中国汽车工程研究院股份有限公司
China Automotive Engineering Research Institute Co., Ltd.

Research Progress and Application Exploration of CAERI Virtual Testing Methods

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1 Background and Current Status

2 Human Body Model Application Exploration

3 Future Research Plan

Background

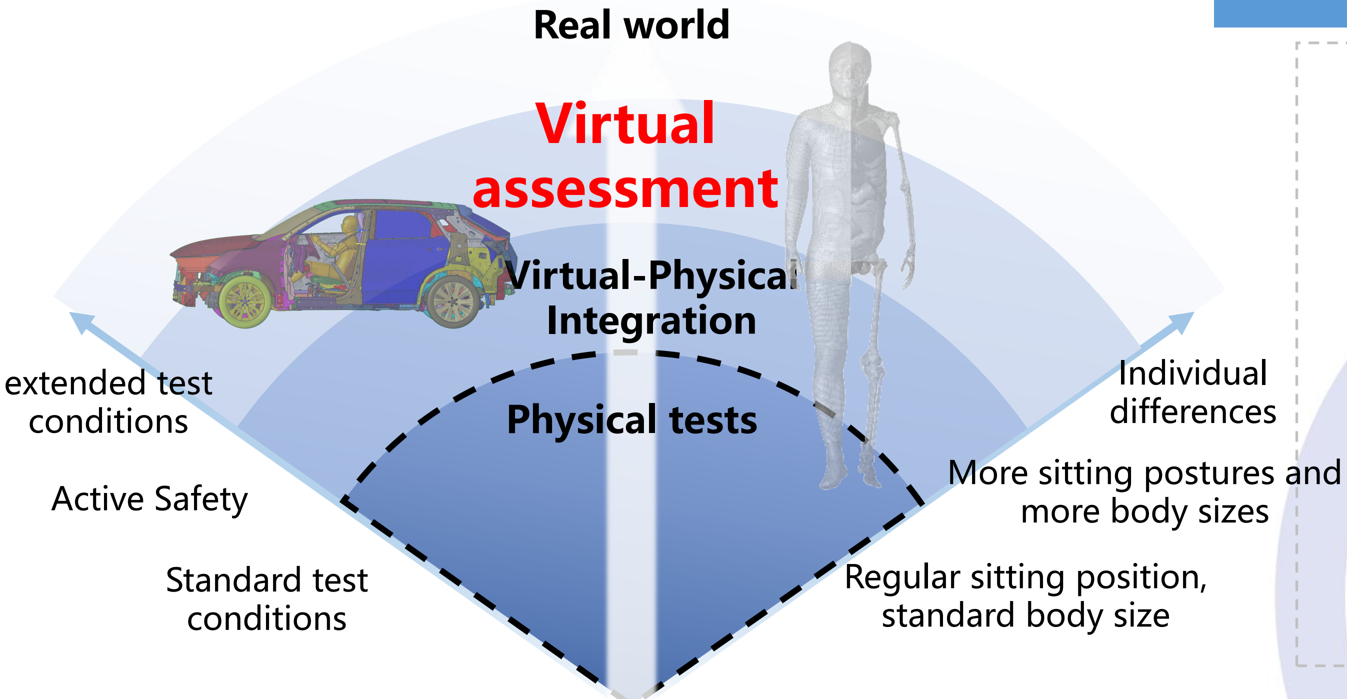
- **Vehicle safety assessment faces the need for diverse occupant protection in complex crash scenarios**

Virtual assessments have the potential to simulate traffic accidents more comprehensively

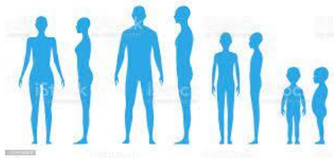
Accident scenarios are complicated


Active and passive integration | **Autonomous driving**

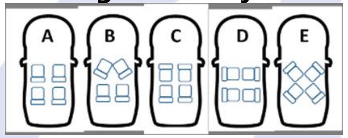

Diversity of collision



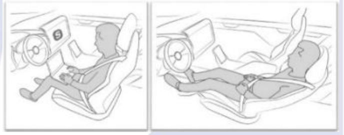
Occupants are diverse



body size & Gender & Age Diversity



Layout diversity

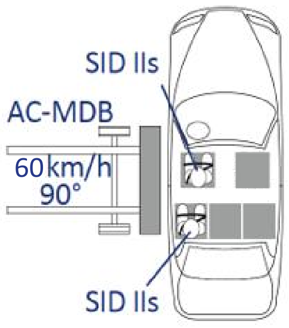


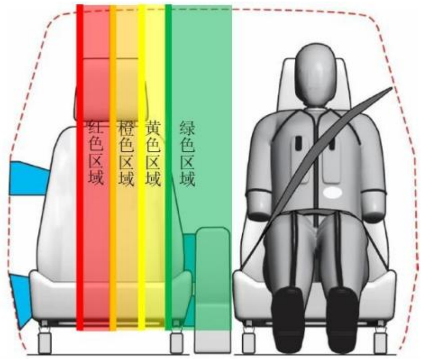
Posture diversity

Current Boundaries of Physical Testing: Standard Scenarios, Conventional Postures, and Standard Body Sizes

