U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

www.nhtsa.gov

DOT HS 811 474 June 2011

NHTSA's Biomechanics Research Plan, 2011-2015

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Executive Summary

Introduction

The Human Injury Research and Applied Biomechanics Divisions of the Office of Vehicle Safety Research conduct research to advance the scientific knowledge in biomechanics to enhance motor vehicle occupant safety through regulatory and non-regulatory efforts, and support NHTSA's mission to save lives, prevent injuries, and reduce economic costs due to road traffic crashes. These divisions disseminate scientific information and conduct cooperative and collaborative research with other organizations around the world to develop tools that will help mitigate injury and death in motor vehicle crashes. This document describes a multi-year research plan that includes rationale, projects descriptions, deliverables, and schedule.

Historical Significance

For over 35 years, these two divisions have helped provide NHTSA with the necessary information to achieve success in issuing new rules that improve occupant safety. This information has included crash dummy development and dummy biofidelity assessment. A substantial effort was devoted to development of injury criteria for the entire family of crash dummies that begin with small child dummies representing infants through the largest size male dummies. The process to obtain this information is built on research efforts carried out at universities throughout the United States and in collaboration with institutions throughout the world. This research, largely geared towards understanding human tolerance to impact at both the component body region level as well as the system level, has paid large dividends. In the program's infancy, there was much that was unknown about the human tolerance to crash impact conditions. Starting in the 1970s and continuing to the present day, numerous studies were funded to understand human response in automotive impact conditions. Research programs focused on the head, neck, chest, abdomen, and lower extremities. Comprehensive crash injury causation data collection and analysis were implemented in the late 1990s through the Crash Injury Research and Engineering Network (CIREN). CIREN has added invaluable knowledge relative to injury mechanisms and to where vehicle and crash dummy designs should focus their efforts. The results of this research and data analysis led to, among other examples, a new side impact dummy and side impact injury criteria, frontal impact injury criteria for both in-position and out-of-position occupants, computer models of brain and other body regions to predict injury, and a variety of tools and data processing methods that help to understand human impact tolerance. These developments were brought into the regulatory environment to assess occupant injury potential in frontal and side impacts. Through the regulations of frontal (FMVSS No. 208) and side (FMVSS No. 214) impact, automotive manufacturers and their suppliers have made substantial improvements to vehicle structure and restraint systems to reduce the forces transmitted to the human body during a crash event. This is evident through the reduction of injuries seen over the last 10 years in the crash field data.

Biomechanics Plan 2011-2015

By the early 2000s NHTSA's biomechanics research efforts had paid dividends. Continued biomechanics research is needed to improve safety and to adapt the research to work in tandem with the emerging fields of crash avoidance and crash severity mitigation as well as expand efforts on vulnerable populations such as children, older adults, etc.

NHTSA continues to collect and analyze crash and test data in order to better understand the injury mechanisms that occur to real-world automobile occupants. This analysis directs the development of new and/or improved crash test dummies that can replicate the human response to a given crash scenario, as well as advanced instrumentation for measuring the dummy's responses that can predict the risk of injury to humans in a given crash test procedure. Once the human-like performance has been demonstrated in a given crash test procedure, they are then used in the safety standards developed and enforced by NHTSA. Vehicle manufacturers are constantly improving the design of cars to improve occupant protection, however fatalities in vehicle crashes continue. Therefore, NHTSA is continuing research on real-world occupant injuries as a result of front, side, and rear impact crashes. This information will lead to the development of an improved frontal dummy (THOR-NT), rear-impact dummy (BioRID), and new advanced side impact dummies (WorldSID) that are being evaluated for potential use in existing or future NHTSA safety standards that can further raise the bar for occupant safety to reduce fatalities and injuries.

NHTSA is conducting research to address the vulnerable occupant population. Previously, child dummies were developed mostly from response data from adults. NHTSA recognizes that during crashes children respond much differently than adults. Therefore, NHTSA is conducting research to gain a better knowledge of child response and injury mechanisms to support long-term (4+ years) development of advanced child crash test dummies that can better replicate those injuries and is developing near-term (0-3 years) child dummies (Q3s for example) to support the agency's need for upgraded safety standards. Additionally, NHTSA is conducting research on injury mechanisms for older occupants who are more prone to risk of injury.

Over the past several years the agency developed a Biomechanics Research Plan (Bio Plan, Ridella et al., 2007) by examining real-world crash data, congressional mandates and administrative priorities, input from industry and academia, and the needs of the agency to achieve the goals listed in the NHTSA Vehicle Safety and Fuel Economy Rulemaking and Research Priority Plan 2011-2013 (NVS Priority Plan: **www.regulations.gov**, docket # NHTSA-2009-0108-0032). The safety needs have been based on the frequency, cost, and fatal outcome of crash injuries.

This plan now establishes the focus of the agency's biomechanics programs to ensure they are properly prioritized to address emerging safety data trends and are aligned with the agency's goals.

Crash Data Observations

To better achieve the agency's goal of reducing motor vehicle injuries and fatalities, biomechanics research can best contribute through focus on those research areas related to the most severe and most frequent injuries occurring in the field. In order to identify those injuries that are most relevant by degree of severity and frequency of occurrence, several studies were conducted. NHTSA crash field databases (FARS, NASS-GES, NASS-CDS, and CIREN) were analyzed to compare the frequency and severity of injuries under different crash conditions, to different occupant age groups, and to different body regions. Figure 1 (left side of figure), shown below, lists major safety needs identified by these studies.

Safety and Agency Needs Relative to Biomechanics Research

Biomechanics research supports projects, rules, and other efforts that the agency is pursuing. These include federalization of anthropomorphic test devices (ATDs) for inclusion in part 572 in support of new or upgraded FMVSS, injury criteria applicable to these ATDs, injury mechanism analysis to support new crash countermeasure technology, analysis of emerging trends such as older occupant fatalities and motorcycle fatalities, global technical regulations arising from the agency's international collaborative initiatives and issues such as the trade-off between offset frontal crash testing and car-to-car crash compatibility. These agency needs are listed in Figure 1 (the right-hand section). It is likely that these needs will continue to evolve so this plan of research must be flexible to accommodate those needs.

This plan also includes biomechanics programs that directly support areas identified in the NVS Priority Plan (right side of Figure 1). This plan includes continued and future work in areas that explicitly identified the need for biomechanics research or areas that will include continued development of dummy technology and injury criteria in support of the priorities. These areas include rollover restraint performance, child frontal and side impact protection, frontal occupant protection including: low delta-v restraint evaluation, narrow offset and oblique frontal, rear-seat occupant, frontal fatal injury analysis, and older occupant protection.

Research Areas Identified

For the years 2011 to 2015, the highest biomechanics priorities, determined through analysis of crash data and as identified in the NVS Priority Plan, include the following areas:

1. Injury causation and mechanisms analysis – Integration of medical and engineering crash data into the research process will be done through identification of injury causation and mechanisms from in-depth analysis of CIREN data.

2. Child biomechanics and child dummy development – Identification of child crash injury response and injury mechanism analysis, particularly in the head, neck, thorax, and abdomen. This work will lead to new response requirements for child dummies, design improvements in the current Hybrid III child dummies, assessment of alternative frontal impact dummies (e.g., Q-series), and/or development of child human models for injury analysis.

3. Adult biomechanics and adult dummy development – Research into injury outcomes, mechanisms and development of devices to address continuing issues of frontal, side, rear, and rollover crash injuries for adult populations with special considerations for head, brain, and thoracic injury leading to improved assessment devices and injury criteria for the prediction of these injuries.

