SENIORS

SAFETY ENHANCED INNOVATIONS FOR OLDER ROAD USERS

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CONTENTS

1 INTRODUCTION

A reduction of almost 48% of total fatalities was achieved in Europe in the past years due to efforts that were put into road safety. This includes also a reduced number of elderly fatalities due to road accidents. However, among all the road fatalities, the proportion of elderly is steadily increasing.

Because society is aging demographically and obesity is becoming more prevalent, the SENIORS (Safety ENhanced Innovations for Older Road userS) project aimed to improve the safe mobility of the elderly, and persons who are overweight, using an integrated approach that covers the main modes of transport as well as the specific requirements of this vulnerable road user group.

Thus, this project primarily investigated and assessed the injury reduction in road traffic crashes that could be achieved through innovative and appropriate passive vehicle safety tools as well as safety systems. The goal was to reduce, in the near future, the numbers of fatally and seriously injured older road users for both major groups: car occupants and external road users (pedestrians, cyclists, e-bike riders).

The project covered research topics such as crash, hospital and behavioural data analysis, biomechanics, the development of test tools, procedures, and assessments. Further, to gain required data tests with volunteers and with post-mortem human subjects were carried out, crash and impactor tests were conducted and numerical human body model simulations were performed.

A special attention was paid to cooperation with industry, academic and governmental bodies in Europe, but also to the United States of America and Japan.

The website www.seniors-project.eu provides substantial information about the project as well as offers the possibility to access publications.

2 OBJECTIVES AND APPROACH

The main goal of SENIORS was to improve the safe mobility of the elderly, including overweight and obese persons, using an integrated approach.

The objectives were:

1) View on anthropometric particularities of the elderly and their injury mechanisms compared with younger persons
2) Development and optimization of test tools, procedures and assessment methods regarding the needs of the elderly
3) Identifying differences in the dynamics of different age groups in the pre-crash and crash phase
4) Customised R-scripts package for the calculation of injury risk curves.
5) Transfer of knowledge and results through cooperation with authorities and consumer protection organizations

Implemented in a project structure, the SENIORS project consisted of four technical Work Packages (WP1 – WP4) which interacted and provided the substantial knowledge needed throughout the project. These WPs are:

WP1: Accidentology and behaviour of elderly in road traffic
WP2: Biomechanics
WP3: Test tool development
WP4: Current protection and impact of new safety systems

In addition, there is one Work Package assigned for the Dissemination and Exploitation (WP5) as well as one Work Package for the Project Management (WP6).

The overall scope for the SENIORS project is shown in the flowchart in Figure 1.

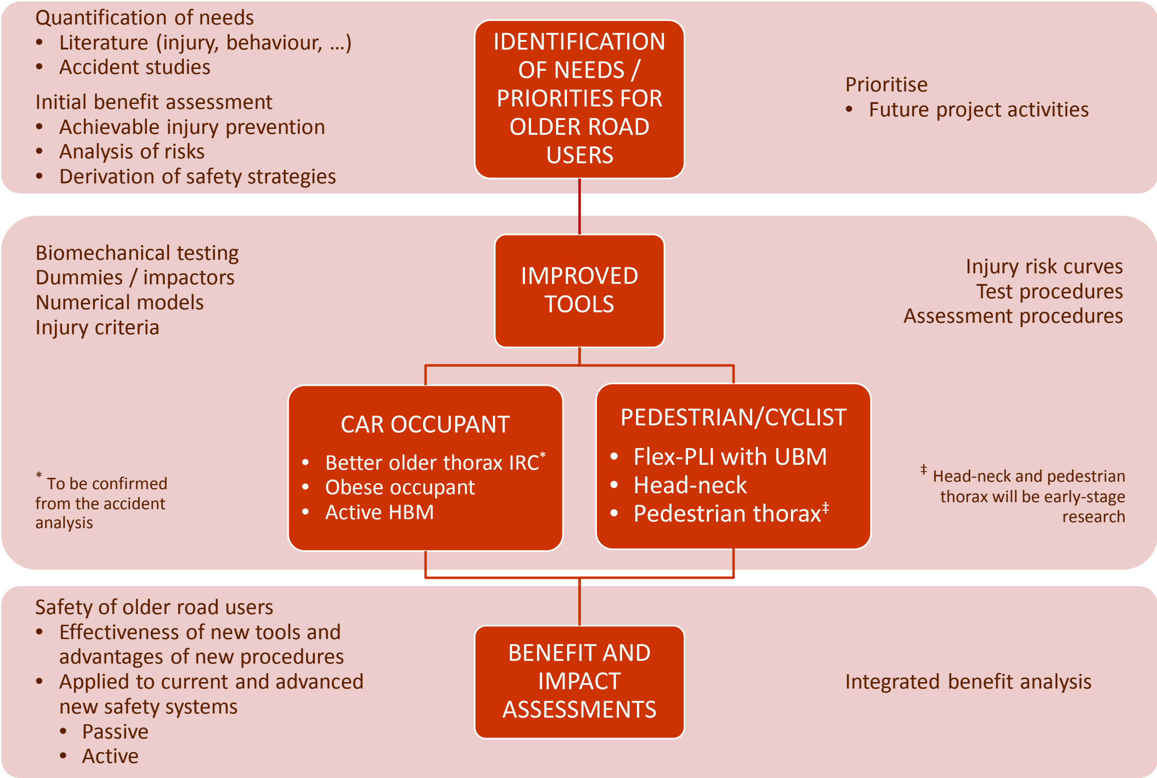


Figure 1: SENIORS project overview

3 Explanation of the work carried out by the beneficiaries within the second project period

The following thirteen points summarize the achievements within the second period of the project. More technical details are given in the explanation of work carried out within each work package.

- ✓ **Further tests with volunteers**

Volunteer tests were carried out to investigate the active muscles response in a real controlled and a virtual environment. The data collected during the experiments simulating hazard and sudden braking situations include information about muscle activations, forces applied and e.g., movements of certain body regions. Hereby, major differences between elderly and young, as well as male and female, were reported.

- ✓ **Further tests with Post-Mortem Human Subjects**

To address the lack of PMHS sled test data in a simple well defined repeatable set-up that is at the same time also representative for loading conditions of a contemporary vehicle, further sled tests with PMHS have been carried out in the SENIORS generic sled set-up. The test conditions (belt, airbag and other restraint parameters) were fine-tuned before the tests in THOR and THUMS human body model simulations. This enabled a very successfully second services of PMHS tests resulting in the desired severity in terms of thoracic injury outcome (number of fracture ribs) in the PMHS tests. The PMHS is a very valuable output for further human body model validation, improvement of dummy biofidelity and development of improved thoracic injury criteria to further enhance the protection level of elderly car occupants.

- ✓ **Updated (age-dependent) injury risk curves and injury criteria**

New age-related thoracic injury criteria and risk functions for the THOR ATD were developed. This was done using an innovative approach based on computer simulations with THOR and HBM to address the previously identified limitations of the traditional approach, which is based on THOR and PMHS testing. A new data set of more representative frontal sled impact loading conditions was generated. This included various restraint parameters (belt load limiter levels, airbag parameters) and impact conditions (velocity, impact angle). Based on the output from matching simulations, THOR dummy chest deflection output and chest injury out (number of fractured ribs) from HBM simulations, new criteria and risk functions were developed. The new PC Scores are proposed based on this extended SENIORS data set. With the existing criteria and the new PC Scores, new risk curves relating the criteria to AIS thoracic injury and to a probabilistic risk for a certain number of rib fractures were developed. The results regarding new risk curves look very promising.

- ✓ **Age-related changes to HBM (THUMS)**

Age-related changes were applied to the human body model THUMS. Two finite element models of the thoracic rib cage were generated by morphing the rib cage anthropometry. One model had a rib cage shape of a young adult (35 years-old), while the other was representing an elderly person (65+ years-old). In addition to the cage shape, the cortical bone thickness of the ribs and the elastic modulus of the costal cartilage were modified as the age-related parameters.

- ✓ **Elderly, overweight dummy**

The elderly population is not represented by any crash test dummy. The elderly, overweight female dummy was used in the project, but is still under development. It is a dummy which addresses the trend of overweight and is closer to the real anthropometry of older people. Additionally, it is designed using innovative production techniques. The testing with this dummy in SENIORS identified necessary updates which form the basis for further biofidelity targets based on human body CAE models and testing and tuning of the dummy hardware.

- ✓ **Experimental tests with advanced restraint systems**

Sled tests with the THOR ATD and EATD were conducted with advanced restraint systems including adaptive restraints and innovative restraint concepts like four-point or split buckle belt systems which distribute the loading on the chest. The sled tests clearly showed the benefit of advanced restraints concepts. The tests also demonstrated the advantages of the new test tool THOR and multi-point thoracic injury criteria for vehicle safety assessment in test procedures. This can enable introductions of advanced restraints, which will help to increase the protection level of elderly car occupant in frontal impact collision.

- ✓ **Recommendations towards legislation and Euro NCAP regarding the improved safety of older car occupants**

Recommendations for modified / new frontal impact test methods have been provided aiming to enhance the protection level of older car occupants. These recommendations have been summarized in Safety Packages addressing three time periods: short-term, mid-term and long-term.

- ✓ **Revised legform impactor (FlexPLI-UBM)**

The FlexPLI-UBM was validated against the Human Body Model THUMS v4 and an upper body mass with flexible element was introduced, to better address on the one hand pedestrian femur injuries (substitute for Upper Legform impactor) and on the other hand high frontend geometries (higher Bonnet Leading Edges, high Bumpers) as well as angled surfaces at the end of the bumper test area. Validations resulted in a significantly improved, more humanlike kinematics of the FlexPLI-UBM in comparison to the FlexPLI Baseline. The time histories (loadings vs. time) correlated much better with those of the human body model in terms of shapes, timings and maxima. As a result, transfer functions between HBM and impactor were established and used for impactor thresholds to assess the risk for lower extremity injuries.

- ✓ **Revised test and assessment procedure for lower extremity injuries**

The incorporation of the upper body mass led to a revised assessment of lower extremity injuries, incorporating new impactor thresholds based on the one hand modified, age-related injury risk functions addressing femur fractures and on the other hand a correlation FlexPLI Baseline vs. FlexPLI-UBM for the assessment of tibia and knee injury risks. Furthermore, femur, knee and tibia injuries were balanced according to their significance estimated from in depth accident data.

- ✓ **Prototype thorax injury prediction tool (TIPT)**

A thorax impactor to address pedestrian thoracic injuries (rib fractures) was developed in theory first and prototyped in a second step. The feasibility of a component test using a thorax impactor was investigated, confirmed and numerous tests were conducted on a generic vehicle frontend as well as an actual vehicle.

- ✓ **Test and assessment procedure for thoracic injuries**

A test and assessment procedure for thoracic injuries of vulnerable road users was developed for the first time. The procedures are, in principle, based on three items: an injury assessment using injury risk curves for the ES2-dummy, a grid procedure based on and thus harmonized with the Euro NCAP headform grid procedure and a new markup, addressing statures from 6YO to 95th.

- ✓ **Test and assessment procedure for head injuries, including cyclists**

The improvements for assessing head injuries were mainly based on a revision of the test and assessment procedures with the aim of including cyclists. Main achievements of the combined procedures were a longitudinal rearward extension of the headform test zone and the modified head impact angles, taking into account cyclist impact scenarios.

- ✓ **Overall assessment procedure for the passive branch of VRU Box 3 of Euro NCAP**

The assessment procedure for VRU Box 3 of Euro NCAP was revised, based on recent accident data and the new and revised test procedures for assessing lower extremity, thoracic and head injuries of pedestrians and cyclists. The procedure can be applied to Euro NCAP and other consumer information programmes.

3.0 Work Package 6 – Consortium Management

3.0.1 Project meetings

General Assembly (GA) meetings have been scheduled, organized and reported as well as phone/web conferences at consortium level. At least one week before each meeting, but four weeks prior to a General Assembly, an agenda was prepared and circulated among all the attendees. After the meeting, the presentations, minutes and action points were collected and circulated among all the partners related to the tasks.

Other meetings have been organised for technical follow-ups within the different Work Packages and for follow-up with the Project Officer(s). As shown in Table 1, three GA were held as planned.

Table 1: General Assembly Meetings during 1st project period

#	Date(s)	Phone or Location	Attendees
05	20/06/2017	Gothenburg, Sweden (Autoliv)	All partners
06	21/11/2017	Munich, Germany (LMU)	All partners
07	02/05/2018	Barcelona, Spain (IDIADA)	All partners + UNIZAR

Executive Board (EB) meetings have been held to monitor the general progress of the project. The timing and progress of the Tasks was monitored as well as of the deliverables and milestones. The meetings were also organised according to current required key discussions and decisions. The EB meetings are detailed in Table 2.

Table 2: Executive Board Meetings during 2nd project period

#	Date(s)	Phone or Location	Attendees
01	12/04/2017	Web conference	WP Leaders + Coord.
02	30/05/2017	Web conference	WP Leaders + Coord.
03	27/10/2017	Web conference	WP Leaders + Coord.
04	02/11/2017	Web conference	WP Leaders + Coord.
05	30/01/2018	Web conference	WP Leaders + Coord.
06	12/04/2018	Web conference	WP Leaders + Coord.
07	11/06/2018	Web conference	WP Leaders + Coord.

SENIORS optimised face-to-face meetings by linking Technical Meetings with GA meetings. Due to timing some additional WP Technical Meetings were also organised and a significant number of web conferences tackling technical issues of particular Tasks were organised as well. All of those are detailed in Table 3.

Table 3: Technical Meetings during 2nd project period

Work Package(s)	Date(s)	Phone or Location (number, if applicable)	Attendees
WP2	12/2016-10/2017	~24 web conferences	Main WP2 participants
WP3	04/2017-10/2017	~10 web conferences	Main WP3 participants
WP4	10/2017-05/2018	~20 web conferences	Main WP4 participants
WP2+WP3+WP4	20/06/2017	Gothenburg, Sweden (Autoliv)	All partners
WP3+WP4	21/11/2017	Munich, Germany (LMU)	All partners
WP4	02/05/2018	Barcelona, Spain (IDIADA)	All partners + UNIZAR

To provide updated information of the project progress timely to the Project Officer and to discuss the issue of the work delay, additional meetings were organised, as detailed in Table 4.

Table 4: PO Meetings during 2nd project period

Type of meeting	Date(s)	Location	Attendees
Web conference	04/08/2017	-	Anca Pasca (INEA), Marcus Wisch (BASt),
Face-to-face	16/04/2018	TRA Conference, Vienna	Octavia Stepan (INEA), Marcus Wisch (BASt)

3.0.2 Milestones

Table 5 shows the milestones achieved within the second SENIORS project period.

Table 5: Overview on Milestones of the second project period

MS	Title	WP	Lead	Due date	Means of verification
4	Selection of Human Body Models	2	LMU	04/2017	Choice of specific THUMS version to be used for car occupant and pedestrian simulations
5	New and updated injury criteria	2	BASt	06/2017	Included in Deliverable 2.5
6	Development of a script package for the statistical software 'R' containing new and updated injury criteria	2	TRL	07/2017	Included in Deliverable 2.5
8	Validated Elderly Overweight Dummy and pedestrian impactor updates available for evaluation testing in WP4 (Hardware)	3	Humanetics	07/2017	Validation could not be finished; however, valuable steps for the validation have been performed in WP3 and WP4 testing
9	Updated test and assessment procedures	4	IDIADA	12/2017	Included in Deliverable 4.2
12	Implementation of results based on workshop discussions with stakeholders	5	BASt	12/2017	Results of SENIORS Experts Meetings and subsequent collaborations have influenced the overall method and helped drawing decisions with an high impact
17	Fourth General Assembly	6	IDIADA	06/2017	Meeting took place.
18	Fifth General Assembly	6	IDIADA	12/2017	Meeting took place.

3.0.3 Deliverables

Table 6 shows a list of the deliverables allocated to the second project period and delayed deliverables from the first project period specifying also the due and submission dates as well as provides comments to each report.

Table 6: Overview of Deliverables allocated to M19-M36

D	Title (nature)	Lead	Due date	Submission date	Comment
1.3	Road Safety measures towards the elderly, Effects of active vehicle safety systems and derivation of safety strategies (Report)	BASt	07/2016	05/2018	**Ready.** Delayed delivery as the corresponding Task 1.4 did not complete its work during the first period and results from other projects (e.g., SafetyCube) were expected.
2.3	Kinematic comparison between the THOR dummy, older volunteers and older PMHS in low-speed non-injurious frontal and oblique impacts (Report)	TRL	09/2015	08/2017	**Ready.** Delayed delivery due to issues with subcontracting. Finalisation of conduction and analysis of remaining tests with post-mortem human subjects in April 2017.
2.4	Updated Human Body Models representing elderly occupants and pedestrians (incl. overweight / obese) (Report)	BASt	03/2017	02/2018	**Ready.** Delayed delivery as the development of the age-modified HBM took much longer than expected and its usage required a number of iterative development steps. In addition, various simulations had to be repeated for technical reasons.
2.5	Updated injury criteria for the THOR (D2.5a) and Updated injury criteria for pedestrian test tools (D2.5b) (Report)	BASt	07/2017	06/2018	**Ready.** Delayed delivery as the required age-modified HBMs were provided later than expected which formed the basis for the evaluation.

3.2	Elderly Overweight Dummy test and validation report (D3.2a) and updated pedestrian impactor test and validation report (D3.2b) (Report)	BASt	05/2017	05/2018	**Ready.** Delayed delivery as the required dummy tests were delayed in time and the development / modification of impactors took much more time than initially expected.
3.3	Elderly Overweight Dummy certification document (D3.3a) and certification documents for updated pedestrian impactors (D3.3b) (Report)	Humanetics	06/2017	10/2017	**Ready.** Delayed mainly due to delayed delivery of the dummy to the project and the summer break.
3.4	Validated Elderly Overweight Dummy (D3.4a) and validated updates to pedestrian impactors (D3.4b) for testing in WP4 (Demonstrator)	Humanetics	06/2017	04/2018	**Ready.** Delayed delivery due to delayed testing in WP3 and WP4.
4.1	Draft Test and assessment procedures for current and advanced passive safety systems (Report)	IDIADA	06/2017	05/2018	**Ready.** Delayed because previous work from WPs 2 and 3 had to be completed first.
4.2	Evaluated Test and assessment procedures for current and advanced passive safety systems (Report)	BASt	11/2017	07/2018	**Ready.** Delayed because previous work from WPs 2 and 3 had to be completed first and delays in experimental testing due to availability of test labs and objects.
4.3	Benefit estimate for integrated approach (using different transport modes) with respect to elderly (Report)	TRL	04/2018	06/2018	**Ready.** Delayed delivery because previous work from WP4 had to be completed first.
5.4	Dissemination and exploitation plan update (Report)	IDIADA	05/2017	02/2018	**Ready.** Delayed delivery because of amendment related changes.

5.6	Final reports of Project Technical Advisory Board meetings (Report)	IDIADA	06/2017	05/2018	**Ready.** Delayed delivery because major changes due to the change of SENIORS Experts Meetings
5.8	Annual newsletter describing new developments and results from the project (Report)	IDIADA	05/2017	11/2017	**Ready.** Delayed delivery because a redefinition of the newsletter process was required.
5.9	Annual newsletter describing new developments and results from the project (Report)	IDIADA	05/2018	05/2018	**Ready in time.**
5.11	Final exploitation status report (Report)	IDIADA	05/2018	05/2018	**Ready in time.**
6.2	Mid-term review report (Report)	IDIADA	11/2016	01/2017	**Ready.** Delayed delivery because timing was not feasible as the review meeting had to be taken place first.
6.3	Final review report (Report)	IDIADA	05/2018	07/2018	**Ready.** Delayed delivery because timing was not feasible as the review meeting has to be taken place first.

3.0.4 Amendment

A request for a second amendment to the Grant Agreement was made to include changes in three major areas of the project:

1) Reallocation of budget to the IDIADA Automotive Technology, S.A.'s linked third party IDIADA Fahrzeugtechnik, GmbH
2) Budget shift from TRL to Autoliv/ALS
3) Budget shift from TRL to BASt

All changes were finally approved by the EC in May 2018.

Regarding the modification 1) there was the following reason reported:

Key personnel involved in the SENIORS activities moved to IDIADA's offices in Germany. An introduction of a linked third party ("IDIADA Fahrzeugtechnik, GmbH") was required for the second half of the project. Therefore, the efforts to be dedicated had been calculated and requested to be included in a reallocated budget without increasing or decreasing the overall partner's budget.

Regarding the modification 2) there was the following reason reported:

When the SENIORS project was bid for, TRL envisaged using its own THOR dummy for testing. The TRL THOR dummy was at a suitable status for sled tests focusing on the thorax, having been upgraded during the THORAX FP7 project. It also had been upgraded with 72 strain gauges on the ribs to enhance the understanding of loading to the rib cage. However, since the SENIORS project started, the US Government (NHTSA) has finalised the specification for the THOR as a production dummy and the TRL dummy is no longer considered to be state-of-the-art.
The Consortium has agreed that the testing should be performed with the latest, THOR-M, specification; however, this would have incurred as much as €50,000 dummy hire costs, which was the majority of the available test budget. TRL therefore proposed to transfer the effort to another partner who already has a suitable THOR dummy. This would also save Consortium budget on the shipping of the generic test rig and restraint system spares. Overall, this proposed change delivered the required testing at a lower total cost to the project in terms of time and budget.

These Other direct costs are:
- Other goods and services: 32,300.00 € for "To carry out 8 to 15 sled tests […]"
- Consumables: 1,420.00 € "To purchase test consumables to be used in the validation of the Elderly, Overweight Dummy as part of Task 3.3 'Tool validations'."

The reallocation of costs foresaw the shift of resources from TRL to Autoliv and its linked third party ALS as follows:

Resources	Shift from TRL (Task 3.3)	to ALV/ALS (Task 3.3)
Personnel direct costs	20,140.00€ (3.8PM)	19,750.00 € (2.5PM)
Other direct costs	33,720.00 €	34,110.00 €
TOTAL	-53,860.00 €	+53,860.00 €

Hence, TRL's budget has decreased by 53,860.00€ (plus indirect costs) and Autoliv/ALS's budget has increased by this amount.

Regarding the modification 3) there was the following reason reported:

TRL released the additional costs for testing to the consortium to spend as they need for SENIORS. This has been caused by the fact that TRL does not intend to carry out the testing (see Modification No. 2) and therefore does not require the €23,580 in relation to the testing.

These Other direct costs were:
- Other goods and services: 20,000.00 € for "To maintain the TRL THOR crash test dummy for usage in testing related to injury risk curves in Work Package 3."
- Consumables: 3,580.00 € "To purchase test consumables to be used in the validation of the Elderly, Overweight Dummy as part of Task 3.3 'Tool validations'."
This budget of 23,580 € shall be moved from TRL to BASt's personnel efforts in WP2 and WP3.

The request was justified as BASt could foresee that there will be a significant overspend of budget (personnel efforts), especially due to a heavily raised number of required computer simulations in WP2 and WP3. More in technical detail, besides the original concept of the Upper Body Mass (UBM) for the FlexPLI, another concept in three different versions and the basic version of the FlexPLI were investigated. Furthermore a sensitivity study for different impact heights of the FlexPLI with UBM was performed in order to achieve the best correlation between the human body models and impactors. Finally, additional simulations were carried out with the latest revision of the UBM, which corresponds to the hardware prototype, to enable a meaningful comparison between testing and simulation.

3.0.5 Summary of exploitable results

Various exploitable results were generated in the SENIORS project. Among them, exploitable results regarding car occupants are:

- Generic Test Rig;
- Updated (age-dependent) injury risk curves and injury criteria (calculations replicable by available script files of the statistic language R);
- Age-related changes to Human Body Models, in particular the THUMS TUC;
- Elderly, overweight dummy;
- Experience with advanced car occupant restraint systems close to the market;

And regarding pedestrians / cyclists exploitable results are:

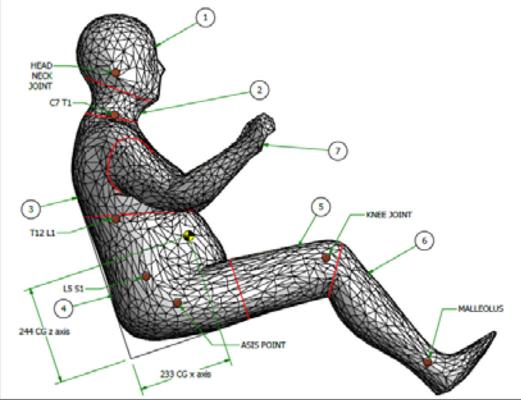
- Revised legform impactor with Upper Body Mass (FlexPLI-UBM);
- Prototype thorax injury prediction tool (TIPT) with the potential to substitute the current Upper Legform test and for the first time, to address thoracic injuries of pedestrians and cyclists in collisions with passenger cars;

Two of these major exploitable results are more explained in detail below.

Elderly 70 Year Old Overweight Female Dummy (EATD).

Motivation. In 2012 approximately 36 million drivers 65 and over where in the U.S with 586 injured every day. By 2030 it is expected 1 in 5 will be 65 or over. Accident data analysis in the Seniors Project showed there is a negative trend of elderly fatalities in vehicle crashes in absolute numbers (decreasing from ~9500 in 2001 down to ~6500 in 2014), but the share of the eldery in the total number of fatalities (all age groups) is increasing (17% to 25% in the same years). The elderly population is not represented by any crash test dummy. The Elderly Dummy Project was initiated by Humanetics and adopted and supported by SENIORS.

Anthropometry. ICAM (International Centre of Automotive Medicine) found between the ages of 67 to 73 mean stature and weight were 1.61m and 72.8kg. For the Elderly Overweigh dummy an age of 70 was selected with stature of 1.61 m and weight 73 Kg (BMI 28). The 3D CAD surface model for the external surface dummy was generated by UMTRI anthropometry software and segmented, giving targets for body segment volumes, masses and centre of gravity.



ITEM	QTY	DESCRIPTION	MASS (Kg)
8	1	FULL BODY	71.15
7	1	ARMS	4.87
6	1	LOWER LEGS	6.62
5	1	UPPER LEGS	8.24
4	1	LOWER TORSO	29.70
3	1	UPPER TORSO	17.02
2	1	NECK	0.89
1	1	HEAD	3.81

BODY SEGMENT WEIGHTS

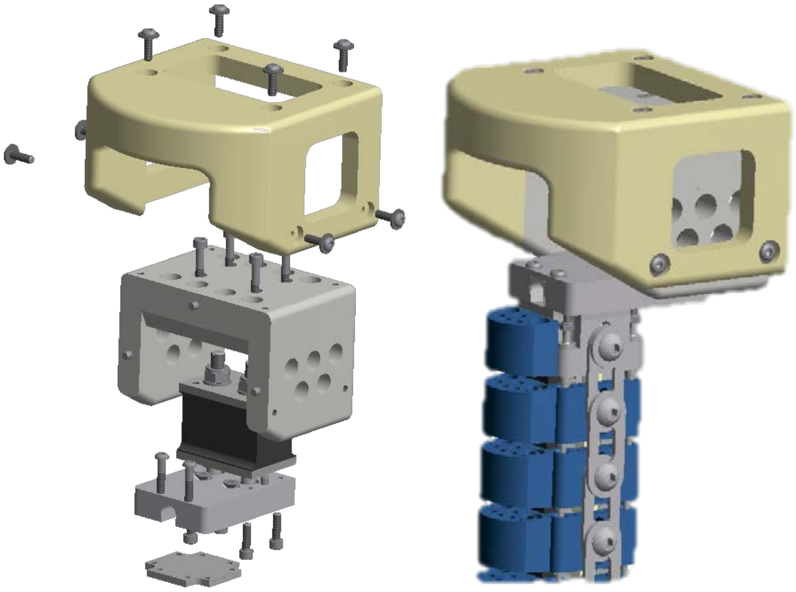
Description. A few existing dummy parts were used which matched target profile and weight. WorldSID small female head and neck were reused. The shoulder is represented by a stable floating scapula using two rubber mounts. The humerus-shoulder joint is represented by a spherical joint and is intended for frontal and side impacts. The ribs are 3D printed fibre reinforced polymer with constrained inner damping, covered by segmented outer parts representing external geometry and soft tissues. Internal organs with high injury risk (liver, spleen) are represented with 3D printed parts, geometry and internal position of which is based on MRI scans of real organs. Preliminary work was done on compressing a liver surrogate with pressure sensor and comparison to biomechanical liver data. Pelvis bony parts are based on Hybrid III small female components, which gave a good match with MRI scan data. The upper arm length was matched with the UMTRI targets with a 3D printed humerus bone and matching 3D printed external flesh. For lower arm and hand, Hybrid III small female components were used. SENIORS contributed development of upper and lower legs to match design targets. The designs were based on Hybrid III small female legs, but femur and tibia were increased in length by 8mm and 24mm. External soft tissue matching UMTRI geometry was developed and 3D printed in soft polymers. Hybrid III small female knees and feet were used to complete the lower extremities. Instrumentation to monitor injuries, with total count of 63 channels, include: accelerometers in head, thorax, T12 and pelvis; load cells in neck, spine, iliac wing, femur and tibia; displacement sensors in chest, abdomen and knees.

Further work. The EATD is still under development. SENIORS testing identified necessary updates. Work will continue to establish further biofidelity targets based on human body CAE models and testing and tuning of the dummy hardware.

FLEX-PLI with UBM

Motivation. The current regulation on pedestrian safety UN-R 127.01 using Flex-PLI assesses lower leg and tibia injuries, but femur injuries are lacking. With introduction of an Upper Body Mass (UBM) mounted on existing FLEX PLI pedestrian legform, femur injuries can also be assessed. The UBM is needed to simulate a portion from the inertia of the torso mass, hip joint rotation and the response time lag between leg and upper body, in order to produce a more human-like leg response. The assessment of the femur injuries and assessment of vehicles with a higher bonnet leading edge (BLE) have become feasible with the introduction of the UBM.

Description. The Upper Body Mass Assembly consists of the steel Upper body Mass, a Urethane Cover simulation pelvis flesh, and a flexible rubber joint containing two steel wires. A base plate is the interface to the existing FLEX-PLI, with an integrated launch guide. The total additional mass of the assembly is 6.9kg. The new tool also improves the test method at the end of the bumper test area, bringing it closer to human-like lower extremity kinematics and loading. The key benefit is that the UBM can be added to the existing standard Flex-PLI hardware being used in the current test procedures. The Flex-PLI UBM showed improved kinematics and biofidelity, less rotation on bumper corner. An FE model of the FLEX-UBM was developed.



Future work will include development of femur injury criteria and a certification test for the flexible joint. The FlexPLI-UBM FE model is currently being validated against a selected load case and will be further validated against additional load cases as they become available.