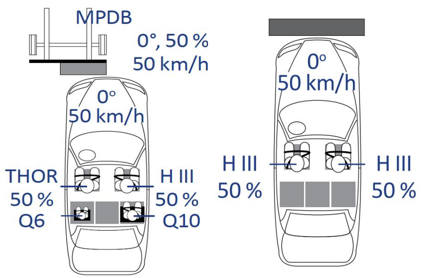
Project Overview

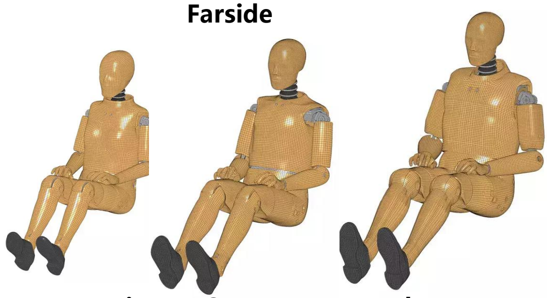
Completed Projects





Farside





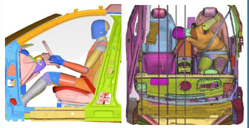
Diverse Occupant Frontal Collision

- Based on China's traffic characteristics, this study conducts farside and diverse-occupant frontal virtual assessment research to improve far-side occupant protection and enhance travel safety for diverse populations

Research Content

Accident Analysis and Injury Pattern Research

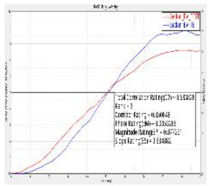
Accident analysis



Injury Pattern Research

Validation method

Research on Model Validation Methods



Research on Validation Metrics and Validation Accuracy

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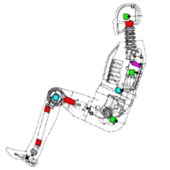
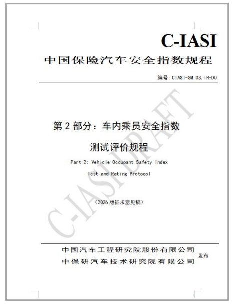
Evaluation Methods



Research on Evaluation Metrics and Thresholds

Research on Evaluation Methods

Evaluation plan

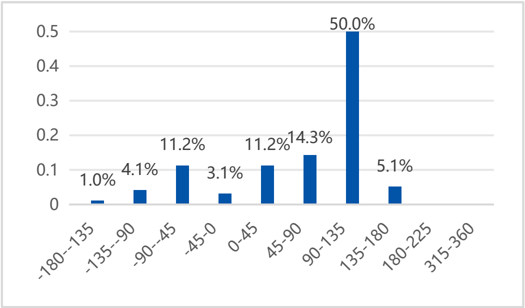


Virtual assessment plan

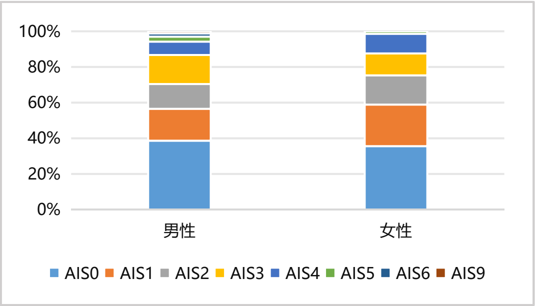
- Conduct research on accident analysis and occupant injury patterns, develop test scenarios, establish validation and evaluation methods for virtual assessment, and form a systematic virtual evaluation workflow framework

Project Summary

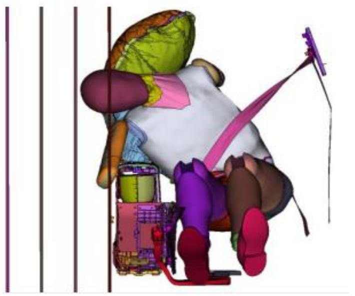
Test Condition Research



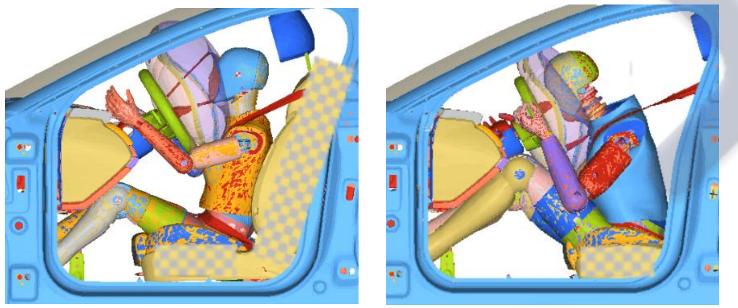
Direction of force on the struck vehicle in a side-impact collision



Maximum AIS values for drivers of different genders in frontal collision accidents



Research on Farside Injury Pattern



Research on Injury Patterns in Frontal Collisions Involving Diverse Occupants

- **Based on analysis of China's road traffic accident data, this study investigates farside and diverse-occupant crash injury patterns and develops a virtual evaluation scenario matrix**

