27th ESV 2023
YOKOHAMA, JAPAN

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INTERNATIONAL TECHNICAL CONFERENCE ON THE ENHANCED SAFETY OF VEHICLES

ENHANCED AND EQUITABLE VEHICLE SAFETY FOR ALL: TOWARD THE NEXT 50 YEARS

ABSTRACT BOOK

03-06
APRIL 2023

THE PACIFICO YOKOHAMA NORTH
YOKOHAMA, JAPAN

Technical Session Descriptions

There are 14 technical session topics listed below. Your abstract/paper should reflect the research or topics as described in the technical session descriptions as provided.

Tuesday April 4 - Morning Sessions

TRACK A:
Protection of Vulnerable Road Users and Child Occupants

Protection of children, pedestrians, and bicyclists from injury due to crashes continues to attract worldwide attention. For children, test procedures for assessing child restraint system side impact performance and ease-of-use, use of child dummies in consumer vehicle test programs, and new research into rear seat performance in crashes has raised considerable attention to child safety issues. Papers for the child safety portion of this session should focus on these issues, methods, or data that can further the protection of children in vehicles. Pedestrian and cyclist protection has been the focus of research worldwide in recent years. Much progress has been made in this area but additional challenges remain. Attention has also been placed on improving the frontal structure of passenger vehicles to mitigate head injuries and improving lower extremity injuries. Many consumer metric programs have implemented rating systems to encourage deployment of these crash mitigation solutions. Despite these efforts, pedestrian safety continues to be a severe problem in several countries. Papers are invited in this session focused on crashworthiness solutions being designed and offered to address the many issues faced by children, pedestrians, cyclists, and other vulnerable road users.

TRACK B:
Safety Performance in Frontal and Rear Crashes

Despite reductions in overall crash-related death and injury, frontal impacts continue to result in the highest numbers of fatalities and injuries. Rear end crashes are the most frequent type of crash that occurs. Car and truck manufacturers have made significant improvement in crash protection over the

last four decades, however new test requirements and ATDs can enhance occupant safety assessment in frontal and rear end crashes. Changing vehicle fleet mix characteristics with expanding adoption of alternative fuel powered vehicles challenge manufacturers to rethink vehicle design and how to manage crash energy. The session will examine how vehicle and crash characteristics affect restraint design and overall occupant safety. Papers are invited to discuss safety issues for frontal and rear crash protection that are being investigated through modeling, testing, or data analysis. Session papers may also include various aspects of frontal crash compatibility, full frontal and oblique safety countermeasures, test devices, test procedures, and performance requirements.

TRACK C:
Active Safety Systems for Crash Avoidance: New Systems and Technologies

Active safety systems focused on crash avoidance, are continuing to advance in both capability and market share with systems proliferating across product lines from luxury to value- focused brands—and even becoming standard equipment in some models. Active safety systems include longitudinal and lateral warning systems (such as forward and rear collision warning, lane and roadway departure, and blind-spot warning), automatic emergency braking or steering, dynamic brake support, lane keeping assist, and rear visibility systems. In addition, opportunities for additional crash avoidance potential exists with the emergence of new technologies and systems addressing opposite direction crashes (head-on collisions), intersection (crossing path) crashes, enhanced rear backover avoidance (rear auto braking), enhanced lane change/merge avoidance through blind spot intervention systems, and pedestrian and bicycle detection and avoidance through enhanced automatic emergency braking systems.

Papers are invited on research for active safety systems, particularly newly emerging technologies and systems designed to provide improvements in active safety functionality for crash avoidance. Specific areas of interest include, estimates of potential safety benefits, results from real-world evaluations such as field tests, long-term adaptation and reliance issues, as well as other vehicle integration, testing, system performance, future product development and customer use considerations.

Tuesday April 4 – Afternoon Sessions

TRACK A:

Advances in Experimental and Mathematical Biomechanics and Human Injury Research

The study of human injuries is essential to continued improvement in occupant and vulnerable road user crash protection. Detailed field data analysis to support an enhanced understanding of the factors associated with injury outcomes, experimental data collection and analysis, and development and application of advanced physical and mathematical tools, all play a role in advancing occupant protection. This technical session seeks papers that address: (1) advances in assessing patterns and causation of injuries in real-world cases; (2) experimental and analytical studies addressing human response and injury mechanisms; (3) development or improvement of human body computational models, including considerations for human variability in anthropometry, stature, age, and injury tolerance; (4) application of human body models in the development of advanced/adaptive vehicle safety systems; (5) advances in development of injury risk curves, injury criteria, and performance specifications for use with ATDs and computational models in evaluating vehicle and restraint performance; and (6) human response, injury mechanisms, and considerations for non-conventional interiors in vehicles with Automated Driving Systems.

TRACK B:

Safety Performance in Side Impact and Rollover Crashes

Side impact crashes continue to account for a significant percentage of crash fatalities and injuries worldwide. The introduction of more biofidelic side impact test dummies, instrumentation, and new test conditions provide new performance targets to enhance occupant safety in side impact crashes. New safety countermeasures have been investigated to reduce occupant kinematics in far side crashes. Additionally, while advanced vehicle control and safety technologies have made great strides in reducing rollover crashes, rollover-related deaths still represent a significant portion of the overall fatalities and injuries. Panoramic sunroofs are raising concerns of ejection risks through roof openings. This session invites papers related to understanding considerations for new test conditions,

performance measures, and the changing worldwide crash environment for side impact and rollover crashes.

TRACK C:
Driving Automation Systems: Product Evolution; Safety Performance Assessment; and Real-World Deployment Challenges

Driving automation systems (SAE levels 1-5) continue to evolve and could eventually become one of the most exciting and important innovations in transportation history. Significant research, development, and testing activities are ongoing worldwide to facilitate their safe deployment. Approaches to building public acceptance, trust, and confidence remains to be among the most important challenges. This session invites papers related to the current state of technology development, new safety metrics; system performance testing and evaluation approaches including utility of track, simulation, and on-road testing; next generation test tools and methods to perform tightly coordinated multi-vehicle scenario tests safely; approaches to addressing the challenges associated with handling a variety and volumes of driving data; approaches to identifying minimum datasets and data trigger points to validate assumptions and confirm performance expectations; approaches to assessing the common sub-functions of driving automation, such as localization, perception, prediction, path planning, etc. independently; and electronics systems safety (functional safety, safety of the intended functionality) and cybersecurity.

Wednesday April 5 - Morning Sessions

TRACK A:
Advances in Crash Test Dummies, Instrumentation, and Data Analysis

One way to enable additional occupant protection opportunities is to develop new ATDs that are more human-like and have enhanced instrumentation. Several new, advanced dummies are in varying stages of development around the world. Dummy development includes assessments for biofidelity, durability, repeatability, and reproducibility, as well as considerations for new analytical techniques to evaluate and improve dummy biofidelity. This technical session seeks papers that address all aspects of advanced dummy development and application, including new dummies, improvements to existing dummies, as well as related

instrumentation and analytical techniques that are under development to address future safety needs for vehicle design, testing, and restraint system development. In addition, papers addressing development and application of computational models of dummies to address safety concerns are sought.

TRACK B:

One Step Ahead Integrated Vehicle Safety Technologies

This session seeks papers regarding research on new safety systems that can anticipate and react to potentially hazardous situations across the entire crash spectrum. These systems integrate information and sensor data, among others, from advanced driver assistance systems (ADAS), from automated driving functions (ADFs), from vehicle-external sources such as the infrastructure and use this awareness to optimize largely occupant and vulnerable road user safety. New vehicles with advanced technology are increasingly better aware of the environment around and within the vehicle and can inform/adjust and/or intervene with other systems in or outward of the vehicle. Vehicle designs that include ADFs anticipate new occupant compartment seating configurations and seating postures. A fusion of sensor data can optimize vehicle response, change occupant posture, and (adaptive) restraint performance as needed to enhance occupant safety. Post-crash telematics could inform first responders of specific vehicle and occupant factors that would assist in triage and level of response. Papers are sought to describe systems under development, pioneering system innovations, opportunities for sensor fusion, interdisciplinary system communication means, system readiness, cost, reliability, performance, and post-crash response.

TRACK C:
Human Factors Considerations for ADAS and ADS Technologies

The success of Advanced Driving Assistance Systems (ADAS) and Automated Driving Systems (ADS) vehicles will depend on the quality of human-machine interface (HMI), adapting ADAS and ADS to human capabilities
and safety needs and potentially the system's ability to manage the driver's state of attention appropriately. There has been extensive work on HMIs for ADAS

systems, including auditory alerts, haptic alerts, visual alerts, and many combinations of those three. Driver monitoring capabilities enable real time adjustments to warning parameters when drivers are identified as being disengaged, distracted, drowsy, or otherwise impaired. In addition, ADS could take advantage of using the driver's estimated engagement state for safe transition of control back to the driver. Papers are invited on research related to the driver-vehicle interface for crash avoidance systems, safety evaluation methods for assisted and automated driving, driver monitoring technology, driver behavior and engagement patterns and estimation, fatigue drowsiness, distraction, and other impairments, and how they relate to ADAS and ADS. In addition, for ADS technologies, particularly those without traditional controls, papers are invited on additional topics such as external signaling to other road users, as well as telltales, and other signaling that may be useful for occupants of ADS vehicles, and human factors design needs for vulnerable and disabled users of ADS vehicles.

Wednesday April 5 – Afternoon Sessions

TRACK A:
Student Safety Technology Design Competition. Finalist Oral Presentations

TRACK B:
Consumer-Focused Approaches to Promote Vehicle Safety in the Automotive Market

Consumer information programs have become widely accepted in the U.S., Europe, Japan, Australia, Korea, China, Latin America, and Asia. These programs provide a range of vehicle safety ratings for passive and active vehicle technologies. The motor vehicle industry continues to improve the safety performance of vehicles as it strives to receive the highest safety marks possible. In addition to assessing occupant crash safety, programs are emphasizing advanced driver assistance systems and considering approaches for automated vehicle technologies. While assessment strategy varies from region to region, the programs all aim to encourage continuous improvements in motor vehicle safety. Papers are invited to discuss test conditions, performance measures, presentation and dissemination of results, public acceptance, promotion of safety relevant mental models for the new driver

roles. Automated Driving Systems (ADS) bring along an integration of active and passive safety ratings and the increasing importance of virtual testing.

TRACK C:
Opportunities and Challenges of Applying Artificial Intelligence (AI) and Machine Learning Techniques to Enhance Vehicle Safety

Artificial intelligence (AI) and machine learning approaches hold potential to synthesize large amounts of unstructured data to learn and address hard problems and are rapidly being explored across a variety of industries and use cases. AI is also among the most misunderstood and erroneously cited fields of study. This session invites discussions around what AI means in the automotive context, how AI algorithms differ from traditional, complex software systems, and what parts of automotive systems are more likely to leverage algorithms that could be considered AI, and whether AI is expected to be used primarily in development stages or could also be deployed. Further, papers are invited to discuss challenges associated with and methods that could enhance the verification and validation of AI systems in automotive applications.

Thursday April 6 – Morning Sessions

TRACK A:
Developing and Adapting Safety Assessment Approaches for Vehicles with ADS (SAE Levels 3, 4 and 5)

Existing vehicle safety regulations, test procedures, and performance requirements were all developed in an era when all vehicles featured manual driving controls. The development of ADS enables vehicle designs without manual driving controls and necessitates reconsideration of certain existing regulations, test procedures, and performance requirements. A vehicle with an ADS might be designed without user interfaces, such as braking, acceleration, steering, or transmission gear selection. Test procedures that presume existence of traditional driving controls may need to be reconsidered. The presence of delivery vehicles without occupants also needs to be considered for the future roadway environment and infrastructure. This session invites papers that discuss how regulations, test procedures, and

performance measures could be adapted or new approaches developed, to encompass the vehicles with ADS designs under consideration. Further, this session invites papers on new approaches to assuring safety of ADS, including test tools, test methods, alternative safety metrics, and alternative frameworks.

TRACK B:

Restraint System Design and Performance Challenges: Addressing the Needs of Diverse Populations (Age, Gender, Stature)

Vehicle restraints in frontal crashes are estimated to be approximately 50 percent effective in preventing fatalities. Occupant protection can be improved through the development of advanced restraint systems that can consider occupant characteristics such as age, gender, size, and posture, as well as the anticipated crash characteristics. Concerns also exist for restraint design with respect to future vehicles that may be smaller and/or lower in mass to improve fuel efficiency. The aging population will be an increasing consideration for restraint design. Adaptive protection systems will be needed to optimally protect an increasingly vulnerable occupant population. Rear seating positions have not demonstrated the same improvement as the front seats. These issues are receiving the attention of safety researchers world-wide. Papers are invited on research related to safety performance for new vehicle and restraint designs, especially as they pertain to older occupants, small females, and heavier populations.

TRACK C:
New and Improved Field Data Collection, Analysis, and Benefits Assessment Methods

Use of crash data helps to stimulate all aspects of vehicle safety from research to policy to regulation and research testing. These data also play a leading role in the development of crash prevention and crash protection countermeasures. However, due to the rapid proliferation of advanced vehicle technologies, the collection and analysis of data from these technologies needs to evolve to better understand the real-world performance and to quantify the benefits and limitations of these technologies. Data collected on event data recorders (EDRs), other data loggers, or over-the-air for close calls or near miss crash events will likely enable new research opportunities. Also, several naturalistic studies and

testing of Automated Driving Systems (ADSs) are in progress in various regions of the world that will provide additional insight into how crashes occur, providing additional information on prevention. Worldwide, data collection programs in Asia, Europe, Australia, and the U.S, are being used more to drive research and facilitate informed decisions. This session invites papers aimed at a discussion of future data collection and analysis methods. Papers related to such topics as EDRs, naturalistic driving data on human-vehicle performance, crash avoidance technologies, and all levels of driving automation, and crash reconstruction are welcome in this session. Also, papers on analytical methods for estimating potential benefits of safety technologies, evaluation methods of video data, universal descriptions of crash causal factors and resulting crash types, and other related topics are invited.

Oral Presentations

*Presenting authors underlined for oral papers only

Protection of Vulnerable Road Users and Child Occupants

Tuesday, April 4, 2023, | 08:30-12:30

Chair: Suzanne Tylko, Canada | Co-Chair: Yasuhiro Matsui, Japan

TRACK A | Room: G303

PAPER NO.23-0025-O

Analysis of the effect of reducing accidents involving pedestrians through the coordination of active safety and passive safety

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NOBUHIKO TAKAHASHI
Japan Automobile Manufacturers Association, Japan

Abstract
In order to efficiently reduce traffic fatal accidents, it is important that all parties involved in traffic safety (traffic participants, road infrastructure, and vehicles) work in unison to implement countermeasures. For this purpose, it is necessary to analyze the reduction effects of vehicle safety measures, the limitations of vehicle safety measures, and the accident patterns that remain after the vehicle safety measures are taken. In this study, the fatal accident reduction effect of vehicle safety measures combined with active and passive safety technologies was estimated for the accidents involving pedestrians, which are the most common type of fatal traffic accidents in Japan. In addition, the characteristics of fatal accidents in which vehicle safety measures are not currently addressed are summarized. First, we estimated the extent to which pedestrian fatalities can be reduced through the AEB for pedestrians and improvement of pedestrian head protection performance. For the remaining fatal accidents, we estimated the number of fatal accidents that could be reduced by expanding AEB functions (additional fatal accident reduction effects are expected by increasing AEB corresponding scenarios) and by other vehicle safety measures (advanced emergency steering systems, etc.). This clarifies the extent of fatal accidents that have not yet been addressed by vehicle safety measures. This study used accident data collected by the Japan Institute for Traffic Accident Research and Data Analysis (ITARDA) from year 2015 to 2017. The analysis assumed a vehicle safety measure penetration rate of

100%. It was found that the number of fatal accidents could be reduced by 20% and 29% by the AEB for pedestrians and improving the performance of pedestrian head protection in the daytime and nighttime, respectively. It could also be observed that AEB function expansion and devices other than AEB covered approximately 38% and 23% in the daytime and nighttime, respectively. The results suggest that the accident reduction effect of AEB for pedestrians is significant, but that 42% and 48% of accidents are left behind even when the functional enhancements of AEB and other vehicle safety measures are added up in the daytime and nighttime, respectively. To further reduce the number of accidents left behind, it is efficient to promote not only vehicle safety measures but also measures for the society as a whole.

PAPER NO.23-0042-O

An overview of road traffic injuries among children in Sweden over 20 years

MARIA KLINGEGÅRD, ANDERS KULLGREN, HELENA STIGSON, ANDERS YDENIUS
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Abstract

This register study, focusing on children from (0-17 years), aimed to investigate traffic injuries (AIS1-5) among children on roads in Sweden between 2000 and 2019. The Swedish national database (STRADA) was used. It includes road traffic crashes reported by the police and by emergency care centers. The data included road user group, age, gender, injury type, AIS level, and use of seatbelt or child restraint. Descriptive statistical analysis and simple linear regression were performed to investigate significant changes in injury distribution between 2010 and 2019. A total of 14 731 registered crashes during the last 20 years involved 15 045 injured children (0-17 years). Six thousand six hundred forty-three were girls and 8088 boys. The total number of injuries decreased over time (40% since 2010). Most injured children (80%) sustained minor injuries (AIS1). Most were 12 to 17 years old (80%). A change in injury distribution was found according to age; for 0-9-year-olds, most injured children were pedestrians, while for 9-13 years old's, bicyclists were most common. For 14-16-year-old children, moped riders were most common. Most injured children (62%) were vulnerable road users (2000-2019). A 15% increase in the proportion of injuries between 2010 and 2019 was found. A 24% decrease in the proportion of injuries for children as vehicle occupants (excl. motorcycle and moped riders) between 2010 and 2019 was found; still, in 2019, 35% of the injured children were vehicle passengers. The most frequently injured body region was the head (26%), followed by the neck (19%). Eleven percent of the injured children in cars were unbelted. Twenty-two percent of the 0-12 years old children did not use a proper child restraint. The study confirms that Sweden's traffic safety for children (0-17 years) has improved since 2000. A 40% reduction in the number of injuries was found between 2010-2019 (including minor injuries that account for 80% of all reported injuries). The study also highlights that for vulnerable road users, the proportion of child injuries (0-17 years) increased by 15%, which was lower than vehicle occupants (24% decrease). Moped riders account for the largest road user group (35%) (2000-2019). Therefore, it is important to improve protection for children as vulnerable road users both regarding severe injuries as well as minor injuries leading to long term consequences for a safe (sustainable) traffic environment.

PAPER NO.23-0144-O

Development of a standard for deployable pedestrian protection systems (DPPS) for Amendments to UN Global Technical Regulation No. 9 and UN Regulation No. 127

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Abstract
World-wide test and assessment procedures for passive pedestrian protection have been in place for many years. Passive safety requirements within UN-GTR9 are prescribed through tests to the front ends of stationary vehicles with instrumented impactors representing the pedestrian's head, pelvis, and lower extremities. However, no specific requirements are included for vehicles equipped with deployable pedestrian protection systems (DPPS). This paper describes the work of the UN informal working group (IWG) to develop procedures on DPPS that are intended to be incorporated into UN-GTR9 and UN-R127 as amendments. DPPS must work as intended during actual vehicle-to-pedestrian accidents. Therefore, test methods and conditions need to reflect the challenges DPPS are facing during actual and representative accident scenarios, but without being design restrictive. Several prerequisites need to be met to assure that DPPS operate properly and offer at least the same level of protection as conventional passive pedestrian protection systems. These prerequisites include system requirements providing pedestrian detection and the timely and safe DPPS deployment. Also, headform tests are run at impact speeds below the DPPS deployment threshold on the undeployed system to confirm the undeployed bonnet is sufficiently safe. Draft amendments intended for UN-GTR9 and UN-R127 are being finalized by the IWG on DPPS to harmonize testing under the agreements of 1958 and 1998 while preserving contracting parties' options for domestic standards. Results reported herein include IWG investigations of: (1) An appropriate impactor to assure pedestrian detection by the front-end sensing system; (2) Real world pedestrian accidents to determine the needed detection test area width; (3) Qualification procedures for Human Body Models (HBM) to determine head impact times (HIT) and impact locations; (4) An empirical formula to determine HIT in lieu of HBM simulations; (5) Experimental determination of the total response time of the DPPS. Altogether, the amendments provide for headform impact test conditions on DPPS against established performance requirements to reduce head injury risk. A DPPS is expected to offer a sufficient level of pedestrian protection while preserving vehicle design freedom. Several shortcomings of the developed procedure are discussed, and limitations identified which could reduce the actual pedestrian protection during a crash: The FlexPLI does not mimic the hardest to detect pedestrian. The detection test area does not fully account for all pedestrian impact trajectories. The bonnet clearance afforded by a DPPS could be compromised by the upper body load. The deployment height and the oncoming speed of the deploying bonnet could differ between testing and real-world scenarios. A valid HIT determination using a HBM simulation on a given vehicle model requires good CAE correlation with the actual vehicle. Experimental testing or an empirical formulation to determine HIT, could increase objectivity. The draft procedures are being developed by the IWG for consideration as

amendment to UN-GTR9 and UN-R127. It will offer an approach for compliance testing of vehicles equipped with DPPS. Since UN-R127 and the Euro NCAP have extended their scopes to the head protection of bicyclists, the DPPS head protection potential should be investigated accordingly in future studies.

PAPER NO.23-0155-O

A study on distractions and benefits of signal light projections with directional indicators

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Abstract
To prevent accidents, the signaling function of automotive exterior lighting is essential to provide other road users with information on the presence of the vehicle and/or changes in its moving direction. Recently, dynamic turn signal indicators, backup indicators, and other light projections with directional indicators have been proposed and studies are being conducted to evaluate their safety enhancement and visibility in different lighting conditions. However, previous studies had limitations since most of them had not been studied or verified under dynamic driving situations. In addition, there aren't any studies on the distraction caused by turn signal projection lamps. Therefore, it is necessary to provide an assessment of the distraction and benefits of turn signal projection lamps under several dynamic scenarios. For this reason, we investigated whether the signal projection lamps, which work simultaneously with directional indicators and project a simple geometric pattern of a certain color and size on the left and right road surfaces in front of the vehicle, are beneficial or distracting to other drivers and VRUs (Vulnerable Road Users) such as cyclists and pedestrians. Twenty participants participated in the experiment. The results showed that the signal projection lamp hardly distracts drivers, cyclists, and pedestrians, but rather helps predict the presence of oncoming vehicles and the moving direction of the vehicles. Particularly with the signal projection lamp, the cyclist test showed a 14% and 9% decrease in detection time when the vehicle turned right and left, respectively. These differences were statistically significant. Our results suggest that a signal projection lamp is more beneficial than a distraction to drivers, cyclists, and pedestrians.

PAPER NO.23-0187-O

Real-world protection of booster-seated children – Needs and challenges in future transportation

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Abstract
Driven by sustainability goals, passenger cars' design and ownership setups are changing. Vehicle safety is constantly improving, yet a trend of larger belt-positioning boosters is seen. The objective is to discuss the challenges of child passenger protection in the current and future mobility context. The study focuses on children who can use the vehicle seatbelt together with a booster, typically 4 to 10-12 years. The study is based on protection principles of booster-seated children, with a vehicle-booster-user entity focus. Studies on restraint awareness and usage today, users' perceptions on future mobility and

evolutions of vehicle design and mobility trends, are summarized and reflected on. Real-world protection needs are formulated based on in-vehicle crash testing/simulations, and studies on child passenger sitting postures during drive and evasive maneuvers. This is put in the context of regulatory and booster development trends. In a real-world crash, children are protected by the vehicle and booster in combination. Crash tests/simulations highlight the importance of the seatbelt interaction, influenced by initial beltfit and the dynamic properties of the booster. On-road driving studies show that awake child passengers spend a non-neglectable duration of the trip with a forward head position, due to visibility and activities. A forward head position could also be a result of a pre-impact braking as well as the added space by the booster seat's backrest. In case of a frontal impact, a more forward head position at time of impact will result in a more forward excursion. Real-world side-impact data shows that the booster-seated child's head is protected like an adult, assisted by the vehicle safety systems. The booster serves as an adapter, not as a primary restraint for the child. Booster-seated children benefit from the vehicle safety systems, given they are raised in position for good beltfit and posture. Addressing the changing trends of passenger cars' design and ownership setups, the role of the booster should be clearly communicated. Future designs must address issues of usability, portability, and acceptance. As examples, the streamlined roof designs driven by sustainability goals, reduce the roominess in the rear-seat, whereby the booster seat backrest's width and height might require larger space than needed for an adult; and the trend from personal mobility towards increased degree of shared mobility, emphasizes the need of the booster to be portable or integrated into the vehicle. Real-world child passenger safety involves protection aspects beyond standardized crash testing scenarios. Most importantly, the booster should be used in every trip, irrespectively of passenger car ownership setup. This study provides insight into modern vehicles' protection capacity in relation to the booster-seated children. It outlines some areas that are affected by the current booster developments, such as the increased size and complexity of booster seats, and the booster cushion ban in some parts of the world. In relation to the current and future transportation context, a booster cushion with appropriate characteristics serves as an essential complement to booster seats (of reasonable size) and will help maintain a positive child safety global trend.

PAPER NO.23-0189-O

Accident simulations of a novel restraint safety concept for motorcyclists

STEFFEN MAIER, JÖRG FEHR
Institute of Engineering and Computational Mechanics, University of Stuttgart, Germany

Abstract

Except for personal protective equipment, riders of powered two-wheelers are currently unprotected when impacting into an accident opponent. This work investigates a motorcycle safety concept that proposes a combination of thigh seat belts, airbags, and leg impact protectors. It gives a virtual prediction of the accident behavior using finite element models of the motorcycle with passive safety systems, an accident opponent, and an anthropometric test device as a rider surrogate in recommended frequent accident scenarios. It shows a meaningful graphical description of the functional and causal principles of a powered two-wheeler rider restraint and a quantified performance evaluation of the concept. The combination of several passive safety systems has shown to be promising in positively influencing accident behavior and mitigating consequences.

PAPER NO.23-0211-O

Activating global collaboration to drive advancements in child restraint systems for children with disabilities

HELEN LINDNER, EMMA CLARKSON
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Abstract
Research shows that children with disabilities face an increased risk of injuries and fatalities in a crash compared with other children. However, a recent literature review concluded that these particularly vulnerable road users continue to be inappropriately restrained in vehicles, constituting an ongoing road safety problem. This also impacts on their human right to safe and accessible transport. Although globally, there are established independent assessment programs for child restraint systems, there is no such program for special purpose child restraints or other restraint types used by children with disabilities. With the formation of a new Australian charity dedicated to advancing the rights of children with disabilities to safe and accessible transport, the objective of this project is to enhance the protection of children with disabilities travelling in child restraint systems in motor vehicles through the establishment of an independent safety and assessment program. The development of the Australian Safety Assessment Program (AuSAP) was supported with funding from the Victorian Transport Accident Commission, and in-kind support from NeuRA and Britax. A mixed methods research approach was used, consisting of: Desktop review - A review of the legislative and regulatory environment impacting on the supply, sale and use of special purpose child restraints and accessories in Australia was conducted. A global product scan identified restraints for inclusion. Governance framework - Several governance framework options were developed, with the recommended option being a not-for-profit lead agency model supported by an Expert Committee. Protocols - The Expert Committee developed the Test and Assessment Protocol based on a review of standards/regulations. Assessments/crash testing - Fifty-four crash tests have been undertaken (forward and side impact testing), with results shared with relevant suppliers and manufacturers. Communication/education - MACA is developing individual Product Guides that incorporate AuSAP findings to support allied health professionals in their prescribing role. AuSAP is implementing a global approach to improve motor vehicle restraint systems for children with disabilities in line with the recommendations in the World Health Organization's global report on Assistive Technology and the Convention on the Rights of Persons with Disabilities. The program has rapidly stimulated the Australian market to supply special purpose child restraints by increasing the confidence of suppliers, prescribers, consumers, and government funders. This has expanded safe motor vehicle transport options for children with disabilities. It has also provided a unique opportunity for global collaboration with manufacturers to improve the design and safety of restraint systems for children with disabilities. AuSAP has facilitated international engagement about the suitability of current requirements in standards/regulations for special purpose child restraints and consideration of potential improvements for future reviews. This has the potential to remove barriers to access not only in Australia but globally. The first program of its kind, AuSAP has achieved early success in encouraging international cooperation and learning to advance the human rights of our most vulnerable road users to safe and accessible motor vehicle transport. Access to such life changing assistive technology is a precondition for equal opportunities and participation.

PAPER NO.23-0217-O

Simulation-based evaluation of a generic Autonomous Emergency Braking system using a cognitive pedestrian behavior model

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LUKAS BROSTEK
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Abstract
In 2020 pedestrians accounted for 21,4% of all deaths in the European Union. Considering all vulnerable road users (VRU: pedestrians, cyclists, motorcycles, and mopeds) they accounted for 51,4% of all deaths. To reduce the number of deaths and improve VRU safety, systems have been developed in the last decades. The autonomous emergency braking system (AEB) is one of these systems and aims to intervene in conflict situations by applying an emergency braking (in some cases only after the driver starts the brake itself). The performance evaluation of an AEB system via simulation reduces cost and time against real tests and allows better robustness evaluation because of the higher number of scenarios that can be simulated. In the virtual-world, safety-critical situations can also be tested without any problems. The modeling of pedestrian behavior plays an important role since the pedestrian is the vehicle's adversary in this context. Current studies use a simple pedestrian model, in which the pedestrian does not have any perception of the environment, moving on a pre-defined path with constant speed. Such trajectory-based models are available in the most common vehicle dynamic simulation tools. In reality, however, pedestrians usually react to the approaching vehicle in conflict situations by adjusting their trajectory, which can change the conflict situation and affect the performance assessment of AEB systems. This study compares the standard model with neuro-cognitive pedestrian model from cogniBIT and investigates if and how these models affect the performance assessment of AEB systems.

PAPER NO.23-0248-O

Investigation on effects of whole-body kinematics during collision on pedestrian injuries

HIDETOSHI NAKAMURA, HIROYUKI ASANUMA, HYEJIN BAE
Honda R&D Co., Ltd, Japan

Abstract

Research Question/Objective: Recently, pedestrian safety performance of vehicles has been improved by the modification of regulations and new car assessment programs (NCAPs). In particular, safety performance of the bonnet has been improved in terms of head protection by reducing HIC. According to the accident statistics, however, pedestrian fatalities account for a high percentage, and the causes of death include not only head injury but also thoracic and pelvis injuries. Therefore, pedestrian protection

technologies need to include protection of these body regions in addition to the head. In order to reduce the number of pedestrian fatalities, this study aimed to investigate the effect of the whole-body kinematics on injury reductions of pedestrians.

Methods and Data Sources: In a collision between a bonnet-type vehicle and a crossing pedestrian, the whole body moves in a chain reaction starting from the input to the legs, subsequently transmitted to the pelvis, the thorax, and the head. Therefore, it is expected that controlled pedestrian kinematics from the time of collision will have an effect on the injury to various body regions. In this study, the GHBMC 50th percentile male model and the vehicle model with general bonnet type was used to simulate car-pedestrian collisions. A model composed of spring and shell elements was affixed to the vehicle model to apply controlled loads to the center of gravity of the pedestrian model by changing the stiffness characteristics of the model, and the relationship between the whole-body kinematics of the pedestrian model and the injury values was investigated at a collision speed of 40 km/h.

Results: The results confirmed that the angular velocity of the upper body around the center of gravity was reduced by the early input to the pedestrian pelvis, effectively reducing thoracic input and the head injury value.

Discussion and Limitations: Input to the pelvis depends on the input through the legs and the external force from the vehicle. Since the vehicle used in this study had a low bonnet height, there was little external force from the vehicle to the pelvic region, potentially diminishing the effect of restraining the center of gravity. Since this study used a specific collision speed and a pedestrian size, it is necessary to consider the influence of these factors in a future study.

Conclusions and Relevance to Session Submitted: This study clarified that pedestrian kinematics control technology may be one of the effective measures to further reduce pedestrian fatalities.

PAPER NO.23-0270-O

The ”typical” car-cyclist collision under the microscope: A GIDAS-based analysis of the prevalent crash scenario

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Abstract
In a world where reducing the carbon footprint is crucial, riding carbon-neutral vehicles such as bicycles or pedelecs is a sustainable and thus desired way of transport. Since motorized and unmotorized bicycles are missing any protective body, their riders are part of the vulnerable road users (VRUs). In order to increase the attractivity of transport by bicycle and pedelec, providing traffic safety for this group must be ensured. To get a better understanding of cycle crashes, this paper’s objective is to deduce the most important crash types of collisions of cyclists with passenger cars. By obtaining the characteristic details of these crashes, strategies for crash avoidance can be derived. The data source used for the results presented in this paper is GIDAS (German In-Depth Accident Study). GIDAS is a unique database as the input data is provided by experts on crash reconstruction who join the police at

the crash site and record the crash in great detail. 8497 relevant crashes involving bicycles, captured from 2000-2021, were evaluated. The methodology consists of the evaluation of the two most common crash types regarding speed distributions and contact points of the crash opponents, street layout, driver intent, traffic density, and visual conditions. The results show that the most common crashes are two crossing crash types accounting for nearly a third of all crashes between cyclists and drivers of motorized vehicles. Both of these crash types are characterized by the cyclist riding on the designated cycling infrastructure, while in the more common one, the cyclist goes against the expected direction for the crash opponent. For the selected crash types, the results also show that more than half of crashes occur at junctions, predominantly where the driver has to yield. Most crashes occur during turning right maneuvers at low traffic densities and speeds below 13 kph. The evaluation of the car driver's maneuvers performed in the last second before the crash indicates a black spot in driving-off situations. In more than 70 % of the cases, the contact point with the cyclist is at the front. The data, analyzed in detail in the discussion, points towards the theory that drivers tend to "fail to look" at cyclists coming from the right and "look but fail to see" cyclists from the left. Furthermore, cyclists crossing from the right might not be expected in right-hand traffic. A general limitation of official crash data sources based on police reports is a high underreporting rate of bicycle crashes. Using the German crash database, also certain bias towards countries with similar traffic infrastructure must also be assumed. This is further analyzed in the discussion. The conclusions drawn from this study show that cycling infrastructure remains of the highest importance and needs to be designed in accordance with the human factor in traffic. Also, communication between involved parties can contribute largely to tackling the most dominating crossing crash types, i.e., virtually enhancing the cyclist's visibility for other traffic participants.

PAPER NO.23-0273-O

Factors influencing upper neck loading in regulatory tests of child restraint systems

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Abstract

Potential neck force and moment limits in UN Regulation No.129 are part of on-going regulatory discussions. Pragmatic limits for the Q0, Q1 and Q1.5 dummies were proposed to regulators in 2020, based on analyses of type-approval monitoring data. However, chin-to-chest contact was acknowledged as potentially skewing the analysis and undermining the proposed limits. The aims of this study were to: 1) investigate the effect of impact direction and child restraint orientation on neck tension force and 2) quantify the effect of chin-to-chest contact on a large study sample of child restraint type-approval tests, for all Q Series dummies (Q0 to Q10). Over 200 official type-approval tests were collected from our internal database with data extracted for neck tension force and head vertical acceleration. The head vertical acceleration multiplied by the head mass was used to calculate the neck tension force due to inertial loading from the head. This was compared with the measured neck tension force to determine the frequency of chin-to-chest contact and its likely influence on neck tension force in type-approval tests. The data were then separated for each Q-Series dummy by impact direction and child restraint orientation to identify trends for each test or installation parameter The inertial neck tension

force calculated from head vertical acceleration was lower than measured neck tension force in almost all front impacts with forward-facing child restraints and in many rear impacts with rear-facing child restraints. Differences were in the region of 30-50 percent depending on the dummy and child restraint installation parameters. This indicated the presence of chin-to-chest contact in a large proportion of the tests in the sample. Forward-facing child restraints generated highest neck loads in front impact, whereas rear-facing child restraints generated highest loads in rear-impact. Our analysis suggests chin-to-chest contact occurs frequently in child restraint type-approval tests with substantial influence on neck measurements. This confirms that pragmatic limits derived for regulation from type-approval data are likely to be skewed upwards by this contact. Subsequent measurements in future type-approval tests are also likely to be skewed upwards and hence mitigating chin-to-chest contact may be incentivised more than limiting inertial neck loading. Although large, our sample comprised tests from one child restraint manufacturer only. A larger sample, comprising a broad range of manufacturers, is needed to validate our findings fully. Nevertheless, this study has demonstrated a robust approach for such analyses. Child restraints are very effective in reducing the risk of serious neck injury to children in collisions. Nevertheless, a relatively large range of neck loads can be measured in type-approval, which can be influenced by dummy chin-to-chest contact, as well as child restraint installation parameters. Quantifying these influences will contribute to ongoing regulatory discussions about the use of neck force and moment limits in UN Regulation No.129.

PAPER NO.23-0290-O

Influence of different parameters of vehicle and pedestrian on chest injury using human body model (HBM)

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Abstract

In Japan from 2000 to 2019, the number of motor vehicle occupant fatalities decreased significantly. Pedestrian road user type contributes to 37% of total traffic fatalities, the highest compared to other road user types since 2009. In pedestrian accidents, head, and chest body regions account for 51% and 40%, covering about 91% of the total AIS4+ injuries, respectively. So, head and chest protection are important elements for reducing pedestrian fatalities. At present, there are test procedures for head and lower extremities injury protection, but no test procedure exists for pedestrian chest protection. BAST has proposed a specific thorax injury prediction tool (TIPT) developed from side impact dummy ES-2. Based on their proposal, an adult chest impactor will be impacted by several predefined impact grid points covering a range from a child's lower rib height (WAD: 770mm) to a 95th_%ile male's upper rib height (WAD:1540mm). Injury criteria for TIPT were based on injury risk curves of 45- to 67-year-old adults. In this paper, the influence of different parameters of vehicles and pedestrians on chest injury using human body models (HBM) and TIPT modules are studied in detail. It can be concluded that (a) similar to the existing head injury evaluation impactors, child and adult TIPT impactors need to be different since the biomechanical characteristics are different (b) based on human body models' CAE simulation with the target generic vehicles models (GVM), the chest impact velocity is considerably

lower than those recommended values of BASt and (c) it has been observed that BLE height, bumper lead upper, hood angle are the significant parameters for the chest impact velocity.

PAPER NO.23-0309-O

Preliminary study on crash pulse influence for child ATD response in child restraint systems

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Abstract

Different vehicle crash scenarios may produce different crash pulses dependent on several variables. Crash simulations utilizing a sled system are more repeatable but may subject anthropomorphic test devices (ATDs) to different input pulse levels depending on sled type and its settings. Those different input pulses may influence the test device's response. The goal of this current study examined different sled pulse inputs and their influence on child ATDs. ATDs were secured in child restraint systems on the proposed updated frontal test bench for Federal Motor Vehicle Safety Standard (FMVSS) No. 213 and subjected to three input pulses with the same target delta-v (48 kph). All three input pulses were within the FMVSS No. 213 boundaries. Hybrid III 10-year-old and 6-year-old test devices were tested using four belt positioning booster seats and one forward facing harness seat. Head, chest, neck, and belt load metrics were examined for coefficient of variation, trends related to input pulse acceleration increases, and any significant differences. Examination of the study results indicate that increased acceleration pulse inputs had the most influence on head accelerations, chest accelerations, and neck tensions but had little effect on chest deflections or head and knee excursions.

Safety Performance in Frontal and Rear Crashes

Tuesday, April 4, 2023, | 08:30-12:30

Chair: Stephen Summers, United States | Co-Chair: Younghan Youn, Korea

TRACK B | Room: G304

PAPER NO.23-0060-O

Passenger cars in head-on crashes with heavy goods vehicles: for what severity should future car restraint systems be designed?

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Abstract

Twelve passenger car-to-heavy goods vehicle (HGV) head-on crash configurations were simulated to identify which of these crashes lead to the highest crash severity for the car and are feasible, i.e., with non-compromised compartment integrity, in order to support the development of occupant restraints in high-severity crashes. These configurations comprised two impact velocities (car 39 km/h, HGV 36 km/h and car 56 km/h, HGV 53 km/h), two car overlaps (50 and 80 %) and three impact angles (0, 30 and 30 deg). Generic finite element models of a 1.7-ton car and a 7.9-ton HGV were used to investigate the crash pulse severity and car compartment structural integrity in all crash configurations; the results were compared to that of a current standard full-frontal rigid barrier 56 km/h crash. Car crash pulse severity was evaluated at the left sill using peak acceleration, delta V, cross-zero time, and occupant load criteria, while car compartment integrity was evaluated by measuring intrusions at the toe pan, instrument panel, A-pillar, and steering wheel. All lower-severity (39/36 km/h) crashes were found to be well represented by the full-frontal rigid barrier 56 km/h crash test. For the higher-severity (56/53 km/h) crashes, three out of six crashes (both -30 deg crashes and the 50% overlap 0 deg crash) were found as currently too severe in terms of compromised compartment integrity to be used in the development of new restraint systems. Two high-severity crashes were identified which can be targeted for new restraint systems development: The 56/53 km/h 80 % overlap 0 deg impact angle crash was determined to be the most severe in terms of peak accelerations (91 g) and OLC (63 g), and with a high delta-V (97 km/h). The 56/53 km/h 50 % 30 deg crash was found to be the most severe in terms of delta-V (105 km/h) and pulse duration in time. Both these crashes were much more severe than the full-frontal 56 km/h crash. The 56/53 km/h 80 % 0 deg crash was similar in crash severity to a full-frontal rigid barrier 90 km/h crash: we believe this configuration may be worth considering in future legislation and rating programs, which would immediately facilitate development of improved restraint system addressing fatalities in high-severity crashes.

PEER REVIEW PAPER NO.23-0076-O

Load distribution structure of rear bumper beam to enhance vehicle body energy absorption in rear-end collision

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Research
This study focused on FMVSS301, which is one of the highest energy test standard for rear-end collisions. Since it is an offset collision, the deformation of the non-collision side frame, which does not directly contact with the barrier, is small. The reason is that the rear bumper beam with curvature is deformed into straight shape by the load from the barrier, resulting in an asymmetrical load distribution from the barrier that is biased toward the collision side. Therefore, the objective of this research was to construct a new bumper beam structure that reduces the difference in the load input to the left and right frames and increases the energy absorption of the non-collision side frame.

Methods
The concept is to keep the load input from the barrier symmetrical to the rear bumper beam. To achieve this, the overall profile of the rear bumper beam was given a trapezoid-like shape, with straight portion at the center which overhangs rearward from both ends where it joins with the rear frames. A time difference is created before the barrier and the beam ends make contact, thereby limiting the area of load input from the barrier to the central flat area. The cross-sectional strength was designed to retain the profile and to maintain symmetrical input conditions even in high load ranges. Based on a C-category sedan, a rear bumper beam was designed from theoretical calculations and simulations.

Results
The designed rear bumper beam and rear floor components equipped with the rear bumper beam were both fabricated and evaluated by drop-test. In the test of the rear bumper beam alone, the load input difference to the left and right frames was reduced to 3 kN, while it was 45 kN for the conventional structure. Tests of the floor component demonstrated that the energy absorption of the non-collision side frame was enhanced by a factor of 30.

Discussion
In the early impact phase of the crash, a gap was maintained between the rear bumper beam ends and the barrier. In the mid-impact phase, only the load on the collision side frame temporarily increased, but in the late impact phase, the barrier deformation bottomed out to the rigid board surface and the non-collision side load increased again, suggesting that the load input has recovered to near symmetry. The load distribution was similar to that of the full-lap rigid-body impact and approached the target condition where both the left and right frames could deform and absorb energy. Further investigations of rear frame deformation modes and new materials are needed to further enhance overall energy absorption capability of the vehicle.

Conclusion
The new rear bumper beam was designed to distribute the load evenly to the left and right frames and to deform both frames, thereby achieving a higher energy absorption of the entire vehicle body. This is

expected to be applicable to EV and FCV, which require more energy absorption with increased vehicle weight.

PAPER NO.23-0081-O

Risk factors affecting severe thoracic injuries of occupants based on age groups and frontal oblique collisions

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Abstract
Frontal collision is the most common type of motor vehicle collision occurring in real-world collisions. This study aims to investigate the risk of thoracic injury depending on age and oblique direction of collision in a frontal collision. This was a retrospective, observational study. The study used the Korean In-Depth Accident Study (KIDAS) database. We selected 1,369 adult occupant patients in frontal collisions and seated only in the first row. The severely injured occupants were defined as those who had AIS3+ injury in thoracic regions. The age of occupants was classified into three groups: <54 years, 55-64 years, and >65 years. The frontal oblique collision was classified by the PDoF. Considering the PDoF, occupants were classified into three groups: Far-frontal oblique, Near-frontal oblique, and longitudinal. The risk of thoracic injury was significant in age, seating position, and delta-V parameters. 55-64 years occupants OR was 1.819 compared to <54 years. In addition, >65 years occupants OR were 1.950, a higher value. The frontal passenger seat had a lower risk of thoracic injury than the driver seat (OR = 0.465). An increase of 1kph delta-V made a 1.018 OR rise. The oblique direction was only significant in the occupants with fastened seatbelts. The OR of the near-frontal oblique direction was 2.964 compared to the far-frontal oblique direction. The OR of the longitudinal direction was 2.229. Occupants with unfastened seatbelts had no risk difference in the oblique parameter. The study result showed that elderly occupants had a higher risk of severe thoracic injury. Furthermore, the oblique collisions affected to the risk of severe injury only seatbelt fastened occupants. This study showed the detailed risk of the thoracic region using the real-world collision database. The research could be used to enhance occupant safety and advance the crashworthiness of vehicle structures.

PAPER NO.23-0083-O

A physics-based fast-running surrogate model for crash-pulse prediction

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Abstract
Recent developments in safety performance assessment of safety technologies by virtual simulation show a trend towards scenario-based approaches, especially for pre-crash technologies and driving automation systems. The models used for such types of simulations are rather fast, so many simulations

can be performed in reasonable time. However, if the application of scenario-based approaches is extended to in-crash occupant protection technologies, finite element (FE) crash models come into play for e.g., determining the crash pulse. These models are very time-consuming and not suited for performing large-scale studies. The research objective therefore was to develop a model that delivers sufficiently accurate estimations of the crash-pulse in a frontal impact depending on crash configuration parameters while being fast enough to be used in large-scale safety performance assessment studies. We built a multi-body-system (MBS) model consisting of the main frontal crash relevant structural elements (crash boxes, longitudinal member, cross member, engine, firewall) as well as the rest of the vehicle (passenger cabin and luggage trunk), which is modelled as one rigid body. Nonlinear force elements are used to model the elastic and plastic deformations. We optimized the parameters of the force elements by using results of 96 FE simulations of a high-fidelity full vehicle model impacting a rigid barrier. In those 96 simulations, we varied the impact speed, impact angle and lateral offset. The physics-based surrogate model provides translational and rotational accelerations, speeds, and positions over time. The results show a good correlation to the results of the high-fidelity model: the mean absolute occupant load criterion (OLC) error for all 96 crash configurations is 0.88 g. The physics-based surrogate model needs less than one second for one run of 200 milliseconds on 1 CPU while the high-fidelity FE model needs more than 15 hours on 16 CPUs for the same task. The model can be used to predict crash-pulses in the range of crash configuration parameters it was optimized for. It can be extended to other crash configurations. Its parameters can be adapted to represent other vehicles by adapting physical parameters like mass, lengths etc. due to the physics-based approach. This is a major advantage compared to non-physics-based black-box surrogate modelling techniques used for the same purpose, where the internal parameters do not represent any physical property. Moreover, the physics-based surrogate model can also be used to simulate a crash between two vehicles (even with different properties) by using another model instance instead of a rigid barrier as opponent. The model delivers an estimation of the crash-pulse, so its main purpose is to be used in large-scale studies, not to exactly reproduce one singular case. So far it can only be used in frontal crashes, but it could be extended for rear-end crashes as well by adding the respective structures at the rear end. The model developed can predict crash-parameter-dependent crash-pulses and can be an essential part in accelerating large-scale safety performance assessment studies of occupant protection systems in frontal crashes.

PAPER NO.23-0165-O

Heavy truck frontal impacts and fires

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Abstract
Industry and government studies have noted the dangers of heavy truck frontal and underrun crashes, suggesting various measures to improve safety in these types of accidents including strengthening front suspension components and adding protective structures. In 1986, The USDOT found post-crash fires were involved in 16% of heavy truck fatalities compared to only 4% for cars. The report identified several mechanisms of fuel tank rupture including frontal impacts resulting in front axle contact with fuel tanks. The hazards of exposed side saddle fuel tanks have been known for decades, yet heavy trucks still use this vulnerable outboard location for fuel tanks. In 1994, the United Nations ECE published a standard for heavy truck front underrun protective structures (FUPS); however, the United States still has no requirements regarding front underrun protection of heavy trucks. A FUPS prevents underrun and engages the energy absorbing structures of smaller impacting vehicles, provides

protection of the trucks steering components, and helps prevent the truck's front axle from being displaced into the fuel tank which can cause rupture and fire. Three real-world crashes are presented wherein heavy trucks experienced a frontal impact, resulting in fire and serious injury. In each of these cases, testing was conducted on a production truck front structural assembly and compared to a similar FUPS equipped assembly. The effectiveness of FUPS in mitigating damage in these frontal crashes was assessed.