3.1 Work Package 1 - Accidentology and Behaviour of Elderly in Road Traffic

3.1.0 Overview and Interaction of the WP within the project

The main goals of this work package were to:

- Identify the most critical accident scenarios and injuries sustained as well as the transport modes that represent a higher risk for the older road user in order to provide the key starting points in the project and to derive safety strategies for the following work packages;
- Understand the characteristics of the most common and critical accidents involving elderly road users;
- Study the effect of this different modal split on road safety in order to correlate mobility with fatalities and injuries.

The key steps to reach these goals are shown in Figure 2.

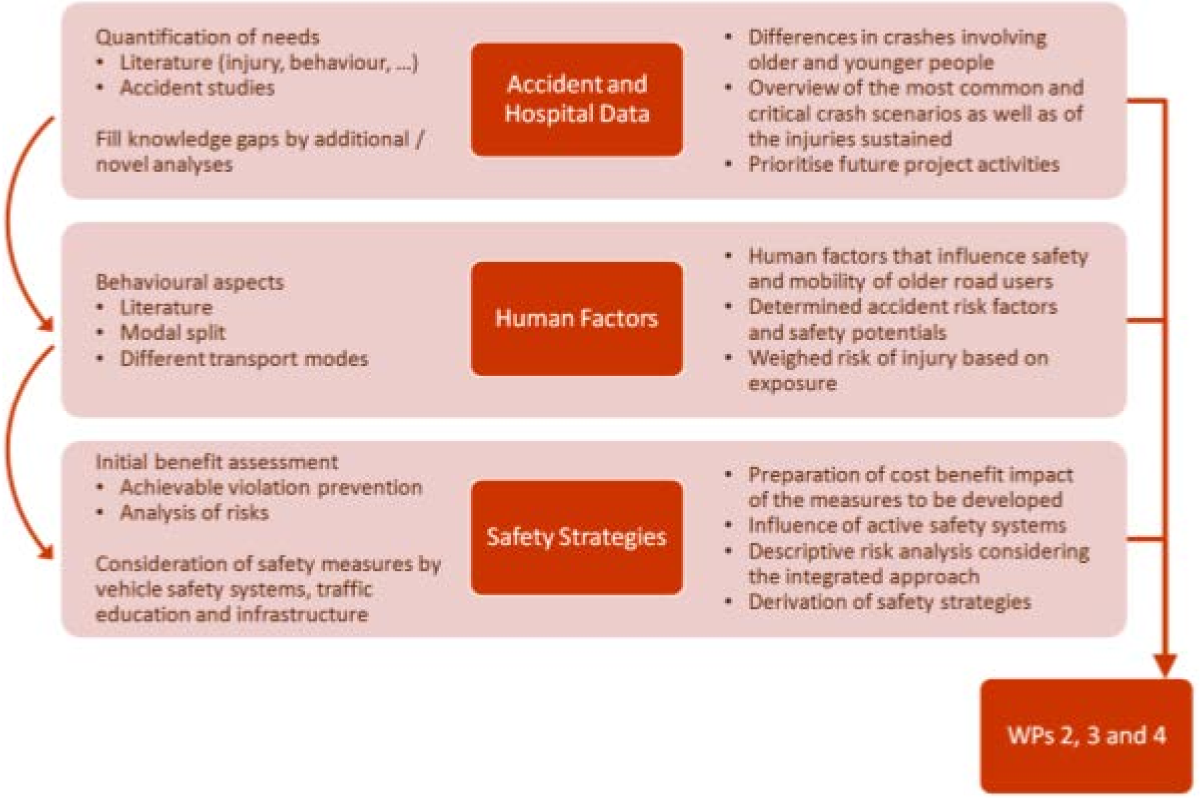


Figure 2: Overview Work Package 1

Work package 1 is subdivided in four tasks:

Task 1.1	Road traffic accidents involving the elderly in Europe	[M1 – M3]
Task 1.2	Novel information	[M3 – M8]
Task 1.3	Behavioural aspects of elderly as road traffic participants within the common modes	[M3 – M12]
Task 1.4	Elderly as participant in road traffic accidents and derivation of safety strategies	[M10 – M14]

WP1 contained two milestones and three deliverables close to its temporal end, see Figure 3.

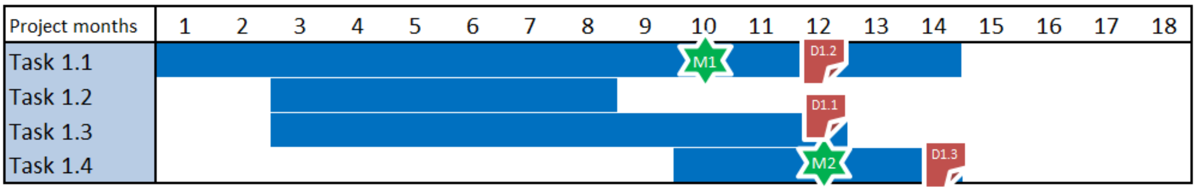


Figure 3: Original Timeline Work Package 1

3.1.1 Task 1.1: Road traffic accidents involving the elderly in Europe

Completed and reported in project period 1.

3.1.2 Task 1.2: Novel information

Completed and reported in project period 1.

3.1.3 Task 1.3: Behavioural aspects of elderly as road traffic participants within the common modes

- Completed and reported in project period 1.

3.1.4 Task 1.4: Elderly as participant in road traffic accidents and derivation of safety strategies

This Task was delayed to the second project period.

The objectives of this Task were to:

- Identify safety measures already taken for older road users;
- Descriptive analysis of the risks of elderly in road traffic considering the integrated approach and regarding safety improvements from vehicle technology, infrastructure and behaviour;
- Understand potential impact of the implementation of the measures to be developed in SENIORS; and to
- Prepare basis to estimate benefit of the developed tools, systems and identified synergy effects.

<u>**Analysis of Euro NCAP data and results from ASSESS and AsPeCSS**</u>

Automatic emergency braking systems for vehicle-to-rear-end-vehicle accidents are already in production since 2003 and have been considered in consumer testing by Euro NCAP since 2014. These look-ahead systems assess the risk of a collision with another vehicle and brake automatically if needed to mitigate or even avoid an accident. The basic requirements for the related Euro NCAP tests were also based on results from the European FP7 project ASSESS. However, in all related activities, neither modern passive vehicle safety measures nor the integrated safety approach were sufficiently taken into account for the final assessment.

Technology has made great progress in the last decade, and today also systems for avoiding or mitigating vehicle-to-pedestrian-accidents are within reach with first systems already on the market. Euro NCAP started to test pedestrian Automatic Emergency Braking Systems (AEB) from 2016 on. Test procedures for these tests had been developed by and discussed between the European FP7 AsPeCSS project and other initiatives (e.g. the AEB group with Thatcham Research from the UK). The test and assessment results of five cars that had been tested by BASt in cooperation with the respective vehicle manufacturers plus a literature study allowed to perform own calculations mainly based on the speed reduction capabilities.
AsPeCSS has also revealed that the best test result – in this time still one year ahead of the test implementation - was around 80% of the test programme, while the worst rating result was around 10%. Other vehicles were between these boundaries.
In AsPeCSS the integrated safety approach was taken into account; however, no modern passive safety technologies were considered.

<u>Safety measures and derivation of safety strategies</u>

The currently running H2020 project SafetyCube was also found as a valuable source for information as it includes a review of already implemented safety measures considering infrastructure, vehicle safety systems and traffic education related to elderly.

The report “ElderSafe – Risks and countermeasures for road traffic of elderly in Europe” (Polder et al., funded by the EC, 2015) was found as valuable input for this Task. Herein coherences and definitions have been described that were considered valuable to be taken over by SENIORS as well. This includes for example:

- <u>Exposure:</u>
  - Urban roads,
  - Rural roads,
  - Transportation mode: car driver, car passenger, PTW-user, pedestrian, cyclist, public transport user.
- <u>Accident risk:</u>
  - Illnesses/functional limitations,
  - Medication,
  - Risk taking/distraction,
  - Self-regulation.
- <u>Injury risk:</u>
  - Fragility.

The document specified the following risk domains requiring prior attention for strongest impact on the reduction of serious road traffic casualties receiving also a strong support by the public in terms of countermeasures:

- Fragility
- Illnesses and functional limitations
- Urban roads
- Pedestrian
- Medication

Further, policy recommendations were given highlighting “Vehicle & ITS technologies”. Within this, it was stated that “Advanced vehicle technologies or driver assistance systems can help the elderly to stay mobile in a safe way by assisting them to compensate for their age-related functional declines”. This statement supports the SENIORS strategy as it is aimed to obtain age-friendly vehicles in future. Further, the introduction of standardized testing procedures to assess advanced vehicle technologies for older drivers will lead to the design of smart vehicle safety technologies adapted to their needs and individual characteristics. Finally, the promotion of new passive vehicle safety technologies will increase the SENIORS project impact.

The described principle “Design for all” covers also the SENIORS approach: “This approach takes the specific needs, opportunities and limitations of different road users into account. As a result, these measures will not only enhance the road safety and mobility of the elderly; younger road users will also benefit from an age-friendly design.”

SENIORS also covers various of the suggested actions for research institutes such as:

- To better understand the accident circumstances in which older road users are involved and propose effective countermeasures,
- To explore the impact of innovative transportation means such as electric vehicles, pedelecs (e-bikes) and intelligent bikes on elderly safety;
- To explore the exposure patterns of elderly road users; and
- To evaluate the effectiveness of countermeasures to improve older road user safety.

However, SENIORS needs also to inform extensively about the potentials of passive vehicle safety technologies as for example the ElderSafe project came up with an questionable and outdated statement on passive vehicle safety technologies: “Since 1996, the European Commission regulates that the car manufactures need to apply minimum requirements regarding the safety of car occupants (CEE 96/79, CEE 96/27…). In this context, several technical solutions were developed and are now applied within the automotive market. These passive safety solutions can no longer be considered as innovative, because these solutions are already present in all vehicles. Therefore, these technologies will not be discussed in this section. Instead, the focus of this section lies on the effectiveness of Advanced Driving Assistance Systems (ADAS) with respect to elderly driver safety.”

3.2 WORK PACKAGE 2 - BIOMECHANICS

3.2.0 Overview and Interaction of the WP within the project

The main goals of this work package were to:

- Define biomechanical requirements for older car occupant and external road user surrogates;
- Understand the effect of pre-collision muscle action on the kinematics of older drivers compared with other age groups, in simulated and real driving environments;
- Update human body models to account for age-related biomechanical changes (e.g. tissue strength and geometry);
- Develop new injury criteria and risk functions for the thorax that are applicable to the protection of older car occupants in low-medium severity collisions;
- Develop new injury criteria for updated pedestrian lower extremity and head-neck impactors, and evaluate the potential to use the thorax of a car occupant ATD as an impactor to assess the risk of pedestrian/cyclist thorax injury.

Work package 2 was subdivided into six Tasks:

Task 2.1	Biomechanical requirements for new or updated test tools	[M1-M4]
Task 2.2	Elderly people muscular reaction in virtual and real environment	[M4-M12]
Task 2.3	Improved IRC for car occupant applicable to low-to-moderate severity collisions relevant for serious injury to elderly car occupants	[M8-M18]
Task 2.4	Updated Human Body Model (HBM) taking into account age-related changes and obesity	[M12-M22]
Task 2.5	Injury criteria for external road users	[M6-M26]
Task 2.6	Injury risk statistics	[M18-M25]

WP2 contains three milestones (MS3-MS5) and five deliverables (D2.1-2.5). One of the three milestones and three of the five deliverables have been submitted in the first period, see Figure 4.

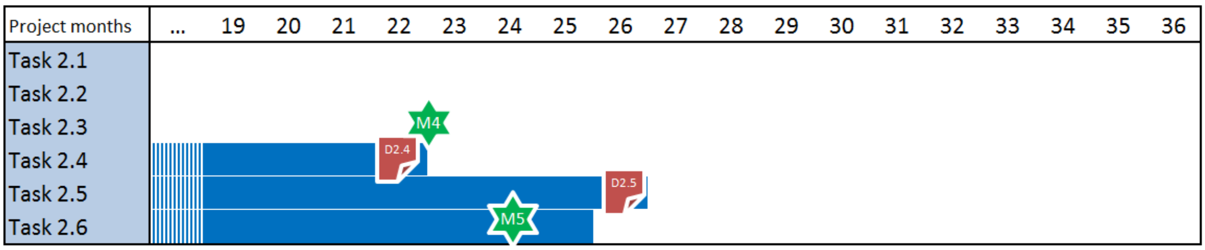


Figure 4: Original Timeline Work Package 2

3.2.1 Task 2.1: Biomechanical requirements for new or updated test tools

This Task had been completed within the 1st project period.

3.2.2 Task 2.2: Elderly people muscular reaction in virtual and real environment

This Task had been predominantly completed within the 1st project period. Remaining tests were performed and reported within the second project period.

3.2.3 Task 2.3: Improved IRC for car occupant applicable to low-to-moderate severity collisions relevant for serious injury to elderly car occupants

In Task 2.3 new multi-point chest injury criteria and risk functions for the frontal impact dummy THOR were developed for improved thoracic injury risk assessment applicable to low-to-moderate severity collisions relevant for serious injury to elderly car occupants.

The main motivation for this work was that thorax injury is still one of main causes of serious injury in frontal collisions. This trend is even more significant for elderly car occupants. Dummies are used to assess the risk of injury in legislative and consumer crash test and assessment procedures. The anthropometric test device (ATD) THOR-M provides chest deflection measurements at multiple locations, which show the potential for improved assessment of the risk of thorax injury. For this purpose, risk functions are needed that relate the potential criteria based on multi-point chest deflection measurement to injury risk.

Several thoracic injury criteria and risk functions for the THOR ATD have been published over the last years. These criteria and functions are mainly based on sled tests with matched ATD and PMHS test data. By relating the injury outcome (i.e. number of fractures) from PMHS tests to injury criteria calculated from ATD deflection measurements in tests performed in matching loading conditions, risk curves are derived. While this approach is not new and has been the basis for the existing THOR injury risk functions, some limitations have been identified in previous projects. In particular the concerns are related to the loading conditions of the data used (mainly three-point-belt loading, but with out-of-date seat-belts that give a high loading severity that is not representative of the restraint systems in modern cars). Other studies like the THORAX project covered broader loading conditions, but used out-of-date ATD versions. Thus, building up a new data set addressing all these requirements is very challenging.

The innovative approach developed in SENIORS is shown in Figure 5. The main idea is to generate a new set of data based on extending the range of loading conditions making use of a computer simulation-based approach. As the new dataset was based on updated versions of the THOR dummy, this methodology also overcomes the limitations described before. This new approach was based on matched frontal impact sled computer simulations with a model representing the latest THOR-M ATD version, and matching simulations with a human body model (HBM) representing an elderly car occupant.

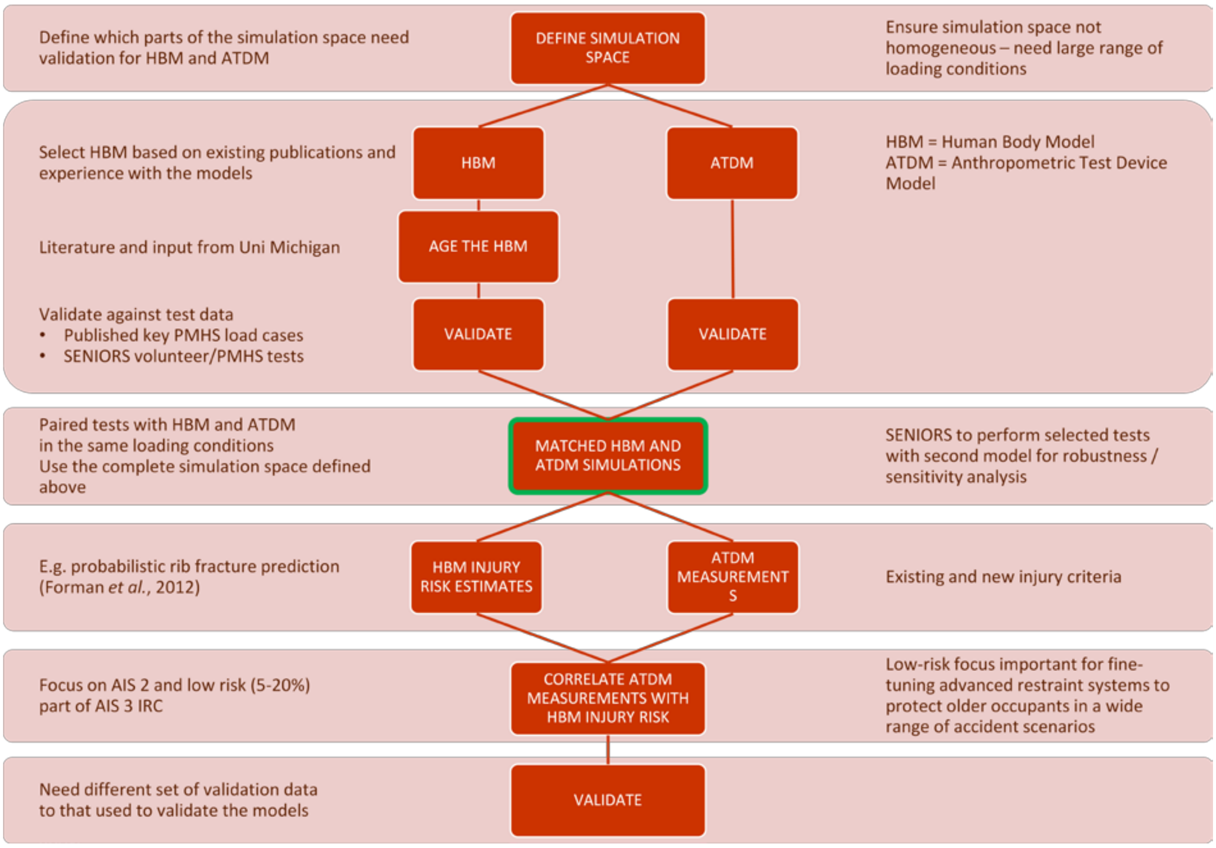


Figure 5: SENIORS approach for improved car occupant thoracic injury criteria and risk functions

To compare output from the THOR dummy and the HBM, a simulation matrix was defined (see Figure 5) to cover a broad range of matching loading conditions using load cases from the literature, e.g. tests based on simplified rigid occupant test fixtures. For these load cases, ATD and matching PMHS test data were available for validation of the ATD and HBM simulations. Furthermore, the experimental test set-up and computer simulation model were available. Also within SENIORS, a new simplified generic - but representative - sled set-up was developed (Figure 6). This generic test set-up was tuned by HBM simulations and tests and simulations with THOR to be much more representative of modern vehicle occupant restraints compared to previously simplified sled test set-ups reported in the literature.

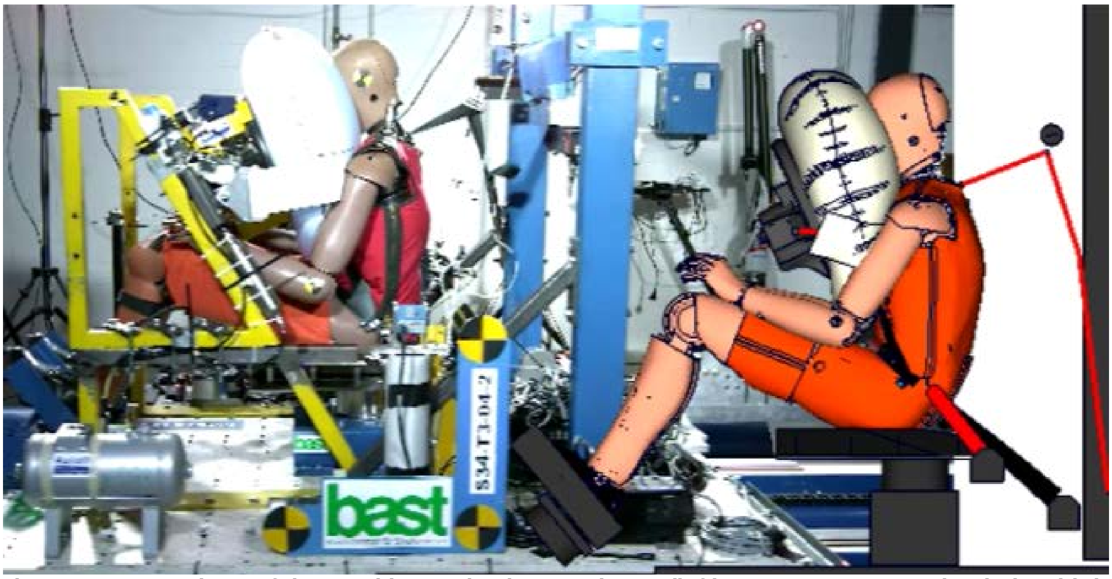


Figure 6: Comparison of dummy kinematics in experiment (left) versus computer simulation (right) in the SENIORS generic sled test set-up

Based on the existing load cases from the literature, an extended simulation matrix was defined by variation of test parameters and conditions. The parameters comprised: impact severity with acceleration pulses between 25 km/h and 56 km/h; impact direction (frontal, far and near side oblique), variation of restraint systems, including loading conditions with and without airbag, with and without pretensioner; variation of three-point-belt load limiter level (no load limiter, high variations of different load limiter levels); and loading by alternative restraints, such as four-point belts or split buckle (Figure 7 and Figure 8).

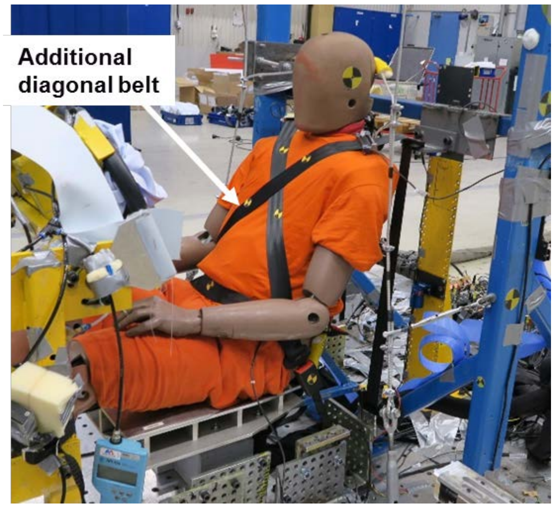


Figure 7: 3+2 two-retractor criss-cross belt with triple pretensioning.

Figure 8: Split buckle belt with triple pretensioning.

The HBM used for this study is a modified version of THUMS-TUC. The modification consisted of material and geometry changes to the rib cage to represent a 64yo+ car occupant (Figure 9). A rib strain-based probabilistic fracture risk prediction method was applied with THUMS-TUC to predict for each load case an injury probability of sustaining equal or more than one, two or three fractured ribs. A strain-based deterministic method was also used to predict the number of fractured ribs in each load condition.

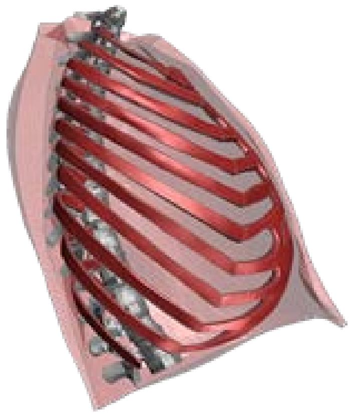


Figure 9: THUMS TUC 65+yo morphed rib cage

Matching simulations with THOR-M were conducted. Care was taken to position the ATD as similarly as possible, matching to the HBM in the sled environment by matching the H-point and aligning the front part of the chest. Based on the rib fracture predictions from HBM simulations and injury criteria from ATD simulations, logistic regression models were used to create injury risk functions.

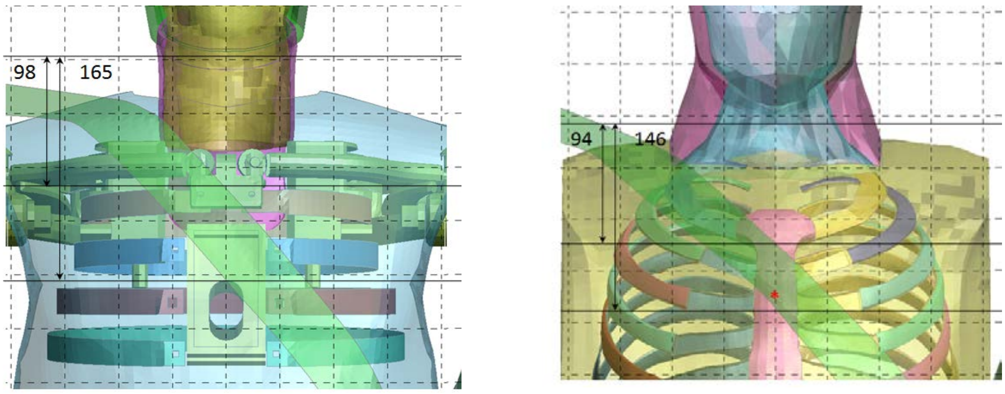


Figure 10: Belt position w.r.t. chin of THOR (left) vs. THUMS TUC (right) with 65+yo-old rib cage

Comparison of the ATD and HBM output in terms of predicted injury and dummy deflections to the experimental results in the literature showed reasonable agreement to provide sufficient confidence in this simulation-based approach. However, it also indicated the need for further improvement of the occupant simulation models and the rib fracture prediction method.

New PMHS tests have also been conducted to validate the HBM based probabilistic rib fracture prediction method and eventually the new dummy-specific chest injury metrics. The sled tests with PMHS have been carried out in the SENIORS generic sled set-up Figure 11. The test conditions (belt, airbag and other restraint parameters) were fine-tuned before the tests in THOR and THUMS human body model simulations. This enabled a successful second series of PMHS tests resulting in the desired severity in terms of thoracic injury outcome (number of fracture ribs) in the PMHS tests (Figure 12).

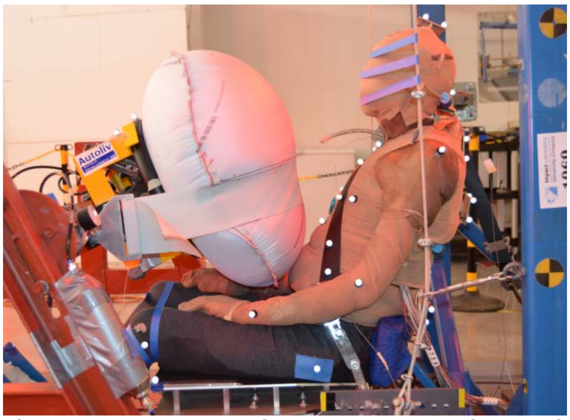


Figure 11: PMHS tests in SENIORS generic test rig

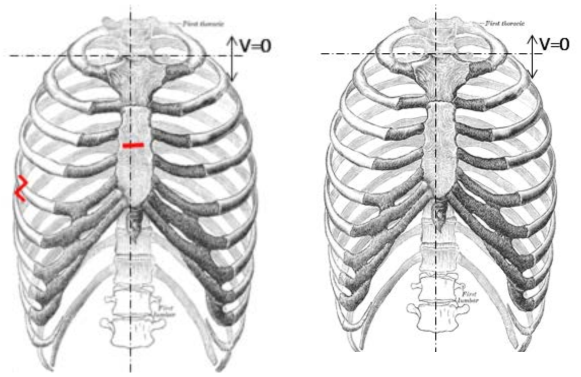


Figure 12: SENIORS PMHS autopsy results (between zero and four rib fx in second test series

The matching simulations with THOR and HBM in various loading conditions resulted in chest deflections and PC Scores covering a broad range. The results for the HBM predicted risk also showed a broad range of injury levels. The main objective of this simulation-based approach was achieved, i.e. to address one major limitation of current experimental-based testing data sets. The results represent a broader range of chest loading patterns in terms of peak and differential deflection indicated by a wide range of R_{max} and PCA values.

New PC Scores were developed based on the extended SENIORS data set. With the existing criteria and the new PC Scores, new risk curves relating the criteria to AIS thoracic injury and to a probabilistic risk for a certain number of rib fractures were developed. The results regarding new risk curves look very promising. Example risk curves are shown in Figure 13 (based on deterministic HBM rib fracture assessment) and Figure 14 (based on probabilistic HBM rib fracture assessment).

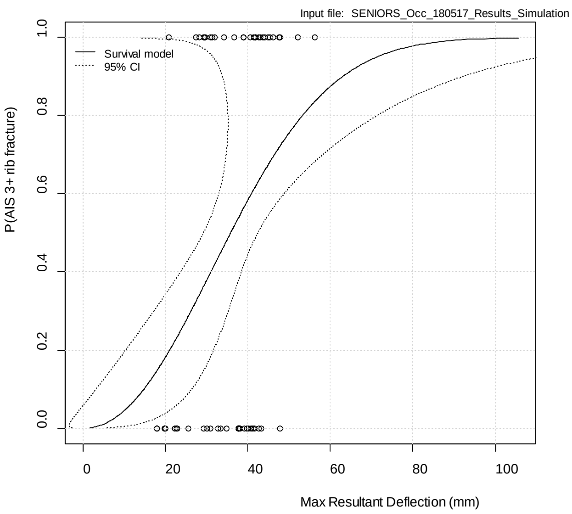


Figure 13: Weibull survival model for AIS 3+ rib injury (NFR 3+), full dataset, maximum resultant chest deflection

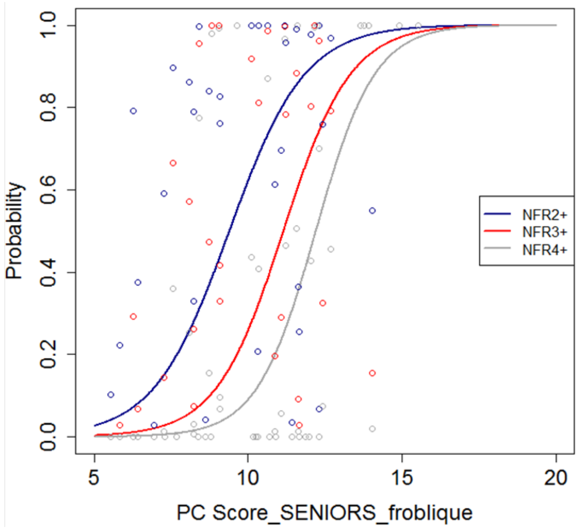


Figure 14: Probability of sustaining two or more (2+), three or more (3+) or four or more (4+) fractured ribs per the injury criterion PC Score_SENIORS_froblique (all 57 load cases)

Limitations of this approach can be seen in the need for an improvement of the validity of the applied simulation models (ATD and HBM) and the rib fracture prediction approach. Therefore, it is recommended to repeat the defined simulation plan of extended loading conditions with an improved version of the ATD model that has recently become available and also improved HBM versions. Matching simulations with a different HBM are also recommended to confirm HBM predicted injuries.