Evaluation Scenarios

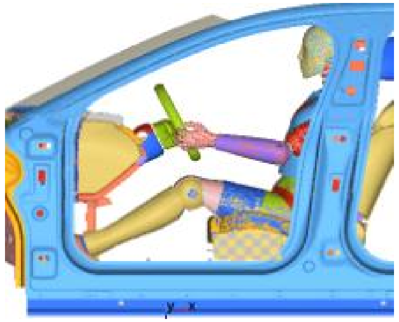
Farside			
No.	Impact angle	Dummy	Seating position
Case 1	75°	WorldSID 50th	In accordance with relevant procedures
Case 2*	75°	WorldSID 50th	Adjust to the highest position based on Case 1
Case 3*	90°	WorldSID 50th	Same as Case 1
Case 4	90°	WorldSID 50th	Same as Case 2
Case 5	60°	WorldSID 50th	Same as Case 1
Case 6*	60°	WorldSID 50th	Same as Case 2
Case 7*	90°	SID-IIs	In accordance with relevant procedures
Case 8	90°	SID-IIs	Adjust to the highest position based on Case 7
Case 9 (Monitoring items)	90°	HBM	Same as Case 1

Diverse Occupants				
No.	Waveform	Driver	Passenger	Second row
Case 1	(AC-MPDB)	Hybrid III 95th	Hybrid III 5th	Hybrid III 5th
Case 2		Hybrid III 5th	Hybrid III 95th	Hybrid III 50th
Case 3	(FRB)	Hybrid III 95th	Hybrid III 5th	Hybrid III 5th
Case 4		Hybrid III 5th	Hybrid III 95th	Hybrid III 50th
Case 5 (monitoring item)		HBM	——	Q10

Project Summary

Validation study


Correlation Study Between Farside Simulation and Testing




Correlation Study Between Simulation and Testing for Frontal Collisions Involving Diverse Occupants

- **Conduct correlation studies between simulation and testing for farside and diverse-occupant frontal collisions, and determine validation metrics for virtual assessment based on expert discussion**

Validation Metrics

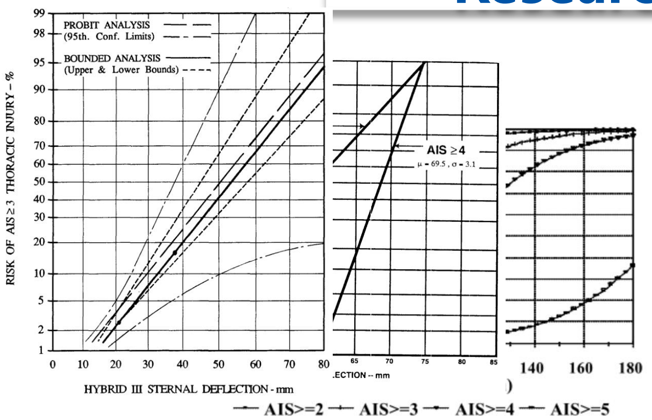
- If the ISO correlation evaluation value of the occupant is less than 0.5 in the verification condition, two defects will be added to the correlation evaluation

Dummy	Defect assessment	Driver
WorldSID 50th or SID-IIs	Head accelerationISO>0.5?	0或2
	Chest accelerationISO>0.5?	0或2
	Pelvic accelerationISO>0.5?	0或2

Dummy	Defect assessment	Driver	Passenger	Second row
Hybrid Ⅲ 5th Hybrid Ⅲ 50th Hybrid Ⅲ 95th	Head accelerationISO>0.5?	0或2	0或2	0或2
	Chest acceleration/chest compressionISO>0.5?	0或2	0或2	0或2
	Pelvic accelerationISO>0.5?	0或2	0或2	0或2

Project Summary

Evaluation Research



Injury Risk Investigation

Expert Discussion

Model Number			01	02	03	04	05	06	07	09	10	11	12	14	16	17
Head	HIC15		31.00	80.00	431.00	55.00	275.00	181.00	37.00	893.00	30.00	87.00	61.00	23.00	76.00	108.00
	Composite acceleration peak		23	34	92	42	98	73	23	232	22	35	29	21	32	40
Upper neck	Neck tension Fz	Tension FZ+	0.94	1.30	1.53	1.02	1.66	1.07	0.95	2.03	0.75	1.43	1.07	0.72	1.18	1.50
		Compress FZ-	0.09	0.01	0.26	0.25	0.15	0.36	0.04	0.21	0.03	0.04	0.01	0.16	0.01	0.06
……																

Evaluation for vehicles

- **Based on literature review, expert discussion, and vehicle evaluation results, the evaluation metrics and injury thresholds for different virtual assessment dummies are determined**

Evaluation metrics and thresholds

Farside Head Protection Evaluation

Part	Protection Measures	Green Zone	Yellow Zone	Orange Zone	Red Zone
Head	Yes	0	0	1	2
	No	0	1	2	2

WorldSID 50th Dummy Injury Rating

Body parts	Parameter	G	A	M	P
Head and neck	HIC_{15}	≤560	≤700	≤840	>840
Chest and abdomen	Average chest compression deformation D(mm)	≤30	≤40	≤50	>50
	Average abdominal compression deformation D(mm)	≤47	≤56	≤65	>65

