

Study on Integrated Evaluation and Development Strategy of Pedestrian Protection in 2024 Edition of C-NCAP

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Abstract: This paper discusses the comprehensive assessment of pedestrian protection in the 2024 edition of China-New Car Assessment Program (C-NCAP) and its development strategies. The assessment plan has been adjusted according to the actual conditions of Chinese road traffic and vehicle characteristics, emphasizing comprehensive testing of vehicle safety performance. Improvement in structural crash safety significantly enhances a vehicle's ability to protect occupants in collision accidents and reduces injury risks. This article particularly focuses on pedestrian protection assessment and proposes a series of development strategies by integrating AEB VRU system testing with head and leg testing. These strategies aim to further enhance the level of pedestrian protection provided by vehicles and contribute to overall traffic safety improvement.

Keywords: C-NCAP, Comprehensive pedestrian protection assessment, Vehicle safety performance, Structural crash safety, AEB VRU system, Traffic safety.

1. Literature Analysis

Vehicle safety has progressively become a paramount aspect of automotive design, influenced largely by the increasing demand for safer roads and the evolving complexity of traffic environments. Pedestrian protection, in particular, has emerged as a critical area of focus within vehicle safety assessments, necessitating the development of sophisticated methodologies to mitigate injuries and fatalities. Historically, the China-New Car Assessment Program (C-NCAP) has played a pivotal role in shaping safety standards tailored to the unique road conditions and vehicle usage patterns in China. Since its inception, C-NCAP has undergone several revisions, each aiming to incorporate more stringent safety measures and advanced technological integrations. The evolution from basic crash tests to more comprehensive evaluations reflects a global shift towards holistic safety assessments that consider a range of real-world scenarios. This shift is mirrored in the development of similar programs worldwide, such as the European New Car Assessment Program (Euro NCAP) and the Insurance Institute for Highway Safety (IIHS) in the United States, each adapting to regional needs and technological advancements. The 2024 edition of C-NCAP marks a significant overhaul with its integration of advanced driver-assistance systems (ADAS) and the emphasis on pedestrian safety. This edition is particularly noteworthy for its forward-thinking approach to integrating Vulnerable Road User Automatic Emergency Braking (AEB VRU) system tests with traditional impact assessments. By enhancing the protocol in this manner, C-NCAP not only aligns with international safety trends but also addresses the increasing concerns over pedestrian accidents in urban and rural settings.

The recently released 2024 edition of the China New Car Assessment Program (C-NCAP) marks a significant overhaul in vehicle safety evaluation standards, set to be fully implemented in July. This new protocol introduces major changes in both testing methodologies and criteria, aiming to more accurately reflect the unique road conditions and

vehicular characteristics prevalent in China.

The updated evaluation system is designed to push manufacturers towards higher safety standards by incorporating more rigorous and detailed testing requirements. These adjustments extend beyond traditional crash tests to include advanced simulations and real-world scenario analyses, thereby ensuring that vehicles are evaluated under conditions that closely mimic everyday driving situations in China.

Furthermore, the new protocol extends its scope to address emerging technologies in the automotive industry, such as advanced driver assistance systems (ADAS) and electric vehicle-specific safety features. This holistic approach not only enhances the reliability of safety assessments but also encourages innovation in vehicle design and engineering to meet these stringent requirements.

In essence, the 2024 C-NCAP is an ambitious step towards elevating road safety, demanding a comprehensive demonstration of safety across various parameters before a vehicle can be deemed road-worthy. This initiative reflects a growing recognition of the need for standards that do justice to the technological advancements and traffic complexities of modern China.

Since incorporating pedestrian protection into the evaluation protocol in 2018, each subsequent edition of the China-New Car Assessment Program (C-NCAP) has seen continuous refinements and improvements, enhancing safety assessments significantly. The 2024 edition introduces pivotal changes, notably integrating the Vulnerable Road User Automatic Emergency Braking (AEB VRU) system tests with head and leg impact assessments. This fusion creates a comprehensive evaluation framework that measures a vehicle's ability to protect pedestrians more effectively by combining the assessment of direct physical impacts with the capability of vehicles to prevent potential collisions using advanced safety technology. This approach ensures a dual focus on mitigating injuries and enhancing preventive measures, aligning better with real-world scenarios where pedestrian safety is critical.