Furthermore, based on the achieved results the conditions defined in the simulation matrix should be evaluated to decide whether to further extend the simulation space or remove loading conditions. Regarding the work on improved multi-point criteria it is recommended to develop and evaluate a multi-component version of the PC Score to take further advantage of the extended data set.

3.2.4 Task 2.4: Updated Human Body Model taking into account age-related changes and obesity

Updated improved Human Body Models (HBMs) were developed to be used in subsequent Tasks and Work Packages of this project and beyond. In particular human models were developed with an updated thoracic rib cage taking into account relevant changes due to aging, HBMs with active muscles representing elderly car occupants and improved pedestrian human models. Furthermore some studies were carried out to investigate the relevance of age and overweight/obesity related to occupant safety.

The work on updating an HBM in terms of eldery rib cage was implemented in the THUMS TUC occupant model. This model was updated regarding age-related material changes and rib cage geometry. The two most relevant material parameters (costal cartilage stiffness and cortical bone thickness) were implemented in THUMS TUC and also in a second occupant model the GHBM model.

The geometry modification of the rib cage were done based on data from medical imaging (CT scans) of almost 1,000 subjects. The data was parameterised according to geometrical two- and three-dimensional rib parameters. Based on this data a geometry was chosen that best fitted an elderly (65+ years) person in most parameters. This geometry was implemented in the HBM, see Figure 15.

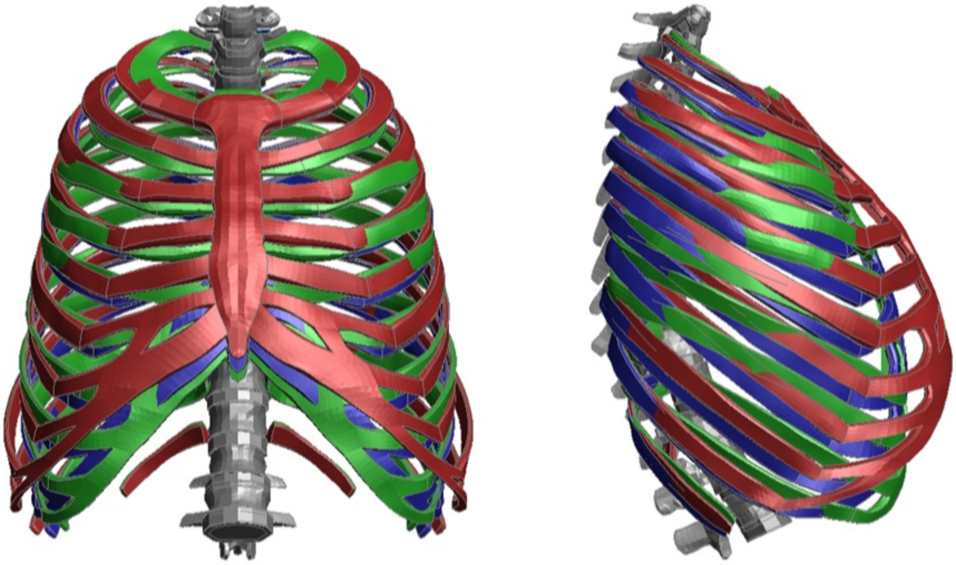


Figure 15: Overlay of the morphed rib cages (blue and red) in comparison to the original THUMS TUC V3.0.1 (green)

Table-top and sled simulations with the aged model taking into account geometry and material changes indicated that age-related modifications show low effect on stiffness response, but have an effect on rib peak strain, which is the most important predictor for rib fractures. Based on this finding it was decided to use the aged HBM including the proposed material and geometric changes for further investigations related to rib fracture risk within the subsequent tasks of the SENIORS project.

Volunteer tests were carried out to investigate the active muscle response in a real controlled and a virtual environment. The data collected during the experiments simulating hazard and sudden braking situations include information about muscle activations, forces applied and e.g. movements of certain body regions. Hereby, major differences between elderly and young, as well as male and female, were reported.

Based on volunteer test data an elderly active human body model was developed to predict the response of elderly occupants during braking events as current primary consequence of the potential activation of an Automatic Emergency Braking system. Simulations were performed with the elderly active human body model in emergency braking events for two individual volunteers, one average and one outlying volunteer. The correlation of the model output against experiments looks promising, but still shows room for improvement. The updated elderly active human body model can be used in further studies of pre-crash events.

An updated improved pedestrian HBM was developed focusing on the enhancement of biofidelity as well as stability and robustness. The biofidelity improvement was focused on head kinematics and bumper forces. The predicted head velocities of the updated model showed improved biofidelity and bumper contact forces were well predicted by the updated model.

To investigate the relevance of overweight/obesity a literature study and a simulation-based study were performed. The literature study pointed out various particularities related to overweight for example lower rib angle. It is recommended to consider all these factors in an occupant model representing an overweight person.

The simulation study was conducted in a frontal impact sled load case comparing a standard small female occupant model with a modified obese small female occupant. It showed that for the small female obese in the middle seat position only a small distance was left between the head and the instrument panel indicating increased risk of bottoming-out the airbag, which would greatly increase the risk of head injury. Also neck forces and moments were higher compared to the average male dummy in some seating positions. Based on this it can be recommended to use an occupant surrogate geometrically representing an obese person to further investigate this issue.

3.2.5 Task 2.5: Injury Criteria for external road users

Injury patterns of pedestrians and cyclists derived from the German In-Depth Accident Study (GIDAS) show a trend of AIS 2+ and AIS 3+ injuries getting more relevant for the thorax region in crashes with newer cars (Wisch et al., 2017), while maintaining the relevance for head and lower extremities. Several crash databases from Europe such as GIDAS and the Swedish Traffic Accident Data Acquisition (STRADA) also show that head, thorax and lower extremities are the key affected body regions not only for the average population but in particular for the elderly:

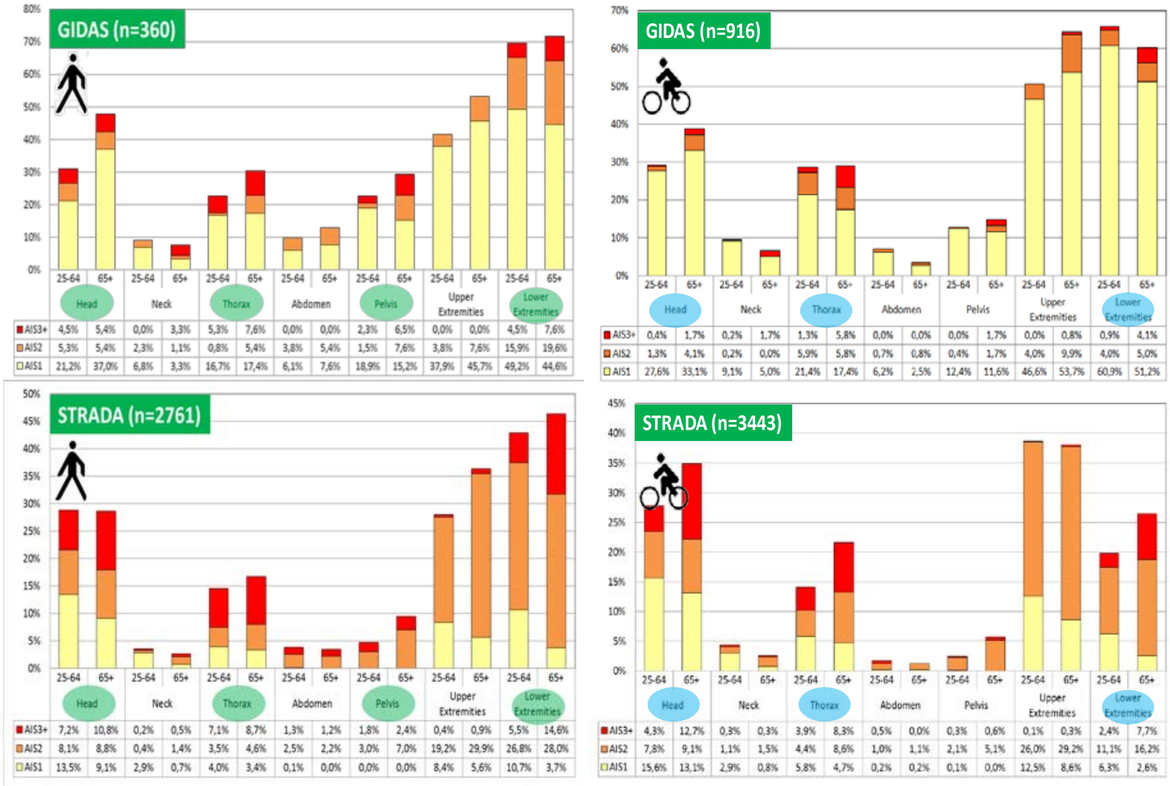


Figure 16: Percentages of injury severities for the different pedestrian body regions within GIDAS and STRADA. Each column adds up to 100 percent by adding all percentages from AIS0 to AIS9.

Therefore, the SENIORS project focused on an improvement of currently available impactors and procedures in terms of biofidelity and injury assessment ability towards a better protection of the affected body regions, incorporating previous results from FP 6 project APROSYS and subsequent studies carried out by BASt. New FE impactor models have been developed and existing impactors have been revised, see Figure 17 and Figure 18.

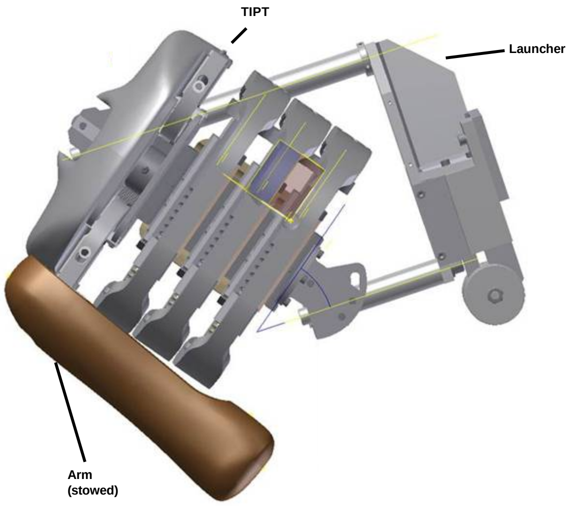


Figure 17: Thorax Injury Prediction Tool (TIPT), jacket not shown.

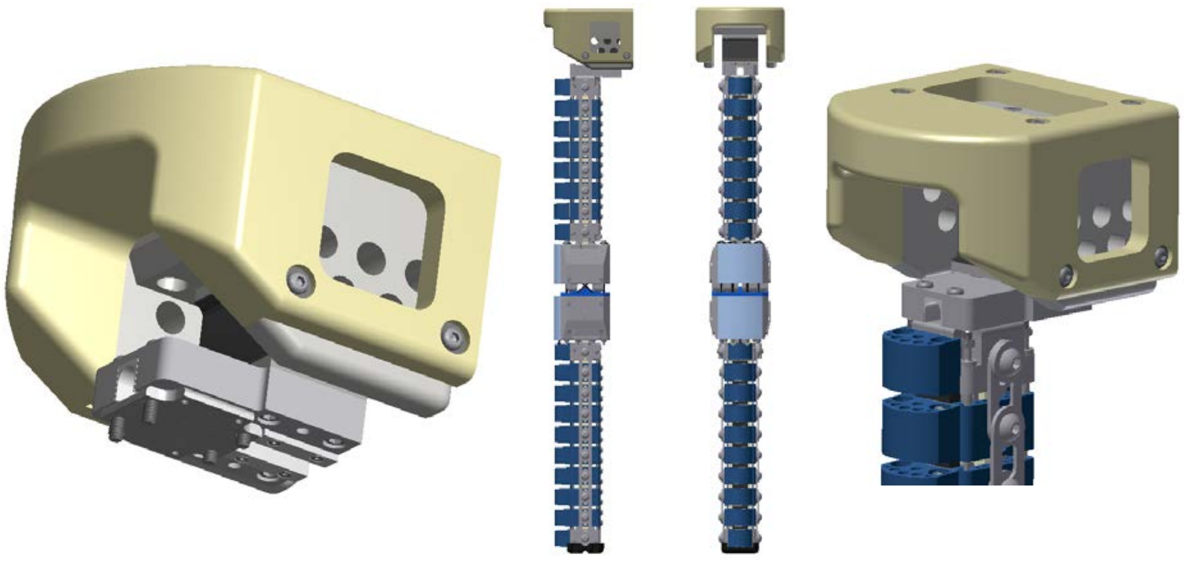


Figure 18 FlexPLI with upper body mass with flexible connection (FlexPLI-UBM$_{rubber}$).

Injury criteria for head, thorax, femur, knee and tibia as mostly affected body regions have been reviewed and modified where necessary, not only for the average population, but in particular for the elderly, see Figure 19:

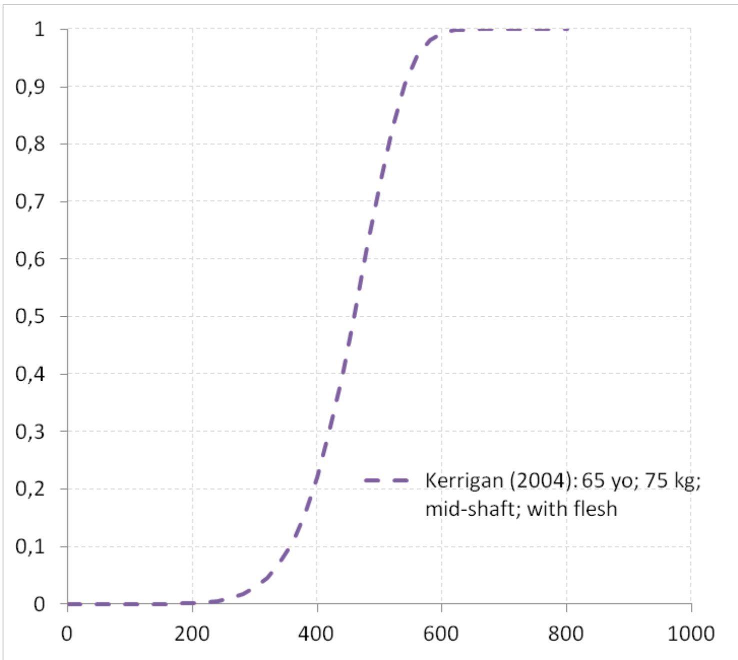


Figure 19: Injury risk curve for femur bending moment, based on analysis of data from Kerrigan et al., 2004

Paired human body model and impactor simulations against generic test rigs provided first transfer functions that were considered for the derivation of impactor criteria from human injury risk functions for the affected body regions.

The work contributed to an improved protection of vulnerable road users focusing on the elderly. The use of advanced human body models to develop applicable assessment criteria for the revised impactors was intended to cope with the paucity of actual biomechanical data focusing on elderly pedestrians. In order to achieve optimized results in the future, the improved test methods needed to be implemented within an integrated approach, combining active with passive safety measures.

In order to address the developments in road accidents and injury patterns of vulnerable road users, established test and assessment procedures needed to be continuously verified and, where needed, to be revised. The demographic change as well as changes in the vehicle fleet, leading to a variation of accident scenarios, injury frequencies and injury patterns of vulnerable road users, were addressed by the work provided by the SENIORS project, introducing updated impactors for pedestrian test and assessment procedures. Deliverable D2.5b provided injury criteria that were introduced for the pedestrian thorax and current injury criteria that were revised and adapted to the needs of the elderly.

3.2.6 Task 2.6: Injury risk statistics

In recent years, there has been a move within ISO TC22/SC12/Working Group 6 to develop a standard way of defining injury risk functions (IRF) and curves (IRC). Since the SENIORS project was proposed, consensus has been reached on the adoption of survival analysis in the derivation of an injury risk curve based on supporting biomechanical data. However, so far, implementation of such a process has offered only one covariate (influencing factor) to be used alongside the parameter being measured (i.e. the criterion) and the injury outcome (probability). To be able to account for diversity in the population it is desirable to be able to consider more than one covariate (e.g. age, gender and Body Mass Index). Therefore the research community seeks to develop an appropriate process built around survival analyses to accommodate this.

This Task started in M18 and has commenced with a review of the biomechanical injury risk literature that has been published since the SENIORS project was proposed. This will be used to identify and document the current state-of-the-art so that the project can build on the current best practice.

This Task has created and evaluated new THOR multi-point injury criteria and injury risk functions (IRF) derived from the deterministic and probabilistic outputs of Tasks 2.3 and 2.4. This compared the older occupant human body model (HBM) with the THOR dummy model in simulations of a range of load cases from the literature as well as new load cases from the SENIORS project.

IRF have been calculated and compared for R_{max}, D_{max} and PC Score. The PC Score has been calculated using four different formulations:

- Crandall (2013), as used in NHTSA (2015).
- Poplin, which is an update of the Crandall formulation published in 2017
- SENIORS PC Scores
    - SENIORS_Frontal, which has been formulated using all the 36 frontal (non-oblique) load cases from the SENIORS matched-pair occupant simulations
    - SENIORS_FrOBlique, which has been formulated using all 57 load cases from the SENIORS matched-pair occupant simulations

The simulated injury level, based on the number of fractured ribs predicted in the older occupant HBM, was compared with several injury metrics calculated using chest deflection measurements made with the THOR-M model. IRF were calculated using the R-scripts developed in Task 2.6 of the SENIORS project, with no-covariates. Since 'R' is a free software environment for statistics which is used in several research areas, the main script bodies were made available to all stakeholders (exploitation).

Figure 20 shows the IRF for the maximum resultant chest deflection at any of the four chest measurement points (R_{max}) at the NFR 4+ level, calculated from the full-width dataset (36 samples). The log(scale) Weibull parameter had a p-value of zero.

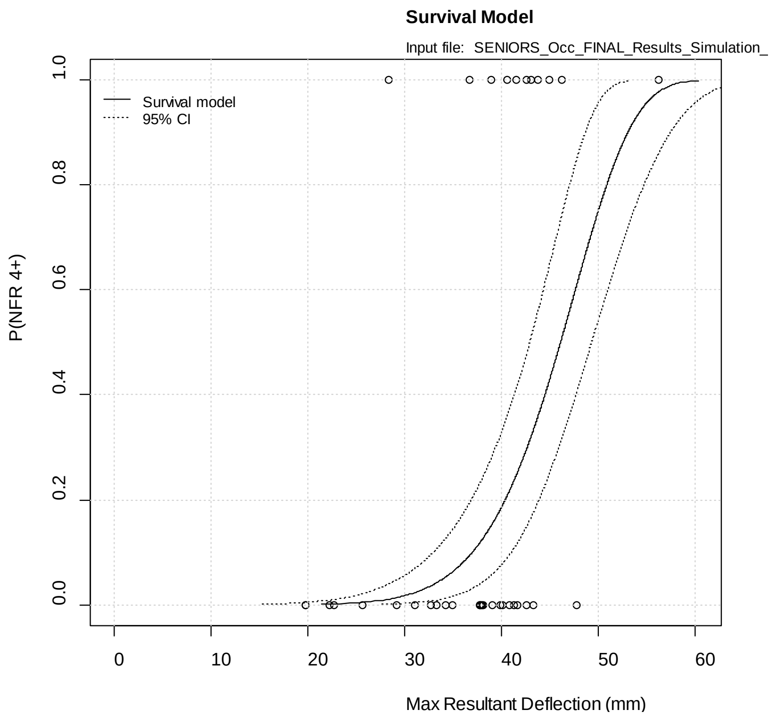


Figure 20: Weibull survival model for NFR 4+, frontal dataset (36 samples), maximum resultant chest deflection

Further, new PC Scores were developed based on the extended SENIORS data set. With the existing criteria and the new PC Scores, new risk curves relating the criteria to AIS thoracic injury and to a probabilistic risk for a certain number of rib fractures were developed. The results regarding new risk curves look very promising.

Limitations of this approach could be seen in the need for an improvement of the validity of the applied simulation models (ATD and HBM) and the rib fracture prediction approach. Therefore, it is recommended to repeat the defined simulation plan of extended loading conditions with an improved version of the ATD model that has recently become available and also improved HBM versions. Matching simulations with a different HBM are also recommended to confirm HBM predicted injuries.

The comparison of risk curves based on R_{max} and the different PC Scores did not show a clear advantage of the PC Score for improved differentiation of injury risk. A high correlation between R_{max} and PC Score was found. The analysis of risk functions suggests that it might be preferable to apply R_{max} for further restraint system evaluation based on statistical significance. However, a further improved multi-component version of the PC Score taking into account more components, which would take full advantage of the extended data set, might lead to different conclusions.

Regarding the work on improved multi-point criteria it is recommended to develop and evaluate a higher order version of the PC Score to take further advantage of the extended data set. For further more on an improved version of the PC score it might be necessary to use four input items and or change the items.

3.3 WORK PACKAGE 3 - TEST TOOL DEVELOPMENTS

3.3.0 Overview and Interaction of the WP within the project

The main goal of this work package was to adopt and modify existing test tools for occupant and pedestrian safety to represent elderly people better as car occupants as well as pedestrians and / or cyclists.

Work package 3 was subdivided in three tasks:

Task 3.1 Design Specifications	[M6 – M12]
Task 3.2 Tool Designs	[M10 – M20]
Task 3.3 Tool Validations	[M10 – M25]

WP3 contains two milestones (MS7 and MS8) and four deliverables (D3.1-3.4). One of the two milestones and three of the four deliverables were completed in the second period, see Figure 21.

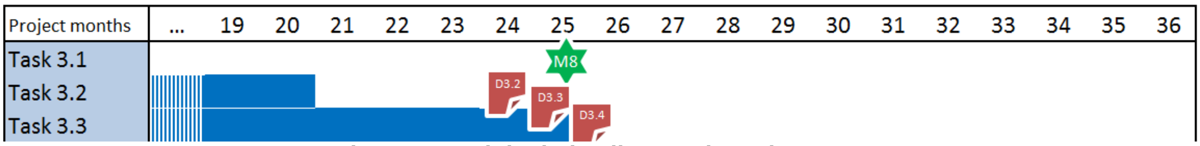


Figure 21: Original Timeline Work Package 3

3.3.1 Task 3.1: Design Specifications

This Task was completed in the first project period.

3.3.2 Task 3.2: Tool design

<u>Elderly overweight dummy (Test and Validation)</u>

Thirteen low speed tests (delta-v 35 km/h) were carried out to assess its validity for elderly occupant protection testing. A further five tests looked at repeatability, again at a delta-v of 35 km/h and five more tests simulating restraint misuse cases in the field. Test setups were repeatable along with deceleration pulse.

<u>Experimental dummy restraint sled tests</u>

Here tests were carried out to investigate the response of the elderly overweight dummy (EATD) to different airbag and seat belt configurations. The aim was to validate the dummy regarding sensitivity to different restraint conditions.

The investigation was carried out by means of mechanical sled tests with the EATD in the SENIORS generic test rig, see Figure 22. This generic buck is comprised of a seat belt system, a rigid seat and a generic driver airbag. The generic driver airbag was pre-inflated to a target value of 19kPa using compressed air and the response was adapted to the impact velocity 35km/h using an active venting device. The venting device was triggered at 10ms which resulted in the opening of the venting hatch starting at 50ms and ending at 60ms. Using an external strap, the depth of the generic airbag was adjusted so that a slight contact was initiated to the chest of the EATD.

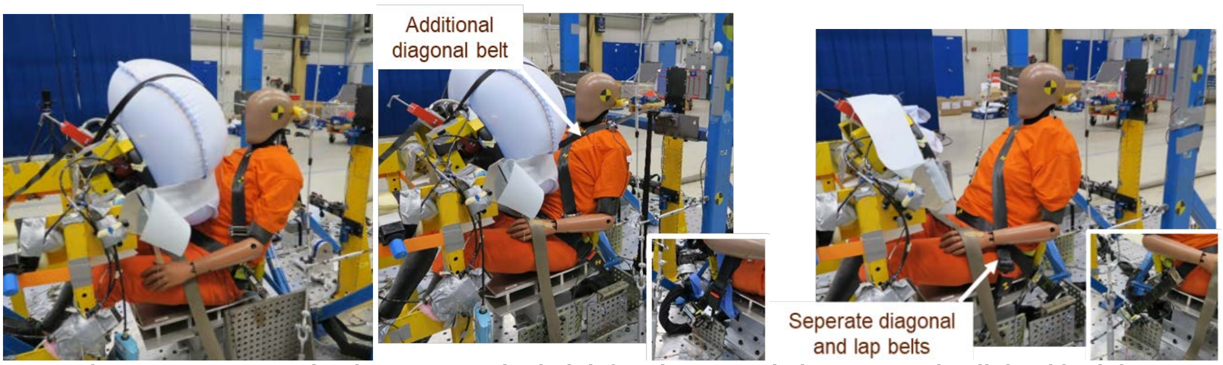


Figure 22: SENIORS buck, EATD 3 point belt left, criss-cross belt centre and split buckle right

The positions of the seat, footrest, steering wheel and the belt system anchorage points were recorded using faro arm measurements. For the tests with generic load limiting, a more rearward position of the two lower belt anchorage points were used. EATD position angles, belt position angles and belt force gauge positions were recorded using tilt and tape measurements. Five belt configurations were tested. The test matrix is shown in Table 7.

Table 7: Elderly, overweight dummy test overview (DAB=driver airbag, LL1-retractor load limiting force high, LL2=retractor load limiting force low, TTF LL2=switch time from high to low limiting force, PLP=pyrotechnic lap pretensioner, RP=retractor pretensioner, LLS=load limiting stop

No	Test No T-17380	Belt Type	Airbag	LL1 (kN)	LL2 (kN)	TTF LL2 (ms)	PLP
1	207	3-pt Generic LL	DAB	2,0	-	-	No pretensioning
2	208	3-pt Generic LL	DAB	2,0	-	-	No pretensioning
3	209	3-pt Generic LL	DAB	2,0	-	-	No pretensioning
4	450	3-pt Belt	DAB	(5,0)	2,0	20	R200 RP LLS
5	444	3-pt Belt	DAB	4,0	-	-	PLP 3.1
6	445	3-pt Belt	DAB	4,0	-	-	PLP 3.1
7	446	3-pt Belt	DAB	4,0	-	-	PLP 3.1
8	449	3-pt 2-ret Belt	DAB	(5,0)	2,0	20	PLP 3.1
9	206	3-pt 2-ret Belt	DAB	(5,0)	2,0	20	PLP 3.1
10	451	3+2 2-ret Criss-Cross	DAB	(3,0)	0,9 + 0,9	20	R200 RP LLS
11	452	3+2 2-ret Criss-Cross	DAB	(3,0)	0,9 + 0,9	20	R200 RP LLS
12	447	Split Buckle	DAB	6,0	2,0	1000	R200 RP LLS + PLP 3.1
13	448	Split Buckle	DAB	6,0	2,0	1000	R200 RP LLS + PLP 3.1

Compared to the reference three-point belt system, the largest reduction in Rmax was obtained with the split buckle belt followed by the criss-cross belt. For the THOR dummy, the largest reduction in Rmax was obtained with the criss-cross belt.

As opposed to the THOR dummy, the reduced loading on the lower torso from the belt systems with enhanced lap pretensioning was not obtained with the EATD due to the larger lower torso and abdomen size. These differences in torso loading indicate that the EATD has the potential as a tool for the development of safety systems which can improve the protection of the overweight population.

For most of the belt systems, the Rmax value was obtained in the lower IR-TRACC positions and thus relatively insensitive to variations in retractor load limiting levels.

Small belt webbing pull-in and short pelvis excursions were obtained using an anchor pretensioner which can be caused by an overly stiff pelvis/abdomen on the EATD. It would be a recommendation to compare the stiffness of the pelvis to an average human subject.

Overall the dummy showed that it could discriminate between the baseline restraint system (3-point belt) and the advanced restraint systems used in this study. These findings indicate that the dummy is sufficiently validated to measure the effect from various loading conditions using advanced belt restraints systems.

Updated pedestrian impactor certification

The aim was to develop certification procedures to ensure test tools are in a repeatable condition before each test series. In SENIORS both the rigid connected UBM and flexibly connected UBM were considered as both are expected to be physically tested to review the best results. The UBM is attached to a standard FlexPLI legform, this legform has well established certification procedures involving quasi static and low and high speed dynamic tests (pendulum and inverse). The leg used in SENIORS showed all the certification results before testing.

For the flexible element rubber part only a hardness test was completed to record and check future parts. A dynamic pendulum test is proposed if this UBM design is selected. This will measure the deflections in the element when subjected to a high decelerating force with a mass attached to the element to swing freely. The force is to be similar to that experienced in a vehicle test.

For the full assembly test an additional inverse test is proposed to load the centre of the femur, see Figure 23. This test is proposed to be additional to the current inverse test to represent the bonnet leading edge of a SUV type vehicle, the type of vehicle the UBM is intended to address. The speed would be the same at 40 km/h as would be the impactor mass (8.15 Kg). The test is called an inverse test as it is the inverse of the vehicle test where the impactor strikes the leg rather than the leg impacting the vehicle. The leg would be hung from wires which would release on impact.

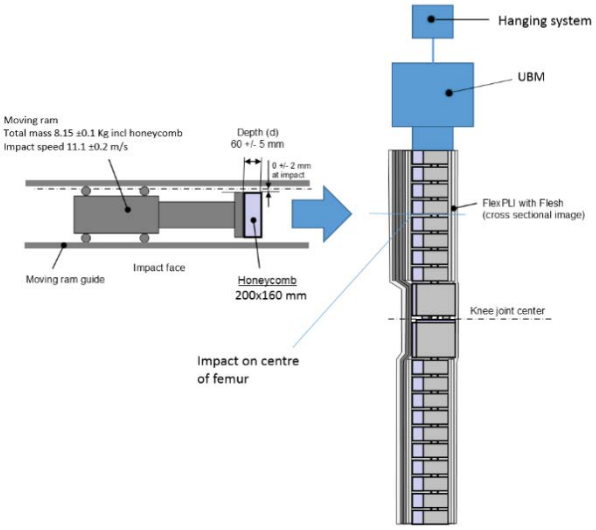


Figure 23: Diagram of secondary inverse test for leg with upper body mass

The UBM required additional attachment brackets to push at the centre of gravity of the UBM. These were attached to the standard fixture. Assembly/dis-assembly details are also provided for both versions on the UBM designs along with a post-test damage check list.

Thorax Injury Prediction Tool (TIPT) certification

The TIPT (Thorax Injury Prediction Tool) also utilises an existing test tool, in this case an ES-2 (Eurosid 2) ribcage. Therefore the ribs are to be certified to the current standard. As this will be a complete test tool on its own (not attached to a dummy) it will need a dynamic certification test.