Hybrid III 95th Percentile Dummy Injury Rating

Body parts	Parameter	G	A	M	P
Head and neck	HIC_{15}	≤560	≤700	≤840	> 840
	N_{ij}	≤0.80	≤1.00	≤1.20	> 1.20
	Tensile force(kN)	≤3.2	≤3.5	≤4.8	> 4.8
	Compressive force(kN)	≤3.8	≤4.0	≤5.8	> 5.8
Chest	Compression deformationD(mm)	≤42.0	≤50.0	≤63.0	> 63.0
	Compression rateV(m/s)	≤6.6	≤8.2	≤9.8	> 9.8

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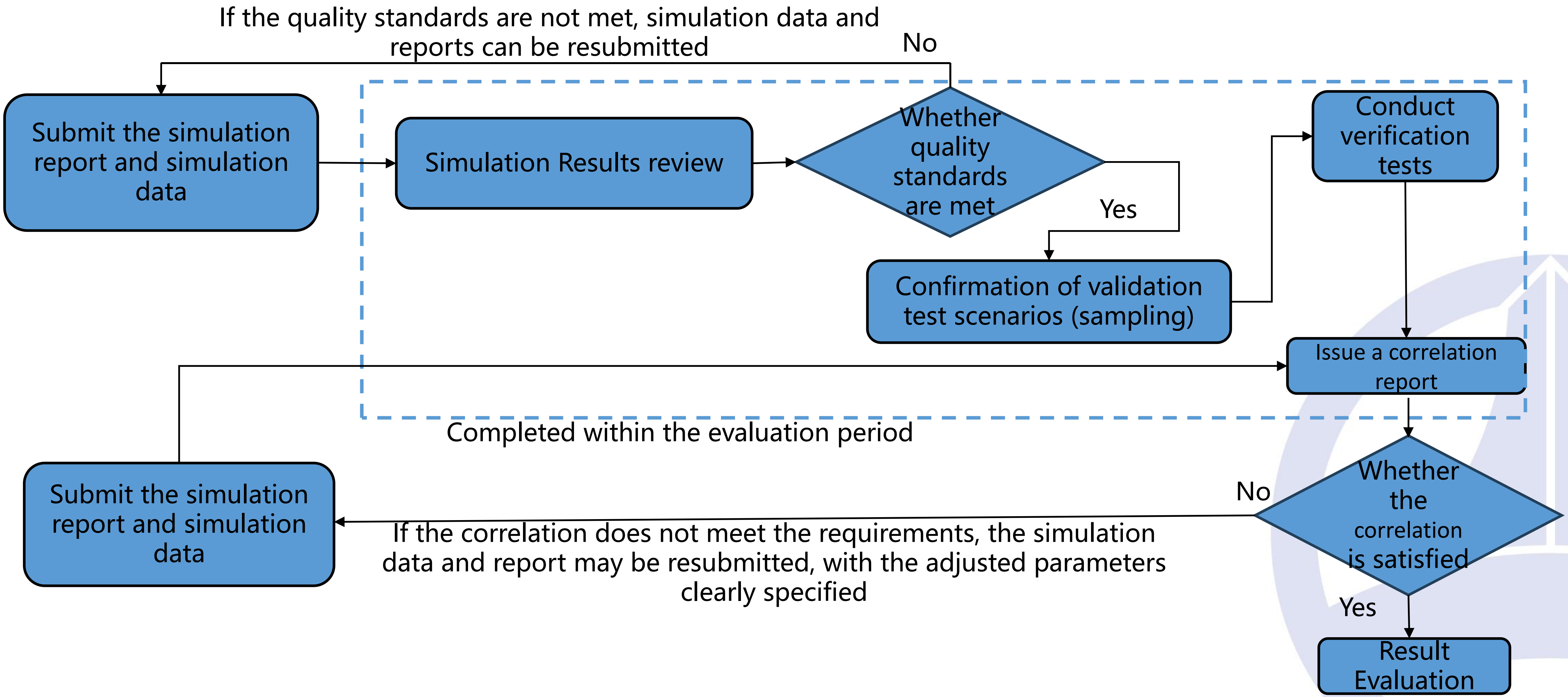
Evaluation Process

- The virtual evaluation process mainly includes **quality inspection, test validation, and result evaluation**