PAPER NO.23-0198-O

Frontal head-on car-to-heavy goods vehicle crashes effect on the restraint system

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Abstract
For car occupants in Europe, a car-to-HGV (heavy goods vehicle) crash is the third most frequent fatal crash type after single and car-to-car crashes. Within car-to-HGV fatal crashes, frontal head-on crashes are most common. These crashes can result in larger structural deformation of the car or higher velocity changes and accelerations than single or car-to-car crashes typically do. Structural compatibility and energy absorbing structures are prerequisites for good crashworthiness, so also for severe head on car-to-HGV crashes. If the car compartment can be kept intact there is a potential to improve the current state-of-the-art frontal restraint systems to provide the occupant with good protection also in high-severity car-to-HGV crashes. The goal of this study was to identify potential limitations in a state-of-the-art frontal restraint system in high-severity car-to-HGV head-on crashes with an intact compartment and propose improvements to the restraint system to reduce and balance the risk of injury for all body regions. Finite element simulations were performed using a frontal sled interior model with a geometry representing a mid-size sedan. The frontal sled model was equipped with the semi-rigid seat, a generic seat consisting of spring-loaded seat and submarining pans, developed to represent the characteristics of a front seat, and a seat integrated belt system consisting of a shoulder belt retractor with a 4 kN load limiter and a 2 kN pretensioner, and a 2 kN lap belt pretensioner. Further, the model was equipped with a driver airbag, a steering wheel, a collapsible steering column, a knee bolster, and a foot support. The model was validated by means of mechanical sled tests using generic 40 and 56 km/h full frontal rigid barrier crash pulses and THOR-50M v1.9. After validation the performance of the restraint system was evaluated with the THOR-50M by implementing crash pulses from two car-to-HGV head-on crashes. For both car-to-HGV crash pulses there were severe strikethroughs of the restraint system. Improved seat stiffness, increased shoulder belt load limiter force, and increased knee bolster energy absorption prevented the strikethroughs and reduced the injury criteria values. However, the injury criteria values were still higher than current NCAP performance limits for most of the body regions. To guide the development of adaptive occupant protection tailored for high severity crashes, injury criteria targets are required. Such targets should be balanced between feasibility and still challenging enough to prompt improvements relative to the current state of risks. Occupant protection in different crash severities is of high priority. The occupant protection system should be designed to be adaptive to the crash, i.e. more compliant in low-severity crashes and stiffer in high-severity crashes. Current occupant restraint systems are most likely capable of the proposed improvements with existing technologies. However, they are

currently not designed with the level of adaptivity that this study indicates may be beneficial. More research is needed to develop injury criteria target values for survival in high severity crashes, as well as sensors that distinguish between low-, mid- and high-severity crashes with the purpose to adapt the restraint system thereafter.

PAPER NO.23-0221-O

Driver airbag solution for next generation steering wheels

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Abstract
The steering wheel as the central vehicle motion control device gives today's drivers a high level of trust in the controllability of their vehicles. Changing vehicle interiors as well as new occupant positions / postures related to highly automated driving are impacting the form and function of steering devices. Three technology trends are influencing future steering wheels: growing electronic content, changing steering wheel geometries and transformation capabilities and seamless designs. Over the last decades the appearance of the steering wheel was determined by a round 360° steering wheel shape, a visible gap between driver airbag & steering wheel, and driver safety enabled by an airbag deployment centrally from the front surface. However, future steering wheels are becoming increasingly seamless with higher integration of HMI functionalities and new surface appearances like wood optic or glass applications. Such innovative designs require new driver airbag solutions. This paper examines an alternative concept capable of revolutionizing the front panel of a steering wheel by incorporating a driver airbag inside of the steering wheel. The airbag cushion can deploy from the top side of the wheel through the rim and covers the front panel, thus helping to protect the driver in case of a crash.

PAPER NO.23-0300-O

Investigating slouching in frontal impacts using an HBM in the rear seat

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Abstract

Car occupants may choose a wide range of sitting postures, including rearward rotation and forward excursion of the pelvis, through slouching. The overall objective of the study was to contribute to the understanding of restraint interaction, as a function of pelvis orientation and lumbar spine posture. Specifically, the aim was to investigate kinematics of and loading to the occupant in frontal impacts by comparing slouched and upright sitting postures using state-of-the-art restraints. A human body model (HBM) of a mid-sized male, the SAFER HBM, was restrained in a simulation model of the rear seat of a large passenger car and exposed to a full frontal 50 km/h impact. Three different sitting postures, with constant seat backrest angle were included; a nominal upright sitting posture and two slouched sitting postures, representing moderate and extreme slouching, respectively. The position of the seat in front of the occupant was varied to the mid-track position and the most forward-track position, respectively, to allow for different knee-interaction. When the front seat was in a mid-track position, submarining did

not occur in any of the slouched postures, while partial submarining occurred for the extreme slouched posture with the front seat in the most forward-track position in the model. During the impact, both slouched postures of the HBM resulted in less torso pitch compared to the nominal posture. The shoulder belt moved up the sternum to a higher extent in the slouched postures, leading to less balanced kinematics with the pelvis moving forward and the upper torso held back by the shoulder belt, contributing to the less torso pitch. These changes in kinematics for the slouched postures resulted in higher lumbar spine compression and lower chest loading, relative to the nominal posture. In summary, slouched sitting postures affect occupant kinematics and loadings in a frontal impact. By exploring variations in sitting posture in terms of slouching using a HBM, knowledge can be gained in understanding the mechanisms of submarining and lumbar spine loading. These findings are relevant for sitting postures in conventional cars today, in addition to a wider range of sitting postures as a result of future seat developments.

PAPER NO.23-0302-O

Comparison of the injury risk prediction of the THOR-reclined dummy and the THUMS HBM

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Abstract
Autonomous vehicles are expected to allow car occupants to position themselves in more relaxed positions inside the vehicle. These new seating positions constitute a new challenge for crash safety analysis. Therefore, new crash test protocols, adapted to this new paradigm, may be required in the future. In the literature, most of the virtual reclined posture analysis has been performed using Human Body Models (HBMs) which are increasingly used to assess vehicle safety and injury risk, as currently regulated ATDs (Anthropomorphic Test Devices) are neither designed nor validated for reclined seating configurations. Nevertheless, these HBM simulation studies need to be correlated against repeatable physical tests that allow future cars to be rated according to regulation and consumer testing protocols. New options for crash dummies such as the THOR-Reclined kit from CELLBOND; which allows adapting the THOR ATD for these new reclined seating postures, are being developed and may enable the performance of physical tests in reclined occupant positions. However, the question of whether its performance is comparable to that of an HBM remains unanswered. A series of simulations were then conducted comparing the behavior of the THOR-Reclined simulation model and the THUMS v4.1 by means of kinematics and injury risk prediction. Also, a series of tests using the THOR-Reclined in IDIADA's deceleration facility have been planned and the results will be shared in future publications. Injury risk prediction was then compared between the HBM and the ATD. The ATD and the HBM FE models were compared by means of kinematics, restraint system outputs, injury criteria, and injury risk prediction. The result of this comparison will be discussed in this paper. Some differences were observed between the models. THUMS allowed to study injury risk criteria based on the strain of the rib cage, while the ATD is mainly designed for measuring displacements and accelerations. The primary limitation of this work is the lack of thorough validation data of the active HBM and the ATD model in the studied position. However, this work provides further insight into the comparability of their performance and the differences found between the studied models. Differences have been found

between the two models, mainly due to their physical dissimilarities. Nevertheless, some comparisons can be made between them from a kinematic and injury criteria perspective and will be shared in this paper.

PAPER NO.23-0314-O

Update on NHTSA's OMDB's half barrier analysis

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Abstract

Research Question/Objective: National Highway Traffic Safety Administration (NHTSA) has developed an Oblique Offset Moving Deformable Barrier (OMDB) test procedure. The OMDB test procedure uses an energy absorbing honeycomb that covers the front face of the OMDB. Originally, this barrier had a full-width design that was representative of a typical passenger car. During the development of this test procedure, it was realized that less than half of the barrier face was being deformed. Since only half the honeycomb was being deformed it was determined this was a waste of material and added cost to perform the test. Also, it was brought to NHTSA's attention that the manufacturing of the full-width barrier face was complicated by the need for straps. Therefore, NHTSA is developing a barrier with a face whose width is about half of the original. It is referred to as the "Half Barrier." Two different versions of the Half Barrier design, V0 and V1, are investigated herein. Methods and Data Sources: The Full, Half V0, and Half V1 barrier faces were tested using the OMDB test procedure with rigid moving barrier and production vehicles, representing different size vehicles. In each test with production vehicles, THOR-50M Anthropomorphic Test Devices (ATDs) were positioned in the driver and right front passenger seat. Differences in barrier, vehicle, and occupant response were assessed using CORA rating software. To eliminate the variability of production vehicles a set of tests using a rigid moving barrier was used as the target vehicle. Differences in barrier, vehicle, and occupant response were assessed using CORA. Results: The impacts into the rigid moving barrier showed a "Good" CORA score for the rigid moving barrier responses, though the barrier crush and energy had different trends. In the production vehicle tests, some differences were seen in the vehicle crash pulses and intrusions when comparing different barrier faces within the same vehicle. For example, the large pickup truck showed a more severe crash pulse using the Half V1 barrier face, suggesting that V1 is stiffer than the other barrier faces Discussion and Limitations: During this testing it was noted that the two layers of honeycomb had a slight separation. This separation was seen in the full-width barrier and both designs of the Half Barrier. It is unknown how much this separation affects the vehicle and ATD response. This study was limited by the number of observations, as only one test was conducted for each barrier face/vehicle combination, and only three production vehicles were tested. However, the range of vehicles was selected to cover a wide range of characteristics. Conclusions and Relevance to Session Submitted: The Half V0 barrier face design has been tentatively selected as a replacement for the full-width barrier for use in NHTSA's OMDB test procedure. It shows comparable results to the full-width barrier for both the vehicle and THOR-50M performance. The Half Barrier V1 design seemed to be too stiff for larger vehicles.

PAPER NO.23-0321-O

Frontal crash incompatibility of heavy goods vehicle in crash test with passenger car

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Abstract

In 1997 the Swedish parliament adopted Vision Zero which reduced fatalities almost by 2/3 to 1.9 road fatalities per 100,000 inhabitants for 2020. One guiding principle is maximum speed limits of 80 km/h without physically separating opposing lanes. Fatal frontal crashes between passenger cars and Heavy Goods Vehicles (HGVs) are a problem for the rural road network with speed limits between 50 and 80 km/h. A road network following the Safe System principles should not lead to fatalities if safe vehicles, safe infrastructure, and safe road users are present. In the scenario described above, a rural road posted at 80 km/h without median separation would need to be operated with safe vehicles, that is, vehicles that are capable of protecting occupants in frontal crashes. While it may be possible for late model cars with good safety performance to protect occupants in crashes with similar cars at relative crash velocities above 120 km/h, the case of a car-to-HGV impact is less obvious A study of real-world crash data and current vehicle technology suggested that a frontal crash between an HGV and passenger car with relative velocity of 100 km/h (50 km/h per vehicle) and 50% overlap would be a reference to assess infrastructure and vehicle safety levels. The test was based on vehicles having active systems that reduce original travel speeds to the proposed test speed before impact. State-of-the-art vehicles (a Euro NCAP 5 star mid-sized sedan and HGV with energy absorbing Front Underride Protection Device (FUPD)) were chosen. The test is also comparable with the Moving Progressive Deformable Barrier test currently used in Euro NCAP. The test results showed that both vehicles need structural protection system improvements to provide consistent protection for road users in these types of high-severity crashes. The car sustained extensive deformations to the outboard area of the vehicle front resulting in significant deformation to the left wheel and A-Pillar area. This focused damage was due to the fracture of the FUPD on the HGV early in the crash event. The FUPD did not engage the energy absorbing structures in the car (longitudinal crash beams, which were essentially undamaged. The 50%ile male Hybrid III (HIII) dummy slid off the driver's airbag and struck the left A-Pillar due to a gap that developed between the side curtain and front airbag, this was related to the excessive A-Pillar motion. High head accelerations exceeded the upper limit for recommended Head Injury Criteria (HIC). Compatibility between HGVs and cars must be improved for frontal impacts, when less than 50% of the car width engages the truck structures. The existing FUPD requirements should be reviewed to ensure that geometric and structural requirements reflect real-world demands in a crash. Opportunities for improved passenger car restraint systems need vehicle structure interactions that maintain a stable passenger compartment and efficiently use energy absorption systems designed into HGVs and passenger cars. The new EC regulation (2019/1892) for extended fronts is an opportunity to achieve better car-HGV compatibility by providing more design space in the HGV front-end.

PAPER NO.23-0324-O

Fireworthiness of cabin exhauster vents and the effects of ageing

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Abstract
In many case studies, post-collision fires originating outside the occupant compartment were found to have propagated into the occupant compartment through the cabin exhauster vents. HVAC systems in modern vehicles include exhauster vents to flow air out of the occupant compartment, while preventing air, moisture, and dirt from flowing in. Cabin exhauster vents are typically constructed with a matrix of elastomeric flaps mounted to a rigid plastic grate and attached directly to the sheet metal of the vehicle body. This study evaluates the ability of production and improved exhauster vent designs to resist fire propagation.

PAPER NO.23-0327-O

A forensic analysis of recliner release via connecting rod in rear impact automotive collisions

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Abstract
Occupant safety in rear impact automotive collisions relies heavily on freestanding seats to restrain front seated occupants without intruding into the survival space of occupants in the rear seat [1] [2]. The seatback must absorb crash energy while remaining sufficiently upright to prevent occupant ramping and injurious contact with rear seated occupants and / or rear vehicle structures. Additionally, the front seats must be designed to accommodate all different occupant statures comfortably [3]. Adjustability is typically achieved by equipping the seats with a number of features including fore / aft adjustment, recline adjustment, and often seat height adjustments. These adjustment features are either manually, or electrically adjustable. A failure mode in manually adjustable dual recliner seats has been identified wherein the recliner connecting rod can disengage one, or both, recliners during a rear impact event, undermining the seat back's ability to restrain the relative rearward movement of the front occupant. This catastrophic failure mode presents both front and rear seated occupants with higher risks of severe injury. Three real world cases are presented wherein manually adjustable recliners were found to release in a rear impact due to the recliner connecting rod. Testing and / or demonstration of the failure mode is shown in each case which shows matching evidence between the accident and test seats.

PAPER NO.23-0334-O

Potential injury criteria for collisions with heavy goods vehicles

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Abstract

Background: Collisions with heavy-goods vehicles (HGVs) comprise approximately 21% of fatalities in two-vehicle collisions in the United States, and 14-15% of car occupant fatalities in Europe. While the immediate need in these collisions lies in compatibility and structural integrity of the smaller vehicle, once these are addressed it will be up to the restraint system to manage protection of the occupants at collision severities that are greater than are commonly evaluated now. For restraint evaluation in high-severity collisions where survivability is the focus, different injury criteria targets may be warranted, focused on balancing injury risk across the body regions to fully utilize the load-bearing capability across the body. In this study we seek to identify potential injury criteria target values for predicting injury risk across the body in evaluations of high-severity collisions. Methods and Data Sources: This study consisted of a literature review, combined with a field data analysis to contextualize the distributions of injuries that occur among collisions of various severity. Data from NASS-CDS (2010-2015) and CISS (2017-2019) were examined to observe the relative distribution of injury severities by injury type, focusing on belted occupants in frontal collisions. Injury risk functions were then reviewed (using simulations) to observe the relative injury risks predicted across the body in collision severities representative of car-to-HGV collisions. Results and Discussion: Across collision severities, injury risks were relatively balanced among the body regions. Most AIS2+ and AIS3+ injury cases occurred in relatively low-severity collisions, due to the very high exposure to low-severity collisions. AIS4+ injury cases occurred with similar total counts in low-severity and high-severity collisions, affected by the balance of exposure and per-crash risk. In high-severity collisions, the most common injury types were to the ankle, tibia & fibula, brain, thorax, and lumbar spine, all occurring with similar frequency. In simulations with the THOR-50M FE model, the injury risk predicted across the body regions exhibits similar balance to that observed in the field data, except for the risks predicted in the chest and the hip. Upon examination of the risks observed in the field data, as well as those observed in the high-severity impact simulations, injury assessment reference values were developed targeting a 40% risk, representing a target that is feasible to achieve and which has a high likelihood of providing a benefit to the field. Conclusions: Injuries occur as a result of both exposure and per-incident risk. Injury reduction likely requires safety systems that can adapt to the crash severity, providing more compliant restraint in low-severity collisions (where the exposure is very high), and stiffer restraint designed to eliminate strike-through in higher severity collisions (where the per-crash risk is high). Such adaptive restraints require injury risk targets designed for the specific collision severities targeted for evaluation – including more conservative targets for low-severity evaluations, and higher targets for high-severity evaluations (focusing on survivability). This study has identified potential means for defining injury criteria values specifically for evaluations in high-severity collision scenarios, targeting a balance among the body regions informed by recent field data.

Active Safety Systems for Crash Avoidance: New Systems and Technologies

Tuesday, April 4, 2023, | 08:30-12:30

Chair: Jost Gail, Germany | Co-Chair: Genya Abe, Japan

TRACK C | Room: G301+G302

PAPER NO.23-0142-O

The estimated potential effectiveness of AEB and LKA systems for head-on crashes

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Abstract

Research Objective In 2019, there were over 3,600 fatal head-on crashes in the US. This represents 10.9% of all fatal crashes despite accounting for 2.7% of all police-reported crashes. Lane departure warning (LDW) and lane keeping assist (LKA) systems could help address cross-centerline crashes. We consider LDW systems to be those that alert the driver prior to the lane crossing event while LKA systems might perform automated steering that may help prevent the vehicle from departing the lane. Automatic emergency braking (AEB) has been effective in preventing or mitigating front-to-rear crashes by providing significant crash-imminent braking. The purpose of this study was to estimate the effectiveness of a simulated LDW or LKA system with a hypothetical AEB system that could activate in cross-centerline head-on crashes. Methods The National Automotive Sampling System Crashworthiness Data System (NASS/CDS) is a representative sample of tow-away passenger vehicle crashes in the U.S. containing in-depth crash data. Trajectory data was extracted from scaled scene diagrams for 232 cross-centerline NASS/CDS cases with available event data recorder (EDR) information. There were 111 cross-centerline crashes reconstructed based on the trajectory and EDR recorded crash pulse. This effort to predict the benefits of LDW and LKA systems for cross-centerline crashes, involved modeling the crash, including the road geometry and vehicle dynamics. The encroaching vehicle that crossed the centerline was simulated with hypothetical LDW and LKA systems and the impacted vehicle was simulated with and without an AEB system. The outcomes of the simulations were combined to estimate the potential crash reduction of a hypothetical LDW and LKA combined with AEB. For simulations that resulted in a crash, a frontal injury model was used to predict the probability of the occupants sustaining a moderate to fatal injury (MAIS2+F). Results The hypothetical LDW system had an estimated crash benefit between 7.5% and 10.8% and the hypothetical LKA system had a higher estimated benefit of 32%. With the AEB system in the impacted vehicle, the estimated benefit for LDW increased to 13% to 15%, but the estimated benefit for LKA remained the same. The AEB system with the LDW system resulted in an estimated 50.8% to 54.3% reduction of MAIS2+F injured occupants and an estimated 68.4% reduction with the LKA system. Discussion/Limitations The simulations indicated that AEB has only a small effect

on preventing head-on crashes. However, AEB can mitigate the crash by rapidly reducing the speed of the impacted vehicle prior to the collision. While the hypothetical AEB system does not prevent many additional simulated head-on crashes, it can assist in reducing the likelihood of passengers sustaining a moderate to fatal injury. Conclusion/Relevance Previous studies have investigated the benefit of LDW and LKA systems for road departure and head-on crashes. This is the first study to investigate the combined benefit of a hypothetical AEB and lane keeping systems for head-on crashes. This paper is relevant to the session because it evaluates the estimated safety benefits of these systems using EDR pre-crash and crash data.

PAPER NO.23-0143-O

Risk assessment and mitigation of e-scooter crashes with naturalistic driving data

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Abstract
Recently, e-scooter-involved crashes have increased significantly but little information is available about the behaviors of on-road e-scooter riders. Most existing e-scooter crash research was based on retrospectively descriptive media reports, emergency room patient records, and crash reports. This paper presents a naturalistic driving study with a focus on e-scooter and vehicle encounters. The goal is to quantitatively measure the behaviors of e-scooter riders in different encounters to help facilitate crash scenario modeling, baseline behavior modeling, and the potential future development of in-vehicle mitigation algorithms. The data was collected using an instrumented vehicle and an e-scooter rider wearable system, respectively. A three-step data analysis process is developed. First, semi-automatic data labeling extracts e-scooter rider images and non-rider human images in similar environments to train an e-scooter-rider classifier. Then, a multi-step scene reconstruction pipeline generates vehicle and e-scooter trajectories in all encounters. The final step is to model e-scooter rider behaviors and e-scooter-vehicle encounter scenarios. A total of 500 vehicle to e-scooter interactions are analyzed. The variables pertaining to the same are also discussed in this paper.

PAPER NO.23-0146-O

Estimating the contributions of automatic emergency braking and lane support systems to achieving vision zero

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Abstract

Vision Zero is an approach to transportation safety that aims to eliminate all traffic-related fatalities and lifelong injuries. A common strategy to achieving Vision Zero is the safe system approach, which employs a multitude of transportation-related branches to create a safe system for all road users. The design and implementation of advanced driver assist systems (ADAS) is one way to contribute to Vision

Zero. This study used real-world nationally representative crash data from the Crash Investigation Sampling System to estimate the contributions of two ADAS to achieving Vision Zero in the United States: an advanced automatic emergency braking system (A-AEB) and lane support systems (LSS). It was assumed A-AEB has crash avoidance capabilities for rear-end crashes, left turn across path opposite direction and lateral direction crashes, and straight crossing path crashes, as well as injury mitigation capabilities due to prevented crashes as well as due to delta-v reduction due to system-induced braking. It was assumed LSS has crash avoidance capabilities for head-on crashes, road departure crashes, and opposite direction sideswipe crashes. The combined contributions were estimated to prevent a cumulative 7,054,894 crashes and 869,456 moderate to fatal injuries by 2050. Despite this, over 125,000 moderate to fatal injuries are still estimated to occur each year, and the total number of crashes is not expected to decline. This emphasizes the need for continuous future contributions from all branches of transportation if the US is to someday achieve Vision Zero.

PAPER NO.23-0169-O

Adaptive distance control – Road safety potentials of an exciting new feature in existing E/E Architecture

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Abstract

The list of driver assistance features is getting longer and longer. All this assistance raises the question: Will driving still be fun in future? Adaptive cruise control (ACC) as SAE Level 1 system adds safety and comfort to the driver. Per definition, ACC takes over driving tasks and offers limited self-determination in terms of driving experience and enjoyment. On the other hand, Automatic Emergency Braking (AEB) systems are designed to prevent a potential collision at latest. Yet, an AEB system has operational constraints depending on its system capabilities and the type and complexity of the sensors used. To expand SAE Level 0 safety systems like AEB, Bosch develops the feature Adaptive Distance Control (ADC). It transfers an early and comfortable distance control to self-driving situations. And it adapts to personal driving style to enable a natural driving experience with a comfortable and noticeable safety benefit. Thus, ADC links between ACC and AEB to relax traffic flow and to prevent incidents at an early stage. The present study evaluates the effectivity of ADC in terms of the above-mentioned safety benefits. It is comprised of a thorough analysis of road traffic observation data (drone data) and the analysis of rear-end collisions involving M1-vehicles on German roads. In the first part of the study, real-world traffic observation data (highD dataset) from six motorways in North Rhine-Westphalia in Germany was used to determine the time headway (THW) among cars. THW equals the ACC time gap between two vehicles. In the second part, data from the German in-depth accident study (GIDAS) was used to identify the number of relevant crashes which can potentially being positively influenced, i.e., the field of effect (FoE) for ADC. The analysis of 89,139 passenger car observations reveals that ADC could support 1 out of 12 drivers to keep a THW ≥ 0.6s if lane changes are neglected. Furthermore, the FoE for ADC was estimated up to 5.3% of all crashes with casualties in Germany, depending on its system capabilities. This corresponds to about 16,100 addressable collisions annually if each car would be equipped with the ADC feature. The present study reveals that ADC can prevent crashes. Moreover,

the system maintains the balance between safety and comfortable driving experience and could support a relaxation of the traffic flow. All this in a standard E/E architecture without adaptations.

PAPER NO.23-0170-O

Partnership for analytics in traffic safety (PARTS) cross-industry assessment of real-world adas effectiveness

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Abstract
In 2020, an estimated 2.3 million people were injured in traffic crashes, and 38,824 people were killed on U.S. roadways. Advanced driver assistance systems (ADAS) in passenger vehicles hold the potential to reduce traffic crashes, prevent serious injuries, and save thousands of lives on our roadways each year. Given the growing rate at which auto manufacturers are equipping vehicles with ADAS, there is an increasing need to study and understand the safety benefits and potential limitations of these technologies. To address this need, the Partnership for Analytics Research in Traffic Safety (PARTS) was formed in 2018 as an independent, voluntary data sharing and analysis partnership among eight automobile manufacturers and the United States Department of Transportation (USDOT). The not-for-profit MITRE Corporation (MITRE) operates PARTS as the independent third party and conducted this study at the direction of and in collaboration with the PARTS partners. The objective of this PARTS study was to explore the real-world effectiveness of ADAS features in reducing system-relevant crashes, specifically front-to-rear crashes for forward collision warning (FCW) and automatic emergency braking (AEB) and single-vehicle road-departure crashes for lane departure warning (LDW), lane keeping assistance (LKA), and lane centering assistance (LCA). This study combined 13 states' police-reported crash data (2016 to 2021) with vehicle equipment data from 47 million vehicles representing 93 vehicle models (model years 2015 to 2020), resulting in the study dataset of 2.4 million crash-involved vehicles. This study defined three crash severities (all, injury, serious) and estimated ADAS effectiveness for each using quasi-induced exposure and logistic regression, comparing vehicles equipped with ADAS against vehicles without those features. For the population of all front-to-rear crashes, the study estimated that crashes were reduced by 49% (Wald 95% CI: 48 to 50%) when the striking vehicle was equipped with both FCW and AEB compared against striking vehicles that were not equipped with either. For FCW alone, the estimated reduction is 16% (13 to 20%). For the population of front-to-rear crashes involving injury, effectiveness estimates were slightly higher. The study estimated that front-to-rear crashes were reduced by 53% (51 to 54%) when the striking vehicle was equipped with both FCW and AEB. For FCW alone, the estimated reduction for crashes with injuries is 19% (13 to 25%). Altogether, this study shows that the combination of warning and active braking reduced more front-to-rear collisions than warnings alone. The study demonstrates that AEB performs well even when weather and lighting conditions are not ideal. This study investigated the effectiveness of Pedestrian AEB with non-motorists but was unable to detect an effect. For single vehicle road departure crashes, this study estimated that LDW and LKA

reduced crashes by 8% (5 to 12%). When adding LCA, crashes are reduced by about the same amount (9%, 4 to 14%). This study did not find significant results for vehicles equipped with LDW alone.

PAPER NO.23-0192-O

Effects of a bicycle detection system on police-reported bicycle crashes

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Abstract
Research Question/Objective Automatic emergency braking (AEB) is effective at preventing vehicle-to-vehicle rear-end crashes and pedestrian crashes. Subaru's driver assistance system that includes AEB, called EyeSight, could detect bicycles in parallel configurations in the United States in its first and second generations, and added bicyclist detection in perpendicular configurations in its third generation. The purpose of this study was to evaluate whether the first and second generations of EyeSight reduced bicycle crashes in the real world. Methods and Data Sources The presence or absence of EyeSight was identified through Vehicle Identification Numbers for model year 2013–2020 Subaru models where the system was optional. All bicycle crashes and single-vehicle single-bicyclist crashes with parallel and perpendicular configurations involving these vehicles were extracted from the police-reported crash databases of 16 U.S. states during calendar years 2014–2020. The association of EyeSight with bicycle crash rates per insured vehicle year was examined with negative binomial regression controlling for calendar year, state, vehicle model year and series, and driver age group and gender. Quasi-induced exposure analyses using logistic regression compared involvement in a bicycle crash to the nonsensitive crash types of being rear-end struck or side-struck, using the same covariates as the negative binomial regression models. These analyses included crash data from 14 states where rear-end-struck and side-struck vehicles could be identified. Results Study vehicles were involved in 856 bicycle crashes, of which 283 had parallel configurations and 387 had perpendicular configurations. EyeSight was associated with a statistically significant 29% reduction in parallel crash rates per insured vehicle year (Rate ratio [RR], 0.71; 95% confidence interval [CI], 0.53–0.96, p = 0.03), and nonsignificant reductions of 5% in perpendicular crash rates (RR, 0.95; 95% CI, 0.74–1.21, p = 0.66) and 9% in overall bicycle crash rates (RR, 0.91; 95% CI, 0.77–1.08, p = 0.28). Effects of similar magnitudes were seen in the quasi-induced exposure analyses. Discussion and Limitations An early version of EyeSight reduced bicycle crashes in the parallel configurations it was designed to detect but did not have much effect on bicycle crashes overall. Crash configuration was identified by bicyclist and vehicle direction of travel when they were available. In states where direction of travel was unavailable, bicyclist precrash actions of cycling along the roadway with or against traffic and crossing were used as proxies for parallel and perpendicular configurations, respectively. The actual configurations of crashes in these states were unknown. Conclusions and Relevance to Session Submitted Although it is promising that an initial bicyclist detection system prevented crashes in parallel configurations, a minority of bicycle crashes are of this type. AEB systems will need to increase functionality and detect perpendicular crash configurations to meaningfully reduce bicycle crashes.

PAPER NO.23-0213-O

Analysis of the European car road crashes for the identification of the main use cases for a significant road safety improvement through V2X

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Abstract
Research question in pursuit of Vision Zero towards traffic-related fatalities and injuries in Europe, the SECUR project (Safety Enhancement through Connected Users on the Road) was initiated in a Euro NCAP context. SECUR aims to study the potential of V2X communications to improve road safety. This paper illustrates the main European crash cases involving Passenger Cars as ego vehicles and their parameters. The following opponents were considered: Passenger Cars, Powered Two-Wheelers, Bicyclists and Pedestrians. Methods and Data Sources An initial study of crashes at a high level was done to draw a general picture based on German (DESTATIS), French (BAAC) and European (CARE) crash databases. Then, an in-depth study was performed to select and define the SECUR crash cases and their characteristics. As part of this in-depth analysis a generic scenario catalog was developed, covering traffic crash situations, that the driver of a passenger might encounter. The most relevant scenarios regarding accidentology were determined providing the baseline to develop a test environment for a useful V2X-system. Based on the German Insurance Association crashes classification (GDV) and the German in-depth crash database (GIDAS), this catalog clusters all the GDV crash types in 28 categories, each crash being analysed from the perspectives of both participants and considering all different opponent types. The data of the most relevant 15 crash scenarios were provided through a GIDAS-based in-depth study, considering a set of 16 parameters. Results According to the in-depth crash analysis, 15 out of 112 crash scenarios were identified as the most relevant ones regarding the number of Killed and Severely Injured (KSI) and the relevance of V2X. These 15 scenarios consider the 4 types of road users and cover 71% of all the KSI crashes from the catalog. Among them Straight Crossing Paths, Left Turn Across Path and Rear-End crash situations. The parameters study has shown that the most significant crash blackspot is at intersections with structural view obstruction. Discussion and Limitations This study is subject to certain limitations. First, it is expected to be European representative, so the study was based on GIDAS and complemented with analyses of CARE and the in-depth database (IGLAD). However, the European representativity is still limited by the GIDAS-weighting upon CARE. Moreover, it is complex to draw conclusions for new vehicles as the current databases naturally include old information and are representative of a past context (vehicle without state-of-the-art safety systems). Therefore, in order to have a dataset more representative of the current context, crashes involving a vehicle without ESC were

filtered out. Conclusion The main crash cases to be ruled out for a significant road safety improvement through V2X are illustrated in this paper. The results have shown that significant white spots that are not addressed by ADAS due to physical sensor limitations (e.g., obstruction) remain. And it is precisely where V2X benefits sit, standalone or fused with current systems. SECUR results will feed Euro NCAP V2X introduction into the protocols and also further NCAP developments in other regions.

PAPER NO.23-0245-O

ADAS in your pocket – a review of the features, functions and future of smartphone-based advanced driver assistance systems

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Abstract
Advanced Driver Assistance Systems (ADAS) are technology systems that rely on a combination of sensors that scan the road environment to detect potentially hazardous situations and assist the driver to either avoid the hazard, or to reduce the severity of outcomes if a crash is unavoidable. Recent developments in consumer-level smartphone technology have allowed third party software applications to make ADAS functionality accessible to millions of mobile phone users. By utilising the smartphone's hardware such as cameras, positioning sensors and processors, together with software-based object recognition and tracking algorithms, these applications purport to allow users to receive real time road hazard detection and warnings. These smartphone-based ADAS applications are compatible with many popular models of smartphone and offer ADAS functionality that includes Forward Collision Warning (FCW), Lane Departure Warning (LDW) and Intelligent Speed Assist (ISA). ADAS related applications are identified and reviewed for claimed features and functionality. Applications with the most promising functionality are acquired for more detailed evaluations. We review the features and functionality of selected ADAS applications using several different smartphone models. We report on the results of on-road performance evaluations that examine the effectiveness and limitations of these. We also explore potential road safety benefits for drivers whose vehicle is not equipped with ADAS, but who have a smartphone available when they drive. The results confirm that ADAS applications are capable of vehicle detection/tracking, lane marking detection, road sign detection, speed zone detection and related warning functionality, however the performance between apps varied and issues such as false alerts, non-detections and incorrect detections were recorded. While smartphone-based ADAS can provide reliable, and potentially useful road safety benefits to drivers, these potential benefits depend on a combination of the hardware capability of the smartphone, the sophistication of the application and, to a lesser extent, the correct set up of the smartphone in the vehicle. Furthermore, while smartphone-based ADAS has the potential to improve road safety, especially where OEM-fitted ADAS is not a feasible option, there are inherent limitations posed by current technology. Finally, subject to appropriate provisions in relevant regulations, the barriers to the adoption of smartphone-based ADAS appear low and the main barrier to adoption is that smartphone users are unaware that ADAS applications exist. We foresee that continued developments in smartphone hardware and processing capability, together with software evolution in ADAS applications, will continue to improve the reliability and effectiveness of smartphone-based ADAS in the future.

PAPER NO.23-0269-O

Active safety of self-propelled trailers: Proposal for safety requirements

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Abstract
Trailers are by definition non-propelled, towed vehicles. They pose resistance forces to the towing vehicle, resulting from e.g., rolling resistance, friction, air resistance. New concepts are proposed where trailers would be able to support the towing vehicle by reduction of the toeball forces, sometimes even pushing the towing vehicle. This would allow for higher traction of the vehicle combination, possibly even a higher overall energy efficiency when the required energy storage system would be distributed to both vehicles. A study conducted by BASt did investigate the possible influence of driven trailers on the driving dynamic properties of the vehicle combinations. Driving experiments with two prototype trailers (caravans) had been carried out in direct comparisons with active and inactive trailer motors. The experiments focused on possible effects on the handling (double lane change test) and lateral stability (yaw damping test). Additionally, calculations had been carried out to investigate the transferability of the results. Based on the available data, it was shown that there is no negative impact of the propelled trailer to the stability of the towing vehicle and vehicle combination, provided that there is always a remaining towing force in the towball, and no torque vectoring between the trailer wheels. It was also found that handling benefits from a driven trailer. Theoretical calculations show that when these two conditions are met (=no torque vectoring, no pushing), propelled trailers are safe with regards to driving dynamics. Theoretical calculations also show that torque vectoring has a potential to even further improve handling and stability, however possible faults of the drive system and control strategy could negatively influence handling and stability. The study had been carried out with only two prototype vehicles. Calculations checked that the results can be transferred to almost all kinds of trailers. Articulated trailers that have a steering of their own, however, need to be excluded from the conclusions without further research. Trailers for single-track vehicles (motorcycles, bicycles) are still under investigation. As a conclusion, it has been identified that propelled trailers where a towing force in the coupling remains (=the trailers compensate their driving resistance only partially, they do not push the towing vehicle) and without torque vectoring do not have negative effects on the stability of the combination and can have possible effects on the handling. This is true for non-articulated trailers, including semi-trailers and central-axle trailers. Regulations could as a next step be adapted, so that the positive effects towards traction and energy efficiency could be demonstrated. Also, as a next step, the benefits and possible issues with torque vectoring should be identified.

PAPER NO.23-0082-O

Reducing fatalities in road crashes in Japan, Germany, and USA with V2X-Enhanced-ADAS

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Abstract

Objective While Advanced Driver Assistance Systems (ADAS) improve safety, on-board sensors such as cameras, radar and lidar have limitations in preventing crashes: a) early recognition of non-line-of-sight (NLOS) vehicles and vulnerable road users (VRU: pedestrians, bicyclists, and motorcyclists) and b) early recognition of the intention of other road users. V2X technology can overcome this challenge. Basic V2X use direct short-range communication between vehicles and provides only a gradual solution toward improving ADAS. First, the slow introduction rate of V2X results in a low likelihood of both vehicles being equipped with V2X and therefore in preventing a crash. Second, there are impediments to VRU participation in V2X communication, resulting in a lack of VRU protection in NLOS scenarios. Collective Perception V2X using sensor data sharing can help to protect vehicles without V2X technology. Collective Perception V2X can also help to protect VRU by sharing information on road users that is collected by sensors in other vehicles or on intelligent infrastructure. The first objective of this paper is to quantify how Basic V2X can address fatal crashes in conjunction with ADAS by improving situational awareness in non-line-of-sight scenarios, and by providing information on the intention of traffic participants in critical situations. The second objective of this paper is to quantify how Collective Perception V2X can further boost the effective equipment rate in vehicles and protect VRU that are not otherwise protected by Basic V2X and ADAS. Method Using crash statistics from Japan, Germany, and the US, we analyzed the share of fatal crashes between vehicles and VRU. Crash scenarios due to limitations of on-board sensors were identified to quantify the target population for V2X. Starting with the V2X introduction rates presumed by the US DOT NPRM, we modeled the effective V2X communication rates for vehicles and VRU over time, assuming that all vehicles were equipped with ADAS. We analyzed the benefit of Basic V2X, in addition to conventional ADAS, in addressing vehicle-vs-vehicle and vehicle-vs-VRU crashes. We investigated whether Collective Perception V2X could increase the effective communication rate between vehicles. Additionally, we examined how Collective Perception V2X could help to detect VRU that are insufficiently addressed in NLOS circumstances. The analysis included intersections with potential intelligent infrastructure and roadways without infrastructure. Results The following three fields-of-action of Basic V2X and Collective Perception V2X were identified, and the potential in addressing vehicle-vs-vehicle and vehicle-vs-VRU crashes, were quantified: - Basic V2X raises the awareness of other equipped vehicles, - Collective Perception V2X boosts the effective vehicle equipment rate, - Collective Perception V2X protects VRU that are otherwise unprotected. Outlook The results indicate that the combination of Basic V2X, Collective Perception V2X, and ADAS can be highly beneficial for road safety. It is therefore important to ensure sufficient and protected frequency spectrum in the 5.9 GHz band for basic and advanced V2X messages like BSM/CAM and SDSM/CPM. Subsequent research should focus on analyzing the potential of V2X for automatic emergency braking, including safety level considerations when utilizing over-the-air V2X data.

PAPER NO.23-0103-O

Automatic emergency braking – How can we set the bar to maximize safety?

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Abstract
It is estimated that Automatic Emergency Braking (AEB) systems could potentially help mitigate 80% of rear end and pedestrian/cyclist crashes assuming they can stop the vehicle under all circumstances. In practice, however, technical limitations of systems (sensors, control unit, and actuators), vehicle dynamics, and environmental conditions (e.g., lighting, road conditions) reduce the overall crash avoidance performance of AEB systems. In an effort to better understand these limitations, Transport Canada initiated a study aiming at establishing the general AEB performance of the Canadian vehicle fleet. Three collision scenarios from recognized test protocols were considered: 1) stopped lead vehicle, 2) slower moving lead vehicle, and 3) crossing pedestrian. A total of 43 light duty vehicles (passenger cars, SUVs, and pickup trucks) from 26 different manufacturers were tested for car-to-car scenarios, and 30 vehicles were tested for car-to-pedestrian scenarios. Vehicles' model years ranged from 2013 to 2022. The large sample size of this study covers a significant proportion of the most popular vehicles sold in Canada. To ensure test repeatability, vehicles were equipped with precision positioning systems, audio alert detectors and driving robots. The optimal AEB operating speed range needed to address most real-world collisions was determined from recent crash data. Overall, the performance of vehicles tested was found to improve over the years when compared to the thresholds defined in the U.S. DOT/NHTSA Commitments, but a large proportion struggled to meet the requirements defined in UN regulation No. 152. Interestingly, the results obtained with the best performing systems suggest that it is now possible to achieve even better speed reduction outcomes than the criteria defined in the selected references The results of this study demonstrate that, with the continuous improvements of AEB systems, it is now possible to exceed performance levels defined in existing requirements. Technological advancements and added capabilities, including pedestrian detection, continue to increase the crash avoidance potential of these systems and, thus, enhance road safety. The methods and criteria evaluated in this study can help to inform future international policy and regulatory requirements.

PEER REVIEW PAPER NO.23-0114-O

Effects on crash risk of automatic emergency braking systems for pedestrians and bicyclists

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Research
The first Automatic Emergency Braking (AEB) systems were introduced in 2008 aimed to reduce rear-end crashes. Since then, several AEB systems aimed to reduce other collision types have been introduced. Studies have been showing that they are effective in reducing crashes. The aim with this study is to show crash reductions of cars fitted with AEB systems with detection of pedestrians and those with detection of bicyclists.

Methods
The Swedish Traffic Accident Data Acquisition (STRADA) was used that includes road traffic accidents reported by the police and by emergency hospitals. Crashes occurring between 2015 and 2020 and with cars of model years 2015 to 2020 were included. The statistical analysis used odds ratio calculations with an induced-exposure approach where the outcomes of sensitive and non-sensitive crashes were studied. The sensitive crashes were hit pedestrians and bicyclists respectively. The non-sensitive crash type used were in both comparisons struck vehicles in rear-end crashes. Evaluations were also made for different light conditions, weather conditions and speed limits.

Results
A total of 903 hit pedestrians and 1475 hit bicyclists were included. The non-sensitive crashes consisted of 1978 vehicles struck in the rear. The overall effect on crash risk for AEB with pedestrian detection was a reduction of 13% (+/- 15%) and for AEB with bicyclist detection 17% (+/- 17%). None of these reductions were statistically significant. When separating for light conditions no reduction in crash risk either for AEB with pedestrian detection nor for AEB with bicyclist detection could be seen in darkness. However, in daylight and twilight conditions AEB with detection of pedestrians was found to reduce pedestrian crash risk with 18% (+/- 17%) and AEB with detection of bicyclists was found to reduce the bicyclist crash risk with 20% (+/-18%). With the data material available no significant findings could be seen when separating for weather conditions and speed limits.

Discussion
It is positive to see that AEB systems with detection of pedestrians and bicyclists both show a crash reduction. The findings regarding the performance regarding AEB for pedestrians in various light conditions were in line with another recent study. The studies clearly show that it is important that detection in darkness is improved. This is especially important regarding pedestrians as studies show that they to a large extent are struck in darkness. The reductions in number of crashes found were the overall reduction at for example all speed limits, road types and weather conditions. The Swedish car fleet has a larger proportion of Volvo models than other countries, which should be considered in comparisons with studies from other countries.

Conclusion
AEB systems with detection of pedestrians and bicyclists were found to reduce the numbers of hit pedestrians and bicyclists, but only in daylight and twilight conditions. In darkness no reduction for either hit pedestrians nor bicyclists were found. To the authors knowledge this is the first study that evaluates crash reduction for AEB with detection of bicyclists.

PAPER NO.23-0306-O

ADAS Reliability against weather conditions: quantification of performance robustness

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Abstract
Advanced Driving Assistance System (ADAS) technologies provide an additional safety layer besides human drivers. Continual evaluation of the safety of the dynamic driving task enables ADAS to initiate a corrective (e.g., automated braking) and/or a preventative (e.g., audio-visual alerts) action if and when an unsafe roadway event is detected. To provide situational awareness, these safety systems principally rely on the vehicle mounted sensors whose performance can be greatly affected by weather events such as strong sunlight, atmospheric precipitation (rain, snowfall, fog), etc. Correspondingly, this study was conducted to characterize the performance of ADAS features in different weather conditions. Automated emergency braking (AEB) was selected as a representative ADAS feature. Two vehicles under test (VUT) were equipped with perception sensors such as LiDAR, RGB camera, infrared camera, radar, inertial measurement unit, GNSS, etc. Relevance and prominent use of these sensors in pre-production and developmental driving automation systems are widely reported in the literature. In addition, the data available through the OBD-II port of the VUTs was also recorded with temporal correspondence with the external sensors. Although weather related tests involving automotive systems have been traditionally performed in weather chambers, adoption of these test protocols for ADAS testing can be challenging. Because testing of ADAS must be performed dynamically, a runway of several hundred meters is necessary, and typical weather chambers cannot accommodate this requirement. Alternatively, this study utilized naturally occurring weather events to record AEB performance. For the purpose of this study, AEB tests performed under optimal weather conditions (sunny and bright) constituted the baseline performance. The same tests were performed in a number of different weather and roadway conditions, e.g., day/night, snow covered asphalt, persistent snowfall, overcast, rainfall etc. A number of metrics resulting from the test data analysis were used to quantify AEB performance in adverse weather conditions. These include distance of the test target when AEB system detected an imminent collision in different weather conditions, distance of the test target when AEB initiated an automated braking action in different road surface conditions (dry/wet asphalt vs snow covered asphalt), and whether AEB was successful in stopping a collision from happening in the test scenarios. These metrics helped to identify the failure modes of AEB in adverse weather conditions. It should be noted that quantification of ADAS performance robustness against adverse weather conditions is closely related to quantification of operational design domain (ODD), which is an emerging topic in driving automation systems literature. Nonetheless, observations and inferences made from this study will be used to design more comprehensive and elaborate test protocols for ADAS that are expected to improve in system capacity and ODD in near future.

PEER REVIEW PAPER NO.23-0104-O

The ideal vulnerable road user – A study of parameters affecting VRU detection

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Research
In 2020, Vulnerable Road Users (VRUs) accounted for 17.5% of total Canadian road fatalities and 18.4% of injuries according to Transport Canada's National Collision Database. Advanced Driving Assistance System (ADAS) technology has the potential to reduce the risk to VRUs the research objective was to determine through track testing activities, which parameters influenced the detection of pedestrians and cyclists.

Methods
Since 2015, Transport Canada and PMG Technologies have been conducting research on ADAS with a focus on Automatic Emergency Braking systems (AEB) and VRU. The track testing methods used followed the Euro NCAP AEB VRU test protocols, and derivatives thereof. The standardized articulated adult male pedestrian (EPTa), eight-year-old articulated child pedestrian (EPTc) and adult bicyclist (EBT) targets were used as the control group. An iterative test approach was used to benchmark the detection capabilities of systems with variations in target configuration and environmental conditions against these control group. Over 1,400 track tests using 38 scenarios have been conducted using 13 vehicles (model year 2019-2021). The environmental conditions included nighttime, snowfall, and snow-covered roads. Pedestrians were dressed in winter clothing and accessories including, hat, jackets of different colours, backpack, and umbrella. Adult and child pedestrian targets were joined to generate obstructions and alter their silhouette with the intent of challenging vehicles with realistic urban-like scenarios. The scenarios were selected and designed to reflect real world situations where drivers could benefit from ADAS assistance. All variation from the test protocols was documented with the purpose of recording influential parameters. The vehicles were equipped with positioning systems, audio, and visual alert detectors, and driving robots. The data collected was used to compare the timing of forward collision warnings emitted by the systems between different test configurations relative to the baseline condition.

Results
This study illustrates how iteration outside the control condition can affect the vehicles' performance. More challenging weather conditions and urban like scenarios on the test track challenged some vehicles more than others as compared to the control condition.

Discussion
ADAS equipped vehicles are increasingly exposed to less-than-ideal road conditions and a wide range of pedestrian profiles. Understanding system limitations in a controlled environment enables to evaluate their potential in the real world, how they perform and what parameters affect their responses. Limitations of this study include the small sample size of the vehicles used as compared to the Canadian fleet and the selected number of VRU scenarios possible on the test track to represent real world conditions.

Conclusion

Vehicles tested have various levels of performance and capabilities when mitigating risk to VRU. This paper presents opportunities to quantify potential safety benefits when vehicles are operated in a more challenging environment. The results also serve as an indicator of robustness of this type of system for all situations. This paper describes a study highlighting the importance of VRU avoidance technologies in making the roads safer.