4. Assessment of needs for older, crash-involved, vehicle occupants – Age-adjusted injury criteria and/or development of dummies, tests and/or models to assess protection for this growing population segment.

5. Vulnerable occupant protection – Research into protection of other vulnerable occupants such as pregnant and obese occupants as well as pedestrians.

6. Computer models to predict injury – Creation, validation, and use of human and dummy models to enhance injury prediction in conjunction with improved vehicle models in all

crash modes. This includes research to improve material models for tissues and organs that are not currently available or need improvement.

7. Post-crash prediction of injury severity – Identification of vehicle crash information that can be transmitted post-crash to predict injury severity and better triage seriously injured crash occupants.

Biomechanics Research Priorities – Continuing, Near-Term, and Immediate

Safety Needs

NASS/CIREN/FARS Field Data Analysis

- Frontal, side, rollover - dominant crash modes for injuries and fatalities
- Head, chest and lower extremities still dominant - all crash modes
- Older occupants - head and chest injuries and fatalities: side and frontal
- Children - high head injury rates: side
- Children - chest and abdomen injuries: rollover and frontal
- Extremity injuries - largest cost in disability
- Motorcycle fatalities are a significant contributor to total fatalities and are increasing

Agency Needs

NVS Priority Plan 2011 - 2013

- Rollover restraint effectiveness
- Child frontal impact protection
- Child side impact protection
- Low speed frontal crash protection for older occupants
- Rear seat occupant protection in frontal crash – children and older occupants
- Narrow offset/oblique frontal crash protection
- Pedestrian Global Technical Regulation (GTR)
- Rear impact GTR
- Side impact dummy upgrade – WorldSID 50^{th} and 5^{th} adults

Figure 1. Field Injury Data Observations and Agency Needs Related to Biomechanics Research

Project Descriptions by Research Areas

The following pages provide a brief synopsis of the individual project areas that are underway and planned for the future based on the seven priority areas identified from the field data. The deliverables, projected schedule, and link to the NVS Priority Plan, as appropriate, are provided for each project. Detailed descriptions for many of the projects will be made available through "roadmaps" that will be posted to the NHTSA Research Web site.

This plan encompasses significant programs and projects that the agency intends to work on in the 2011-2015 timeframe. These dates are shown as targets because unanticipated events may influence the agency's agenda, such as petitions that require action, congressional requests, Administration requests or priorities, or some other event that may influence NHTSA's priority agenda.

Injury Causation and Mechanisms Analysis

Understanding injury causation and mechanism from real-world crashes provides significant insight into creating future biomechanics projects. Data from the CIREN program has the ability to act as a catalyst for additional long-term, focused research projects that are relevant to NHTSA. Past examples include the knee-thigh-hip injury criteria developed by the University of Michigan (Rupp et al., 2009), research on long-term disability and cost associated with lower-extremity injury conducted by the University of Maryland (Dischinger et al., 2005) and the narrow-offset frontal-impact research and testing conducted by the Department of Neurosurgery at the Medical College of Wisconsin and its Zablocki VA Medical Center (Pintar et al., 2008). CIREN data continues to contribute to the understanding of injury causation as evidenced in use for rollover injury mechanisms (Ridella & Eigen, 2008) and child side impact injury analysis (McCray et al., 2007).

<u>The CIREN Program</u>

CIREN is a multi-center research program involving a networked collaboration of clinicians and engineers in academia, industry, and government pursuing in-depth studies of crashes, injuries, and treatments to improve processes and outcomes. Gathering 300 to 350 cases per year since 1996, the program has more than 4,000 published cases to use for research purposes. A new CIREN funding cycle began in June 2010 and includes:

- Six NHTSA-funded centers collecting 315 total cases per year for 5 years. Three centers will focus on injury causation and mechanisms research and minor data collection requirements (40 cases per year) and three centers implementing high case collection (65 cases per year) using research center personnel as additional case review experts.
- Short-duration, focused research projects that directly address agency and research priorities. These projects will focus on analysis of current and future CIREN data that directly address current and emerging agency and research priorities.
- NHTSA will publicize a CIREN roadmap with additional details on NHTSA's research Web site

Deliverables: About 1,500 new researchable cases and research results on select topics will be added to the existing CIREN database. A public version of a subset of the complete CIREN database is available at **www.nhtsa.gov**.

Schedule: Ongoing with new 5-year agreements running from fiscal years (FY) 2010-2015

NVS Priority Plan: The CIREN program supports NVS Priority Plan items including dynamic rollover test research, small overlap/oblique frontal crashes, older persons, rotational brain injury criteria, and advanced automatic collision notification.

Child Biomechanics

Current pediatric crash test dummies have been developed by geometrically scaling down adult dummies to the size of children. The overall goal of this project is to directly measure the biomechanical properties of children so that the information can be used to develop more biofidelic child dummies and computer models. However, it is recognized that some scaling from adult data may still be necessary. To support that aspect, there are projects including the documentation of pediatric rib properties and pediatric thoracic compliance during cardiopulmonary resuscitation (CPR) that may be used to assist in scaling.

The following project descriptions summarize research that is in progress or planned that covers various body regions. The first project, "New Child Anthropometry, Response, and Injury Criteria," describes the coordinated child biomechanics effort that is utilizing many of the deliverables from the individual projects. These projects support the planned development of advanced 3-, 6- and 10-year-old child dummies per the NVS Priority Plan and as described in the Child Dummy Development section of this document. Table 1 shows the schedule of the projects. A Child Biomechanics roadmap with more in-depth information of the projects will be published on the NHTSA Research Web site.

Table 1. Schedule for Child Biomechanics Projects

Research Area	Project	2011	2012	2013	2014	2015
Child Biomechanics	New Child Anthropometry, Response, and Injury Criteria	■	■	■		
	Child Anthropometry	■	■			
	Brain Injury Criteria for 6- and 10-yr-old Children	■				
	Child Head Biomechanics	■				
	Child Neck Biomechanics	■				
	Child Shoulder Anthropometry, Range of Motion and Dynamic Response	■				
	Pediatric Thoracic Compliance - CPR	■	■			
	Pediatric Thoracic Response and Spinal Kinematics - Surrogate Testing	■				
	Biomechanical Properties of Ribs	■				
	Pediatric Abdomen Analysis	■				
	Dummy Model Parameter Analysis and Biofidelity Requirements Dev.	■	■			

<u>New Child Anthropometry, Response, and Injury Criteria</u>

NHTSA is coordinating the research tasks listed below in an effort to collect and document anthropometry, injury criteria, and response data that together can be used in the development of a new 6-year-old frontal ATD. The body regions of interest include the head, neck, thorax, and abdomen. For each of the body regions, both NHTSA-funded and non-NHTSA-funded research projects are being done to produce a set of response data that is unique to the pediatric human and not scaled from adult data. Pediatric response will be directly used to support the development of new biofidelity requirements and/or the optimization of a dummy-based model that will be used in the development of biofidelity requirements.

Deliverables: Dummy response requirements, anthropometry, and injury criteria specific to 6-year-old for frontal impact and potentially adaptable to other size child dummies

Schedule: Work to be completed in FY 2013

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Child Anthropometry

Child surface anthropometry data will be gathered using a whole-body laser scanner. Newer scanning techniques allow for obtaining accurate 3-D, whole-body contours in about 15 seconds. Plans include scanning a population of children in the 3-, 6- and 10-year-old age ranges in an automotive seating position that will contribute to improved anthropometry of child ATDs.

Deliverables: Generate a definitive surface anthropometry database for children in currently regulated child dummy age ranges to be used as a template for future dummies in same age ranges

Schedule: Work to be completed in FY 2012.