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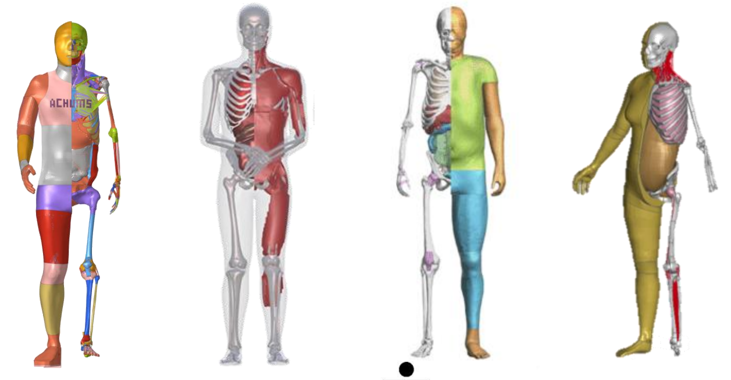
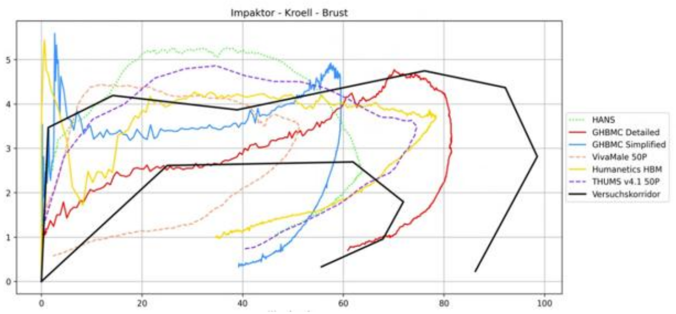
Application Challenges of Human Body Models with Diverse Anthropometry

Qualification



AC-HUMs GHBMC Thums® VIVA+

- ☐ Different HBMs, Different modeling method

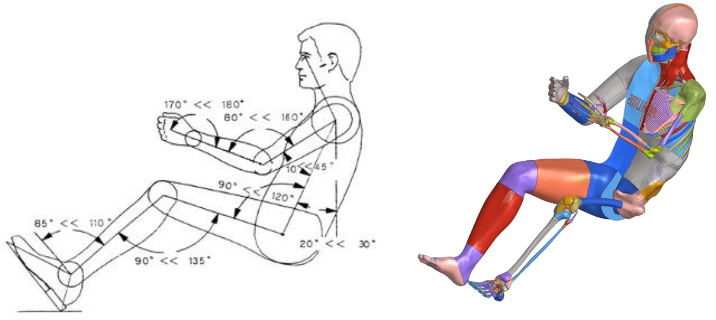


不同模型在胸部冲击下的响应差异

- ☐ Different dynamic responses under the same load cases

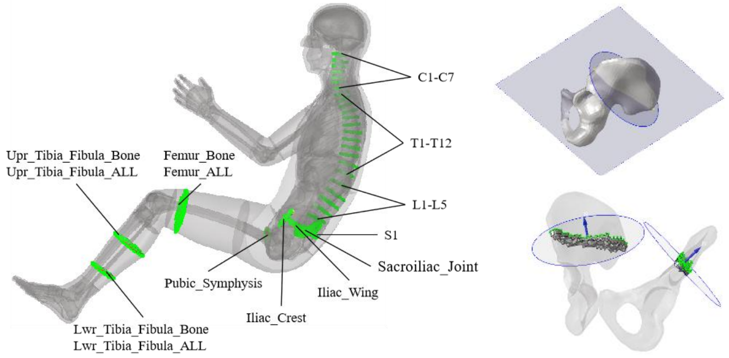
Positioning

- ☐ HPM device for positioning a dummy

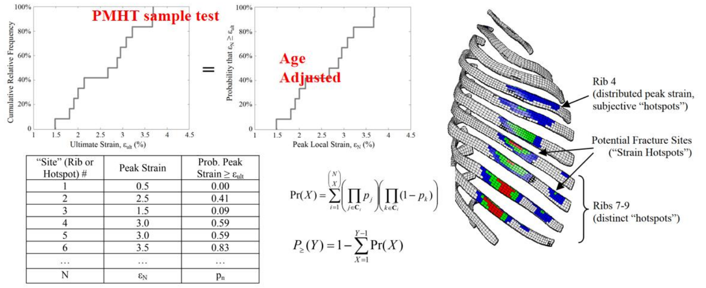


- ☐ How should human body models be aligned with human driving postures to achieve standardized seating adjustment and positioning?

IRF



- ☐ the specific injury criteria to be selected for HBMs and the definition of how each criterion's output is quantified have not yet been clearly defined



"Site" (Rib or Hotspot) #	Peak Strain	Prob. Peak Strain ≥ ε_{ult}
1	0.5	0.00
2	2.5	0.41
3	1.5	0.09
4	3.0	0.59
5	3.0	0.59
6	3.5	0.83
…	…	…
N	ε_N	p_n

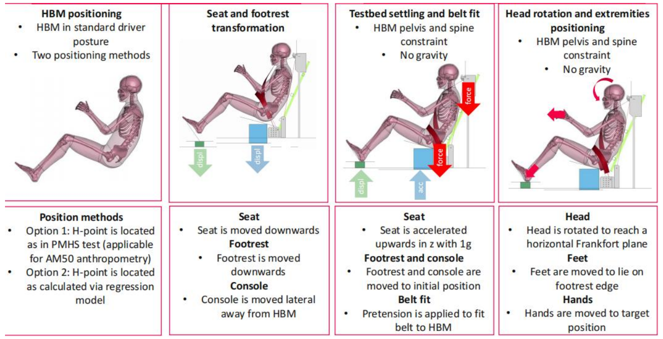
$$\Pr(X)=\sum_{i=1}^{\binom{N}{X}}\left(\prod_{j\in C_i}p_j\right)\left(\prod_{k\notin C_i}(1-p_k)\right)$$

$$P_{\geq}(Y)=1-\sum_{X=1}^{Y-1}\Pr(X)$$

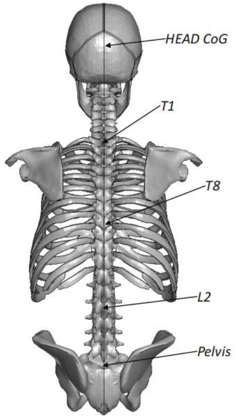
- ☐ The methods for developing injury risk curves still require verification