Simultaneously, the criteria for achieving a coveted five-star safety rating have become more stringent, now requiring a minimum score of 70%, up from the previous 65%. Additionally, the overall score for head and leg impact tests must now meet or exceed 62%. This change underscores an

increased focus on pedestrian passive safety, specifically targeting the effectiveness of head and leg impact performance. The enhanced standards reflect a commitment to improving vehicle safety in scenarios involving pedestrian interactions, aiming to reduce injuries in real-world collisions.

Table 1. Pedestrian Protection Evaluation Content

2024 C-NCAP			2021 C-NCAP		
Evaluation content	Score	Proportion	Evaluation content	Score	Proportion
Head shape test	10	25%	Head shape test	10	15%
Leg shape test	5		Leg shape test	5	
AEB VRU Ped	12		/		
AEB VRU TW	12		/		

Table 2. Requirements for pedestrian protection score rate

Star rating	Minimum score rate for pedestrian protection in 2021	Minimum score rate for VRU protection in 2024
5 stars +	≥75%	≥75%
5 stars	≥65%	≥70%
4 stars	≥50%	≥65%
5 stars	/	/
2 stars	/	/
1 star	/	/

Pedestrian head protection collision evaluations require high accuracy in prediction cloud maps, achieved through random sampling verification in experiments to ensure predicted results align with actual outcomes. To maintain high simulation accuracy, it is crucial to focus on the quality and specifications of the materials and components used in automobiles, as these elements play a significant role in the effectiveness of safety features during collisions.

2. Research Methods and Variables

2.1. Material factors

An accurate database of metal and non-metallic materials is essential for the foundation of any simulation, particularly when assessing pedestrian protection in vehicular collisions. The energy involved in such collisions is typically low, yet the hardening properties of non-metallic materials and sheet metal play a crucial role in influencing the simulation outcomes. These materials' ability to undergo work hardening—a process where materials become stronger and more brittle as they deform—can significantly affect the results of collision simulations.

Impact resistance, a key factor in such simulations, involves the absorption and dissipation of kinetic energy generated during a collision. This energy absorption is critical not only for protecting the safety of individuals involved in low or high-speed impacts but also for minimizing material and structural damage. Ideally, the materials used in automotive construction should absorb enough energy to prevent severe injuries, yet not compromise the integrity of the vehicle's structure. This requires materials that can deform to an extent that maximizes energy absorption without leading to catastrophic failure.

By understanding these dynamics, engineers can better design vehicles that are capable of reducing the severity of injuries in pedestrian accidents. This approach not only enhances personal safety but also contributes to the overall resilience of vehicles, thereby reducing economic losses from potential damages.

The principles of impact resistance are fundamental in vehicle design, focusing on key aspects such as energy absorption and diffusion, and the deformation behavior of the vehicle body during collisions. This includes the absorption of impact energy through materials capable of elastic-plastic deformation, which allows for energy dissipation without compromising structural integrity. Furthermore, the design of vehicle structures takes into account the need to disperse impact forces over a larger surface area. This dispersion helps in reducing localized stress on the vehicle body, thereby minimizing the severity of passenger injuries in the event of a crash. By implementing these principles, engineers aim to enhance the overall safety features of vehicles, ensuring that both the vehicle structure and its occupants are better protected during accidents. This approach not only safeguards passengers but also contributes to the durability and resilience of the vehicle design.