Advances in Experimental and Mathematical Biomechanics and Human Injury Research

Tuesday, April 4, 2023, | 2:00-6:00

Chair: Matthew Craig, United States | Co-Chair: André Eggers, Germany

TRACK A | Room: G303

PAPER NO.23-0030-O

Development of a human body model (THUMS Version 7) to simulate kinematics and injuries of reclined occupants in frontal collisions

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Abstract

This paper describes the development of THUMS Version 7 which is a virtual human body model (HBM) to be used for simulating impact kinematics and injuries of occupants assuming a reclined seating posture in vehicle frontal collisions. In highly automated vehicles, it is expected that occupants wish to take various sitting positions including a reclined posture. Prior research has found that there is a relatively high possibility of injury to the occupant for a reclined posture in vehicle collisions. If the lap belt engagement with the pelvis is lost in a frontal collision, there is the possibility that the internal organs are highly loaded. The latest released Version 6 does not have precise representation of the small intestine but has a generic soft solid. It was decided to upgrade THUMS for accurate prediction of internal organ injury. The geometry and mechanical properties of the small intestine and the other relevant body parts were fundamentally revised in Version 7. The interaction between the pelvis and lap belt was most important in simulating occupant kinematics leading to the abdominal loading. The pelvis dimensions and soft tissue thickness of the anterior pelvis were carefully reviewed to represent the belt-pelvis interaction in the average body-size occupant. Three anthropometry models were generated: 5th-percentile adult female (AF05), 50th-percentile adult male (AM50), and 95th-percentile adult male (AM95). The geometry and material properties of the abdominal soft tissue, small intestine and mesentery were carefully defined to realistically reproduce the mechanical responses during the abdominal loading by referring to the loading test data on actual human tissues reported in the literature. The lumbar spine was also revised. Prior research has found that the lumbar spine receives a high load when the pelvis is firmly restrained to prevent disengagement of the lap belt in a reclined posture. The material properties of the intervertebral discs and spinal ligaments were carefully reviewed. The validity of the updated models was examined by comparing the mechanical responses with the test data from Post Mortem Human Subjects (PMHS). It was confirmed that the Version 7 responses generally matched the test data or fell within the test data variability. The validations were performed at both component and whole-body level by referring to the available test data.

PAPER NO.23-0050-O

Determination of best practices for human body model gravity settling

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Abstract

The simulated action of coupling a computational human body model to a vehicle seat, commonly referred to as model settling, is an essential, initial aspect of any crash simulation. There is a gap in knowledge related to the necessary duration of this activity to sufficiently couple the human model to the seat. In this study, THUMS v4.1 was gravity-settled in two postures, an upright driver, and a reclined occupant, into a seat model. Simulations were performed using three seat foam stiffnesses, three friction coefficients and both with and without a constraint on the motion of the pelvis for a total of 18 simulations per posture. Each simulation was run for 800 ms, a time determined to be sufficiently long to identify a settled end state. In separate simulations, a 0.5g magnitude, 200 ms half sine wave pulse was applied to the seat in the backwards direction to measure coupling between the human body model (HBM) to the seat. Model quality metrics were measured at the first four kinetic energy local maximums and local minimums to compare physically consistent time points between simulations. Kinetic energy, contact penetrations, change in HBM element quality, seated contact area and seat pressure were measured and compared to this settled end state. A pass/fail range was assigned to each metric. A pass was assigned if the value fell within ±1 standard deviation of the average simulated end state value at 800 ms (contact area, seat pressure) or between the simulated end state value and the baseline THUMS value (contact penetrations, model quality, perturbation test). A passing time point for a simulation received a score of 1, a failing time point for a simulation received a score of 0. Scores for all simulations were added and normalized for each local maximum and local minimum, and the first time point to receive a score greater than 3 (out of 5) and pass the perturbation test was determined to be sufficiently settled. The third kinetic energy local minimum was selected for the upright driver posture and third local maximum for the reclined occupant. Both have average gravity settling times of approximately 405 ms. The pelvis constraint appeared to contribute to a more rapid arrival at the long term settled state for the upright seated posture. Constraining the pelvis is not recommended for the reclined posture. The results suggested that for best practice a settling time of at least 400 ms is required to sufficiently couple the model to the seat in either posture.

PAPER NO.23-0094-O

Investigation on effective approaches of brain FE modeling to improve its validation performance on brain deformation during head impact

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Abstract

The finite element (FE) model of the human brain is an effective tool for predicting brain strain during head impacts that can result in traumatic brain injury (TBI). Although many brain FE models have been proposed and updated upon thus far, it was unclear what kind of modeling approaches would critically contribute to improving the biofidelity of the models. This study investigated whether the implementation of material anisotropy of the brain tissue or the appropriate representation of the boundary conditions around the ventricle would affect the validation performance of modeling brain deformation during head impact. Axonal fiber tracts of the whole brain were extracted from diffusion-weighted images in the Amsterdam Open MRI Collection using tractography. The direction of the material axis in each element of the white matter of the previously developed human brain FE model was determined based on axonal fiber tracts. Incompressible fluid dynamics (ICFD), including perfusion pressure, was also applied to the intraventricular cerebrospinal fluid (CSF) of the model. Validation of the displacement and strain in the brain during head impact was performed based on cadaveric test data, wherein quantitative evaluation of validation accuracy was conducted using the CORrelation and Analysis (CORA) method. The CORA scores of the model were compared with those of the model with isotropic material or those of the model without ICFD. The difference in CORA scores for brain displacement was minimal among the models. On the other hand, the CORA scores for brain strain of the model with ICFD were higher than those without ICFD. However, CORA scores for the brain strain of the anisotropic model based on the axonal fiber tracts were similar to or lower than those of the isotopic model. Comparing CORA scores among the models indicated that introducing ICFD to the intraventricular CSF improved the validation performance of the brain FE model. However, implementing anisotropy of the white matter based on tractography at the element level does not necessarily improve the validation performance of the brain FE model. In addition, evaluating the validation accuracy of the brain FE model using brain displacement did not reflect the difference in the accuracy of predicting brain strain during head impact. A limitation of this study includes the spatial registration of axonal fiber tracts with the FE model using affine transformation. It would be more desirable to consistently conduct FE modeling and tract extraction so that the differences in brain geometry and axonal fiber pathways for each subject could be considered. The findings in this study indicate that the appropriate representation of the boundary condition around the ventricle using ICFD would affect the validation performance on the brain strain in the brain FE model rather than the accuracy of the description of the anisotropy at the element level. These findings may provide useful insights into modeling strategies of the human brain to predict TBI due to head impact associated with traffic accidents.

PEER REVIEW PAPER NO.23-0118-O

Response of small female and average male model with active musculature in pre-crash braking and low-speed impacts in frontal-oblique direction

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Research
The need for human body models capable of predicting occupant kinematics in pre-crash and low-speed scenarios has led to the development of active models. It is equally important to validate these active models using volunteer data. The objective of this study was to validate computationally efficient small female (54.1kg, 149.9cm) and average male (78.4kg, 174.9cm) models with active muscles using volunteer data in a frontal-oblique loading direction.

Methods
The Global Human Body Models Consortium small female (F05-OS+Active) and average male (M50-OS+Active) simplified occupant models with active musculature were used in this study. Both models have been previously validated in the frontal loading direction. The models use a PID controller-based muscle activation strategy, which uses joint angles and muscle lengths as control variables. Occupant responses of six 5th percentile female and six 50th percentile male volunteers (n=12 total) were recorded in two muscle conditions (relaxed and braced) at two acceleration pulses representing pre-crash braking (1.0g) and a low-speed impact (2.5g). All experiments were performed in a rigid buck with a principal direction of force of 330°. Kinematics were measured using a VICON motion capture system. Multi-axis load cells were used to measure reaction loads at each test buck interface. A total of 48 experimental tests were performed. The data from these experiments were used to simulate a total of 16 simulations in a full factorial series with; two acceleration pulses (1.0g and 2.5g), two models (F05-OS+Active and M50-OS+Active), two muscle states (activation and control, i.e., no activation), and two muscle conditions (relaxed and braced). Each model's kinematics and reaction forces were compared with experimental data. A CORA analysis was carried out using reaction load time-history data. The difference between the active and control model was checked for statistical significance by performing Wilcoxon signed-rank tests using peak forward and lateral excursion data.

Results
The occupant peak forward and lateral excursion results of both active models reasonably matched the volunteer data in the low-speed sled test simulations for both pulse severities. The differences between control and active models were statistically significant in 7 out of 8 cases. The CORA scores calculated using reaction loads were higher for active models than control (average CORA scores: M50-OS+Active= 0.568, male control= 0.491, F05-OS+Active= 0.612, female control= 0.481).

Discussion
There are a limited number of studies that have focused on validating 5th female active human body models due to the limited availability of 5th female-specific experimental data. This study bridged that gap by validating the F05-OS+Active model using experimental data and at the same time comparing its results with the average male model, which was the focus of many prior studies. One limitation of this study was the lower CORA scores for the active model. However, this can be resolved in follow-up studies by adjusting PID controller parameters for acceleration severity and muscle condition.

Conclusion

The response of the F05-OS+Active and M50-OS+Active models were in good agreement with the volunteer data. The results highlight their ability to predict occupant kinematics in pre-crash maneuvers and low-speed impacts in the frontal-oblique direction.

PAPER NO.23-0123-O

Field assessment of GM/OnStar occupant-based injury severity prediction models

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Abstract

Injury Severity Prediction (ISP) models provide emergency responders with a rapid assessment of potential serious injury for occupants in vehicle accidents around the globe. ISP models predict the need for high level trauma care so that appropriate Emergency Medical Services (EMS) can be dispatched as quickly as possible to improve patient outcomes. In 2020, OnStar implemented its first occupant-based ISP models which predict outcomes for specific seating locations.[1] Models were developed and validated with NHTSA NASS CDS [2] and CISS [3] data. This paper seeks to assess model performance in the field using vehicle-based crash data and real-world occupant outcomes. This study leverages data from a sample of over 1,500 Michigan Advanced Automatic Crash Notification (AACN) events involving over 1,700 front row occupants to assess model performance. Vehicles include model years 2013 to 2020 and span several segments, including passenger cars, SUVs, and light trucks. AACN telemetry data and ISP-predicted outcomes are compared to actual Injury Severity Scores (ISS) for transported occupants. For non-transport cases, police reported injury severities (KABCO scores) are also examined. Measures of sensitivity, specificity, and likelihood ratio are calculated. False negative cases are used to understand model limitations. A range of threshold values used to assess "high" injury risk are also explored to highlight potential tradeoffs. Statistical analyses show that front row occupant models predict ISS 15+ injuries with high levels of accuracy. Metrics compare occupant-based model performance to prior vehicle-based ISP formulations. This study demonstrates that models based on government-sampled data sets are producing reliable results in the field.

PEER REVIEW PAPER NO.23-0129-O

Thoracic and pelvic responses and injuries to Post-Mortem Human Subjects (PMHS) in rear-facing seat configurations in high-speed frontal impacts

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Research
One potential non-standard seating configuration for vehicles with automated driving systems (ADS) is a reclined seat that is rear-facing when in a frontal collision. There are limited biomechanical responses and injury data for this seating configuration during high-speed collisions. The main objective of this study was to investigate thoracic and pelvic biomechanical responses and injuries to male post-mortem human subjects (PMHS) in the rear-facing scenario with varying boundary conditions.

Methods
Fourteen rear-facing PMHS tests were conducted at two different recline angles (25 deg and 45 deg) in 56 km/h frontal impacts. PMHS were seated in two different seats, one used a fixed D-ring (FDR) belt, and one used an All Belts To Seat (ABTS) restraint. A reinforcing frame that included load cells to quantify inertial loading from the PMHS was installed behind the seat back of the OEM seats. For thoracic instrumentation, strain gages were attached to ribs to quantify strain and timing of fractures. A chestband was installed at the mid-sternum level to quantify chest deflections. For pelvic instrumentation, three accelerometers and three angular rate sensors were installed on each iliac wing to quantify pelvic kinematics. Data from these thorax and pelvis instrumentation were analyzed to determine injury mechanisms.

Results
Rib fracture location, distribution, and frequency were quantified to understand the influence of the seat, restraint type, and seat back recline angle. The PMHS sustained more rib fractures in the 45-degree recline condition (average of 30 fractures for FDR and 12 for ABTS) than the 25-degree recline condition (average of 16 fractures for FDR and 6 for ABTS). Four PMHS sustained pubic ramus fractures due to eccentric inertial loading from the lower extremities during the occupant's motion into the seat.

Discussion
The rib fractures from the ABTS condition were not as symmetric as the FDR condition in the 25-degree recline angle due to a belt retractor structure located at one side of the seat back frame. However, this was not as obvious as in the 45-degree recline angle. Average peak chest compression occurred around 44 ms and 47 ms in the ABTS and FDR conditions, respectively. Over 65% of the rib fractures occurred after peak chest compression when the abdominal contents shifted rearward and upward into the thorax due to the ramping motion of the PMHS. This implies that most rib fractures likely occurred due to a combination of chest compression and expansion with upward shear loading. PMHS with pubic ramus fractures exhibited more extensive off-axis rotations (e.g., over 10 deg rotation about the Z-axis) due to outward deformation of the pelvis. Since PMHS responses and injury information in rear-facing high-speed impacts are very sparse in the literature, these limited findings should assist to better understand PMHS thoracic and pelvic injuries.

Conclusion
The thoracic and pelvic responses and resulting injuries from this study will guide the improvement of FE human body models and anthropomorphic test devices to better reflect occupant response in rear-facing seat configurations during high-speed frontal impacts.

PAPER NO.23-0133-O

Comparison of injury predictors and kinematics of Human Body Models representing average female and male road users in car crashes.

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Research
The aim of the study was to investigate the effect of gender-specific differences in anthropometry for kinematics and injury risk in car occupant and vulnerable road user (VRU) crashes.

Methods
The open-source VIVA+ human body models (0.3.0) were used, which have been previously validated on component and full-scale levels. The 50th percentile male (50M) and the VRU models differ from the baseline, seated 50th percentile female (50F) model only in terms of geometry (derived from regression models) and mass distribution. Kinematics and injury predictors (head and neck criteria; strain-based rib and lower extremity fracture risks) of the 50F and 50M VIVA+ models are compared for five different crash scenarios: pedestrian/cyclist impacted by a car and car occupant in rear/frontal/near-side impacts. For the VRU impacts, a generic car front was used for simulation of collisions with 40 km/h at the vehicle centreline. For the occupant simulations, a generic vehicle interior was used for the frontal and side impacts, while a developed open-source seat model was used for the rear-end impacts, which was validated with the novel Seat Evaluation Devices (SET), matching the VIVA+ anthropometries. Generic crash pulses representative for consumer-test load cases were applied. For the rear-end impacts, real-world crashes with known injury outcomes were simulated additionally. All tools and results described in the paper will be openly and freely accessible.

Results
For the frontal impacts, different interactions with the airbag and submarining are observed for the female. Rib fracture risk was slightly higher in the female (10% higher 3+ risk), while brain injury risk was twice as high for the male. In the side impact, higher (+20%) rib fracture and brain injury risk were observed for the male. Differences in belt interaction caused higher strains for the female on the non-struck side of the ribs. In the rear-end impacts, kinematic differences between female and male were observed in all load cases. With the Euro NCAP pulse, higher T1 peak accelerations and NIC values were observed in the male. In the reconstructed real-world cases, no clear trend for NIC was visible. In the VRU impacts, differences in impact locations were observed. The strain-based assessment showed remarkable higher injury predictors for the femur (e.g., 99% vs. 15% fracture risk for proximal femur), thorax (three times higher risk) and pelvis for the 50F compared to the 50M.

Discussion
Material models were not modified between the male and the female HBM. This enables to compare geometric effects, but considering additional sex-specific effects (e.g. bone density) could further increase the differences. NIC values did not differ significantly between females and males nor between injured and non-injured real-world cases, showing the need to consider alternative criteria such as pressure transient in the cervical spinal canal, which showed better correlation with the observed injuries. Further research is needed to map the observed differences to injury risks.

Conclusion
Differences between the response of an average female and male model were observed throughout all load cases. This indicates a benefit of adding the average female anthropometry for safety evaluations to ensure gender-equal protection.

PEER REVIEW PAPER NO.23-0140-O

The effect of follower load on Lumbar Spine Flexion-extension response

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Research

Reclined occupants without knee restraint in frontal crash tests and computational simulations have exhibited high magnitude combined axial compression and flexion bending, and compression-flexion fractures of the lumbar spine have been produced in sled testing with post-mortem human surrogates (PMHS). We hypothesize that the mechanical response of the lumbar spine to flexion loads is affected by superimposed axial compression. The goal of this study is to measure the biomechanical response of the human spine in flexion and extension bending both with, and without, a superimposed axial compression load.

Methods
A highly repeatable 6DOF force/torque- and position-controlled robotic test device was employed to subject seven PMHS lumbar spine (T12-Sacrum) specimens to combined loading experiments. The device was modified to incorporate parallel closed-loop feedback control of a follower load mechanism that applied and directed 0N, 900N, or 1800N of axial compression load along the curvature of the spine and maintained the load while the robotic test device applied non-injurious pure flexion and pure extension bending loading. The data collected include force/moment data (from load cells) and 6DOF kinematics data for each vertebra (using a stereophotogrammetric motion tracking system). The kinetic (moment/angle) and kinematic (L3/L1 or L5/L1 rotation) responses of the individual specimens were analyzed to evaluate variations across the sample for each of the test conditions. These data were organized into biomechanical response corridors to facilitate their use in evaluating biofidelity of anthropomorphic test devices (ATDs) and computational human body models (HBMs).

Results
The lumbar spine specimens exhibited a nonlinear kinetic response in flexion and a generally linear kinetic response in extension in the absence of axial load. With increasing axial compression load, the response in flexion became more linear, and the responses in both flexion and extension showed

increases in stiffness. Kinematically, the deformations of the spines were asymmetric, with the greatest intervertebral rotation occurring at L5-S1 in flexion, and this locus of deformation moving to the L2-L3 joint in extension.

Discussion

We hypothesize that these changes in response are due to axial compression causing greater engagement of the lumbar's facet joints, which creates a parallel load path, ligament unloading and intervertebral disc pre-stressing. The methodology of the study was devised to isolate specific loading modes of the spine and for the specific purpose of using the collected data to evaluate the response of occupant surrogate models like ATDs and HBMs. However, because multiple directions were assessed in multiple tests with the same specimens, the magnitudes of loading were relatively low (+/-22.5 deg in flexion/extension), so this analysis should be carried forward to loading magnitudes that approach failure in the future.

Conclusion

The mechanical response of the lumbar spine is affected by the presence and magnitude of axial compressive load. Since the lumbar spine is subjected to substantial combined compression-flexion loading in reclined frontal impacts, occupant surrogates like ATDs and HBMs targeted to predict occupant response in such postures should ideally be able to represent the complex loading response of the spine to facilitate their use in predicting injury risk.

PAPER NO.23-0149-O

Injury risk estimation in far-side impacts using small female and average male finite element human body models

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Abstract

Far-side crashes are the second-highest, after near-side impact crashes, cause of MAIS 3+ injuries to occupants for ΔV above 48 kph. The objective of this study was to estimate and compare injury risks between a small female and an average male occupant in far-side crashes using finite element human body models (HBM) in a simplified vehicle environment. To study far-side crashes, 126 simulations were conducted as a design of experiments (DOE) by varying lateral ΔV (10-50kph; 5kph increments), the principal direction of force (PDOF 50°, 60°, 65°, 70°, 75°, 80°, 90°), and occupant model. Occupant models used were the Global Human Body Models Consortium (GHBMC) 5th-percentile female (F05) and 50th-percentile male (M50) simplified models (-OS) with a modular detailed brain (+B). Overall skeletal structures are shared between the detailed and simplified models which allows the modular use of detailed parts in simplified models. Models were gravity settled and belted into a simplified vehicle model (SVM) modified for far-side impact simulations. The far-side SVM (FSVM) has both driver and passenger seats and door intrusion on the far side implemented. Acceleration pulses and vehicle intrusion profiles used for the DOE were generated by impacting a 2011 Camry vehicle model with a mobile deformable barrier model across the 7 PDOFs and 9 lateral ΔV's in the DOE for a total of 63 additional simulations. The impacted surface of the Camry was instrumented to measure relative

displacement into the vehicle to generate an intrusion profile. Injury risks were estimated for the head and chest (AIS2+; AIS3+) and abdomen and pelvis (AIS3+). Overall AIS3+ injury risk for each occupant was calculated using AIS3+ injury risk estimations for the head, chest, abdomen, and pelvis. A Wilcoxon signed-rank test was used to test for significant differences between estimated risks for F05-OS+B vs. M50-OS+B. Statistically significant differences between F05-OS+B and M50-OS+B were found for AIS2+ risk of head injury and AIS3+ risk of head, chest, and pelvis injury. No significant differences were found for AIS3+ risk of an abdominal injury and AIS2+ risk of chest injury. The overall risk of AIS3+ injury was higher for the M50-OS+B than the F05-OS+B in 84% of cases. Injury risk increased with an increase in lateral ΔV which was in agreement with studies found in the literature. An investigation of injury risks associated with far-side crashes was undertaken for both an average male and small female HBM. Differences observed in the estimated injury risks suggest that occupant size should be taken into consideration in safety system design. While this study used an FSVM with a rigid center console and dashboard, the relative differences between models were investigated. The effect of occupant size/sex on injury risk was highlighted by differences in overall injury risk for small female vs. average male HBMs. The study describes a method for simulating far-side crashes with an SVM that can include an estimation of intrusion.

PEER REVIEW PAPER NO.23-0152-O

Analysis of injury mechanism & thoracic response of elderly, small female PMHS in near-side impact scenarios

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Research

In 2019, 7,214 occupants 65 and older were killed in car crashes in the United States, which is a 31% increase for this age group since 2010. When compared to occupants less than 65 years of age, older occupants are more frequently killed in near-side crashes. Crash data has also revealed that for small, older female occupants, thoracic related injuries are among the leading causes of fatality. Historically, biofidelity response corridors and injury criteria for small females have been determined by scaling values from mid-size male data sets. In addition, the majority of past near-side impact PMHS studies used a generic load wall to capture external loads that were applied to PMHS. While these data were helpful in documenting biofidelity, they did not represent a realistic response an occupant would undergo in a near-side impact due to the lack of door intrusion, airbag deployment and use of standard restraints with pretensioners. The objective of this research was to test small, elderly female PMHS and 5th female ATDs in a repeatable, realistic near-side impact crash scenario to look at the appropriateness of the ATD and currently accepted injury criteria as they relate to this vulnerable population.

Methods
Ten small, elderly PMHS and both the SID-IIs and WorldSID 5th percentile ATDs were subjected to a more realistic near-side impact loading condition. The boundary conditions included an intruding driver's side door that was controlled using the Advanced Side Impact System (ASIS) (DSD, Austria) on a HYGE sled. The sled acceleration matched the acceleration profile of an impacted vehicle, while four pneumatic cylinders of the ASIS, covered by a typical door liner, produced realistic door intrusion. The PMHS were targeted to be elderly females age 65+, approximately 5th percentile in height and weight, with osteopenic areal bone mineral density. Each subject was seated on a mass-production driver seat, equipped with a side airbag and standard three-point restraint with a pretensioner. Instrumentation on each PMHS included strain gages on ribs 3-10 bilaterally, to help identify fracture timing. Two chestbands were used to measure chest deflection (on both PMHS & ATDs), one at the level of the axilla and one at the level of the xiphoid process.

Results
Injuries observed were primarily rib fractures, particularly on the struck side, and in multiple cases a flail chest was observed. Eight subjects resulted in AIS3+ injuries, despite the ATDs predicting less than a 10% chance of AIS3+ injury.

Discussion
Subjects crossed the threshold for AIS3 injury in the range of only 1% - 9% chest compression at the level of the xyphoid process. Additionally, mechanism of injury varied, as some injuries were incurred by door interactions while others came during airbag interactions.

Conclusion
This research points to two areas of concern that need to be further analyzed: (1) the appropriateness of simplified PMHS testing to document injury thresholds and define injury criteria for complicated crash scenarios; (2) the importance of understanding the timing of injuries to better understand the use of current passive restraint systems.

PAPER NO.23-0183-O

Influence of time constants and directional interaction of a kinematics-based brain injury metric on its predictive capability of brain strain response in car crashes

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Abstract
Among the studies focusing on criteria for brain injuries induced by the rotational motion of the head, one of the recent studies has compared the predictive capability of various injury criteria proposed by different studies, with the results showing that the best predictor depends upon specific impact configurations. This suggests the need for a more robust injury criterion across a variety of impact configurations with different duration of an impact event. The aim of this study is to investigate the effect of incorporating additional time constants and modifying directional interactions on the predicting accuracy of the physical model-based criterion called CIBIC (Convolution of Impulse Response for Brain Injury Criterion) proposed by the author's group. A Maxwell model was parallelly added to the simplified physical model (standard linear solid) of the CIBIC criterion to improve the time-dependent responses. One simplest candidate formulation of the cross-terms was tried to replace the originally

used root sum square to combine the three components of the strain. The Global Human Body Models Consortium (GHBMC) head/brain model was used to obtain the target response of the maximum principal strain (MPS). A step function with the magnitude of 10,000 rad/s2 was used to optimize the spring and damping coefficients. The spring and damping coefficients were optimized by maximizing the CORA (CORrelation and Analysis) score. The modified CIBIC was further validated against the GHBMC model using a total of 256 time histories of the head rotational acceleration representing those of the four groups of load cases (occupants in full-frontal, oblique-frontal and side impacts as well as pedestrian impacts). The coefficient of determination calculated from the correlation of peak MPS and the average value of the CORA score were compared between the original and the modified CIBIC. The modified CIBIC with the modified time constants was found to improve both assessment metrics for all of the four groups of the load cases, while both assessment metrics predicted by the modified CIBIC with the directional interaction was not improved. The effect of the modifications shown by the modified CIBIC suggest that further consideration of the directional interaction is needed to develop a robust criterion, requiring thorough investigations on the method to combine the responses of the three axes.

PAPER NO.23-0197-O

Test method for developing updated neck biofidelity corridors for a small female occupant

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Abstract
The continued development and improvement of crash evaluation tools for a variety of anthropometries, especially the small female, call for experimental testing to generate anthropometric-specific biofidelity targets. The effect of active musculature on head and neck response in impact loadings cannot be ignored, but data from volunteer testing at impact severities performed in the 1960s and 1970s at the Naval Biodynamics Laboratory (NBDL) is limited to the male response. To generate biofidelity targets for the head and neck response of the small female that include the effect of active musculature, modern testing must rely on combining PMHS data from different anthropometries and retrospective analysis of the original NBDL testing outputs and other volunteer studies. This paper describes the methodology to replicate the original NBDL testing for small female and average male PMHS for the purpose of informing new biofidelity corridors for the 5th percentile female neck. Publications related to the original testing were reviewed for qualitative and quantitative measures detailing the setup of the NBDL configuration. A custom buck with an upright seat (90° between seatpan and seatback), five-point rigid harness, footpan, and tether head support system was designed and fabricated for use with an acceleration sled. Of critical importance, the head and neck angle in the PMHS tests will be matched to NBDL initial positioning of -0.9° for head and 20.75° for neck. Two input pulse severities for frontal PMHS testing were chosen: a low severity at 3g peak acceleration and a moderate severity at 8g peak acceleration. These curves were chosen to avoid damage or injury to neck structures and to investigate the head and neck response at multiple severities. The boundary conditions on the sled will be measured via load cells and the PMHS kinematics will be measured through bone-mounted instrumentation packages and motion tracking arrays. This methodology will be used in experimental testing of small females and average males in the NBDL frontal impact condition.

PAPER NO.23-0242-O

The SAFER HBM – A human body model for seamless integrated occupant analysis for all road users

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Abstract
The development of the SAFER human body model (HBM) started in 2008 and is still ongoing. SAFER HBM is an omni-directional model that can be tuned and scaled (morphed) to correspond to humans of different age, sex, weight, and stature. The model can be positioned to the posture of occupants, pedestrians, bicyclists, motorcyclists etc. to enable analysis of road users inside as well as outside the vehicle. SAFER HBM is capable of predicting human kinematics in evasive maneuvers (low-g) as well as in crashes (high-g). The capabilities also include injury risk predictions in crashes. The model has been thoroughly validated and used in numerous studies. Some examples: The effect of reversible pre-tensioning of the diagonal belt on occupant kinematics and injury risk for pre-crash evasive maneuvers followed by a crash, the influence of different postures and anthropometries on occupant kinematics, and the injury reducing benefits of a helmet in bicyclist to car impacts have been evaluated. Based on results from these studies, the SAFER HBM is considered to be an efficient and biofidelic tool for development and validation of protection systems for road users inside and outside the vehicle.

PAPER NO.23-0276-O

Comparison of head-neck kinematics between isolated Finite Element (FE) head-neck model and full-body model in low severity rear-end impact

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Abstract

The objective of the present study was to analyze whether the kinematics of an isolated head-neck model can replicate those observed on a whole-body model in order to reduce simulation time in development or optimization tasks. Previous studies have shown how muscle controllers improved head-neck kinematics responses over a passive neck muscle implementation. These studies used volunteer T1 displacement time histories prescribed on the model T1 as the loading input to develop the neck controller characteristics. It was not clear whether the implementation of a controller based on

volunteer kinematics with an isolated head-neck model was directly transferable to a full-body model. The current study shows that the head-neck model produced almost identical responses as the full body model for the first 200ms of the event for most kinematic variables. The head rotational displacement corresponded well during the first 150ms. The isolated head-neck model predicted more displacement and rotations than when mounted on a full-body model. The current simplification of a head-neck model still produced reasonable kinematic responses during the critical time period to assess soft tissue neck injuries, making it suitable for developing and tuning neck muscle controllers.

Safety Performance in Side Impact and Rollover Crashes

Tuesday, April 4, 2023, | 2:00-6:00

Chair: Thomas Belcher, Australia | Co-Chair: Cecilia Sunnevång, Sweden

TRACK B | Room: G304

PAPER NO.23-0033-O

The analysis of mechanism and countermeasure for reducing thoracoabdominal injury risk caused by far-side impact

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Abstract

The European New Car Assessment Programme (Euro NCAP) added requirements in 2020 for the protection of far-side occupants. This is because in a side-impact accident, serious injuries can occur to passengers not only on the near (collision) side but also on the counter-collision (far) side. Analysis of National Automotive Sampling System/Crashworthiness Data System (NASS-CDS) far-side accidents from 2002 to 2015 revealed that serious injuries occurred not only to the head but also to the chest and abdomen. Liver injury accounts for 48% of all abdominal injuries in occupants with seat belts and is a type of trauma that must be noted in traffic accident lifesaving. For head protection, the Euro NCAP test provides criteria for head movement, but no method has been established to quantify liver injury. We attempted to quantify liver injury by simulation using a human body model. The simulation used the THUMS (Total HUman Model for Safety) human body model in which the shapes of major organs had been modeled. First, the load-displacement characteristics of the liver were modeled from the specimen level to those of the whole organ. Using the liver model, we simulated the behavior of the body in the far-side sled test performed by Pintar et al. and investigated the liver injury index. We found the maximum principal strain in the liver to range from 60% to 120% in the current model, resulting in laceration of the liver. Using the human body model, we then clarified the injury mechanism of the liver and examined how to reduce injury. In far-side accidents, it was found that the injury was caused by the upper body being catapulted toward the impact side. A simulation was conducted to determine whether a load on the right side of the occupant to prevent this sudden and forcible upper body could lessen liver injury. Simulation results show that the maximum principal strain on the liver can be cut from 120% to 60% by reducing the displacement of the tenth thoracic vertebrae (T10), corresponding to the height of the liver, to within 190 mm on the impact side.

PAPER NO.23-0283-O

Evaluation of THOR-50M, WorldSid-50M and GHBMC M50-O v6.0 Models in far-side crashes

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Abstract
This study is conducted to assess biofidelity of three occupant models (GHBMC human 50th%ile male occupant model M50-O v6.0, Humanetics male THOR dummy model v1.8.1 and WorldSid-50M model v7.6) in far-side crash test conditions and to better understand the kinematics and response of a far-side mid-sized driver in a compact size vehicle crashed to a 285° oblique right-side rigid pole at 31.01 km/h (NHTSA FMVSS 214 Test # 210915). Far-side occupant simulations for various sled and vehicle crash tests have been conducted. Firstly, the GHBMC human body model (HBM) is correlated with the three post-mortem human subjects (PMHS) far-side sled tests performed by University of Virginia (UVA) [1] at two crash severities and two impact directions. Secondly, a series of the far-side sled test simulations with paired HBM and anthropomorphic test device (ATD) cases are conducted, varying with severities and impact directions, seats, and central console presence. Lastly, occupant simulations are performed for a belted far-side mid-size male driver, represented by the HBM and the WorldSid-50M model respectively, in the subject compact passenger car in the FMVSS 214 pole test. Comparative analysis is made for the kinematics and responses of the HBM and the WorldSid-50M model at the vehicle crash. The HBM correlation results show that the GHBMC M50-O v6.0 human model reasonably correlates well with the PMHS kinematics and response from the 60-degree oblique far-side UVA sled tests. The HBM estimated high injury risk for the thorax is in line with the post-test PMHS injury outcomes. The comparative HBM-ATD studies at both the far-side sled tests and the vehicle pole crash test indicate that both ATD models have positive and negative biofidelity outcomes compared to the HBM. The THOR dummy has similar head/neck/torso kinematic and response measures compared to the HBM under the oblique sled test conditions, while its pelvis and lower leg respond poorly to the lateral inertia loads. The WorldSid-M50 dummy model has the whole-body kinematics similar to the HBM under the oblique sled test conditions, while it shows stiffer lateral bending of the torso and smaller chest deflections than the HBM especially under the lateral far-side loadings. The subject vehicle side crash test occupant simulation with the HBM predicts that the mid-size male driver may suffer severe injuries on the chest and moderate injuries on the head and abdomen.

PAPER NO.23-0130-O

Factors of severe injuries associated with side pole collisions based on field vehicle collision investigation

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Abstract
Side pole collision is the most devastating road traffic injury (RTI) that causes death or severe injuries among side collisions. Since pole-type materials have a relatively narrow width and fixed rigidity, side pole collisions cause severe deformation and consequent intrusion resulting in direct contact with the occupants. This study aimed to investigate the risk factors that contributes to a severe injury of motor vehicle occupants (MVOs) inside pole collisions. This study used the Korea In-Depth Accident Study (KIDAS) database collected from 2011 to April 2020. Among the total data, we analyzed 392 patients who were engaged inside collisions by excluding multiple collisions and rollovers. The collision type was classified into pole and non-pole (i.e., vehicle-to-rigid wall) collisions within a single collision. Moreover, we classified the collision severity according to the amount of crush extent (CE) zones. In this study, the incidence of non-pole collisions (n=362, 92.35%) was nearly 12 times higher than pole-related collisions (n=30, 7.65%). Factors affecting severe injuries showed statistical significance in the collision object ($p<0.001$), seat location ($p=0.001$), and CE zone ($p<0.001$). However, passive safety devices, such as seatbelts and airbags, showed no significance. In the case of side collision objects, there were statistical differences between the chest ($p=0.004$), pelvis, and extremities ($p=0.016$) between pole and non-pole side collisions. Particularly, the highest risk of severe injury had dramatically increased since the amount of CE zones was higher (odds ratio OR, 9.604; confidence interval, 3.739–24.672). MVOs colliding with pole structural materials had the risk of severe injury (ISS16+) in side collisions (OR, 5.285; 95% CI, 1.358–20.571). Compared with the far-side occupant, the near-side occupant had increased risk of severe injury (OR, 3.123; 95% CI, 1.438–6.783). In this study, factors affecting severe injuries in side collisions were identified as the collision object, seat location, and crush extent. In frontal and rear-end collisions, it is necessary to seek weakness of crashworthiness caused by the lack of structural performance (e.g., bumpers, engine room, truck leads) to protect occupants from collision capacity in side pole collisions.

PAPER NO.23-0027-O

The effect of microcars' lightness and compactness on safety in side impacts

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Abstract

In this paper, the term 'microcar' refers to a car which is categorized as L7 by the UN and conforms to the Ultra Compact Mobility regulation in Japan. The car is much lighter and smaller than a conventional passenger vehicle. It is generally understood that a microcar has poorer crash safety performance than a conventional passenger car. In particular, the microcar would seem to have a disadvantage in terms of side-crash protection performance, since a smaller gap between an occupant and the door means a shorter distance to absorb the impact energy. On the other hand, having a lighter mass, it moves earlier when struck, meaning that the speed and depth of the door intrusion is reduced: an advantage. Thus, the severity of a microcar side crash is not obvious. The aim of this study is to find out how the lightness and compactness of the microcar affect its side-crash protection performance. This study was conducted using a numerical simulation of a Japanese K-car full-vehicle model. Two kinds of parameters were created. One is the Vehicle mass; the other is the Gap between the door inner panel and an occupant. Three levels of mass were investigated (351 kg, 658 kg, and 1000 kg) by removing parts which do not contribute to vehicle body strength or adding weight to the center of gravity. The UN R95 load case was selected for the evaluation. To simulate the microcar, the crash dummy and the seat were repositioned outboard laterally from the original position, the seatbelt was fastened without a pretensioner, and there was no airbag. The struck microcar's velocity was obviously affected by its vehicle mass: the lighter the mass, the sooner the vehicle moved after the Moving Deformable Barrier (MDB) impact. However, the door velocity profile was almost the same in every vehicle mass condition up to the time of the peak injury value, so the injuries were at the same level—except for the head region, which was impacted by the roof rail. The lighter vehicle produced the higher head impact velocity, resulting in higher head injury values. As for the effect of door clearance, larger clearance seemed to reduce the injury level—slightly but demonstrably. This study indicated that the effect of vehicle mass (in the 358 kg–1000 kg range) on crash severity seems to be very small for the chest-to-pelvis region. On the other hand, the lighter vehicle mass seems to carry a higher injury risk for the head region. Thus, it is suggested that the focus for microcars' side-impact safety should be on protection performance for the head rather than the chest-to-pelvis area.

PAPER NO.23-0259-O

Lateral impact crash tests for powered two-wheelers

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Abstract

Protection of the Powered Two Wheelers (PTW) is a major concern due to the increase of this mode of transportation in the accident statistics during the last years. In fact, nowadays, more than 12 riders die on European roads every day and more than 100 are severely injured. In that scenario, IDIADA has promoted and coordinated the European project PIONEERS within the H2020 EU funding programme. This project aimed to reduce the number of PTW fatalities and severely injured by increasing the safety performance, comfort, and usage rate of Personal Protective Equipment (PPE) and the development of new on-board vehicle safety devices. To be able to evaluate the effectiveness of the on-board vehicle safety devices, a lateral testing protocol has been developed considering specifications of the sensor mounting, fixing of the PTW into the test rig, etc. to ensure the repetitiveness of the tests. Four lateral barrier (AE-MDB Euro NCAP) impact tests with two different on-board systems have been performed within the scope of the PIONEERS project according to the impact protocol defined. A Motorcycle Anthropomorphic Test Device (MATD) has been attached to the upper part of a standard Hybrid III dummy from IDIADA to perform the crash tests. Simulations have been performed by UNIFI and compared with the physical tests performed in the laboratory. Results show significant differences between the use of lateral airbag and safety leg cover. The differences are observed not only in the biomechanical values of the MATD but also in the kinematics of the PTW and dummy and in the final relative position of both. By developing new test protocols, more realistic and robust test methodologies will provide better physical data for PTW manufacturers, as well as for on-board protective equipment OEMs (Original Equipment Manufacturers) and PPE suppliers. The data from the tests can be considered as a baseline for further development of the injury assessment for PTWs and it's believed that this data will help to develop more sophisticated testing devices. This paper covers the preparation of testing protocols and execution of PTW lateral safety testing activities performed in IDIADA.

PEER REVIEW PAPER NO.23-0077-O

New load transfer structure to reduce body deformation in side collision

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Research
This research focused on the new IIHS MDB, which is closer to actual accident forms and has been updated to higher-energy test standards. Conventional body structure supports most of the load received from the barrier by bending deformation of the door beams and B-pillar, and therefore, it is subject to large deformation before the maximum load is reached. Reaction force generated by a part during its bending deformation is often disadvantageous compared to the force generated by its axial deformation, and the body deformation increases further in a high-energy collision. Therefore, the objective of this research was to construct new door beam and B-pillar structures that can increase the load from the initial stage of the crash to reduce the body deformation.

Methods
The concept is to transfer the lateral loads received from the barrier as axial loads in the front-back and downward directions of the vehicle. The door beams were given a bow-like shape with curvature toward the outside of the body. It will stretch-deform on the front-back direction by the lateral input from the barrier. The axial load generated in this process enhances the lateral load capacity of the door beam. In addition, a load transfer mechanism is added in the lower section of the B-pillar. It generates a downward axial load during the bending deformation of the B-pillar, creating a new load path to the side sill and increasing the lateral load of the B-pillar. Based on a C-category sedan in mass production, the new structures were designed from theoretical calculations and simulation.

Results
The designed door beam and the B-pillar were fabricated and evaluated by a drop-test. It was demonstrated that the generated load of the B-pillar was increased by 100% and the load of the door beam was increased by 300% compared to the conventional structure. A full-car simulation was also conducted with the new structure. It was shown that a body deformation was reduced by 30%, a body intrusion velocity by 40%, and a SID2S DUMMY G by 60%.

Discussion
The validity of the concept was demonstrated by the fact that the door beam was crushed at the front and rear ends due to its extension, while the mechanism added to the B-pillar resembled downward crushing mode after the drop-test. As for the dummy G reduction, the relationship is roughly consistent with the general theory that G is proportional to the square of the door penetration rate. As the time margin before the vehicle body collides with the occupant has been increased, it is a future issue to further enhance safety by, for example, optimizing the air-bag.

Conclusion
A new load-transfer structure was proposed to increase the load from the initial stage of the crash and to reduce body deformation. It is expected to be applied to EV, which requires a larger amount of energy absorption, and to reduce injuries of the occupants, especially the elderly.

PAPER NO.23-0282-O

A Comparison of the SID-IIs ATD to the Global Human Body Model Consortium fifth percentile female model in the Insurance Institute for Highway Safety (IIHS) updated side impact crash test (Side 2.0)

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Abstract
This paper will present a study comparing the response of the SID-IIs Anthropomorphic Test Device (ATD) to the Global Human Body Model Consortium fifth percentile female model (GHBMC F05 v5.1) in the Insurance Institute for Highway Safety (IIHS) updated side impact crash test (Side 2.0). The study was conducted using a CAE model correlated to a barrier crash test with a small SUV. The occupant kinematics as well as injury response of the SID-IIs was compared to that of the Human Body Model (HBM). The SID-IIs response generally agreed well with the human body model except for clockwise pelvis Z-axis rotation resulting from the 'M-shaped' door deformation pattern characteristic of the IIHS Side Impact 2.0 test; additionally, the femur moment measured on the SID-IIs was significantly higher than that measured in the HBM. A CAE model of a simplified bending test was created to study the loading mechanism driving the femur moment responses and clarify the reasons for the differences observed for the HBM and SID-IIs. Through this study it was found that the SID-IIs hip allows for only 10-12 degrees plan view articulation before mechanical joint lockout occurs. In the barrier test the clockwise pelvis rotation of the SID-IIs resulted in the lockout of the hip joint on the SID-IIs. As a result, the femur moment unrealistically increased exponentially compared to that of the HBM after hip joint lockout occurred. As such the SID-IIs as currently designed does not provide a biofidelic response for femur moments and pelvis rotation in the IIHS Side Impact 2.0 test.

PAPER NO.23-0036-O

Crash simulations of FMVSS No. 214 safety performance

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Abstract
Objective: Federal Motor Vehicle Safety Standard (FMVSS) No. 214 requires doors in applicable vehicles to meet minimum force requirements when subjected to a static load in addition to the occupant protection requirements for the dynamic moving deformable barrier (MDB) and vehicle-to-pole (VTP) side impact tests. This paper explores how non-compliance of a single test condition affects the compliance and performance of the other two tests. Additionally, potential dynamic measurements that could be considered as a surrogate for the static test procedure, are discussed. Methods: Validated FE

models of a 2015 Toyota Camry sedan, and a 2020 Nissan Rogue SUV were used to understand the mutual effect of FMVSS-214 non-compliance. Modifications to the baseline model(s) were developed that demonstrated non-compliance to the static test. Simulations were then performed to evaluate how this affected vehicle and occupant responses in the dynamic tests. The effect of MDB and VTP non-compliance on the respective other two configurations were studied in the same manner. Measurements from the dynamic tests, such as deformation metrics, accelerometer, and load cell force data, were analyzed to determine if they can indicate performance in the static door crush test. Results: Baseline simulation results showed FMVSS-214 compliance of the sedan vehicle for all three impact conditions. A first modified FE model was developed by reducing the door beam strength, resulting in non-compliance in the static test. Using this model, higher vehicle and occupant metrics were observed in the dynamic tests, while still clearly complying with FMVSS-214 requirements. A second and third modified FE model was developed by mainly reducing the strength of B-Pillar and sill components, resulting in non-compliance to the dynamic MDB and VTP conditions, respectively. Reduced door strength was observed using these models in the static test, while complying with FMVSS-214 static requirements. Limited correlation between measurements from the dynamic tests and door strength in the static test was observed Discussion and Limitations: The three FMVSS-214 configurations engaged different main load paths. Door beam strength was most relevant for the static test but did not significantly affect performance in the dynamic tests. B-Pillar and sill strength were most relevant for the MDB and VTP tests, respectively, but did not notably affect performance in the static test. The static door crush test impactor does neither overlap with the B-Pillar nor the sill. Similar results with respect to the static door crush test were observed using a validated FE model of a 2020 Nissan Rogue SUV. Since two specific vehicles representing the sedan and SUV categories were used, conclusions can not necessarily be generalized for other vehicles. Conclusions: The research is relevant to understanding side impact performance measures. Structural vehicle modifications that resulted in non-compliance for the FMVSS-214 static test did not cause non-compliance in the dynamic MDB and VTP tests, and vice versa. There are significant limitations of using dynamic performance measurements from the dynamic tests as a surrogate for the static test due to the different main load paths engaged by the respective FMVSS-214 configurations.

Driving Automation Systems: Product Evolution; Safety Performance Assessment; and Real-World Deployment Challenges

Tuesday, April 4, 2023, | 2:00-6:00

Chair: Lori Summers, United States | Co-Chair: Philippe Vezin, France

TRACK C | Room: G301+G302

PAPER NO.23-0070-O

Introducing a qualification scheme for virtual test environments for driving automation systems

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Research

Due to the large number of scenarios that will be needed to be executed for the testing of Driving Automation Systems (DAS), virtual testing will be essential to generate evidence to prove the safety of the DAS. For that to happen, it is a prerequisite that the virtual test environments (VTE) can be trusted and produce results that are representative of real-world testing. While efforts have begun at various international regulatory forums like UNECE (VMAD SG2) to create a credibility assessment framework, a detailed methodology for proving the trustworthiness of VTEs is missing in industry. This paper aims to introduce an initial qualification scheme for VTEs by comparing the outputs of real-world and virtual sensor models.

Methods

Drawing inspiration from the credibility assessment framework developed by UNECE VMAD SG2 working group, the fidelity of the VTE used for testing a DAS will need to be a function of the system-under test (i.e., the Operational Design Domain (ODD), test objective and the scenarios being used for the test). A scenario execution in a VTE will have two main aspects: 1) static elements (e.g., buildings, trees, roads etc.) and 2) dynamic elements (e.g., pedestrians, vehicles, cyclists, other road users). Factors like weather will impact the DAS' sensor suite's ability to detect these entities. Our proposed methodology compares the output of the real-world sensors and the virtual sensor models (created in simulation). As a result, the sensor outputs for static and dynamic elements are compared separately. A similarity metric is then calculated between the real-world outputs and virtual sensor outputs for both static and dynamic elements.

Results

We have developed metrics for comparing point-clouds from real-world LiDAR sensor and virtual LiDAR sensor when used in a different ODDs. The methodology has been implemented with LiDAR sensor in multiple configurations (vehicle speed and LiDAR rotation speed). As a result, we have created a qualification scheme which compares the output of sensor models (real and virtual) as a function of the ODD of the DAS.

Discussion
The proposed methodology has been undertaken for a LiDAR sensor (real-world and virtual). However, further work is needed to perform a similar comparison for other sensors (e.g., camera and radar). Furthermore, while a novel approach has been developed to compare sensor outputs (real-world and virtual), thresholds for similarity / dissimilarity will need to be agreed as standards and / or industry best practices.

Conclusion
We present a novel qualification scheme for virtual test environments which has the advantage of combining the fidelity of the simulation environment and sensor model into a single qualification metric. The proposed approach verifies the VTE quality using the fidelity of the sensor response as it is fundamental to the DAS operation. Many VTEs exist which aim to focus of their photorealistic nature. However, none of them consider the fidelity of the sensors' output in the VTE. We have chosen the session on "Driving Automation Systems" as simulation-based testing of DAS will be critical in the safety assurance process, including qualification of virtual test tools.

PEER REVIEW PAPER NO.23-0080-O

Implications of the positive risk balance on the development of automated driving

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Research
Automated driving (AD) from SAE level 3 represents a paradigm change from human driver controlling the vehicle to a technical system controlling it. In this light different regulatory bodies (European Commission, Germany, etc.) have defined ethical guidelines for the operation of such a system. One core principle of these guidelines is that the automated operation needs to be at least as safe as the human driving – often referred to as the "positive risk balance". However, these guidelines stay on a general level and do not provide any details on what this means in a practical sense. This paper will provide a practical approach to consider such ethical requirements.

Methods
Starting from a detailed analysis of corresponding guidelines and a literature review of possible risk assessment frameworks, a comprehensive approach has been developed to consider such ethical requirements for the development of AD. This approach covers different development stages. For the reporting of the work the PROACT-URL approach has been chosen. The different steps of the approach are demonstrated by an exemplary AD system.