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Brain Injury Criteria for 6- and 10-year-old Children

This work will determine the relationship between local brain tissue strain and axonal injury in a prepubescent human, which can then be used directly in any biofidelic computational model of the 6- to 10-year-old human brain. The deliverables will provide injury predictive capability that includes prediction of moderate to severe head injuries including traumatic axonal injury (TAI).

Deliverables: Surrogate child finite element (FE) brain model and strain response requirements

Schedule: Work to be completed in FY 2011

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Child Head Biomechanics

Head injuries comprise a large portion of injuries sustained by children in car crashes. The properties of the pediatric head change from birth to adulthood, and scaled versions of adult response data are not appropriate to use when studying child head injuries. The response of the child head to impact will be studied to support the development of injury criteria, more biofidelic dummies, and more representative computational models.

Deliverables: Pediatric head impact response requirements and injury tolerance

Schedule: Work to be completed in FY 2011

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Child Neck Biomechanics

The biomechanics of the neck determine when, where, and how the head moves relative to the torso in a crash. As neck properties are very different for an infant compared to a teenager and are constantly changing during the intervening years, a significant research effort has been dedicated to quantifying the age-dependent biomechanics of the child neck. This work includes measurement of physical geometry of cervical vertebrae to support the development of computational models. Deliverables from this project are supporting the "Dummy Model Parameter Analysis and Biofidelity Requirements Development" task described later in the Child Biomechanics section.

Deliverables: Child cervical spine geometry for multiple age ranges; ligamentous cervical spine response properties; 6-year-old neck multi-body/finite element model; scaling relationships; injury tolerance

Schedule: Work to be completed in FY 2011

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Child Thoracic Biomechanics

Pediatric Thoracic Compliance - CPR

This work evaluates the thoracic response of pediatric subjects age 4 to 22 during cardiopulmonary resuscitation (CPR). Force-deflection data is being collected and has been presented most recently at the 2008 Stapp Car Crash Conference (Maltese et al., 2008). The force-deflection data from this study will be used together with other pediatric force-deflection data to assist in the development of a new set of thoracic response biofidelity requirements that could potentially be used in the development of future child ATDs. Deliverables from this project are supporting the "Dummy Model Parameter Analysis and Biofidelity Requirements Development" task described later in the Child Biomechanics section.

Deliverables: Age-dependent thoracic force-deflection properties derived from CPR on human subjects; scale factors to convert and compare adult cadaver based thoracic biofidelity responses down to child ATDs and virtual models

Schedule: Work to be completed in FY 2012

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Pediatric Thoracic Response and Spinal Kinematics – Surrogate Testing

This effort includes a series of sled tests using pediatric age-matched surrogates. The experiments to be performed involve sled tests with motion capture. The thoracic response and spinal/head kinematics of the surrogate specimens in these experiments will be used together with other human adult and child response data to describe thoracic response and spinal kinematics appropriate for use in developing a 6-year-old child dummy. Deliverables from this project are supporting the "Dummy Model Parameter Analysis and Biofidelity Requirements Development" task described later in the Child Biomechanics section.

Deliverables: Thoracic response and spinal/head kinematics in low-speed and high-speed tests for a belted child

Schedule: Work to be completed in FY 2011

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

<u>Biomechanical Properties of Ribs</u>
Current efforts involve testing of pediatric and adult ribs in collaboration with an anthropologist / skeletal biologist who has developed an innovative histological analysis procedure where several quantifiable variables are defined at the microscopic/histological level related to the development of the bone in the rib specimen.

In another effort, bending and indentation experiments of surrogate rib specimens will be performed. The goals of the research include the following: (1) provide a source of biomechanical characterization data for use in the development of pediatric thorax models, both physical and computational and (2) to provide data that can be used to assist in the process of scaling adult data to represent pediatric responses.

Deliverables: Pediatric rib properties

Schedule: Work to be completed in FY 2011

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

<u>Pediatric Abdomen Analysis</u>
In collaboration with an SAE subcommittee, a new abdomen was developed for the 6-year-old Hybrid III child dummy that incorporated improved pelvis anthropometry, a new pelvis structure, and a new fluid-filled abdomen design that includes injury predictive displacement sensors. Table-top belt loading tests will be done followed by a larger round-robin testing effort by several laboratories to assess repeatability, reproducibility and durability in an actual sled test environment.

Deliverables: Quantitative comparison of Hybrid III 6-year-old with updated abdomen/pelvis versus previously published child surrogate data.

Schedule: Round robin testing to be initiated in FY2011

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

<u>Dummy Model Parameter Analysis and Biofidelity Requirements Development</u>
Due to limited availability of validation data directly targeted towards the child population at the time of development of current ATDs and models, the biofidelity of dummies and numerical models representing children remains questionable.

The objective of this project is to update a dummy-based 6-year-old model and to perform a numerical sensitivity analysis and optimization of that model using many of the deliverables from the pediatric biomechanics efforts described above. The optimized model then will be used to assist in the development of biofidelity test procedures and response requirements that can be used in the potential future development of a new 6-year-old dummy.

Deliverables: Updated and optimized Hybrid III-based 6-year-old MADYMO model; biofidelity test procedures and response corridors that can be used for a future 6-year-old frontal ATD

Schedule: Work to be completed in FY 2012

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Adult Injury Mechanisms in Frontal, Side, Rear, and Rollover Crashes

Field data indicates that adults continue to experience head, thoracic, abdominal, and lower extremity trauma from vehicle crashes despite increasing seat belt use and more restraint systems. The economic cost of these injuries is very high due to intensive hospital and long-term care, especially for brain and lower extremity injury. The following projects address each of these body regions with the intent to understand the mechanisms and sequellae of injury as well as lead to new indicators of injury that can applied to crash dummy technology. The projects are listed starting with the head and continuing down the body by region. Table 2 shows the schedule of the projects. Roadmaps for brain and thoracic biomechanics will be published on the NHTSA Research Web site.

Table 2. Adult Biomechanics Projects

Research Area	Project	2011	2012	2013	2014	2015
	Adult Biomechanics					
	Football Player Head Impact Analysis	▒	▒	▒		
	Axonal Strain/Functional Response	▒				
Head/Brain Biomechanics	Diffuse Axonal Injury Assessment	▒	▒	▒	▒	
	Brain Regional Properties/Strain Function	▒	▒			
	Brain Angular Acceleration/Velocity Injury Criterion	▒				
Neck Biomechanics	Neck Biomechanics and Injury Response	▒	▒			
	Multi-point Thoracic Deflection Injury Criteria Development	▒	▒			
Thoracic Biomechanics	Thoracic and Abdominal Response and Injuries in Oblique Impacts	▒	▒			
Abdominal Biomechanics	Abdominal Lateral Response	▒	▒			
Pelvis and Lower Extremity Biomechanics	Knee-Thigh-Hip IARV and Model	▒	▒			

To develop angular acceleration/velocity injury criterion (BRain Injury Criterion or BRIC) several gaps in knowledge were identified and projects were initiated to improve the performance and injury predictability of NHTSA's Simulated Injury Monitor (SIMon) FE model (Takhounts et al., 2003, 2008) from which BRIC was developed. Currently, the SIMon model uses one set of viscoelastic material properties for every part of the brain. It was noted that the outcome of the model may change if the viscoelastic material properties and tolerance levels were different for each part of the brain. The projects "Brain Regional Properties/Strain Function" and "Axonal Strain/Functional response" address the issue of the material response and tolerance for various regions of brain tissue in various loading regimes. This new information will be used to not only modify the SIMon brain model itself, but also to modify its injury criterion (cumulative strain damage measure or CSDM) that currently does not take into account possible strain rate dependence. This may or may not change the BRIC. To further evaluate the volumetric and functional component of CSDM the project “Diffuse Axonal Injury Assessment” was initiated. Finally, further evaluation/development of BRIC is using human volunteer data from the project “Football Player Head Impact Analysis” to evaluate scaled BRIC curves for mild and moderate brain injuries (AIS 2+).