The main indicators of impact resistance are crucial for evaluating a vehicle's safety characteristics. They include the maximum load that the structure can withstand during the impact process, the energy absorbed per unit mass of material, also known as absorbed energy, and the average load sustained throughout the impact. These metrics provide a comprehensive assessment of a vehicle's ability to absorb and effectively distribute energy during a collision, reflecting its overall impact resistance. By analyzing these indicators, engineers can determine how well the vehicle can protect its occupants in the event of an accident by minimizing the forces transmitted inside the cabin. Such evaluations are essential for designing vehicles that not only meet safety regulations but also exceed them, ensuring enhanced protection for all occupants.

An accurate database of metal and non-metallic materials is essential for realistic and reliable simulation of pedestrian protection in vehicular collisions. These simulations require precise material properties because the collision energy involved in pedestrian impacts is generally low, yet the hardening of non-metallic materials and sheet metal significantly affects the outcome. Impact resistance, which

involves the material's ability to absorb and dissipate kinetic energy without substantial damage, is critical for protecting individuals and minimizing damage at various impact speeds. This process entails converting the kinetic energy into internal energy, which ideally does not compromise the material or structure but maximizes energy absorption.

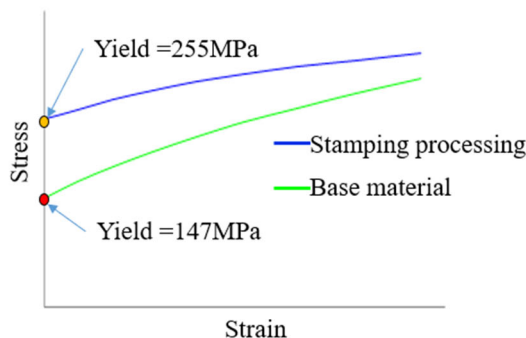
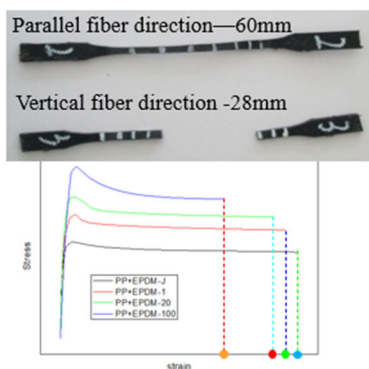
There are several critical indicators employed to assess a vehicle's resistance to collisions, including intrusion levels, maximum deceleration, average impact force, steering column collapse, and firewall intrusion. These metrics are essential for understanding the structural integrity and safety mechanisms of a vehicle. They help gauge how well a vehicle

can protect its passengers during a crash by examining the degree of intrusion into the passenger cabin, the forces exerted on occupants, and the structural collapse that could potentially harm passengers. This comprehensive evaluation ensures that vehicles are tested not only for their ability to withstand crashes but also for their effectiveness in safeguarding occupants from serious injuries in various crash scenarios.

All in all, collision resistance is an important factor in vehicle safety design: reasonable structural design and material selection can improve a vehicle's collision resistance and protect passengers from collision injuries.

CATARC_1180HS_1.4mm	1	CATARC_EPDM	1
CATARC_6061-T6_3.0mm	2	CATARC_PVC	2
CATARC_FC340-410_1.5mm	3	CATARC_ABS	3
CATARC_6063_2.5mm	4	CATARC_GF20	4
CATARC_DP780_1.4mm	5	CATARC_PC	5
CATARC_FC340-410_1.0mm	6	CATARC_PC/ABS	6
CATARC_FC420-780DP_1.6mm	7	CATARC_PDM	7
CATARC_ST03D_1.6mm	8	CATARC_PP+EPDM-TD20	8
CATARC_ST06D_0.7mm	9	CATARC_EPDM/PP	9
CATARC_ST07D_0.65mm	10	CATARC_PP-GF20	10
CATARC_ST13D_0.8mm	11	CATARC_PP-GF30	11
CATARC_C1500HSAS-7575_1.4mm	12	CATARC_PP-LGF35	12
CATARC_FC340-590DP_1.2mm	13	CATARC_PP/EPDM+PP	13
CATARC_6351-T6_2.8mm	14	CATARC_ASA	14
CATARC_DP590_2mm	15	CATARC_PAC	15
CATARC_FC180-340HD_0.65mm	16	CATARC_PMMA	16
CATARC_P180_2.0mm	17	CATARC_PP	17
CATARC_P210_1.2mm	18		
FAW_SAPH400_2.5mm	19		