An inverse type test was proposed, see Figure 24, utilising the FlexPLI inverse test rig with a similar impactor mass for practical purposes as most labs will already have this equipment. This allows the TIPT to be tested in an unrestrained condition as per the vehicle test. To represent the average bonnet impact angle the face on the impactor is 20 degrees. The simulated impact speed is expected to be around 20 km/h this would mean the impactor mass can be higher than the FlexPLI impactor due to the lower acceleration required. Like with the FlexPLI the TIPT would be suspended over its cg using 3 to 4 wires for stability and released on impact. Accelerations and deflections would be recorded. The arm is fitted to the TIPT and if there is a problem with repeatability the arm can be removed.

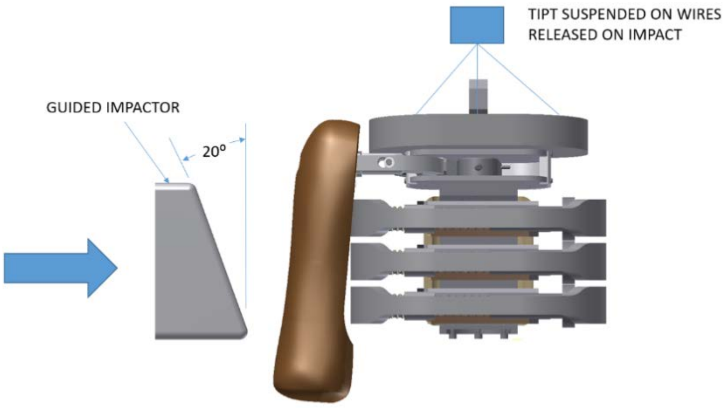


Figure 24: TIPT full dynamic certification setup (suit not shown)

Pedestrian impactors design validation updates

FlexPLI-UBM design validation

Further design considerations were considered in the project to strengthen the standard FlexPLI leg particularly in the femur and knee. However such changes would have affected biofidelity and modification would have caused cost issues for users so were not incorporated. Spares were provided in case of any failure in testing to avoid delays. An exercise to review a design change to the knee was also reviewed in FE simulation to see if these changes would reduce the high un-biofidelic behaviour seen in testing of the ACL and PCL knee ligaments. These simulations did reduce but elongation but very slightly.

It was decided to test both the rigid and flexible UBM designs as both had shown similar performance in simulation. The flexible UBM was designed in SENIORS and followed the rigid APROSYS design for mass. The idea behind putting the UBM on a flexible element was to obtain hip rotation and time lag of the mass as seen in the HBM simulations. The cg was kept low for the UBM in the flexible design to reduce height for bonnet interactions and reduce bending moment stress on the standard FlexPLI leg. It would also help with stable launching against the vehicle. A hanging point to launch the leg was positioned similarly to the rigid design and a cover was added to protect the vehicle and leg against hard contact damage. See Figure 25 for pictures of the flexible UBM design.

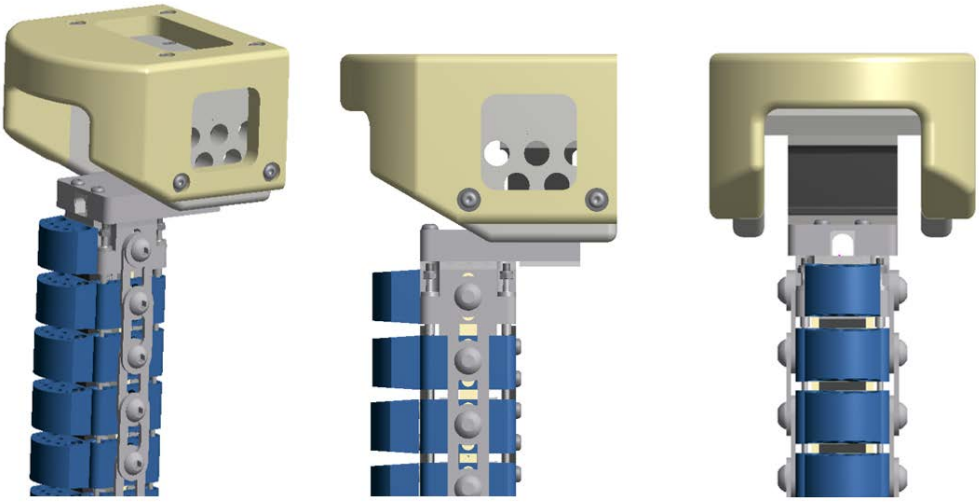


Figure 25: UBM with flexible element assembled to top of FlexPLI (flesh covers not shown)

Regarding the design and manufacture of both the flexible and rigid UBM the parts meet the design specification. This also applies to the new fixtures to launch the leg with the UBM.

Thorax Impactor (TIPT) design validation

Two test labs supplied an ES-2 torso to test. A fixture to adapt the tool to existing guide rails on each partner's launcher guides was designed in SENIORS. The mass of the torso with launch adaptors was around 22kg. Therefore the launcher needed to accelerate a mass of around 26kg as the pusher was expected to weigh around 4kg. The expected impact velocities were between 15 and 21 km/h and pointing downward. This is the torso speed to the bonnet after a 40 km/h vehicle impact to the lower legs.

A special Neoprene jacket covered the TIPT. The arm is to be fixed on the TIPT by sowing the sleeve onto the body of the jacket in a downward position, in line with the spine. This should improve repeatability as the ES-2 dummy arm and shoulder were designed to move away from the impact when inside a vehicle to expose the ribs for injury. Removing the arm could be an option for later testing but some kind of protective cover like a urethane sheet over the ribs would likely be needed to avoid damage.

Design for TIPT launch fixture

Three different launch vectors and three different impact angles were required to test with the TIPT for the sedan, SUV and van/MPV. Therefore the fixture had to be adjustable to accommodate all launch requirements. See Figure 26.

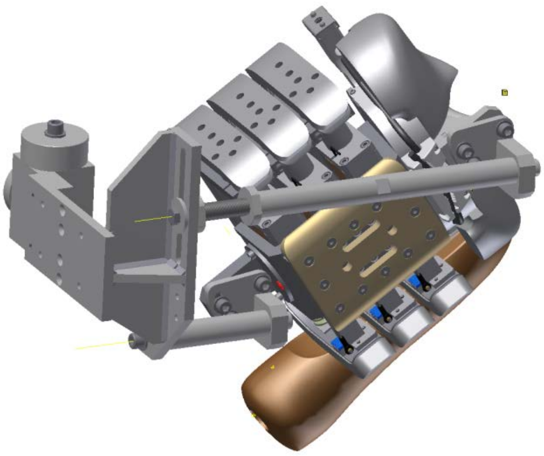


Figure 26: TIPT pusher fixture with adjustable brackets, jacket not shown

The fixture cg needed to match that of the ram and the TIPT itself however the fixture did not have a perfect cg match and therefore created some rotation in free flight. An additional pusher was designed and manufactured in SENIORS. This launched the TIPT perpendicular to the vehicle. This was designed to fire at the grille area of the higher bumper vehicles to represent a struck child but mainly to see the effect of direct loading to the linear deflection sensors on the TIPT. See Figure 27. The cg of this fixture matches the ram and TIPT.

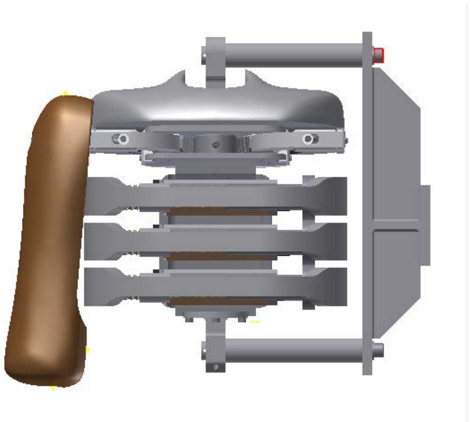


Figure 27: Pusher adapted for parallel launch, jacket not shown

The jacket for the TIPT was adapted from the Eurosid jacket, modified for the TIPT. This had a longer sleeve on the struck side, cut down jacket, sleeve sown in with no struck side sleeve removed and a shorter zip. The jacket provides protection to the TIPT and encourages repeatability with regard to friction. See Figure 28.

Figure 28: TIPT jacket

Only the design has been validated, full validation could only be completed after testing and comparison to Human body model responses. The TIPT meets the design criteria set out in the design specification.

3.3.3 Task 3.3: Test tool validation

Elderly, overweight dummy - Certification

Certification requirements were important to ensure a test tool is in a repeatable condition before a test series and can be checked with the same laboratory processes after testing to ensure the tool is in the same condition. This applies to component parts as well as assemblies and the fully assembled test tool. As the EATD is new there were no established corridors to work to, therefore the initial test results would set a baseline performance.

Head and neck

The EATD uses existing Worldsid 5th percentile head and neck. The certification requirements for these parts are shown in the user manual for this dummy.

Upper thorax certification

This test involves a blunt impact to the upper chest with a 23 kg probe suspended from wires with an impact speed of 4.3 m/s. Figure 29. Both sides of the chest are impacted at the deflection sensor locations, deflections and forces are reported.

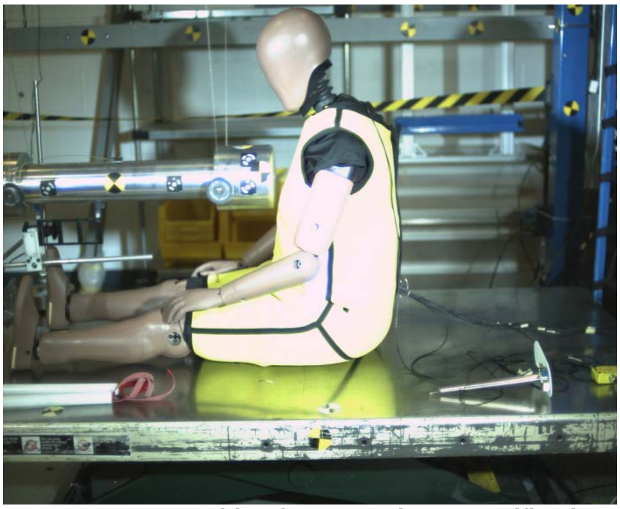


Figure 29: Dummy position for upper thorax certification test

Lower thorax certification

The same 23 kg probe is used on the lower thorax with the same 4.3 m/s speed at impact. The probe is impacted at the centre location of the right hand (liver side) and left hand (spleen side) deflection sensors. Figure 30. Deflections are calculated with respect to the local co-ordinate system. The probe force is also reported.

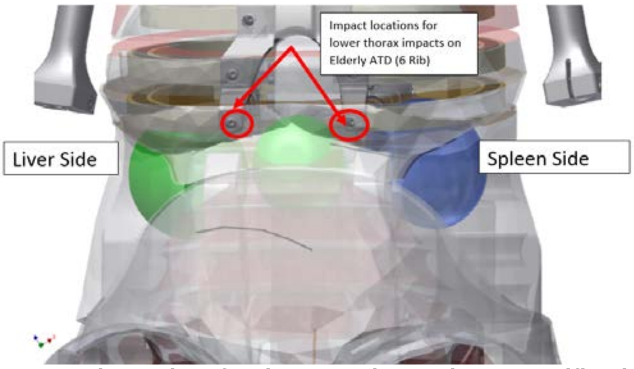


Figure 30: Location points for the EATD lower thorax certification test

Abdomen certification

This test uses a heavier 32 kg probe at a lower speed of 3.3 m/s which has a narrow rectangular impact face to clear the pelvis and load only the abdomen. Deflections are calculated with respect to the absolute value between the left peak and right x-axis deflections in the local co-ordinate system. The probe force is also reported. Figure 31 shows the test setup. Test procedure and data processing is also detailed.

Figure 31: Abdomen certification setup

Lumbar spine and knee certification

Currently there is no lumbar spine test, only a biofidelity test has been performed on the lumbar abdomen region. The knee is a current Hybrid 5th female whose certification details can be found in the HIII 5F user manual.

Dummy procedures

Detailed descriptions and pictures are shown to assist users in all areas of the assembly/dis-assembly, handling of the dummy. A damage check list is provided to inspect the dummy and information on seating the dummy in a vehicle is shown.

EATD re-design
For the EATD the lower legs were redesigned. The tibia was made 24 mm longer while the femur was extended 8 mm. The flesh parts were modified accordingly. Mass increases in the upper leg are compensated by holes in the flesh and a reduction in the steel bone. For the tibia additional load cells were accommodated in the upper and lower regions. As shown in the Figure 32 the new design matches well with the UMTRI anthropometry requirements.

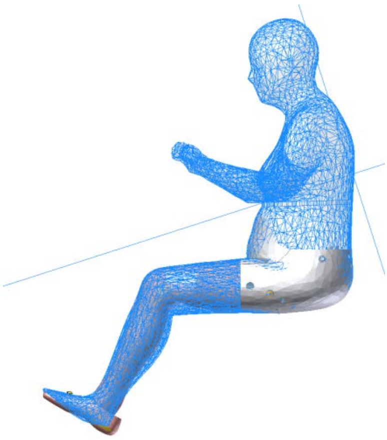


Figure 32: Overlay of 3D UMTRI profile over EATD lower body CAD

In addition, a new suit for the EATD was designed facilitating the belt interactions. The suit was fitted and after two iterations the design was finalised. A first prototype dummy was built in the US and deflection instrumentation was fitted to thorax and abdomen. Some improvements were made to the abdomen but further tuning was to be expected from results in SENIORS to improve the dummy. No simulations could be carried out with the dummy as currently no FE model has been developed due to its recent design.

Biofidelity
The head and neck use existing dummy parts therefore biofidelity is already established although injury criteria for an elderly female would need to be established. For the thorax biofidelity targets still need to be established and the dummy tuned to match. A biofidelity test was carried out on the abdomen region (Hardy 2001) which is a bench test with quasi static belt loading, see Figure 33 with a low and high belt position.

Figure 33: OSU abdominal belt test positions 1 left, position 2 right

In the project only repeatability could be checked which was dynamically carried out in vehicle tests. An issue was picked up during certification as the abdomen could move due to a lack of connection to the pelvis. The pelvis abdomen and pelvis connection is to be redesigned to avoid this. The probe diameter for the lower thorax test was also too large for repeatable testing and it was recommended to have a narrow rectangular probe like that used on the abdomen.

Sensitivity was required so that the dummy could distinguish between good and bad belt occupant restraint systems. The dummy did show sensitivity to these but improvement is required regarding the flesh system and stiffness of the thorax and pelvis.

Regarding the dummy's durability, there were three failures, both upper arms failed at the shoulder joint due to a delamination on a 3D-printed part and a flesh tear in the 3D-printed pelvis flesh. The arms were replaced with new revised printed parts. The tear was late in testing so was not repaired. The 3D printed flesh needed to be more robust.

EATD - repeatability sled tests

Five low-speed tests looking at repeatability were performed with a Body in White (BiW) vehicle structure to establish if results were reliable.

The position of the dummy on the seat was performed in compliance with the requirements of Euro NCAP for the positioning of the HIII 05F (5^{th} percentile) dummy in frontal full-width impact test on driver side. Four off-board high speed cameras (1 kHz framerate) were used to capture the kinematics of the dummy in the sled tests. Dummy position details, all sensor traces and lap belt forces were recorded.

The pulse was correctly obtained with very good repeatability. Head acceleration had good repeatability with the exception of one test. Chest acceleration showed good repeatability except for the first test having a slightly different vertical acceleration.
Chest and abdomen deflections were generally quite low. The first test was similar to the others on the right upper rib and left upper rib but generally higher in other locations. The dummy's behavior was quite similar for all other tests in all body regions, even if repeatability seems worst for abdomen deflections. Furthermore, both on left and right side, abdomen IR-TRACC showed a compression at the beginning of the test, when seatbelt started to load, followed by a marked extension, which could be caused by inertia.

Conclusions

In Table 8 the most important biomechanical parameters are shown. The head, chest and pelvis acceleration have a good repeatability, while the relative standard deviation is higher for the chest (in particular on lower ribs) and, most of all, abdomen deflections. This is partly due to the low values of lower rib and abdomen deflections.

Table 8: Repeatability results standard deviation

	11090_ZG	11091_ZG	11092_ZG	11093_ZG	11094_ZG	**Mean**	**Rel. Std. Dev.**
Head Res. Acc. [g]	39.35	33.66	34.48	35.46	33.22	**35.23**	**6%**
Chest Res. Acc. [g]	27.9	29.94	30.05	29.89	29.46	**29.45**	**3%**
Pelvis Res. Acc. [g]	38	39.61	39.55	37.76	39.43	**38.87**	**2%**
Upper Left Rib Defl. [mm]	11.58	7.16	7.79	8.45	7.72	**8.54**	**18%**
Upper Right Rib Defl. [mm]	12.67	8.89	9.83	12.12	10.47	**10.80**	**13%**
Lower Left Rib Defl. [mm]	4.95	4.61	5.61	4.77	8.67	**5.72**	**26%**
Lower Right Rib Defl. [mm]	14.15	10.78	10.92	10.85	6.17	**10.57**	**24%**
Left Abdomen Defl. [mm]	-4.24	-4.45	-3.53	-2.58	-2.44	**-3.45**	**24%**
Right Abdomen Defl. [mm]	-7.83	-4.29	-2.87	-1.42	-1.75	**-3.63**	**64%**

The first test was shown to have the most variation, and it is also confirmed by the video frames, which show a slightly different kinematics. However kinematics is part of the repeatability, so it must be repeatable when the dummy is accurately positioned.

The EATD also showed to have some durability issues, which are probably due to the materials and technologies used for this prototype. The usage of more conventional materials and technologies as used on the Hybrid III dummy, for example, could probably improve durability. Alternatively the 3D-printed material would need to be improved.

<u>Misuse and D-ring position sled tests</u>

Five belt misuse sled tests were performed with a Body in White (BiW) vehicle structure looking into bad belt positions by reproducing field misuse (seat belt extender) and not optimal D-ring positions on two different vehicles categories: SUV and sedan. The purpose of these tests was to look at the sensitivity of the dummy differentiating between good and bad belt positions.

The five tests are detailed in the report regarding accident occurrence, occupant details, injuries sustained and dummy reconstruction set up in the vehicle. Again positioning details are reported for each case along with sensor result traces.

<u>Conclusions</u>

Considering the standard restraint system used different belt routings seem to have an important effect on upper chest deflections: in general, a higher belt routing resulted in a lower deflection on upper outwards ribs, but causes an increase of upper inwards rib deflection. In case of the SUV, the interaction between the driver airbag and the EATD thorax also caused an increase of upper chest deflection (both on inwards and outwards side), while in case of the sedan, the interaction between the passenger airbag and the dummy chest was weaker.

The use of a seatbelt extender in test 3 may have caused submarining by going over the iliac wing of the pelvis bone.

In general the chest deflections measured in the dummy were low, considering the injuries sustained in the case studies reproduced in tests 1, 2 and 5. The occupant of accident reproduced in test 5 had rib fractures and a neck fracture, the occupant of accident reproduced in test 1 had rib fractures and liver damage and the occupant of accident reproduced in test 2 was fatally injured. Maximum deflection was seen in the reproduced fatal test 2 with 25 mm on upper chest and 17 mm on lower chest. In the real accident reproduced in test 1 the belt was likely not over the pelvis bones and placed on the top of the abdomen which probably caused the belt to submarine into the abdomen area, lacerating the liver. This was not visible in the dummy results with only 7 mm of abdomen compression measured.

Generally, the results suggest that the ribcage system on the dummy is too stiff for the elderly person as these deflections would be considered relatively low. It should also be considered that elderly bones are likely to be more fragile hence the need for lower injury thresholds for the elderly. Currently the EATD lacks a well-established biomechanical biofidelity definition and comparison of the dummy kinematic response. This should be established next to enable comparison of the dummy biofidelity and tune body segment responses to accepted targets.

Pedestrians / Cyclists

The refined impactors were validated by simulations against actual vehicle front-ends. The performed work resumes the results of baseline pedestrian simulations with human body models and impactor models against generic test rigs. For that purpose, subsequent to the work from Work Package 2, various impactor simulations vs. actual vehicle models and a generic SAE Buck and its derivatives (representing a Sedan, an SUV and a Van/MPV frontend) have been carried out and compared to the results from HBM simulations against identical frontends, see Figure 34:

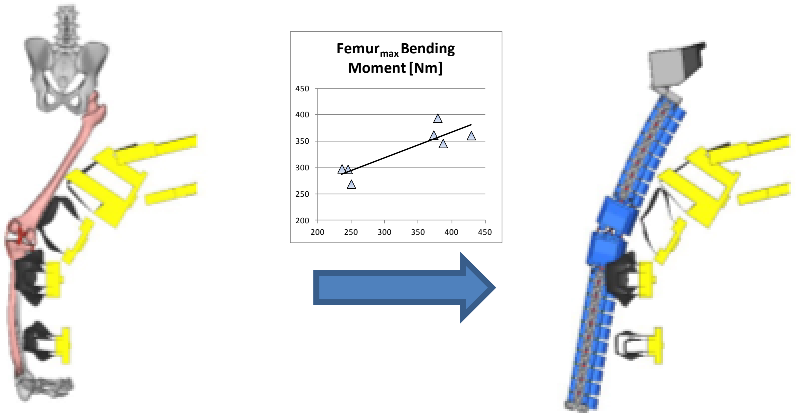


Figure 34: Correlating HBM and impactor simulations of identical frontends.

Kinematics, time histories as well as peak loadings were compared and possible correlations between the loadings to the HBM and the impactor models (FlexPLI-UBM and TIPT) were identified. The results were used to establish test and assessment procedures and to be evaluated by means of physical component and full-scale tests later in the project.

Improved pedestrian safety tools (test and validation simulations)

Simulations were first carried out with a human body model (THUMSv4) against an SAE buck for Sedan, SUV and Van/MPV as well as against vehicle models Sedan, SUV and Van/MPV. Only vehicle centreline tests could be run with the SAE bucks. For the vehicle models, tests were also run on the end of the bumper beam (EoB) curved surfaces. See Figure 35 for the SAE buck Sedan setup.

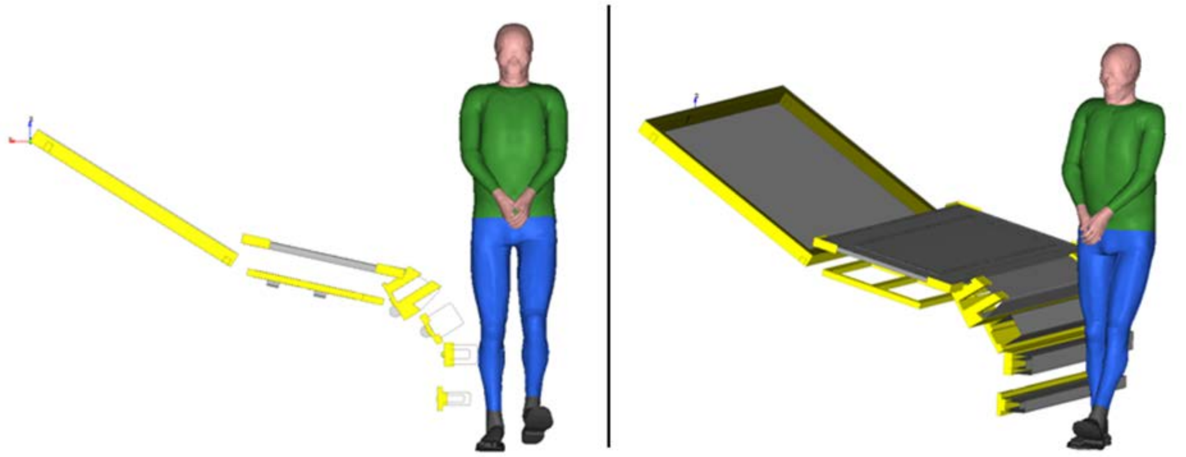


Figure 35: THUMSv4 positioning for SAE buck

It was found that the Van/MPV was the most aggressive for femur and MCL ligament injury while the Sedan was the worst for tibia injury. It was also noticed that the ACL ligament was more sensitive to different vehicles than the PCL ligament. For the SUV the highest loading was on the centreline of the vehicle. For the Sedan two vehicles were represented a compact car and a limousine. For the compact car the centreline produced the highest femur bending while the maximum tibia loading, PCL and MCL ligament deflections were on the RHS end of bumper beam. For the limousine the highest ACL, PCL and femur were on the RHS end of bumper beam and tibia on the centreline. The MCL gave virtually the same deflection for both locations. See compact car results in Figure 36. It was noted that the LHS end of bumper beam produced lower ligament elongations which was likely due to the knee geometry.

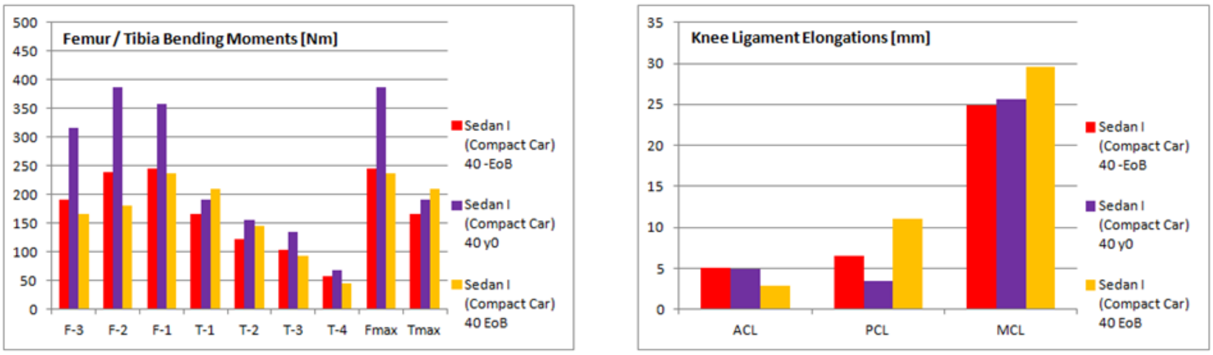


Figure 36: Peak bending moments and ligament elongations, THUMSv4 Sedan compact car

For the impactor simulations two UBM designs were tested along with the baseline FlexPLI one with a rigid mass and one with a mass on a flexible rubber element. A low cg of the UBM produced the best correlations so this position was used in the rigid adjustable UBM design.

FlexPLI Baseline
Testing with the baseline against the SAE buck confirmed the aggressive Van/MPV results which had the highest femur, MCL and PCL results, the SUV had the highest tibia moments and ACL elongations. When the baseline was tested against an actual SUV vehicle model, end of bumper beam results were symmetrical. Like with the HBM the centreline results produced the highest ligament and femur results.
The peak results from the compact car again showed symmetrical results for both ends of the bumper beam. The highest moments were at the centreline while the ligament deflections were higher at the ends of the bumper beam. Again HBM tendencies were confirmed. With regard to the limousine this also produced symmetrical results either side of the bumper beam but produced different tendencies, the ends of bumper beam had the highest bending moments and ligament deflections opposing that seen in the HBM.

FlexPLI Rigid Upper Body Mass
Simulation against the SAE buck and its derivatives draw a clearer picture in terms of aggressiveness of vehicle front ends. The highest results for femur, tibia and knee were against the SUV buck which is not in line with the HBM. See Figure 37.

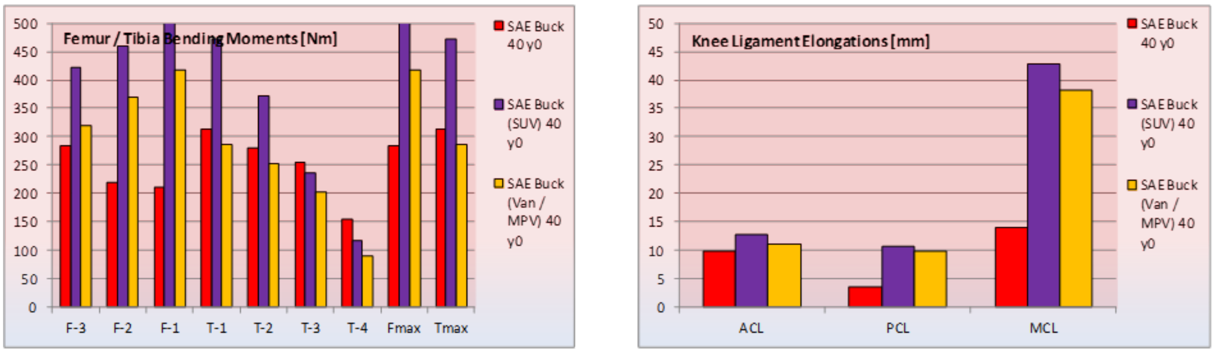


Figure 37: Peak bending moments and ligament elongations FlexPLI rigid vs SAE buck

For the Van/MPV representative the ends of the bumper beam did show symmetrical results. Like with the HBM the femur bending moments were highest on the vehicle centreline. The tibia, MCL and PCL were highest at the ends of the bumper beam which was not in line with the HBM.
The SUV SAE buck produced symmetrical results. The ends of the bumper beam generally had the highest bending moments and ligament elongations accept for moments close to the knee. HBM results were more aggressive on the centreline.
For the compact car all the results were highest on the centreline accept for the PCL, again symmetry at the ends of the bumper beam were good. The results for the limousine had the same trend. Therefore the comparison on the FlexPLI with UBM to the HBM could only be confirmed for tibia, PCL and MCL.

Comparison FlexPLI derivatives to HBM
For the sedan, SUV and Van/MPV time histories at 9, 30, 48 and 69 ms are discussed. For all models it was clear the UBM derivatives were generally more like the HBM than the baseline FlexPLI. This was shown in the loading time histories

curves were the loading is applied for a longer period of time. The baseline model rebounded much sooner. The femur peak loads are also more realistic and a better match with the HBM. The high MCL elongation seen in the HBM did not match the legforms with the UBM for the sedan. However the shape of the MCL waveform with the rubber element was comparable to the HBM. The kinematics of the legforms against the SUV SAE buck are shown in Figure 38. Here it can be seen that the two UBM derivatives are more like the HBM as the baseline FlexPLI is already rebounding at 30 ms. At 48 ms the baseline has completely rebounded but the UBM derivatives are still sustaining biofidelic loads. At 69 ms the UBM derivatives are rebounding but the HBM is still being loaded. The peak results for the SUV buck did not show an improvement with the UBM derivatives over the baseline FlexPLI.

