRETS was accustomed to work. This trained staff obtained the informed consent of parents:

- an information sheet, in French language was distributed to relatives (parents) to ask for their agreement / signatures for the measures.

These measurements were made in schools with the required agreements of:

- the vice-chancellorship
- the school.

2. CEESAR sociological data collection

a/ The purpose of the subtask 3.1.1 entitled 'Social safety demand' of the CASPER WP 3 was to provide a sociological overall understanding of safety practices concerning child environment in car transportation. Some social factors explained the gap between the fact all parents want to protect their children and the
reality of road situation: they badly secure children in the car and the misuses of child restraint are still an important factor of injury. From a French study carried out in 2007 (press release of Association Prevention Routiere, 21 February 2009), 8 children out of 10 are not or badly restrained in cars.

- In order to understand this situation, two sociological and quantitative methods were used to collect data: the questionnaire and the focus groups.

b/ Questionnaire
The survey was totally anonymous; it did not contain any identifying information. As it was indicated in the model of the first page on which people arrive when they want to fill the form, people were informed of the respect of the anonymity. The questionnaire didn't hold personal data (name, address, etc.).

Focus groups
Within the context of focus group, CEESAR needed to film the participants. In France legal aspects regarding people's image right are largely based on Article 9 of the Civil Code: every person has a right to respect for his privacy and a right to the image. In case of video recording of the persons in specific context, people must be informed before that they will be filmed.

In case of video filming CEESAR:

- informed the participant of video recording;
- needed the consent of each participant to use their pictures through written agreement;
- the following items were specified in the form: why CEESAR needs to film the participant, aims of the use and publication of the pictures, which mediums may publish the pictures (internet, reports, presentations);
- pictures will be blurred before each diffusion;
- use of the picture for a limited period. CEESAR needs to have a new agreement from the participant to repeat his picture.

CEESAR wrote an ethical protocol named 'Questionnaire on children safety in cars and focus group' to notify the implementation of the CASPER database and its characteristics:

- CNIL declaration.

And to comply with any national legal requirements regarding the distribution of questionnaires and organisation of focus groups in schools:

- agreements of the education authorities.

The CEESAR protocol (accompanied by the above-mentioned documents) and the final version in English of the questionnaire have been formally agreed by the CASPER ethical board in mid-June 2010.

d/ Moreover, the sociological questionnaire was translated in different languages (French, Spanish, German, Italian and particular English for United Kingdom) and distributed as an electronic survey via the
internet (CASPER website). The original text has been slightly modified to enable the usage of the same document for several different countries (i.e. the age range had the child age range modified to fit the regulation of all countries). For the countries in which the survey was conducted: in Germany (location of the web server), in France (locations where data was analysed), in Spain, in Italy, in United Kingdom, the method of collecting information and the data collected in the surveys fulfilled their current data protection law as it did not collect any personal details of people who have participated.

- The protocols and a copy of all the above-mentioned approvals from the CASPER ethical board, from national and local authorities and/or ethics committees have been provided to the EC.

Dissemination and exploitation of project results:

All dissemination activities have been reported in the two deliverables dedicated to that: publications and workshop. During these events the CASPER's partners have been in constant dialogue with the audience and considering remarks or adapting the ways research works have been conducted. This ensured results to be in line with the expectations of the actors of child safety and that they will be integrated in their development process. This has worked pretty well and most of the findings of CASPER have already been discussed and integrated when necessary in the development of the new regulation for CRS approval (ECE R129). Dissemination activities have been compatible with the protection of intellectual property rights, confidentiality obligations and the legal interest of the owner of the project results. A validation of all publications was necessary prior to forward the final version of papers or presentations to conferences and workshops. Then all partners or task leaders could verify the content of all of them and authors were required to make the necessary changes, and re-circulate the final version. This rule was already proposed at the time of the proposal of the project: 'Partners are entitled to publish research results generated under the project in the usual scientific reviews and conferences. However, all publications must be submitted to the project coordinator and to interested project partners for review and approval. Approval shall be notified within 15 days of receipt of the proposed publication or is deemed to have been granted after this period. To be granted the approval of the EC project officer is necessary. Furthermore all publications shall indicate that the project results were generated with financial support of the EC.' All electronic copies of the published versions or the final manuscripts accepted for publication have been provided to the EC. For the university partners, dissemination has also been integrated in the student lessons curses through research students working on the project, either directly or indirectly.

The final workshop was dedicated to present the results obtained during the whole duration of the project to a wider public. Other outcomes such as methodologies and tools have been shown and discussed. The website that contains general information about the different partners of the project, the description of the goals of the project has been regularly updated with public deliverables, publications and announcement of events.

Most participants in the CASPER project are involved in European working groups and have particular expertise regarding the problems related to child safety in road accidents.

During all the life of the project, exchange of information and knowledge, meetings with some of the working groups have been carried out first to consider their needs, then to have their opinion on the methodologies used in the CASPER project and finally to give them the main findings on the subjects they
were interested in. Some of these groups are not only limited to European participants, so experts from non-European countries (United States, Canada, Australia, Japan) have also been in the information exchange process, so works conducted in CASPER can be widely spread.

A consortium agreement, including a confidentiality agreement among all partners, has been set up. This agreement contains a time span for publication of results of major importance for specific duration, in order to secure the gain of competitiveness of the partners in their respective areas. This consortium agreement is not only listing the details of organisational and management aspects, but is also addressing the subject of the project, the purpose and duration of the agreement, the responsibilities of the members, the financial provisions, the intellectual property rights, data protection.

Related documents

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