Improve the material database and material warehouse



The influence of sheet metal stamping strengthening

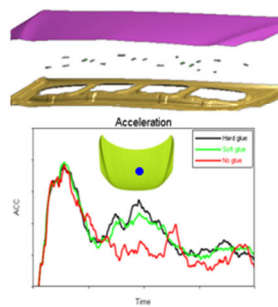


Figure 1. Metal/non-metallic material database

2.2. Automotive Component Factors

In the intricate arena of vehicle design and engineering, the precise modeling of automotive components such as glass panels, headlight systems, and windshield wipers becomes a cornerstone for achieving reliable simulations and enhancing real-world performance. These components are integral to the multifaceted aspects of a vehicle's design, impacting functionality, driver comfort, and above all, safety.

The glass used in vehicles, for example, is not just a barrier to the elements but a critical part of the safety structure, influencing visibility and contributing to the vehicle's aerodynamic profile. Sophisticated simulations that consider the varying shapes, sizes, and positioning of glass can unveil the subtle effects of glare, distortion, and wind noise. They also ensure that glass integrity remains uncompromised in the event of a collision, thereby playing a role in the protection of occupants.

Headlights, another pivotal element, extend beyond their primary function of illumination. Their design and simulation are crucial for enabling optimal night-time visibility and,

consequently, safety. Modern simulations must account for the spread and intensity of light, ensuring that drivers have maximum visibility without impairing oncoming traffic. Similarly, the modeling of wipers is not trivial; it must predict performance in diverse weather conditions, maintaining visibility through rain, snow, and debris, thus upholding the driver's ability to navigate safely.

Beyond these components, simulations incorporate dynamic scenarios, testing the vehicle's response to sudden gusts of wind, changes in road texture, and variable lighting conditions, which could all potentially affect a vehicle's stability and the driver's reaction time.

By harnessing the power of advanced computational models and simulations, engineers can predict and refine the impact of each component on the vehicle's overall aerodynamics, stability, and energy efficiency. This includes streamlining the body to reduce drag coefficients, which directly translates to better fuel economy and lower emissions. Furthermore, the intricate analysis of structural integrity ensures that, should an accident occur, the vehicle's design minimizes injury risk to occupants and pedestrians alike.

This holistic and meticulous approach to component modeling underscores the auto industry's dedication to not just meet, but exceed, current safety standards and performance expectations. It enables the crafting of vehicles that not only perform well under ideal conditions but are also robust and dependable when faced with the unpredictable

variables of real-world driving. Through this lens, automotive engineering transcends the realm of functionality, becoming a disciplined art form that balances aesthetics, performance, and the unwavering promise of safety.

The following figure shows the results of our testing and simulation that can accurately predict the glass area.