Football Player Head Impact Analysis

A novel algorithm is used to extract linear and angular acceleration about each axis of the head from a sample of Virginia Tech football players whose helmets are instrumented with 6 degrees of freedom sensors. Any time a player experiences a head impact during any game or practice that results in any single accelerometer exceeding 10 g, data acquisition is triggered. This project extends the data collection through the 2012 season with an estimated total of 15,000 additional impacts. Coupled with previously collected data, this research will lead to improvements understanding the tolerance for lower severity head impacts and lead to a mild to moderate brain injury risk function.

Deliverables: Injury risk functions and thresholds for mild traumatic brain injury

Schedule: Work to be completed in FY 2013

NVS Priority Plan: Rotational brain injury criteria

Axonal Strain/Functional Response

Diffuse axonal injury (DAI) is an important consequence of severe brain injury. DAI results from tension or shear on the axons in the white matter tracts of the brain and is produced by rapid head acceleration/deceleration during blunt head impact. Due to the inability to directly measure strain or strain rate in brain, axonal injury tolerance due to trauma has still not been directly quantified at high strain rates. A recently developed *in vivo* model of axonal injury in a biological system will be used in which axonal injury and strains can be measured directly in spinal nerve roots. The specific aim of this project is to combine force, strain, strain rate, and axonal injury data to determine axonal injury tolerance to tensile loading.

Deliverables: Axonal injury tolerance measures for use in a brain injury model

Schedule: Work to be completed in FY 2011

NVS Priority Plan: Rotational brain injury criteria

Diffuse Axonal Injury Assessment

Better knowledge of the response of the brain and mechanisms of brain injury development could lead to more effective approaches to injury mitigation, diagnosis and treatment. A primary goal of this study is to establish the nature and course of injury development after head impact, with focus on factors important to long-term functional deficit. This knowledge would facilitate the development of a graded scale related to the severity of specific brain injuries to assess the potential for harm during automotive crashes.

Deliverables: Functional injury criteria for mild to severe brain injury

Schedule: Work to be completed in FY 2014

Brain Regional Properties/Strain Function

This project is to support the research program by generating critically needed data for NHTSA's SIMon model to ensure it accurately predicts the brain's induced mechanical response and furthermore, will accurately predict the biological consequences of that mechanical loading (i.e. injury prediction). The SIMon head model uses dummy head response data (rotation and translation) to estimate the potential for traumatic brain injury. Specifically, the project will focus on the following areas:

1. Measure constitutive properties of brain anatomical structures at a spatial resolution to accurately measure material inhomogeneity at the same spatial resolution as the brain's anatomical structures. This data will equip SIMon to make anatomically relevant predictions of tissue deformation.
2. Assessment of electrophysiological function from precisely controlled mechanical impact to cultured living brain material will provide functional tolerance criteria relating input mechanical parameters (tissue strain and strain rate) to alterations in function. These criteria will provide SIMon with the enhanced capability to predict functional consequences of traumatic loading, engendering a virtual living surrogate for crash testing.

Deliverables: Regional brain material properties and strain injury thresholds for use in SIMon model

Schedule: Work to be completed in FY 2012

Brain Angular Acceleration/Velocity Injury Criterion

This project is using NHTSA's SIMon model and its cumulative strain damage measure (CSDM) risk curve for probability of DAI and ATD data to develop a kinematic brain injury criterion (BRIC) that can directly uses dummy head rotational acceleration and velocity to predict the probability of brain injury. For the current study, full-scale crash test results involving three 50^{th} percentile male dummies (Hybrid III, WorldSID, ES-2re) were used to find the best fit between BRIC and CSDM in efforts to define critical rotational velocity and acceleration intercepts to be used for each dummy. The optimization was done for BRIC = 1.0 when CSDM = 0.425, which represents a 30% probability of DAI (AIS 4+). The project will also expand the risk curves associated with CSDM and BRIC to cover AIS 1+ up to AIS 5+ injury thresholds.

Deliverables: Injury criterion that uses measured dummy head response to predict probability of rotationally induced brain injury

Schedule: Work to be completed in FY 2011

NVS Priority Plan: Rotational brain injury criteria

Neck Biomechanics and Injury Response

Significant work has been conducted to develop a biofidelic adult neck model for frontal crash loading, but this work needs to be conducted for other loading directions as well – including side impacts and rollovers. The work will support development of computational models of the mid-size male and small female, which will enhance ATD design and injury criteria development. Much of the geometry measurements have been conducted under prior research projects. This work will study response properties and failure modes for the non-frontal loading modes.

This project is to define head-neck kinematics and develop a method of obtaining upper neck loads in frontal sled testing and in dynamic tension-extension/flexion. An assessment of lower neck injury criteria representative of common lower neck trauma will also be made. Differences in body anthropometry shall also be assessed. As a direct assessment of head neck biofidelity, dummies of different sizes shall be run in the same test configurations as the tests with surrogates.

Deliverables: Multi-directional adult neck response and tolerance characteristics; validated computational models; lower neck injury criteria; test method for evaluating neck kinematic biofidelity

Schedule: Work to be completed in FY 2012

NVS Priority Plan: THOR 5th and 50th percentile dummies

Multi-point Thoracic Deflection Injury Criteria Development

This project involves paired sled testing of post-mortem human subjects (PMHS) and the THOR-NT in various pulse and restraint conditions. Multi-point thoracic deflection response from the PMHS and the observed injuries in those tests is being coupled with the multi-point thoracic deflection response measured in the respective paired THOR-NT test to develop multi-point thoracic injury criteria for the THOR-NT. The THOR-NT being used in this project is the version with the modification kit described later in this document.

Deliverables: Multi-point thoracic injury criterion

Schedule: Work to be completed in FY 2012

NVS Priority Plan: Multi-point chest injury criteria; THOR 5th and 50th percentile dummies

Thoracic and Abdominal Response and Injuries in Oblique Impacts

Two projects are underway to assess thoracic response in the antero-oblique directions. The first project involves the development of a new sled test protocol to determine the oblique impact response of the human and to evaluate dummy biofidelity in an oblique mode of loading. The program involves the use of chestbands on dummies in full-scale vehicle tests accompanied by sled tests with PMHS. The second project involve a continuation of previous work to study thoracic response in lateral and oblique loading conditions at much higher energy levels that will result in damage to the post-mortem human subjects. This research will provide the data needed to develop Injury Assessment Reference Values (IARVs) for the human and lead to the development of injury criteria for side impact dummies.

Deliverables: Response requirements and injury criteria for oblique thoracic and abdominal impacts

Timing: Work to be completed in FY 2012

Abdominal Lateral Response

Much of the prior research on lateral abdominal response has not reproduced the exact type of loading experienced by a vehicle occupant being struck by an intruding door. Two projects are assessing updated loading conditions for whole body.

The first project will investigate the exact type of loading experienced by a vehicle occupant being struck by an intruding door and has lead to the development of a side impact test apparatus capable of delivering loads similar to those seen in side NCAP-type tests. Tests will be conducted with PMHS to determine response corridors and tolerance levels. Similar tests will be conducted with available side impact ATDs to compare responses to PMHS and compare back to vehicle tests.