Model Qualification

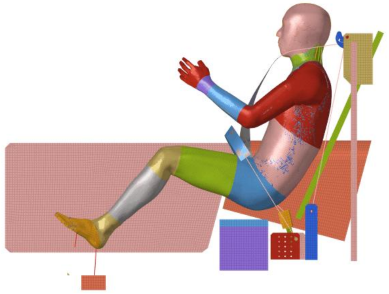
Standardized PMHS Test Reconstruction



PMHS Test Scenario Setup Process



Standardization of Response Output Settings



Scenario Reconstruction

*HBM 4VT

gender	Mass/kg	Height/ mm
male	79	165
male	57	170
male	64	170
male	77	175

PMHS Subject Anthropometric Characteristics（Uriot 2015）

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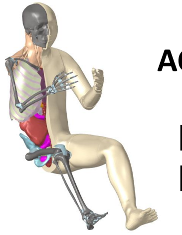


AC-HUMs 50M：

Height：168cm
Mass：67.7kg

Route 1: corridor scaling

Dynamics Metrics (Example)

$$\lambda_m = \left(\frac{m_{50}}{m}\right)^{1/3}$$

$$\text{acceleration}_{scaled} = \text{acceleration}_{unscaled} \times \frac{1}{\lambda_m}$$

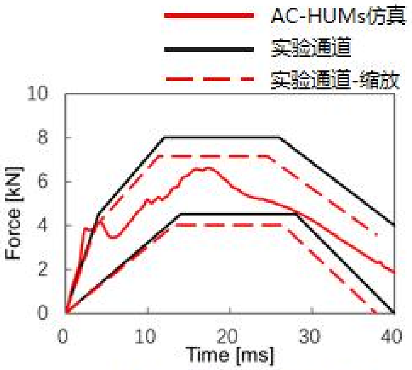
$$\text{time}_{scaled} = \text{time}_{unscaled} \times \lambda_m$$

$$\text{force}_{scaled} = \text{force}_{unscaled} \times \lambda_m^2$$

$$\text{angular rate}_{scaled} = \text{angular rate}_{unscaled} \times \frac{1}{\lambda_m}$$

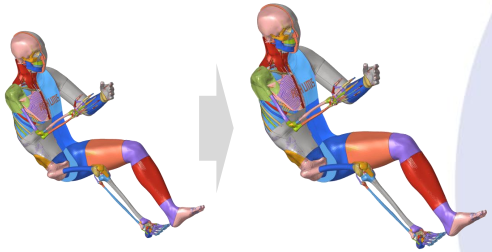
*m_{50}和m分别是第模型和测试对象的体重

*Forman 2006;

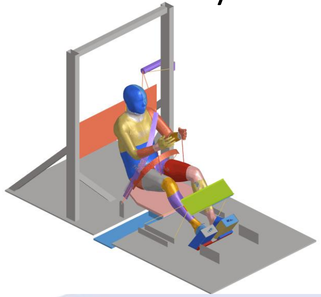


动力学响应通道缩放

Route 2: Scaling Model to PMHS Test Body Size



Model scaling



Validation

Process of Model Positioning

□ Target Parameters and Calculation Methods for HBM Positioning：

Target Parameters（mm/°）	Calculation Formula
Seat reference point（X）/H_Point_X	H_Point_X=16.8+0.433*Stature-0.24*H30-2.19*L27+0.41*L6
Seat reference point（Z）/H_Point_Z	H_Point_Z=SgRP_Z+(SgRP_X-H_Point_X)*tan(STA)
Hip_X（H point of the model）	Hip_X= 12.2-3.5*BMI+3*L27+H_Point_X
Hip_Z(H point of the model)	Hip_Z= -97.1+1.2*BMI+0.1068*L6+1.1*L27+H_Point_Z
颈部角/Neck_Angle	Neck_Angle= 16.1-0.01197*Stature+0.0109*L6
胸部角度/Thorax_Angle	Thorax_Angle= -42.7+0.00497*Stature+45.2*SHS+0.0128*L6
腹部角度/Abdomen_Angle	Abdomen_Angle= -94.5+0.0109*Stature+184.5*SHS+0.0222*L6
骨盆角度/Pelvis_Angle	Pelvis_Angle= -16.3+0.0102*Stature+90.2*SHS+0.0177*L6+0.39*L27

**L27 is the seat cushion angle; L6 is the x-direction distance from the steering wheel to the reference point of the accelerator pedal; Stature is the height of the model, SHS is the sitting height ratio of the model; STA is the seat rail angle.*