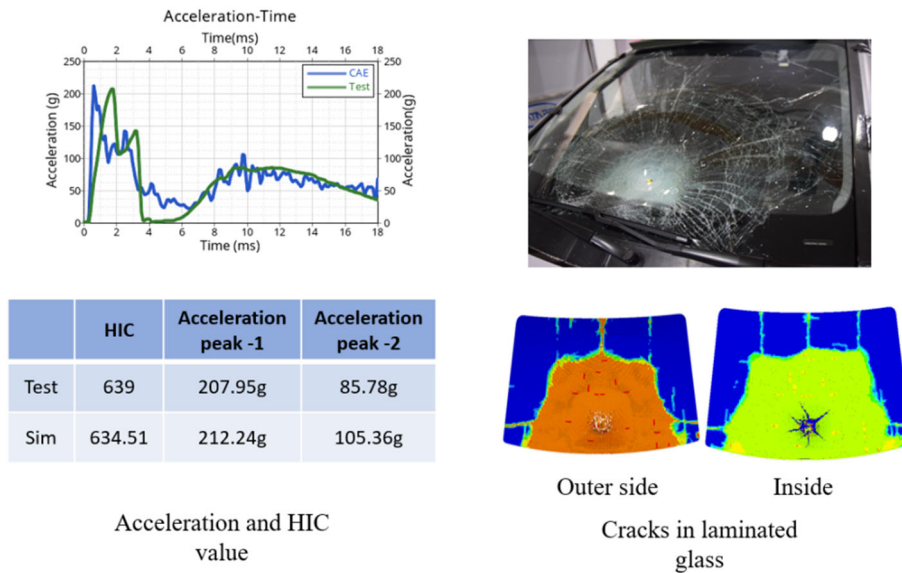


Figure 2. Accurate prediction of glass area results

Through the above methods, the accuracy of pedestrian protection head collision simulation can reach 85% (ISO 6487 standard).

The accuracy of the head acceleration curve is critical in assessing the potential risk of injury in pedestrian-vehicle collisions. Achieving an 85% accuracy rate, as outlined by the ISO 6487 standard, represents a significant step forward in precisely predicting and mitigating such risks. This curve provides essential data on the severity of impacts and aids in assessing the likelihood of head injuries, which are particularly dangerous and can lead to long-term consequences. Accurately modeling and simulating these curves allows researchers and engineers to better understand the dynamics involved in pedestrian collisions. This understanding is crucial for designing safer vehicles and enhancing road infrastructure to protect pedestrians more effectively. This progress not only elevates safety standards but also supports the broader mission to decrease fatalities and injuries on the road. Enhanced simulation accuracy leads to better predictions of how vehicles interact with pedestrians, which in turn informs more effective safety designs and policies. Ultimately, these advancements contribute to the development of safer automotive technologies and promote a safer environment for all road users.

Figure 3 demonstrates the correlation between simulated and actual test data for head acceleration during vehicle collisions, which is crucial for assessing the potential for head injury. The head acceleration curve is a vital part of pedestrian safety analysis as it helps predict the risk of injury in the event

of a collision.

In the graph, we see two lines: one representing the test data (usually derived from crash test dummy readings) and the other from the simulations (typically computed using a model that predicts what happens during a collision). The Y-axis measures the Head Injury Criterion (HIC), a recognized standard for assessing head injury risks. The X-axis measures time, showing the duration of the impact event.

The closer the lines are to each other, the more accurate the simulation model is in predicting the actual impact effects on the human head during a collision. If the red and black lines closely overlap, as they appear to do in Figure 3, it suggests that the simulation can very reliably predict real-world outcomes. This kind of high fidelity between test and simulation is critical for developing effective pedestrian protection systems in vehicles.

For automotive safety development, such accurate simulations allow for the prediction of pedestrian injuries in a variety of scenarios without the need for extensive physical crash testing. This not only makes the development process more efficient but also safer and potentially less costly, while still ensuring that vehicles meet the stringent safety standards required by the C-NCAP.

Figure 3's indication of very accurate correlation supports the paper's assertion that the methodologies and technologies applied in their research can indeed provide a reliable foundation for enhancing pedestrian protection in the design of new vehicles.

Collision point	Accuracy	Collision point	Accuracy
C.3.-1	89.09%	C.7.6	81.67%
C.3.-5	81.40%	C.8.8	87.99%
C.4.6	87.23%	C.9.-8	91.49%
C.4.-4	79.65%	A.10.-4	78.03%
C.5.4	83.56%	A.11.0	84.37%
C.5.-7	84.77%	A.11.8	80.21%
C.6.2	92.08%	A.12.1	84.37%
C.6.7	87.96%	A.12.-5	85.65%
C.6.-6	82.41%	A.13.6	85.73%
C.7.-1	93.34%	A.14.7	90.49%
C.7.4	91.83%		
Average accuracy		85.87%	