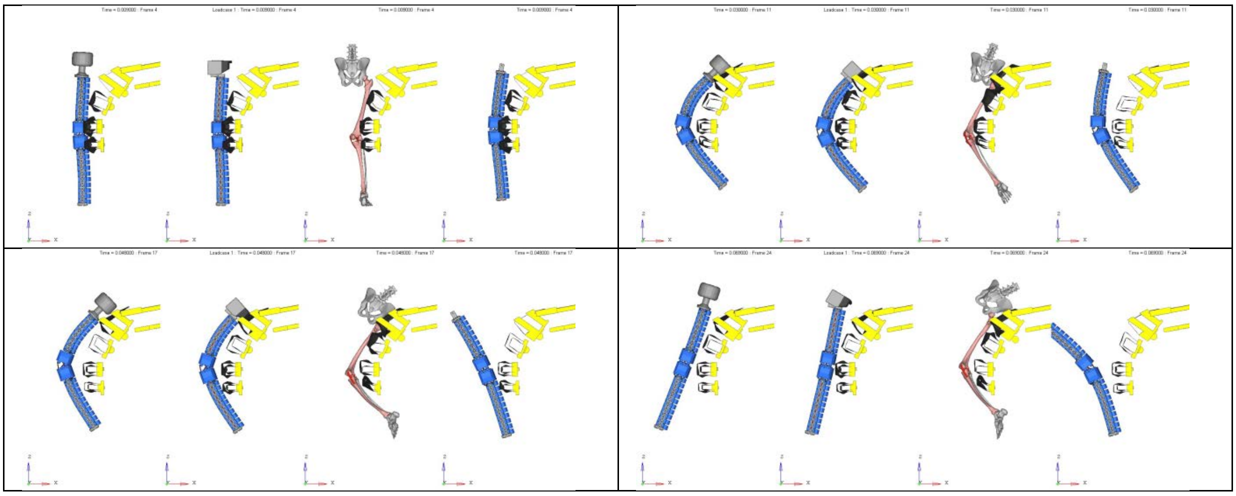


Figure 38: Impact kinematics during simulations against SAE buck (SUV)

For the Van/MPV buck simulations the kinematics for the derivatives were similar to the HBM up to 30 ms but with lower loading with the FlexPLI baseline. At 48 ms the baseline is completely released from the vehicle while the UBM derivatives are still in forward movement with the upper part within the assessment interval. The MCL time histories for the UBM derivatives are much better than the baseline FlexPLI but the peak values are more in line and baseline having a lower value.

In most cases the peak loadings on the lower extremities are overpredicting the UBM versions, however the high MCL of the THUMSv4 is well matched with the UBM legs.

In all SUV cases the rigidly attached UBM showed an over prediction of femur bending moments, while the peak bending moments of the HBM are best represented by the flexible UBM. The high peak seen on the HBM SUV centreline was not represented with the FlexPLI derivatives.

<u>Quantitative correlations all impacts (transfer functions)</u>
The application of a pedestrian torso mass to the FlexPLI contributed in most cases to a significant improvement of the kinematics and impact biofidelity when being compared to the human body model under identical loads. Nonetheless, this improvement was not always reflected in peak femur and tibia bending moments and knee elongations closer to those of THUMS.

To summarize, the FlexPLI rigid and Flexible UBM legs reveal improvements compared to the FlexPLI baseline when tested on areas at or around the end of the bumper beam. Further analysis of peak values results in overall good correlations between THUMSv4 and FlexPLI-UBM for the Sedan category with a superior behavior to the FlexPLI Baseline. The individual number of data points of SUV and Van/MPV categories did not further allow a reliable correlation of peak results.

A reason for the altogether not always good correlations could be due to the results from SUV (upper femur and tibia) impacts with unintended or premature interactions between the UBM and the vehicle frontend. The FlexPLI-UBM maxima are driven by the impact of the additional torso mass at a point in time different to the human pelvis being loaded. It can be concluded that with a humanlike mass modification of the UBM the femur would reach its maximum at a later point in time and thus would correlate better with the human femur in terms of peak loadings. Removing the premature interactions with the UBM is expected to contribute to a better peak correlation. Simulations against all three sedans with good femur correlations support this hypothesis as the femur max loads have reached their maximum value before interaction with the vehicle front end.

To investigate the benefit of the changed procedure simulations were carried out against an actual Van/MPV using the HBM and both the rigid and flexible UBM. A comparison of the impactor kinematics is shown in Figure 39.

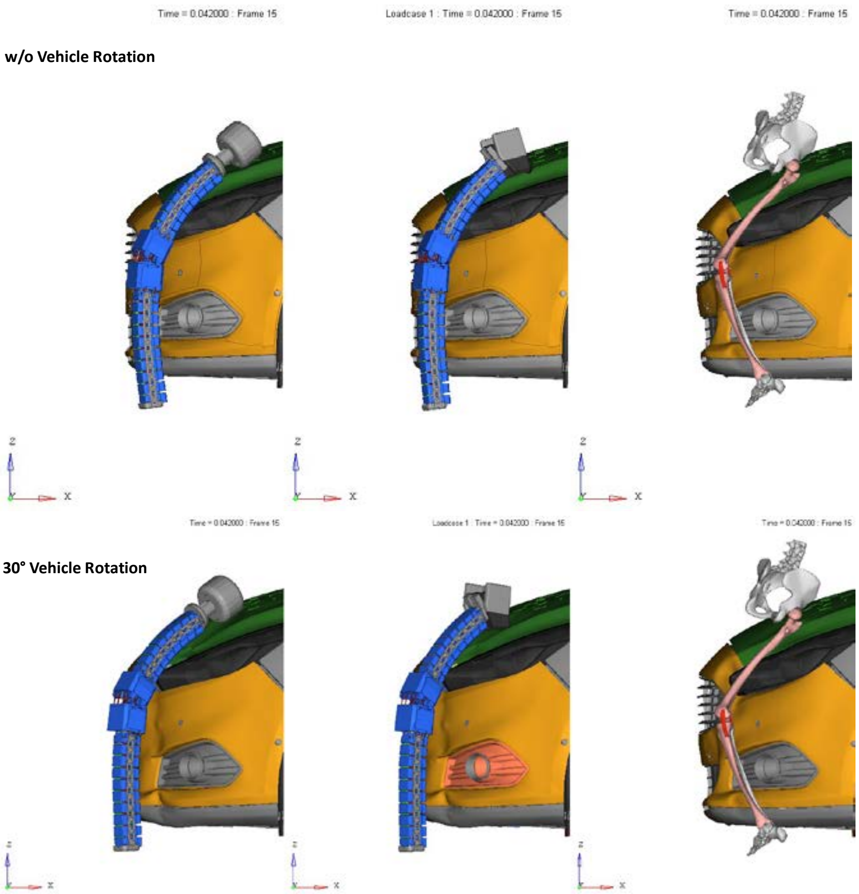


Figure 39: Impactor and HBM kinematics during impact against rotated and non-rotated vehicle (time of maximum loading)

It was seen that during impact against non-rotated vehicle the impactor is transferred into z rotation after having reached maximum loadings. When impacting at 30 degrees no additional impactor rotation can be noted at the same point in time. It can be concluded that perpendicular impact can contribute to minimising unrealistic impactor rotation.
The comparison of quantitative correlations for the Van/MPV shows a significant improvement for the rotated vehicle with respect to the maximum femur and tibia bending moment results with decreasing degree of correlation for MCL at the same time.

Head Neck Impactor (HNI)
Since baseline simulations with the HNI did not show a potential benefit in terms of improved kinematic behaviour on two dimensional generic front ends this test tool was not assessed further in the project.

Thorax Injury Prediction Tool (TIPT)
The tool is a EuroSID (ES-2) dummy rib cage. Five simulation loops were carried out. The first loop simulated the TIPT at different angles, speeds and arm positions identical to that of the HBM at impact. Tests were performed with the HBM at 20, 30, 40 and 50 km/h against the three different generic bucks. The same tests were performed with the TIPT. The signals from rib intrusion, spine acceleration at T1 and T12 were identified to compare to the HBM. This model version had a lumbar spine and a mass above the shoulder. From the leg impact speed thoracic speeds and impact angles and vectors to the bonnet were established to each of the three car types. See Figure 40.

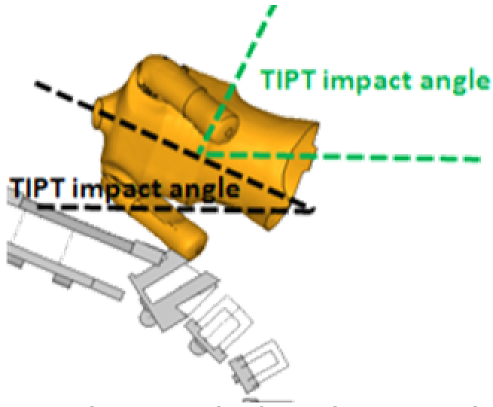


Figure 40: TIPT impact angles for Sedan, SUV and Van/MPV

The result from loop 1 regarding deflections was that the ES-2 rib at low speed had low sensitivity but had better sensitivity at high speed.
Loop 2 had additional neck mass and loop 3 locked the Z rotation, however no improvement could be achieved regarding quantitative correlation between THUMS and TIPT rib deflection. Loop 3r1 has the TIPT neglecting the initial impact around the local z-axis. This configuration resulted in acceptable correlation with THUMS at low impact velocity for all vehicle types. For higher velocities the rib deflection is

overestimated by the TIPT. This could be due to the different impact locations of THUMS ribs compared to those of the TIPT. Loop 4 had the arm removed.

Loop 5 was carried out using a new FE TIPT impactor model with a stowed or fixed arm on the struck side, no abdomen and arm removed from the non-struck side. The mass was reduced from 32.85 to 22.51 kg. This was for launch feasibility and a higher repeatability for physical testing. See Figure 41 below.

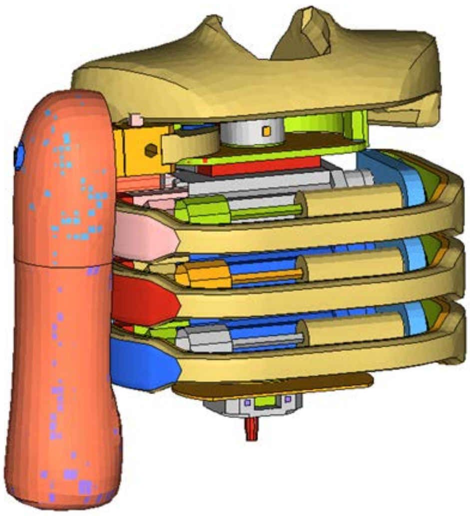


Figure 41: TIPT loop 5 model

Vehicle speeds of 30 and 40 km/h on MPV and SUV were replicated. Impactor positions and velocities were the same as in loop 3r1. Results showed lower rib deflections mainly due to the lower mass and the stowed arm. Linear correlation with THUMS showed reasonable results, especially for the 4th rib.

Further simulations were carried out on an actual SUV vehicle model. Four tests were performed with the TIPT in different bonnet areas with the same setup used in loop 5 simulations. Three more simulations were performed in the grille of the vehicle to replicate an impact with a child pedestrian. Examples of the tests are shown in Figure 42.

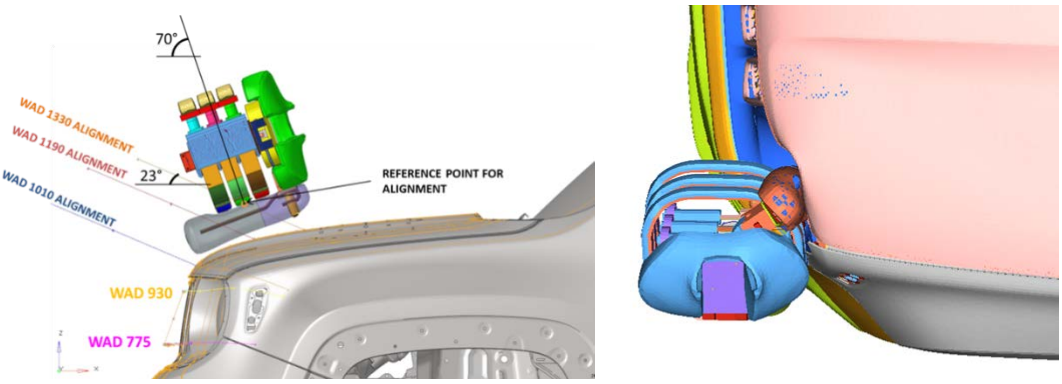


Figure 42: Examples of bonnet and grill TIPT tests against an SUV

3.4 Work Package 4 - Current Protection and Impact of New Safety Systems

3.4.0 Overview and Interaction of the WP within the project

Work package 4 was subdivided into three Tasks:

Task 4.1 Test and assessment procedures	[M25 – M28]
Task 4.2 Evaluation of test procedures with current and new safety systems	[M28 – M34]
Task 4.3 Benefit analysis and impact	[M32 – M36]

WP4 contains one milestone (MS9) and three deliverables (D4.1-4.3). The milestone and all three deliverables were submitted in the second period, see Figure 43.

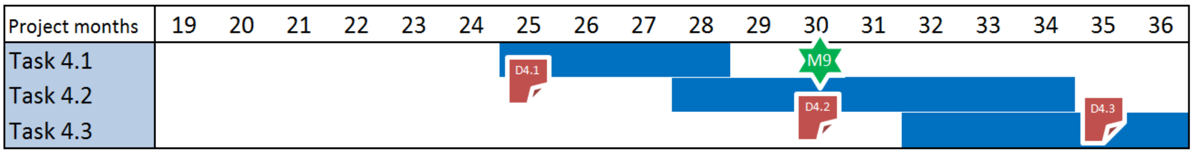


Figure 43: Timeline Work Package 4

3.4.1 Task 4.1: Test and assessment procedures

<u>Car Occupant Safety</u>

The car occupant safety branch addresses the safety needs of the elderly by defining new safety requirements to passenger cars within test and assessment procedures, alongside provision of new and revised test tools.

Task 4.1 summarized historical stages of the car occupant safety, starting with the early biomechanical programmes and describing the test procedures representing different collision types and crash test dummies until the currently applied state of the art tests, assessment procedures and testing tools within legislation and the consumer test programme Euro NCAP.

Extensive literature reviews, but also investigations in SENIORS regarding the requirements of older car occupants in the field of passive vehicle safety showed that the current testing and its evaluation address the basic demands, but they have also shown a huge potential by the introduction of further measures, here called “proposed solutions”. This is in particular true, as rarely specific means were found that address clearly older car occupants. For example, crash test dummies reflect different human body heights and weights, but do not differentiate sufficiently for age.

Accident data analysis highlighted the continuing need to protect the thorax region of older car occupants and that frontal impacts still belong to the most important crash types. Therefore, the THOR dummy is highly recommended in future safety assessments. Medical and biomechanical studies demonstrated the differences between younger and older persons regarding the geometry of the rib cage and the material properties. These differences seem largely influence the higher injury risk of older car occupants compared to younger ones. Whereas these characteristics cannot sufficiently be addressed by current crash test dummies, HBMs offer great potential to address human diversities including age-related changes.

Basic parameters regarding passive safety test procedures, tools and assessments were compiled, compared and combined for a first approach aiming to improve the safety of older car occupants. It became obvious that measures interact with each other greatly and hence the biggest effects will only be seen if the “potential solutions” are introduced in a bundle (e.g., use of THOR dummy together with specific age-related injury criteria and risk curves).

For example, Table 9 shows selected parameters of current test assessments which are used for frontal impact crash tests and reviews their suitability regarding the identified needs of elderly car occupants. The defined issues are based on the aim to improve existing restraint systems, to call for innovations and to reduce the impact related loads on the occupant. Most issues associated with elderly car occupants will also be beneficial for all age groups.

Table 9: Parameters of frontal impact crash test assessments reviewed towards their suitability for elderly

Parameter	Suitability for elderly	Issue / Required adaption
Injury criteria		Chest deflections at more than one measurement point need to be evaluated jointly to improve the current thorax injury assessment. Current criteria should be improved towards being more realistic for real injuries and to discriminate between similar, but different loadings.
Injury risk curves		More realistic injury risk curves adapted to the corresponding criteria needed. Injury risks should be aligned with age-specific characteristics.
Injury thresholds		Age-specific injury thresholds needed.
Addressed body regions		All body regions are already addressed.
Addressed types of injuries		Current ATDs do not allow for specific evaluations of the injuries of the thorax, head and internal organs. New ATDs, but also FE simulations will support addressing specific injury patterns.
Differentiation of body regions		Different pass/fail criteria in legislation do not interact sufficiently. The assessment of whole body regions and combinations of more criteria is useful. The thorax should be ranked highest, followed by the head (by keeping minimal requirements for other body regions).
Weighting of frontal impacts compared with other impacts		Importance of frontal impacts is reflected by current assessments.

 Sufficient for the elderly  Improvable  Insufficient for the elderly

All parameters within the created tables that were assigned being "improvable" or "insufficient" should be addressed in the future. Therefore, SENIORS provides recommendations to most of the mentioned issues to either solve or to improve. Note, the provided recommendations ("potential solutions") could be assigned to more than one issue.

Assuming the partial or full implementation of all proposed changes by SENIORS towards the improved protection of older car occupants, the expected outcome could be:

1) Improved (adaptive) restraint systems;
2) Introduction of an age-dependent injury assessment;
3) More realistic and differentiating assessments of thorax injuries
4) Improved vehicle structures reducing the overall loading to car occupants.

It was also clearly indicated whether SENIORS addresses specific, identified issues or not. Finally, it could be seen that the potential solutions proposed by the SENIORS project mainly focus on currently used tools in terms of their biofidelity, diversity and instrumentation, and the assessment in terms of addressed types of injuries and the quantification of loads and injuries. Not addressed in detail, are changes in procedures except for the implementation of moderate velocities for the assessment of restraint systems which could end up also in sled tests or FE simulations.

<u>Pedestrian / Cyclist Safety</u>

The external road user safety branch of SENIORS addressed special safety needs in particular of the elderly by defining equivalent safety requirements compared to average age pedestrians within current test and assessment procedures. This will be, alongside new and revised test tools, to obtain appropriate assessment of the vehicle protection potential, also taking into account the ongoing changes in injury patterns of vulnerable road users since the introduction of consumer test programmes and regulatory requirements.

In Task 4.1 the history of pedestrian safety has been summarized, starting with the early biomechanical programmes and describing the development of test procedures for different body regions using impactors until the currently applied state of the art test and assessment procedures within legislation and consumer test programmes. A study of recent collision scenarios alongside injury patterns of pedestrians and cyclists revealed the coverage of actual needs by the current procedures and identifies open injury protection gaps.

Based on a review and evaluation of the current test and assessment procedures for the head, the upper leg and the lower leg including the knee, Task 4.1 proposed updates, where necessary and emphasized by recent accident data, incorporating the new test tool TIPT and updated impactor FlexPLI-UBM together with updated biomechanical limits.

A set of new and modified test and assessment procedures for the most relevant body regions, led to a draft rating scheme for Box 3 of the European New Car

Assessment Programme (Euro NCAP). This achievement has the power to synthesize the particular assessment tools to an overall rating for vulnerable road users (VRU).

Impactor thresholds were derived from studies of impact biomechanics along with correlation studies between impactor simulations and HBM simulations. A synthesis of the particular assessments are proposed as an example overall rating for vulnerable road users (VRU) within Euro NCAP. The developed test and assessment procedures served for physical tests whose results are reported in Task 4.2.

3.4.2 Task 4.2: Evaluation of test and assessment procedures

Background

Previous work showed that regarding older car occupants the thorax is the most important body region to protect. While the elderly seem to have a higher risk for thorax injuries in side impacts up to a delta-v of 20 km/h the risk of thorax injuries in frontal crashes remains higher up to a delta-v of 40 km/h. The speed range between 0 and 40 km/h is currently not addressed by frontal impact crash tests. Frontal impact crash tests in legislation and consumer programmes use impact speeds between 50 and 64 km/h to test restraint systems and vehicle structures. Furthermore the currently used tests are designed mainly to test the occupant safety for average male adults with a few exceptions for children and small women. However, this leads to a lack of the important representation of other population groups such as older people.

To improve the protection of elderly car occupants it is therefore necessary to test the vehicles and restraint systems in a way which represents the relevant impact conditions in terms of speed and direction. It is therefore proposed to regard moderate speed tests (e.g. 35 km/h) to assess the vehicle and the restraint system in a way to align it with the accident situation of elderly and to react to Automatic Emergency Braking (AEB) systems (and similar) from which overall reduced vehicle impact speeds are expected.

Comparisons of the kinematics between the THOR dummy, PMHS, younger and older volunteers showed the high amount of variances between the test subjects, observed parameter-specific differences and revealed that further research is required in order to better understand the differences in kinematics and hence, to refine test and assessment methods accordingly. Medical and biomechanical studies demonstrated the differences between younger and older persons in particular regarding the geometry of the rib cage and the material properties. It is believed that these differences largely influence the higher injury risk of older car occupants compared to younger ones.

Moderate speed test

The sled tests performed in SENIORS demonstrated that a non-adaptive restraint system that is only optimized for high impact speed (56 km/h) would result in a similar injury risk in an accident with a moderate velocity (35 km/h). A direct comparison of the sled tests with non-adaptive restraints and adaptive restraints (like four-point belts or split buckle in combination with velocity adaptive load level limiters) clearly showed the benefit of adaptive restraint systems in terms of chest injury risk reduction predicted by the THOR injury chest criteria. The sled tests at lower impact velocity (35 km/h) demonstrated that a test configuration with this speed can be used to demonstrate the benefit of impact severity adaptive restraint systems.

The THOR dummy is recommended as a test tool with instrumentation that is more sensitive to assess the benefit of distributed chest loading of advanced restraint systems and could be implemented realistically in short- to mid-term testing.

EATD

To address also the specific characteristics of elderly occupants a completely new developed ATD, the Elderly Overweight Dummy (EATD), can be beneficial in the future, even though the prototype dummy has still deficiencies in term of durability and lack of biofidelity. The EATD represents the older population in terms of anthropometry and material characteristics and enables a full exploitation of all age relevant issues discussed in the SENIORS project including addressing the issue of overweight and corresponding changes to the outer geometry of the body.

Further sled tests using a body in white vehicle structure and standard and advanced restraint systems were performed with the EATD. The results in the driver and passenger position were highly affected by the dummy's geometry and deterioration during the test loops, see Figure 44. Considering the head, thorax and pelvis acceleration with a lower significance, the focus for the choice of the optimized restraint system configuration was on the chest deflection (according to the main focus of SENIORS). Unfortunately, these signals were affected by the dummy limits, even if the chest was the component with less damage it had to be considered that the dummy configuration did not allow to have a repeatable initial configuration. In the pre-testing phase it was observed that the suit did not adhere perfectly to the dummy and there was a lot of fabric in the iliac and shoulder area and the fabric structure could create friction with other dummy components. Consequently the suit arrangement, in order to have a good belt route, could change the internal sensor position. Driver displacements without the initial set to zero showed perfectly how a pre-compressed chest could affect displacements. The suit needs to be revised to have more adherence and less fabric. In addition the rear opening is not user-friendly because it did not allow a quick access to the frontal thorax area. A suggestion is to create a zippered suit in the iliac area, with a front and not rear opening. The abdominal IR-TRACCs showed an extension behavior which might be caused due to the pelvis geometry. Also, the abdominal belt insisted on the pelvis flesh while the brackets connected with the IR-TRACCs were in an upper position. Consequently their movement was due to inertia. In addition, especially the right IR-TRACC had often a flat route, due probably to geometric sensor extension limit. The thorax might also be affected by the detachment of the lumbar spine. This gave a higher flexibility to the area, and the upper thorax detachment changed the kinematics.

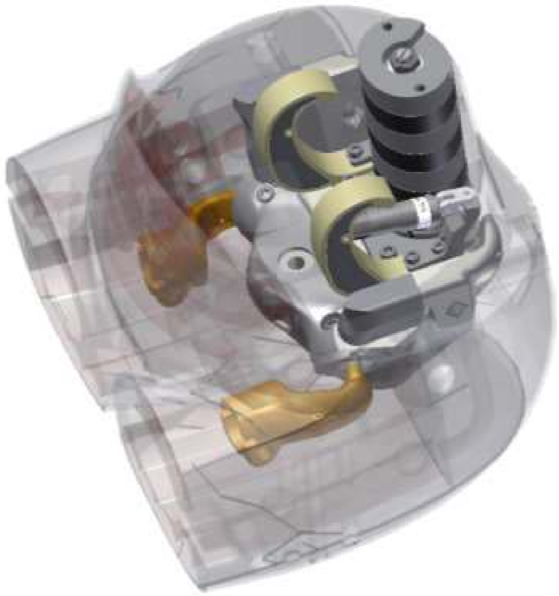


Figure 44: Pelvis area deterioration

Comparing the results of driver and passenger tests, in driver tests the more compressed area was found in the right upper chest. In the driver case the belt route could move up while the dummy moves frontward. On passenger side the belt route was mirror-inverted. It is possible that the driver loop deformed permanently upper right compartment. On the contrary, the lower thorax displacement, according to belt routing, was worse in the lower right area for the driver side (buckle region) and the opposite for the passenger side. The permanent change involved all upper thorax and it was visible from the initial displacements.

The DLLA belt for both, driver and passenger side, was best the performing restraint system to minimize chest deflections, because the load from the belt was less (2.5 kN compared to 3.5 kN) and the load from the bag was not in time but comprised the entire thorax surface. On the contrary, even with that belt, in driver tests a displacement of 52 mm was recorded which accounts for the capping score for current Euro NCAP Female Assessment.

It is highly recommended to revise the EATD in several aspects, considering for example the use of more durable components and the introduction of geometry checks during dummy lifetime. In addition, a storage system should be implemented in order to minimize dummy damage in times when it is not used. This of course is a new dummy with new 3D-printed materials so these tests were its first durability trial and results here will greatly help in its further improvement.

Virtual Testing

Virtual testing by FE simulations shows a great potential to complement the catalogue of test conditions. The age-modified HBM developed within SENIORS was used to contribute to the development of age-related ATD based injury criteria and risk functions. Overall, HBMs show a great potential to address human road user diversities, which is only possible to a limited extent by ATDs. Furthermore, HBMs show a great potential to predict injuries more in detail than current crash test dummies. The use of different HBMs (THUMS TUC, GHBMC etc.) is recommended on a comparable basis. However, harmonization of the requirements is required regarding biofidelity and injury prediction capability that all different HBMs fulfil. Furthermore, the use of active HBMs enables also the possibility to consider the influence of active muscles allowing a realistic assessment of the influence of pre-crash safety systems such as Automatic Emergency Braking (AEB) systems.

Injury Criteria

New improved THOR thoracic injury criteria (updated PC Scores) and age-related injury risk curves to predict AIS3+ risk and NFR3+ were developed within SENIORS.
The criteria and injury risk curves were applied to THOR sled test results in different conditions (two vehicles, two crash pulses, various advanced restraints). The new age-related criteria and risk functions showed comparable results in terms of thoracic injury prediction related to impact severity and restraint parameters. The new criteria were able in similar ways compared to the current age-related THOR multi-point chest injury criteria to show the benefit of advanced and adaptive restraints. Based on this it is recommended to use age-related THOR dummy multi-point injury criteria to assess the benefit of occupant vehicle safety systems which will improve the safety of elderly car occupants in frontal vehicle accidents.

A clear benefit of the new THOR criteria and risk functions developed within SENIORS could not be shown based on the evaluated sled test results. However, further work on improved PC Score based criteria using an extended data set is recommended. For the time-being, the injury criterion R_{max} is proposed for the chest injury assessment. A further improved version of an advanced multi-point PC score like thoracic injury criterion might show an additional benefit regarding a better assessment of the load distribution and hence, the benefit of advanced restraint systems.

Safety Packages

Safety Packages are proposed for testing in (Euro) NCAP and towards legislative bodies for the three time periods short-term (<5 years), mid-term (5-9 years) and long-term (>9 years) considering costs, working efforts, implementation times and demands by other safety fields, see Table 10.

Finally, it is believed that all introduced measures towards the improved protection of older car occupants could also be beneficial for younger ones.

Table 10: Safety Packages for (Euro) NCAP and legislative bodies indicating the introduction of recommended "potential solutions" to raise the protection level of (older) car occupants by time periods (baseline is the year 2018)

	NCAP	Legislation
Short-term (< 5 years)	THOR	
Mid-term (5-9 years)	New injury criteria; Age-specific thresholds; Adapted injury risk curves; Age-specific rating; Moderate speed assessment	THOR
Long-term (>9 years)	FE simulation; HBM; EATD	Adapted injury risk curves; New injury criteria; Age-specific thresholds; FE simulation; Age-specific rating; Moderate speed assessment; HBM

<u>Pedestrian / Cyclist Safety</u>

Tests with the Flexible Pedestrian Legform Impactor FlexPLI, the FlexPLI with applied pedestrian torso mass (FlexPLI-UBM) and the Thorax Injury Prediction Tool (TIPT) on the generic SAE Buck as well as actual vehicle models evaluated the applicability and potential benefits of introducing the modified test and assessment procedures.

A revised test and assessment procedure for the evaluation of the passenger cars' protection potential related to injuries to the lower extremities of pedestrians caused during an impact has been developed.

Physical tests with the FlexPLI with applied upper body mass (FlexPLI-UBM) showed in most situations a good correlation with the human body model THUMSv4 in terms of kinematics, characteristics of time histories and maximum values. Figure 45 shows a test with the FlexPLI-UBM against the generic SAE buck.

A study of human injury risk resulted in injury thresholds that could be transferred to impactor limits using the corresponding transfer functions. Those limits were used within revised assessment procedures.

These procedures are proposed to be implemented within the Euro NCAP Box 3 assessment alongside a redistribution of points allocated to the different body regions, based on recent in-depth accident data.

Figure 45: FlexPLI-UBM to SAE Buck test

For the thorax area, a new test tool for prediction of thoracic injuries of pedestrians and cyclists in case of a collision with a passenger car has been developed. The prototyped impactor is based on the ribcage of the ES2-dummy and despite of first very promising test results, several modifications will be necessary prior to implementation within consumer or regulatory test procedures. However, based on recent in depth accident data, a scenario for implementation within Box 3 of Euro NCAP has been developed. Figure 46 shows a test with the TIPT against the SAE buck.