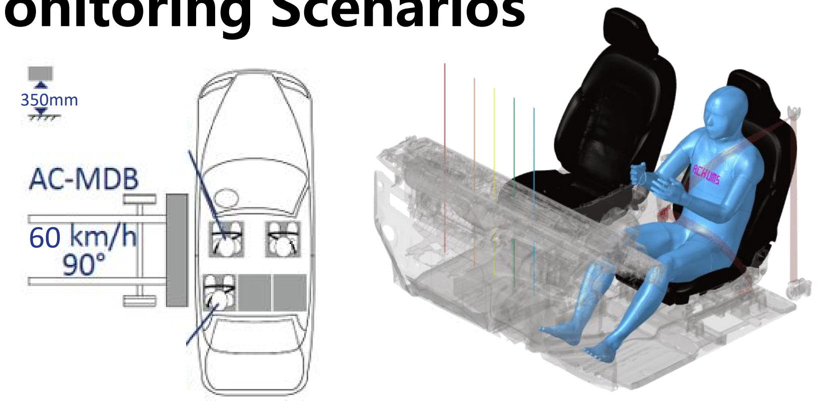
Total Process

①Seat Position： Based on H_Point_X → **②HBM H_Point：** Based on Hip_X&Hip_Z → **③Trunk Angle：** Pelvis→Abdomen→Thorax→Neck → **④Limb Position：** HOS

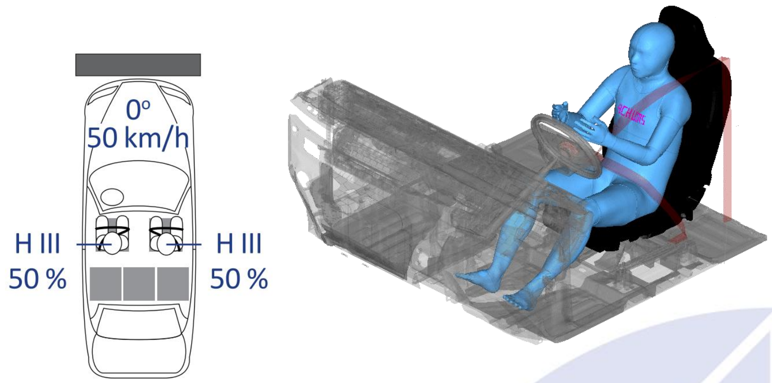
Human Body Model Monitoring

☐ **Human body model monitoring is currently underway, and future research on human body model evaluation schemes will be conducted based on the monitoring results**

➢ **Monitoring Scenarios**



Far-side



FRB

Human Body Model Requirements

Meet the entry criteria:

- Chinese 50th percentile male
- Sensor setup: head, neck, chest, and abdomen
- Response requirement: correlation with PMHS test results

Model Positioning

Ergonomic seating position setup:

- Seat adjustment and H-point adjustment of the human body model
- Adjustment of the torso angle and limbs of the human body model

Monitoring Result Requirements

Submitted results:

- Mesh quality monitoring before and after human body model positioning adjustment
- Posture adjustment parameter monitoring
- Simulation result monitoring

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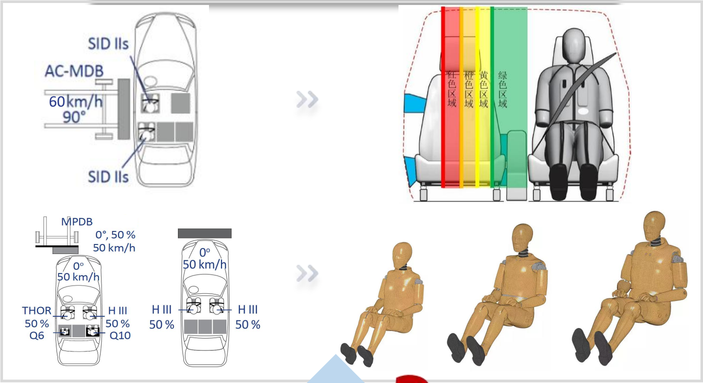
Virtual Assessment Challenge

- Vehicle safety assessment faces certain challenges in terms of **scenarios, methods, and tools**

scenario



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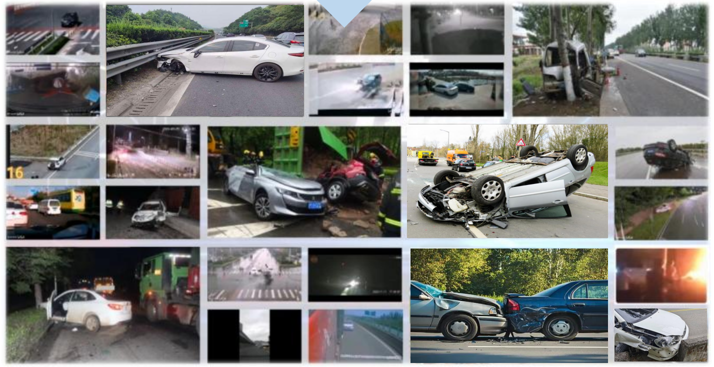
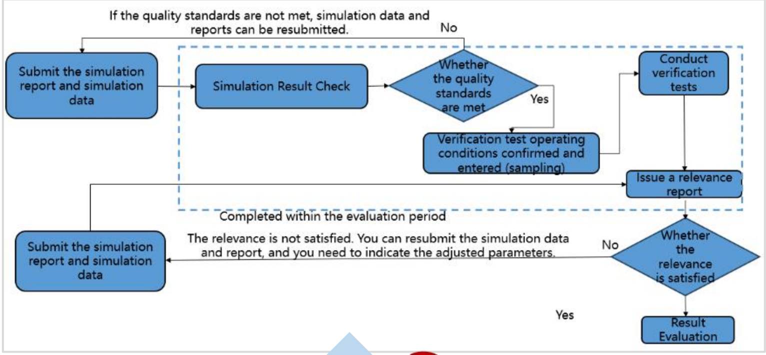