Results
The paper will present the approach developed by BMW to ensure that AD achieves a positive risk balance for an AD system. The approach will be presented and discussed in detail per development stage (concept phase, AD development phase, verification & validation phase, post SOP phase). In the concept phase the scope is on defining how good a human driver is and how good an AD needs to be. For this purpose, accident databases need to be evaluated. In the AD development first the relevant system requirements need to be derived. Here, Monte-Carlo Experiments in combination with Bayesian Nets are applied. The fulfillment of these requirements is later checked in the verification phase through simulations, test track and real-world tests. For the validation of the risk balance the safety impact of

the AD in terms of traffic safety is derived by means of simulation. The post SOP covers the field of field observation. For each stage practical examples by means of the exemplary AD will be given.

Discussion
The approach is not a single solution to ensure the safety of AD, but it adds to already existing development processes in the context of vehicle safety (functional safety, SOTIF etc.). The relationship with existing safety standards is going to be discussed in the paper.

Conclusion
The safety of AD is paramount when it comes to its operation and ensuring trust in this technology. The described approach contributes directly to building this trust by a comprehensive consideration of the principle of a positive risk balance throughout the development in addition to existing safety standards.

PAPER NO.23-0110-O

Characterization and mitigation of insufficiencies in automated driving systems

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Abstract
Automated Driving (AD) systems have the potential to increase safety, comfort, and energy efficiency. Recently, major automotive companies have started testing and validating AD systems (ADS) on public roads. Nevertheless, the commercial deployment and wide adoption of ADS have been moderate, partially due to system functional insufficiencies (FI) that undermine passenger safety and lead to hazardous situations on the road. In contrast to system faults that are analyzed by the automotive functional safety standard ISO 26262, FIs are defined in ISO 21448 Safety Of the Intended Functionality (SOTIF). FIs are insufficiencies in sensors, actuators, and algorithm implementations, including neural networks and probabilistic calculations. Examples of FIs in ADS include inaccurate ego-vehicle localization on the road, incorrect prediction of a cyclist maneuver, unreliable detection of a pedestrian in rainy weather using cameras and image processing algorithms, etc. The main goal of our study is to formulate a generic architectural design pattern, which is compatible with existing methods and ADS, to improve FI mitigation and enable faster commercial deployment of ADS. First, we studied the 2021 autonomous vehicles disengagement reports published by the California Department of Motor Vehicles (DMV). The data clearly show that disengagements are five times more often caused by FIs rather than by system faults. We then made a comprehensive list of insufficiencies and their characteristics by analyzing over 10 hours of publicly available road test videos. In particular, we identified insufficiency types in four major categories: world model, motion plan, traffic rule, and operational design domain. The insufficiency characterization helps making the SOTIF analyses of triggering conditions more systematic and comprehensive. To handle faults, modern ADS already integrate multiple AD channels, where each channel is composed of sensors and processors running AD software. Our characterization study triggered a hypothesis that these heterogeneous channels can also complement each other's capabilities to mitigate insufficiencies in vehicle operation. To verify the hypothesis, we built an open-loop automated driving simulation environment based on the LG SVL simulator. Three realistic AD channels (Baidu Apollo, Autoware.Auto, and comma.ai openpilot) were tested in the same driving

scenario. Our experiments suggest that even advanced AD channels have insufficiencies that can be mitigated by switching control to another (possibly less advanced) AD channel at the right moment. Based on our FI characterization, simulation experiments and literature survey, we define a novel generic architectural design pattern Daruma to dynamically select the channel that is least likely to have a FI at the moment. The key component of the pattern does cross-channel analysis, in which planned trajectories and world models from different AD channels are mutually evaluated. The output of the cross-channel analysis is combined with more traditional fault detections in a safety fusion component. The safety fusion then feeds an aggregated per-channel safety score to the high-level arbiter, which eventually selects the AD channel to control the vehicle. The formulated architectural pattern can help manufactures of autonomous vehicles in mitigating FIs.

PAPER NO.23-0119-O

Evaluation of safety and mobility around low-speed autonomous vehicle through real world deployment in urban roadway system

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Abstract
Low-speed automated vehicles (LSAVs) are a new type of road transportation option that can be deployed in densely populated areas to connect passengers to existing transit systems. These vehicles are designed to operate at low speeds (often in the < 25 mph range) in complex operational design domains and can be retrofitted to accommodate at-risk road users, thereby making transportation even more accessible. Also, as many LSAVs are electric vehicles, they also show great potential for benefiting the climate. Even though there are numerous benefits to deploying LSAVs, several hurdles must be overcome to achieve success. For example, it is unclear how an LSAV deployed in a regular lane with a 25 mph or higher speed limit may affect other traffic. Also, it is unclear how vulnerable road users like pedestrians and bicyclists behave around LSAVs, as human machine interfaces for such interactions are not yet properly developed. These variables pose multiple questions for the safety, mobility, and operation of LSAVs in unrestricted operational domains. For example, an LSAV's low speed may cause other vehicles to operate at a lower speed, causing more vehicles to queue behind it. This may also make some drivers frustrated and lead them to become involved in dangerous driving situations like overtaking and cut-ins. In this work, we studied real world deployment of an LSAV on the US roadway to understand driver behaviors via 360 degree camera views from cameras installed on the LSAV. We examined the problems encountered during the deployment of an EasyMile (EZ-10) LSAV. We specifically investigated events from a real-world deployment during which the EasyMile LSAV needed to stop. The EasyMile deployment studied in this work included cameras that captured the 360 degrees of roadway environment around the vehicle. We developed a scene perception algorithm using computer vision technology to track other roadway agents like cars, pedestrians, and bicyclists around the EasyMile LSAV. We used object detection and tracking algorithms to track the trajectories of each of the roadway agents. Then we used perspective geometry and camera specifications to find the relative distances and speeds of these agents with respect to the EasyMile. This helped us understand the configurations of the traffic around the LSAV and study other drivers' temporal behavior. For example, the collected data shows the approach of any vehicle towards the EasyMile. Finally, we used this

information to study other vehicles' maneuvers and show how the information from the cameras can be used to study simple maneuvers of other vehicles such as cut-ins, lane changes, and following behavior.

PAPER NO.23-0128-O

Investigation on the conditions for disturbances in the safety performance assessment on the perception function of automated driving vehicles

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Abstract

This study focuses on perception as a fundamental part of the function chain of automated driving systems. The dynamic control of automated driving vehicles will be operated based on the perception function resulting from processing information gathered by sensors. Factors influencing perception should be identified and determined for the safety performance assessment because such factors consequence the behavior of automated driving vehicle. Especially, the characteristics of radar on perception function in ADS was investigated, and conditions for disturbances to developing safety performance assessments was discussed.

PAPER NO.23-0150-O

Evaluating and rating the safety benefits of advanced vehicle technologies: Developing a transparent approach and consumer messaging to maximize benefit

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Abstract

In 2012, a major traffic safety organization tasked the MIT AgeLab with developing a data-driven system for rating the effectiveness of new technologies intended to improve safety. Such a system was envisioned as having the potential to educate and guide consumers towards more confident and strategic purchasing decisions, ideally encouraging adoption of technologies with demonstrated safety benefit. In addition, an evaluation of the status and extent of existing data was seen as a way of identifying research gaps in the state of knowledge about safety systems. The focus was on technologies as a class, not on a rating review of individual vehicle model implementations. As conceptualized, the system aimed to complement traditional NCAP style ratings as well as to provide consumers with transparent information on early stage and often improving safety technologies. Development of the rating system and identification of data was undertaken in consultation with a range of academic, industrial, consumer, NGO, and governmental experts as well as with representatives of many of the major automotive manufacturers and suppliers. A key observation that emerged was that data on objectively demonstrable real-world benefits were generally sparse and often lower than expectations based on theoretical considerations, simulation studies, or pre-production evaluations. A number of experts and industry representatives expressed some surprise at both the divergence between

theoretical and observed benefits and the relative scarcity of data upon which to make objective assessments, while others were quite aware of these issues and the need for the development of objective data under real-world operating conditions. A number of factors that might be relevant to understanding why such differences between expected and observed benefits exist were identified. One outcome of this effort was the founding of the Advanced Vehicle Technology (AVT) consortium to collect and examine objective data under naturalistic driving conditions of how drivers interact with, engage, or don't engage, various production safety and driver assistance systems. This ongoing effort is contributing to insights concerning actual benefits and reasons for benefit gaps. Drawing from our initial work, as well as newer sources of data, we argue that the evaluation and rating of safety and driver assistance technologies for informing the consumer and the public at large should consider both theoretical potential and existing demonstrated benefit of specific technologies. This position is increasingly relevant as the effectiveness of many newer technologies have the potential to actually improve over the lifecycle of a vehicle through software updates. The emphasis on ratings based on observed benefit for actual drivers under real-world conditions is proposed to be complementary, rather than competing with, ratings focused largely on controlled test track evaluations of engineered capability. In addition, a case is made for providing ratings that assesses benefit relative to overall crash, injury, and fatality rates – and in relation to the specific scenario / crash event type that a given technology is intended to address. This approach should aid consumers in considering the extent to which a specific technology is or is not relevant to their particular driving needs.

PAPER NO.23-0160-O

A method for the characterization of perception sensors

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Abstract
Vehicle perception systems for both advanced driver assistance systems (ADAS) and automated driving systems (ADS) rely on a plurality of sensors and sensor modalities to "see" the surrounding environment. Each sensor type has its own inherent strengths and weaknesses (e.g., cameras perceive color but need ambient light, radar is insensitive to light but does not perceive color). The goal of this study was to develop systematic and adaptable tests and analysis methods that would allow the performance characterization for a variety of sensors and sensor types. Three common sensor modalities (radar, LiDAR, and camera) were selected for demonstrating the application of the methodology. Three test maneuver templates were developed to exercise the relative motion of target objects within the sensor's field of view (FOV). These allowed a broad set of conditions to be configured that corresponded to ones that might occur during real-world driving. These were combined with external conditions (e.g., simulated rain, variable ambient light, sensor degradations) to identify compounding factors that may affect sensor performance. Sensor characteristics and test factor sensitivities were then calculated across different metrics, including distance accuracy and maximum detection range, to demonstrate the process and efficacy of the method in characterizing perception sensor performance.

PAPER NO.23-0251-O

Evaluation of different ADS material concepts using various safety metrics

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Abstract
Research Question/Objective: New vehicle concepts of occupied and un-occupied Automated Driving Systems [(U)ADS] are fast evolving. Their design, materials used, and energy absorbing structures can significantly differ from traditional vehicles. Appropriate analysis methods and safety metrics can help to evaluate their crashworthiness and compatibility when colliding with other vehicles or road-side hardware. This paper explores the effect different material concepts of an ADS vehicle's outer body has on self-protection and partner protection. The research is considered an example to demonstrate how various impact configurations and simulation analysis tools and metrics can be used to assess structural and occupant aspects for this new type of vehicle class. Methods and Data Sources: Previously developed Finite Element (FE) models of generic ADS vehicles in combination with validated road-side hardware, crash barrier, and occupants were used to understand the effect different material concepts can have on self- and partner-protection. Partner-protection was analyzed using EuroNCAP's mobile progressive deformable barrier (MPDB) and its respective compatibility metric Occupant Load Criterion (OLC), where lower values represent better compatibility. Self-protection was studied using occupant injury metrics recorded during a run-off road impact scenario, where the ADS vehicles impacted a New Jersey Barrier (NJB). Results: Differences in crash compatibility were observed depending on the material concepts used. The impact of a mid-size ADS vehicle using thermoplastic material for select components with the MPDB resulted in an OLC value of 18. The same vehicle with a composite material concept showed an OLC value of 19, while an OLC value of 22 was recorded for the baseline vehicle with a steel material concept. Differences in occupant metrics HIC, BRIC, chest deflection, and femur loads were small when comparing the three material concepts in a 35-mph oblique impact into an NJB. Discussion and Limitations: The use of different material concepts resulted in different total vehicle mass. The vehicle using thermoplastic material for select components had a mass of 3,653 kg. The same vehicle with composite material concept had a mass of 3,718 kg, while the baseline vehicle using steel had a mass of 4,273 kg. Lower vehicle mass correlated with better partner-protection based on OLC metrics. Occupant metrics were mainly affected by the interior concept, which was identical for all three vehicles. Differences in occupant load was therefore small. The same vehicle design and underlying structure was used during this study and no optimization towards the respective material concept was performed. Conclusions and Relevance to Session Submitted: The research is relevant to demonstrate how simulation tools can contribute to assessing this new type of ADS vehicle class. Material concepts that resulted in a smaller vehicle mass tended to show better partner protection. The interior concept, which was the same for all three ADS vehicle variations, was the main factor for producing similar occupant injury metrics for the evaluated impact scenario.

PAPER NO.23-0274-O

Safety grading scheme for highway assisted driving technology

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Abstract

There is increasing availability of assisted driving technology on vehicles and manufacturers are developing innovative features and functionality. When the driver engages assisted driving technology, the vehicle supports the driver with the steering and speed control, however the driver retains the responsibility for the safe driving. Assisted driving offers the potential safety benefits of improved speed and headway regulation and lane guidance, addressing the most common front-to-rear crash type and lane drifting and run-off road crashes. Because the systems relieve some of the driving workload, fatigue is also addressed. However, system implementation must be carefully considered to ensure the driver remains engaged with the driving task. Assisted driving systems are implemented differently by individual vehicle manufactures. The objective of this research was to identify the key features that lead to safe implementation of assisted driving technology, enabling the development of a consumer safety grading scheme to guide vehicle manufacturers to safe implementation and provide an independent, objective means of assessing systems. Vehicle Assistance and Driver Engagement were identified as the two critical aspects. The level of assistance provided must be matched by the perception of the driver and the ability of the system to keep the driver engaged. Vehicle Assistance assesses the steering support technology and the selection and application of appropriate speed control. Driver Engagement assesses driving collaboration, driver monitoring and system status in use, and also the consumer information including how the system is named, marketed and its appropriate usage described. A third key area identified for safe implementation was Safety Backup, namely the advanced emergency supports the system provides in case of an imminent collision beyond the capability of the assistance, in case of an unresponsive driver who becomes disengaged for a long period, or a system failure. The research was implemented by developing test and assessment protocols in association with Euro NCAP acknowledging the results of broad range of research vehicle testing. A four-tier grading scheme was developed (Entry, Moderate, Good and Very Good) ranking vehicles on the sum of Assistance Competence (balancing Vehicle Assistance and Driver Engagement) and Safety Backup. To date, 21 vehicles have been assessed and a range of results have been achieved that span across the four grades, indicating the relevance of the scheme and its ability to differentiate systems. The scheme has identified an apparent imbalance between Vehicle Assistance and Driver Engagement in one case. In another, a vehicle has been reassessed and gained an improved grading after an over-the-air update. A limitation of the grading scheme is it is currently focused on highway functionality, whereas assisted driving technology can be utilised by the driver wherever the system deems it is capable of operating. In this first iteration of the grading scheme, only interaction on highway-like roads with other restricted vehicle types has been considered. Expanding the assessment beyond highway usage will necessarily involve assisted driving relevant interactions with a broader range of road types and features, traffic control and road users etc.

PAPER NO.23-0280-O

Proposal for an in-use safety and security monitoring framework for Automated Vehicles (AV)

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Abstract
The UK government are committed to bringing forward legislation to allow the safe and secure deployment of self-driving vehicles, as set out in the recent policy paper, "Connected and automated mobility 2025: realising the benefits of self-driving vehicles". As part of the Connected and Automated Vehicle Process for Assuring Safety and Security (CAVPASS) programme, TRL was commissioned to propose a concept for assuring the safety of Automated Vehicles (AVs) throughout their operational life. The work involved developing technical, procedural, and administrative approaches for safety incident identification, investigation and reporting based on an evidence review of current and proposed in-vehicle datasets, safety metrics and collision investigation methodologies and supported by expert judgment. A Hazard Analysis and Risk Assessment (HARA) and an analysis of domestic traffic rules was conducted to assess the monitoring coverage of relevant risk events. Based on these activities, an overall framework for in-use safety and security monitoring has been proposed. The study identified the need to monitor compliance against the behavioural competencies and safety arguments stated prior to deployment in order to continually assess the performance of the AV and the validity of the safety case during operation. A taxonomy for event classification has been developed to specify events to monitor safety and rules compliance. The study proposes that event-based data capture is the most feasible method of capturing data required to understand event context and causation to enable investigation. A minimum dataset specification has been developed which specifies a set of data metrics and thresholds for event detection as well as the data to be recalled supporting incident investigation. The HARA found that the proposed measures could not cover all safety relevant events and data sources external to data processed by the AV are required. Therefore, a set of operational processes for monitoring have been proposed. A concept for monitoring traffic rules compliance has been introduced whereby AV perception data is processed independently. Analysis of domestic traffic rules identified requirements to record relevant dynamic objects, static objects, and AV behaviours to enable monitoring of rules compliance. Processes for in-depth investigation and data analysis have been developed to enable the identification of compliance issues, produce learnings to be shared across the industry, and continuously improve the safety scheme. In-use monitoring data was found to be vital in ensuring accountability of AV safety performance by the manufacturer and contributes to an open and transparent safety culture by enabling just and proportionate regulatory sanctions to be applied. Due to their paucity, data from AV collisions could not be used to base monitoring approaches on. The approach taken in this work was to identify safety monitoring protocols based on known approaches from conventional driving and other transport domains. A principle of continuous improvement was proposed such that the accuracy, quality, and relevance of the monitoring framework can be assessed through AV deployment. This

independent study proposes a framework for the safety performance assessment of AVs during operation to provide regulatory oversight, accountability and improve public trust in the technology.

PAPER NO.23-0032-O

Harmonized approaches for baseline creation in prospective safety performance assessment of driving automation systems

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Abstract
In the last years, virtual simulations have become an indispensable tool for safety performance assessment of driving automation systems (DAS) and pre-crash technologies which are part of advanced driver assistance systems (ADAS). Different approaches and tools are used in this domain, making comparison of results of different studies difficult. Therefore, the P.E.A.R.S. (Prospective Effectiveness Assessment of Road Safety) initiative was founded to harmonize methods for prospective safety performance assessment and by this make results of such studies more trustworthy and comparable. One essential pillar of such a harmonization is the establishment of the baseline, the set of data to which the performance of the technology under study is compared to when performing prospective assessments. Various ways have been presented in literature for setting up a baseline. For harmonization, these ways need to be analyzed and categorized so that recommendations can be given on when and how to use a certain baseline approach. The research objective of this paper is first to develop general approaches to establish a baseline based on existing ways and second to identify areas of application for each baseline approach. Based on existing ways, we defined general approaches for setting up a simulation baseline. These baseline approaches can structure all existing ways based on their characteristics and requirements and impacts on safety performance assessment results. Relevant information for each baseline approach is discussed, such as the used data type(s), data processing steps, applied variations to the original data, application of simulation models, and statistical methods, etc. We identified three types of baseline approaches: A) Using concrete real-world scenarios without modifications. B) Using modifications of concrete real-world scenarios. Here, real-world scenarios are the basis, but some of the existing measured properties are altered or even new properties are added. C) Creating synthetic cases where more general data such as distributions of relevant parameters (e.g., from collision, road user behavior, traffic data) and mechanisms possibly leading to collisions are used.

The paper will provide examples for each baseline approach. The three approaches can be clearly distinguished and should be able to cover the generation of a baseline for all studies in the field of prospective safety performance assessment. Each of the approaches has its pros and cons, e.g., with respect to their representativeness, and the effort to obtain the required data. Also, the evaluation objective to be addressed needs to be considered when selecting an appropriate baseline approach as it has a strong influence on this selection. The categorization of the three approaches allows for defining common recommendations on when to use which approach. By the baseline approaches presented, P.E.A.R.S. contributes to the harmonization and acceptance of virtual safety performance assessment of driving automation systems (DAS) and pre-crash technologies. This will greatly enhance trustworthiness, comparability and, transparency of results of prospective safety performance assessments.

PAPER NO.23-0064-O

Validation and plausibilization of X-in-the-Loop tests for driving automation

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Abstract
Virtual X-in-the-Loop (XiL) environments are gaining significant importance in the test of Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS). In order to derive reliable test results, credibility of XiL environments must be evaluated using suitable methods for XiL validation. This typically involves a back-to-back comparison to reference proving ground (PG) tests. Due to uncertainties inherent to PG and XiL, this validation requires the analysis of multiple test executions. Since this may not always be feasible with limited data availability, we define plausibilization as a preliminary step towards validation, comparing two single test executions in PG and XiL. A plausibilization method is presented, combining the evaluation of pass/fail criteria (PFC) and scenario distance measures. Finally, the application of the method in an ADAS series development project by evaluating three example Software-in-the-Loop (SiL) scenarios confirms that this is a reasonable plausibilization approach. Furthermore, it is shown that the method can be adjusted in a flexible way to meet requirements from different automation levels, systems, or scenarios.

Advances in Crash Test Dummies, Instrumentation, and Data Analysis

Wednesday, April 5, 2023, | 08:30-12:30

Chair: Kevin Moorhouse, United States | Co-Chair: Atsuhiro Konosu, Japan

TRACK A | Room: G303

PEER REVIEW PAPER No.23-0041-O

Biofidelity assessment of 5th Percentile Female ATD abdomen responses relative to recently developed belt and bar loading corridors

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Research

Quantitative evaluation and comparison of the THOR-05F and Hybrid-III-05F ATD abdomen responses when subjected to PMHS belt and bar loading conditions.

Methods

Both ATDs were subjected to two different loading conditions: fixed-back belt pull at 4 m/s and free-back rigid bar impact at 6 m/s. The stroke of the impact was manipulated to produce both injurious and non-injurious conditions so that both conditions could later be used to develop injury risk functions. Quantitative comparisons were made between the ATD abdomen force and compression responses and post-mortem human subject (PMHS) biofidelity corridors obtained from matched pair PMHS tests under identical loading conditions, using the most recent version of the NHTSA Biofidelity Ranking System (BRS).

Results

The THOR-05F exhibited an abdominal force-compression response similar to PMHS, while the HIII-05F was stiffer in comparison reaching higher peak loads in both belt and rigid bar loading conditions. Using the updated BRS methodology, the THOR-05F displayed good biofidelity (BRS score < 2) in compression and force, in both belt pull and rigid bar impact tests, with an average BRS score of 1.5. However, the HIII-05F displayed poor biofidelity with a BRS score > 2 in both loading conditions, as the force deviated from the target response in addition to not achieving similar compression levels due to abdomen stiffness, when compared to THOR and PMHS. The average abdomen pressure measured by APTS sensors ranged from 45 to 130 kPa in THOR-05F, increasing proportionally with higher stroke and loading rate, while the HIII-5F abdomen does not contain instrumentation.

Discussion

This study provides an assessment of abdominal response biofidelity between small female sized PMHS and 5th Percentile Female ATDs under identical loading conditions. The abdominal insert in the HIII-05F made of urethane foam covered with vinyl skin is stiffer when compared with the PMHS corridor. Additionally, the placement of the abdomen in the pelvis and their interaction may be a contributing

factor to the worse BRS score. The design and construction of the THOR-05F abdomen allows for a gradual loading similar to the PMHS. Because of practical challenges in measuring abdomen deflection in a soft ATD abdomen component, APTS sensors in THOR-05F provide measurements of restraint loading to the abdomen and assessment of abdomen injury risk. With good BRS scores observed in the THOR-05F, external measurements such as compression and force may be correlated with the pressures measured by APTS to develop injury risk functions.

Conclusion

BRS scores revealed that the THOR-05F with its advancements proved to have a more PMHS or human like response under abdominal loading conditions. ATD measurements from the testing in this study can be used with PMHS injury outcomes to develop injury risk functions for use with the THOR-05F.

PEER REVIEW PAPER NO.23-0097-O

Comparative biofidelity of the Hybrid III and THOR 50th Male ATDs under three restraint conditions during frontal sled tests

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Research

The purpose of this study was to provide a full-body biofidelity assessment of the Hybrid III (HIII) and THOR 50th percentile male anthropomorphic test devices (ATDs) during frontal sled tests, incorporating data from test buck reaction load cells to provide a novel assessment of external biofidelity. Additionally, the accuracy of the injury risk curves for each ATD were evaluated against injuries from post-mortem human surrogates (PMHS).

Methods

Sled tests designed to simulate a United States New Car Assessment Program (US-NCAP) frontal test were conducted using the HIII 50th male ATD, THOR-50M ATD, and eight approximately 50th-percentile male PMHS under three restraint conditions: knee bolster (KB), KB and steering wheel airbag (SWAB), and knee bolster airbag (KBAB) and SWAB. Each ATD underwent two tests per restraint condition, while three PMHS tests were conducted for each restraint condition except for the KB condition, which only had two PMHS tests. The test buck was designed to match the interior of a Toyota Camry and included a production seat, steering column and wheel, SWAB, and three-point belt system with pretensioner and load limiter. Rigid polyurethane foams were used to simulate the KB and KBAB. The test buck was instrumented with multi-axis load cells on the steering column, KB supports, and foot supports. ATD and PMHS reaction force time histories were quantitatively compared using the ISO/TS-18571 objective rating metric. Previously published biofidelity analyses of kinematic and chest deflection data from the same tests were combined with the reaction force analyses to perform an overall assessment of the comparative biofidelity of each ATD. Injury risk predictions from existing HIII and proposed THOR injury risk curves (IRCs) for the US-NCAP were compared to observed injuries.

Results

The reaction load cell time histories from both ATDs generally had poor similarity to those of the PMHS, with average ISO scores of 0.54 and 0.49 for the HIII and THOR, respectively. Across all reaction load cells, the THOR typically produced the largest forces, while the PMHS produced the smallest. The similarity of the HIII response to the other surrogates varied with load cell location and restraint

condition. Combining the reaction load ISO scores with previously published data yielded overall scores of 0.52 and 0.50 for the HIII and THOR, respectively. Both ATDs were able to predict the observed injuries except for the HIII chest and THOR neck IRCs, which both under-predicted PMHS injury outcomes.

Discussion

The reaction loads indicated that the three surrogates had different interactions with the steering wheel/column, KB, and foot supports. Despite this, the ATDs had similar ISO scores for both the external and overall analyses, indicating that the THOR and HIII had similar biofidelity under these test conditions. However, this study was limited by a low PMHS sample size.

Conclusion

This study is relevant to the indicated session because it provides novel biofidelity data on the THOR and evaluates its most recently proposed IRCs. Results indicated that the THOR and HIII had similar overall biofidelity and provided mostly accurate injury risk predictions under test conditions representing the current frontal US-NCAP.

PEER REVIEW PAPER NO.23-0127-O

Characterizing neck and spinal response in a booster seated reclined children in frontal impacts

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Research

Belt-positioning booster seats (BPB), pretensioner and pre-pretensioner (PPT) belts may be effective in preventing injuries from submarining and head excursion in reclined children (Hauschild et al 2021, Bohman et al 2021). It is unknown if injuries at the neck and spine could still occur. This study's goal is to characterize neck and spine responses to understand spinal injury risk for reclined children with and without the BPB and the PPT.

Methods

Eleven frontal impact sled tests were performed (56 kph) with a Large Omni-directional Child (LODC) dummy on a production vehicle seat. A 3-point simulated seat-integrated-belt was used with a load-limiter (~4.5 kN). Testing was conducted with and without the BPB with the seatback at ~25° (nominal), ~45° and repeated once. One test was conducted at ~60° with the BPB. 100 mm of belt-slack was removed to simulate PPT in two of four 45° BPB tests and the BPB 60° test. The LODC peak thoracic spine accelerations and angular rotations, and peak neck and lumbar force/moment loads were compared between conditions.

Results

Neck axial forces were the highest without the BPB and PPT (25 º noBPB 3.4kN, 45 º noBPB 4.3kN) compared to the BPB conditions (1.9–3.0kN). Neck shear forces were the highest in the 60º BPB & PPT (-1.9kN) and 45º noBPB (-1.3kN) than all other BPB conditions (-0.5 to -0.8kN). The highest neck moments were found in the 45º noBPB (-40.5 N-m), and in the 60º BPB & PPT (-34.2 N-m) conditions compared to all others (-20.8 to -27.9 N-m.). The 60º BPB and PPT condition demonstrated thoracic forward rotation similar to the 25º noBPB condition (25º noBPB -24.8 to -35.0 deg, 60 º BPB&PPT -27.5 to -43.2 deg..).

Thoracic spine resultant accelerations (T1, T6, T12) were higher in the 25º and 45º noBPB conditions (53 g to 71g) and in the 60º (T6: 61.8g) compared to all other BPB conditions (48.4 g to 53.1g). The lumbar shear forces and moments were the highest in the 45º noBPB (4.9 kN, -296 N-m) and the 60º BPB & PPT condition (1.7kN, -146 N-m).

Discussion

These findings show similarities in neck, spine, and lumbar responses between the severe reclined condition with BPB and PPT countermeasures and the upright and moderate reclined conditions without the same countermeasures. In severe reclined condition with BPB, 60º, the LODC exhibited increased peak neck shear force and lumbar forces and moments similar to the condition with no BPB. The 60º condition showed increased upper thoracic accelerations (T6) compared to all other BPB conditions These findings suggest that the BPB and PPT may not be sufficient countermeasures to protect neck and spine in severe reclined child occupants. Limitations of this study was the investigation of one BPB and vehicle seat.

Conclusion

Neck and spine injury risks may increase in severe reclined booster seated children. This study highlights the need for future restraint developments to protect reclined child occupants. The LODC is an advanced ATD which was tested in a novel configuration, reclined, analyzing small occupant responses in a BPB.

PAPER NO.23-0132-O

A novel Powered Two-Wheeler rider dummy; specifications and initial testing

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Abstract

Powered Two and Three-Wheelers (PTWs) are a popular means of transport. Fully electric PTWs can be operated locally emission-free and, therefore, may support sustainable transport options. However, in terms of the safety offered to PTW riders there is still a long way to go compared with other means of transportation. As such, PTW riders are a vulnerable road user group that stands to benefit from improved protection. Primarily, this paper provides a detailed description of the work-in-progress regarding a new crash test dummy, an ATD (Anthropometric Test Device), intended principally for use in testing PTWs. The question posed was if a new dummy can facilitate evaluations of PTW protective systems. The end goal being to promote more widespread evaluation of protective systems for PTW riders. Importantly, the development of the PTW riding dummy has paired physical and finite element models together, from the start, to support both physical and virtual testing in the future. The ATD development is based on collision (and injury) statistics of PTWs worldwide, a brief summary of previous research is presented. As with the development of the Motorcyclist Anthropometric Test Device (MATD- ISO 13232-3) an updated modification of the Hybrid III pedestrian is proposed as the principal solution. To this base dummy a small set of modifications are made to allow simple and yet adequate representation of a PTW rider. Demonstration of the dummy in use as a PTW rider is provided

by performing full-scale crash tests. Finite element crash simulations are compared with the physical tests, demonstrating the suitability of using the finite element dummy model in virtual PTW tests. Details of the PTW dummy anthropometry are provided as well as the rationale for design updates in comparison with the MATD. An overview of testing with the dummy is provided and the results from two full-scale reference tests (without protective system) are given. Injury predictions based on dummy measurements are compared with an injury statistics summary. Differences between the outputs from the physical and finite element models are discussed in the context of the injury statistics and additional validation of the tools is suggested. The paper also indicates potential areas where the dummy could be improved in the future, depending on injury prediction needs and application, such as to include additional instrumentation in the abdomen region, for example. Worldwide road traffic statistics suggest that the number of deaths of PTW riders form an equally large group as deaths among drivers and passenger of four-wheeled vehicles. In contrast, the former group has not benefitted from the advancement of protection systems as implemented in the latter. The availability of new tools in the form of a hardware ATD and its finite element model representing the PTW rider, will support development and evaluation of protective systems for PTW riders.

PAPER NO.23-0171-O

Pressure-Based abdominal injury prediction for the THOR-50M

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Abstract
The standard THOR-50M dummy is equipped with sensors to measure the abdomen deflection and assess the risk of abdominal injuries. Since 2016, the “ABdominal Injury and SUbmarining Prediction” (ABISUP) consortium has developed a pressure-measuring abdomen for the THOR-50M to predict abdominal injuries and submarining as a potential alternative to the current THOR-50M abdomen design. A new lower abdomen including Abdominal Pressure Twin Sensor (APTS) was designed and four

identical prototypes were built and shipped to consortium member test houses. Numerous abdominal belt loadings replicating tests from the literature were carried-out to check the prototype biofidelity, sensitivity and define a pressure-based AIS3+ injury risk functions (IRFs). Two compression-based IRFs were defined using porcine test results from the literature. Compressions were defined as the ratios between the abdomen deflection and the full abdominal depth, or between the abdomen deflection and the abdominal depth in front of the spine. The abdominal depth in front of the spine was used in an attempt to minimize possible differences between species. It was estimated using simple assumptions and led to compressions exceeding 100% in a few cases. Then transfer functions between THOR abdominal compressions and pressures were applied to obtain the pressure-based IRFs. Twenty-five sled tests were performed to assess the new abdomen under various restraint conditions and to evaluate the relevance of the IRFs. The THOR-50M new abdomen showed similar or better biofidelity than the standard abdomen without modifying the dummy kinematics. The abdomen was sensitive to loading height and no damage to the APTS was encountered during tests. Relationships between THOR-50M mean APTS pressure and abdominal compressions were modelled using a 3rd degree polynomial with 0.98 R^2. The IRF with a log-logistic distribution obtained the lowest Akaike Information Criterion. For the compression based on the full abdomen depth, the AIS3+ injury risks of 25%, 50% and 75% corresponded to APTS pressures of 133, 201 and 304 kPa, respectively. For the compression based on the abdomen in front the spine, the AIS3+ injury risks of 25%, 50% and 75% corresponded to APTS pressures of 108, 197 and 361 kPa, respectively. The new abdomen discriminated between the restraint conditions: lower pressures (between 90 and 190 kPa) were obtained when the lap belt remained below or on the ASIS and higher pressures (170 to 450 kPa) were obtained when the lap belt loaded the abdomen. Using the IRF, a risk up to 50% could be obtained without submarining, i.e., with the lap belt still engaging the ASIS. This is not consistent with a risk expected to be low for a proper restraint. Possible adjustments are discussed in the paper to decrease APTS sensitivity when the lap belt is positioned below or on the ASIS.

PAPER NO.23-0239-O

Construction of a prediction model for the time series of brain strain of a novel head surrogate using deep learning

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Abstract
An effective brain injury risk assessment is required to minimize the risk of brain injury from traffic accidents. Thus, anthropomorphic test devices (ATD) have been used for overall vehicle safety evaluation. We developed a novel ATD head that incorporates detailed intracranial structures with the brain and can measure the relative displacement between the brain and the skull. However, the strain inside the deep brain of the head surrogate cannot be measured or estimated. Although we can simulate the brain strain waveform using the finite element model, the computational cost is high, and the real-time evaluation of brain strain during crash tests is difficult. To compute the brain strain response in real-time, deep learning (DL) methods can be used to predict brain strain behavior. Therefore, this study aims to propose a method to predict the waveforms of maximum principal strain in the brain using a DL method called long short-term memory (LSTM). Reconstructed simulations for impact tests using a finite element head model were conducted to obtain the principal strain waveforms

of the brain and construct a dataset for machine learning. The impact tests included 125 occipital head impact tests, 7 frontal sled tests, 35 vehicle frontal crash tests, and 53 American football impact tests, constituting a total of 220 head impact tests. Furthermore, the LSTM model was trained on triaxial angular velocity and acceleration waveforms, and the models were constructed to predict the principal strain waveforms in the cerebellum, brainstem, and right and left cerebrums. Subsequently, to validate the predictive model of brain strain, CORA was calculated as an index of the prediction error. The average CORA score between the brain strain waveforms predicted by LSTM and those of the dataset was 0.963 for occipital head impact tests, 0.928 for frontal sled tests, 0.898 for vehicle frontal crash tests, and 0.875 for American football tests. The occipital head impact tests, vehicle frontal crash tests, and frontal sled test cases were predicted with high accuracy. However, the football impact test cases were inferior to the other three test cases. The football impact cases included more multidirectional impact patterns and failed to learn similar collisions. However, an error in the waveform was observed in the rebound phase of the head impact in the latter half of the brain strain waveform. Therefore, the impact test dataset should be expanded, including cases with rebound behavior of the head, and the set of features that can reflect the rebound behavior of the head should also be examined further. In conclusion, the maximum principal strain waveforms of the brain can be rapidly and accurately predicted from the angular acceleration and angular velocity of the ATD head in occipital head impact, frontal sled, and vehicle crash test cases using LSTM. This method enables real-time evaluation of brain strain waveforms during impact tests.

PAPER NO.23-0271-O

A simulation study on the knee-thigh-hip loading of the THOR compared to human body models

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Abstract
The THOR-50M dummy is instrumented with acetabulum force sensors which is a novelty when compared to previous dummies like the Hybrid III. It has been proposed to use the acetabulum resultant force to predict hip injuries. Injury Risk Curves (IRCs) for cadavers have previously been developed, however it is not clearly established if the cadaver IRCs can directly be applied to the THOR measurements or if a transfer function is needed. As femur and acetabulum forces are located on the same load path, it is also questionable if it is necessary to use two different injury criteria to predict knee-thigh-hip injuries. To investigate these questions, a simulation study was performed using a THOR model and two human body models (HBMs). Load cases included impactor tests derived from published cadaver testing as well as sled simulations in belted and unbelted configurations with a validated environment. The knee, femur and acetabulum forces measured in the different models were compared and the ratios between these forces were also analyzed. Additionally, based on the measurements from the THOR and HBMs simulations and published Injury Risk Curves for cadavers and the THOR, the risks of hip and knee/femur injuries were calculated for each load case. Results show that the relationship between the forces measured in the THOR model and in the HBMs could depend on the loading conditions. The forces measured in the unbelted sled simulations are similar between the three models, however the acetabulum forces measured for the HBMs in the belted sled configuration are significantly lower than that of the THOR. For impactor configurations, the risk calculated at the hip for the THOR overestimates the likelihood of cadaveric injuries. For sled configurations, no cadaver test result was available, findings are based on simulations only and comparison with field data. For all simulations, the

risk of hip injury predicted for the THOR was significantly higher than the risk predicted for both HBMs. The risk of hip injuries for the THOR was also, for all simulated load cases, higher than the risk of knee/femur injuries which is contrary to the injury frequencies observed in the field for belted occupants. Overall, the risks calculated for the THOR from the acetabulum forces seem overestimated which is likely caused by the transfer coefficient used to calculate the THOR risks based on the human IRCs. An adjustment of the transfer coefficient is necessary and might require a different value for belted and unbelted cases. This study has limitations. Firstly, the ability of the human body models to measure accurately the acetabulum force in sled configurations is not established due to the lack of relevant cadaver data. Secondly, parameter studies and real car simulations would be needed to generalize the results. To conclude, it is necessary to define a transfer function for the acetabulum force to predict hip injury risks properly. This transfer function might be load case dependent.

PAPER NO.23-0275-O

Development of a multi-point chest deflection measurement system for the Large Omnidirectional Child (LODC) anthropomorphic test device (ATD)

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Abstract
OBJECTIVE The objective of this study is to evaluate the feasibility and accuracy of a multi-point chest deflection sensing system installed in the LODC using static, quasi-static, and two dynamic test conditions. METHOD The multi-point LED chest deflection system was evaluated at four levels: (1) calibration verification, (2) quasi-static, (3) dynamic probe impact, and (4) dynamic drop tower in order to demonstrate that the sensor gave a reasonable and accurate measurement of chest deflection. RESULTS Individual sensors were found to be quite accurate in static verification tests, and sensors installed in the LODC ribcage were also observed to match well with CMM measurements. In dynamic testing with the full array of sensors installed in the ribcage, LED deflection matched probe-measured deflection closely. In both frontal and oblique drop tower tests, individual sensor deflection time histories showed how the full array could capture full ribcage deformation. CONCLUSIONS A novel non-contact sensor array to measure LODC chest deformation has been developed. This system has gone through a battery of both static and dynamic tests thus far to evaluate the system's performance. Initial results indicate that the system is promising for monitoring overall chest deformation in the LODC. Future work will include more dynamic testing to further understand how the system can describe three-dimensional ribcage deformation.

PAPER NO.23-0278-O

The influence of the reproducibility of Anthropomorphic Test Devices on injury risk functions

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Abstract

The design of advanced ATD is moving towards being more human-like and therefore is more complex. More complexity generally leads to more degrees of freedom, the uncertainty of an ATD as a measurement tool rises. The uncertainty of a measurement tool is described by the repeatability and the reproducibility. An ATD alone can only provide measurements. These measurements do not directly reveal the safety level of a vehicle in a crash test. By using a mathematical function, a so-called injury risk function, the ATD measurements can be related to injury risks. The injury risk is a measure to show how well a vehicle protects the occupant or vulnerable road user. The influence of a poor repeatability or reproducibility on the calculation of the injury risk is obvious. For a given measurement variability it is simple to check the associated risk variability by putting the values in the relevant injury risk function. Much less obvious is the effect of poor repeatability and reproducibility on the injury risk function itself. The injury risk function for an ATD is typically a combination of PMHS test results and matched ATD test results. This simple fact reveals that the repeatability as well as the reproducibility of an ATD can already influence the development of the injury risk function and not only the calculation of the injury risk. This study aims to get a basic understanding how the measurement variability of ATD can influence the resulting injury risk function. The study uses data from real repeatability and reproducibility tests with the THOR-50M. For reasons of simplicity the study focuses on the influence of the reproducibility, that is, a perfect repeatability is assumed. Two theoretical PMHS data sets are used to study the reproducibility influence: one with current status data (left and right censored data) and one with exact data. In addition, two different methods for the mapping of ATD measurements onto PMHS results in the risk function development are deployed. This study shows that injury risk curves depend on ATD reproducibility. Current injury risk function development is only reliable with a good ATD reproducibility. Data of THOR-50M used in this study reveals that the current injury risk function development procedure should consider the reproducibility of the ATD. The study used only one data set for the reproducibility of the ATD which limits the generality of the results. In addition, only a theoretical and simple injury risk function was applied. More complex injury risk functions with additional co-variants or complex criteria may lead to diverging results. The general effect that the reproducibility is influencing the injury risk function is unaffected. As reproducibility cannot be easily improved because of technical and practical reasons, a methodology needs to be developed that includes the effects of reproducibility in the calculation of injury risk curves.

PAPER NO.23-0288-O

Investigation of the biofidelity of human body models and ATD models in sled test conditions

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Abstract
Unique cabin configurations associated with Automated Driving System (ADS) equipped vehicles offer seating options, such as recline, not previously available in conventional vehicles. Occupants seated in a reclined posture may be at an increased risk of submarining. There is relatively little known about the effectiveness of current restraint systems to protect reclined occupants as these systems are traditionally optimized for only upright seated postures. Anthropomorphic Testing Devices (ATDs) with the ability to differentiate between submarining and non-submarining events are vital for the development of restraint systems capable of protecting reclined occupants. This study evaluates the biofidelity of the GHBMC, THUMS, THOR, and THOR-AV finite element (FE) occupant models against two post-mortem human subject (PMHS) test series in respect of submarining behavior. The first test series evaluated upright occupant kinematics in two seat configurations defined in Uriot et al. 2015: a front-seat configuration expected to prevent submarining and a rear-seat configuration expected to allow for submarining. The second tests series evaluated upright and reclined occupant kinematics in a seat configuration as defined in UMTRI test conditions: both configurations expected to prevent submarining. Special consideration was given to pelvis kinematics and submarining response. The four FE occupant models properly differentiated between non-submarining and submarining responses in each of the evaluated test conditions. The NHTSA Biofidelity Ranking System (BRS) was used to objectively evaluate the biofidelity of the models with respect to overall occupant kinematics, as well as interaction with the restraint system (seat, anti-sub ramp, and belts). The BioRank score classifies biofidelity as excellent, good, marginal, or poor. In the first test series, the BRS scores for the interaction between all FE occupants and the restraint system corresponded to good biofidelity, except for THOR in the rear-seat submarining configuration (marginal biofidelity). In the second test series, the BRS scores for the interaction between the FE occupants and the restraint system corresponded to marginal biofidelity. With respect to kinematics, the BRS scores for the FE occupants ranged from good to excellent biofidelity in both test series. For each FE occupant, an average BRS score was calculated from the four test conditions. In terms of the interaction between the occupant and the restraint system, the average BRS scores for the GHBMC, THUMS, and THOR-AV corresponded to good biofidelity, while the average BRS score for the THOR corresponded to marginal biofidelity. With respect to kinematics, the GHBMC, THUMS, THOR, and THOR-AV FE models demonstrated good biofidelity.

PAPER NO.23-0301-O

Sensitivity of chest deflection measurements in THOR-5F and Hybrid III small female dummies to different seat and belt settings

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Abstract

In frontal impact test procedures, the Hybrid III small female dummy is used to increase the protection of small car occupants. To address the increased thoracic injury risk for elderly occupants it is planned to introduce more stringent chest assessment criteria. However, previous studies raised concerns regarding the efficiency of criteria based on chest deflections measurements in the Hybrid III due to sensitivity of the measurements to variations in belt routing due to seat and D-ring settings. The seat in the most forward position and the D-ring in the highest position is mostly used in assessment tests. These settings result in a belt routing closer to the neck and reduced mid sternum chest deflection, which is not presentative of the actual peak deflection and therefore not meaningful to assess the chest injury risk. The objective of this study was to investigate the effect of chest deflection sensitivity in the Hybrid III small female dummy in a generic sled test setup to variations of belt routings representative of contemporary vehicles. The study was complemented by sled tests with the THOR-5F in the same configurations to investigate the potential of this dummy as a future alternative. Furthermore, an analysis of field data was done to evaluate the preferred seat and D-ring settings of real small car occupants. The results of the tests with the Hybrid III small female could confirm the findings from previous studies with shoulder belt routings representing contemporary vehicles. A routing with the belt closer to the neck showed a reduced sternal chest deflection in the Hybrid III small female. Corresponding tests with the THOR-5F showed a similar reduction of peak chest deflection at the maximum loaded IR-TRACC, but an increase at another location. Therefore, THOR-5F multi-point criteria might have the potential to address the issue of belt routing sensitivity. The analysis of field data showed that small occupants representing the small female dummy in terms of height prefer to set the D-ring to the lowest position (driver and passenger). For the front seat passenger, the seat longitudinal and height setting mid/mid is preferred. In conclusion the recommendations regarding seat and D-ring settings that were provided in previous studies can be confirmed. To enable an effective evaluation of chest injury risk with the Hybrid III small female the D-ring should be set to the lowest position for the driver as well as for the passenger side. For the passenger side the seat should be set to the mid/mid-position. Furthermore, these seat and D-ring settings are the most relevant preferred by small occupants based on field data. For additional improvement of chest injury risk assessment considering the specific needs of small female occupant's further research is recommended related to the THOR-5F and advanced multi-point chest injury criteria, which might be less sensitive to test parameters and resulting variation of belt routing. Repeatability and reproducibility of the chest deflection response of the THOR-5F dummy related the sensitivity of multi-point defection measurements should be further investigated and improved if necessary.

PAPER NO.23-0339-O

THOR-50M fitness assessment in FMVSS No. 208 unbelted crash tests

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Abstract

Research Question/Objective: A prerequisite for entering a dummy design into CFR Title 49, Part 572 is to demonstrate that the specifications yield ATD units capable of implementation in a regulatory environment. Specifications for the THOR-50M have produced units that are repeatable, reproducible, and durable in many test conditions, including belted sled tests and qualification testing. Herein, two THOR-50M units are implemented in a series of unbelted vehicle crash tests run in accordance with FMVSS No. 208 procedures, and evaluated based on usability, durability, and the successful collection of sensor data for use in injury risk prediction. Methods and Data Sources: Two THOR-50M units, both conforming to NHTSA's 2018 THOR-50M design and qualification specifications, were run in a series of unbelted crash tests. Nineteen tests were run with four 2020-21 vehicle models: Honda Accord, Mazda CX-5, Chevy Equinox, Ford Escape. Four were run against a full-frontal barrier and fourteen against an angled barrier in accordance with FMVSS No. 208 procedures, with the exception of using NHTSA's THOR 50th Percentile Male Dummy Seating Procedure instead of using FMVSS No. 208 seating. Dummy qualifications were performed periodically throughout the test series following NHTSA's THOR-50M Qualification Procedures. Results: The two units held up well to the rigors of the crash tests. Both were fully instrumented, one of which included an internal DAS system. Sensor anomalies and failures during tests were traced to cable damage, which was repaired between tests. The parts and assemblies within both units did not sustain any damage beyond scuffs and cuts to exterior vinyl components. There were no parts that needed to be replaced. Dummy qualifications posed no issues. The test lab was able to maintain a testing schedule typical of other regulatory tests with other types of dummies. Discussion and Limitations: This test series demonstrated that the THOR-50M could be implemented in vehicle crash testing consistent with regulatory compliance testing in that the ATDs showed sufficient usability and durability. Both units successfully collected sensor data for use in injury risk prediction. The minor sensor anomalies that did occur were mostly isolated to the ATD without the internal DAS system. A limitation of this study was that only four vehicle models were tested, and all tests were run at a single lab. Conclusions and Relevance to Session Submitted: In a series of FMVSS No. 208 unbelted frontal rigid barrier crash tests, two THOR-50M units were implemented and successfully completed the test series. Scripted procedures for dummy assembly, qualification, and handling were followed without issue, and the seating procedures resulted in highly uniform positioning. Sensor anomalies observed over the course of testing were consistent with those common in dummies already in Part 572. There were no broken parts or part replacements throughout testing. Based on the experiences of this testing series, the THOR-50M appears fit for use in standardized testing.