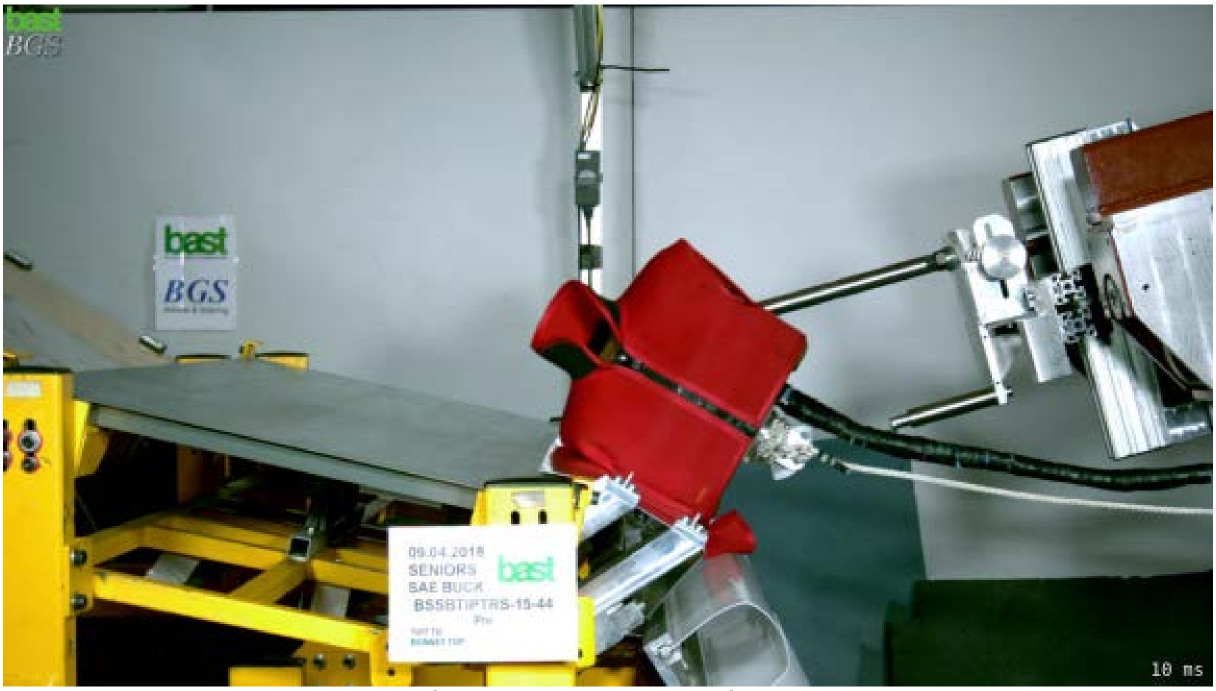


Figure 46: TIPT to SAE Buck test

Regarding head injuries, a modification of the test procedure to include protection of cyclists rather than a modification of impactors has been developed. These modifications are proposed to be implemented within Box 3 of Euro NCAP. Based on the above mentioned in-depth accident data, a redistribution of points for the headform tests is proposed.

A further evaluation of these tests shows the degree of correlation between FE simulation and physical testing on the one hand, but also reveals potential room for improvements of the procedures regarding test area, ambient conditions, impactors and assessment of the results. These improvements are addressed by the finalized procedures.

3.4.3 Task 4.3: Benefit analysis and impact

Elderly occupant safety has been the priority for this project: literature reviews and data gathering from accident and hospital datasets revealed that elderly occupants were sustaining serious injuries to the thorax in moderate-severity vehicle collisions. As such, current restraint systems were assessed because thorax loading led to the most significant amount of AIS 3+ injuries within this demographic.

Front seat restraint systems have improved over the last few decades and as such the loading applied to the occupant's thorax has been greatly reduced, reducing the injury risk for younger and mid-aged occupants. Older occupants, however, have a lower biomechanical tolerance and the collision data shows that they can sustain serious and life-threatening thorax injuries (especially rib fractures) despite the advances in restraint system and vehicle design. To reduce the thorax loading for senior occupants, novel restraint system concepts were tested, with the aim of reducing the risk of serious or life-threatening chest injuries.

The benefits of applying these new technologies to the entire fleet were also modelled within this Task 4.3. The model focused on two restraint system designs in particular – the Split Buckle and Criss-Cross seat-belts – and how they would reduce European wide casualties, fatalities and the associated costs. The model calculated the benefit for car occupants of regulating each design in 2020 with mandatory fitting in 2022. Note that it is not expected that such a regulation would be implemented in this timescale; rather, this study uses this scenario as a way to explore the potential casualty savings and the societal cost reductions that could be delivered by these systems.

The analysis showed that, in this scenario, the EU has the potential to prevent between 800 and 1,200 car occupant fatalities among the 65+ age group by implementing one of the seat-belt designs. There is also the potential to prevent between 6,500 and 10,500 serious occupant injuries and have an economic benefit in the range of €4.7-8.1 billion, over the period 2020-2030.

SENIORS wanted to assess how changes to head testing tools and methods, the Thorax Injury Prediction Tool (TIPT), and the FlexPLI with Upper Body Mass (FlexPLI-UBM) test tool would affect the Euro NCAP test parameters.

Head impact tests, literature reviews and data assessment indicated that the current Euro NCAP head impact test area was not capturing cyclist head impacts or some taller pedestrians. Extending the upper boundary WAD (Wrap Around Distance) to 2500 mm, would address an additional proportion of pedestrians, and a higher proportion of cyclists, even without changing the head half-diameter exemption zones at the edges, or the head performance limits. However, for OEMs there would be little incentive for additional benefit in protecting VRUs from impacts with the A-pillars.

The completely new test tool TIPT (Thorax Injury Prediction Tool) was found to offer the possibility of more informative and biofidelic ways of testing vehicles with higher BLE (Bonnet Leading Edges) especially concerning the growing SUV and MPV market share.

Finally benefits of the FlexPLI-UBM were mainly qualitative such as improved biofidelity. Euro NCAP's existing lower leg tests would become more relevant to the real world as they are more biofidelic, particularly for femur and knee injury risk assessment.

3.5 WORK PACKAGE 5 - DISSEMINATION AND EXPLOITATION

Work package 5 is subdivided in three tasks:

Task 5.1 Dissemination and exploitation [M1 – M36]
Task 5.2 External Dissemination actions [M4 – M36]
Task 5.3 Monitoring exploitable results including IPR [M7 – M36]

WP5 contains three milestones (MS7 and MS8) and eleven deliverables (D5.1-5.11). One milestone and five of the eleven deliverables have been submitted in the second period, see Figure 47.

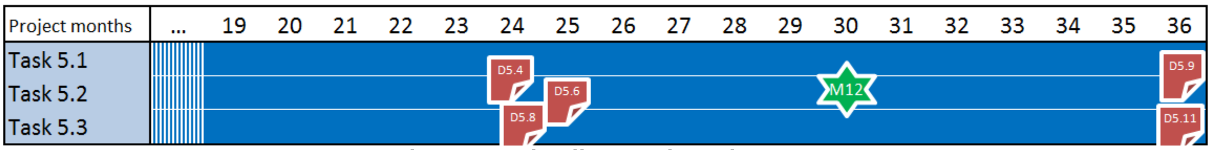


Figure 47: Timeline Work Package 5

Table 11 shows the milestones of the final term of the project and the estimated deadline date.

Table 11. Milestones for the second period

Milestones	Lead beneficiary	Estimated Delivery date
Implementation of results based on workshop discussions with stakeholders	BAST	01/12/2017
4th General assembly	IDIADA	01/06/2017
5th General assembly	IDIADA	01/12/2017

Table 12 shows a list of the final term deliverables and the estimated delivery dates.

Table 12. Derivables for the second period

Nº	Deliverables	Lead beneficiary	Estimated Delivery date
D5.4	Dissemination and exploitation plan update	IDIADA	31/05/2017
D5.6	Final report Technical Advisory Board meetings	IDIADA	30/06/ 2017
D5.8	Second annual newsletter	IDIADA	31 /05 2017
D5.9	Third annual newsletter	IDIADA	31/05/2018
D5.11	Final exploitation status report	IDIADA	31/05/ 2018

3.5.1 Task 5.1: Dissemination tools

Dissemination plan

The dissemination plan was created and updated and consists of the following 4 stages:

1. Target audience identification;
2. Development of the dissemination material and tools;
3. Usage of dissemination channels;
4. Dissemination efforts for each of the various channels (during and after the run time of the project).

The dissemination plan is reflected in Deliverable 5.4. Dissemination and exploitation plan update

Webpage

The website is online since 3rd of May, 2015 and is divided in seven different sections to guide the visitor and help providing the requested information in the most efficient and clear way possible.

- Home: project description and goals, latest news and consortium overview.
- About: project concept, project objectives, project structure and work packages short description, main (exploitable) results.
- Partners: Description of each partner linked to its website.
- Agenda: scheduled and past dissemination events.
- Downloads: public deliverables, project overall presentation, public presentation and subscription to newsletter.
- News: all released news and subscription to newsletter
- Private area: Access to internal server and access to website edit.

During the second period of the project, the website was continuously updated using the materials generated in the project. The following materials and information were updated:

- Presentations and reports
- Newsletters
- News

Presentations and reports

The following documents were uploaded to the website during the second period:

- Project general presentation: A SENIORS overall project presentation was uploaded at the website. Also, public presentations from Seniors expert meeting had been uploaded. 1st SENIORS Expert Meeting Presentations
- 2nd SENIORS Experts Meeting Presentations
- SENIORS Deliverable 1.1 Behavioural aspects of elderly as road traffic participants and modal split - Draft – Update
- SENIORS Deliverable 1.2 - Road traffic accidents involving the elderly and obese people in Europe incl. investigation of the risk of injury and disabilities - DRAFT

- SENIORS Deliverable 2.2 - Part A - Muscle Activity in a Non-injurious Sled Test Programme - Draft
- SENIORS Deliverable 2.2 - Part B - Virtual Reality for Driver Pre-Crash Response Analysis - Draft
- SENIORS Deliverable 2.3 - Kinematic comparison between the THOR dummy, older volunteers and older PMHS in low-speed non-injurious frontal impacts - Draft
- SENIORS Deliverable 3.1B Design Specifications For Improved Pedestrian Tools – Draft
- Transport Research Arena 2018 materials:
    - SENIORS Diptic 20x18cm 29-03-2018 Web Version
    - SENIORS EATD
    - SENIORS FlexPLI
    - SENIORS ProjectPresentation TRA

Newsletters

SENIORS newsletter: In total three newsletters were created in the SENIORS project, comprising the description of new developments and results as well as inform about current activities. These newsletters had been published at the website with other news related to the project, as follows:

News

The following news were uploaded to the website to inform the site visitors of the main progress of the project.

- 3D printing to improve the safety of the elderly (November 3, 2017)
- Optimizing the safety of the elderly (November 3, 2017)
- Interview with Mr. Marcus Wisch, the SENIORS Project Coordinator (November 6, 2017)
- 2nd Newsletter Released (November 6, 2017)
- New needs on the road in a changing society (November 6, 2017)
- Improving Human Body Models for better elderly protection (March 23, 2018)
- Showcasing results of the SENIORS project at #TRA2018 (April 12, 2018)
- New generic test rig (April 20, 2018)
- SENIORS at TRA Vienna 2018 (April 26, 2018)

Website Impact

The website impact can be measured by the amount of downloads of the public documents. A total of **266 downloads** were carried out for the information of TRA 2018 conference as it can be seen in Table 13.

Table 13. TRA2018 conference downloads

TRA2018	
Name	***Hits***
SENIORS Diptic 20x18cm 29-03-2018 Web Version	64
SENIORS EATD	54
SENIORS FlexPLI	76
SENIORS Project Presentation TRA	72

For the public deliverables a total of **3,276 downloads** had been carried out as it can be seen in more detail in Table 14.

Table 14. Public deliverables downloads

Public deliverables	
Name	Hits
SENIORS Deliverable 1.1 Behavioural aspects of elderly as road traffic participants and modal split - Draft - Update	672
SENIORS Deliverable 1.2 - Road traffic accidents involving the elderly and obese people in Europe incl. investigation of the risk of injury and disabilities - DRAFT	449
SENIORS Deliverable 2.1 - Biofidelity Requirements for Older and Obese Car Occupants and External Road User Surrogates - Draft	726
SENIORS Deliverable 2.2 - Part A - Muscle Activity in a Non-injurious Sled Test Programme - Draft	255
SENIORS Deliverable 2.2 - Part B - Virtual Reality for Driver Pre-Crash Response Analysis - Draft	210
SENIORS Deliverable 2.3 - Kinematic comparison between the THOR dummy, older volunteers and older PMHS in low-speed non-injurious frontal impacts - Draft	283
SENIORS Deliverable 3.1B Design Specifications For Improved Pedestrian Tools - Draft	681

The overall presentation of the project had a total of **753 downloads** as it can be seen in Table 15.

Table 15. Overall presentation downloads

Overall presentation	
Name	Hits
SENIORS - Overall Project Presentation - Status April 2016	753

The public presentation had a total of **1.209 downloads** as it can be seen in Table 16.

Table 16. Public presentation downloads

Public presentation	
Name	Hits
1st SENIORS Expert Meeting Presentations	665
2nd SENIORS Experts Meeting Presentations	544

<u>Dissemination database and stakeholders list</u>

The database is based on a query regarding potential experts that attended the events and conferences where SENIORS Project results were presented and potential profiles interested in the project development and final results. Additionally, contacts from previous EC projects (e.g. dissemination database from the FP7 project AsPeCSS) are considered.

The database was updated during the second period of the project.

Brochure

A general brochure was designed to present the SENIORS project at conferences. The brochure, Figure 48 and Figure 49, explained the main objectives of the project and the firsts results obtained. The brochure can be downloaded from the SENIORS website.

SENIORS

SENIORS investigates and assesses the injury reduction that can be achieved through innovative tools and passive safety systems targeting the protection of the elderly as car occupants and external road users (road users such as pedestrians, cyclists and e-bike riders).

THOR on generic crash sled

It is expected that the safety improvement of the main modes of transport used by the elderly will contribute to the achievement of the European policy objective of halving the number of road fatalities by 2020, and, in the longer term, to the Transport White Paper's "Vision Zero" objective.

Figure 48: SENIORS brochure first page

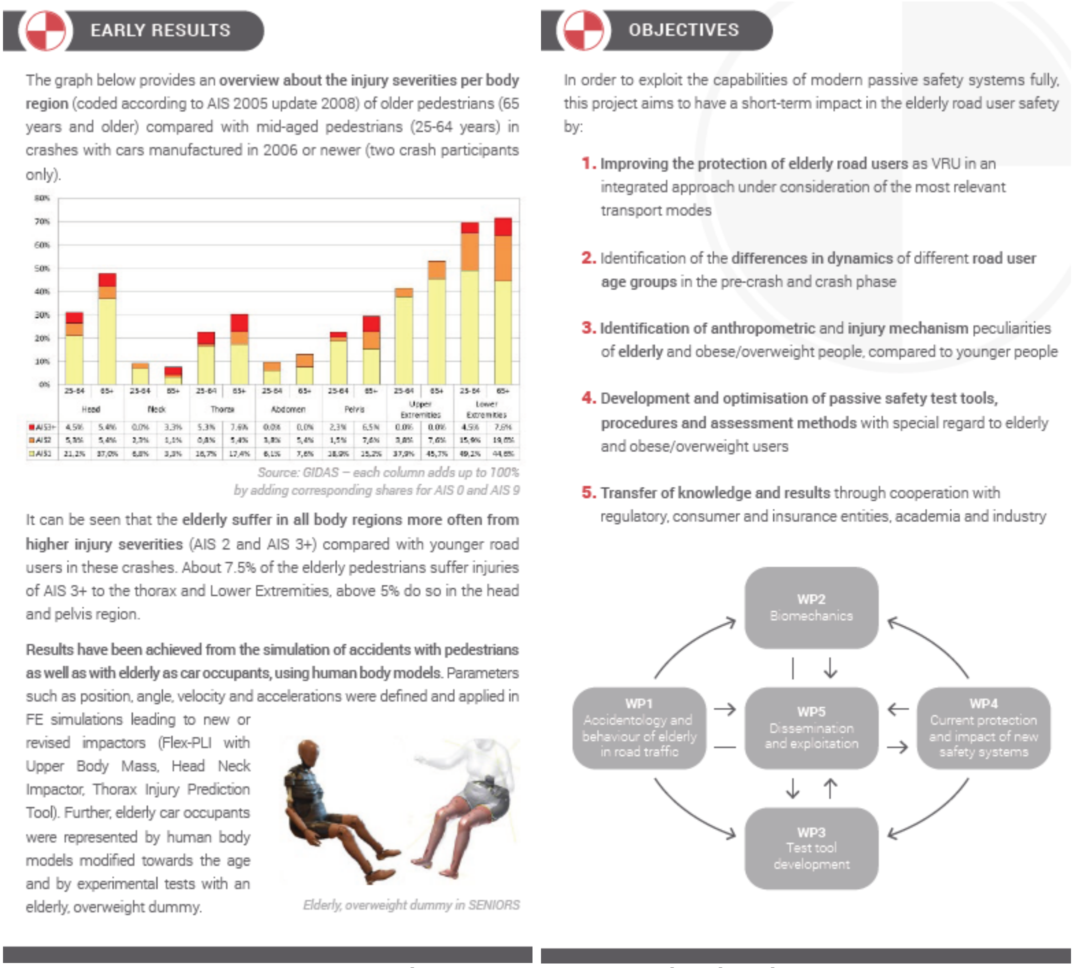


Figure 49: SENIORS project brochure

<u>Newsletters</u>

The newsletters were disseminated using two main channels: mailing campaigns and the website. The mailing campaign contained a summary of the most relevant information of the newsletter. The newsletters in an embedded pdf-format were uploaded at the website with the whole content. Also, the newsletters were presented as “News” at the website. During the second period the second and third newsletter of the project were released.

2nd Newsletter: The second newsletter had an introduction of the project, explained major results as the probability of thorax injury severity for mid-aged and older car occupants in frontal collisions. Also, the development of a new Elderly Anthropometric test device and pedestrian impactors (Thorax, Flex-PLI, Head Neck Impactor) were explained. Lastly, an interview with Mr. Marcus Wisch (SENIORS Project Coordinator) was published.

3rd Newsletter: The third newsletter included the work done improving human body models for better elderly protection. Also, the development of a generic test rig was explained. Lastly, the newsletter included a summary of the participation of SENIORS project at TRA Vienna 2018 and information about the SENIORS project final event.

Impact of the newsletters

Second Newsletter: The results impact of the second newsletter showed that it has been delivered 365 times and delivery errors (soft/hard bounces) were a total of 57 as it can be seen in Figure 50.

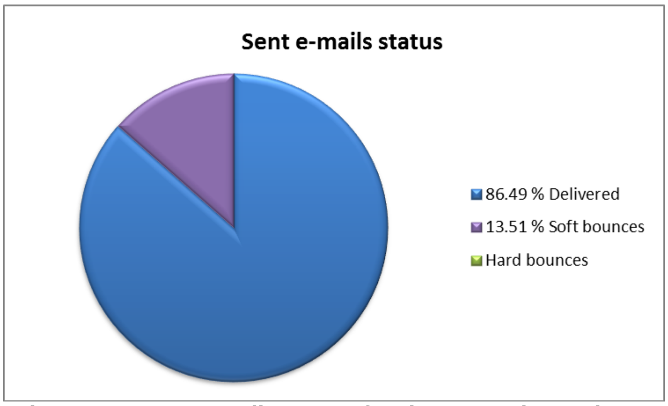


Figure 50: Sent e-mails status for the second newsletter

Once delivered the second newsletter was unread 263 times, read 102 times and zero complaints were received, as it can be seen in Figure 51.

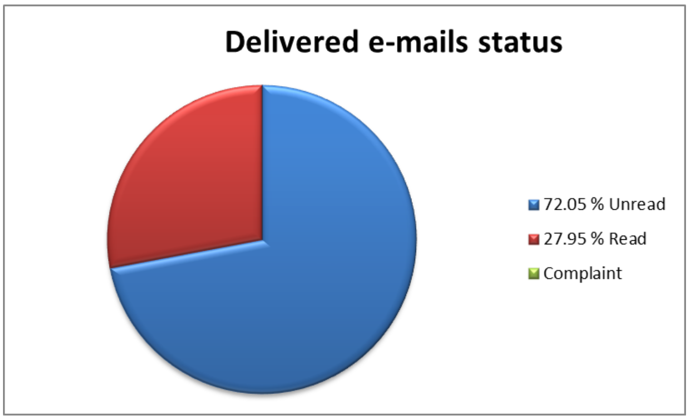


Figure 51: Delivered e-mails status for the second newsletter

An analysis of the visited websites, linked to the second newsletter was carried out and the results showed that the 3D printing of the EATD was the most visited as it can be seen in Figure 52.

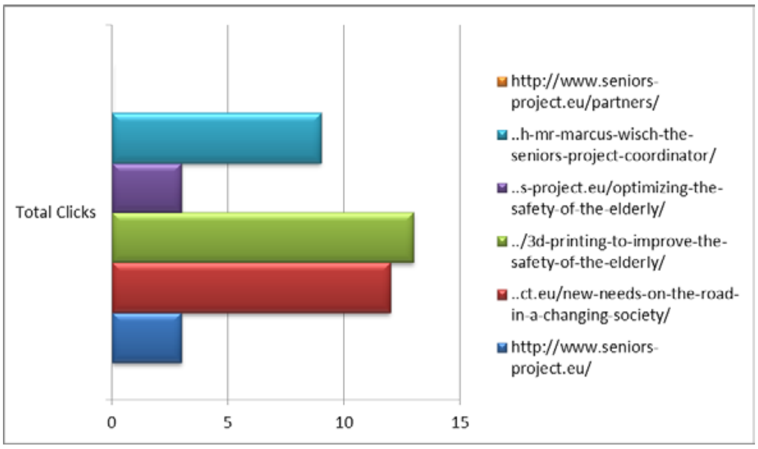


Figure 52: Visits linked to the second newsletter.

Third Newsletter: The results impact of the second newsletter showed that the Third newsletter has been delivered 357 times and delivery errors (soft/hard bounces) were a total of 65 as it can be seen in Figure 53.

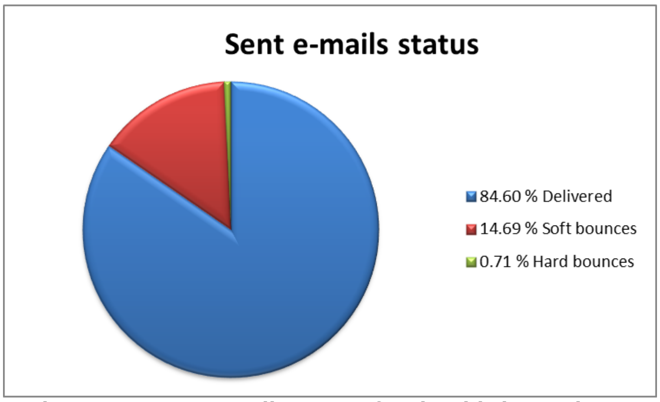


Figure 53. Sent e-mails status for the third newsletter

Once delivered the third newsletter was unread 275 times, read 82 times and zero complaints, as it can be seen in Figure 54.

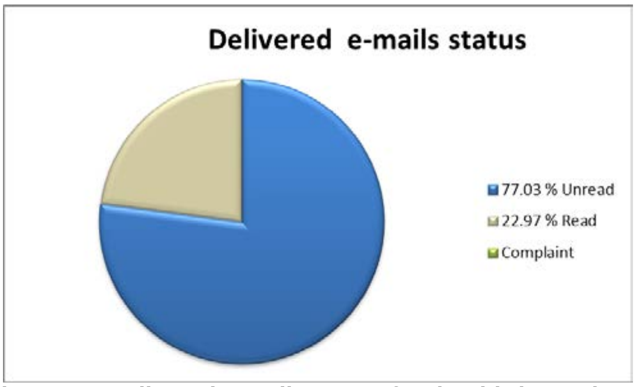


Figure 54: Delivered e-mails status for the third newsletter

An analysis of the visited websites, linked to the third newsletter was carried out and the results showed that the human body models for better elderly protection was the most visited as it can be seen in Figure 52.

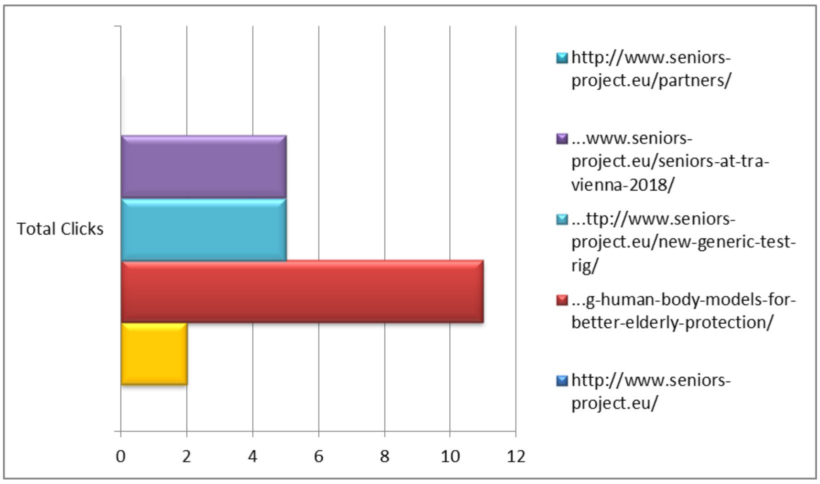


Figure 55: Visits linked to the third newsletter.

3.5.2 Task 5.2: External dissemination actions

Publication of Results

The partners had been entitled to publish research results and development results obtained from the project in the usual scientific form[1]. However, all concept publications had been submitted to all partners together with a request for permission to publish as agreed in the Consortium Agreement.

This procedure was established to ensure a proper and coordinated dissemination of the project results but also to protect particular interests of any of the partners in the project. The project website contains an overview and archive (when possible due to copyright issues) of all published information: scientific articles, publications, press releases, conference papers, etc.

Public presentations

- M Burleigh(2017) Introduction of a new Elderly Anthropomorphic Test device. Safety Week, carhs, Aschaffenburg Germany
- M Burleigh(2017) EC SENIORS Project. BSI committee meeting, London, UK
- Wisch, M.(2017) Application example for data usage / analysis. CIVITAS forum
- Wisch, M.(2017) SENIORS – First Results. 1st Results H2020 Road Transport Research
- Wisch, M.(2018) Vehicle secondary safety priorities to protect older road users – field data analysis results. SAE Government / Industry Meeting
- Oliver Zander(2018) Main Results from EU Project SENIORS. Praxis Conference on Pedestrian Protection
- Andre Eggers, Krystoffer Mroz, Bengt Pipkorn, Francisco José López-Valdés, Steffen Peldschus (2018) A New HBM Simulation Based Approach for Improved Thorax Dummy Injury Criteria. Carhs Human Modeling Symosium
- Wisch, M.(2018) SENIORS – Results. Results H2020 Road Transport Research

Technical publications (including conferences)

The following technical publications have been accepted for publication in the second period of the project:

- Fornells, A., Parera, N., Ferrer, A., and Fiorentino, A. (2017) Senior Drivers, Bicyclists and Pedestrian Behavior Related with Traffic Accidents and Injuries. SAE Word Conference.
- Beebe, M. Ubom, I., Vara, T., Burleigh, M., McCarthy, J. (2017) The Introduction of a New Elderly Anthropomorphic Test Device (EATD). ESV Conference.
- Zander, O., Ott, J., Wisch, M., Eggers, A., Fornells, A., Fuchs, T., Hynd, D., Lemmen, P., Burleigh, M., Lopez-Valdez, F., Luera, A., Lundgren, C. (2017) Safety Enhanced Innovations for Older Road Users (SENIORS): Further Development of Test and Assessment Procedures Towards an Improved Passive Protection of Pedestrians and Cyclists. ESV Conference

[1] Usual scientific form refers to journal scientific papers, presentations in scientific conferences and other usual means of scientific dissemination.

- Wisch, M., Lerner, M., Zander, O., Hynd, D., Vukovic, E., Schaerfer, R., Fiorentino, A., Fornells, A (2017) Road Traffic Crashes in Europe Involving Older Car Occupants, Older Pedestrians or Cyclists in Crashes with Passenger Cars – Results from Seniors. ESV Conference
- Eggers, A., Ott, J., Pipkorn, B., Bråse, D., Mroz, K., Lopez-Valdes, F., Hynd, D., Peldschus, S. (2017) A New Generic Frontal Occupant Sled Test Set-Up Developed Within the EU-Project Seniors. ESV Conference
- Wisch, M., Lerner, M., Vukovic, E., Hynd, D., Fiorentino, A., Fornells, A (2017) Injury patterns of older car occupants, older pedestrians or cyclists in road traffic crashes with passenger cars in Europe – Results from SENIORS. IRCOBI conference
- Lopez-Valdes, FJ., Juste, O., Lorente, A., Piqueras, A., Maza, M., Muehlbauer, J., Schick, S., Pipkorn, B., Mroz, K., Peldschus, S. (2017) Comparison of the kinematics and dynamics of the THOR-50M dummy and elderly volunteers in low-speed frontal decelerations. IRCOBI conference
- Lopez-Valdes, FJ., Juste, O., Lorente, A., Piqueras, A., Muehlbauer, J., Shick, S., Sumenonidis, I., Maza-Frechin, M., Peldschus, S. (2017) Kinematics and dynamics of young and elderly occupants in low speed frontal tests (2017). Traffic Injury prevention. AAAM
- Andre Eggers (2018) Assessment of chest injury risk of elderly vehicle occupants with human body models. VDI Conference
- Bengt Pipkorn (2018) Using Human Body Model to design PMHS test set-up. VDI Conference
- Eggers, A., Wisch, M., Ott, J., Barlog, T., Van Ast, P., Pipkorn, B., Mroz, K. (2018) Evaluation of new frontal test and assessment procedures proposed by the EU-project SENIORS for improved protection of elderly car occupants results. Crash.Tech
- Mroz, K., Pipkorn, B. et al. (2018) Investigation of Various Adaptive Belt Restraint Systems for the Protection of Elderly in Frontal Impacts. IRCOBI conference
- Chirag Shah, Geoge Hu, Julian Ott, M Burleigh, Oliver Zander (2018) Development of an FE model for FlexPLI with Upper Body Mass for enhanced pedestrian safety assessment. IRCOBI conference
- Andre Eggers, Marcus Wisch, David Hynd, Bengt Pipkorn, Krystoffer Mroz (2018) A Simulation-based Approach for Improved Thorax Injury Risk Function for the THOR ATD. IRCOBI conference
- Lopez-Valdes, FJ., Muehlbauer, J., Schick, S., Eggers, A., Peldschus, S. (2018) Chest injuries of elderly Post Mortem Human Surrogates (PMHS) under seat belt and airbag loading in frontal sled impacts. Comparison to matching THOR tests. AAAM

Other publications

EUCAR Project Books

The European Council for Automotive Research & Development (EUCAR) has published the 2017 edition of the project book. The EUCAR project book contains an overview of all the current research and innovation projects in their priority fields for ‘Safe and integrated mobility’, ‘Sustainable propulsion’, ‘Affordability and competitiveness’ and ‘Commercial vehicles’. The SENIORS project, with two EUCAR members in the Consortium (i.e. Ford and FCA), published a project summary including the main relevant information of the project as also in the year before. The publication is available in page 21 of the book (http://www.eucar.be/wp-content/uploads/2016/12/Projectbook_2017_WEB.pdf)

H2020 Magazine

Horizon 2020 Magazine is the science and innovation magazine from the European Union. The magazine published an article on older road user safety based on the SENIORS results and featuring an interview to two members of the project (WP3 and WP5 leaders). The article was published on June 11th and is available in:
https://horizon-magazine.eu/article/crash-test-dummies-based-older-bodies-could-reduce-road-fatalities_en.html

Centro Zaragoza Magazine

Centro Zaragoza is a research institute in Spain that publishes a scientific magazine every three months. An article on SENIORS is expected to be published during the first week of September, 2018.