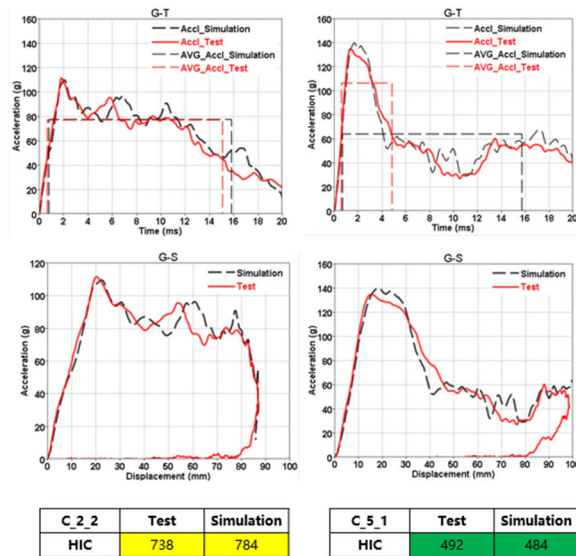


Figure 3. Accuracy of Head Acceleration Curve

The adoption of the aPLI (Advanced Pedestrian Legform Impactor) leg form by the China-New Car Assessment Program (C-NCAP) in 2021 for leg collision assessments marks a significant advancement in vehicle safety evaluations. This decision highlights the importance of specifically addressing the high collision energies associated with leg impacts, which are critical in reducing serious injuries in pedestrian accidents. It also emphasizes the necessity for robust front-end vehicle structures that can effectively absorb and mitigate these forces.

By implementing response plans tailored for different vehicle types—including sedans, SUVs, and pickup trucks—C-NCAP ensures that safety standards are not only met but

are effectively applied across a wide range of automotive designs. This nuanced approach to safety evaluation reflects a deep commitment to enhancing protection for both vehicle occupants and pedestrians, ultimately contributing to the improved overall safety within the automotive industry. Furthermore, this strategy helps in setting a precedent for other safety assessment programs globally, advocating for advancements in pedestrian protection technology and methodologies. We can refer to Figure 4 below for the specific response strategy of the aPLI, illustrating how varied vehicle designs necessitate customized safety features to meet these rigorous standards.

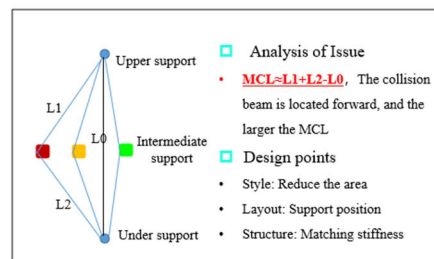
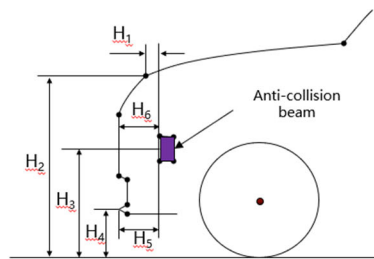


Figure 4. aPLI Response Strategy

The active pop-up engine hood is a pivotal innovation in the field of vehicular pedestrian safety, marking a substantial progression from traditional safety approaches. This advanced system is engineered to afford pedestrians an elevated degree of protection in the event of a collision. By harmonizing critical technologies such as sophisticated pedestrian detection systems, precise Head Impact Time (HIT) simulations, comprehensive stiffness analysis, and the simulation of false action signals, it crafts a robust safety mechanism. These integrated components collaborate to form a responsive system that can quickly and accurately react to potential pedestrian impacts. When a collision is imminent, the hood is designed to lift automatically, creating a buffer zone that can help to absorb the impact force, thereby reducing the likelihood of serious injuries to pedestrians. This

feature exemplifies a shift towards proactive pedestrian safety measures in automotive design, emphasizing the industry's commitment to utilizing cutting-edge technology to safeguard vulnerable road users.