PAPER NO.23-0340-O

WorldSID-50M fitness assessment in FMVSS No. 214 moving deformable barrier and oblique pole crash tests

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Abstract

A prerequisite for entering an anthropometric test device (ATD) design into the Code of Federal Regulations (CFR) Title 49, Part 572 is to demonstrate that the specifications yield units capable of implementation in a regulatory environment. Specifications for the WorldSID 50th percentile male (WorldSID-50M) ATD have produced units that are repeatable, reproducible, and durable in many test conditions. Herein, three WorldSID-50M units are implemented in a series of vehicle crash tests run in accordance with the Federal Motor Vehicle Safety Standard (FMVSS) No. 214 procedures, and evaluated based on usability, durability, and the successful collection of sensor data for use in injury risk prediction. Methods and Data Sources: The National Highway Traffic Safety Administration (NHTSA) investigated WorldSID-50M performance in FMVSS No. 214 moving deformable barrier (MDB) and oblique pole crash tests. Performance metrics assessed included uniformity in periodic qualification testing during the crash test series, the durability of the ATD, successful collection of sensor data, and general usability. All qualification and crash tests were run at one lab with three WorldSID-50M units. Each ATD was the standard build level F with an in-dummy data acquisition system (IDDAS) setup (DTS G5 units), a RibEye Multi-Point Deflection Measurement System, thorax pads, modified shoulder pads, and a sleeveless suit. Before the test series, each ATD was fully qualified per NHTSA's WorldSID 50th Percentile Male Qualification Procedures Manual, and additional qualification tests were conducted throughout the crash series. Eighteen crash tests with model year 2019 and 2020 vehicles were ultimately conducted. Results: The three WorldSID-50M units met qualification test requirements throughout the crash test series with minimal issues. Results were within performance specifications after tightening loose bolts in the upper and lumbar spine prior to being used in the crash tests. The WorldSID-50M Dummy Seating Procedure was followed and resulted in repeatable and reproducible seating positions. In crash tests, the WorldSID-50M ATDs were durable and successfully collected sensor data. Apart from a broken ankle in one test, no permanent damage was seen on any ATD. One pole test resulted in loss of the maximum thorax rib deflection due to a RibEye LED blockage by another rib. The issue was resolved by relocating the rib's LEDs. The WorldSID-50M posed no other difficulties in performing the crash tests. Conclusion and Limitations: This controlled study of the WorldSID-50M in FMVSS No. 214 testing showed that the ATD is durable and successfully collects sensor data in both qualification and crash testing. There were few sensor anomalies throughout the test series, and any instrumentation issues were quickly resolved. Collectively, this series of crash tests demonstrates that the design of the WorldSID-50M appears robust and provides a tool suitable for use in standardized side impact testing. A limitation of this study is that all tests were conducted at a single lab. Further, few small, compact, and sub-compact size vehicles were included in this test series. Additional analysis of data from ongoing crash tests encompassing a more comprehensive vehicle fleet will yield more wholistic results assessing the WorldSID-50M.

One Step Ahead Integrated Vehicle Safety Technologies

Wednesday, April 5, 2023, | 08:30-12:30
Chair: Jac Wismans, The Netherlands | Co-Chair: Matteo Rizzi, Sweden
TRACK B | Room: G304

PAPER NO.23-0015-O

Combining knowledge and information - Graph-based description of driving scenarios to enable holistic vehicle safety

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Abstract
Currently, vehicle safety is based on knowledge from injury values, crash pulses, and driving kinematics which leads to intervention strategies separated into isolated domains of active and passive safety. In this contribution, it is shown how vehicle safety can be approached holistically, allowing for human-centered and scenario-based safety decision-making. For this purpose, information from interior and exterior vehicle sensors can be linked by a mathematical framework, combining the knowledge that is already available in the individual domains. A universal graph representation for driving scenarios is developed to master the complexity of driving scenarios and allow for an optimized and scenario-based intervention strategy to minimize occupant injury values. This novel approach allows for the inclusion of sub-models, expert knowledge, results from previous simulations, and annotated databases. The resulting graph can be expanded dynamically for other objects or occupants to reflect all available information to be considered in case of urgency. As input, interior, and exterior vehicle sensor data is used. Further information about the driving situation is subsequently derived from this input and the interaction between those states is described by the graph dynamically. For example, occupant attentiveness is derived from measurable eye gaze and eyelid position. From this quantity, reaction time can be estimated in turn. Combined with exterior information, it is possible to decide on the intervention strategy like e.g., alerting the driver. Physical or data-based functional dependencies can be used to represent such interactions. The uncertainties of the inputs and from the surrogate models are included in the graph to ensure a reliable decision-making process. An example of the decision-making process, by modeling the states and actuators as partially observable Markov decision process (POMDP), shows how to optimize the airbag efficiency by influencing the head position prior to an impact. This approach can be extended by additional parameters like driving environment, occupant occupancy, and seating positions in further iterations to optimize the intervention strategy for occupants. The proposed framework integrates scenario-based driving dynamics and existing knowledge from so far separated safety systems with individual activation logic and trigger points to enable holistic vehicle safety intervention strategies for the first time. It lays the foundation to consider new safety hardware, sensor information, and safety functions through a modular, and holistic approach.

PAPER NO.23-0034-O

Comparison of injury severity prediction using selected vehicles from real-world crash data

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Abstract
Advances in automotive telemetry technology have the potential to predict occupant severity from vehicle conditions at the time of an accident, and appropriate triage, as well as transport to a trauma center, can greatly improve subsequent treatment. The National Automotive Sampling System Crashworthiness Data System (NASS-CDS: 1999-2015) was used to filter for new case selection criteria based on vehicle type and matched to Subaru vehicle categories. We have proposed four types of injury severity prediction algorithms that were matched with the categories of Subaru vehicles. Specifically, 1) ISP model that categorized the principal direction of force (PDOF) into four impact directions (front, left, rear, and right) , 2) ISP-R model that considers the effect of the right-front passenger in addition to the four impact directions, 3) ISP-f1R model that represents PDOF as a continuous function using periodic basis splines, called functional data analysis, and 4) ISP-f2R model in which the knot position was modified in 3). In this study, five-fold cross-validation was performed within the training data (NASS-CDS 1999-2015) to evaluate the performance of these four models. In addition, external validation was performed using the National Automotive Sampling System Crash Investigation Sampling System (NASS-CISS: 2017-2019). The results of the cross-validation showed that the area under the receiver operating characteristic curve (AUC) was used to evaluate the model performance, which was 0.854 for the ISP model and 0.862 for the ISP-R model, indicating that the ISP-R, which considered the influence of the right-front passenger, was more accurate. The AUC values were 0.847 for the ISP-f1R model and 0.856 for the ISP-f2R model using a continuous function for the direction of impact, indicating that the ISP-R model had the highest AUC value among the models. On the other hand, the validation results with NASS-CISS were 0.817 for the ISP model and 0.828 for the ISP-R model, and 0.831 for the ISP-f1R model and 0.828 for the ISP-f2R model, indicating that all models had AUC values above 0.8. The important factors for the occupant injury prediction algorithm were delta-V, belt use, age, and crash direction, and the presence of a right-front occupant was a significant injury risk modifier, especially in side impact crashes.

PAPER NO.23-0063-O

Study on the improvement of pedestrian's visibility by geometric patterns projection lighting

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Abstract
A growing proportion of traffic accidents with pedestrian fatalities are occurring at night. With conventional lighting technology, using stronger illumination to increase the visibility of pedestrians contrarily causes the issue of increasing glare. The present research therefore devised geometric pattern

projection lighting that is aimed at extending the distance at which drivers can detect pedestrians while at the same time reducing glare for pedestrians. Test subject verification regarding visibility of pedestrians by drivers was performed and the effectiveness of the devised lighting was made clear.

PAPER NO.23-0067-O

Dynamic testing with pre-crash activation to design adaptive safety systems

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Abstract
Pre-crash occupant dynamics change more and more with the broad usage of advanced driver assistance systems (ADAS) and automated driving (AD) functions. Occupant interaction with pre-crash activated seatbelt systems (SBS) represent a challenge and an opportunity at the same time for providing restraint solutions tailored to the individual passenger and to the actual driving situation. To fully understand the dynamics, and to design robust control parameters, the increased complexity can eventually only be assessed by means of a virtual approach. Consequently, this requires compulsory realistic advanced physical tests and development targets to ensure that integrity and functionality of all system components are fully understood and modeled appropriately. Focusing on the most frequent crash types: frontal and rear end crashes, allows to use a specially designed, stripped-down Anthropomorphic Test Device (ATD) to dynamically load the seatbelt system in a representative way. In addition, a high-precision surrogate with different selectable upper body moments of inertia, seated on a generic steel seat with an adjustable backrest is available to extend the range of the applicable load. In both cases the retaining effect caused by friction on a real vehicle seat is accounted for by an adjustable viscous damper, retarding the motion of the lower body. These reduced setups guaranty by design a direct and accurate positioning of the ATD, minimizing test setup variability. As a novum, a seamless transition from initial pre-crash dynamics to the final crash pulse loading can be realized when mounting these ATDs on an innovative test bench using closed-loop controlled electric linear motors to accelerate a linear ball bearing guided carbon sled along a 6-meter track for achieving a maximum in reliability and in repeatability. This physical bench test represents the foundation not only for demonstrating benefits of pre-crash activation on seat belt systems but also for validating functional SBS simulation models, so that numerical simulations become its digital twin. Reliable digital SBS simulation will be the key to generate more and advanced seat belt functions. However, the capability to measure efficiently and accurately via physical tests the performance of these SBS products throughout the entire range of their functional design space, will promote not only the product, but further raises the credibility of simulation. A new rating criterion Characteristic Shoulder Force Level (CFL) evaluating the SBS performance virtually is proposed, which assess the performance of the SBS intervention up to force-closure and demonstrates the strength of a hybrid approach. Different vehicle configurations, crash pulses, load scenarios and SBS activation strategies can be rated and directly compared to each other. This supports improved integrated safety systems solutions and allows detailed analyses of active safety pre-crash interventions as triggered by ADAS or AD. The combined virtual-physical approach is illustrated via load cases combining braking intervention with conventional and actively controlled seatbelt systems. The potential benefit to occupant safety of different combination of braking and SBS activation is measured and discussed.

PEER REVIEW PAPER NO.23-0148-O

Multi-Sensor driver monitoring for drowsiness prediction

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Research
The questions addressed in this paper are: 1. Does the addition of heart rate data to a camera-based DMS improve the performance of a drowsiness model? 2. How far in advance of lane departures and long eye closures can drowsiness be detected with a camera-based DMS and with a multi-sensor approach

Methods
Data from 48 participants were collected in the high-fidelity National Advanced Driving Simulator at the University of Iowa. The simulator consists of a 24-foot diameter dome enclosing a full-size 2014 Toyota Camry sedan with active steering and pedal feedback. A 13-degree of freedom motion system provides participants accurate acceleration, braking, and steering cues. Sixteen high-definition projectors display seamless imagery on the interior walls of the dome with a 360-degree horizontal field of view. Drivers completed a three-hour simulator drive along a nighttime interstate loop. Participants completed a protocol prior to their overnight driving session such that they had at least 16 hours continued wakefulness before the drive began. Data were collected from several sources. Self-reported drowsiness (KSS) was collected every 10 minutes throughout the drive. Observer ratings of drowsiness (ORD) were also conducted during the same ten-minute intervals. Driver state information was collected via two Aisin DMS units integrated into the NADS-1 cab and synchronized with the other data sources. Physiological data was collected from an Empatica E4 wristband and millimeter wave radar integrated into the simulator cab. Finally, engineering data from the simulator included control inputs as well as driving performance measures.

Results
Data from the vehicle, driver behavior, and driver physiological signals were collected and analyzed to extract features appropriate for the prediction of drowsiness. These features were used to train driver drowsiness models. A cross validation approach was used to test model performance in which participants in the test set were distinct from participants in the training set. A model trained with data from a camera-based DMS was compared with one that also includes features extracted from heart rate data.

Discussion
Common measures such as PERCLOS and lane departures may come too late to mitigate drowsiness. If we wish to improve the performance of a drowsiness model, emphasis must be given to other signals, such as steering activity, blink rates, head pose, and heart rate. We consider a wearable source for heart rate, but less invasive measurement methods are also available.

Conclusion
The field of driver monitoring continues to advance, and while cameras currently dominate the space, other types of sensors are maturing to the point that they may be included in a vehicle. Their capabilities to detect drowsiness must be weighed against the risk of nuisance alerts, false negatives, privacy concerns, and cost. Driver monitoring falls under the wider field of in-cabin monitoring of driver and

occupants, to which various sensors are being applied. The signals are applicable to ADAS and ADS applications that warn the driver or adapt automation capabilities around the driver's state.

PAPER NO.23-0166-O

Proposed speed limits for the 2030 motor vehicle

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Abstract

Vision Zero builds on the aspiration to keep kinetic energy below human tolerance to prevent fatalities and serious injuries. In this work, a Swedish expert group within the SAFER arena estimated the maximum safe speed limits for the 2030 motor vehicle based on the boundary conditions of vehicles, road infrastructure and human crash tolerance to achieve close to zero road fatalities and serious injuries. The present work was based on expert consensus, rather than a retrospective quantitative analysis of crash data. Different load cases were discussed separately, with the involvement of a passenger car being the common denominator. The passenger car and its collision partner were assumed to be of model year 2030, thus reflecting the base safety level of the Swedish car fleet by approximately 2050. The boundary conditions were set based on pre-crash autonomous braking ability and the maximum acceptable impact speeds that would result in a very low risk of death or serious injury among the car occupants and the car's collision partner. In the case of car to pedestrian impacts, the acceptable impact speed was set to zero, as any impact with pedestrians can lead to serious injuries as a result of ground impacts. It was expected that the responsibility to comply with speed limits will move from the driver to the car itself, and that travel speeds will be autonomously reduced when low road friction, sight obstructions, and other challenges in the traffic environment are detected. This function was expected to be non-overridable. Lateral control was also expected to be further enhanced with lane support technologies, although it was assumed that it will be still possible to override such technologies. Over time, increased performance of vehicle safety technologies will likely be able to prevent an increasingly large proportion of crashes in all load cases. However, in line with Vision Zero design principles, human crash tolerance will always be the ultimate boundary condition to guarantee a safe outcome in a crash. As a result, the recommended maximum travel speeds in the road transport system containing motor vehicles only of model year 2030 and beyond are: - 5-7 km/h in pedestrian priority areas, - 40 km/h in mixed traffic urban areas, if there are no obstructed sensor sightlines, e.g. due to parked vehicles along the sidewalk, - 50 to 80 km/h on roads without mid- and roadside barriers, - 100+ km/h on roads with continuous mid- and roadside barriers, - 40 to 60 km/h in intersections, depending on vehicle mass differences. The results from this work can be used to inform the development and amendment of transport planning guidelines when moving away from the economical paradigm into Safe System boundary conditions in the setting of speed limits.

PAPER NO.23-0178-O

Safety of electro mobility - White paper of the FISITA Intelligent Safety Working Group

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Abstract

Battery electric vehicles and plug-in hybrid electric vehicles experienced significant increases in sales volume, reaching a worldwide market share of 7% of all newly registered vehicles by the middle of 2021. One of the central challenges of this paradigm shift lies in the safety aspects of electric vehicles and their components. For vehicles with combustion engines, safety aspects have been carefully investigated over decades, standards, regulations, test requirements and system limitations are widely established and acknowledged by vehicle manufacturers, suppliers, government authorities, NGOs, and customers. For electric vehicles, this process has just started; yet its objective must be to establish a comparable level of safety taking in consideration the specific needs of those vehicles and their individual risk assessment. This paper represents a pre-publication of a White Paper on the Safety of Electromobility, to be published by FISITA, the Fédération Internationale des Sociétés d´Ingénieurs des Techniques de l´Automobile. The chapters are designed by dedicated experts from all around the globe and from a variety of institutions within the engineering society under the umbrella of FISITAs Intelligent Safety Working Group ISWG. The White Paper is supposed to be published in autumn, 2023 during the FISITA World Congress in Barcelona and it summarizes the current state of the art as well as new research results for safety aspects during the product lifecycle of electric vehicles and their components. The book will be a precious handbook for all those who develop, produce, use, repair or work otherwise with vehicles with high voltage batteries and powertrains. The structure of the White Paper follows the product lifecycle and covers the safety aspects for all phases in the following chapters: - EV-components, - Manufacturing, - Use & Operation, - Repair, Inspection, Maintenance and Service, - Crash protection, - Thermal events prevention or control, - Rescue, - Cyber Security, - End-of-Life, Second Life of batteries and Recycling. In separate chapters the specific Insurance aspects and the use of CAE for safety development, validation and verification are addressed. Last but not least the White Paper will give a forecast on future challenges in this area and also provide references to existing standards and best practices. In this pre-publication the focus lies on the two chapters “Crash protection” and “Thermal events prevention or control”. Other chapters are planned to be pre-published during the time frame between today and autumn 2023.

PAPER NO.23-0234-O

Predictive safety: Towards holistic top-down systems engineering for pre-crash systems

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Abstract
Since the first equipment of vehicles with environmental sensors for driver assistance systems more than 20 years ago, engineers are working on employing this data to improve or enable the activation of existing or envisioned passive safety systems. This task is motivated by potential benefits in occupant safety. In particular by an increased robustness of activation logic or by innovative actuators which promise to enable more degrees of freedom for new vehicle interior designs and the positioning of occupants. New regulations for ADAS functionalities lead to high equipment rates with environmental sensors which can foster the integration of active and passive safety technologies. Signals with an appropriate quality can be used smart to improve occupant safety in holistic safety strategies combining active and passive safety systems still offers big potentials. In this paper we aim to detail challenges in the multidisciplinary field of “Pre-Crash”, the field of using environmental sensing to improve occupant safety. This requires considering the whole functional chain: sensor – perception – prediction - function logic - actuator, and further system properties like functional safety (including SOTIF topics) or validation strategies. As an example, throughout this paper, we will use a new functionality of a reversible pretensioner to reposition a forward leaned occupant by seatbelt retraction, called Active Occupant Repositioning. By getting into details, the complexity and mutual influences becomes apparent. Discontinuous relationships and dependencies on scenario details exist. The challenge is to divide the problem into manageable tasks. To get a clear understanding and a basis for communication we classify Pre-Crash systems in different base architectures and elaborated principal differences to assess the suitable next step for Pre-Crash system development. Methodologies are reflected to develop Pre-Crash systems, and strategies are derived to adjust the variety of dependent system parameters. Therefore, properties of an electromechanical actuator are analyzed to come towards a holistic Pre-Crash system development.

PAPER NO.23-0244-O

Research on V2X communication system to reduce pedestrian accidents

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Abstract

Everyone deserves to feel safe on the road. The goal is to strive for zero traffic collision fatalities involving motorcycles and automobiles globally by 2050. Many traffic fatalities are categorized as vulnerable road users such as pedestrians and cyclists. In particular, pedestrian fatalities account for the largest portion. Pedestrian accidents have occurred not only through drivers' errors but through pedestrians' errors. Thus, in addition to advanced driver-assistance systems, safety behavior by pedestrians is effective for reducing pedestrian accidents. Research was therefore conducted on the vehicle-to-everything (V2X) communication system connecting vehicles and pedestrians to assist both drivers and pedestrians. The system used 5G standalone mobile communication system and a cellular-V2X communication system. With an in-vehicle camera, the system detected a pedestrian walking across a street ahead and in an area that is in a blind spot for the driver. Then, the total time required for the pedestrian to receive notification after detection by the in-vehicle camera was estimated. Also, the reactions of pedestrians were observed, and the time required for pedestrians to react to notification was measured as well. The result in the assumed use case was that the system promoted safety behavior by supporting drivers and pedestrians before collision occurred. However, considering the reaction time of pedestrians, assisting system users before collision is a challenge if the time to the collision is extremely short. Therefore, the system is required to notify the users in plenty of time before the collision. In order to utilize the system, it is desired to promote widespread adoption by installing the system on smartphones rather than on dedicated equipment. Also, the accuracy of location ascertained using smartphone needs to be improved to establish acceptability. The safe use of communication technologies was considered as one of the one-step-ahead integrated vehicle safety technologies. This report details the structure, results, and issues of the V2X communication system.

PAPER NO.23-0257-O

Integrated safety for occupant protection

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Abstract
Integrated vehicle safety aims to connect active and passive safety technologies and has the potential to go far beyond what each can achieve separately. Improving integrated vehicle safety has become highly relevant for the development of automated vehicles. The goal of the ISOP project is to investigate whether applying active safety features and manoeuvres during the pre-crash phase can negatively influence the performance of the vehicles' restraint systems in a way that the state-of-the-art passive safety systems are no longer as effective in preventing fatalities and avoiding or mitigating injuries in road accidents. A couple of test protocols have been defined within the project to analyse the effects of pre-crash manoeuvres on the initial occupant posture. The data from the tests with volunteers in proving ground performing cut-out manoeuvres have been collected and have been used as input database for the simulations with the Human Body Models (HBM). Due to the limitations of the Anthropometric Test Devices (ATD) in responding to a pre-crash manoeuvre, the effectiveness and sensibility of the restraint systems has been evaluated by HBM. In contrast to ATDs, virtual Human Body Models (HBM) represent the anatomic structure of human beings including bones, flesh, skin, fat, and soft tissue. The high model detail allows a direct assessment of the injury risk based on the damage applied to the respective body region (e.g., in form of stress or strain), assuming a correct damage prediction of the model. Integrated safety enhances comfort, convenience and can help assist in critical driving situations and in protecting occupants. However, the state-of-the art restraint systems need to

be evaluated in such novel load cases including the activation of vehicle active safety systems and the pre-crash manoeuvres. This paper focuses on the influence of active safety systems towards the protection of vehicle occupants in the event of a crash that has not been avoided, by developing a combined series of test protocols, performing volunteer tests and HBM simulations.

Human Factors Considerations for ADAS and ADS Technologies

Wednesday, April 5, 2023, | 08:30-12:30

Chair: Peter Burns, Canada | Co-Chair: Stacy Balk, United States

TRACK C | Room: G301+G302

PAPER NO.23-0068-O

System limitation experiences by Swedish drivers using ACC and LKA

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Abstract

For many ADAS to reach its full safety potential they need to be activated and used by its drivers. There are thus several known (technical) limitations that could, as indicated by research, potentially affect the perception and use of the ADAS. This paper explores limitations as experienced by users for the lateral assistance systems Adaptive Cruise control (ACC) and Lane Keep assist (LKA). The paper partly reports on a larger online survey launched (n=1822) in 2021 aimed to explore self-reported use and non-use of six different ADAS among Swedish drivers using a 5-point Likert scale. Descriptive statistics including frequencies and a calculated summative level of agreement % is presented together with 95% confidence levels. Included in the analysis is those respondents reporting using ACC (n=1002), and/or LKA (n=461). Presented are limitations as experienced, frequency of use/non-use, and perceived driving experience. Results show that ACC is being activated (always/often) to a greater extent (84%) than LKA (57%), and for LKA it varies by frequency of driving. The majority of the participants had experienced more than one limitation (ACC:72%, LKA:68%), on a regular basis, which results in deactivation of the system. Only about 20 % (ACC:20%, LKA 18%) had never experienced that they could not use the ADAS. Those who do not experience any limitations, never experience the need to deactivate the ADAS to a greater extent- ACC: (38% vs 22%) and LKA (48% vs. 23%). Statistical significant tests relived a significant difference between LKA and ACC, in which LKA was affected to a greater extent for bad weather (48%), glare (48%), position in lane (27%), complex traffic (27%) while ACC was affected to a greater extent by dirty sensors (45%), complex traffic (43%), weather (31%). ACC also contribute (significantly) to a higher degree to a positive driving experience than LKA, likewise are more trusted and easier to use. This study highlights some of the reasons why ADAS are regularly turned off, diminishing their safety potential. Technological developments, together with standardization and infrastructure adaptation, may be required for ADAS to fully realize their safety potential.

PAPER NO.23-0263-O

Key human factors development principles for DMS enhanced collision avoidance system development

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Abstract

Driver monitoring systems (DMS) can enhance Collision Avoidance Systems (CAS) in numerous ways, for instance by adjusting warnings or interventions when drivers are inattentive or in other ways disengaged or impaired. However, the driver interaction principles applied when using DMS to enhance CAS must be based on State-of-the-Art Human Factors research and have a clear focus on understanding driver needs and in what way assistance should be provided to be appreciated by the driver. Otherwise, one risks implementing interactions that either do not make sense or are perceived as disturbing, both of which degrade the CAS's safety potential. Some of these interaction principles may not be fully intuitive unless your background is in behavioral psychology. For example, it may be surprising that DMS is best used to delay certain collision avoidance warnings rather than supply them earlier. It may also not be fully intuitive that DMS is best used for detection of generic degradations in the behavioral patterns that define normal driving rather than for diagnosis of specific impaired states. To use a CAS properly, you need to interact with it regularly to learn what its outputs mean. However, current accident and mileage statistics suggest that driving conflicts where a CAS could save you from an unrecoverable error that otherwise would have resulted in a high severity crash are rare; maybe as infrequent as once in a decade or lifetime depending on how one does the calculation. From a design perspective, CAS are therefore best approached as lifetime driving companions. You may only need them once, but they still need to be interacted with regularly to work as intended. Hence, the conversation between driver and CAS should adhere to the same principles as applied between humans. For example, if your colleague is busy, you only interrupt for good reason, and if you interrupt regularly, both of you must agree its relevant and the message must be clear (though not necessarily loud) so the other person quickly can decide whether to interrupt the current task. In this paper, first a general framework and corresponding design approach for CAS is formulated based on accident statistics, driving mileage and CAS interaction frequency analysis. Next, three specific development principles for DMS enhanced CAS are described to illustrate what the outcome is when the framework and design approach are applied in practice. These include how DMS enhancement can be used to avoid "cry wolf" effects in CAS interactions, how DMS enhancement can be used to get CAS timing right for both distracted and aware drivers and finally, how DMS offers a more efficient way than specific state diagnosis when tackling driver impairment. By explicitly describing these fundamental Human Factors development principles for DMS enhanced CAS to the traffic safety engineering community, one may avoid unnecessary development pitfalls that could counteract DMS enhanced CAS deployment.

PAPER NO.23-0315-O

Methodology and test protocol development for driver engagement during assisted driving

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Abstract
One of the great challenges around the advent of driver assistance systems is to ensure that drivers understand the true capability of technology, such that they can behave accordingly for safe vehicle operation. This understanding can be influenced by a range of factors including vehicle instructions, user interface and warnings, and system control behavior. Validation accounting for these important aspects is therefore central to understanding and comparing safety performance for real world use for overall system design implementations. This paper presents a test methodology specified for implementation on an automotive proving ground facility capturing pre-use information, and driver-vehicle interaction during assisted driving regarding user interface and system control behavior. Data collection was defined around the quantification of driver engagement with the driving task using subjective measures to assess progressive effects of system use and objective metrics considering driver behavior and capability to respond to an emergency scenario. In a pilot assessment, a between-subjects test was conducted using two vehicles with differing assisted driving concepts. A sample of naïve drivers (n=39) was recruited and, following a customer focused description of system functionality, was instructed to drive on a test track in continuous highway driving scenario with longitudinal and lateral driver assistance features active. Subsequently, a critical 'cut-out' event was presented requiring a driver response to avoid an in-lane obstacle. Results indicate variability in how drivers interact with the system during 'normal driving' with subjective measures demonstrating differences in metrics associated with engagement. Likewise, objective measures for driver reaction to the critical event signify differing levels of driver vigilance associated with perceived functionality of individual systems. Outcomes from this experimental test mark a step in the development of test methods for global assistance system assessment and provide a platform for further progression and refinement of tests. This has implications system design verification with highly replicability whilst accounting for use by representative drivers, alongside possible applications in consumer and regulatory testing with representative drivers.

PAPER NO.23-0162-O

Development of a performance-based procedure for SAE Level 2 driver engagement assessments

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Abstract
Adapting the performance and design of Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS) to human capabilities and safety needs is an important requirement for a safe market introduction of new technologies in this field. A specific challenge for SAE Level 2 systems is the engagement of the driver in the driving task. A high level of driver engagement is necessary to ensure that drivers are able to fulfill their role and responsibility to monitor the system performance and to

intervene in system limit situations. However, effectiveness of current driver monitoring technologies to ensure driver engagement are limited with broadly diversified performance parameters. Therefore, the aim of the current research was to develop and validate a standardized procedure for performance-based assessments of driver engagement of Level 2 systems with a direct link to safety by focusing on controllability in accident-prone system limit situations. In total, 39 drivers without prior experience in continuously assisting systems participated in the evaluation study on a test track. To assess the validity of the procedure and the standardized test scenario, half of the participants experienced a Level 2 system (Tesla Autopilot) while the other half drove the same vehicle (Tesla Model 3) conventionally (fully manual). The participant's task was to constantly follow a lead vehicle, driven by a second experimenter, on a round course for approx. 30 minutes. At the end of the test drive an accident-prone system limit situation without a prior system-initiated warning was triggered: The lead vehicle performed a cut-out maneuver revealing a stationary crash target in front of the participant. Without driver intervention, the Level 2 system was not able to avoid a collision. Therefore, the participant was required to react by braking and/or steering. Results indicate that the test scenario is controllable by conventional drivers. No driver of this group caused a collision or had a Time-To-Collision minimum below 1 second. However, drivers of the Level 2 system specifically used in the study had difficulties in controlling the system limit situation and intervening adequately to avoid a collision with the stationary target. 15% of these drivers collided with the target and approx. 50% had a Time-To-Collision minimum below 1 second. Furthermore, the median Time-To-Collision minimum of the Level 2 drivers was approx. 1.5 seconds lower compared to conventional drivers. Concluding, it can be stated that the test scenario is in general controllable by conventional drivers but, due to a lack of driver engagement of the Level 2 system tested in the study, participants of this group had problems in intervening adequately to the system limit. In summary, the developed procedure is a pragmatic, reliable and valid way to assess driver engagement independently and in a design-neutral way by focusing on safety critical interaction behavior in system limit situations.

PAPER NO.23-0295-O

Evaluation of simulated Level 2 hands-free driving in real traffic – an innovative method for an early SOTIF Human Factors assessment of ADAS under realistic driving conditions

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Abstract
Objective: Recent activities in the development of assisted and automated driving involve vivid discussions about the necessity to evaluate the interaction between the driver and the system, especially while using high performant SAE Level 2 functions (see SAE, 2016). The assessment of safety in use of these systems is fundamental and includes several methods that can be applied to evaluate the controllability of the systems, e.g., simulation, driving simulator studies, and realistic driving studies on test tracks or in real traffic. In early development stages, it is barely possible to assess the functions in real traffic. However, some research questions need to be addressed early and can be answered the most appropriate by studies in real traffic. Therefore, a method to simulate new SAE Level 2 and even Level 3 systems in test vehicles has been developed. Method: A new method to assess driver behavior and controllability of system limits in real traffic is presented: By using assisted driving functions of

series vehicles, higher assisted functions can be simulated in the user interface and additional functional features can be implemented, such as automated lane changes that can be triggered by a trained safety driver sitting on the passenger seat. Thereby, it is possible to assess fundamental Human Factors aspects, such as mode confusion, overreliance or overtrust, under highly realistic study conditions or even assess controllability of lateral steering errors in real traffic. A realistic driving study to assess controllability of such system limits while driving SAE Level 2 hands-free is presented. Results: Simulating new SAE Level 2 functions by using special test vehicles and trained safety drivers enables researchers to evaluate the driver's interaction with these functions under controlled and very realistic conditions. The results of such studies can help to identify risks and, thereby, define appropriate measures to address and minimize them. Moreover, hypotheses about driver behavior can be tested and validated to support a safety-oriented development process. The results of the presented study on controllability of sudden steering errors show that attentive drivers are able to control system-detected as well as system-undetected lane drifts while driving SAE Level 2 hands-free. Differences in reaction times were significantly correlated with if the steering error occurred and an urgent warning was triggered or if the lane drift was undetected by the system and no warning was issued. Conclusion: Evaluating driver behavior in real traffic while using SAE Level 2 systems is necessary to assess safety in use of these functions before introducing them into the market. Simulating new systems in series vehicles helps getting important insights into driver behavior while using such functions. System limits to be expected can be presented and controllability of the resulting situations can be assessed as well as driver reactions in terms of reaction times and quality of intervention.

PAPER NO.23-0296-O

Preventing driver misuse with proactive ADAS

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Abstract
As a consequence of the fast adoption of driving automation systems, most vehicles available on the market are the result of a robot-centered development approach. A few decades ago, the major challenges faced by the engineers were to implement sensors and control capability enabling the vehicle to follow and remain within a lane. For safety and to ensure compliance with the evolving regulations, driver monitoring systems (hands-on detection, head, and gaze cameras) and override or takeover strategies completed the necessary equipment. The human driver has been considered afterward the development of the robot-like vehicle. Focusing on lateral control, the majority of level-2 vehicles use an override strategy, which segregates manual from automated steering operation. Sometimes, this causes confusion resulting in distrust and ultimately misuse. Consequently, the level of acceptance of ADAS functions remains under the expectation. Active interaction with the automation is proposed to leverage driver engagement, which is considered as one of the key indicators for assessing safety of ADAS functions. The concept of haptic shared control of the steering enables manual intervention over the automation without deactivation. Systematic and consistent reconsideration of level-2 ADAS functions becomes possible when haptic interaction is exploited. Two proactive ADAS functions: active lane centering assistance and assisted lane change are proposed to enhance driver engagement while reducing the risk of misuse. Furthermore, it raises the question of the relevance of the driver monitoring system.

PAPER NO.23-0307-O

Evaluation of interfaces for augmenting a driver's ability to anticipate front risks in real traffic

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Abstract
Effective alerts are often subject to a tradeoff between relevance and utility. While it is easier to acknowledge the relevance of a warning about an imminent hazard than a more distant threat, the possibilities to act appropriately in response to notifications decrease with threat distance. To benefit from the advantages of early notifications without creating annoyance and ignorance, we introduce a variety of Human-Machine Interfaces that provide driver assistance by scaling stimulus saliency in accordance with the urgency of a front risk in traffic. Further, we report an initial investigation of the influence of the HMIs on measures of front collision risk and subjective driver experience after prolonged use in real traffic. Three functional HMI prototypes were implemented in a roadworthy vehicle, equipped with additional hardware for front risk detection, stimulus presentation, assistance control, and data logging. Participants with advanced driving practice received these vehicles for 12 days in total for personal daily use, consisting of 3 guaranteed days of use for one of each HMI prototype and 3 days of driving without any added front risk notifications. Besides continuous logging of driving data and risk estimates, subjective data were acquired in the form of logbook entries and interviews. Measures of driving safety were high across all conditions, indicating no occurrence of critical situations. No HMI specific safety effects on top of high baseline levels were observed. Subjective ratings show a trend for an increasing perceivability and usefulness of a sound-based HMI with extended system exposure. Participant feedback suggests that no such adaptations may have been necessary for the remaining vision-based HMIs because intuition could be gained quickly. Future HMI iterations should refine the balance between salience and subtlety to better align with actual safety levels while future investigations might benefit from longer individual exposures or an experimental control of safety levels.

PAPER NO.23-0137-O

Drivers' response to automation-initiated disengagement in real-world hands-free driving

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Abstract
Driving automation features in the form of advanced driver assistance systems (ADAS) that can control the longitudinal and lateral vehicle kinematics on sustained bases (SAE Level2) are becoming increasingly available in consumer vehicles, making the study of drivers' behavioral adaptation and the impacts of automation central to driving safety. This study used real-world data to assess drivers' responses to automation-initiated disengagements by quantifying changes in drivers' moment-to-moment visual attention and vehicle control behaviors. Fourteen drivers (36% female) drove for one-month each a Cadillac CT6 equipped with a data acquisition system that recorded driving kinematics,

miles driven, automation use, GPS, and video of the driver and driving environment. Cadillac's Super-Cruise (SC) is one of the most advanced, commercially available partial automation systems that, when engaged, enables hands-free driving while directly monitoring the driver's head orientation. A total of 265 SC initiated disengagement events were identified (mean=18.9; SD=16.5 per driver) across 5,514 miles driven with SC. In general, SC initiated disengagements were associated with substantial changes in glance distribution. Immediately after disengagement, the proportion of glances to the Road decreased from 83% to 68% and at the same time the proportion of glances to the Instrument Cluster increased substantially, from 8% to 27%. The period following SC initiated disengagement was also characterized by a 44% increase in the overall number of transitions between glance areas (from 845 transitions before to 1218 after the disengagement across events). The most dominant visual attention patterns after SC disengagements were Road to Instrument Cluster (57% increase) and Instrument Cluster to Road (222% increase). Linear quantile mixed-effects models were used to estimate glance duration before and after disengagements. Findings indicate that on-road glance duration following SC disengagement decreased significantly and was 4.86sec shorter in the 85th quantile (Q15Before=0.5, CI=[0-2.24], Q15After=0.43, CI=[0-2.11], p=.04; Q50Before=2.02, CI=[0.8-3.24], Q50After=1.45, CI=[1.02-1.88], p=ns; Q85Before=6.63, CI=[2.06-11.2] to Q85After=1.77, CI=[0-3.67], p<.001). Analysis of driver hands on-wheel behavior indicate that drivers adopted SC's hands-free feature to a substantial degree, taking both hands off the steering wheel more than 75% of the time SC was engaged. Takeover duration when driving hands-free was significantly longer (2.4sec) compared to driving with at least one hand on the steering wheel (1.8sec). In conclusion, concerns over the phenomenon of driver out-of-the-loop, coupled with known limitations of partial automation systems, have led research to focus on driver response to automation-initiated disengagement and the ability to regain manual control. We find that real-world automation-initiated disengagements trigger substantial changes in driver glance behavior including shorter on-road glances and frequent transitions between the Road and the Instrument Cluster glance areas. This behavior pattern likely represents drivers' searching for information related to the disengagement or the automation state and may be shaped by the automation design. Higher levels of automation may introduce more substantial changes in visual and vehicle control behaviors during automation-initiated disengagements. This data provides useful information to designers charged with developing assistive and automated systems and empowers regulators and safety advocates with insights needed to better guide appropriate utilization of ADAS technologies.

PAPER NO.23-0135-O

Measuring the transition window in conditional automation

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Abstract
Conditional (SAE driving automation level 3) automation is projected to see broader deployment by several manufacturers in multiple countries. L3 Automated Driving Systems (ADS) target performing the entire dynamic driving task (DDT) within an operational design domain (ODD), allowing the user to disengage while the system is active, but expect that the driver remains "takeover ready." In practice, one expectation of conditional automation is that the system will issue a request to intervene (RTI) prior to exiting its ODD, with a "sufficient" time window for the user to reengage in manual driving. To date,

research has yet to provide an understanding of what a sufficient transition window will be in the context of near-production systems, specifically in those designed to operate in low-speed traffic jams. This study used an adaptive approach to adjust the timing of the request to intervene during transitions of control in a high-fidelity driving simulator. The transition adjusted from transition event to event based on whether participants were able to successfully take control in the previous event. Success was defined in reference to a baseline group who drove with expectations of being fully engaged in driving (i.e., SAE driving automation level 2). The results show that most participants were able to successfully make transitions with transition windows in the range of 4.5 to 5 seconds. However, some participants took several seconds longer to make successful transitions and for the subset of participants looking away from the forward road at the onset of the RTI, transition windows in the range of 7-7.5 seconds led to more successful transitions. This study provides a starting point for developing an objective definition of a "sufficient" transition window in the context of low-speed conditional Automated Driving Systems.

PEER REVIEW PAPER NO.23-0087-O

Silent failure detection in partial automation as a function of visual attentiveness

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Research
The objective of this study is to determine how driver visual attentiveness contributes to the likelihood of silent failure detection.

Methods
Data from 24 participants were collected in the high-fidelity National Advanced Driving Simulator. Participants completed a study drive with a partially automated (SAE L2) driving system. The driving task transitioned between periods of free flow traffic (55mph) and lower-speed traffic jams (22mph). Throughout the drive, participants were incentivized to engage with a realistic email task while also being instructed that they were expected to monitor the driving scene and state of the automation. At the end of the study drive, participants encountered a "silent failure" event. This event consisted of a deceased deer covering half of the participant's lane of travel. The deer was revealed by a lead vehicle at four seconds time-to-collision. Critically, the event was "silent" in that the automated system did not detect or respond to the low-profile object. Driving simulator, eye tracking, and video coding data were used to provide response measures and metrics of driver attentiveness.

Results
Thirteen of the twenty-four participants in the study completely failed to detect the deer. Of the 11 participants who detected the deer, 7 were able to successfully respond to avoid the revealed object. Visual attention preceding the silent failure was quantified through coding of glance location. Of particular interest was the frequency, timing, and duration of glances to the forward roadway leading up to the reveal event. The data show significant variability with respect to how drivers deploy attention in the presence of an engaging non-driving task while partial automation is active. These patterns of visual attention were predictive of likelihood of responding to the silent failure.

Discussion
Many studies have examined driver response to takeover requests at different levels of automation. Silent (i.e., unalerted) failures, however, pose a particular challenge for partial automation, where drivers are expected to monitor the road and automation. The results of this study show that silent failures are unlikely to be detected when drivers are engaged in a non-driving task. Furthermore, these results speak to individual differences with respect to the deployment of visual attention between a non-driving task and the driving scene. It is important to note that this study included a single silent failure and may not reflect the actual frequency of such failures in real driving.

Conclusion
This study helps map the relationship between patterns of visual attentiveness and detection of silent failure events in partial automation. Silent failures are one of the most difficult challenges in partial automation and therefore it is important to understand how human limitations will impact the design of automated systems. The results of this study can be used to develop models of driver attention in automation under variable conditions and help define thresholds for driver monitoring technologies.

PEER REVIEW PAPER NO.23-0069-O

Driver eye glance behavior and performance with camera-based visibility systems versus mirrors

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Research
Drivers' ability to extract visual information efficiently from mirrors or camera-based visibility systems will impact their performance carrying out driving maneuvers (e.g., lane changes). The objective of the research was to compare drivers' eye glance behavior and driving performance with mirrors versus camera-based visibility systems (i.e., CMS, or camera monitor system) to identify any differences and consider the possible impact of differences on safety.

Methods
The paper will describe two complementary studies. The first was a test track study comparing drivers' eye glance and lane change behavior when driving a vehicle equipped with outside mirrors versus a prototype CMS in daylight and darkness. Participants' opinions about usability and comfort in using mirrors versus the tested CMS were obtained using a questionnaire. The second study was conducted in a stationary vehicle and used a modified Posner Cueing Task to elicit shifts in gaze between the forward view and the mirror or CMS display. Speed and accuracy of response were examined. The second study had two parts: one comparing outside mirrors to a CMS and another comparing an inside mirror to a camera-based electronic alternative.

Results
Test track study results showed that with the tested CMS, participants took longer to pass a slower moving vehicle and maintained a greater resultant distance from the passed vehicle. Additionally, participants fixated more on the CMS displays under certain conditions compared to the outside rearview mirrors. Participants subjectively rated outside rearview mirrors as having better ease of use, comfortability, and visibility than the tested CMS. When asked to choose which rear visibility technology they would prefer to use in everyday driving, most participants indicated a preference for the outside

rearview mirrors over only the CMS or having both systems. Results for the stationary assessment of drivers' accuracy and speed of responding to a visual stimulus presented in inside or outside mirrors or CMS display are pending. Hypotheses predict that responses will be faster and more accurate for mirror conditions, indicating drivers have more difficulty focusing on images in the CMS electronic displays than they do focusing on images in mirrors.

Discussion

Aside from driver's subjective preferences regarding technology, it is believed that some percentage of drivers may have difficulty effectively using images produced by camera-based visibility systems due to issues with visual accommodation, age-relation vision issues, or eyewear (e.g., bifocals). Limitations of this research include, for the test track study, the low number of participants (9) for one test vehicle condition and the use of a prototype CMS, for which results may not be generalizable to production systems.

Conclusion

Test track study participants' longer time to pass a slower moving vehicle with the tested CMS may indicate difficulty in focusing on the electronic CMS image. Hypotheses for the stationary testing suggest that drivers' accuracy and speed of responding to a visual stimulus visible in inside or outside mirrors or CMS display will be different for mirror conditions than for CMS. This paper is applicable to the noted session because it relates to driver interaction with new camera-based visibility system technology.

PAPER NO.23-0195-O

Research on attention keeping technology to reduce careless driving accidents

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Abstract

We explore how a driver's attention changes when exposed to auditory and haptic stimuli. In many cases, accidents caused by internal factors, typified by drowsy driving and careless driving, result in serious accidents. Therefore, it is important to keep the driver from losing attention. Thus far, manufacturers have built systems to promote arousal by engaging visual and auditory alarms when the driver loses attention. However, in such cases the driver has already lost attention when the alarm is engaged. Depending on driving circumstances, it is impossible to immediately stop the vehicle or take a break, and in some cases the driver has no choice but to continue driving despite their decreased level of attention. This paper focuses on auditory and vibratory stimuli as realistic methods of stimulus that can actually be supplied to the driver by products and establishes stimulus methods with indications of a relationship to autonomic nerve activity. The paper also evaluates the effectiveness of these methods in preventing loss of attention, by supplying the established stimulus under conditions in which drivers have begun to lose attention in the past. The stimulus methods are as follows. (1) Music: Comparatively high-tempo music at around 100–130 beats per minute (bpm). (2) Music with amplified bass: The same music described in (1), but with its bass range amplified. (3) Music with vibration: Music with superimposed vibrations in sync with the bpm of the music described in (1), from a sound source in the seatback peaking at 60 Hz. Test subjects were put into a driving simulator that employed these stimuli and asked to follow the vehicle in front of them for 30 minutes. Each of the 11 test subjects repeated four trials, including trials with no stimuli. Several indicators were collected during these trials. For driving behavior, the indicator was Time-to-Collision (TTC), for subjective sleepiness it was time-

dependent change in the Karolinska Sleepiness Scale (KSS), and for a parasympathetic indicator it was Standard Deviation of NN intervals (SDNN), which is the standard deviation of the R-R Interval. The eight test subjects for which data was properly collected tended to exhibit higher minimum TTC during the trails with stimulus than those without. This increased greatly ($p < 0.01$) when bass amplification and superimposed vibrations were used. It was found that subjective sleepiness, which was the time for which test subjects were aware of being sleepy, decreased by 58% with the music stimulus (1), 86% with the music with amplified bass stimulus (2), and 77% for the music with vibration stimulus (3), compared to with no stimulus. Moreover, the SDNN trend revealed parasympathetic acceleration when there was no stimulus, but this was suppressed for both (1) music only and (3) music with vibration. For (2) music with amplified bass in particular, it remained in the same state from the beginning of the test. Applying the knowledge above to inhibit loss of concentration before it occurs can be expected to help reduce traffic accidents associated with internal factors such as drowsy driving and careless driving.

PAPER NO.23-0216-O

Benefits of tactile warning and alerting of the driver through an active seat belt system

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Abstract
Research Question/Objective: Strengthening human ability to perform the driving task in emergency situations is a key ambition of vehicle design. This work aims to further improve driver reaction time by utilizing the tactile sensory channel in multi-modal warning concepts. A specific emphasis of the work is the evaluation of unique characteristics of tactile warning through an active seat belt system in contrast to other modalities. Methods and Data Sources: Two complementary user studies were conducted by two independent research facilities with two dynamic driving simulators. With 87 participants in total there was the aim for statistical relevance of the measurements. The setup included alternative driver warning concepts for both drivers, during manual and assisted driving, and drivers engaged in another task during conditional driving automation. The tactile warning by the active seat belt system consisted of a series of retract pulses on low force levels. The assumption is that drivers will benefit from a high exclusivity of the modality in comparison to a tactile seat, steering wheel, or pedal. Results: In a first setup (manual driving, undistracted), the replacement of the acoustic/auditory warning by a tactile warning, when combined with a visual signal, resulted in an improvement of reaction time of 250 milliseconds for brake initiation. In a second setup (AD SAE Level 3) the driver took over vehicle control 1.0 second earlier with a combination of auditory, tactile, and visual warning compared to a warning without vibrotactile alerting. Discussion: Until now, only a few studies existed aimed to evaluate a tactile warning provided by a seat belt system. The work may support, within the limitations of these studies, the initial assumption that a seat belt system providing vibrotactile stimuli to the torso – specifically chest and shoulder – shows some unique benefits. The exclusivity of the sensory channel and a low interference with other signals in the vehicle lead to high degrees of detectability, discriminability, and intelligibility. Limitations and outlook: Is the use of a tactile warning always positive, or what are effects

of training or habituation? A differentiated semantic design of such tactile stimuli, the incorporation in escalating and multi-modal warning concepts, and the combination with a holistic occupant monitoring are seen as levers for improvement and subjects of further investigations. Conclusion: This research has found that tactile warning of the driver, through an active seat belt system, can contribute significantly to improved warning effectiveness and can help to improve the driver's ability to react in vehicles equipped with Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS). Functions like take-over request (TOR) or forward collision warning (FCW) may benefit by more robust alerting of the driver as part of the emergency warning procedure.