Another study involves whole body PMHS testing with the liver re-pressurized to physiologic pressure and pressure transducers positioned non-invasively into the hepatic vein. This work builds upon a previous study had demonstrated that a criterion using the product of liver pressure and pressure rate is a strong predictor of liver injury.

Deliverables: Human abdominal response corridor and tolerance requirements; ATD comparison results

Timing: Work to be completed in FY 2012

NVS Priority Plan: N/A

Knee-Thigh-Hip IARV and Model

A significant amount of research has been dedicated to study response and tolerance of the knee-thigh-hip complex, and the results have produced design targets and injury assessment criteria for use in crash tests. Continued knee-thigh-hip work will result in the development of a series of computational models representative of different occupant characteristics. This model will lead to the development of IARVs for different occupant ages and sizes with different muscle activation conditions.

Knee air bags have become standard features in some new vehicles. Investigation of available field and laboratory data will be done to gain a better understanding of the effects of this restraint type on lower extremity injuries in general. This analysis should provide a starting point for development of future research efforts in modeling and/or testing knee air bags.

Deliverables: IARVs; computational models of different occupant sizes; report on knee air bag field experience

Timing: Work to be completed in FY 2012

NVS Priority Plan: THOR 5th and 50th percentile dummies

Child Dummy Development and Enhancement

The work performed in the Child Biomechanics project area described above will lead to development of new child dummy response requirements and dummy development projects and evaluations. The following sections detail the child dummy projects planned. Regarding frontal dummy development, the efforts are split between near-term enhancements planned for the Hybrid III 6- and 10-year-old and long-term development of advanced 3-, 6- and 10-year-old child dummies. Table 3 shows the schedule of the projects.

Table 3. Child Dummy Projects

Research Area	Project	2011	2012	2013	2014	2015
Child Dummy Development	Child Side Impact (Q3s and 6- and 10-year-old)					
	Enhancement of Hybrid III 6- and 10-year-old Dummies					
	Advanced 6-yr-old ATD (Frontal)					
	Advanced 3- and 10-yr-old ATD (Frontal)					

Child Side Impact (Q3s and 6- and 10-year-old)
A revised Q3s neck, thorax, and pelvis will be evaluated for biofidelity, repeatability and reproducibility, and durability. When these items have met expectations at the component level, biofidelity sled tests will be conducted using the complete dummy. Assuming the dummy's responses are acceptable, supporting documentation for incorporation into Part 572 will be prepared. This will include establishing certification procedures and preliminary response corridors, acquiring and preparing the Procedures for Assembly, Dissassembly, and Inspection (PADI).

The assessment of 6- and 10-year-old side impact child dummies, such as the Q6s and the Q10s, will follow the lead of the Q3s regarding changes to hardware, but these older child dummies are conceptual at this time and potential development is on a timeline that is several years behind the Q3s (Table 3).

Deliverables: Documentation related to potential incorporation of Q3s (and 6- and 10-year-old side impact dummies, TBD) into Part 572; development and documentation of injury criteria to be used for these child ATDs at the appropriate point in their development.

Schedule: Q3s-FY 2011, 6- and 10-year-old ATD: FY 2013

NVS Priority Plan: Child Restraints in Side Impacts

Enhancement of Hybrid III 6- and 10-year-old Dummies
Per the supplemental notice of proposed rulemaking (SNPRM) for FMVSS No. 213 (www.regulations.gov, docket # NHTSA-2010-0158-0001), efforts to support near-term upgrades to the Hybrid III 6- and 10-year-old dummies are in process. In addition to the pediatric abdomen work described in the child biomechanics section, NHTSA plans to implement updates that may include revisions to the shoulder, thoracic spine and neck of the two dummies. Component-level and full-dummy testing will be done to compare the kinematics/response of the current dummy, current dummy with modified components, and other

existing dummies within this age/size range. Kinematic and response targets and injury criteria are being developed from existing sled test and injury information that represents a subset of the child biomechanics outputs discussed earlier in this plan.

Deliverables: Technical report summarizing the development/evaluation of Hybrid III 6- and 10-year-old dummy enhancements and drawings/procedures for assembly, disassembly and inspection (PADI)/parts list reflecting the changes

Schedule: Work to be completed in FY 2013

Advanced 6-year-old ATD (Frontal)

Using data produced from biomechanics research of pediatric subjects and related 6-year-old ATD modeling described in the pediatric biomechanics section, future work is planned to support the development and evaluation of an advanced 6-year-old frontal ATD. Upon completion of the referenced biomechanical and modeling focused efforts, there will be a period where the existing 6-year-old pediatric frontal ATDs (Hybrid III, Q-Series, e.g.) will be evaluated against a new set of biofidelity requirements. Pending the results of those evaluations, considerations will be made regarding the need for developing an all-new 6-year-old ATD versus enhancing an existing 6-year-old ATD. A Child Biomechanics roadmap with more in-depth information concerning the development of an advanced 6-year-old ATD will be published on the NHTSA Research Web site. In addition to this being an NVS Priority Plan item, this task of developing an "advanced" or "new" 6-year-old ATD was referenced in the FMVSS No. 213 SNPRM (www.regulations.gov, docket # NHTSA-2010-0158-0001).

Deliverables: Technical report summarizing the development/evaluation of an advanced 6-year-old frontal dummy, PADI and list of changes (as appropriate)

Schedule: Work to be completed in FY 2015

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Advanced 3- and 10-year-old ATDs (Frontal)

By 2015, it is expected that prototype evaluations of the advanced 6-year-old child ATD will be complete. Efforts related to the development of advanced 3- and 10-year-old child frontal impact ATDs are currently scheduled to follow those of the advanced 6-year-old frontal ATD. The pediatric specific response requirements developed for the 6-year-old ATD will be scaled as appropriate for use in the development of advanced 3- and 10-year-old ATDs. Lessons learned from the development and evaluation of the advanced 6-year-old ATD prototype will be used in planning the design and development of advanced 3- and 10-year-old child ATDs. A Child Biomechanics roadmap with more in-depth information concerning 3- and 10-year-old ATD development will be published on the NHTSA Research Web site. In addition to this being an NVS Priority Plan item, this task of developing "advanced" or "new" 3- and 10-year-old ATDs was referenced in the FMVSS No. 213 SNPRM (www.regulations.gov, docket # NHTSA-2010-0158-0001).

Deliverables: Scaled response requirements for advanced 3- and 10-yr-old child dummies; technical report summarizing the development of advanced 3- and 10-year-old frontal dummies

Schedule: Work to be completed in FY 2015

NVS Priority Plan: Advanced 3-, 6-, 10-year-old child dummies

Adult Dummy Development and Enhancement

Sufficient biomechanical response data has been collected to enhance existing and develop future adult dummies that can be used by the agency for current frontal and side impact rules as well as future rules or consumer tests to help assess vehicle safety. Critical to dummy design is a method to objectively assess dummy biofidelity. The updated system includes development of an absolute scale for biofidelity and the sensitivity of that scale. Future work will involve improving and enhancing the quality and quantity of the human data against which a particular dummy can be assessed. Table 4 shows the schedule of the adult dummy projects.