Applus Innovation Blog

Applus is a multi-domain corporation based in Spain. It publishes innovation articles in its R&D blog on energy, transport and other sectors (http://blog.applus.com/). An article on SENIORS is expected to be published in September 2018.

EC Dissemination Booster

The SENIORS project has come together with PROSPECT and XCycle to benefit from a service offered by the European Commission: the Common Dissemination Booster. All three projects are focused on traffic safety analysis and integrated approach towards the safety of vulnerable road users under complementary perspectives. The Common Dissemination Booster programme which encourages projects to come together to identify a common portfolio of results and shows them how best to disseminate to end-users, with an eye on exploitation opportunities.

Although the results of this analysis came at the latest stage of the project and therefore were no fully usable for dissemination, the results will be considered for the final event and for the exploitation of results after the project lifetime.

Primary stakeholders for SENIORS project were defined such as:

- Civil society, NGOs, citizens
- Research & academia

The analysis showed that the project group has low engagement with their top priority stakeholders as Civil Society, NGOs and citizens, and Enterprises. On the other hand Research and Academia and Policy Makers, although were placed at the bottom of the priority ranking of stakeholders, were the ones that had the most engagements so far.

As conclusion, the group had to have a complete shift of focus and effort to achieve the desired results for their final event. Due to that a set of actions were defined to promote the engagement with the desired target groups and the most appropriate dissemination networks at European and international level for the Project Group in order to improve the dissemination for the final event.

3.5.3 Task 5.3: Monitoring exploitable results including Intellectual Property Right

Exploitation plan - Objectives

The exploitation of project results has been carried out by the project consortium team headed by a dissemination manager, IDIADA, and supported by BASt which main objective was to:

- Coordinate and align the individual interests of the involved parties.
- Keep track of market developments through contacts with relevant governmental bodies, consumer organisations, relevant industry stakeholders, etc.
- Keep track of harmonisation and standardisation issues.
- Provide assistance with respect to the protection of knowledge and results.
- Prepare an exploitation plan.

Exploitation plan – route and strategy

The preliminary exploitation route is defined as follows:

2018

- Preparation of market introduction of new restraint systems addressing the special needs of elderly people by testing in the project.
- Preparation of market introduction of new testing methods in order to assess the restraint systems considering in particular elderly people and their requirements through test houses.
- Preparation of market introduction of new test tools designed to assess the safety of older road users by test house.
- Start preparation Euro NCAP draft test procedures and protocols.

2019

- Test and assessment tools validated using on the market or close to the market systems.

2020 – 2025

- Possible implementations of new test, and assessment methods, regarding elderly road users to Euro NCAP protocol.

2030

- 20% of new cars in the high end segment cars equipped with restraint systems based on knowledge gained in SENIORS, resulting from the implementation of the new test, evaluation and assessment methods.

2050

- 15% fleet penetration with restraint systems addressing especially older road users.

The exploitation plan has been described in Deliverable 5.4 “Dissemination and exploitation plan update”. The following points describe its main characteristics.

Exploitation Plan review and changes

The current exploitation plan has been reviewed according the activities that had been carried out during the SENIORS Project.

The management and legal intellectual property agreements are still valid as well as the route and strategies defined. The exploitable knowledge and its use, however, are defined as described in Table 17 but are likely to be reviewed during the lifespan of the result itself in order to adapt them to an evolving market.

Table 17. Overview of exploitable knowledge, products and measures

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	Timetable for commercial use	Patents or other IPR protection
-	Test objects or suits for test objects to represent pedestrians and car occupants	Automotive design and testing	2-5 years	Potential patenting currently being studied
-	Test and assessment protocols	Automotive testing	2-5 years	No
Results from accident and hospital data analyses	-	Advice to governments	After the project end	No
Virtual Models	-	Automotive design	After the project end	To be studied
New injury criteria	-	Automotive design and testing	2-5 years	No
-	Restraint systems	Automotive design and testing	5-7 years	To be studied

As shown in Table 17, exploitable knowledge results from accident and hospital data analyses had been published in form of project presentations. Also, finite element (FE) simulation model of a human had been updated in order to comprehend the kinematics and biomechanics of an older person. This model had received input from external project partners (e.g., University of Michigan, US) regarding all the needed biomechanical requirements. The update according to age includes new geometry and material properties. With the help of virtual dummy and human body models it was possible to create and assess new injury criteria. The new injury criteria were a core part of the assessment and testing protocols.

Exploitable products or measures had been developed during the project as it is shown in Table 17, regarding pedestrian protection, the SENIORS consortium worked to update of the FlexPLI with Upper Body Mass with a new design in order to fulfil the biomechanical requirements.

Regarding occupant safety, injury risk curves used for crash tests were developed for the THOR dummy considering in particular older persons. Further, an innovative and completely new elderly, overweight crash test dummy had been further developed in conjunction with project external US experts.

Test and assessment protocols, specifically addressing older road users had been developed in order to assess the performance of the safety systems. Once adopted by the consumer testing (e.g., Euro NCAP) or governments for regulatory testing a significant turnover in testing is expected.

Lastly, novel restraint system concepts and other safety devices had been tested in order to assess their safety potential to address the elderly persons by finally offering safety measures for all road users.

Partners Exploitation Plan

In this section an exploitation plan for each type of partner is explained. The consortium partners had been categorized in three groups:

- Test tool suppliers;
- Technology, engineering and academic partners; and
- OEMs and Tier1 suppliers.

Test tool suppliers exploitation plan

The only test tool supplier in the consortium is Humanetics. In the Humanetics exploitation plan the key partners are engineering and technology partners to validate and test the new tools, and also OEMs and Tier 1 and 2 partners to provide needs on new testing capabilities.

The key activities carried out in this project by Humanetics had been the further development of an elderly, overweight dummy and the further development of pedestrian testing tools and the associated simulation models.

Humanetics is known for its activities as a main developer of Anthropometric Test Devices (i.e. crash test dummies), specialists in biomechanics and manufacturing resources. But also for special knowledge of development based on Human Body Models, market strategy aligned with Euro NCAP roadmap and the know-how of testing devices.

Technology, engineering and academic partners

The technology, engineering and academic partners for this exploitation plan have Humanetics as supplier of new testing tools and other universities/RTOs for joint research initiatives.

The key activities to be carried out for the exploitation of the results are test tool validation, state of the art studies, HBM and CAE simulation modeling and development of new test protocols and new assessment tools. These entities had been known also for their main activities in R&D Innovation capabilities, laboratories, instrumentation and environments for testing and virtual simulations, the development of computing platforms and their know how in research activities and in vehicle development services. Also, they are known for their special access to new testing tools assessment of new testing tools, research data in elderly and HBM development.

<u>OEMs and Tier1s</u>

In the OEM's and Tier1s' exploitation plan the key partners are the test tool providers in order to provide new testing tools, the Tier 1 and 2 partners to provide material to test the new tools and the engineering / technology partners to validate and test the new tools developed.

The key activities to be carried out to enable further exploitation of the project results is the assessment and further development of the new tools and safety systems developed. The OEM's and Tier1s' partners are known for their main activities as manufacturing capabilities, market knowledge, laboratories, instrumentation and environments for testing but also for special knowledge of new safety features.

<u>Intellectual Property Right</u>

The required IPR procedures will be clearly stated in the Consortium Agreement and the exploitation of results will conform to them. The Consortium Agreement will reflect the rules of the European Commission for the protection and dissemination of knowledge, including the following:

- Transfer of knowledge (access rights to background): all partners will identify pre-existing know-how granting access to this body of knowledge for the implementation of SENIORS to the members of the consortium. This pre-existing knowledge will be described in the Consortium Agreement.
- Property of the foreground: partners participating in specific tasks will share intellectual property rights of the results.
- Protection of the foreground: if foreground is susceptible of commercial application, its owner (or owners) shall provide mechanisms for its protection. If there is a patent application as result of the project, the financial support of the European Commission will be acknowledged.

All IPR issues are described in detail in the Consortium Agreement, section 8.
The Consortium Agreement is included in Deliverable 6.1.

The IPR (Intellectual Property Rights) and exploitation issues had been handled by the Exploitation manager (IDIADA) supported by BASt who have wide experience in such matters having also access to internal and external specialists in patent and legal affairs. The main objective of the Exploitation Manager was to achieve the objectives of the Exploitation Plan.

4 IMPACT

An elderly pedestrian (>65 years old) has a 50% higher risk of being fatally injured compared to an average adult at typical crash speeds, and similar findings have been shown for occupants in frontal crashes. Furthermore, benefit studies as in recent EU research under the THORAX project estimated that considering age dependent risk curves may result in a benefit of 37 M€.

Significant reductions in fatalities and injuries can be achieved by implementing the project findings and results in future regulatory and rating procedures for vehicle safety. Restraint and vehicle technologies to protect the elderly are currently available and wide-spread introduction of these technologies is to be encouraged via consumer testing and regulatory procedures. As such the SENIORS project is also providing input to on-going definitions of legislation, for instance the regulations on frontal impact and pedestrian protection.

The SENIORS project aimed to enable this same level of safety for the elderly by developing the measures mentioned, and thus potentially saving up to 1,500 lives of elderly people on European roads in medium term, as we have it proportionally nowadays for the younger generation.

In addition, implementing improved elderly protection criteria is expected to give benefit to younger road users taking advantage of the synergies found in various disciplines of road safety of elderly as an integrated approach.

Elderly occupant safety has been the priority for this project: literature reviews and data gathering from road traffic accident and hospital databases revealed that elderly occupants were sustaining serious injuries to the thorax in moderate-severity vehicle collisions. As such, current restraint systems were assessed because thorax loading led to the most significant amount of AIS 3+ injuries within this demographic.

Front seat restraint systems have improved over the last few decades and as such the loading applied to the occupant's thorax has been greatly reduced, reducing the injury risk for younger and mid-aged occupants. Older occupants, however, have a lower biomechanical tolerance and the collision data shows that they can sustain serious and life-threatening thorax injuries (especially rib fractures) despite the advances in restraint system and vehicle design. To reduce the thorax loading for senior occupants, novel restraint system concepts were tested, with the aim of reducing the risk of serious or life-threatening chest injuries.

The benefits of applying these new technologies to the entire fleet were also modelled within this report. The model focused on two restraint system designs in particular – the Split Buckle and Criss-Cross seat-belts – and how they would reduce European wide casualties, fatalities and the associated costs. The model calculated the benefit for car occupants of regulating each design in 2020 with mandatory fitting in 2022. Note that it is not expected that such a regulation would be implemented in this timescale; rather, the study used this scenario as a way to explore the potential casualty savings and the societal cost reductions that could be delivered by these systems.

The analysis showed that, in this scenario, the EU has the potential to prevent between 800 and 1,200 car occupant fatalities among the 65+ age group by implementing one of the seat-belt designs. There is also the potential to prevent between 6,500 and 10,500 serious occupant injuries and have an economic benefit in the range of €4.7-8.1 billion, over the period 2020-2030.

Regarding pedestrians and cyclists, SENIORS wanted to assess how changes to head testing tools and methods, the Thorax Injury Prediction Tool (TIPT), and the FlexPLI with Upper Body Mass (FlexPLI-UBM) test tool would affect the Euro NCAP test parameters. It was not possible to combine reliably the project's achievements with any calculation of the number of potentially reduced casualties or reduced societal costs.

The new 2025 roadmap of the European New Car Assessment Programme that has been published in 2017 foresees, amongst other things, a revision of the subsystem tests for pedestrians and cyclists, in particular in terms of the headform test and evaluating possibilities for the introduction of a surrogate upper body for the FlexPLI. The aim is the implementation of these new tests for rating as from 2022 onwards. It is highly recommended to present the results from the SENIORS project as valuable input to this new work item of Euro NCAP.

Head impact tests, literature reviews and data assessment indicated that the current Euro NCAP head impact test area was not capturing cyclist head impacts or some taller pedestrians. Extending the upper boundary WAD (Wrap Around Distance) to 2500 mm, would address an additional proportion of pedestrians, and a higher proportion of cyclists, even without changing the head half-diameter exemption zones at the edges, or the head performance limits. However, for OEMs there would be little incentive for additional benefit in protecting VRUs from impacts with the A-pillars.

The completely new test tool TIPT (Thorax Injury Prediction Tool) was found to offer the possibility of more informative and biofidelic ways of testing vehicles with higher BLE (Bonnet Leading Edges) especially concerning the growing SUV and MPV market share.

Finally benefits of the FlexPLI-UBM were mainly qualitative such as improved biofidelity. Euro NCAP's existing lower leg tests would become more relevant to the real world as they are more biofidelic, particularly for femur and knee injury risk assessment.

5 USE OF RESOURCES

Based on the Financial Statements provided by all partners, used resources for the second project period and the entire project runtime are summarised in Table 18 and Table 19. **Please note:** According to agreements during the mid-term review, Ford claims all of its costs in the second period only, although parts of the work were performed in the first period.

Table 18: Actual number of Person Months and Costs in the 2nd SENIORS project period (M19-M36)

			Person Months								
WP	**Months**	**Leader**	**BAST**	**Autoliv**	**FCA**	**Ford**	**Humanetics**	**IDIADA**	**LMU**	**TRL**	**TOTAL**
1	1-14	BASt	0,46			3,90		0,07		0,23	**4,66**
2	1-26	TRL	5,80	10,00	5,23	1,70		0,02	6,43	3,03	**32,21**
3	6-25	Humanetics	9,14	3,00	5,42	2,50	10,52	0,24		0,04	**30,86**
4	25-36	IDIADA	14,90	6,00	14,59	1,80	0,40	31,13		5,89	**74,71**
5	1-36	IDIADA	2,53	1,00	1,03		0,26	4,81	0,56	0,01	**10,20**
6	1-36	BASt	3,54					9,23		0,32	**13,09**
		TOTAL	**36,37**	**20,00**	**26,27**	**9,90**	**11,18**	**45,50**	**6,99**	**9,52**	**165,73**
			Costs (in €)								
		Personnel Costs	235.251,41	143.171,00	113.979,86	103.736,36	70.838,45	160.034,01	38.250,39	62.280,42	**927.541,90**
		Other costs	99.484,94	76.643,00	57.676,24	74.062,08	88.403,41	14.968,31	9.382,11	6.921,81	**427.541,90**
		TOTAL Direct costs	**334.736,35**	**219.814,00**	**171.656,10**	**177.798,44**	**159.241,86**	**175.002,32**	**47.632,50**	**69.202,23**	**1.355.083,80**
		Subcontracting (without OH)							79.016,00		**79.016,00**
		Third Party		153.925,00				25.145,61			**179.070,61**
		Indirect costs **(25% FlatRate on direct costs)**	83.684,09	54.953,50	42.914,03	44.449,61	39.810,47	43.750,58	11.908,13	17.300,56	**338.770,95**
		Costs	**418.420,44**	**428.692,50**	**214.570,13**	**222.248,05**	**199.052,33**	**243.898,51**	**138.556,63**	**86.502,79**	**1.951.941,36**
		Funding	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	
		Percentage from Budget	**64%**	**108%**	**72%**	**100%**	**62%**	**50%**	**52%**	**37%**	

Table 19 specifies the overall project costs. It can be seen that partners BASt, FCA, Ford and LMU have met the cost expectations quite well. Autoliv did overspend. Partners Humanetics, IDIADA and TRL did underspend. Justifications for that are provided in Section 6.3.2.

Table 19: Actual number of Person Months and Costs in the SENIORS project (M1-M36)

			Person Months								
WP	**Months**	**Leader**	**BAST**	**Autoliv**	**FCA**	**Ford**	**Humanetics**	**IDIADA**	**LMU**	**TRL**	**TOTAL**
1	1-14	BASt	9,55	1,83	7,00	3,90		6,15		7,26	**35,29**
2	1-26	TRL	20,49	23,09	11,02	1,70		0,02	12,62	10,62	**79,36**
3	6-25	Humanetics	16,35	5,29	5,42	2,50	14,92	0,24		0,07	**44,79**
4	25-36	IDIADA	14,93	6,00	14,59	1,80	0,40	31,13		5,89	**74,94**
5	1-36	IDIADA	3,28	1,06	1,03		0,26	7,22	0,56	0,01	**13,92**
6	1-36	BASt	5,52					13,63		0,32	**19,47**
		TOTAL	**70,12**	**37,27**	**39,06**	**9,90**	**15,58**	**58,39**	**13,18**	**24,17**	**267,77**
			Costs (in €)								
		Personnel Costs	430.480,74	285.117,00 €	179.302,80	103.736,36	103.622,06	206.939,14	70.937,96	129.472,42	**1.509.608,48**
		Other costs	138.394,92	99.699,00 €	64.050,18	74.062,08	92.362,74	25.628,00	12.477,24	20.547,40	**527.221,56**
		TOTAL Direct costs	**568.875,66**	**384.816,00 €**	**243.352,98**	**177.798,44**	**195.984,80**	**232.567,14**	**83.415,20**	**150.019,82**	**2.036.830,04**
		Subcontracting (without OH)							169.032,75		**169.032,75**
		Third Party		170.490,00				25.145,61			**195.635,61**
		Indirect costs **(25% FlatRate on direct costs)**	142.218,92	96.204,00	60.838,25	44.449,61	48.996,20	58.141,79	20.853,80	37.504,96	**509.207,51**
		Costs	**711.094,58**	**651.510,00**	**304.191,23**	**222.248,05**	**244.981,00**	**315.854,54**	**273.301,75**	**187.524,78**	**2.910.705,91**
		Funding	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	
		Percentage from Budget	**108%**	**165%**	**101%**	**100%**	**76%**	**65%**	**102%**	**79%**	

6 DEVIATIONS FROM ANNEX I

6.1 TASKS AND OBJECTIVES

Work Package 1

The work of Task 1.4 took much longer than expected, because it was envisaged to integrate results from other studies on the benefit of active vehicle safety systems and projects such as the in parallel running H2020 project SafetyCube.

Work Package 2

For the development of car occupant injury risk functions, the original plan to implement a strain gauge injury criterion approach was changed to the probabilistic rib fracture prediction approach. This was based on new experience within the consortium between bid submission and the start of this task. The change was discussed with and approved by the external Expert Group.

A new deliverable, D7.1 on the ethics approvals for PMHS testing, was provided. This deliverable was required by the Commission, but the requirement was not defined at the project proposal stage.

The frontal impact PMHS data identified in the literature primarily uses older designs of restraint system that are not representative of restraint systems in modern cars and which apply much higher loads to the thorax than modern restraint systems. Most tests use also use a seat-belt, but no airbag; the few test series that have used an airbag have used projection airbags that are no longer available or prototype airbags, neither of which can be reproduced so these test series cannot be replicated with new dummies or PMHS. In order to solve both of these challenges, SENIORS developed a generic sled test rig. All aspects of the design of the rig, including the design of the driver's airbag, are freely available as CAD and FE models, so future studies can use the same test configuration indefinitely.

Additional EMG (muscle activation) measurements were made during the volunteer tests at Unizar, supplementing the EMG measurements made in the FCA volunteer tests.

Overall, approximately double the number of occupant simulations were performed compared with the original plan in the proposal. Numerous additional simulations were also performed for the external road user simulations, including simulations to account for updated FlexPLI-UBM models and simulations to improve the analysis of TIPT and HNI test tools.

Age characteristics were implemented for the car occupant HBM, but not implemented for the pedestrian HBM. Unlike the occupant thorax, SENIORS was not attempting to predict injury with the pedestrian HBM; rather using it as a route to get a transfer function between human and test tool. Instead, improvements were made to the model.

The head-neck impactor (HNI) was evaluated but not taken forward at this time because improved kinematics could not be demonstrated using the 2D vehicle models available when this task was performed. Therefore, no transfer function between HBM and HNI was developed. As a result, effort focused on FlexPLI-UBM and TIPT tests.

Work Package 3

Only one elderly, overweight dummy had been manufactured, and thus, only one was provided for testing. No biofidelity tests were run relating to PMHS or HBM as elderly targets would have been required to compare. Therefore no injury risk curves could be established for the EATD. For the same reason TRL and Autoliv did not run sled or pendulum tests.

Reproducibility tests could not be run as there was only one dummy and no improvements were made on the dummy in the project as testing was late and would have needed feedback sooner to make changes.

For pedestrian and cyclists the HNI was not pursued in design and hardware. Hardware test reporting for FlexPLI UBM and TIPT was moved to WP4.

Regarding the TIPT, only the design has been validated, full validation could only be completed after further testing and comparison to Human body model responses. However, the TIPT meets the design criteria set out in the design specification.

Work Package 4

The activities in WP4 could only start delayed (~4-5 months) caused by the required finalization of work in previous Work Packages. Finally, this has also caused issues regarding the timing of the experimental tests (sled tests) planned in the laboratories at BASt, FCA and IDIADA.

For Task 4.3 TRL was able to modify an existing benefit analysis model that TRL had developed for another project (for the Commission), which was not expected at the beginning of the project and thus, this introduced a significant efficiency to finish in time.

Work Package 5

There were no major deviations from the DoA in WP5 during the second period. The main deviations are related to timing and delays and the sudden and late participation to the EC's Common Dissemination Booster, as detailed before.

All milestones were fulfilled, but were 7-8 months later than the original date. Only the milestone "Implementation of results based on workshop discussions with stakeholders" and the ones related to the General Assemblies were achieved on time.

As for the deliverables only D5.4, D5.6 had a deviation of 9 and 11 months. The other deliverables were delivered within the expected timing.

6.2 MODIFICATIONS REGARDING THE DELIVERABLES AND MILESTONES

Most deliverables have been submitted delayed as some activities in the project suffer from a delay of work of around 4-5 months since the start.

Deliverable 1.3: The report could not be finished within the first project period due to the missing technical input from Deliverable 1.2 and the corresponding missing personnel resources. The report was further delayed in the second project period as the corresponding Task 1.4 did not complete its work as it was expecting valuable input from other projects (e.g., SafetyCube). In accordance to this Milestone 2 could only be achieved delayed.

Deliverable 2.3: The report has been submitted with delay as parts of the volunteer and PMHS tests were not conducted in time. This is also related to the required increase of the subcontracting budget of LMU which was finally solved by the first Amendment to the Grant Agreement. The report could only be finalised after the conduction and analysis of remaining tests with post-mortem human subjects in April 2017.

Deliverable 2.4: Delayed delivery as the development of the age-modified HBM took much longer than expected and its usage required a number of iterative development steps. In addition, various simulations had to be repeated for technical reasons.

Deliverable 2.5: Delayed delivery as the required age-modified HBMs were provided later than expected which formed the basis for the evaluation. Further, the work of Task 2.6 related to the injury risk statistics revealed completely new and time-consuming scientific issues as the method to calculate injury risk curves on the basis of probabilistic injury prediction based on HBM simulations was never applied before in this way.

Deliverable 3.2: Delayed delivery as the required dummy tests were delayed in time due to the delayed end of previous Tasks and because the development / modification of impactors took much more time than initially expected.

Deliverable 3.4: Delayed delivery due to delayed testing in WP3 and WP4. Some related tests were shifted between the project partners as requested with the second Amendment to the Grant Agreement.

Deliverable 4.1: Delayed because previous work from WPs 2 and 3 finished delayed and hence, the start of work on Task 4.1 was delayed by around 4 months. In addition, the Deliverable was wrongly timely planned from the beginning as the submission month was the same as the first month of its official Task working start.

Deliverable 4.2: Delayed because previous work from WPs 2 and 3 had to be completed first and delays in experimental testing in Task 4.2 due to availability of test labs and objects and the delivery of updated statistical methods developed in Task 2.6.

Deliverable 4.3: Delayed delivery because previous work from WP4 had to be completed first.

Deliverable 5.4: An overall delay of the project due to unforeseen changes in some technical aspects had an impact on the definition of the exploitation plan. One of the main results was improved (as detailed in the first amendment of the project) and thus, the exploitation plan needed to be redefined from the defined at the beginning of the project.

Deliverable 5.6: One of the main deviations in WP5 in the first period and in the overall project is the replacement of the Advisory Board for SENIORS Experts Meeting at the IRCOBI conference. This brought a lot of benefits such as high attendance, low organisational costs and better international cooperation but was restrictive in terms of timing. This restriction was transferred to this deliverable as new content was not available until the end of the project. However, the strategy followed led to better international cooperation in the project and this is included in the deliverable, which was not foreseen.

Deliverable 5.8: Use of the dissemination database has been a constraint in the overall dissemination process. The redefinition of the newsletter process to improve the content compared to the first newsletter caused a significant delay. This process was further improved for the third newsletter which had no delay.

Deliverable 6.3: Delayed delivery because timing was not feasible as the review meeting has to be taken place first.

6.3 USE OF RESOURCES

6.3.1 Related to the Amendment

The following budget changes were required and accepted by INEA according to the second Amendment, Modification 1), mentioned in Section 3.0.4:

- IDIADA:
  - Budget shift of 84,360.00€ plus indirect costs (25%) in the section “Personnel costs” from the main beneficiary IDIADA Automotive Technology, S.A. to its Linked third party IDIADA Fahrzeugtechnik, GmbH relevant for the second half of SENIORS.

The following budget changes were required and accepted by INEA according to the second Amendment, Modification 2), mentioned in Section 3.0.4:

- TRL:
  - Budget decrease of 20,140.00€ plus indirect costs (25%) in the section “Personnel costs”
  - Budget decrease of 33,720.00€ plus indirect costs (25%) in the section “Other direct costs”
- Autoliv/ALS:
  - Budget increase of 19,750.00€ plus indirect costs (25%) in the section “Personnel costs”
  - Budget increase of 34,110.00€ plus indirect costs (25%) in the section “Other direct costs”

The following budget changes were required and accepted by INEA according to the second Amendment, Modification 3), mentioned in Section 3.0.4:

- TRL:
  - Budget decrease of 20,000.00€ plus indirect costs (25%) in the section “Other goods and services”
  - Budget decrease of 3,580.00€ plus indirect costs (25%) in the section “Consumables”
- BASt:
  - Budget increase of 23,580.00€ plus indirect costs (25%) in the section “Personnel costs”

The beneficiary LMU reported costs as “Unit costs” although the Grant Agreement specified “Actual costs” (note: this was already accepted in the first project period).

<u>Related to Humanetics</u>

Humanetics has reported in February 2018 that due to unforeseen consumable expenses, namely the extension to further hire the Flex PLI leg and the development of fixtures for the TIPT launcher they have over spent in this area. However, as they have more labour hours than expected 61% up to end of November 2017 and from 1 December to the 21 February 2018 Humanetics have used 221 hours. This left 775 hours remaining for the upcoming 3 months. Further, in consumables Humanetics estimated to have an estimated overspend of 8,000 Euros. Therefore Humanetics formally requested 160 working hours to be transferred to consumables. This was estimated with 9,033 Euros. This calculation left 615 hours over for the remaining 11 weeks. So there was no concern running out of hours. This request was formally sent to the EC on 22 February 2018. Finally, the current EC's Project Officer accepted this requested transfer without any further amendment by e-mail on 26 February 2018.

6.3.2 Justifications related to overspending and underspending of budget

Autoliv has used in total 179% of its grant. Reasons for this can be summarized to:

1) Additional time was required to establish the method and specific activities in WP3 and WP4; and
2) Way more discussions were required than expected to set the conditions for the FE HBM simulations in WP2.

Humanetics under spent by 24% on its labour budget. Reasons for this are:

1) The original plan to design two fat suits for the THOR dummy was replaced with one elderly, overweight dummy that was already developed in the U.S. Therefore the 3D CAD work was not as extensive as only new legs and jacket were developed in the project.
2) The Head Neck Impactor development was stopped. Therefore no hardware design was required for this test tool.

TRL under spent by 21%. Reasons for this are:

1) Use of a different mix of staff (and therefore staff rates) than originally envisaged.
2) For Task 4.3 TRL was able to modify an existing benefit analysis model that TRL had developed for another project (for the Commission), which was not expected at the beginning of the project. This introduced a significant efficiency on T4.3.
3) TRL did not run pendulum impactor certification tests in WP3 with the EATD, because no performance targets were available for comparison.

IDIADA has not requested 100% of the budget. However, all the activities described in the DoA have been performed as requested and the reduction of submitted expenses is due to the facts described below.

The general delay of the project reduced the timing of WP4 and therefore all the activities needed to be reorganized, especially testing and evaluation tasks. IDIADA crash laboratory is currently at 100% of its capacity, so any test must be planned some months in advance. Consequently the continuous delays meant it was not possible to plan the deceleration tests with enough time. Nonetheless, IDIADA solved this issue and was able to perform the sled tests on time thanks of the following actions: On the one hand, IDIADA used two THOR dummies at the same time, at driver and passenger position, reducing the number of deceleration tests from 18 to

11, which reduced around 20% of the test costs originally intended and 40% of the time. On the other hand the sled tests were finally performed in an IDIADA sister company, CETAG-IDIADA, whose costs are unfortunately not eligible without an amendment and therefore are not requested as part of the expenses. The costs and effort of the mentioned sled tests (petition, offer and invoice) can be proven (on request). If these costs were eligible, the total expenses would be around 100% of the initial budget.

7 Publishable Summary - Long version

7.1 Summary of the context and overall objectives of the project (For the final period, include the conclusions of the action)

European countries face great challenges because the demographic structure in the EU is changing rapidly, due to reducing birth rates and increasing life expectancies. In 2012, 17% of Europeans were aged 65 and older and in 2020 this will rise to 28%. Meanwhile, the mobility needs of the elderly are also changing. Maintaining a driver's licence is an important issue of independence today, both for males and females. Furthermore, there is an increasing rate of overweight in EU populations, which introduces changes in injury patterns and risks.

Also technological developments like the introduction of e-bikes enables access to other means of transport. These demographic and behavioural changes are of growing concern to mobility and road safety. While accident data show a decreasing number of fatalities and serious injuries on EU roads, data from the ERSO showed an increasing proportion of elderly in the fatality statistics. This trend is a serious threat to the achievements of recent decades and posed a challenge that must be addressed to meet goals set for further reduction of road fatalities.

The major objective was to develop the required understanding of accident scenarios, injury mechanisms and risks and to implement these findings in test tools and test and assessment procedures. An integrated approach considering the elderly in multiple transport modes is applied to reduce the portion of elderly fatalities.

In an ageing society, the SENIORS (Safety ENhancing Innovations for Older Road userS) project aimed to improve the safe mobility of the elderly, and overweight, using an integrated approach that covers the main modes of transport as well as the specific requirements of this vulnerable road user (VRU) group. Thus, this project primarily investigated and assessed the injury reduction that can be achieved through innovative and suitable test tools as well as passive vehicle safety systems targeting the protection of the elderly as car occupants, pedestrians or cyclists being involved in vehicle impacts. SENIORS aims to have a short- to mid-term effect on the elderly road user's safety, also by transferring nowadays younger generations' safety standards, with the following achievements listed by five key objectives:

1) Improve the protection of elderly road users (key transport modes)
2) Understand the influence of age in pre-crash and crash occupant dynamics
3) Identify the specific anthropometric and injury mechanism of elderly, including overweight/obese people, compared to younger people.
4) Develop and optimise test tools, procedures and assessment methods;
5) Transfer knowledge and results to interested experts, regulatory bodies, consumer entities etc.