PAPER NO.23-0232-O

A human machine interface suggested from neuroscientific analysis of human factor

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Abstract
Honda aims for zero traffic collision fatalities involving Honda motorcycles and automobiles globally by 2050. To realize a zero traffic-incident society, we need to minimize human driver errors. Improper processing of information should trigger human errors during driving, however, despite its importance for our society, neural mechanisms during driving that can lead to catastrophic traffic consequences remain unclear. To clarify these, we have researched the relationships among drivers' manipulation, gaze, and brain activation. In particular, we have focused on the human eye gaze because it is not only a passive input organ, but also reflects dynamic information processing in the brain. To investigate the human brain mechanisms involved in safe and secure driving, we scanned the human brain using functional magnetic resonance imaging(fMRI) while driving in an MRI-compatible driving-simulator. We introduce one of the experiments showing differential brain activation between safe drivers and control drivers manipulating a vehicle in ordinary traffic conditions. In this experiment, participants were healthy adults, and they manipulated the driving-simulator in the MRI scanner, while their driving manipulation and gaze were monitored. The participants encountered risk factors in the driving scenarios. We extracted the difference in the brain activation at gazing some risks between the safe drivers and control drivers, then the differences in brain activity between safe drivers and others were found in the precuneus, V1, and SMA. Then we constructed a human-machine interface (HMI) that aimed to complement and enhance the cognitive processing which is necessary for safe driving. To verify the efficacy of our HMI, we conducted experiments by using driving-simulator composed of the front part of N-BOX(Honda) and 5 displays (65 inches), the original system. As a result, the suggested HMI could have effect on early noticing and avoiding high-risk object. It is possible, therefore, that general drivers began to drive more safely with a safe driver-inspired information processing assistance system. Our findings will help elaborate the specification of devices for ADAS and ADS.

PAPER NO.23-0293-O

Driver Alcohol Detection System for Safety (DADSS) – A vehicle safety technology approach to reducing alcohol-impaired driving – A status update

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Abstract

Alcohol-impaired driving continues to take a significant toll among road users both in the United States and around the world. In 2021, an estimated 42,915 people died in motor vehicle traffic crashes, a 10.5% increase from 2020. The projection is the highest number of fatalities since 2005 and the largest annual percentage increase in the Fatality Analysis Reporting System's (FARS) history. In 2020, in the U.S. alone, motor vehicle fatalities from crashes involving alcohol totaled 11,654, a 14% increase over 2019, which accounts for approximately 30% of all traffic fatalities in the US for the year. To better address this ongoing problem, in 2008 the National Highway Traffic Safety Administration (NHTSA) and the Automotive Coalition for Traffic Safety (ACTS) formed a cooperative research partnership to explore the feasibility, the potential benefits of, and the public policy challenges associated with the widespread use of non-invasive technologies to prevent alcohol-impaired driving. This partnership, known as the Driver Alcohol Detection System for Safety (DADSS) Program has made great strides forward in the development of in-vehicle technologies that will measure blood or breath alcohol and may prevent alcohol-impaired drivers from driving their vehicles. Exploratory research in earlier phases of the program established the feasibility of two sensor approaches, breath- and touch-based, for in-vehicle use. The sensors have since been refined, in terms of both hardware and software, as the program strives to meet the performance specifications required for unobtrusive and reliable alcohol measurement. In late 2021 the program announced that the first zero-tolerance breath alcohol sensor product equipped with new alcohol detection technology will be available for open licensing in commercial vehicles. "Open licensing" means that the technology, which measures a driver's breath alcohol concentration, will be made available to any product integrator for preparation into fleet vehicles. The breath sensor is designed for fleet operators implementing a zero-tolerance alcohol policy for their drivers, staff, or employees. It requires a directed puff of breath and provides a "pass/fail" reading of the driver's breath alcohol concentration. Currently the DADSS program is focused on transitioning the latest generations of consumer breath and touch sensors from research to product development. Numerous parallel research programs continue including sensor development, development of calibration processes, materials and instrumentation that will verify the technologies are meeting these elevated performance specifications, human subject testing in conditions that replicate those likely to be experienced in the real world, and real-world field trials in diverse settings. The goal for DADSS technologies is commercialization. This paper will outline the technological approaches and the status of the various DADSS research programs.

Student Design Competition

Wednesday, April 5, 2023, | 2:00-6:00
Chair: Whitney Tatem, United States |

Co-Chair: Peter Striekwold, The Netherlands

TRACK A | Room: G303

Consumer-Focused Approaches to Promote Vehicle Safety in the Automotive Market

Wednesday, April 5, 2023, | 2:00-6:00

Chair: Andre Seeck, Germany | Co-Chair: Michiel van Ratingen, Belgium

TRACK B | Room: G304

PEER REVIEW PAPER NO.23-0085-O

Increasing seat belt use in the United States by promoting and requiring more effective seat belt reminder systems

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Research

In the US, 90 percent of front row occupants use a seat belt, but nearly half in fatal crashes are unbelted. Federal Motor Vehicle Safety Standard (FMVSS) 208 requires every passenger vehicle to provide a continuous or intermittent auditory signal lasting 4-8 seconds and a visual display lasting 60 seconds when the driver is unbelted at ignition. Unfortunately, this requirement does not result in seat belt reminder systems that increase seat belt use.

Methods

This paper summarizes the state-of-the-art in using vehicle technology to increase seat belt use, the pertinence of safety standards worldwide, and the development of a consumer information program that addresses regulatory deficiencies in the U.S.

Results

Most people routinely buckle up. Those that do not typically forget, are going on a short trip, or find belts uncomfortable. Visual and audible seat belt reminders can cue forgetful occupants to buckle up and motivate more stubborn occupants to do the same. For several decades, manufacturers have equipped U.S. vehicles with “enhanced” seat belt reminders that exceed FMVSS 208. Enhanced reminders increase belt use by 6 percentage points relative to ones that only meet the requirement, but not all enhanced reminders are identical. More persistent reminders, like those required in Europe, with a continuous audible signal lasting at least 100 seconds are the most effective and increase belt use 30%-34% among drivers who do not routinely buckle up. Seat belt interlocks are an alternative to reminders but have a politically charged past. In 1973, the National Highway Traffic Safety Administration (NHTSA) required interlocks in vehicles without passive restraints that prevented the vehicle from starting when the driver was unbelted. The resulting public outcry resulted in a law prohibiting NHTSA from requiring or allowing seat belt interlocks and restricted NHTSA from requiring more stringent reminders. The restrictions were relaxed nearly 40 years later, but sentiment towards interlocks remains negative. Opinions towards front and rear reminders are far more favorable, and, critically, interlocks that prevent shifting into gear or that restrict speed are no more effective for increasing seat belt use than persistent audible signals lasting at least 100 seconds. FMVSS 208 only

requires reminders for the driver but belt use in rear seating positions is lower. Rear occupants also commonly forget to buckle up which provides an opportunity for reminders to increase rear belt use. Existing European and Japanese requirements for rear seat belt reminders provide a model for similar requirements in the U.S.

Discussion

Based on existing research and safety standards worldwide, the Insurance Institute for Highway Safety developed a rating program to promote effective seat belt reminders for every seating position in new vehicles sold in the U.S. The highest ratings are given to vehicles with persistent audible reminders lasting at least 90 seconds for each front row seating position, and that give information about second row seat belt use at ignition and when use changes.

Conclusion

The program provides a path for strengthening safety standards in the U.S., harmonizing U.S. standards with those abroad, and saving 1,500 lives each year.

PAPER NO.23-0147-O

Assessment and comparison of advanced driver assistance system test procedures

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Research

Vehicle safety testing programs such as the National Highway Traffic Safety Administration's (NHTSA's) New Car Assessment Program (NCAP), the Insurance Institute for Highway Safety (IIHS), Euro NCAP, and other regional NCAPs, have been established to provide consumers with vehicle safety information to help them make informed purchasing decisions. These testing programs have historically focused on the crashworthiness safety performance of a vehicle across a variety of collision types (e.g., frontal and side impacts) and assigning safety ratings to vehicles based on how well vehicles perform in a series of crash tests. In the early part of the last decade, however, rapid development of advanced driver assistance systems (ADAS) and increased capabilities thereof, have spurred continued integration of crash avoidance safety technologies into the established rating systems across the global testing organizations. These crash avoidance systems increase road safety by helping the driver to either avoid crashes altogether, or, in the event of a crash, mitigate the severity of the crash. Although ADAS technologies are now a part of each testing program's vehicle assessments, the technologies evaluated, and the pace of incorporating such tests into overall safety rating measures varies across testing organizations. Objectives consisted of gathering and reviewing test procedures, quantifying differences between available and upcoming test procedures, and summarizing differences among ADAS test procedures across testing organizations.

Methods

Currently, there is no globally accepted single set of test procedures for crash avoidance systems, which means that each testing program's assessment and rating methods may differ. The analysis presented offers a thorough review of varying testing and rating approaches and provides insights on the rationale and justifications for differences based on a literature review and expert stakeholder input.

Results
The review of available test information for all test organizations revealed that a large number of crash avoidance technologies are currently included in vehicle assessments, and revisions and additions are planned for upcoming years.

Discussion
General differences were observed between testing organizations and were consistent across protocols available from each testing organization—most notably, the scoring assessments and how those were communicated. Importantly, differences pertaining to test scenarios, parameters, number of trials, and test equipment received most of the attention due to their direct impact on the vehicle's overall assessment.

Conclusion
Ultimately, the analysis conducted throughout this project provided a comprehensive snapshot of the current crash avoidance test procedure landscape across vehicle assessment programs. Differences are highlighted to emphasize the varying approaches employed.

PAPER NO.23-0173-O

Development of rear seat occupant safety metrics for the moderate overlap frontal evaluation test

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Abstract
Rear seat safety advancements have lagged those in the front. To address this gap, this research aimed to develop assessment metrics to evaluate the relative protection provided by rear seat restraint systems across a series of vehicle crash tests. Thirty-two full-scale vehicle crash tests were conducted with a Hybrid III 5th percentile female dummy seated in the left rear seating position in a 64.4 km/h, 40% offset deformable barrier test. Vehicles varied in size, class, and presence of belt pretensioners and load limiters. Dummy injury metrics for the head, neck, thorax, and femur were evaluated along with occupant kinematic metrics including head excursion and submarining. Of the 32 tests, 18 also included a pressure sensor on the rear occupant's thorax to locate the dynamic shoulder belt position. Shoulder belt tensions ranged from 3.4 to 8.3 kN, and higher shoulder belt tensions were generally associated with higher head and neck injury values, but sternum deflection did not show a similar relationship. High (> 40 mm) and low (~20 mm) sternum deflections were observed for vehicles with and without pretensioners and load limiters and for a wide range of belt tensions. Higher dynamic belt positions were correlated with lower chest deflections and compensating for the effect of belt position aligned sternum deflections with expectations based on shoulder belt tensions. Head contact only occurred in one vehicle, but head excursion boundaries in the absence of impact remain important to ensure that restraint systems limit excursion and the risk of head injury for higher severities or larger occupants. The dummy showed propensity for submarining, an important risk factor for abdominal injuries. Femur axial forces were low for all vehicles, even in cases where the knees contacted the front seatback. Assessment metrics were developed to evaluate the relative protection of rear occupants across a range of vehicles. A novel dummy-based metric, called the Chest Index, was developed that allows the comparison of chest protection across vehicles with a range of dynamic belt fit.

PAPER NO.23-0190-O

The effectiveness of Seat Belt Reminder(SBR)s by analyzing the result of the pilot project of an interurban bus with SBR

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Abstract
It is a widely accepted fact that seat belts have been saving numerous lives in traffic crashes. However, if the effectual means are not used, discussing the effects is meaningless. This is why many countries make seat belt reminders (hereafter SBR) mandatory or introduce SBR assessment in their New Car Assessment Programs (hereafter NCAP). Although a SBR is a good solution for raising the seat belt wearing rate, the opinion on how many seat-belt non-users can be restrained by SBRs is arguable. This paper discussed the effect of SBR systems through the pilot project of an SBR-equipped interurban bus. Korea Automobile Testing and Research Institute (hereafter KATRI) developed the customized SBR system for an interurban bus, which is actually being operated between two cities in Korea. The system consisted of a visual warning device, an occupancy detection sensor, and a buckle-up detection sensor (buckle-switch) on each passenger seat. There was a monitoring display system on the bus driver seat, so which seats are unfastened can be monitored and recorded. In order to figure out how many passengers wore seat belts; both the observational investigation and recorded data analysis were conducted. The results were compared with the one of buses without the SBR system. According to the observed result, the wearing rate of seat belts in a bus without the SBR was 9.6% and the rate in a bus with SBR was 59.0%. To figure out how effective the SBR system is, the recorded log data was also analyzed. The overall average seat belt use rate of the SBR-installed bus was calculated to be approximately 55.82%. There was a difference between both results of the observational investigation and log data analysis, but it is clear that the SBR system noticeably increased seat belt wearing rate. The SBR system applied to this pilot project did not include an audible warning. This means that the system reminded passengers of not wearing seat belts only by a warning light when they did not buckle up. Therefore, the effectiveness of SBR in this paper is only limited to the type of SBR with a visual warning. SBR systems do influence the seat belt use rate. This paper showed that the SBR with occupant detection and visual warning could increase the rate by about 40 to 50%, compared to the case without the SBR. The current regulation does not require mandatory SBR for all seats and most NCAPs do not equally assess SBR in front and rear seats. Mandatory SBRs in the rear seats of M2 and M3 and the introduction of more advanced SBR assessment for NCAPs need to be studied and discussed.

PAPER NO.23-0191-O

Virtual simulation-based assessment of ADAS in consumer tests by openPASS

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Abstract
Test of consumer protection organizations like the New Car Assessment Programmes (NCAPs) play an important role in the overall safety of modern vehicles. Being focused on passive safety over the past decades, the importance of active safety systems has grown in recent times more and more. To assess the performance of active safety systems, standardized test scenarios which are supposed to represent real world accidents are used today. The constantly increasing requirements and the goal of ensuring the robustness of those active safety systems lead to a vast amount of test scenarios. This trend is accompanied with the aim of testing more complex scenarios. In the future, it will hardly be possible to cover this amount of test by track tests alone. Therefore, new virtual methods to support the assessments are required. This paper aims to discuss the question: What are the requirements for these virtual methods to be implemented on manufacture and consumer rating organization side? To discuss the posed question, a two-stage process is foreseen. In the first step, an exemplary virtual assessment of safety oriented ADAS is conducted. For this purpose, consumer rating test scenarios are set-up within the simulation software openPASS. After the implementation, an assessment for one vehicle and one active safety function is conducted in this virtual environment. Finally, the difference between simulation and real vehicle tests is analyzed. In the second step, the learnings and findings from this study will be used to discuss the requirements for future virtual assessments. The demonstration study in openPASS will cover only an exemplary set of test scenarios. Furthermore, the study will only be conducted for one vehicle. The generalization of the study's findings needs to be investigated further.

PAPER NO.23-0208-O

User-centered communication of automated driving to promote road safety

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Abstract
Both research literature and fatal accidents on roads worldwide question whether users and manufacturers of a driver assistance system indeed share the same understanding of the intended system use, and the extent of assistance provided. Traditionally and until today, irrespective of whether assistance systems (SAE Level 1 and 2) are active or not (SAE Level 0), the person on the driver's seat is in charge of the driving task, and any driver assistance systems only support the driver, but do not relieve him or her. In the near future, further driving automation systems of SAE Levels 3 will become available. A first Level 3 function on a series production vehicle has been granted type approval in Germany in December 2021. With increasing driving automation, the driving-related role changes for the person seated on the driver's seat. For instance, when Level 3 driving automation is active, the role changes from the "driver" to the "fallback-ready user" with fundamentally different responsibilities. Considering that misconceptions about the driver role already exist today, it is to be expected that with increasing diversity of the role, misconceptions will likewise grow. Researchers point out non-expert users' difficulties in understanding the provided extent of assistance or automation and highlight negative examples of misleading communication. Raising awareness to these problems may constitute a first step towards finding a solution. Social psychological research on social influence, however, shows that social norms strongly influence our behavior. Considering these findings on the influence of social norms, this article reminds how a focus on (a) some drivers' system misuse and (b) negative examples of some automakers' misleading communication may just promote these among the respective target groups ((a)system users, (b) automakers). Instead, this article provides a concept for user-centered

communication that focusses on how to use respective systems, rather than on what not to do. In this context, the user-centered communication concept by the German Federal Highway Research Institute (BASt) is presented. The communication concept provides the central information that users of different driving automation systems need to know. The target group of such communication are non-expert users and the communication's aim is to convey the relevant information about their responsibilities when using different driving automation systems. The communication concept can serve as a basis to develop specific communication campaigns or strategies in different contexts, such as driver education and training, tutoring, or marketing. The concept has been adopted by the Round Table for Automated Driving of the German Federal Ministry for Digital and Transport and is currently applied in the context of consumer protection by EuroNCAP and other national consumer protection associations.

PAPER NO.23-0209-O

Euro NCAP's first step toward rider safety with new car-to-motorcyclist scenarios

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Abstract
Embedded collision avoidance systems such as Autonomous Emergency Braking Systems, Forward Collision Warnings or Emergency Lane Keeping Systems have largely contributed to reducing the number of car collisions over the past decade. Although those systems have demonstrated ever-increasing performance in case of imminent risk of collision against pedestrian, bicyclist, or car in recent years, most of them were not capable of intervening in the case of a motorcyclist. Since motorcycle crashes remain a major concern across Europe and for most of them are the result of collisions between cars and motorcycles, those systems were identified as relevant technologies to address this issue. In that context, UTAC led the MUSE European project between 2017 and 2019 with the ambition to promote motorcyclist safety through car consumer information programs such as Euro NCAP. As this topic was well identified in the Euro NCAP 2020-2025 roadmap, the organization showed interest in the outcomes of the project and their integration into the new generation of car active safety testing protocols. This paper presents the background established during the MUSE project, its outcomes, and their integration into the so-called Euro NCAP safety rating, as well as the outlook for motorcyclist safety as part of Euro NCAP Vision 2030.

PAPER NO.23-0235-O

Selection of test parameters for a consumer information crash test program to evaluate the safety of rear-seat occupants

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Abstract
Regulatory and consumer information frontal crash testing programs in the United States have historically focused on the front seat occupants. The result has been significant safety improvements for people in those seating positions but not necessarily for rear-seat occupants. The objective of this research was to select a crash configuration, anthropomorphic test device (ATD), and seat position for a crash test program to evaluate and incentivize rear-seat safety improvements in frontal crashes. Twelve full-scale vehicle crash tests were conducted with two different crash configurations (25% and 40% offset deformable barrier tests at 64.4 km/h) and four different ATDs (H3-50th male, H3-5th female, H3 10-year-old, and THOR 5th female) seated in the left and right rear outboard positions. Vehicles with rear-seat pretensioners and load limiters were compared with their previous generation counterparts without advanced belt technology in test conditions matched by crash configuration, ATD, and seating position. The H3-5th female dummy represents an average stature for rear-seat passengers in frontal crashes, and the study showed that a 40% offset deformable barrier with an H3-5th female dummy positioned in the second-row seat behind the driver best reproduces common injury mechanisms documented in the field data and best discriminates between restraint system performance. The 40% offset deformable barrier test was more severe than the 25% offset test, which resulted in higher head and neck injury values and higher incidence of submarining in the 40% offset test. For all ATDs except the H3-50M, the left rear seating position was more challenging than the right, producing higher head and neck injury numbers, similar or higher chest injury numbers, and increased incidence of submarining. All ATDs tested showed reduced injury risks for vehicles equipped with pretensioners and load limiters. However, the ATDs also showed potential tradeoffs for occupants of different sizes. The smallest dummy (H3 10-year-old) had the highest incidence of submarining, while the largest dummy (H3-50th male) had the largest head excursions and the only cases in which the dummy's head made contact with the interior of the vehicle. The shoulder belt remained on the ATD shoulder in all cases except in one instance with a THOR 5th female ATD seated in the right seating position.

PAPER NO.23-0264-O

Developing a consumer safety rating for heavy goods vehicles

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Abstract
In Europe, Heavy Goods Vehicles (GVW>3,500kg, aka trucks), represent around 1.5% of registered vehicles, and about 6% of traffic (vehicle km) but are involved in collisions resulting in nearly 15% of road fatalities. Goods transport is an essential fact of modern life, delivering most of our food and luxuries. This link to standard of living will tend to drive increasing truck use and Vision Zero clearly will not be achieved unless action is taken to improve HGV safety. Size and mass bring significant difficulty, but the challenges are not only technical. Freight transport runs on slim margins. Payload capacity, vehicle uptime, fuel and maintenance bills can all outweigh the latest safety innovation when it comes to vehicle specifications. How can we ensure a rating has influence when the relationship between Euro NCAP and the vehicle buyer will be business to business and not business to consumer? How can we create the market for safety that manufacturers need to allow innovation? One make and model can

cover variants from an 18 tonne rigid for urban distribution, through off-road construction vehicles and on to 60 tonne multi-trailer combinations for long haul. How can the rating be applied in a meaningful yet economic way? This paper summarises several years of work to find the answer to these questions, that has involved analysing collision data, investigating the availability, effectiveness and operational constraints of different technical safety measures that could be promoted, and engaging extensively with road owners, safety organisations, the freight operations industry, and the vehicle industry. New and quite stringent regulation of HGV safety is imminent in Europe, and this has also been a major consideration. Does this already solve the problems? Is there a need to go further? These questions are considered via a case study of measures intended to protect vulnerable road users The end result is what we believe to be a globally unique application of the consumer rating approach to solve a complex and multi-faceted problem.

PAPER NO.23-0284-O

Euro NCAP virtual testing - Crashworthiness

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Abstract
The European New Car Assessment Programme (Euro NCAP) began using numerical simulations in its vehicle ratings in 2009. Virtual testing with human body models was first used in the assessment of vehicles equipped with deployable pedestrian protection systems. In 2019, Euro NCAP created the Virtual Testing Crashworthiness (VTC) working group. This working group is supported by Euro NCAP, Euro NCAP's members along with industry representatives from both the European Automobile Manufacturers Association (ACEA) and the European Association of Automotive Suppliers (CLEPA). The far side occupant assessment was selected as the first load case for this work. The objective of this paper is to introduce the procedures defined by the Virtual Testing Crashworthiness working group and present the results generated within the two pilot test series. In addition to the standard load cases

defined in the current far-side assessment protocols, robustness load cases were defined with varying impact angles and seat heights. Simulations of the specified load cases were performed by the car manufacturers with their internally developed and validated vehicle models. Two series of physical far side sled tests were performed in accordance with the Euro NCAP Far side occupant sled test procedure with the corresponding vehicles. These test series were used to evaluate the validity of the vehicle models and the capabilities of the simulation models to predict the trends observed within the tests. Processes and acceptance criteria were established to ensure that the simulation models are as representative as possible of their physical counterparts while protecting the intellectual property of the car manufacturers and suppliers. The validated vehicle models are used in a series of robustness simulations. The physical sled test results from the pilot phase showed reasonable test scatters, even when using two different WorldSID dummies, and were shown to be a suitable test result to be used for validation of the vehicle models. The developed procedure was applicable within the pilot tests. The ISO Scores, used as objective validation metrics, were comparable between standard and the new robustness load cases, indicating that the procedure and the model used were robust. Further room for improvement of the assessment procedure was identified, specifically regarding the acceptance criteria of signals with low amplitudes. The current study outlines the procedures for introducing virtual testing of occupant safety into consumer information. When viewing vehicle safety ratings from a consumer perspective, it is acknowledged that computer simulations cannot completely replace physical testing. However, a combination of physical and virtual testing offers a powerful and flexible assessment of vehicle safety. The robustness load cases will be assessed in the future based on the virtual tests only and complement the existing far-side occupant assessment in the final vehicle rating.

PAPER NO.23-0286-O

Euro NCAP's current and future in-cabin monitoring systems assessment

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Abstract
Informed by international research and crash data, Euro NCAP has developed a Test and Assessment protocol to measure the performance of direct Driver State Monitoring (DSM) systems, which is implemented from January 2023 as part of the Safety Assist – Safe Driving protocol of the star rating. This protocol was developed in collaboration with experts from several OEMs and Tier 1 and 2 suppliers, and it is aimed at promoting standard fitment of driver monitoring systems that effectively detect impaired and distracted driving, eventually triggering the appropriate vehicle response strategies to warn driver and/or mitigate risks. Getting the full score in the Occupant State Monitoring (OSM) area will only be possible with direct monitoring systems. The protocol describes the DSM system requirements across three areas: Sensing (system performance degradation in the presence of several noise variables such as stature, light, facial features); Driver State (system capability to effectively deem the driver as distracted, fatigued, or unresponsive); and Vehicle Response (vehicle deploying timely and appropriate response strategies, eventually avoiding the accident, or mitigating its severity). This paper discusses the rationale behind the assessment methodology and the resulting protocol, and how Euro

NCAP envisions DSM as an effective tool to reducing/mitigating a wide variety of traffic accidents. Over the course of 2023 test campaign, Euro NCAP will collect extensive insights from both a practical implementation and technology capability perspective, opening the door for on-going improvements and further requirements. In the coming decade, Euro NCAP expects Driver (or Occupant) State Monitoring systems to tackle areas such as driver engagement, intoxication, optimized passive restraints, child presence detection, optimized passive safety, as well as enhancing the performance and intuitiveness of other ADAS by making them work in synchrony with the driver behavior – eventually increasing driver acceptance. Lastly, the 2023 requirements for direct DSM are based on parameters related to eye gaze and head posture – these are subject to be expanded, allowing for new methods and systems to be used in future.

PAPER NO.23-0298-O

Developing a consumer safety rating for vans

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Abstract
Home delivery is one of many trends driving a strong increase in the use of light commercial vehicles (≤ 3,500kg GVW, aka vans). In Europe, vans have for many years been subject to less stringent safety regulations than passenger cars and had fewer safety systems fitted. The research objective was, therefore, to assess the safety risks posed by the increasing use of vans and to develop a programme of consumer testing to promote relevant risk mitigations. The work involved a wide range of Euro NCAP Member organisations under the umbrella of the Commercial Vehicle Working Group, chaired by Thatcham Research, and subsequent evolution under its own unique working group chaired by CSI. The work programme undertaken by the group included: Collision data analysis Market research to assess ADAS fitment Full scale collision test Track testing of ADAS solutions Across 5 Euro NCAP member countries vans were involved in around 8% of road fatalities. The types of collisions they were involved in, the causes and consequences were similar to those of passenger cars. The most common collision opponent was other passenger cars, but the fatalities were not evenly distributed between each vehicle. In collisions involving vans, a larger proportion of the total fatalities occurred in the car than in the van. A full-scale vehicle to vehicle crash test was undertaken between a van and a 5-star car. The van exhibited limitations in terms of both self-protection and compatibility. Both van occupants showed a high risk of injury to the chest, knee, femur, and pelvis. The good design of the passenger car helped limit the consequences for its occupants, but they still showed significantly higher risk of injury than in the equivalent barrier test. Market research showed that the availability of ADAS was low, almost always optional and, even when available, was poorly understood by dealers making it hard to actually get hold of vehicles. Tests of the ADAS showed that they could be effective but, in some cases, offered significantly lower performance than similar systems on passenger cars from the same manufacturer. A new van rating scheme was developed, based on adaptation of existing passenger car protocols for ADAS but not for full scale crash. Ratings of the whole market in the EU have been undertaken in 2021 and 2022 and the scores have improved substantially.

PAPER NO.23-0312-O

Euro NCAP mobile progressive deformable barrier testing

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Abstract

The European New Car Assessment Programme (Euro NCAP) implemented an updated Adult Occupant Protection assessment in 2020. This saw the adoption of the Mobile Progressive Deformable Barrier (MPDB) frontal impact test and the use of the THOR anthropometric test device. The procedure was developed by the Frontal Impact Working Group (FIWG) supported by Euro NCAP and its members, alongside representatives from both the European Automobile Manufacturers Association (ACEA) and the European Association of Automotive Suppliers (CLEPA). This paper summarises the implementation of this new procedure and the work of the FIWG over the last five years. Data from official Euro NCAP testing has been analysed to provide an overview of results from the first three years of MPDB assessments. Euro NCAP is the first consumer rating programme in the world to include an assessment of a vehicle's compatibility. The assessment is based upon three measured parameters: standard deviation (SD) of the post-test barrier face deformation, the Occupant Load Criterion (OLC) of the MPDB trolley, and whether or not the barrier face has been crushed beyond a designated limit. The performance of the THOR dummy and its impact on vehicle ratings has also been examined. In particular, the assessment of chest and abdomen compression, iliac crest loading, and acetabulum loading were considered as they have never been included in previous assessments. An investigation of the MPDB tests found that it is not uncommon for the diagonal belt to slide from the shoulder clavicle towards the neck of the THOR dummy. The effect of this belt movement has been investigated and improvements to the dummy hardware have been considered. As the THOR dummy is also able to measure rotational movement of the head, the group implemented a two-step approach to evaluate brain injury criteria. The first step analysed signal-based criteria culminating in the adoption of DAMAGE for assessment in 2023 ratings, another world first. The group is also reviewing existing advanced brain injury criteria that utilise FE based brain models for adoption in 2026. The test data analysis was based on the results of Euro NCAP official tests; there was no access to manufacturers' in-house or preliminary Euro NCAP test data. Therefore, this paper does not address any repeatability or reproducibility issues. The current assessment of THOR chest compression uses the maximum peak resultant displacement of the four thoracic ribs (Rmax). The intention is to adopt a more sophisticated chest criterion in future assessments which will be performed alongside an evaluation of THOR certification data. Euro NCAP has evaluated the implementation of a new frontal impact test in a consumer rating programme and is the first such programme to utilise the THOR ATD, advanced injury criteria and a vehicle compatibility assessment. Further developments in the assessment are being considered and will be incorporated into the vehicle rating scheme in 2026.

PAPER NO.23-0329-O

Challenges in evaluating automated driving systems using current ADAS and active safety test track protocols

SCOTT SCHNELLE, KRISTOFER KUSANO, FRANCESCA FAVARO, GUY SIER, TRENT VICTOR
Waymo, United States

Abstract

A number of public safety stakeholders have advocated for the application of traditional consumer-focused testing protocols (e.g., NCAP programs) currently used to evaluate some ADAS and active safety technologies (i.e., SAE Level 0, Level 1, Level 2) for the evaluation of safety for Automated Driving Systems (ADSs). To gain practical insight into the types of challenges and limitations arising from the application of these existing test protocols to ADSs, the Waymo Driver, a SAE Level 4 ADS, was the subject of a testing campaign that leveraged several of the most difficult currently available ADAS and active safety test procedures. The main challenge discovered was that most protocols designed to evaluate collision avoidance behavior could not be evaluated as designed due to the increased capabilities of the Waymo Driver that prevented the vehicle from even entering into a conflict to begin with. Difficulties encountered included creating the type of occlusions envisioned in some test protocols due to the location and performance of the Waymo Driver's sensor suite and insufficient information in the test procedure regarding the roadway and map information. For example, in the occluded vulnerable road user (VRU) scenarios, the Waymo Driver could sense the test target prior to it starting to move and could proactively slow down, resulting in the desired collision avoidance interaction in the scenario not being tested. To make the test conditions representative of the intended collision avoidance interactions in the test procedure, either extra vehicles and/or different vehicle types were used as the occluding vehicles (e.g., large trucks). Similarly for the car-to-car tests, a larger obstructing lead vehicle was used for the cut-out test so the Waymo Driver could not see over the lead vehicle. Also, without specifying additional details for the roadway that were not in the original test procedure, the Waymo Driver would proactively slow down due to the presence of parked cars or other roadway features on the test track, such as intersections. Beyond these required modifications to enable the interactions described in the test procedure, additional optional modifications were made to the test to increase the difficulty of the test. For example, in the NCAP cut-in test, the distance at which the vehicle was cutting in was reduced from 7.5m to 3m to try to elicit collision avoidance behavior. For all the test runs, including those run to specification and those with modifications, the Waymo Driver was able to avoid collisions which would have resulted in the highest rating for this evaluation. Our conclusion is that existing ADAS and active safety test protocols cannot be applied as-is for an ADS such as the Waymo Driver. The highlighted challenges result in ambiguous requirements for both the test developers, the test facilities, and the test site administrators. This further indicates that Level 0-2 systems need to be separately considered from Level 4 ADS, such as the Waymo Driver. Furthermore, the results of this testing calls into question the feasibility and utility of adapting ADAS and active safety test for ADSs.

Opportunities and Challenges of Applying Artificial Intelligence (AI) and Machine Learning Techniques to Enhance Vehicle Safety

Wednesday, April 5, 2023, | 2:00-6:00

Chair: Marcus Wisch, Germany | Co-Chair: Dee Williams, United States

TRACK C | Room: G301+G302

PAPER NO.23-0047-O

R-Peak detection from noisy ECG data using multi-channel 1D-CNN with accelerometer input

TETSUYA HIROTA, RYUGO FUJITA, ATSUSHI HARADA, DAISUKE KAWAMURA
TOKAI RIKA CO. LTD, Japan
KEIICHI YAMADA
Meijo University, Japan

Abstract
In order to prevent traffic accidents due to abrupt changes in the driver's health condition, we have proposed a non-contact type electrocardiographic sensor that monitors the electrocardiogram (ECG) of a driver holding a steering wheel while seated. However, the heart rate detection accuracy degrades while driving due to the lower signal-to-noise ratio (SNR) of the ECG caused by the noise from vehicle vibration and static electricity, among others. In this study, we propose a method of detecting R-peaks of the ECG from the low SNR ECG signal with high accuracy using a multi-channel one-dimensional convolutional neural network with accelerometer signals as an input. As the results, we achieved an F-score of 78.5% and a root-mean-square error (RMSE) of 1.99 ms. The R-peak detection performance was significantly improved when the input data length of around 1100 ms was chosen.

PAPER NO.23-0048-O

Verification and validation of machine learning applications in advanced driving assistance systems and automated driving systems

CHUNG-JEN HSU
Bowhead Mission Solutions, United States

Abstract
The verification and validation processes of machine learning applications in advanced driving assistance systems or automatic driving systems are presented, and the processes are implemented by using the forward collision warning of pedestrian automatic emergency braking. Supervised learning is one of the machine learning branches using image datasets to train the deep neural network for detecting or identifying the target object or scenario in a vision-based application. The verification process consists of specifying the requirements of a safety functionality, identifying the target objects in the Operation Design Domain (ODD) and pre-crash scenarios, and evaluating the quality and quantity of images based on safety requirements, also the coverage of ODD and pre-crash scenarios. The validation process

consists of designing test procedures based on the specified ODD and pre-crash scenarios, conducting a sufficient number of tests, recording the test results, and evaluating the test results based on specified metrics. Eight published pedestrian datasets from 2010 to 2020 are reviewed. Three datasets contain the raining condition, but no dataset had images collected during snowing days. Fog or smoke images are not available in all datasets, and the headlight condition is not addressed in all datasets. The 3 datasets containing pedestrians in the nighttime did not label the vehicle's headlight status as low or high beam. All reviewed datasets had no annotations of pre-crash scenarios that the subject vehicle is maneuvering or not. The validation of pedestrian detection uses the activation of forward collision warning as the evaluation metric. Eleven vehicles were tested in 4 pre-crash scenarios with different pedestrian orientations and speeds: the test pedestrian crossing from the nearside, crossing from the offside, stationary facing away, and walking away in front of the vehicle. The vehicle speed under test is 40 kph and the test pedestrian's speed is 5 or 8 kph. The light conditions are daytime, nighttime with low beam, and nighttime with high beam without streetlighting in a test track. The statistical test results show that some vehicles under test behave inconsistently when the test pedestrian is crossing or not crossing. Test results in the nighttime with high beam are similar to that of the daytime; however, the test results in the nighttime show significant variations compared with that of daytime. No trend or similarity can be found among all vehicles under test, the same vehicle may behave inconsistently under different light conditions and pedestrian orientations. Also, the pedestrian detection time is longer when the test pedestrian is not crossing for some vehicles. The vision-based machine learning application for the vehicle safety functionality reveals the underlying uncertainty of a deep neural network, and it results in the inconsistent performance in differentiated ODD conditions and pre-scenarios.

PAPER NO.23-0055-O

Evaluation approach for machine learning concepts in occupant protection based on multi-attribute decision making

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Technische Hochschule Ingolstadt, Germany
AXEL SCHUMACHER
Bergische Universität Wuppertal, Germany
PEDRO PAULO ANDRADE JUNIOR
Federal University of Santa Catarina, Brazil

Abstract
The systems for occupant protection in passive vehicle safety are primarily developed with single statistical representations of humans, so-called Anthropomorphic Test Devices (ATDs). Unfortunately, those ATDs cover additional features like age and body shape insufficiently during development. Augmenting finite element simulations with a metamodel trained by machine learning is promising to overcome this barrier. However, the database design, the machine learning architecture, and the requirements for quality and robustness influence each other. Therefore, objective criteria must be defined to compare the alternatives taking cost and benefit aspects under changing preferences into account. Having complex criteria can be framed as a multi-attribute decision-making problem. This paper's objective is the development of a transparent assessment scheme for virtual statistical simulation for rapid vehicle occupant safety assessment using supervised learning. PROMETHEE is selected as an appropriate decision-making approach. A process, consisting of a sequential definition of

the criteria leading to the final assessment, is proposed to adapt the method in this paper's domain. The methodology is tested on sample alternatives, generated using a calibration-type machine learning architecture and data from finite element simulations. The original PROMETHEE algorithm cannot handle a vast number of alternatives. Since, typically, numerous alternatives occur during the development of a machine learning application, a sorting-based modification is implemented. Finally, the findings are discussed, and recommendations for related use cases are given. The proposed method seems applicable to the described domain and near-related ones. Moreover, multiple tendencies between an alternative's parameters and rank can be identified in the test samples.

PAPER NO.23-0136-O

Analysis method for a traffic accident using motorcycle probe data

OSAMU ITO, TAKAYUKI KAWABUCHI, HIDEO KADOWAKI, YUJI TAKAGI, HIROKI TANAKA
Honda Motor Co.,Ltd, Japan

Abstract

To reduce the number of the fatalities among the motorcyclist in Asian countries, it is necessary to analyze and clarify the cause of the accident, however, the accident data are insufficient in these countries for the accurate analysis. To compensate for insufficient accident data, the authors approached to analyze the accident using the probe data obtained from vehicles. The investigation was conducted by the riding data acquired from the 50 cc motorcycles, including the location information in 1 second cycle, the vehicle speed and the throttle opening signals in 0.2 seconds cycle acquired from the Global Navigation Satellite System (GNSS) and the Electronic Control Unit (ECU), respectively. The time historical data from GNSS and ECU were divided into 5798 trips, separated by the time interval longer than 1 minute. During all trips, there was only one accident. The acquired data were processed by the autoencoder model to extract the characteristics of the trips and riding behavior. The autoencoder model has the latent space between the encoder and decoder to analyze the trips and riding behavior. The information of trips and riding behavior in the latent space was quantified using Kernel Density Estimation to express the anomaly of the trips and riding behavior. In addition, riding simulations were conducted based on GNSS and ECU information to validate the results of abnormality detection by the autoencoder. The results showed that the accident data were classified as abnormal behavior. The anomalies could be expressed as changes with time history. It proved that the riding abnormalities appeared 30 seconds before the accident occurred. When the simulation was also performed to reconstruct the accident, it was observed that the rider was riding dangerously such as slipping past the car or accelerating and decelerating rapidly. The authors devised a method to analyze the causes of traffic accidents by using the autoencoder model and riding simulation. This method is expected to improve the efficiency of accident data collection and analysis in regions where accident data for motorcycles is lacking, such as in developing Asian countries.

PAPER NO.23-0210-O

Applying AI methods on Video Documented Car-VRU front crashes to determine generalized vulnerable road user behaviors

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PATRICK LERGE, LENNART VINCENT NÖLLE, SYN SCHMITT
Institute for Modelling and Simulation of Biomechanical Systems (IMSB), Germany

Abstract

Urban traffic is characterized by limited traffic areas, varying traffic flows and the occurrence of different types of road users. To further advance automated mobility, the severity of injuries sustained by vulnerable road users (VRUs) in unavoidable accidents must be minimized. The project “ATTENTION”, supported by the German Federal Ministry for Economic Affairs and Climate Action, was set up to tackle this issue by developing a method for the real-time prediction of VRU injury risk using artificial intelligence (AI). The present study represents the first step in the ATTENTION project and evaluates behavioral aspects of VRUs in real-life car crash scenarios. Firstly, a comprehensive, hand labeled database of video documented VRU crashes from South Korean dashcams was set up. Secondly, the data was analyzed to determine relevant characteristics like pedestrian pre-crash movement and behavior. Afterwards a comparison against the German in-depth accident study database was performed. Finally, relevant scenarios were extracted, and AI-based preprocessing was applied. Body-shape-estimation methods were used to extract pedestrian poses and kinematics for further statistical processing. In 9,724 video documented crashes, 369 frontal primary collision against VRUs were deemed usable. The analysis reveals that every 4th crash in this sample is potentially not avoidable due to physical limitations. The VRU recognized the car before impact in every 2nd crash, possibly performing evasive actions prior to first impact. Comparisons revealed that 31,000 similar car-VRU crashes were documented in the German In-Depth Accident Study (GIDAS) database. The estimation of plausible shapes and kinematics was possible in 37 of 319 pedestrian cases (12%), while 10 of 50 videos (20%) involving cyclist could be processed. Distinct pre-crash poses and kinematics were objectively identified and were shown to be different from standard gait-cycle kinematics. The VRU shapes and poses were used to define average pre-crash body shape appearances and hull-spaces for use in future human body model simulations. The results of this study show that a VRU pre-crash behavior can be objectively determined from low-quality in-field video data using AI-driven methods and that it differs from regular human motion patterns. Furthermore, it shows that this video data can be used to setup a position and movement database. Both lay the foundation to estimate an injury risk index of VRUs in the later stages of the ATTENTION project.

PAPER NO.23-0215-O

A method for efficient generation and optimization of simulation-based training data for data-driven injury prediction in VRU-vehicle accident scenarios

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Fraunhofer-Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, Germany
DIRK FRESSMANN
DYNAmore Gesellschaft für FEM Ingenieurdienstleistungen mbH, Germany

Abstract

Urban traffic is characterized by limited space, varying traffic flows and multiple types of road users. Despite increasing automation and design efforts, the joint use of traffic areas poses a particular risk for vulnerable road users (VRUs). In order to make traffic as safe as possible, the severity of injuries to VRUs in unavoidable collisions must be reduced. In future applications, predicting situation-specific injury risks for VRUs in real-time using machine learning (ML) could support decision making in determining risk minimization strategies. The predictive capability of any ML model is determined by the quality of the used training data. While there are no real-world training data available for injury prediction, simulation data, which is frequently employed in passive safety engineering, can be used as synthetic data. Since deliberate training data generation consumes substantial resources, particular attention is focused on the iterative generation of optimized simulation data sets. This study presents and discusses an adaptive simulation data generation pipeline to generate simulation data sets that reflect the overall system's behavior with the overall goal of efficiency and sustainability. The novel pipeline involving nine steps is divided into two phases, "Data Generation" and "Data Exploitation". The "Data Generation" phase predominately focusses on the adaptive strategies to generate a generalist training data set. Along with the fundamental techniques for adaptively adding new points, metrics for assessing the information content of the present data set and for tracking the iterative sampling progress are also discussed in this study. Additionally, experiments to understand the effects of batch size is conducted and the potential use of information content metrics for process termination and dynamic, adaptive batch size adjustment is discussed. The pipeline is initially tested using a generic example and is then applied to a simulation setup modeling a human head crashing onto a vehicle windshield. The observations from applying the pipeline to the simulation setup are compared with the observations from applying it to the generic function to evaluate the novel pipeline. It is shown that the pipeline is generally applicable to such real-world problems and that the anticipated dynamic behavior of the data generation process is confirmed in the generic and real application example. This lays fundamental groundwork which needs to be extended along multiple routes in future work.

PAPER NO.23-0219-O

Prediction of all rib deflections of THOR-ATD by means of deep neural network model

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KOTA KATSUSHIMA
IDAJ Co., Ltd., Japan
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Abstract

The fatality rate of thoracic injury for elderly occupants in vehicle accidents is significantly high. Its major cause is the rise of internal organ injury rates due to an increase in the number of fractured ribs (NFR). Therefore, NFR reduction is crucial to enhance elderly occupant protection and is one of the key issues for achieving zero fatalities. In order to improve NFR prediction accuracy, the previous study proposed the criterion using the weighted averaged displacement of all ribs (WADAR), which indicated a higher correlation coefficient with NFR than that of the criterion, Rmax, using four Infra-Red Telescoping Rod for the Assessment of Chest Compression (IR-TRACC) installed on the thorax of the Test device for Human Occupant Restraint Anthropometric Test Dummy (THOR-ATD). While WADAR requires all rib deflections, it is difficult to install IR-TRACCs on all ribs inside the limited space in the thorax of THOR-ATD. The objective of this research is to predict the deflections of all ribs by means of a neural network model using time-histories of rib deflections from four IR-TRACCs and the crash velocity without any installation of additional measurement devices. The architecture of the neural network model is based on U-Net, which is one of the convolutional neural network models. The model was trained by time-historical X, Y and Z displacements of 14 ribs and the crash velocity derived from the 56 FEM simulation data, which represented frontal and oblique sled experiments with THOR-ATD. The model learned the physical relationships among the ribs with and without IR-TRACCs. The predicted rib deflections were validated by the THOR-ATD experiment, where the displacements of the 2nd to 6th ribs on the left side were measured three-dimensionally by the set of two cameras installed on the upper and lower thoracic spines. The predicted deflections during 0 to 150 ms were processed into a resultant deflection and compared to the actual deflection through the 2nd to 6th ribs on the left side. The maximum differences in the peak deflection were 2.3 mm, respectively. Furthermore, the root mean square error (RMSE) was calculated at each rib for prediction accuracy evaluation, which resulted in minimum and maximum RMSE of 0.6 mm and 2.7 mm, respectively. Although the number of training datasets was small, the neural network model trained by FEM simulation data could predict all the rib deflections with small error without physical measurement devices.

PAPER NO.23-0265-O

A concept to support AI models by using ontologies - presented on the basis of German technical specifications for lane markings

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Abstract
Artificial Intelligence (AI) and Machine Learning (ML) deliver promising approaches to the development of assisted as well as automated and autonomous driving technologies. However, learning all possible traffic situations and outcomes is almost not feasible. Furthermore, machine learning-based models are usually regarded as a black box, and we cannot trace their decisions for a certain behavior. To counteract this, we propose an ontology-based model, which integrates normative knowledge, to support the decision making of the AI for automated and autonomous vehicles. Since traffic rules and laws are explicitly defined in the model, we can easily track any derived decisions, eliminating the necessity of learning all possible traffic situations. We formalize the German Technical Specifications on Lane Markings into an ontology for a better representation of the traffic environment and thus improve the situational awareness of automated and autonomous vehicles. Additionally, the reasoning capacity of an ontology based-model allows for deriving concepts in multiple ways, which can serve as redundant information about lane and lane markings to enhance the understanding of the traffic situation. Finally, in contrast to learning-based models, our transparent ontology-based model allows for the validation and verification of automated and autonomous systems and vehicles.

PAPER NO.23-0326-O

A study on the possibility of machine learning-based classification of Collision Deformation Classification (CDC) on the KIDAS database for traffic crash reports

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Department of Emergency Medicine, Chungbuk National University Hospital, Korea, Republic of

Abstract
This is a study that automatically classifies codes based on accident data collected in the pre-hospital stage to secure the effective time of treatment for emergency patients in traffic accidents. In order to automatically classify the codes, learning data is composed of VEHICLE INDEX, VEHICLE DYNAMIC, ROAD-INVIRONMENTAL INDEX, ACCIDENT INDEX, CRASH INDEX data and CDC-code among the KIDAS data. Although this study is primarily to create a classifier to identify CDC-codes from traffic accident data, the main contribution lies in the development of state-of-the arts machine learning methods that exploit correlations between different types of attributes. The classification methodology focuses on how to automatically determine codes using an optimal classification model and describes how to rank

them according to the degree of inclusion of traffic accident attribute information. In the future, it is planned to derive a model for classifying the AIS-code by combining and reflecting the classification results according to the classification model derived from this study and patient/vehicle safety/vehicle information/hospital transfer information among the KIDAS accident data.

PAPER NO.23-0331-O

Safe control transitions: Machine vision based observable readiness index and data-driven takeover time prediction

ROSS GREER, NACHIKET DEO, AKSHAY RANGESH, MOHAN TRIVEDI
University of California San Diego, United States
PUJITHA GUNARATNE
Toyota Collaborative Safety Research Center, United States

Abstract
To make safe transitions from autonomous to manual control, a vehicle must have a representation of the awareness of driver state; two metrics which quantify this state are the Observable Readiness Index and Takeover Time. In this work, we show that machine learning models which predict these two metrics are robust to multiple camera views, expanding from the limited view angles in prior research. Importantly, these models take as input feature vectors corresponding to hand location and activity as well as gaze location, and we explore the tradeoffs of different views in generating these feature vectors. Further, we introduce two metrics to evaluate the quality of control transitions following the takeover event (the maximal lateral deviation and velocity deviation) and compute correlations of these post-takeover metrics to the pre-takeover predictive metrics.

PAPER NO.23-0333-O

Salient sign detection in safe autonomous driving: AI which reasons over full visual context

ROSS GREER, AKSHAY GOPALKRISHNAN, NACHIKET DEO, AKSHAY RANGESH, MOHAN TRIVEDI
University of California San Diego, United States

Abstract
Detecting road traffic signs and accurately determining how they can affect the driver's future actions is a critical task for safe autonomous driving systems. However, various traffic signs in a driving scene have an unequal impact on the driver's decisions, making detecting the salient traffic signs a more important task. Our research addresses this issue, constructing a traffic sign detection model which emphasizes performance on salient signs, or signs that influence the decisions of a driver. We define a traffic sign salience property and use it to construct the LAVA Salient Signs Dataset, the first traffic sign dataset that includes an annotated salience property. Next, we use a custom salience loss function, Salience-Sensitive Focal Loss, to train a Deformable DETR object detection model in order to emphasize stronger performance on salient signs. Results show that a model trained with Salience-Sensitive Focal Loss outperforms a model trained without, with regards to recall of both salient signs and all signs combined. Further, the performance margin on salient signs compared to all signs is largest for the model trained with Salience-Sensitive Focal Loss.