Table 4. Adult Dummy Projects

Research Area	Project	2011	2012	2013	2014	2015
Adult Dummy Federalization	WorldSID 50th Male	■				
	Hybrid III 95th Percentile Large Male Dummy	■				
Adult Dummy Evaluation	THOR-NT - Short Term Modification Kit Assessment	■	■			
	WorldSID 5th Female	■	■	■		
	THOR Lx	■				
	Rear Impact Dummy	■				
	Gold Standard Test Development	■	■	■		
Adult Dummy Development - Current	THOR-NT - Long Term Improvements	■	■	■	■	■
	THOR-05F - 5th Percentile Female Frontal Dummy	■	■	■	■	■
	THOR FLx	■	■	■		
Adult Dummy Development - Future	Rollover Dummy		■	■		
	Active Dummy		■	■	■	■

<u>THOR-NT – Short-Term Modification Kit Assessment</u>

NHTSA completed a project in FY 2010 aimed at producing an enhanced THOR-NT dummy that is suitable for use in standardized testing in terms of repeatability, reproducibility, and durability. The enhancements (called mod kits) were done to the head, neck, thorax, abdomen, pelvis, femur, and knee. Future work includes modification of all existing THOR-NT dummies owned by NHTSA followed by an extensive test plan to evaluate the dummies biofidelity as well as assess reproducibility and repeatability. A THOR roadmap with additional project details will be published on the NHTSA Research Web site.

Assessment of injury risk curves and criteria for the head, neck, thorax, abdomen, knee-thigh-hip, and lower extremities for THOR has been under development. Further testing of the updated THOR (with mod kit enhancements) will be done to compare to PMHS tests and other biomechanical data and assist in development of final risk curves and criteria.

Deliverables: Enhanced dummy based on short-term changes, injury criteria

Schedule: Work to be completed in FY 2012

NVS Priority Plan: THOR 50th percentile dummy

THOR-NT – Long-Term Improvements

As more biomechanical knowledge is gained, it may be possible to allow THOR to evolve. The revisions may be integrated into the THOR under regularly scheduled upgrade kits made available to all THOR users worldwide. These revisions may include updates to knee-thigh-hip design and response, lower neck injury criteria and fluid filled abdomen.

Other longer term improvements involve instrumentation, such as a multi-point non-contact deflection measurement system (Ribeye) and an in-dummy data acquisition system. The improvements shall also coalesce with the European Union's THORAX project now underway. This project will focus on reduction and prevention of thoracic injuries. As part of this project, a demonstrator dummy consisting of a modified THOR-NT will be developed that provides a better assessment of new, modern restraint systems. A THOR roadmap with additional project details will be published on the NHTSA Research Web site.

Deliverables: Revised THOR design based on long-term enhancements.

Schedule: Work to be completed in FY 2015

NVS Priority Plan: THOR 50^{th} percentile dummy

THOR-05F – 5th Percentile Female Frontal Dummy

The THOR 5th percentile female dummy is a new anthropomorphic test device (ATD) with many notable features, including a biofidelic neck design with built-in curvature that segregates load paths within the cervical spine. Similar to the program that the THOR-NT underwent for short-term modifications, the THOR-05F will be subjected to a test protocol aimed to further assess its biofidelity and to identify requirements for any design enhancements that may be necessary in order to make the dummy suitable for use in standardized testing.

Deliverables: Completed assessment and injury criteria for THOR-05F

Schedule: Work to be completed in FY 2015

NVS Priority Plan: THOR 5^{th} percentile dummy

Gold Standard Test Development

The development of frontal crash dummy thoraces, designed to respond with biofidelity to an impact to the central sternum, was driven by catastrophic thoracic injuries sustained by unrestrained drivers hitting the steering wheel hub. However, these injuries rarely occur for drivers of contemporary vehicles equipped with energy absorbing steering columns (post-1968) and occupant restraints. The gold standard test development, which simulates a frontal crash environment, will quantify PMHS response to restraint loading in order to develop performance criteria for advanced frontal impact dummy thorax response. Sled tests are being conducted on a simplified universal buck to facilitate 360-degree visualization of the impact event. The buck is generic in nature and is sufficiently simple to serve as a standardized evaluation tool at multiple laboratories. The subjects are restrained on a rigid planar seat by bilateral rigid knee bolsters, pelvic blocks, and, for the first test condition, a custom 3-point lap and shoulder belt that approximated the restraint geometry of the front passenger position of a standard sedan.

Deliverables:

1. Detailed kinematics data from cadaver tests conducted with various restraint systems using a simplified buck and geometry
2. Performance corridors will be generated for the evaluation of future dummy (and any future thoracic computer models used in a SIMon-like injury prediction) biofidelity

Schedule: Work to be completed in FY 2013

NVS Priority Plan: THOR 50th percentile dummy

Hybrid III 95th Percentile Large Male Dummy

This project involves the evaluation of the Hybrid III 95th large male dummy using the standard Federalization process (Rhule et al., 2005) as a roadmap to assess its value as a viable scientific measurement tool and as advanced preparation for possible future rulemaking activity. Dimensional analyses have been completed on two Hybrid III 95th dummies, and the initial SAE drawing package has been reviewed and corrections and changes have been recommended. Further work will go towards the Federalization process for this dummy.

Deliverables: Complete test reports and documentation to support potential future incorporation into Part 572

Schedule: Work to be completed in FY 2011

WorldSID 50th Male and 5th Female Dummies

Over the past several years, NHTSA has conducted an evaluation of the WorldSID 50th male dummy. This evaluation has included, among other things, an assessment of the dummy's response biofidelity, long-term durability, repeatability, and reproducibility. NHTSA's BioRank (Rhule et al., 2009) method has shown the WorldSID to have improved biofidelity as compared to the ES-2re dummy, which is currently specified for use in FMVSS No. 214.

Meanwhile, NHTSA has obtained two 5th percentile small female WorldSID dummies and is completing similar evaluations as have been done with the WorldSID 50th including the comparison of its responses to the SID-IIs dummy that is currently specified for use in FMVSS 214.

NHTSA intends to work with the international vehicle safety community in a cooperative effort to complete the development of this dummy. Resources are being directed toward the 5th in order to develop the pair of small and mid-sized adult side impact dummies simultaneously. Additional project details will be published in a roadmap on the NHTSA Research Web site.

Deliverables: Complete all WorldSID 50th materials (drawing package, etc.) for potential Part 572 incorporation, WorldSID 5th evaluation and development.

Schedule: WorldSID 50th – work to be completed in FY 2011; WorldSID 5th – work to be completed in FY 2013

NVS Priority Plan: Side Impact Dummies - Adults

THOR Lx/FLx

The THOR Advanced Lower Leg contains extensive capabilities for measuring forces and assessing injuries to the lower leg, ankle, and foot and represents a potential device for preventing injuries and reducing economic costs due to road traffic crashes. The THOR Lx is for use with the 50th male Hybrid III and THOR-NT dummies. The FLx is a 5th female version of the THOR Lx. The THOR Lx ankles have been redesigned to improve durability, serviceability, and biofidelic range of motion.

Through a cooperative effort with the SAE THOR Evaluation Task Force, the new ankles will be evaluated and certification procedures and response criteria will be developed. The legs will then be evaluated for repeatability, reproducibility, biofidelity, and durability. The drawing package will be reviewed and revised to comply with NHTSA standards. The PADI will be generated.

Deliverable: Documentation for potential incorporation of the Lx legs into Part 572

Schedule: Work to be completed in FY 2011

Deliverable: Document the development of the FLx

Schedule: Work to be completed in FY 2012

Deliverable: Documentation for potential incorporation of the FLx legs into Part 572

Schedule: Work to be completed in FY 2013

NVS Priority Plan: THOR 5th and 50th percentile dummies

Rollover Dummy

Development of a dynamic rollover test procedure indicates the need for a dummy that can replicate human kinematics and predict human injury in a rollover crash environment. Work will be developed that seeks a greater understanding of the human injury issues, potential response requirements and provisional injury criteria that would be required for a new rollover dummy.