Referencing the intricate details provided in Figure 5, we gain a comprehensive understanding of the dynamic response mechanisms engineered into vehicles. This showcases the complex interplay between vehicle structure and safety requirements, emphasizing the need for adaptive design strategies to accommodate various collision scenarios while adhering to strict safety protocols. There are four main components depicted: Integrated Development: A flowchart shows how sensing systems, algorithm development, submodular design, and integrated performance indicators contribute to pedestrian protection performance. Stiffness vs.

Mass Matrix: This chart illustrates the relationship between stiffness and mass for various objects that a car might encounter (e.g., stone, tree, warning signs, etc.). The concept of Flex-PLI (Flexible Pedestrian Legform Impactor) is mentioned, which is likely related to the testing of pedestrian protection systems. **Dummy Motion Analysis:** This portion of the image depicts a colored diagram showing the movement of a crash test dummy within a vehicle during impact, which is a part of the safety analysis. **HIT Analysis:** The last chart shows a comparison between WAD (Wrap Around Distance) and HIT (Head Impact Time), which are critical metrics in assessing pedestrian safety during vehicle impacts.

The diagram of dummy motion analysis illustrates the rigorous testing that goes into ensuring the hood's automatic lift mechanism effectively cushions an impact. Upon detecting a potential impact, the active hood automatically lifts, creating a cushioning effect that significantly reduces the risk of severe head injuries to pedestrians, a fact underpinned

by the analysis of dummy movement in simulated collisions. Furthermore, the stiffness vs. mass matrix in the image elucidates the careful consideration of various real-world obstacles, contributing to the overall structural design that ultimately enhances the protection of pedestrians. This feature is not only a testament to the vehicle's ability to protect pedestrians but also influences the overall design process, promoting enhanced structural integrity and optimal pedestrian protection performance. Such innovations underscore the automotive industry's commitment to safety and its ongoing efforts to develop and refine measures that mitigate the impact of accidents on road users. By incorporating advanced technology and comprehensive safety analysis, as detailed in the provided image, manufacturers not only comply with stringent safety standards but also demonstrate a proactive approach to addressing the complex challenges of road safety in modern traffic environments.