Developing and Adapting Safety Assessment Approaches for Vehicles with ADS (SAE Levels 3, 4, and 5)

Thursday, April 6, 2023, | 08:30-12:30

Chair: Peter Striekwold, The Netherlands | Co-Chair: Toshiya Hirose, Japan

TRACK A | Room: G301+G302

PEER REVIEW PAPER No.23-0051-O

The role of driver behavior models in the simulation-based safety assessment of automated driving

ALEXANDRA FRIES, FELIX FAHRENKROG, ARUN DAS
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Technische Universität Dresden, Germany

Research
Highly automated driving systems are on the edge of entering the market. Before this, the safety of these systems needs to be assessed prospectively. BMW has introduced a holistic approach that uses stochastic traffic simulations. These simulations require a realistic driver behavior modeling ranging from performance in non-critical everyday driving towards performance in critical situations. In the simulation the model represents a part of the baseline for the comparison with automated driving as well as behavior of the surrounding traffic. The associated research question is: how should a driver model for this purpose be designed?

Methods
Therefore, BMW has developed the Stochastic Cognitive Model (SCM). SCM models cognitive processes in traffic situations which range from information acquisition by gaze behavior, recognition of situations from the visual information and reaction to the situation. The model combines the cognition aspects of humans with stochastic processes and parameters to obtain a variation in the virtual driver population. The paper describes the cognitive approach of SCM. Special emphasis will be put on the visual attention modeling because this is key to traffic interaction modeling. The recognition of the situation and the reaction is highly dependent on the information perceived by the gaze behavior. Gaze behavior in SCM is modelled through stochastic processes by applying gaze distribution matrices which specify frequency of gaze allocation and gaze duration. Gaze directions are further influenced by top-down or bottom-up attention. Top-down is the voluntary allocation of attention according to drivers' intentions and goals whereas bottom-up attention is the involuntary allocation of the attention to salient stimuli in the environment. Data as input for the models has been recorded in BMW naturalistic driving studies and simulator experiments.

Results
SCM will be applied in traffic scenarios in which the gaze behavior and reaction of SCM is evaluated and compared to real-world data. Especially a non-critical as well as a critical traffic scenario will be analyzed regarding certain parameters like gaze direction, brake reaction time and time-to-collision in the

predefined situations. Due to the stochastic approach of SCM a collective of virtual test drivers is evaluated and compared.

Discussion
The question which arises for the gaze behavior and for the overall behavior of SCM is the trustworthiness of the simulation results. Therefore, one main focus lies in the validation and verification of the driver model. The behavior of SCM is evaluated both in short conflict situations and in larger traffic endurance simulations. These validation and verification aspects and the related toolchain will be presented in the paper.

Conclusion
The final paper presents the SCM driver behavior modeling and discusses its role in the safety assessment approach of automated vehicles. This includes a description of cognitive processes in combination with stochastic variations to represent realistic traffic in the simulation. Special focus will be placed on the gaze behavior of the model as this is the input for the sequential cognitive processes. Realistic driver and traffic behavior is shown in certain critical and non-critical scenarios and compared to real-world data.

PAPER NO.23-0072-O

A pragmatic approach to safe operation for driverless shuttles during development

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DANILO DA COSTA RIBEIRO, WOLFGANG SCHRAMM
Continental Autonomous Technologies GmbH, Germany

Abstract
Driverless shuttles are a modern vehicle platform designed to operate autonomously, constituting a very promising building block of future mobility solutions. At Continental, there is a long experience with these types of vehicles. In this paper, some of this experience regarding operating such vehicles during development is shared. In particular, the focus is on how a safe operation can always be ensured. To this end, a release process for such an operation, how a pragmatic safety assessment can be done and some of the peculiarities of driverless shuttles are presented.

PEER REVIEW PAPER NO.23-0099-O

How certain are we that our automated driving system is safe?

ERWIN DE GELDER, OLAF OP DEN CAMP
TNO, Netherlands

Research
Regulations are currently being drafted by the European Commission for the safe introduction of automated driving systems (ADSs) with conditional or higher automation (SAE level 3 and above). One of the main challenges for complying with the drafted regulations is to prove that the residual risk of an ADS is lower than the existing state-of-the-art without the ADS and that the current safety state at

European roads is not compromised. Therefore, much research has been conducted for estimating the residual risk of an ADS. One proposed method for estimating the risk is data-driven scenario-based assessment, where tests are partially automatically generated based on recorded traffic data. Although this is a promising method, uncertainties in the estimated risk arise from, among others, the limited number of tests that are conducted, the limited data that have been used to generate the tests, and inaccuracies in the same data. This paper addresses the following question: "Given the limitations of the data and the number of tests, what is the uncertainty of the estimated residual risk of the ADS?"

Methods
To compute the residual risk, parameterized test scenarios are based on large-scale collections of road scenarios that are stored in a scenario database. The exposure of the scenarios and the parameter distributions are estimated using the data as well as confidence bounds of these estimates. Next, virtual simulations are conducted of the scenarios for a variety of parameter values. Using a probabilistic framework, all results are combined to estimate the residual risk as well as the uncertainty of the estimated risk.

Results
The results are used to provide confidence bounds on the calculated fatality rate in case an ADS is implemented in the vehicle. For example, using the proposed probabilistic framework, it is possible to claim with 95% certainty that the fatality rate is less than 10-7 fatalities per hour of driving. The proposed method is illustrated with a case study in which the risk and its uncertainty are quantified for a longitudinal controller in 3 different types of scenarios. The code of the case study will be made publicly available.

Discussion
If results show that the uncertainty is too high, the proposed method allows to answer questions like "How much more data do we need?" or "How many more (virtual) simulations must be conducted?" Therefore, the method can be used to set requirements on the amount of data and the number of (virtual) simulations. For a reliable risk estimate, though, much more data are needed than the data that have been used in the case study. Furthermore, since the method relies on (virtual) simulations, the reliability of the result depends on the validity of the models used in the simulations.

Conclusion
The presented case study illustrates that the proposed method is able to quantify the uncertainty of the estimated residual risk of an ADS. Future work involves incorporating the proposed method into the type approval framework for future ADSs of SAE levels 3, 4, and 5, such as proposed in the upcoming EU Implementing Regulation ADS.

PAPER NO.23-0108-O

Research of LSTM model for vehicle control system of Automated Driving Systems (ADS)

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Abstract
Research Question/Objective: This study aims to construct a long short-term memory (LSTM) model of the vehicle control system for automated driving systems (ADSs) that does not cause annoyance or distrust. Furthermore, this study investigates the effect of LSTM hyperparameters on model accuracy. A

survey showed that certain drivers did not use levels 1 and 2 of the ADS function because they were annoyed with the driving behavior of the ADS-controlled vehicle. Although the driving behavior of the ADS-controlled vehicle causes distrust in passengers, it cannot effectively enable safe driving. This study focuses on a novel vehicle control method that reduces annoyance and distrust in passengers and contributes to the safe operation of ADSs. These control methods involve the application of a long short-term memory (LSTM) model that learns long-term time-series data. This system enables the construction of ADS control algorithms from LSTM models based on personalized driver operations during ordinary driving. Methods and Data Sources: LSTM models were constructed for highway driving in the following three driving scenarios. Scenario-1: following a preceding vehicle, Scenario-2: passing a preceding vehicle at low speed with lane change, Scenario-3: a sudden lane change by a vehicle in the passing lane in front of the vehicle. The effect of LSTM hyperparameters on the accuracy of the LSTM model was investigated for each driving scene. The data of these models were sourced from an experiment using a driving simulator conducted to determine driver behavior. Results: The results verified the accuracy of the model that simulated the driving operation of the driver. The model accuracy was improved by setting LSTM hyperparameters. In Scenario-1, the number of units, learning rate, and the number of epochs affected the coefficient of determination. The coefficient of determination tends to be particularly high for a large number of units. In Scenario-2, unlike Scenario-1, a large number of units was not required to obtain a high coefficient of determination. The coefficient of determination did not change with the epoch. In Scenario-3, similar to Scenario-1, the number of units, learning rate, and epoch affected the coefficient of determination, whereas the coefficient of determination decreased at epochs above 800. Discussion and Limitations: In each scenario, the hyperparameters affecting the accuracy were different. A limitation of this study is that it focuses on the driver model. The LSTM model applying ADS was evaluated. Conclusions: For the ADS control algorithm (SAE Levels 3, 4, and 5), we constructed LSTM models that reflect the characteristics of personalized drivers. The results showed that the LSTM hyperparameters affecting the coefficient of determination tended to differ among different scenarios. In the future, evaluation of the effectiveness of the LSTM model when applied to ADS is necessary. Novel control systems for ADS with LSTM models contribute to the development of ADS system design.

PAPER NO.23-0121-O

Capability-based routes for development, testing and operation of safe automated vehicles

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Abstract
Ensuring safety of automated vehicles (AVs) within their operational design domain (ODD) is essential for a release. In some parts of the ODD, ensuring safe operation is more challenging, requiring more sophisticated driving capabilities. For example, the same intersection requires different capabilities depending on the selected turn, i.e., if driving right, left, or straight ahead. To guarantee safe operation, only route sections for which capabilities for safe driving are available and validated should be selected. So far, the direct relationship between routes within ODDs and the driving capabilities of AVs has not been explicitly addressed. This paper presents for the first time an approach to identify routes with driving requirements that do not exceed driving capabilities of AVs. To this end, this approach builds on the Behavior-Semantic Scenery Description (BSSD), which links behavioral demands for AVs directly to the scenery as a central element of the ODD. Based on the BSSD, route-based behavioral requirements

are derived. Geometric characteristics of the scenery are used to specify driving requirements and driving capabilities that can be matched as a function of route and developed matching criteria. This matching is integrated into a conventional route planner, which as a result determines routes that are drivable based on the driving capabilities of an AV. The application to a real road network shows that the identification of capability-based routes is generally possible. Different intersections demand different requirements and lead to different routes. Nevertheless, several challenges are discussed that need to be overcome for a real-world application for development, testing, and operation of AVs.

PAPER NO.23-0126-O

Towards modeling driver performance within crash-relevant scenarios as virtual reference for the safety of automated vehicles

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Abstract
Technological advancements have shown the viability of Automated Driving (AD) and have created high expectations on its benefits – especially in terms of safety. An important step for the introduction of AD on public roads is providing an acceptable proof of AD's positive risk balance compared to today's traffic consisting of human-driven vehicles. Simulation of scenarios has become an essential tool for such analyses, since field operative tests have been shown infeasible as only means for such proof. Nonetheless, data is needed from which to derive human driver behavior as a reference within simulated scenarios. This paper presents an approach for modeling human driver behavior within defined scenarios to serve as a reference for AD. As a fundamental step to establish a suitable reference, we outlined the architecture of a parameterizable model of driver performance within crash-relevant scenarios, in which the driver model switches from a continuous control to a reactive behavior. The structure is based on well-established concepts like abstraction levels for the driving tasks, cognitive processes, and steps within information processing. A decision tree-like structure serves as guidance for the modularization of the driver reaction within different scenarios, which allows creating modules of decision-making processes as well as implementation of possible reactions within a scenario. To show the feasibility of the architecture and modules, and to demonstrate the applicability of the model, we conducted a driving simulator study of a scenario with a vehicle crossing from the right. Within the scenario, we varied the configuration of the potential crash (ego striking and borderline case) as well as apply two values of the available time to react. The study follows a within-subject design with 24 participants. The observed reaction choice, time and intensity were measured and then used to parameterize the driver model. Braking was the most frequently observed driver reaction, while potential crash configuration apparently influences the reaction choice. The observed driver behavior was in line with assumptions based on the state of art, which were used for the initial architecture and decision making of the developed driver model. Re-simulating the scenario with the parameterized model led to a similar frequency of crashes as in the simulator study. The experiment provided evidence that the driver model is built on reasonable assumptions for structuring the decision-making process

and modeling dependencies between situational variables and reaction parameters. Due to sample characteristics such as age, gathered parameters cannot serve as a general reference. However, it is not expected that a more diverse sample will disprove the assumptions for the model architecture. The theoretical considerations for modeling the decision-making process and its dependency on situational variables make apparent which complexity lies within modeling driver reactions. The proposed model for driver performance within crash-relevant scenarios aims to serve as a reference to prove the positive risk balance of AD. It provides a clear path for the establishment of a general reference model. Yet, the paper shows that the establishment of a baseline for all relevant scenarios comes with a tremendous effort and complexity.

PAPER NO.23-0174-O

Adapting approval regulations to accommodate automated vehicles

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Abstract
The UK government are committed to bringing forward legislation to allow the safe and secure deployment of self-driving vehicles, as set out in the recent policy paper Connected & Automated Mobility 2025: Realising the benefits of self-driving vehicles in the UK. As part of the Connected and Automated Vehicles Process for Assuring Safety and Security (CAVPASS) programme, TRL was commissioned to propose approaches to vehicle classification, and suitable technical requirements for aspects not related to the Automated Driving System (ADS). These included crashworthiness, occupant protection, protection of Vulnerable Road Users (VRUs), and the lighting, braking and steering systems. The initial focus of this work was on Low-Speed Automated Vehicles (LSAVs). The work involved selection and adaptation of existing pre- and post-deployment regulation to enable it to be applied to LSAVs. A main part was the adaptation of the technical regulations for M- and N-category vehicles, laid down in Great Britain's Road Vehicles (Approval) Regulations 2020 (SI 2020 No. 818), which implements retained Regulation (EU) 2018/858. The study proposed the introduction of two new vehicle categories (for LSAVs with and without occupants, respectively) to allow approval of designs not compatible with the M- and N-category definitions, such as passenger shuttles with six seats and space for standing passengers, or goods vehicles without any seats. Of 132 technical items collated from the existing body of regulations, 65 were found to be generally applicable for LSAVs with occupants, and 53 for LSAVs without occupants. Technical clarifications for regulations were developed relating to references to the driver or driver's seat, controls, warnings, and tell-tales and relating to bi-directional vehicles in general. The study further found that a general permission to carry standing passengers in light vehicles could present unreasonable risks to occupants in braking manoeuvres or collisions, but that it could be safe in some Operational Design Domains (ODDs). A concept was proposed which offers manufacturers a choice between two Crashworthiness Approval Levels (CALs). The less demanding CAL allows standing passengers but restricts the subsequent ODD of the vehicles. VRU impact protection was a high priority due to the expected operation in areas with a high density of pedestrians and cyclists. However, LSAV aspects such as their typically flat-fronted shape cause issues for the application of the current regulation, so modifications were proposed. Low-speed vehicles are not in widespread use today, which

means no directly relevant real-world collision data was available to base safety decisions on. The guiding principle applied in this study was to provide 'at least equivalent safety', i.e., to offer safety levels relating to non-ADS aspects, which, based on the limited data available and expert judgement, are comparable to or better than those of current vehicles used in similar scenarios. This study proposes a novel approach to link approval regulations to the vehicle's ODD and a set of technical requirements for non-ADS-related aspects of passenger- and goods-carrying LSAVs, which could help enable the approval of new vehicle concepts. The proposals have been presented to the United Kingdom Department for Transport for consideration.

PAPER NO.23-0224-O

Evaluation of ADS safety metrics with logged vehicle trajectory data

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Abstract
Assuring safe operation remains as one of the main challenges for developing and deploying automated driving systems (ADS). Real-time safety risk metrics may play important roles in calculating a risk measure of driving situations. Although a number of safety metrics have been proposed previously, it is difficult to compare different safety metrics and assess their performance because different behavioral assumptions underly for each. In this paper, a method to assess the behavior of safety risk metrics by determining the subject vehicle (SV) situational safety using logged vehicle trajectory data is proposed. Specifically, it is examined whether the SV is in a collision unavoidable situation at each moment, given the near-future trajectories of all surrounding principal other vehicles (POVs) recorded in the dataset after this moment. The main benefit of using logged vehicle trajectory data is the elimination of behavior prediction errors caused by model assumptions and approximations. This establishes a ground truth for crash outcomes independent of the risk metrics. Using the proposed methodology, the performance of different real-time safety metrics can be evaluated using simulated and/or real-world vehicle trajectories. The proposed methodology also has the potential to be applied in scenarios with vulnerable road users (VRU) interactions. In the case study, three real-time safety metrics are considered: time-to-collision (TTC), the PEGASUS Criticality Metric (PCM), and the Model Predictive Instantaneous Safety Metric (MPrISM). The results can help practitioners to better understand the characteristics and applicability of different safety metrics for different situations. The evaluation results can also help researchers improve and refine existing safety metrics.

PAPER NO.23-0345-O

Assurance through safety cases—There's a claim for that

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Abstract

Designing, developing, testing, and deploying an Automated Driving System (ADS) is challenging for a variety of reasons, not the least of which is that there are no defined Federal Motor Vehicle Safety Standards that govern ADS performance requirements. While there are a growing number of relevant industry developed consensus standards and best practices, developers still need to take it upon themselves to define and ensure safety assurance for an ADS. A safety case-based approach is an appealing way to provide such assurance. A safety case is a structured argument, supported by evidence, intended to justify that a system is acceptably safe for a specific application in a specific operating environment. A structured argument is important because an argument without evidence is baseless, and conversely evidence without an argument is trivia, or just a set of facts without anything to bring it together. While not entirely new—safety cases have been incorporated into other industries, including oil and gas exploration, nuclear energy, aviation, rail, and medical devices—safety cases are novel in the automotive sector. A safety case is both flexible and rigorous. It is flexible because it provides the developer with the latitude to determine what claim to make, and it is rigorous because there must be evidence to substantiate it. For example, there are now several standards and public guidance spanning many important topics related to the development and safe operations of AVs. These topics include functional safety, behavioral safety, and safety assurance for machine learning systems. The emergence of these standards provides a common baseline that all AV developers can consider and incorporate. How an ADS developer implements these standards can be the basis of a safety case claim related to adhering to industry standards. This presentation will present Aurora's experience and lessons learned in developing and implementing its Safety Case Framework. This includes integrating these standards into the AV development process, as well as how vehicle product engineering requirements, enterprise-wide processes, and operational elements (such as a Safety Management System) are incorporated into the development of an ADS. A safety case-based approach is important to ensure that the integration of many new, overlapping standards is managed correctly. And ultimately, a safety case-based approach provides transparency and insight into safety assurance.

Restraint System Design and Performance Challenges: Addressing the Needs of Diverse Populations (Age, Gender, Stature)

Thursday, April 6, 2023, | 08:30-12:30

Chair: Jim Hand, United Kingdom | Co-Chair: Nils Lubbe, Sweden

TRACK B | Room: G303

PAPER NO.23-0058-O

Classifying diverse population for adaptive restrain system by using finite element human body models

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Research

Vehicles are expected to meet standard crash tests requirements for both structural and occupant performance specified by governments and consumer advocacy groups. These tests command a specific ATD size in well-defined seating position with a certain impact speed of the vehicle or a moving barrier. In these standardized tests, typically, the 5th percentile female dummy and 50th percentile male dummy are specified, and the vehicle's occupant restraint system is optimized simultaneously for these dummies. With adaptive restraint system, the system can be optimized independently for 5th percentile, 50th percentile, and 95th dummies to maximize the protection. The objective of this research is to establish a methodology to classify diverse population such that a best set of optimized restraint systems derived from dummies can be tailored to an individual of any size.

Methods

A validated finite element vehicle sled model was selected for this study. US-NCAP standardized crash condition was simulated to optimize three vehicle restraint system designs for HIII small female, midsize male, and large size male independently. Twelve design variables of the airbag, seatbelt systems, and steering column were selected for such optimization. Fifty female and fifty male human body models (HBMs) morphed from GHBMC M50-OS model were used to represent diverse driver populations with various age, stature, and BMI of the US population. Automated process was developed for positioning the HBMs into the driver position for occupant safety simulations. The three optimized restraint systems developed for small female, midsize male, and large size male dummies independently, were then applied to each of the 100 HBMs. To evaluate the safety performance of the three optimized designs on each of the HBM, the joint probability of injury for each of the simulations were calculated.

Results

Three sets of restraint systems were optimized for the Hybrid III 5th, 50th, and 95th by minimizing the occupant injury risk in a regulated 35mph impact condition. Each of the three sets of restraint systems was used to assess the safety performances of each of the 100 HBM's. Based on the best fit restraint system selected for each of the 100HBM's, the boundaries dividing the diverse population are drawn. The population classification methodology is established for a vehicle with adaptive restraint system.

Discussion

The vehicle pulse used in this study was NCAP 35mph rigid barrier crash pulse only and the occupant classification boundary based on this pulse may change for lower speed or different types of barriers impacts. The 100HBMs were developed based on simplified GHBMC model and the classification boundary could be different if detailed GHBMC models were used to morph the 100 HBMs.

Conclusion

The processes discussed in this study show the potential of classifying a diverse population based on the best-fit restraint system from the three systems which were optimized originally for the dummy sizes: 5th female, 50th male, and 95th male.

PAPER NO.23-0092-O

FE analyses of the lap belt interactions with the pelvis for diverse occupants in various sitting postures

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Abstract

Passengers of different body shapes and sizes such as male, female, obese, and lean can sit in a car seat assuming various postures. This study aims to understand the interaction of the lap belt with the pelvis in a vehicle frontal impact scenario for occupants of various shapes, sizes, and sitting postures. A mid-size male Total HUman Model for Safety (THUMS) was morphed to develop a high and a low body mass index (BMI) human model using computer tomography (CT) images of sitting participants wearing a lap belt. Frontal impact finite element (FE) simulations were conducted for various occupant models (THUMS high-BMI, AM50, low-BMI, AF05, and Hybrid III AM50, AF05) under standard, reclined, and slouched sitting postures in the rear seat. The lap belt interactions with the anterior superior iliac spine (ASIS) were compared using the belt-pelvis angle and the overlap of the lap belt with the ASIS in the lap belt direction (belt-ASIS overlap). From FE simulations, submarining occurred more in the reclined and slouched postures than in the standard posture because of the large initial rearward pelvis tilt. Submarining occurred in fewer cases in the high-BMI model due to smaller pelvis rotation and larger belt-ASIS overlap than in other models. In the THUMS AF05, even though the belt-ASIS overlap was comparable, the pelvis began to rotate earlier and rotated more than in male models. The pelvis of Hybrid III showed a small initial tilt and rotation angle, resulting in fewer submarine occurrences than human body models. Submarining occurred in more cases in the slouched posture than in the reclined posture. This is because the belt-ASIS overlap was smaller in the slouched posture due to the shallow belt angle. In this study, a new parameter, the belt-ASIS overlap in the lap belt direction, was proposed to evaluate the belt engagement with the ASIS. The occurrence of submarining in various occupants and postures could be examined by using the lap belt-pelvis angle and the lap belt-ASIS overlap. These two parameters will be useful in designing a restraint system to interact with the pelvis in various conditions.

PAPER NO.23-0120-O

Evaluation of seatbelt use among pregnant women in Sweden

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Abstract
A digital questionnaire was distributed through social media targeting women who were or had been pregnant. The primary objective was to investigate self-reported seatbelt use and misuse during pregnancy. The second objective was to study if, and to which extent, women had received information regarding seatbelt use and how to wear it during pregnancy. The survey of 2,030 women who were or had been pregnant showed a total seatbelt wearing rate of 99%. However, 39% were wearing the seatbelt wrongly. In 35% of cases, the shoulder section of the seatbelt was incorrectly positioned, and the lap section of the seatbelt in 8% of cases. In 4% of cases, both the shoulder and lap belt parts of the seatbelt were incorrectly positioned. The majority (66%) had not received any information regarding proper seatbelt use during pregnancy. Of the 700 women (34%) who had received information, most of them had actively sought out information about how the seatbelt should be worn during pregnancy. This subgroup had significantly lower misuse rate, although a third of the group wore the seatbelt incorrectly. Very few (6%), had received information via a health care provider. Present data highlight the need for improved seatbelt fit for pregnant women. The result from the survey shows that misuse was lower among the women who actively searched for information regarding how to wear the seatbelt. To reach other user groups, it should be a priority for several stakeholders to communicate information regarding proper seatbelt use during pregnancy.

PAPER NO.23-0176-O

Comparison of the impact kinematics of an elderly female, the HIII 50th male and the HIII 5th female dummies as drivers, front passengers, and rear passengers in full-width frontal impacts

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Abstract
The objectives of this study were to analyse and compare the impact kinematics of an early prototype version of an Elderly Female, the HIII 50th Male, and the HIII 5th Female dummies as drivers, front passengers, and rear passengers in full-width frontal impacts. Three full-width frontal impact tests were conducted with a popular midsize station wagon based on Regulation UN R137 – except for the front passenger seat, which was adjusted in its longitudinal mid-position instead – in which the different ATDs were either placed in the driver, front passenger, or right back seats. The measured loads indicate that

second-row seats offer less protection than first-row seats. The HIII 50th Male dummy experienced the greatest torso forward rotation on all seats, with changes in the forward leaning angle of both the Elderly Female and HIII 5th Female dummies dependent on their respective seat positions. More research into the biofidelity of the Elderly Female Dummy is necessary to improve ATD design and to develop injury assessment reference values and injury risk functions.

PAPER NO.23-0186-O

Assessment of passenger safety in future cars - Identifying the real-world needs towards safety system development

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Abstract

Future cars will likely include further collision mitigation systems, seat positions and seating configurations compared to current cars, in addition to an increased degree of shared mobility solutions. At the same time the population is becoming older and the diversity in car passenger dimensions is growing. This calls for assessment tools and evaluation methods beyond the current standardized crash test methods. This paper summarizes the results of a Swedish research project on how to assess the protection of the heterogeneous population of passengers (i.e., non-drivers) in future car crashes, focusing on restraint interaction. With the overall purpose of further improving passenger protection, the specific aims were to achieve method developments based on the enhancement of tools (physical and virtual human substitutes) as well as to create knowledge on passenger protection needs. This comprehensive research project combined multiple competencies and international collaborations, and a large number of studies have been performed using different methods. The applied methods include real-world crash data analyses to identify scenarios and situations, crash testing and simulation, and additionally user-studies conducted in cars to evaluate sitting posture, beltfit, kinematics, comfort, experiences, and attitudes. Furthermore, the project included studies on crash test dummies (ATDs) and Human Body Models (HBM). Moreover, adult morphed HBMs were developed in various sizes, ages, and sexes, for investigating various protection principles. In novel studies, crash interventions strategies were applied to predicted residual crash configurations. User-studies provided evidence of self-selected passenger postures in real car settings and, thus, deviations from standardized ATD positions. The importance of body shape was highlighted in a beltfit user-study including older adults. Essential booster design parameters were identified for children in upright and reclined seat positions. Restraint principles were investigated for adults in reclined seat positions and with the seat in rearward positions, away from the frontal airbag and knee bolster, along with an evaluation of the capabilities of the assessment tools. The adult HBM morphed to various sizes, ages and sexes were validated for prediction of in-crash kinematics in different impact scenarios and provided enhanced insights in passenger protection assessment compared to the three standardized sizes of ATDs. Simulations with PIPER6y, a child-sized HBM, emphasized the importance of vehicle-booster-user system interaction. The results from the research project provided input to safety system development, ATD/HBM design, assessment methods

development, and a number of identified research challenges for future work. Specifically, there is a need to further explore car passenger interaction with the restraint system in terms of seat positions and variations in body sizes, shapes, and postures. The inclusions of the heterogeneous population into more advanced tools such as HBMs are essential, acknowledging that when moving closer to “zero injuries”, the situations to address are more unique and specific. Although a large range of studies using different methods was conducted, many challenges still remain to cover the entire scope of passenger safety in future cars.

PAPER NO.23-0228-O

A study on the method to reduce thoracic injury in frontal crash using elderly human and THOR FE model

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Abstract

In Japan, the ratio of the elderly in traffic accident fatalities has been increasing, and the thorax is the most frequently injured body region. Therefore, preventing chest injury to the elderly is one of the key issues to achieve zero fatalities. For this reason, several detailed analyses of the chest injury mechanism have been performed using elderly human body models (HBM). In a previous study, under frontal crash condition, it was observed that the forward motion of the internal organ and the forward rotation of the upper torso push up the lower ribs, potentially leading to rib fractures. In this study, a novel occupant restraint concept was devised that could reduce chest injury due to the mechanism above, and its effectiveness was verified using an elderly HBM and THOR. On the devised restraint system, a pair of shoulder belts that pass from left and right sides of the occupant shoulder to the same sides of flank were placed. The aim of them was dispersing the restraint force applied to the thorax of an occupant. A membrane was placed wrapping the abdomen between the two shoulder belts, which aimed to reduce the protrusion of the internal organ during a frontal crash. For the devised restraint system, a series of CAE calculation using the elderly HBM was performed in the two crash conditions of FR56K and OMDB in comparison with the conventional 3P belt, and the effect for reducing the number of fractured ribs (NFR) was confirmed. Then, another series of CAE calculation using the THOR FE model was performed in the same conditions, and several chest injury criteria such as Rmax, PC Score, TIC_NFR, and TIC_NSFR were calculated. Finally, injury probabilities for these criteria of THOR and NFR of the HBM were compared. Comparing the devised restraint system with the 3P belt, NFRs of the elderly HBM were significantly reduced, and all chest injury criteria of THOR were reduced, under both load cases. In the OMDB condition using the devised system and THOR, the chest deflection at inner lower was the largest, and Rmax was relatively high than other chest injury criteria. In the same condition, TIC_NSFR showed the best correlation with the NFR of the elderly HBM. It was considered the reason why Rmax was high on OMDB was that THOR had a more protruded ribcage around the lower region than the elderly HBM, which caused higher concentrated load on this region pushed by the shoulder belt. The reason why the TIC_NSFR on OMDB was low was considered to be that the devised system restrained the chest evenly on the left and right, and the value of the term that indicates the left-right difference of the upper chest deflection in the TIC_NSFR formula became smaller. It was found that the devised chest

restraint system could significantly reduce rib fractures of the elderly HBM in a frontal crash. It was also found that when the devised system was evaluated with THOR, every chest injury criterion was reduced.

PAPER NO.23-0277-O

Comparison of injury risk of different child restraint systems between regulated and realistic frontal impact tests

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Abstract
Motorized vehicle crashes represent the highest injury risk for children. Furthermore, new devices and new transportation applications potentially bring new challenges and injury risks. Therefore, the main objective of this work is to analyze the safety performance of seat belt alone, booster seat and belt guide only devices in frontal impact tests under regulatory and realistic conditions. We analyzed the kinematics of the dummy, calculated the injury risks, and compared it with the meta-analysis of past published crash analysis complemented with the most recent accident data retrieved from the EU CARE database. We calculated the risk attributable to the studied restraint solutions and test conditions. Test on belt guide only devices show that they are statistically equivalent to seat belt alone solutions. Therefore, replacing an appropriate booster seat with belt guide only devices potentially increase the number of injured children by 33% (95 confidence interval:16%, 50%). Finally, we performed gap analysis to improve the fitness-for-purpose of regulations for future mobility applications.

PAPER NO.23-0285-O

Mapping the path forward toward equity in crash safety: Recommendations from an expert workshop

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Abstract
Crash testing historically has focused on the use of midsize male anthropomorphic test devices (ATDs). These tools and, more recently, ATDs representing a small female have been used to drive improvements for a diverse population with many differences that can affect injury risk. However, there are still gaps in protection for some population groups that may require different strategies to optimize their protection. To address this, 23 experts from industry, academia, and government convened in October 2022 for a 2-day workshop to reflect on opportunities and challenges in protecting both male and female occupants of different ages and sizes. Workshop participants included experts in biomechanics, behavioral science, human factors, communications, and policy. The discussion focused on how current tools and resources can be used to better protect a range of occupants and what future tools and data are needed to improve safety evaluations and incentivize robustness across the occupant protection design space. This paper reports on the workshop discussion and recommendations along the following key themes: the need to understand the current state of occupant protection to identify priority populations; the need for fundamental data on the populations of interest to improve ATDs and

computational tools; computational modeling and human body models as critical tools for studying injury causation and evaluating countermeasures; currently available tools and strategies that can benefit a diverse population; and the importance of collaboration. The recommendations provide several paths to improve safety today and work toward improved protection in the future for a broader range of occupants with diverse needs.

PAPER NO.23-0323-O

An NCAP rating for females

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PRIYA PRASAD
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Abstract
This paper defines NCAP rating factors that would be useful to improve the safety of females in frontal crashes. The study is based on an analysis crash tests available on the NHTSA website and analysis of Crash Investigation Sampling System (CISS) and Crash Report Sampling System (CRSS) data. Analysis of NHTSA databases of crash tests and collision data suggest that a Female NCAP should focus on encouraging crash safety countermeasures in three priority areas – reducing chest injuries, reducing lower limb injuries (especially foot and ankle injuries), and reducing the crash severity in lower speed crashes. Based on the available literature and the additional data analysis, proposals are offered for a Female NCAP to address the three principal issues. These include better controls of the safety belt and foot positioning, measuring chest and foot/ankle injury risk more accurately, limiting brake pedal motion and limiting the initial frontal stiffness of vehicles.

PAPER NO.23-0337-O

How gender preferences for vehicle size/class influences fatality outcomes

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Abstract
In recent years, the issue of gender equity in real-world crash protection has been the focus of a great deal of research [1, 2, 3, 4]. Concerns that females may be subject to elevated risks of injury relative to their male counterparts under similar circumstances have prompted a debate over the need for a 50th percentile female dummy. Early automotive testing concentrated on crash test dummies with 50th percentile male characteristics. By the mid 1990s there was general recognition of a need to expand the family of dummies to address a wider range of the population. Initially, the use of a smaller female dummy was prompted by the introduction of frontal airbags and the need to put design controls in place to address proximity issues to the airbags. However, this was quickly followed by an appreciation of the benefits and the need for the "family of dummies" approach in side impact testing as well as in

frontal testing. More recently, the possibility has been raised that some of the risk disparity between males and females may not be physiological but may be related to vehicle preferences between males and females [5]. The present study is one in a series of investigations which seek to determine the extent to which injury outcome differences by gender are driven by different male and female preferences for vehicle size and class.

New and Improved Field Data Collection, Analysis, and Benefits Assessment Methods

Thursday, April 6, 2023, | 08:30-12:30

Chair: Rikard Fredriksson, Sweden | Co-Chair: Tetsuya Niikuni, Japan

TRACK C | Room: G304

PAPER NO.23-0024-O

A comprehensive evaluation of car safety evolution using model change year classifications and traffic accident data in Japan

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Abstract

To reduce the number of traffic accidents and injuries caused by vehicles, crash safety performances for saving occupants and pedestrians have been improved, and also various advanced driver assistance systems have been introduced for a wide range of vehicles in recent years. The aim of this study was to elaborate on whether newer generations of car models have fewer casualty accidents due to such safety evolutions from a broader perspective. As for the classification of the cars, 411 models of standard passenger cars including SUVs were grouped into four categories by the year of full-model change (Mo.CY) which meant either fully remodeled or newly introduced to the Japanese market. Specifically, the classification were as follows; G1 (Generation 1): 2000-2002 Mo.CY, G2: 2003-2010, G3: 2011-2015, G4: 2016-2019. Regarding accident data, fatal, serious, and minor injury accidents reported to the police in Japan between 2017 and 2020 were utilized. This applied in common to the four Mo.CY groups. As the evaluation index, the numbers of accidents per 100,000 vehicles registered per year were used. Then it was assessed whether there was a difference among the groups of Mo.CY, i.e., whether the newer vehicle group has fewer accidents. This evaluation was conducted from a comprehensive viewpoint including many safety systems and crash safety performance improvements, rather than strictly assessing the effectiveness of a specific safety system. In conclusion, analyzing accident data for the same period of 2017 to 2020, the number of accidents for the newer Mo.CY groups in several types of accidents were lower than that for old ones. Regarding fatal accidents, pedestrian and single-vehicle accidents accounted for a large percentage in the G1 group. Specifically, the analysis proved that the number of fatal accidents per 100,000 registered vehicles has dramatically decreased by 55% for pedestrians, and 69% for single-vehicle accidents from G1 to G4. In addition, the casualty accidents for rear-end collisions have greatly reduced by 64% from G1 to G4. That was because the newer cars had more various safety features and better-improved passive safety performance. It was also clarified that the degrees of accident reduction depended on the severity of injury and the type of accident. The method presented here, utilizing Japanese elaborate statistical accident data, demonstrated that it was possible to quantify the overall benefits of safety features and performances, or car safety evolution. Therefore, it could lead to a better understanding of real-world performance and a way to go for a safer world.

PEER REVIEW PAPER No.23-0026-O

A novel method for the automated simulation of various vehicle collisions to estimate crash severity

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Research
Vehicle collisions are described with the help of collision severity parameters such as EES and the collision-based change of velocity (delta-v). These serve as an input for injury outcome estimations through injury risk functions (IRF) or for the virtual assessment of Active Safety Systems (ADAS) in case of a mitigated collision. Different methods to simulate vehicle collisions are described in the literature. Two main groups were identified: The first one delivering only a few, partly inaccurate results obtained during a short time frame and the other delivering detailed and accurate results but requiring high computing time. We have developed a novel method to simulate various vehicle collisions within a short time frame while ensuring the computation of accurate collision severity parameters.

Methods
Three-dimensional EES-models developed in previous research were used in this study. They represent different passenger vehicle classes and are based on real world crash data. In order to obtain unbiased EES values, additional crash data from crash tests has been used in the development of these EES models. Here, they were used to compute 2D vehicle substitute models, which are deformed during the new, iterative method. By using fundamentals of mechanical impact calculation and vehicle kinematics the collision is calculated. These steps are executed in an own developed tool named impactEES, written in C++. The results obtained were validated against measured crash test data from the European New Car Assessment Programme (Euro NCAP) and Allgemeiner Deutscher Automobil-Club (ADAC) Technical Center. ImpactEES combines a graphical user interface with various single or batch crash calculations. Because of the predefined input interface, it can be linked to any existing pre-crash-simulation software.

Results
The novel method enables the automated computation of various car-to-car and car-to-object collisions. The output of impactEES includes the deformation area, EES and delta-v and the following time-dependent data for each vehicle: translational and angular accelerations, translational and angular velocities, and the position of the center of gravity in addition to the heading of the vehicle. Without the need of highly sophisticated hardware, a single simulation of a collision between two vehicles providing accurate collision severity parameters takes only a few seconds. Based on the comparison of measured crash test data and results obtained from impactEES the mean percentage error (MPE) and its standard deviation (SD) were calculated for EES (MPE=-1.4%, SD=10.2%, n=13) and delta-v (MPE=3.2%, SD=16.8%, n=22).

Discussion
The method described above is much faster than finite element analyses and more reliable than present momentum-based or stiffness-based simulation approaches. Currently it is implemented in 2D only,

with the intention to develop a 3D-method in the future. Current limitations are the simplified description of indirect deformations and the missing contact-friction mechanism.

Conclusion
The novel method allows for the 2D computation of various car-to-car and car-to-object collisions. Using predefined IRF makes possible the assessment of injury probabilities relative to the change of collision severity parameters. This could be used for the virtual assessment of injury mitigation capabilities of ADAS systems and thus represents an important contribution to its targeted development.

PAPER NO.23-0039-O

Development of simulation-based method for benefit estimation of automatic emergency braking and lane departure warning in traffic collisions

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Abstract
In this study, a simulation-based method was developed for benefit estimation of Automatic Emergency Braking (AEB) and Lane Departure Warning (LDW). The collision avoidance effect and the injury mitigation effect of AEB and LDW were probabilistically estimated through large-scale simulations of near-miss scenarios leading to traffic collisions. The top nine near-miss scenarios were selected from the fatal collision data in Japan. The simulation parameters such as vehicle speed and its position in the lane were varied based on the statistical data to realistically simulate various situations in the field. A total of 17,000 simulations were conducted for each with or without AEB or LDW in order to calculate the reduction of collisions cases. For the collision cases, crash simulations were conducted using a virtual human body model “THUMS” to predict the fatality risk. In this study, the head injury value, HIC15, was used to determine whether the injury level was fatal. The benefit of AEB/LDW was estimated by multiplying their effect for each collision scenario by the percentage of the scenarios in the total number of fatal collisions in Japan. When neither AEB nor LDW were activated, collisions occurred in 117,031 out of 153,000 cases. When AEB or LDW was activated, collisions occurred in 48,030 cases. The collision avoidance effect by AEB or LDW was estimated to be 59.0 %. In the collision cases, there were 415 fatal cases where AEB was not activated while in 76 cases with AEB was activated. Based on the results, the injury mitigation effect was estimated to be 81.5 %. The simulation results for the top nine scenarios indicated 29.9 % for the benefit in collision avoidance and 52.4 % for the benefit in injury mitigation.

PAPER NO.23-0040-O

EDR reported driver usage of crash avoidance systems for Honda vehicles

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Abstract
Starting with the 2016 Model Year, Honda Motor Co. (Honda) began to phase-in vehicles equipped with an Event Data Recorder (EDR) that captures the status and activation of crash avoidance technologies

such as forward collision warning/automatic emergency braking and lane departure warning/lane keeping assist. While not defined under the National Highway Traffic Safety Administration's (NHTSA) EDR regulation 49 CFR Part 563, Honda has elected to add these data elements. For this study, Honda EDR data were collected from the NHTSA's 2017 – 2021 Crash Investigation Sampling System (CISS) for vehicles equipped with this recording capability. The data were then assessed to identify the use and activation statuses of these crash avoidance technologies at the time of their respective crash events. If drivers choose to disable these technologies, they will not be afforded the potential collision avoidance and/or severity mitigation benefits of these systems in relevant crashes. The 150 crash-involved Honda vehicles in this study are equipped with EDRs that captured data elements related to the function and alert status of several crash avoidance systems in the time leading up to the crash event. The results indicate that drivers of Honda vehicles equipped with crash avoidance systems are much more likely to have forward collision warning/automatic emergency braking systems "On" and the lane departure warning/lane keeping assistance systems "Off." Specifically, 99% of drivers for this study had the forward collision warning/automatic emergency braking systems "On" in the time leading up to the crash and thus could be afforded the potential benefits of these systems if they were involved in a system relevant crash situation. With respect to lane departure warning/lane keeping assistance, 49% of the drivers had these systems "Off" at the time of the crash, and therefore were not afforded the potential benefits of these systems during an appropriate situation. Differences were not identified for drivers that had the lane departure warning/lane keeping assistance "On" compared to those that had it "Off" with respect to the driver's sex, age, and race/ethnicity. Since data on these crash avoidance technologies are collected on the vehicle's Bosch compatible EDR, information regarding the status for these systems at the time of the crash event is readily accessible. This will permit a future assessment for whether a system relevant crash event may have occurred because the system was turned "Off." Alternatively, if the system was turned "On," follow up assessment could be conducted for whether the system "Engaged" and mitigated the severity of the crash. If the system was "On" but is reported as "Not Engaged," further investigation may be warranted to understand factors that may have prevented system activation. Vehicle level crash avoidance system data captured in the EDR is invaluable and relevant for assessing new field data collection, which will in turn contribute to assessing the real-world benefits of these crash avoidance technologies.

PEER REVIEW PAPER NO.23-0053-O

Female crash fatality risk relative to males for similar physical impacts

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Research
To determine if later-model-year vehicles with enhanced occupant protection technologies (dual air bags, pretensioners and load limiters) reduce the disparity in fatality risk between males and females compared to earlier vehicles.

Methods
This study uses the Fatality Analysis Reporting System (FARS), a yearly census of fatal crashes in the United States. Fatal crashes involving vehicles of model years 1960-2020 are included when a driver and a right front (RF) passenger aged 16-96 are present, both have identical belt use and air bag availability,

and at least one of them dies. Logistic regression and double pair comparison are used to estimate female fatality risk relative to males within earlier and later model-year vehicle groups.

Results

Compared to a peak female fatality risk relative to males for drivers in vehicle model years 1975-1979 (19 ± 5.0%), the female relative fatality risk reduced to 0.5 (± 17.5) percent for drivers in 2015-2020 model year vehicles. For RF passengers, the peak female relative fatality risk was 27.9 (± 10.6) percent for 1960-1966 vehicle model years. This decreased to 5.3 (± 16.4) percent for 2015-2020 vehicle model years. Female fatality risk relative to males was significantly reduced in 2010-2020 model year vehicles compared to 1960-2009 model year vehicles (-12.0 ± 5.5%). Female relative fatality risk was also significantly reduced in vehicles with dual air bags compared to vehicles without dual air bags, both when the occupants were belted (-11.3 ± 4.1%) and unbelted (-6.4 ± 4.0%). When the vehicles with dual air bags and belted occupants were restricted to only those with pretensioners and load limiters, the reduction in female fatality risk relative to males was -15.2 (± 5.2) percent.

Discussion

The sex disparity in fatality risk decreased consistently over model year increments for both drivers and RF passengers. Significant reductions were found with dual air bags whether occupants were belted or not, suggesting that the reduction in sex disparities in later vehicles is not due entirely to increased belt use. . Later model year vehicles had smaller sample sizes, resulting in wider confidence intervals and more uncertainty in risk estimates than earlier model year vehicles.

Conclusion

Later model year vehicles with more advanced occupant protection technologies are associated with significantly smaller female fatality risk relative to males in crashes with similar physical impacts. This paper provides evidence that advanced occupant protection technologies are beneficial in tackling the problem of sex disparity in crash fatality risk.

PAPER NO.23-0075-O

Representative pedestrian collision injury risk distributions for a dense-urban US ODD using naturalistic dash camera data

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Abstract

Automated Driving Systems (ADS; SAE levels 3 through 5 technologies) are currently being deployed in several dense-urban operational design domains (ODDs) within the United States (US). Within these dense-urban areas, vulnerable road users (VRU) generally comprise the vast majority of injury and fatal collisions. One challenge with the study of VRU collisions is a lack of crash data sources with pre-impact kinematics. Understanding the pre-impact kinematics is a key factor in assessing the potential injury risk for pedestrian-vehicle impacts. The purpose of this study was to determine injury distributions for pedestrians within a dense-urban ODD (Los Angeles, California) using data from vehicles instrumented with forward-facing cameras and vehicle sensors. This study leveraged data from a fleet of vehicles equipped with aftermarket, in-cabin dash cameras operating in Los Angeles, California. From approximately 66 million miles of driving data, 42 collisions were identified. Each vehicle was equipped with a forward-facing camera, an accelerometer sampling at 20 Hz, and GPS. A global optimization

routine was used on the accelerometer, GPS, and video data to correct for sensor orientation and asynchronicity in data sampling. For each event, two key video frames were identified: the frame associated with impact and a frame associated with key vehicle kinematics (e.g., vehicle start/stop, hard braking [> 0.2 g]). These key frames were then mapped to the processed vehicle speed kinematics to determine vehicle speed at impact. For the events included in this dataset, impact speeds ranged from approximately 1.6 kph (1 mph) to 65 kph (40 mph). In most events, the front of the vehicle struck the pedestrian. Existing pedestrian injury risk curves were then used to calculate the level of risk associated with the reconstructed impacts, and the probability of AIS3+ injury risk was observed to vary from minimal risk (<2%) to approximately 55%. These data highlight the wide range of impact speeds and injury risk that may occur during vehicle-pedestrian collisions. Assessing injury severity for collisions involving VRUs is highly impactful for the continued development of traffic safety, including ADAS, ADS, and roadway design. Using naturalistic VRU collision data collected from dashboard cameras, a methodology for assessing event severity by pairing accelerometer and GPS data with video to compute impact speed was presented. This is the first known analysis of pedestrian severity distributions using a naturalistic US database. The methods presented in this study may be applied to larger datasets or other sensing systems to enable further ODD-specific modeling.

PAPER NO.23-0086-O

The knowledge for tomorrow's road safety bases on harmonised data - The global safety database does its contribution

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Abstract
Road traffic accidents remain to be a leading cause of death worldwide with nearly 1.3 million fatalities each year. To develop safety systems according to real-world challenges, harmonized information is needed. Therefore, vehicle and road traffic safety experts are constantly looking for real-world data to answer the open challenges and to ultimately reach the “Vision Zero”. Numerous data on road traffic accidents exist and can be split into national and in-depth databases. The latter are characterized by a significantly lower number of cases then the national databases but a substantially higher level of detail and enable a microscopic view on the accident scenario. By using in-depth databases, new safety systems may be developed and validated. The results of analyses are extrapolated to assess the impact on road safety for a specific country, continent or even for the whole world. However, it is not always obvious which database is suitable for which type of development approach or extrapolation. The Global Safety Database (GSD) solves this issue by offering access to a one of its kind up-to-date worldwide collection of road traffic accident statistics and database on a meta-data level. In addition to the objective evaluation of databases by matching them to research questions, the GSD also provides knowledge on the representativeness of each database. In order to identify similarities and differences in road safety within the countries, the latest publication of the Global Status Report on Road Safety from 2018 is used to develop a clustering methodology. The goal of this method is to point out the possibilities and limitations of transferring information from the initial countries to other areas of interest. The core of the investigation is the clustering methodology, which generates derivatives on countries or regions with similar road safety standards. The objective matching algorithm within the GSD

helps to find the necessary information for the qualitative assessment of representativeness. Once the representative database within a country is identified, the clustering results are used to determine which countries represent the chosen database. As the clustering relies on the latest Global Status Report from 2018 (and even partly from 2016), more recent data on road safety is desirable to narrow the spread to a steadily growing GSD. For a more integrated road safety approach, the GSD is also prepared to cover more topics related to road safety e.g., infrastructure or medicine. Additionally, an extension of the qualitative assessment of representativeness to a quantitative is more robust. The clustering may be used to find derivations to the initial country and to transfer the results from these to the target countries by similarities in road traffic safety. From a global perspective, the GSD is one essential tool to push forth the worldwide harmonisation of traffic accident statistics and databases. Knowing what really happens on the roads by putting together everything we know empowers the data-driven development of safety systems and thus brings us one step closer to reach a road system without casualties – fulfilling the Vision Zero.