Selected achievements and conclusions from the abovementioned key objectives were:

Regarding 1)

Crash and hospital data analysis regarding older road users of several European databases have been performed resulting into similar conclusions. It could be confirmed that elderly suffer more often from higher injury severities compared with younger road users. The most important body regions were identified for car occupants (thorax) and for pedestrians / cyclists (head, thorax and lower extremities).

Further, specific measures were derived from this data including adaption of test and assessment procedures by: Injury Risk Curves, Modified or new test tools, Adopted assessment procedures, etc.

Regarding 2)

Two series of volunteer tests were conducted to understand differences in braking manoeuvres (also link to active safety) focusing on the kinematics and muscle activities of older and younger car drivers. The analysed data was used to advance an Active Human Body Model.

Regarding 3)

A comprehensive analysis of the correlation between chest geometry, age and weight/BMI was performed using mainly studies available from the US. However, rarely data was available related to pedestrians and cyclists. As examples, it was found that the width of the lower rib cage is much larger than the upper portion in a person with a high BMI while no significant difference was found for normal BMI. Further, obesity seems to be the strongest predictor for rib angulation. So older and more heavyweight individuals tend to have more horizontally orientated ribs.

In addition, age-related material properties were identified from literature and key findings were implemented in three human body models: THUMS V4, THUMS TUC and GHBMC. Regarding the THUMS TUC SENIORS morphed rib cage models. Best fitting geometries were chosen representing a “young adult” (35yo) and an “elderly” (65+) occupant in most parameters (based on 995 CT scans).

Regarding 4)

A generic sled test set-up and CAE model was developed to provide greater understanding of thoracic injury risk at AIS 2+ (moderate) and low risk (e.g. 5%) at AIS 3+ injury. The work was implemented by performing paired sled simulations with HBMs and ATDs covering a wider range of loading conditions than is currently available in literature (e.g., belt and airbag usage, low-speeds). This allows research on a repeatable and reproducible basis using the open source approach.

Various experimental tests with current and future crash test dummies (Hybrid III, THOR, EATD) were performed as well as sled tests with current and future car occupant restraint systems.

Regarding pedestrians and cyclists the focus was set on the Legform Impactor with Upper Body Mass (FlexPLI-UBM), the completely new Thorax Injury Prediction Tool (TIPT) and the head neck impactor (HNI). Latest results showed the FlexPLI-UBM and the TIPT having a high potential.

Regarding 5)

Results were and will be presented at technical meetings of the ISO and Euro NCAP but also forwarded to regulatory bodies.

What next?

- Tests with ATDs are still required. However, HBMs offer great potential for traffic safety increase. Simulations even offer a possibility to cover a wider range of injury causing collision scenarios.
- Additional PMHS and volunteer tests are required to further enhance HBM developments and to update injury risk curves. ATDs will also benefit.
- SENIORS has facilitated this by making a well-defined and well-documented test environment publically available (Generic Test Rig).
- If restraint loads can be lowered, this should be done whenever feasible; leading to a benefit for everybody, but even to a higher benefit for older persons!
- In future experimental testing will partly be replaced / added by simulations.

If the proposed methods by SENIORS gain acceptance, this would lead to more innovative, adaptive passive vehicle safety systems. Finally, it is believed that all introduced measures towards the improved protection of older road users could also be beneficial for younger road users.

Take-away messages:

- Passive Vehicle Safety is indispensable and has still potential!
- Knowledge about crashes and biomechanics needs further enhancement!
- Future requests the hybrid testing approach: Experiments and Simulations.

7.2 WORK PERFORMED FROM THE BEGINNING OF THE PROJECT TO THE END OF THE PERIOD COVERED BY THE REPORT AND MAIN RESULTS ACHIEVED SO FAR (FOR THE FINAL PERIOD PLEASE INCLUDE AN OVERVIEW OF THE RESULTS AND THEIR EXPLOITATION AND DISSEMINATION)

7.2.1 Literature analysis on specific requirements of older road users and the analysis of crash and hospital data as well as mobility studies.

Various European, national and in-depth accident databases and hospital statistics were analysed regarding elderly injuries (as car occupants, pedestrians or cyclists) sustained in road traffic incidents. These were compared to mid-aged adults (25-64 years). It can be seen that the elderly suffered in all body regions more often from higher injury severities (AIS 2 and AIS 3+) compared with younger road users in these crashes. About 7.5% of the elderly pedestrians suffered injuries of AIS 3+ to the thorax and lower extremities; over 5% did so in the head and pelvis region.

A comprehensive literature search was performed to gain a complete picture on the issues older road users face in road traffic including their mobility and physiological changes. Seniors of today are more mobile than seniors of earlier generations and along with an aging society has led to an increase in the number of elderly road users therefore having a higher probability of being involved in accidents. Further, for the countries Germany, Italy, and Spain the frequency of trips, travelled distances, and trip purposes were analysed for elderly persons as car occupants, cyclists and pedestrians.

Work was proposed based on reports from the USA that obese car occupants were at an increased risk of injury and death in frontal impacts, compared to occupants with a “normal” BMI. However, the SENIORS analysis of accident data and hospital statistics showed that the prevalence of “obesity” (BMI > 30) was lower than expected in Europe. Instead, the results show the importance of occupants with “overweight” (BMI 25-29) in road crashes and could not confirm the effects for a significant increased risk of injury of obese car occupants (BMI > 30, obesity classes I-III) as seen in the USA.

All the knowledge gained is reported in deliverables but also presented at conferences (e.g., ESV 2017 and IRCOBI 2017) and thus, publically available. It is intended to spread the information further to traffic and insurance institutions by initiating related meetings. The results will be used as well for papers and journals in the near future, such as the SAE International in Detroit (2019) and at ESAR (Expert Symposium on Expert Research, 2019).

7.2.2 Investigation of age-related changes to Human Body Models (HBMs) including bone material properties and anthropometric changes

A Human Body Model (HBM) was modified within SENIORS to represent an older road user. The activity started with a literature review on biomechanical bone material properties. The material properties of body tissues and how they change with age and the anthropometric changes that occur with age were identified and tabulated. Age-related changes were applied to the human body model THUMS (Total Human Body Model for Safety). Finally, two finite element models of the thoracic rib cage were generated by morphing the rib cage anthropometry. One model had a rib cage shape of a young adult (35 years-old), while the other was representing an elderly person (65+ years-old). In addition to the rib cage shape, the cortical bone thickness of the ribs and the elastic modulus of the costal cartilage were modified as the age-related parameters. The age-modified HBM was used SENIORS to create and assess new injury criteria which was a core part of the project. After the project it will also be available for further research and investigations.

Also, age-related material property changes have been applied in a comparable way to the Global Human Body Model (GHBMC) during the project. Investigations with the GHBMC model comparative to THUMS simulations have been conducted in SENIORS for the occupant by LMU and at BASt in cooperation with a GHBMC member.

All the knowledge gained is reported in deliverables but also presented at conferences (e.g., VDI Human Body Modelling 2017) and therefore publically available. Also, the age-modified model will be further developed by the SENIORS partners to extend its usefulness and hence, its impact in the research field. Further scientific publications are expected that can be the basis for future collaborations on HBM research.

As several SENIORS partners are also part of the running H2020 project OSCCAR, the knowledge, including the experiences on the HBM development are directly transferable. However, it is also envisaged to provide information to other projects such as VIRTUAL.

7.2.3 Generic Test Rig

A generic sled test set-up for car occupant safety evaluation was developed based on findings from previous decades of research and new findings within the SENIORS project. It has to be noted that it was the first time a generic airbag and a generic load limiter were added to a test rig forming a new basis for future application. This development was completed with the help of external experts. The biggest advantage is the independency from current restraint system technologies that would not be available for any further testing in a couple of years. Thus, a basis for a repeatable and reproducible test method was created. With this test rig it is also possible to evaluate and to improve new safety systems.

The test rig was used within SENIORS in several testing and simulation related tasks. Validation tests were performed as a basis for the simulation-based approach for new thoracic injury risk functions. A major part of the simulations for new risk curves were done in the generic test rig simulation model. The generic test rig was also used for testing of new advanced restraint systems. Furthermore, it was extensively used within SENIORS for biomechanical testing. PMHS tests and volunteer tests were carried out with this generic test rig. The test rig will also be provided to other research projects such as the H2020 project OSCCAR. These actions started in July of 2018.

7.2.4 Tests with Volunteers

Based on an in-depth examination of the identified types of instinctive reactions, a specific scenario to evoke a spontaneous driver pre-crash response was developed. This enabled not just a better understanding of how older drivers anticipate the collision, but a real characterization of onset and entity of the driver's pre-crash response, achieving the possibility to build a set of parameters in a Human Body Model. The data collected during the experiments simulating hazard and sudden braking situations include information about muscle activations (also by extensive EMG measurements), forces applied, anticipated driving postures and the muscular activity relative to last evasive manoeuvres executed by drivers and their anticipatory reactions during pre-crash phase. Hereby, major differences between elderly and young, as well as male and female, were reported.

7.2.5 Tests with Post-Mortem Human Subjects

To address the lack of PMHS sled test data in a simple well defined repeatable set-up, representing the loading conditions of a contemporary vehicle, further sled tests with PMHS were carried out in the SENIORS generic sled set-up. The test conditions (belt, airbag and other restraint parameters) were fine-tuned before the tests in THOR and THUMS human body model simulations. This enabled a very successfully series of PMHS tests resulting in the desired low severity in terms of thoracic injury outcome (number of fracture ribs) in the PMHS tests. The PMHS tests are a very valuable output for further human body model validation, improvement of dummy biofidelity and development of improved thoracic injury criteria to further enhance the protection level of elderly car occupants.

A Human Body Model working group has been created and SENIORS work will be continued beyond the project. A validated reference simulation model of the generic test rig and the SENIORS PMHS test data will be used for HBM. It will be prepared in a way that can be publically made available to help standardize HBM validation. The working group includes BASt, Autoliv, LMU, Audi, Honda and Comillas Univ., thus representing SENIORS, the THUMS User Community (TUC) and GHBMC members.

7.2.6 New Injury Risk Curves and THOR (test results)

New age-related thoracic injury criteria and risk functions for the THOR ATD were developed. This was done using an innovative approach based on computer simulations with the THOR and HBMs to address the previously identified limitations of the traditional approach, which is based on THOR and PMHS testing. A new data set of more representative frontal impact loading conditions was generated. This included various restraint parameters (belt load limiter levels, airbag parameters) and impact conditions (velocity, impact angle).

Based on results from matching simulations, THOR dummy chest deflection output and chest injuries (number of fractured ribs) from HBM simulations, new injury criteria and risk functions were developed. The new Principal Component (PC) Scores are proposed based on this extended SENIORS data set. With the existing criteria and the new PC Scores, new risk curves relating the criteria to AIS thoracic injury and to a probabilistic risk for a certain number of rib fractures were developed.

With this work, the partners' knowhow about developing injury risk curves was greatly increased. All the knowledge gained is reported in deliverables but also presented at conferences (e.g., IRCOBI 2018) and therefore publically available to experts. The steps towards these results were discussed with world-wide recognized experts from the University of Virginia (UVA). The results will be transferred to future H2020 projects and will be presented to the Euro NCAP Frontal Impact Working Group by BASt. A group of experts from the SENIORS consortium, representatives from car industry, governments and other biomechanical experts will jointly continue to work on this topic.

7.2.7 FlexPLI with UBM

Regarding the safety of pedestrians two options for the development of an upper body mass for the flexible pedestrian impactor (FlexPLI) were followed during the first project stage: the first one was the modification of a rigid mass derived from the FP6 project APROSYS, having four adjustable positions of its centre of gravity. The second option was an additional mass connected to the FlexPLI impactor with a flexible rubber element, offering two versions with different characteristics which were investigated in terms of quality of correlation and kinematics to a HBM during the first phase of the impact.

The UBM was introduced to better address pedestrian femur injuries, high frontend geometries (higher Bonnet Leading Edges, high Bumpers) and angled surfaces at the end of the bumper test area. The FlexPLI-UBM could also serve as substitute for the current Upper Legform impactor.

The FlexPLI-UBM was validated against the Human Body Model THUMS v4. Validations resulted in a significantly improved test tool, more humanlike kinematics of the FlexPLI-UBM in comparison to the FlexPLI Baseline. The time histories (loadings vs. time) correlated much better with those of the human body model in terms of shapes, timings and maxima. As a result, transfer functions between HBM and impactor could be established and used for impactor thresholds to assess the risk for lower extremity injuries.

The European New Car Assessment Programme (Euro NCAP) has published its 2025 roadmap in 2017 and foresees, amongst other things, a revision of the subsystem tests for pedestrians and cyclists, in particular in terms of the headform test and evaluating possibilities for the introduction of a surrogate upper body for the FlexPLI. The aim is the implementation of these new tests for rating as from 2022 onwards. SENIORS representatives will present their results as valuable input to this new work item of Euro NCAP. The FlexPLI with UBM developed in SENIORS has a good chance to meet their criteria. This would have to be based on good biofidelic performance, durability and cost. All these features so far have been met by the UBM developed in SENIORS. Exploitation actions will start in August 2018.

The exploitation actions to be made are to publish simulation and hardware results for industry awareness as well as further studies, FE and hardware testing to fully evaluate its performance. As this is a global test tool it will need to shown to a global audience, mainly Europe, Japan and U.S. Sales of hardware and FE models will be achieved.

Exploitation will also be performed by establishing new collaborations with OEMs and research centres, like setting up a consortium for round robin testing to obtain further results. These activities will help validate the FE model. The more the hardware and software are used the more the FlexPLI-UBM will be accepted. Laboratory fixtures will need to be updated to adapt the UBM version of the impactor, information or parts can be supplied for this by the SENIORS partners.

To further help exploit and put the new design into the market the hardware and software will be offered for free testing. Results from testing with the free parts and software will help provide further feedback on performance and durability. More parts will be manufactured and certified for the physical testing. Training and workshops will also be offered to promote the use of the FlexPLI-UBM.

Along with consortium collaborations testing can be carried out with future R+D H2020 in Passive Safety, future working groups and any OEM or test house interested.

7.2.8 TIPT

The Thorax Injury Prediction Tool (TIPT) is a completely new test tool for pedestrian / cyclist protection to address thoracic injuries (rib fractures). Therefore there should be interest inside the safety industry (OEMs, research centers, working groups and institutions) in understanding the concept and the protection against the high incidence of thoracic injuries identified in SENIORS. Completely new test tools take time to gain awareness and develop to become accepted.

A series of virtual tests were conducted using HBMs and a thoracic impactor generated from the ES-2 FE model with different configurations to assess reliability, robustness and reproducibility of the configuration. After that, the impactor was prototyped. The feasibility of a component test using a thorax impactor was investigated by numerous tests which were conducted on a generic vehicle frontend as well as on an actual vehicle.

A test and assessment procedure for thoracic injuries for both, pedestrians and cyclists, was developed for the first time. The procedures are, in principle, based on three items: an injury assessment using injury risk curves for the ES2-dummy, a grid procedure based on and thus harmonized with the Euro NCAP headform grid procedure and a new markup.

However, further research is needed as, amongst other things, the applicability of the ES2 ribcage for oblique impacts as well as the test parameters for frontend areas different to the bonnet need to be further investigated. In this context, the TIPT needs to be understood as a first development test tool for the assessment of thoracic injuries, potentially leading the way to a specifically designed test tool. The tool can be used by other research initiatives due to the clear descriptions provided by the SENIORS project.

To exploit the work done in SENIORS, further development on the TIPT must be pushed for. Highlighting the injury statistics, design, test setups, test results and cost benefits reported in SENIORS would be required. This is to be done through presentations at various conferences and working groups to ultimately gain interest for further development. The following conferences and locations are to be targeted for this action.

- SIAT (Simposium on International Automotiv Technology)
- SAE international conference
- JSAE (Japan SAE) conference
- IRCOBI conference 2018 and 2019
- Europe/U.S/China/Korea
- Praxis Conference on Pedestrian Protection 2018 and 2019
- Safety week carhs conference

Presentations are to be made by the SENIORS partners directly involved in testing and reporting on the TIPT. Once a clear need for the TIPT is established further research and development can move forward based on the findings in SENIORS, either with institutional or private funding to obtain further understanding of injuries to establish design specifications to achieve good biofidelity. A revised or new test tool can then be designed and manufactured to start the development process.

Exploitation actions are to start from September 2018 onwards. The target will be to have a TIPT in consumer testing (Euro NCAP) and then to have in regulation but this will take time. The direct benefits to the SENIORS partners will be to make the safety community aware of their expertise, testing, design and manufacturing abilities.

7.2.9 Elderly, Overweight Dummy

The SENIORS project highlighted how the elderly car occupant (65+) can be injured at much lower impact speeds than a younger one. Also the geometry relating to an overweight person which is more the average for an elderly person has different restraint interactions than a younger person. Females are also more vulnerable regarding injury and have a tendency to live longer. For these reasons and that we have an ageing population, the Elderly, Overweight Dummy (EATD) was updated and tested in SENIORS. Such a dummy is not expected to be exploited highly in the short term this will be a more long term test tool for consumer or regulation use. For the short term the dummy is aimed at research and development and awareness of using a specific dummy to further protect the overweight elderly. This is the first dummy to represent the elderly. It is a dummy which addresses the trend of overweight and is closer to the real anthropometry of older people.

The EATD was tested in SENIORS with new restraint systems, e.g. split buckle and criss-cross seat belts, various use of load limiters and belt pretensioning and pro-active airbags. Along with the dummy these new systems can be exploited for further research. This expertise and provision of systems and the dummy for sale or use can now be made.

The EATD has obtained important feedback from testing in SENIORS, this will help with its further development. The dummy is now going through revisions that should improve biofidelity, durability and repeatability. These actions are due to be completed at the end of 2018. New instrumentation is also being reviewed on the dummy which includes sensors on the liver and spleen to detect injury to these vital organs. The 3D materials will also be reviewed and working with the 3D material suppliers, aim to create new materials for better performance. A FE model will also be created to allow testing to be carried out in the virtual world, so important for vehicle and restraint system development.

There is a growing interest for car manufacturers to protect the elderly and certain cars could be updated specifically to protect them.

Papers and presentations have already been made on the EATD and more are to be made as the dummy is improved. This awareness is vital to move the dummy forward in its development. This dummy uses 3D printed parts in its construction, something not done before with crash test dummies. So it is a new innovative platform for future dummies to potentially follow. The manufacturer of the dummy, Humanetics will be promoting the dummy to its customers and reporting on results and updates along with other SENIORS partners.

As with the other test tools, OEMs, research centers, working groups and institutions will become stakeholders in the development and use of this dummy providing vital feedback to improve. Overweight elderly people and an aging society is a global issue so exploitation will be global.

7.2.10 Sled tests and Safety Systems

Standard and novel restraint system concepts were tested to assess their safety potential to car occupants, in particular to older persons. Sled tests with the THOR ATD and the EATD were conducted with advanced restraint systems including adaptive restraints and innovative restraint concepts like four-point or split buckle belt systems which distribute the loading on the chest. The sled tests clearly showed the benefit of advanced restraints concepts. The tests also demonstrated the advantages of the new test tool THOR and multi-point thoracic injury criteria for vehicle safety assessment in test procedures. This could enable the introduction of advanced restraints, which will help increase the protection level of elderly car occupant in frontal impact collision. With this work, the consortium partner's knowledge about safety systems increased widely, providing awareness and potential sales for new advanced safety systems.

7.2.11 New Test and Assessment procedure for car occupants

SENIORS proposes to introduce a moderate-speed (e.g., 35 km/h) for frontal impact testing. This test would allow and demand the introduction of adaptive restraint systems into passenger cars. Therefore, SENIORS partners will forward this recommendation directly to the Frontal Impact Working Group of Euro NCAP but also other stakeholders such as other consumer protection programmes (e.g., other NCAPs) and regulatory bodies (GRSP) starting still in the year 2018.

Recommendations for modified / new frontal impact test methods have been provided aiming to enhance the protection level of older car occupants. These recommendations have been summarised in Safety Packages addressing three time periods: short-term, mid-term and long-term.

7.2.12 New Test and Assessment procedure for pedestrians and cyclists

A combined test and assessment procedure is proposed covering the demands of pedestrians and cyclists in collisions with passenger cars.

The improvements for assessing head injuries were mainly based on a revision of the test and assessment procedures with the aim of including cyclists. Main achievements of the combined procedures were a longitudinal rearward extension of the headform test zone and the modified head impact angles, taking into account cyclist impact scenarios.

Altogether, the assessment procedure for VRU Box 3 of Euro NCAP was revised (applicable also for other NCAPs), based on recent accident data and the new and revised test procedures for assessing lower extremity, thoracic and head injuries of pedestrians and cyclists. A validation of the proposed procedure showed its feasibility not only in Euro NCAP but also applicable for other consumer information programmes.

Presentations to Standardization Institutions will be done of the work done, the main project results and recommended actions in order to make safety colleagues aware of the work done and if these results could be adapted or further developed to improve safety for elderly. These activities are expected to start in 2019.

7.2.13 Dissemination and Exploitation Activities in General

SENIORS activities were presented on several conferences, among them the Transport Research Arena 2016 and 2018, Crash.Tech 2016 and 2018, International Cyclist Safety Conference 2016, IRCOBI 2017 and the Praxis Conference on Pedestrian Protection 2017 and 2018. At the TRA 2018, SENIORS exhibited key results at the booth of the European Commission. Here, the elderly overweight dummy and the FlexPLI with the Upper Body Mass were presented along with a general project presentation.

Two SENIORS Experts Meetings were organised during the first period of the project that involved many experts from the biomechanics and human body modelling field from all over the world. As well as introducing the SENIORS concept, current results and working steps were discussed. The experts provided valuable input. Synergies appeared during the meetings and collaborations were established towards the achievement of project results that lead to an increased impact, especially in the area of injury prediction (rib fractures).

Other dissemination activities were used as well, such as three newsletters, a leaflet and various articles for key research topics on the SENIORS website.

The project's Final Event will be a pre-conference workshop at the IRCOBI 2018 where presentations of the key project achievements will be made along with presentations from well-respected guest speakers.

It is envisaged that between 2020 and 2025 new test and assessment methods regarding elderly road users could be integrated into Euro NCAP test protocols. For 2030 it was predicted that 20% of all new cars in the high segment could be equipped with advanced restraint systems based on knowledge gained in SENIORS, resulting from the implementation of the new test evaluation and assessment methods. Finally in 2050, estimations suggest that 15% of the car fleet will be using new restraint systems having options to specifically address older users.

7.3 Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

An elderly pedestrian (>65 years old) has a 50% higher risk of being fatally injured compared to an average adult at typical crash speeds, and similar findings have been shown for occupants in frontal crashes. Furthermore, benefit studies as in recent EU research under the THORAX project estimated that considering age dependent risk curves may result in a benefit of 37 M€.

Restraint and vehicle technologies to protect the elderly are currently available but wide-spread introduction of these technologies is to be encouraged via consumer testing and regulatory procedures. As such the SENIORS project is also providing input to ongoing definitions of legislation like in the regulations on frontal impact and pedestrian protection.

Collision and hospital data analysis undertaken at the start of the SENIORS project confirmed the findings of previous studies that older occupants (65-years-old and above) are at greater risk of serious and fatal injury than younger occupants. The analysis also showed that these injuries most often occur at surprisingly moderate collision severities, e.g. 30-40 km/h frontal impacts. This is important, because it demonstrates that improvements to vehicle crash structures and restraint systems, which have delivered enormous benefits for younger occupants, have been less effective for older occupants, possibly because they are not well tuned for moderate collisions. The analysis showed that the key body region for injury mitigation in frontal impacts was the thorax.

In response, SENIORS has developed injury risk functions for the THOR-M anthropometric test device (ATD – also known as a crash test dummy). The injury risk functions that have been developed are specific to the 65+ year-old occupant and have been developed using a novel approach. Conventionally, sled tests are performed using Post Mortem Human Subjects (PMHS) and replicated with ATDs; the injury outcome in each PMHS test is compared with the measurements made with the ATD using agreed statistical methods and a function is generated that maps ATD measurements to risk of injury. This is known as an injury risk function and they are used to set performance limits for regulations and other collision safety standards. In contrast to the conventional approach, SENIORS performed simulations using Human Body Models (HBM) and ATD models; this injury predicted by the HBM was then compared with the measurements predicted by the ATD model.

A key aspect of this approach was to update the HBM to represent the older occupant target population. Material properties (e.g. bone stiffness) and thorax anthropometry (e.g. rib cage shape) were adjusted to represent 65+ year olds. These modifications were implemented in one HBM and validated against similar modifications made to a second HBM and against PMHS tests from the literature and those performed within the project. The approach and updates have been document such that they can be applied to other HBM in the future.

Another main advantage of this simulation-based approach was the possibility to extend the range of boundary conditions specifically to the loading relevant for the protection of elderly car occupants. PMHS test data from literature was mainly limited to high severity loading with concentrated belt loading. By this new approach it was possible to include a more relevant loading condition with combined belt and airbag loading, lower impact severities, different impact directions, variations in belt load limiter setting and advanced restraint systems that distribute the load on the chest.

To support the development of new injury risk functions, a new 'generic sled rig' was developed for volunteer, PMHS and ATD testing. Most of the frontal impact PMHS sled test data in the literature uses older designs of seat-belt that apply very high loads to the shoulder and rib cage. These loads are not representative of those seen in modern cars. Also, very few test series are available with an airbag and those that are available often use production airbags; this means that it becomes impossible to repeat the tests with new dummies once the airbag unit is no longer in production. SENIORS therefore developed a new sled test rig that implemented a more representative seat and seat-belt with load limiter, along with a generic airbag. The designs for all aspects of the rig are publically available, including full CAD and FE models, so other researchers can replicate the SENIORS tests or use the same configuration in their own studies.

SENIORS also demonstrated several new restraint system concepts that can greatly reduce the risk of serious thorax injury to older car occupants in frontal impacts. The novel restraint systems demonstrate a good reduction in risk of serious injury at typical regulatory collision severities and a very good reduction in the risk at the 30-40 km/h collision severity that is more typical of the older occupant group. While benefits will also accrue for other occupant ages, it was estimated that the new restraints have the potential to save 800 to 1,200 lives and 6,500 to 10,500 serious injuries over ten years if implement in all new cars in Europe, with an economic benefit of 4.7 to 8.1 billion Euros.

In sled tests with the THOR dummy and advanced thoracic injury criteria it was demonstrated in test conditions with a moderate impact speed (35 km/h) that crash severity adaptive restraint systems, e.g. adaptive load limiter or airbags, can significantly reduce the risk of thoracic injury compared to non adaptive systems. Further injury risk reduction to a very low level was achievable with advanced restraint systems like four-point-belt or a split buckle system that separated the lap and shoulder belt. The test results also demonstrated the potential benefit of a new moderate severity frontal impact test procedure which would encourage the implementation of crash severity adaptive systems.

More and more driver assistance and automated driving systems are becoming available on cars. Many of these perform automatic braking and/or steering manoeuvres and some perform automatic emergency braking and/or steering manoeuvres. It then becomes important to understand how occupants will move and react under the applied braking and steering forces and whether this will affect the protection offered by the restraint system. One method for assessing this is to use Active HBMs, where the muscle forces generated in response to vehicle manoeuvres are included in the HBM. In order to advance the development of Active HBM, two sets of volunteer tests were performed: tests in simulators and real cars with marker tracked kinematics and muscle recruitment from EMG measurements; and the generic sled tests with EMG measurements. These data have been used to update partners' Active HBM.

SENIORS contributed to the on-going development and evaluation of a new ATD representing an elderly overweight mid-height female (EATD). The EATD represents the older population in terms of anthropometry and material characteristics, and is designed to assess the efficacy of restraint systems for this group. The EATD features novel construction and manufacturing features that may enable an entirely new generation of ATDs. Further research is required to deliver these benefits with the durability that is necessary for application of ATDs in full-scale crash testing.

SENIORS evaluated a head-neck impactor (HNI) and found that it is unlikely to drive vehicle design changes that reduce headform rotation on impact, at least for the current level of development of the HNI. Nevertheless, improvements to head injury protection can still be made with existing tools through modifying the test zone and impact angles to address a bigger proportion of pedestrian and cyclist collisions. SENIORS therefore developed and evaluated updated pedestrian headform test procedures that extend the tested area to include a greater proportion of the cyclist head impact locations. The procedures also adjust the impact conditions to represent both pedestrians and cyclists. An additional benefit of the updated test procedure is that the effect of ADAS sensors mounted to the windscreen can be assessed. As the HNI was only assessed on a 2D vehicle test rig it is recommended that further research is carried out on 3D actual vehicles to assess realistic rotation of the HNI.

The collision analysis performed at the start of the SENIORS project identified injuries to the thorax as a priority for mitigation, particularly for older pedestrians and cyclists. Research was performed to investigate the feasibility of a pedestrian thorax impactor (TIPT), including modifying existing leg/headform launchers for a large, high-mass thorax impactor. The feasibility of this approach was demonstrated, but there are several areas of refinement needed to be able to quantify the scale of improvement and the associated benefits. A TIPT would benefit not only pedestrians and cyclists impacted by the bonnet of a vehicle, but also offers the possibility of a more informative and biofidelic way of testing the risk of vehicles with high bonnet leading edges, such as large SUVs and pickups. This may also be important for new classes of vehicle for which aerodynamics is not a priority, such as last-mile shuttles. Further research is required to define the most appropriate tool for a dedicated pedestrian/cyclist thorax injury risk assessment.

SENIORS' newly developed FlexPLI with upper body mass (FlexPLI-UBM) delivers a number of important advantages over the standard FlexPLI used in UN regulations and Euro NCAP. Firstly, the kinematics of impact are greatly improved, with corresponding measurement time histories that are closer to that of the HBM (and therefore human). This allows more biofidelic assessment of knee and tibia injury risk, and facilitates the assessment of risk of injury to the femur in the same tool (previously a separate upper leg impact has been required).

Secondly, the FlexPLI-UBM enables more appropriate testing of pedestrian safety near the end of the bumper beam, where modern cars often have an angled profile. The new tool eliminates the excessive and unrealistic motion of the standard FlexPLI about its Z-axis in this test condition. Finally, vehicles with very high front-end geometries can be tested and assessed with a more humanlike test tool. All three of these benefits give more realistic design guidance to the vehicle developer to produce safer vehicle front-ends.

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DISCLAIMER