Deliverables: Rollover dummy response requirements

Schedule: Work to be completed in FY 2013

NVS Priority Plan: Dynamic Rollover Test Research; Restraint Effectiveness in Rollovers

Active Dummy

New dummy technology is under development that can make dummies respond in human-like fashion to pre-impact vehicle maneuvers. Current dummies are passive and have no active elements to respond to braking or other pre-impact dynamic events. This could lead to dummies that can be used in assessment of pre-crash and crash technologies thus bridging the active/passive safety issues. NHTSA will monitor the activity underway and may evaluate prototypes developed.

Deliverables: Report on active dummy development; evaluation of technology

Schedule: Work to be completed in FY 2015

NVS Priority Plan: Forward Collision Avoidance and Mitigation

<u>Rear Impact Dummy Evaluation</u>
Rear-end collisions are frequent, and neck injuries are the most common injuries reported in these automobile crashes. The overall goal of this project is to evaluate the two rear impact dummies (BioRID II and RID3D) with respect to their biofidelity, durability, repeatability, reproducibility, and ease of use.

Current efforts in this project are focused on the moderate-speed biofidelity of the two dummies. Therefore, an experimental seat for rear impact testing was designed with the following features:

1) Exhibits realistic seat back rotation response, overall geometry, and padding/upholstery characteristics
2) Instrumented with 14 load cells (six in seat back, four in seat pan, and four in head restraint) so that it is capable of measuring the occupant loading on the seat to assess external biofidelity
3) Reusable and durable
4) Provides a repeatable test environment

Moderate-speed rear impact sled tests (10.5 g, 24 kph) are currently being conducted using this experimental seat with PMHS to generate mean human response curves. The BioRID II, RID3D, and Hybrid III will also be tested under identical conditions and their response compared to the PMHS to assess their internal and external biofidelity using the updated NHTSA BioRank method.

The design and evaluation of the experimental seat have been completed and the cervical instrumentation technique has been developed and validated. The sled testing for both the PMHS and dummies will be completed in FY2011.

*Deliverable*s: Report on dummy biofidelity and potential for injury prediction.

Schedule: Work to be completed in FY 2011.

NVS Priority Plan: Head Restraints – Phase 2

Older Occupant Biomechanics

The U.S. is witnessing a growing segment of older occupants that will certainly continue to drive and ride in passenger vehicles. Current data shows that older drivers and occupants have a higher risk of injury for a given crash severity than their younger counterparts. Hanna (2009) showed that occupants over 75 years had twice the risk of experiencing a rib fracture in a frontal crash compared to younger occupants. NHTSA is developing a comprehensive plan for assessing the crash involvement and injury scenarios of older occupants. This plan includes ongoing analysis of NASS, FARS, CIREN, and other databases to identify potential impact response and behavioral components unique to older occupants. Ultimately, this will help to identify countermeasures (active and passive) that are focused on these occupants. The following projects have been started as a result of the field data analysis conducted to support this plan and will support a better understanding of the biomechanics of older occupants. Table 5 lists the schedule of the projects.

Table 5. Schedule of Older Occupant Projects

Research Area	Project	2011	2012	2013	2014	2015
Older Occupant Biomechanics	Efficacy of Current Dummies for Older Occupant Crash Injury Eval.					
	Brain Morphing Analysis					
	SIMon Age Specific					
	Older Occupant ASDH Mechanism and Injury Criterion Development					
	Rib Cage Morphometrics					

Efficacy of Current Dummies (WorldSID & THOR) for Older Occupant Crash Injury Evaluation

An analysis of the older occupant injury problem will be performed and the relevant crash scenarios will be defined. The ability of current and near future crash dummy tools will be evaluated for sensitivity to the appropriate older occupant crash scenarios.

Deliverables: Crash data analysis for the older occupant situation

Schedule: Work to be completed in FY 2011

Deliverables: Test scenario development and dummy sensitivity evaluation

Schedule: Work to be completed in FY 2012

NVS Priority Plan: Older Persons

Brain Morphing Analysis

Head injury continues to be the leading cause of death in motor vehicle crashes. One project has been undertaking a study to develop morphing functions for the SIMon brain model such that its shape can be changed to reflect the brain of an infant, and can be changed so that it reflects a young adult. Powerful tools have been developed for geometry and shape data collection and interpretation. This project expansion entails extending the SIMon morphing project to the older occupant. Older occupant CT and MRI data is much easier to obtain than pediatric data. In this project they will extend the morphology to the older occupant population, providing shape analysis and other information on the brain from ages 20-100. These data will be merged with the pediatric data in order to be able to morph the shape and size of the brain and skull from pediatric to old age.

Deliverables: Data to be used for SIMon morphing

Schedule: Work to be completed in FY 2013

NVS Priority Plan: Older Persons

SIMon Age Specific

Previous approaches to scaling SIMon have employed a method that takes an existing SIMon mesh and scales it using affine transformations that does not account for all of the variation in size and shape. A superior approach is to use the data from the Brain Morphing Analysis project to generate the different age SIMon models from scratch. This approach would produce properly-scaled (size and shape) brain and skull models with sufficient anatomic detail, and allow the user to understand the nuanced and large differences in model response with age. The scalable SIMon will be used to assess the variation in response with age for a variety of rotational and translational acceleration pulses. Regional variation in response as well as overall head injury response variation with age will be explored. The result will be an age-specific injury metric and an understanding of the effect of age-related changes in the brain and skull on head injury metrics that are state of the art at the time.

Deliverables: Scaled SIMon models representing various ages

Schedule: Work to be completed in FY 2014

NVS Priority Plan: Older Persons

Older Occupant Acute Sub Dural Hematoma (ASDH) Mechanism and Injury Criterion Development

An analysis of the sensitivity of the older occupant to this particularly serious and usually fatal injury has been performed and the mechanisms of injury are being defined. The existing theory of sagittal bridging vein rupture has been found to be simplistic and insufficient to explain the majority of ASDH. An improved general mechanism will be developed and verified through PMHS testing and a mechanical measure and injury criterion for ASDH will be developed. The intent is for this injury criterion to be applicable to both physical dummies and analytical models of the human (SIMon).

Deliverable: ASDH crash data analysis report

Timing: Work to be completed in FY 2011

Deliverable: Definition of mechanism and injury criterion

Timing: Work to be completed in FY 2013

NVS Priority Plan: Older Persons

Rib Cage Morphometrics

Similar to the approach for the pediatric brain and skull, one project will develop preliminary data on the ability to create and “morph” a finite element model of the rib cage for the young adult to older adult population. A preliminary study of the geometry of this has been completed but this model requires additional data points for finalization of the shape functions and a study of the rib thickness changes to be able to describe their morphology as well. Additionally, the model could be used in biomechanical analyses to study the effects shape and properties versus mechanics of the rib cage and their contribution to injury.

Deliverables: Model to "morph" human thoracic ribcage geometry

Schedule: Work to be completed in FY 2013

NVS Priority Plan: Older Persons

Vulnerable Occupant Biomechanics

Table 6. Schedule of Vulnerable Occupant Projects

Research Area	Project	2011	2012	2013	2014	2015
Vulnerable Occupant Biomechanics	Pregnant					
	Pedestrian					
	Obese Occupants					

<u>Pregnant</u>

Pregnant occupants involved in motor-vehicle crashes can sustain injuries that lead to fetal death or fetuses not being carried to term. The most common cause of fetal loss is placental abruption; however, the understanding of the mechanism of injury is unclear. A computational model of the pregnant abdomen is a key element to gaining a better understanding of the injury, but improved tissue properties are needed to produce reliable results. This work will study the tissue properties of the uterus, placenta, and the utero-placental interface. Strength and failure properties will be studied using surrogate tissues, and the results will be incorporated into computational models to determine abdominal loading parameters that may lead to placental abruption.