•Current evaluation scenarios cannot fully represent the characteristics of traffic accidents

method



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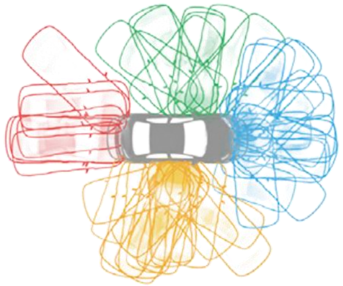
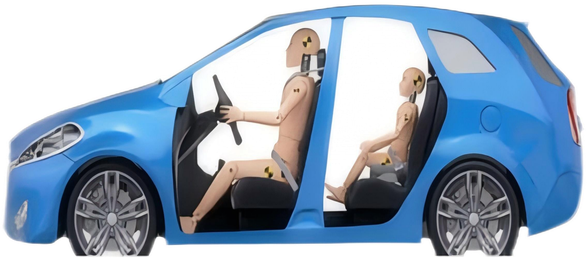


•Current sampling inspection methods are insufficient to fully support model consistency validation

tool



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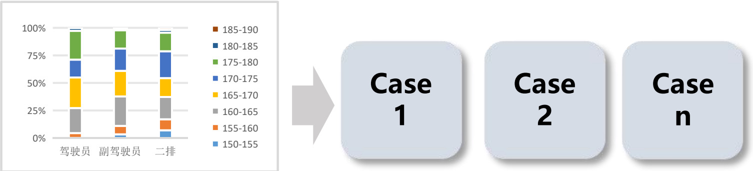
•Crash test dummies cannot fully represent the true biomechanical response of occupants

Future Research Plan

- Consider conducting related research focusing on evaluation scenarios, evaluation methods, and evaluation tools

scenario

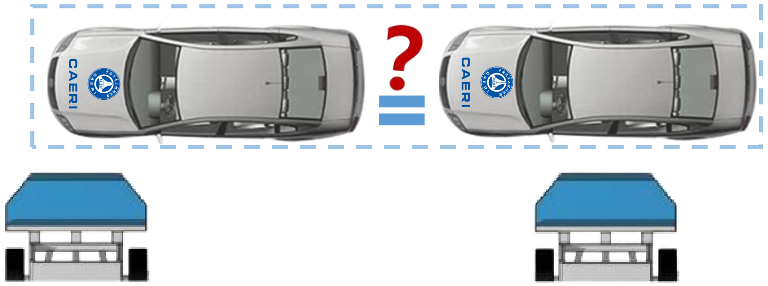
•Conduct research on expanding evaluation scenarios based on a traffic accident database



	case 1	case 2	...
body size 1	weight a	weight b	...
body size 2	weight c	weight d	...

•Develop a weighted scenario synthesis method based on accident data

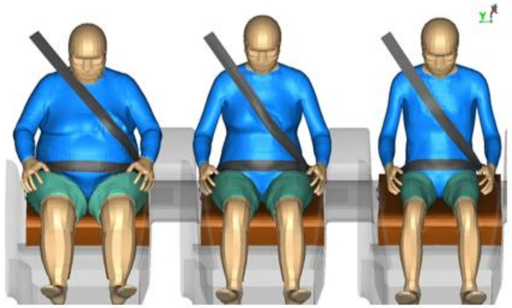
method



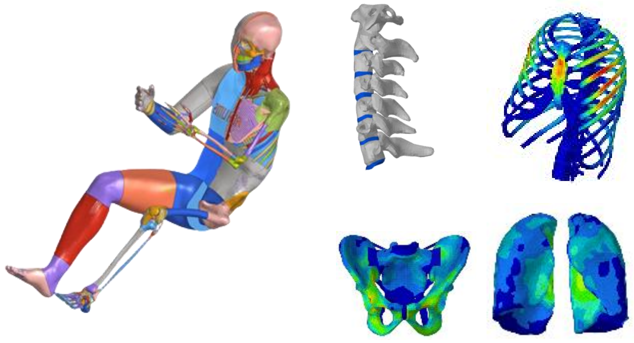
•Research on Model Consistency Verification Methods

•Research on Model Confidentiality Mechanism Methods

tool



•Research on the Application of Diverse Human Body Models



•Research on Human Body Model Evaluation Methods

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