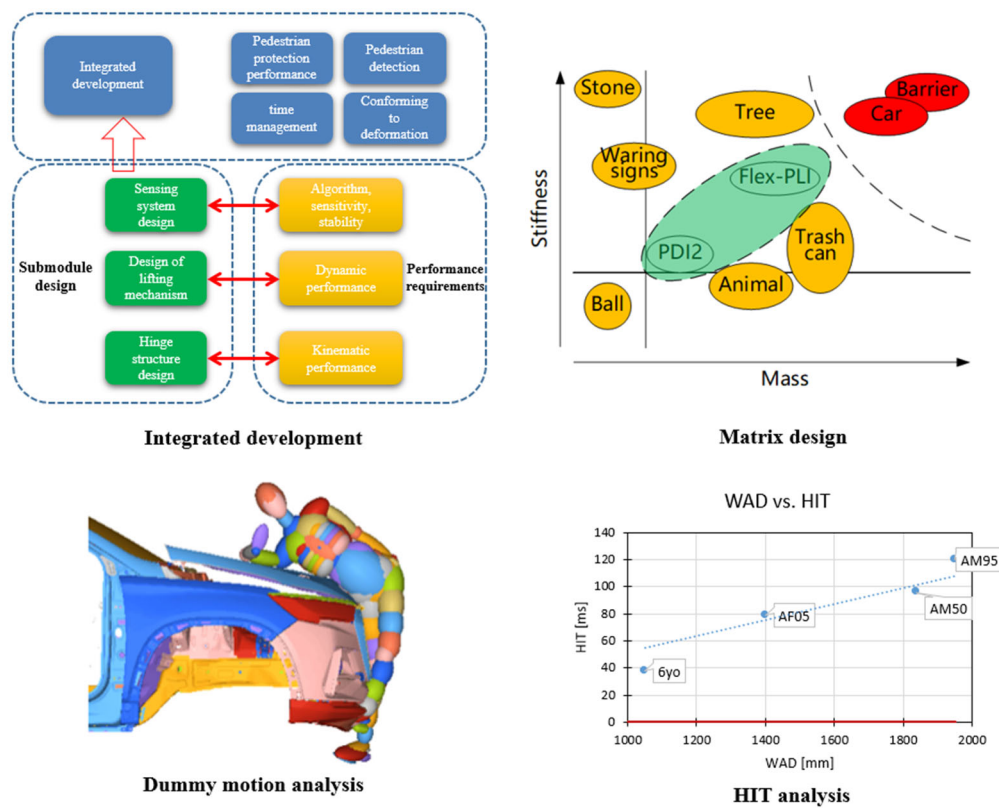


Figure 5. Active hood development

3. Results and Summary

The implementation and analysis of the 2024 edition of the China-New Car Assessment Program (C-NCAP), especially concerning pedestrian protection, yielded significant insights and measurable advancements in vehicle safety. The integration of the AEB VRU system tests with head and leg impact assessments has proven effective in enhancing pedestrian safety. These modifications have led to the creation of a comprehensive evaluation framework that significantly boosts a vehicle's capacity to safeguard pedestrians.

Key findings from the testing phase reveal significant advancements in vehicle safety standards and pedestrian protection systems:

Firstly, the updated safety ratings mandate a minimum score of 70% for vehicles to attain a five-star rating, up from

the previous requirement of 65%. This elevation underscores the heightened safety expectations in the 2024 C-NCAP, signaling an encouraging trajectory towards enhanced vehicle safety standards.

Secondly, the research underscores the critical role of material properties, particularly the phenomenon of work hardening in both non-metallic materials and sheet metal, in influencing pedestrian safety outcomes. Utilizing advanced simulations during evaluations enables more precise predictions of vehicle behavior during collisions, thus facilitating the development of better-informed safety designs.

Thirdly, the adoption of innovative technologies such as the aPLI leg form and the active pop-up engine hood has led to a tangible reduction in the risk and severity of pedestrian injuries. These advancements mark a significant leap forward in the design and implementation of pedestrian protection

systems, showcasing a commitment to mitigating pedestrian injury risks.

In summary, the key findings underscore a comprehensive approach towards enhancing vehicle safety, encompassing stricter safety ratings, advanced material analysis, and the integration of cutting-edge pedestrian protection technologies. These findings not only signify progress in the automotive safety domain but also pave the way for further advancements aimed at safeguarding both vehicle occupants and pedestrians alike.

The study's findings underscore the pivotal role of continuous refinement and the integration of advanced technologies within the C-NCAP framework in advancing vehicle safety standards. These results not only reflect an enhancement in evaluation criteria but also signify a shift towards designing vehicles that consistently meet stringent safety benchmarks. By prioritizing the integration of cutting-edge safety features and robust testing methodologies, the automotive industry demonstrates a steadfast commitment to mitigating risks and improving overall road safety.

Furthermore, the study highlights the ongoing advancements in pedestrian protection as a critical aspect of reducing fatalities and injuries on the road. By implementing innovative technologies such as the aPLI leg form and active pop-up engine hoods, the automotive sector demonstrates a proactive approach to addressing pedestrian safety concerns. These measures not only protect vehicle occupants but also prioritize the well-being of pedestrians, contributing to safer road environments for all road users.

Looking ahead, the dedication to advancing safety technologies within the C-NCAP framework is poised to drive further innovations in vehicle safety. As the C-NCAP standards continue to evolve, they are likely to set a benchmark for global safety standards, influencing broader

changes across the automotive industry. This ongoing commitment to safety underscores the industry's proactive stance in addressing emerging safety challenges and fostering a culture of continuous improvement in vehicle safety standards worldwide.

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