Deliverables: Uterine, placental, and utero-placental interface tissue properties

Schedule: Work to be completed in FY 2011

<u>Pedestrian</u>

Current pedestrian impact work includes support of pedestrian rulemaking activities, as well as research to support future improvements to pedestrian safety. Rulemaking support activity includes ongoing testing of the U.S. fleet to determine the benefit of adopting the lower legform portion of the global technical regulation (GTR), and generation of technical specifications of pedestrian test tools for incorporation into a pedestrian regulation. Comparison testing is being performed to evaluate the ability of the current test tools (headforms and legform) to differentiate vehicles with good levels of pedestrian protection from vehicles with poor levels of pedestrian protection. Research is being performed to determine the effects of upper body mass on legform test results and to develop a surrogate upper body mass that can be incorporated into the planned next-generation legform that is expected to be included in the GTR in the future. Epidemiological research is under way to evaluate the risk of injury from the hood leading edge area of vehicles, and the injury risk related to child torso injuries.

Deliverable: Analysis of the efficacy of the TRL and GTR legforms for testing in the U.S. crash environment

Schedule: Work to be completed in FY 2012

NVS Priority Plan: Pedestrian

Significant work is ongoing on pedestrian crash avoidance, including development of a pedestrian test procedure and performance criteria. This work is in its early stages, but will eventually include an analysis of whether a pedestrian crash avoidance dummy device is required. It is yet unknown to what extent that dummy needs to be biofidelic, but this may be an additional area of work in NHTSA's biomechanics efforts.

<u>Obese Occupants</u>
Field data and CIREN crash investigations indicate that obese and large statured occupants do not have the same injury risk compared to occupants with average weight and stature. There are currently no models or dummies that can address this issue. As over 30% of the American adult population is classified as obese, a research effort is proposed to better understand the needs of this population. A review of research done to date, analysis of field crash data, and development of a research plan are warranted.

Deliverables: Report on obese occupant injury risk; develop and institute research plan on possible testing, modeling and dummy development for the obese population

Schedule: Work to be completed in FY 2013

Computer Modeling

Computer modeling techniques have been used in vehicle crashworthiness for many years. As the research in human biomechanics has progressed, the use of this research to create advanced models to predict human injury has become practical. The following projects propose the development and use of a variety of human and dummy computer models to enhance occupant protection. Table 7 lists the schedule of the projects.

Table 7. Schedule of Computer Modeling Projects

Research Area	Project	2011	2012	2013	2014	2015
Computer Modeling	Global Human Body Modeling Consortium					
	Foot / Ankle Model					
	THOR FE Model Validation / Enhancement					
	Crash Reconstruction Methods					

<u>Global Human Body Modeling Consortium</u>
The Global Human Body Modeling Consortium, LLC (GHBMC) is an on-going effort by several vehicle and equipment manufacturers to develop and carry-out out a multi-phase research and development program that seeks to produce improved human body models. The comprehensive nature of the approach, involving many interested parties and the use of significant resources, appears promising for the development of improved human body models. Because of this, and its potential to impact the development of injury criteria, the agency has a need for access to the data from the human body models produced by GHBMC, and for a limited role in working with the organization to share NHTSA's human injury data. Access to improved human body models

will produce a better assessment of the human experience in a motor vehicle crash, which in turn will assist the agency in developing better injury criteria and in understanding injury causation in crashes.

Deliverables: Initial deliverable is a finite element models representing a 50th percentile male with future development of child and other adult models

Schedule: Work to be completed in FY 2015

<u>Foot / Ankle Model</u>
Using FE simulations, this study aims to determine the tolerance of the ankle joint to the type of combined loading (e.g. axial compression, eversion, and dorsiflexion) that may occur in a frontal crash. A subject-specific FE model of a human foot will be developed in from the computer tomography (CT) scans of the Visible Human Male (VHM). Combinations of non-injury kinematic (rotations/displacements) or loading (force/moments) parameters will be applied to the ankle FEM and the injury response surfaces will be predicted.

Deliverables: A biofidelic foot and ankle FE model that may be used to: (1) better understand ankle injury mechanisms under combined loading conditions; (2) improve the THOR Lx and Flx legs

Schedule: Work to be completed in FY 2013

NVS Priority Plan: THOR 5th and 50th percentile dummies

<u>THOR FE Model Validation / Enhancement</u>
Further refinements to the THOR FE model work will focus on the following: (1) further validation/verification of the THOR FE dummy at component level (e.g. thorax, leg) and the full-body level, and (2) continuous update of the THOR FE model according to current and further design modifications.

Deliverables:
1. An efficient THOR FE model with high ratings in crash environment simulations for use by the automotive research community
2. An achievable and highly organized methodology of validating and updating the THOR dummy
3. A THOR FE model with good prediction capability that can be used as a research tool for evaluation of various new designs of the physical dummy in a effort to improve its biofidelity relative to PMHS

Timing: Work to be completed in FY 2013

NVS Priority Plan: THOR 5th and 50th percentile dummies

<u>Crash Reconstruction Methods</u>
This is an internal project, the objective of which is to use detailed injury data from the CIREN database along with the modern parametric and statistical computational modeling techniques for

development of reconstruction methodologies. Besides CIREN and NASS databases, this project utilizes several modeling software packages for accident reconstruction and crash pulse generation, simulation of occupant response to the crash pulse and Design of Experiments, stochastic, and parametric analyses. The goal of this project is to gain additional insights on the complex occupant kinematics during a crash event and to provide a probabilistic assessment of injury causation.

Deliverables: Improved reconstruction techniques

Schedule: Work to be completed in FY 2015

NVS Priority Plan: This project supports many crashworthiness and biomechanics projects found in the NVS Priority Plan.

Post Crash Analysis

Recent research indicates that a severely injured car crash victim has a 25% greater chance of survival if they are immediately transported to a Level 1 Trauma Center compared to a non-trauma center. The decision to transport an injured occupant is usually not made until EMS arrives on scene. With new vehicle technology that includes Advanced Automatic Collision Notification (AACN) being offered on more vehicles, there is a need to develop tools to predict injury that uses telemetry of “vehicle information consistent with serious injury." This can enhance the decision process of patient transport even before arrival of EMS. An AACN Roadmap providing additional details will be provided on the NHTSA Research Web site.

<u>AACN - Injury Prediction and Estimation of Benefits</u>

Work is underway to study previously described algorithms that can predict serious occupant injury based on vehicle crash attributes such as delta V, direction of impact, belt use, etc. Future work will use more recent data and coupled with prospective studies, help to create a more robust injury prediction algorithm. Evaluations include both injury- and hospital care-based outcomes that may be best associated with the need for the highest level of hospital care (Level I trauma center, e.g.). This effort also entails looking at the various considerations that may influence the potential benefits that will come with AACN and its integration into the emergency response and trauma community.

Deliverables: Report summarizing injury and outcome prediction considerations and status of field trial; draft report on potential benefits of AACN

Timing: Work to be completed in FY 2011 (draft report on benefits) and FY 2013 (injury prediction; field trial status)

NVS Priority Plan: AACN

Biomechanics Database

The NHTSA Biomechanics database has a rich history of information on work sponsored by NHTSA over the last 30 years. The database continues to be a source of information for researchers around the world. Future work will increase user-friendliness of the database and create enhancements for data input, retrieval and research.

Deliverables: Enhanced Biomechanics Database

Timing: FY 2011-2015

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DOT HS 811 474
June 2011

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