PAPER NO.23-0093-O

Determining the prevalence and profile of speeding in vehicle crashes using Event Data Recorders (EDRs)

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Abstract
Travelling at a speed above the speed limit is commonly known as speeding. Prior studies examining the prevalence and profile of speeding in Australia (and other countries) have used data from various sources, including speed enforcement data, speed measurement surveys, self-report studies, and naturalistic studies. Attempts have been made to determine the prevalence of speeding in crashes using police reports, but these have conflated inappropriate speed for the conditions with speeding. The objective of the present study was to use data from event data recorders (EDRs) that record pre-crash speed to determine the prevalence and profile of speeding in crashes that occur in South Australia. Data from the Centre for Automotive Safety Research's Event Data Recorder database (CASR-EDR) was used in the analysis. Separate analyses were conducted for all bullet vehicles (n=319) and for those travelling at a free, or self-selected, speed (n=160). It was found that 27% of bullet vehicles involved in the crash sample were speeding. The most common category of speeding was 1-5 km/h above the speed limit, but 6% of bullet vehicles were found to be speeding by more than 20 km/h prior to their crash. When only free speed vehicles were considered the percentage of vehicles speeding rose to 39%. Speeding was found to be more prevalent in crashes where the bullet vehicle was driven by a young driver, a driver with a provisional license, or the vehicle was black, red, or grey in colour. Speeding was also most prevalent in crashes that occurred on a weekend night, on a curve, at a mid-block location, on a local road, in regional areas, on a wet road, in low-speed zones, and in single vehicle crashes. These findings reinforce the need to reduce the prevalence of speeding through means such as education, enforcement, road design or vehicle technology. Young drivers should be a particular focus of efforts to reduce speeding. The findings can also provide some guidance on where enforcement activities should be further focussed.

PAPER NO.23-0122-O

Generating representative test scenarios: The "Fuse for Representativity" (FUSE4Rep) process model to collect and analyse traffic observation data

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Abstract
Scenario-based testing is a pillar of assessing the effectiveness of automated driving systems (ADSs). For data-driven scenario-based testing, representative traffic scenarios need to describe real road traffic situations in compressed form and, as such, cover normal driving along with critical and accident situations originating from different data sources. Nevertheless, in the choice of data sources, a conflict often arises between sample quality and depth of information. Police accident data (PD) covering accident situations, for example, represent a full survey and thus have high sample quality but low depth of information. However, for local video-based traffic observation (VO) data using drones and covering normal driving and critical situations, the opposite is true. Only the fusion of both sources of data using statistical matching can yield a representative, meaningful database able to generate representative test scenarios. For successful fusion, which requires as many relevant, shared features in both data sources as possible, the following question arises: How can VO data be collected by drones and analysed to create the maximum number of relevant, shared features with PD? To answer that question, we used the Find–Unify–Synthesise–Evaluation (FUSE) for Representativity (FUSE4Rep) process model. We applied the first ("Find") and second ("Unify") step of this model to VO data and conducted drone-based VOs at two intersections in Dresden, Germany, to verify our results. We observed a three-way and a four-way intersection, both without traffic signals, for more than 27 h, following a fixed sample plan. To generate as many relevant information as possible, the drone pilots collected 122 variables for each observation (which we published in the ListDB Codebook) and the behavioural errors of road users, among other information. Next, we analysed the videos for traffic conflicts, which we classified according to the German accident type catalogue and matched with complementary information collected by the drone pilots. Last, we assessed the crash risk for the detected traffic conflicts using generalised extreme value (GEV) modelling. For example, accident type 211 was predicted as happening 1.3 times per year at the observed four-way intersection. The process ultimately facilitated the preparation of VO data for fusion with PD. The orientation towards traffic conflicts, the matched behavioural errors and the estimated GEV allowed creating accident-relevant scenarios. Thus, the model applied to VO data marks an important step towards realising a representative test scenario database and, in turn, safe ADSs.

PEER REVIEW PAPER NO.23-0141-O

Evaluation of intersection crashes using naturalistic driving data through the lens of future I-ADAS systems

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Research

Intersection crashes account for approximately one-in-six fatal crashes and one-in-five crashes in the US. Intersection advanced driver assistance systems (I-ADAS) are in development to detect imminent intersection crashes and potentially avoid the impact with automated braking. Based on simulations of real-world crashes, although I-ADAS could prevent many intersection crashes but could be limited by sightline obstructions. Most studies evaluating, I-ADAS are based on real-world, police reported crash reports, which often are unable to identify the presence of non-contact vehicles that obstructed the view of the driver. The purpose of this study is to use naturalistic driving data to identify challenges for future I-ADAS systems in straight-crossing path (SCP), left-turn across path lateral direction (LTAP/LD), and left-turn across path opposite direction (LTAP/OD) crash configurations.

Methods

Intersection crashes were selected from the Second Strategic Highway Research Program (SHRP 2) naturalistic driving study. The SHRP 2 dataset includes front-facing, driver facing, rear facing, and a hands/feet facing video footage in addition to the vehicle speed, steering, accelerator, and brake time-series data. From SHRP2 data, all SCP crashes (12), LTAP/LD crashes (17), and LTAP/OD crashes (17) were selected for in-depth analysis. The driver facing video, front facing video, and vehicle network data were reviewed together in the Virginia Tech Transportation Institute (VTTI) secure data enclave to understand driver sightline obstructions, driver distractions, and initiation of driver responses. The TTC (Time to Collision) during the precipitating event, when either vehicle entered the intersection without the right-of-way, was computed based on the distance to the impact point divided by the current velocity. Because the vehicle approaches for SCP and LTAP/LD crashes are similar, the analysis of these crash modes was combined.

Results

The median impact speed was 18.0 mph for SCP and LTAP/LD crashes and 16.1 mph for LTAP/OD crashes. The median TTC during the precipitating event was 1.35 s for SCP and LTAP/LD crashes and 1.44 s for LTAP/OD crashes. For SCP crashes, the three main sightline obstruction scenarios were slower vehicles traveling in the same direction waiting to turn right, vehicles in the closer crossing lane, and a parked truck. For LTAP/OD crashes, the sightline obstruction was often oncoming vehicles in a closer lane blocking the view of another vehicle.

Discussion

The analysis of SHRP 2 intersection crashes found that most non-distracted drivers were not looking in the right direction to observe the collision partner. The TTC of the precipitating event suggests that I-ADAS may be able to prevent the collision provided the collision partner is not obstructed by other vehicles. While this study investigated every applicable crash in SHRP 2, this is a small sample that likely does not represent every possible intersection crash.

Conclusion

Sightline obstructions could present a challenge for future I-ADAS to activate in SCP, LTAP/LD, and LTAP/OD crashes. This study utilized naturalistic driving data to complete a comprehensive analysis of intersection crashes including driver distractions, evasive maneuvers, and sightline obstructions that can assist development of I-ADAS systems and is not possible with police reported crash data only.

PAPER NO.23-0156-O

Application of a modified integrated safety chain using in-depth crash data to identify factors associated with serious injury crashes: A method to prioritise currently available active safety systems and to identify new opportunities to advance vehicle safety

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Abstract
Introduction Recognising the ambition of Vision Zero, vehicle safety will play a critical role in reducing the number of road users seriously injured globally. The objective of this research, therefore, was to identify currently available and required future countermeasures that will lead to the elimination of serious injury. To meet this objective a systematic approach to the analysis of in-depth crash data using case-by-case analysis linking contributing factors to safety countermeasures was developed. Method In-depth crash investigation data collected as part of the MUARC-TAC Enhanced Crash Investigation Study (ECIS) was used. 400 drivers (MAIS 3+: 47%) admitted to a major trauma centre in Victoria, Australia, were included. Data sources included: driver or next-of-kin/family interview, ambulance and medical records, and police data. Vehicle and scene analysis was undertaken. Crashes were reconstructed and EDR data was accessed where available. Using a modified version of Tingvall's Integrated Safety Chain, contributing factors and safety countermeasures across the 10-phase crash chain were examined using a case-by-case approach. Contributing factors were those associated with crash occurrence and injury severity. A countermeasure library was established with each of the 278 countermeasures linked to a specific contributing factor. Countermeasures included those focussed on the driver, passive and active vehicle safety systems, road infrastructure and post-crash response. The efficacy and time-horizon of each was assessed and estimated for future active safety systems. All applicable countermeasures for each crash and injured driver were identified; these were considered to be sensitive to the countermeasure effect. Results Driver distraction (48.8%), sudden sickness (10.0%), drowsy driving (24.5%), and impaired driving (19.8%) resulted in lane departure and cross-path vehicle movements; this, combined with low proportion of driver pre-crash braking (55%, 1.3 s) and exceeding the speed limit (27.0%) demonstrates the need for intervening safety systems (e.g., ISA, AEB). Intervening systems to correct lane deviations and intersection entry are also required. Discussion The findings highlight the importance of in-depth data in establishing the use case for existing but relatively new systems as well as the identification of system capability limits in addressing current crash scenarios. These crash scenarios represent development opportunities for new standalone active safety systems. However, for full safety benefits to be realised, and to address the full range of driver performance and impairments, next generation systems that are fully integrated with one another are required (e.g., AEB + driver monitoring systems, DMS). Occupant status monitoring, on-board sensors, V2I and V2V enabled technologies linked to chassis control systems will be central to the future safety architecture of the

vehicle. The findings are relevant to passenger vehicle crashes where at least one driver was seriously injured and admitted to hospital. Other limitations associated with the sample and data collection methods must also be considered. The analysis method represents a powerful approach to analyse in-depth crash data and to understand crash causation, injury occurrence and applicable countermeasures. Adoption of this method using other datasets is recommended so that the full range of countermeasure needs across jurisdictions and other road user groups can be understood.

PAPER NO.23-0167-O

Observation-based pedestrian scenario extraction for virtual testing

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Abstract
An overall reduction of pedestrian-vehicle collisions is expected with the market penetration of Advanced Driver Assistant System (ADAS) and autonomous driving (AD) functions. The performance of ADAS is commonly evaluated through virtual scenario-based testing. Hence, scenario catalogs that represent realistic pedestrian-vehicle interactions are needed. This study shows an approach to automatically extract pedestrian-vehicle scenarios at a selected road intersection, which was observed with a dual-lens stationary observation system. A deep learning-based visual perception pipeline was implemented to reconstruct road user trajectories via state-of-the-art object detection, visual multi-object tracking and object re-identification models. These models were trained and fine-tuned on a manually annotated, diverse dataset, randomly sampled from recordings over multiple weeks. All models were evaluated using common performance metrics. Additionally, localization precision of reconstructed trajectories was assessed using georeferenced ground truth measurements conducted at the intersection. The visual perception pipeline was applied on selected video data and extracted trajectories converted according to the openSCENARIO standard, including a virtual representation of the selected road intersection. The compiled scenarios were further simulated with the openPASS framework. The results show that pedestrians and vehicles were tracked with high accuracy (Multiple Object Tracking Accuracy > 83.2%) and trajectories were reconstructed with a mean deviation of 0.9 m for pedestrians and vehicle paths with a deviation of 0.68 (SD 0.5) m. The observation system allowed both the obtaining of typical pathways and also speed profiles. An exemplary reconstructed scenario was successfully resimulated in the openPASS framework. T The described approach is promising and can be used to create new scenario catalogs for scenario-based assessments in line with the openSCENARIO standard. Furthermore, the view-point of the observation system allows the reconstruction of pedestrian attributes including poses, age, or gender, which, alongside an analysis of the recorded pathways and speed profiles with respect to influencing factors, is a focus of ongoing research.

PAPER NO.23-0253-O

In-depth accident study on D-Call Net vehicles by medical engineering collaboration

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Helicopter Emergency Medical Service Network, Japan

Abstract
D-Call Net, which Japan was the first country in the world to implement for practical use, is an extremely unique advanced automatic collision notification system in which a helicopter emergency medical service (HEMS) with a doctor and a nurse on board is requested by a vehicle involved in a collision. Six years have passed since the start of a pilot operation and four years since the start of a commercial operation, and more than twenty cases have been reported in which D-Call Net has activated HEMS and transported drivers or passengers to trauma centers. Since 2018, the Ministry of Economy, Trade, and Industry (METI) has been supporting the international standardization activities of the injury estimation algorithm used in D-Call Net. Based on the newly established Japanese Industrial Standard (JIS) D0889 [1], ISO standardization activities are continuing to develop the technical specification under ISO TC22/SC36/WG7. On the other hand, from FY2021, the Ministry of Land, Infrastructure, Transport and Tourism initiated the "D-Call Net In-Depth Accident Study" in which experts in emergency medicine and automotive engineering collaborate to establish an accident database for developing safer vehicles, replacing the previous "Medical Engineering Collaborative In-Depth Accident Study". Institute for Traffic Accident Research and Data Analysis (ITARDA) has been in charge of both ISO standardization activities and the accident studies. This paper provides an executive summary of ITARDA's D-Call Net In-Depth Accident Study for FY2021. A total of twenty-one collisions were investigated during the study period, and several characteristic collisions were selected and detailed among them. The consideration of ΔV recorded by EDR, the time saving effect of D-Call Net and the evaluation of the algorithm according to the ISO technical specification are also discussed.

PAPER NO.23-0266-O

The creation and application of harmonized pre-crash scenarios from global traffic accident data

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Abstract
The development and test of future Advanced Driver Assistance Systems (ADAS) and Autonomous Driving (AD) AD functions requires sophisticated data from pre-crash scenarios. As real-world traffic provides an infinite variety of scenarios and vehicles are usually sold in many markets, valuable simulation datasets from several countries seem indispensable. The paper describes how we combined the format of the Pre-Crash Matrix (PCM) with global accident data from IGLAD. The goal was to create harmonized pre-crash simulation files from real accidents coming from several countries/continents and to use them exemplarily within a field-of-view analysis for future ADAS. The basic data source is the IGLAD database. Within the "Initiative for the Global Harmonization of Accident Data" (IGLAD) traffic safety researchers from Europe, North America, South America, Asia, and Australia bring together road accident data in a harmonized dataset. Each single accident is reconstructed and contains relevant information like vehicle data, injury severities, anthropometric data, and scaled sketches. The PCM format describes the vehicle dynamics (trajectories) in a defined time before the collision. It is similar to the OpenX formats and contains relevant information about the road layout, markings, view obstacles, etc. The paper describes the process of creating IGLAD-PCM data, including the establishment of requirements, the harmonization of country-specific characteristics, and the definition of quality features. In 2022, IGLAD-PCM was released for the first time providing 200 pre-crash simulations from real accidents coming from seven countries on three continents. The paper presents descriptive statistics (e.g., accident characteristics, accident configurations, injury severities) from these cases and a comparison to the current IGLAD dataset (with approximately 9,400 accidents from 10 different countries). We provide an overview of relevant accident situations and country-specific characteristics for different regions of the world, e.g., US, India, China, Germany, France, Italy, etc. The paper also highlights the benefit of PCM data as one essential source for data-driven system development. During the concept definition of safety systems, pre-crash trajectory data is used to derive the required functional behavior. First, the relative positions and orientations of other traffic opponents are the basis for defining the necessary sensor field-of-view in given accident scenarios. Second, the speed distributions of ego and opponent serve as key performance indicators for the vehicle actuation system. Here, a relevant accident scenario is discussed, and relevant regional differences analyzed. The IGLAD-PCM forms a unique global dataset of pre-crash simulations based on reconstructed traffic accidents. Of course, case numbers are quite low at this early stage, but will increase annually by more than 200. Using the data can enhance the development of ADAS and AD functions and help to adjust systems towards country-specific characteristics. We have demonstrated that the PCM allows to harmonize pre-crash data from different countries and still can cover regional specifics. As the PCM is an open data format, various scenario descriptions can easily be generated, and existing development tool chains can

be supported. Thus, we believe that the PCM can serve as a standard format for data-driven system development and simulation.

PAPER NO.23-0328-O

Framework for a conflict typology including contributing factors for use in ADS safety evaluation

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Abstract
The aim of a successful conflict typology (also sometimes called crash or maneuver typology) is to group conflicts, some of which may result in a collision, into groups that have common characteristics influencing avoidability and potential severity. A conflict typology can be used in safety impact methodologies that analyze and predict the potential performance of a safety countermeasure or system within a set of defined crash modes. More generally, conflict typologies are used across many traffic safety analyses, including those related to evaluating the safety of an Automated Driving System (ADS). The objective of this paper was to describe a conflict typology including contributing factors that can be used in both Automated Driving System (ADS) and human driven vehicle safety evaluations. The proposed typology is comprised of 5 layers: (1) conflict partners - the types of the actors or objects involved in a conflict, (2) conflict group - the high-level description of a conflict, (3) conflict perspective - assigned to each actor based on their relative maneuvering, (4) the actor role - either the initiator of some surprising action that leads to a conflict or the responder, and (5) contributing factors - factors that in combination contributed to the conflict initiating or non-nominal response that caused the conflict. The main contribution of the proposed conflict typology and contributing factors are applicable conflicts from both retrospective crash data and near-crashes from a naturalistic driving study (NDS), and in the future ADS conflicts. The results also highlight potential difficulties reconciling differences in contributing factors observed in high-severity crash data having limited contributing factor information and those contributing factors observed in lower severity NDS data.

Government Status Report

PAPER NO.23-0347-O

Government Status Report - Sweden

MATTEO RIZZI
The Swedish Transport Administration, Sweden

Introduction

The Ministry of Infrastructure is responsible for road traffic safety in Sweden. However, due to the decentralized structure in Sweden, the Ministry works with budget, targets, and policy related issues while the operations are managed by the Swedish Transport Administration based on the directions from the Ministry. The Administration is responsible for the planning of the entire transport system with all modes of transport. It is also responsible for building and maintaining roads and railroads. The Swedish Transport Administration also has an overarching role in the development of long-term strategies and plans for all modes of transport in the transport system, contributing to the targets set up by the government for the transport sector. The Transport Administration holds responsibility for research within the fields of mobility, environment, and traffic safety. In-depth studies of each fatal crash in road traffic are also performed. The Transport Administration has the task of coordinating the road safety work in Sweden in collaboration with other stakeholders.

PAPER NO.23-0348-O

Government Status Report - Germany

MARKUS OESER
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Introduction

The total number of police registered road crashes has decreased by 4 percent since 2010 – from 2.4 to 2.3 million crashes in 2021. The number increased slightly between 2010 and 2019, with yearly changes between -2 and 5 percent. The highest value was reached in 2019 with 2.7 million road crashes. In 2020 and 2021, during the COVID-19 pandemic, the number of crashes steeply declined. The number of road crashes with personal injury has decreased by more than 10 % since 2010, resulting in 258,987 crashes with personal injury in 2021. Between 2010 and 2019, the number of personal injury crashes were relatively constant and stagnated around 300,000. This figure declined substantially in 2020 and 2021. According to provisional data for the first nine months of 2022, the number increased by more than 12 percent compared to the same period in 2021.

PAPER NO.23-0349-O

Government Status Report - Japan

KENJI SATO
Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT)

Introduction

Recent change of Traffic Accidents in Japan and the Government Targets In 2021, the number of fatalities (those who died within 24 hours) in traffic accidents in Japan was 2,636. This is a significant decrease from the previous year, down to about one-sixth of the 16,765 fatalities in 1970, when the number of fatalities peaked. Further, the numbers of accidents with casualties and the number of injuries have both decreased for 17 consecutive years since 2004, the year they were the worst. As a further step, Japan announced in March 2021 the 11th Master Plan for Traffic Safety (2021-2025), which sets a new goal of reducing the number of fatalities (those who died within 24 hours) to less than 2,000 and the number of serious injuries to less than 22,000 by 2025.

PAPER NO.23-0352-O

Government Status Report - Republic of Korea

JUN HYUNGPIL
Ministry of Land, Infrastructure and Transport

Introduction

The fatalities from road traffic accidents has been steadily decreased in Korea even though the number of vehicle registrations has been consistently increased over the past two decades through the Korean government's continuous efforts and the implementation of policies. The number of motor vehicle registrations increased by 35% in 2021 to about 2,491 thousand compared to that in 2011, but the fatalities due to traffic accidents decreased by half to 2,916 for the first time in 2021 to less than 3,000. The number of traffic fatalities per 100,000 people had also continued to decline since 2014, when it fell below 10 for the first time, and was halved to 5.6 in 2020, but as of 2019, it was 1.3 times higher than the OECD averaged of 5.2(6.5 in Korea) and ranked 29th out of 36 countries, therefore, it will be still requiring steady efforts.

Written Presentations

Active Safety Systems for Crash Avoidance: New Systems and Technologies

Chair: Jost Gail, Germany

Co-chair Genya Abe, Japan

PAPER NO.23-0164-W

Collision risk prediction utilizing road safety mirrors at blind intersections

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Abstract
Traffic accident number in Japan has been reduced year by year by growing ADAS technologies, revising the traffic rules, improving traffic environment. However, to realize the Vision Zero world which is zero traffic accidents, zero fatal accidents and zero injured seems far away currently. According to the traffic accident statistics data in Japan, more than half of accidents are occurring both in and around intersection areas [1]. The accident number at the intersections without traffic light is bigger than that with traffic light and has been seen at residential areas. To reduce the accident number at the intersection without traffic light, road safety mirrors have been installed in the intersection frequently [2]. In our study, using the front camera, which is one of ADAS sensors, even if it is a scene where the front camera cannot detect the object directly, our purpose is to reduce the collision risk by detecting the approaching vehicle using its image in road safety mirrors. In this paper, our collision avoidance method which consists of the 3 steps "Road safety mirror detection", "Object detection in the road safety mirror" and "Risk prediction" has been proposed. Especially, in road safety mirror detection, one countermeasure for false positives (FP) has been introduced. Our proposed method has been verified using front camera as a feasibility study, and the effectiveness of our proposed method has been demonstrated by experimental results on the public road. If the effectiveness of our proposed method is proven, since road safety mirrors will be utilized, which are a legacy infrastructure element, new investment at poor visibility intersection can be reduced which will be one of the merits of the proposed method. Also, the scalability of the system supporting not only Autonomous Driving (AD) systems of level 3 and higher, but also AD level 1 and 2 such as Advanced Driver-Assistance System (ADAS) will be an advantage.

PAPER NO.23-0225-W

Motorcycle state estimation using visual-inertial odometry

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Abstract
The authors propose a visual-inertial algorithm to estimate the kinematic states of a motorcycle traveling at high speeds along an extra-urban road. The approach comprises the following steps: First, a monocular camera takes video of the road ahead. Key features from sequential video frames of the road surface are extracted using the Harris corner detector. Matching features are identified using the Fast retina keypoint descriptor (FREAK). Next, correct the perspective warping of the feature locations by applying inverse perspective mapping. The motion of the transformed features is registered using the Singular Value Decomposition (SVD) variant of the Iterative Closest Point (ICP) algorithm. Finally, this measurement is combined with readings from inertial navigation system using a Kalman filter to produce a filtered estimate and correct integrator drift. The approach was validated using data from simulations of three scenarios created in BikeSim. In the first, the motorcycle performs a series of slaloms along a straight road at 50 km/h. In the second, the motorcycle navigates an S-shaped bend at 80 km/h. Lastly, the motorcycle performs a double-lane change across both lanes of a straight road at 110 km/h.

PAPER NO.23-0267-W

Automatic braking systems and blind spot as examples for new approaches in type approval regulations towards robust active safety systems

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Abstract
Traditional type approval regulations typically define a small set of very precisely defined test cases that act as an implicit requirements definition. Especially for active safety regulations, this leads to two major problems: Firstly, the implicit requirements are given only for a small number of operating points, and secondly, the prescribed test cases will typically happen only on an ideal test track. The newest type approval regulations, such as especially the new regulation on automated emergency braking systems for heavy vehicles, define requirements in a broader way over the whole operating range, in a certain range of parameters (such as: for centerline offsets between -20 and +20 cm) and leave provisions for technical services and/or market surveillance authorities to test in different, more realistic conditions. They also require the systems to not change strategy for cases out of the specifications (e.g.: for higher centerline offsets). As a consequence, this shifts the specification responsibility away from the regulator, towards the vehicle manufacturer. In this way, there is more freedom of design while still maintaining an appropriate level of safety. Also, the verification task is shifted towards the technical service, who

now has the responsibility to certify that the vehicle or system matches the given overall requirements by specific test cases. The market surveillance authority, however, has the freedom to check each and every aspect of the system against the requirements. Market surveillance therefore acts as a supervisor for the technical services. In the proposed paper, this new approach is presented in detail with the examples of Regulation 131-02 (automated emergency braking for heavy vehicles) and Regulation 151 (blind spot information systems). The new approach is described in detail with examples from the regulation, as well as the necessary equipment to perform the test runs in the case of Regulation 151: driving robots, robot-controlled bicycle dummy etc. Finally, proposals will be given on how to judge whether a system complies with the requirement to not change strategy; a topic that will become relevant in the coming years. The combination between broad requirements, not changing system strategy when out of the main operating range, vague defined test cases and market surveillance as a supervisor for technical services has the potential to make the type approval system fit for the future, and especially for all intelligent or flexible or programmable safety systems, on the one hand. On the other hand, technical services will have to adapt to the new responsibility and manufacturers to the new flexibility, since the regulation now does not exactly specify (overspecify?) a safety system, but more specifies the expected risk balance. It will certainly take some time and discussions until the new approach will fully unfold its potential.

Advances in Experimental and Mathematical Biomechanics and Human Injury Research

Chair: Matthew Craig, United States

Co-chair: Andre Eggers, Germany

PAPER NO.23-0090-W

Development of simulation-based thoracic injury probability function for elderly female occupants in side impact

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Abstract
Despite the high morbidity of elderly female car occupants in near side crashes, not many studies have been performed to predict the probability of injury to this population. A methodology to compensate for limitations in the amount of available biomechanical data is essential to derive an injury probability function for elderly females in near-side crashes. This study aims to establish a methodology to develop an injury probability function (IPF) by means of computational impact simulations using a human body model (HBM) that also includes variability in the material properties of human ribs. Focus was given to the prediction of rib fractures because of their high frequency in these near-side crash scenarios. Variation in the material properties of ribs from the 5th percentile elderly female population were applied to a HBM developed in a past study by applying eight different stress-strain curves. The variability in the prediction of rib fracture was accounted for using a probabilistic approach derived from the literature. This altered HBM was then scaled to the size and mass of subjects used in experimental studies. The predicted thoracic deflection was validated against both isolated lateral thoracic impacts and side impact sled tests which included a side-airbag and a pretensioning seatbelt. The probability of three or more rib fractures predicted by the probabilistic approach was used to validate the altered HBM against the previous PMHS experiments. Additional sled test simulations were conducted with reduced energy by decreasing the impact velocity and also by varying the use of the airbag. IPF predicting the probability of rib fractures was developed using the logistic regression and compared between the original dataset based on the PMHS sled tests and the modified dataset created by the additional simulations conducted at reduced severity. Chest deflection from the experimental thoracic impactor tests fell within the predicted range from the HBM simulations. In addition, chest deflection from the majority of the PMHS sled experiments that were simulated fell within the predicted range by the HBM. The probability of 3+ rib fractures was 100% for both the simulations and the experiments against realistic lateral sled tests. The IPF developed from the modified dataset predicted a significantly lower probability of rib fracture than that from the original dataset. This study qualitatively evaluated the idea of predicting injury probability for a specific population by representing the variability in the material properties of ribs to an HBM, specifically a near-side impact load case for 5th percentile elderly

female occupants. The effect of the geometry, such as the shape of the rib cage and rib thickness, was not reproduced in this study. The method used to derive the IPFs could also be done for other load cases and populations.

PAPER NO.23-0218-W

Probability functional evaluation of chest injury based on rib strain of human body model in frontal collision

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Abstract
This study examined the influence of chest restraint force on the chest injury probability of the human body model (HBM) in frontal collision. Total Human Model for Safety (THUMS) Version 4.1 AM50 was seated in the driver's seat of a finite element (FE) model represented a prototype midsize vehicle, and frontal collision simulations were performed. The probability of three or more rib fractures from 20YO to 80YO were predicted from simulated THUMS rib strain based on prior work. The probability increased with age and showed a tendency to rise sharply beginning around the 60YO in particular. The trend was shown to be similar to the probability predicted statistically from the NASS-CDS field accident data. Furthermore, a collision simulation was also conducted in which the restraint balance between the seatbelt and airbag was changed while keeping the same amount of forward excursion of the occupant. As a result, it was found that the probability of rib fracture was reduced by the combination of reducing the seatbelt force and increasing the initial restraint force of the airbag compared to a base specification. This was due to the improved ride-down efficiency and reduced seatbelt contact force, which reduced the strain on the upper ribs on the path of seatbelt.

PAPER NO.23-0261-W

Methodology to predict strain of bridging vein due to rotation of head

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Abstract
The brain stem can be damaged by the herniation of the brain tissue, potentially leading to fatality. Mass lesion could lead to fatality due to brain stem herniation, necessitating the prediction of the strain of the bridging veins (BVs). A number of trabecula forming a web-like structure of the sub-arachnoid space (SAS) may allow the assumption that the strain of the BVs correlates with that of the SAS. The objective of this study is to investigate the predictive capability of the strain in both the brain parenchyma (BP) and the SAS using a simplified physical model based on the CIBIC (Convolution of Impulse Response for Brain Injury Criterion) criterion proposed by the authors. A viscoelastic model consisting of a series of two sets of standard linear solids (SLSs) used in the CIBIC criterion (extended version of CIBIC; e:CIBIC) was developed to represent both the BP and the SAS. The Global Human Body Models Consortium (GHBMC) head/brain model was used to obtain the target response of the maximum principal strain (MPS) in the BP and the SAS. Three angular acceleration time histories to be used to optimize model parameters were determined by combining twenty sine waves with the

frequency ranging 10-200 Hz. The optimization of the spring and damping coefficients was performed by maximizing the CORA (CORrelation and Analysis) score for the time histories of the MPS in the BP and the SAS obtained from the GHBMC model. The optimized e:CIBIC was further assessed against a total of 256 sets of head rotational acceleration time histories obtained from frontal and side impacts and pedestrian impacts. The assessment was performed for the coefficient of determination of the correlation of the peak MPS with the GHBMC model along with the average value of the CORA score with the strain in both the BP and the SAS. The two-assessment metrics were also compared against the original CIBIC criterion for the brain strain to clarify improved prediction. The results of the performance assessment using the two metrics showed that e:CIBIC is capable of simulating the MPS in the BP with an accuracy similar to the original CIBIC. It was also found that the predictive capability of e:CIBIC for the MPS in the SAS is higher than that of the original CIBIC for the MPS in the BP. This study revealed that e:CIBIC with the two sets of the SLS in series is capable of predicting the strain in both the SAS and the BP simultaneously. The results obtained in this study is dependent upon the validity of the head/brain FE model used. The relationship between the strain of the SAS and the probability of BV failure needs to be further investigated.

PAPER NO.23-0262-W

Effect of seat belt use and airbags deployment on clinical outcomes in road traffic injury patients

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Abstract
Objective: Seat belts and airbags are safety devices designed to prevent road traffic injuries (RTI). They reduce fatal outcomes in patients with RTI. This study aimed to compare their effectiveness on the clinical outcomes of injured patients with RTI. Methods and Data sources: A multicenter cross-sectional study was conducted using the Emergency Department-based Injury In-depth Surveillance (EDIIS) registry between Jan 2011 and Dec 2020. All patients who sustained RTI in a vehicle with fewer than 10 seats were eligible. The target population was categorized into four groups: seat belt use and airbag deployment, seat belt uses only, airbag deployment only, and non-use. The primary outcome was intracranial injury. The secondary and tertiary outcomes were intensive care unit (ICU) admission and in-hospital mortality. The adjusted odds ratios (AORs) (95% confidence intervals [Cis]) of the safety device for related outcomes were calculated. Results: Among 82,262 patients, 13,929 (16.9%) were classified as seatbelt and airbag deployment; 47,123 (57.4%) as seatbelt use only; 1,820 (2.2%) as airbag deployment only; and 19,300 (23.5%) as the non-use group. Compared to the non-use group, AORs (95% CIs) for intracranial injury were 0.49 (0.42-0.56) in the seat belt use and airbag deployment groups, 0.39 (0.35-0.44) in the seat belt use only group, and 1.34 (1.08-1.67) in the airbag deployment only group. For in-hospital mortality, AORs were 0.29 (0.22-0.36) in the seat belt use and airbag deployment groups, 0.17 (0.14-0.21) in the seat belt use only group, and 1.74 (1.30-2.32) in the airbag deployment only group. Conclusion: Seat belt use had a significant preventive effect on intracranial injury and in-hospital mortality. The airbag deployment only group had worse outcomes. Public efforts to increase the proper use of safety devices are needed to reduce the RTI burden.

Safety Performance in Side Impact and Rollover Crashes

Chair: Thomas Belcher, Australia

Co-chair: Cecilia Sunnevång

PAPER NO.23-0220-W

A process to qualify a dummy model for the use in a virtual testing application

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Abstract
Finite element models of crash test dummies are extensively used throughout the development process of new cars. Each model has to go through various validation steps to meet user- or manufacturer-defined quality requirements. However, there is no standardized process established to qualify a model for a specific virtual testing application in general. A consumer rating organization intends to include virtual testing in their rating protocol. The pilot use case will be a far side impact using the WorldSID 50th. Virtual testing requires validated models of environment, restraint systems, and dummy but there is no standard available to determine the level of validation. This paper presents the work of an ACEA working group that developed a process to qualify WorldSID 50th dummy models for the use in a far side virtual testing application. The validation processes including validation data of different WorldSID 50th models were reviewed. A multi-level procedure covers general properties, fundamental dynamic behaviour, and application specific loadings. The assessment is based on pass/fail criteria as well as on objective rating methods. For final confirmation of the methodology four state of the art models and an artificially degraded model were used. The designed process comprises three levels that need to be passed. It is only valid for applications that have very similar load levels and load patterns (reference application). The first level checks general properties of the model against the hardware. It includes drawing conformity, external dimensions, range of motion of joints and mass properties. The second level checks the fundamental dynamic behaviour of the model. The model must pass all qualification requirements. The third level is derived from the reference application. It checks the performance of the most important components (body segments) and of the whole dummy. The boundary conditions of these checks are derived from the reference application. The relevant dummy signals are assessed by using the objective rating method defined in ISO/TS 18571 [3]. All signal scores are weighted and combined to a total rating. The assessed responses cover kinematics as well as internal loads. The model must achieve a minimum total rating score to pass this third level. A model is validated or qualified for the virtual testing application if all three levels are passed successfully. The far side application requires

a dynamic assessment of lumbar spine and neck. An additional sled test with a simplified vehicle environment evaluates the performance of the whole dummy model. The process offers the opportunity to assess the level of validation based on objective criteria. It can distinguish between different levels of validation. The process provides a method to qualify models for use in virtual testing based on objective parameters and rating schemes. It might become a standardized method to qualify the WorldSID 50th model as one component to introduce virtual testing.

Driving Automation Systems: Product Evolution; Safety Performance Assessment; and Real-World Deployment Challenges

Chairperson: Lori Summers, United States

Co-chair: Philippe Vezin, France

PAPER NO.23-0009-W

Validation of safety of the intended functionality for autonomous driving systems

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Abstract
International organisation for standardisation (ISO) safety of the intended functionality (SOTIF) is a relatively new standard that explains the verification mechanism for handling the intended functionality of a system as well as reasonable misuse of the system. It is required to practically implement the ISO SOTIF based validation of advanced driver assistance system (ADAS) and autonomous driving. The objective of this paper is to explain the strategy of virtual simulation and synthetic scenario creation for the validation of ISO SOTIF by taking intelligent speed assistance (ISA) as an example. ISO SOTIF suggested process flow is taken as a reference for the derivation of test strategy by keeping technical and functional safety requirements as the foundation for testing. Hazard identification and risk evaluation are implemented by following the defined standard procedure. Virtual simulation tools are utilized for ISO SOTIF synthetic scenario creation. A scenario elicitation approach is proposed with elaborate examples. A tree diagram with all possible and relevant static and dynamic actors is used for generating scenarios. 'One' or 'two-liner' pseudo scenarios are created first, which are then extended to full-fledged scenario details. These detailed scenarios are then implemented in a virtual simulation tool. The algorithm under test is exposed to these ISO SOTIF scenarios in a SIL / MIL / HIL environment, to evaluate how the system responds to such corner cases. It is also possible to generate additional ISO SOTIF scenarios from the input requirement specification. A few scenarios involving varying environmental conditions and hazard simulation instances are showcased in the paper. The paper explains through real-world examples, on how to do ISO SOTIF based testing for autonomous driving systems. A novel and implementation independent ISO SOTIF validation strategy is proposed in this paper. Use cases of residual risks deemed acceptable are also explained in the paper intuitively. ISO SOTIF validation strategy is studied with intuitive examples.

PAPER NO.23-0019-W

Identifying effective STPA control structures to characterize SOTIF areas 1,2,3, and 4 in automated vehicles

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Abstract
Developing and automated driving system (ADS) for an automated vehicle with a sufficient level of safety has turned out to be a much more difficult problem than anticipated by the industry. The challenges are multiple, for example the existence of a very large number of critical scenarios that would require testing vehicles for billions of miles to guarantee safety. In this paper we propose using System Theoretic Process Analysis, STPA, to characterize SOTIF areas 1, 2, 3, and 4 for SAE automation levels 3 and 4. A key challenge of STPA is the identification of an appropriate dynamic control structure that is efficient for the purpose at hand. We propose a control structure built around the decision hierarchy of strategical, tactical, and operational decisions, used to structure an ADS including its relations to the user, the environment, and all other traffic actors. More specifically, we show how an analysis based on this control structures at the strategic, tactical, and operational levels can be used to identify safe and unsafe control actions (UCAs) in known scenarios.

PAPER NO.23-0222-W

New assessment and testing methodology for vehicle type approval

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Abstract
In the context of a deep transformation in the automotive technology, specially with the wide introduction of ADAS functions and the first commercially available vehicle with automated functions, the classic type-approval procedures have been challenged and new methodologies are required. This paper describes the actions being carried out at different levels in order to tackle such challenge, as well as the main future trends with regards to the new assessment and testing methodologies for the type-approval of vehicles and their systems.

PAPER NO.23-0223-W

Cyber Security regulation – Practical application from a technical service point of view

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Abstract
It is widely known that the future of vehicles is a progressive evolution from conventional vehicles to fully autonomous/connected vehicles able to deal with all the situations on the road. This process starts with new ADAS (Advanced Driver Assistance Systems) functions that are gradually taking the control of the vehicle, in controlled situations, over the driver. Based on these new technologies, and always from the safety point of view, the European Union introduced the new General Safety Regulation. This regulation introduces advanced safety requirements that will become mandatory from 2022 for new vehicle types. One of the regulations that will cause a major impact on manufacturer's internal procedures, but also on the way in which Approval Authorities and Technical Services assess the system, is the regulation on Cyber Security, UN R155, that requires a new approach on how to validate and certify a system

PAPER NO.23-0294-W

Infrastructure connectivity to improve automated driving safety and information quality

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Abstract
All actors in road transport share and aim for the same mutual goal of safe, clean, and efficient Connected and Automated Driving (CAD). The aim of the research was to study how infrastructure connectivity improves Automated Vehicle (AV) safety in three selected motorway environment use cases of traffic jam, adverse weather and static/dynamic road works as well as quality indicators and requirements for the communication. Information priority with safety criticality in mind was assessed for the three actors of road works or (winter) maintenance operator, traffic manager and AV or Automated Driving System (ADS) developer. The results present Operational Domain Design (ODD) and local condition attributes information priority recommendations, ADS developers trust issues when using information via infrastructure communication, information quality recommendations as well as quality monitoring and management methods.

PAPER NO.23-0320-W

Transfer of reconstructed real-world accident data into scenario catalogues for the development and test of ADAS and ADS

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Abstract

The development and test of ADAS and Automated Driving Systems (ADS) require appropriate scenario data. To ensure the correct functionality and functional safety of such systems, an incredible amount of scenarios is necessary, containing normal, critical, and accident situations. These scenarios are usually used for virtual simulations. However, selected scenarios should be also physically tested on proving grounds. We developed a method to extract and describe maneuver-based and parameterized scenario catalogues for development and test of ADAS and ADS. We used real accident data from GIDAS (German In-Depth Accident Study). The focus was on car accidents in urban areas as the complexity in urban traffic is much higher than on highways (heterogeneous infrastructure, large variety of road users and behavior). At first, we clustered the (weighted) GIDAS accidents into different scenario groups. Then, we identified relevant parameters that are necessary for the description of the static and dynamic content of scenarios. The static content was extracted within the “environment analysis”. With this, the scenarios can be parameterized in terms of weather and lighting conditions, road layout (e.g., number of lanes, road width etc.). For the “dynamic analysis” we additionally used the GIDAS-PCM, containing reconstructed maneuvers, time- and location-resolved trajectories, accident sequences. Here, we generated statistical descriptions about speeds, trajectories, braking or steering maneuvers. Finally, some concrete example scenarios have been transferred to IPG CarMaker and OpenDRIVE / OpenSCENARIO files. With the developed method it is possible to transfer thousands of single traffic events and/or accidents with concrete characteristics into generic (test) scenarios. Within the project, scenario groups have been created using a maneuver-based approach. There are currently four main categories (following in one lane, crossing scenarios, turning scenarios, and lane change) which are further divided into sub-maneuver groups. The created parameter sets per scenario group contain several static and dynamic parameters. These distributions can be used by system engineers for virtual simulation runs (e.g., with randomly varied scenarios) but also by test engineers to parameterize physical tests. The approach was already tested with partners with demonstrations in physical tests. The implementation in concrete formats (IPG CarMaker, OpenX) showed that an automated transfer is not possible at the moment due to the complexity and multitude of implementation options. The developed method works for accident data out of GIDAS and was already tested in physical tests. However, the method was not yet applied to normal/critical situations, but this should also work with the presented static and dynamic parameter sets. Another limitation is the lack of automatic data transfer from the PCM format into the open ASAM standards (OpenX). As scenario catalogues are essential for virtual simulations as well as for physical tests of ADAS and AD functions the presented method helps to provide appropriate scenario data out of real-world accidents. The big advantage is that the created parameter sets and scenarios base on reconstructed accident data and can be used independently from certain software solution or format.

Advances in Crash Test Dummies, Instrumentation, and Data Analysis

Chair: Kevin Moorhouse, United States

Co-chair: Atsuhiro Konosu, Japan

PAPER NO.23-0199-W

THOR M50 and F05 submarining probability

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Abstract
During a crash test, submarining detection of the dummy is possible, either from film analysis or from measurements taken on the pelvis, especially when a force drop is observed in the Antero Superior Iliac Spine (ASIS). In the absence of submarining, it can sometimes be difficult to know if submarining was close to occur or if the configuration remained in a safe zone. In other words, was the situation really safe and stable with respect to submarining, or may small variations in test conditions lead to dramatic consequences? The objective of this study, carried out within the framework of the ABISUP project (Abdominal Injury and Submarining Prediction) was to determine a criterion for evaluating the submarining risk of occurrence for the THOR-M50 and THOR-F05 dummies. The ABISUP consortium was composed of Toyota Motor Europe (TME), University Gustave Eiffel (former IFSTTAR), University Claude Bernard Lyon 1, Transpolis, Faurecia, Humanetics, CEESAR, NHTSA and LAB PSA Renault (coordinator). The ASIS transducers allow the measurement of the forces applied on the iliac wings in the antero-posterior direction (Fx) as well as the moments along the medio-lateral axis (My). This latter provides an indication of the position of the belt relative to the ASIS. To establish more precisely the point of application of the force, a lever arm can be calculated by dividing the moment by the force. When the value of this lever arm approaches the upper edge of the sensor, the risk of submarining increases significantly. The lever arm, identified as a submarining criterion, was calculated for a whole series of sled tests carried out with the THOR-M50 and THOR-F05 dummies and compared with the occurrence of submarining. Risk curves were constructed using the lever arm. This paper provides a list of the tests performed, together with the maximum lever arm values calculated at the time of submarining. Risk curves are provided for both dummies. Very few cases were identified where the criterion was decreasing prior to the occurrence of submarining. Furthermore, the range of values obtained during submarining indicated that influential factors were not accounted for. These two limitations suggested that further investigations are needed, although the proposed criterion could give a first indication of the risk of submarining. A submarining criterion associated with risk of occurrence curves was proposed for the THOR-M50 ABISUP and THOR-F05 dummies. This criterion provides an aid to the analysis of dummy tests, which justifies its publication.

Human Factors Considerations for ADAS and ADS Technologies

Chair: Peter Burns, Canada

Co-chair: Stacy Balk, United States

PAPER NO.23-0061-W

Using accident location and interpretable risk to fine tune advanced rider assistance systems for motorcyclists

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Abstract
Motorcycle riding is a popular activity among riders of all ages and the number of motorcyclists is still increasing, despite safety issues being tricky to resolve for this mode of transport. Motorcycle rides constitute a type of vulnerable road user (VRU) since accidents tend to have more severe consequences for them due to the lack of physical protection for riders compared to passengers in passenger cars. Since this is a consequence of the very nature of the vehicle (being less heavy and more dynamic to move) potential safety interventions for motorcyclists need to be based on predictive indicators for unsafe situations and aim to avoid crashes altogether. This paper presents the results of ongoing work to improve motorcycle safety by finding causally interpretable risk characteristics based on accident data and motorcycle riding dynamics collected from test rides by individual riders. Dynamics data at known accident spots and representative data for individual rider-typical motions is associated to the type of historical accident in order to produce an estimate not only of risky areas and maneuvers, but also to associate types of riding dynamics that put the driver at risk. The relation to potential causes is essential for the inclusion of the resulting risk warnings in the activation of an Advanced Rider-Assistance System (ARAS), in order to produce a tailor-made response to the individual.

PAPER NO.23-0111-W

Spatial sound assistance system for 360-degree hazard awareness and safe driving

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Abstract
In everyday driving situations, potential sources of collisions can appear from any direction around the driver. Driver assistance systems have been highly desired to assist driver's hazard awareness from all directions in order to eliminate any kinds of traffic accident fatalities. The current study addressed whether simulated spatial sounds providing directional and hazard attribute cues for potential collisions can facilitate drivers' identification of traffic hazards and reduce collision incidence in the front and rear spaces. Forty-eight participants took part in our simulator experiment. We used a driving simulator (Honda Driving Simulator Type-DB Model S) to present them various traffic scenes with respect to the

hazardous direction and recorded their driving operations. Participants' gaze directions were also recorded with an eye tracker implemented on the simulator. To provide a directional cue of hazardous traffic participants, we presented spatial sounds on the directions of hazard participants, using two speakers implemented in a driver's seat. To provide an attribute cue for hazardous objects, we classified the traffic participants into four categories (vehicles, motorcycles, bicycles, pedestrians) and presented a corresponding imitative sound for each hazard object. Presentations of monaural sound without directional cue and signal sound without attribute cue were also used as a comparison basis. The current study observed a decrease in collision frequency and a significant reduction of onset time for pushing down the brake pedal for frontal hazard when spatialized signal sounds were presented compared with no HMI condition. A decrease in collision frequency with gazed hazards in the rear space was also observed when spatialized imitative and signal sound were presented relative to no HMI condition. The results lend to support our hypothesis that the directional cue can be effective for safer driving behaviors. On the other hand, improvements were not obtained when attribute cues were presented for both behavioral responses or the collision frequency. Significant facilitations were found in gaze responses and decelerate operations especially for rear hazards, but they did not result in a reduction of collision frequency. Although the well-known front-rear ambiguity was confirmed in stationary sound localization, the current study observed the effectiveness of directional cue in reducing the collision frequency. It is possible that movements of spatial sound sources with hazard traffic participants could improve the resolution of front-rear sound localization. The influence of front-rear ambiguity might have also been reduced by extended spatial attention from the rear to the front under the auditory directional cue towards the rear space. The attribute cue did not provide any effective improvements in the current study. However, we believe that in certain traffic situations where the type of hazards involved could represent more important information to the driver, the effects of attribute cue could reveal a potentially larger impact. Our observations of the effective assistance of directional cue in spatial sound provide important references in terms of human factors for considering informative HMI that facilitates hazard awareness from all directions and help safer driving behaviors.

PAPER NO.23-0196-W

Novel interfaces that enhance a driver's ability to perceive forward collision risks

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Abstract
Forward Collision Warning (FCW) systems that alert a driver about the risk of rear-end collisions can contribute to a reduction of traffic accidents caused by human errors. Typically, FCWs create alerts that appear late when the risk is already high and are of binary nature, i.e., either in an alerting state during high risk or not producing any alert at lower risks. The choice at what risk level to start alerting in a binary manner is subject to a tradeoff between how much time an alert gives the driver to react and how necessary the alert appears to the driver. Our goal is to circumvent this limitation of classical binary FCWs to allow drivers to perceive developing risks early and in an intuitive manner and, accordingly, better avert developing risks with foresight. To that end, we propose a new system that assesses

potentially hazardous situations in real time and continuously outputs a signal that alters its strength depending on the risk level. Here we report a study on the effect of variations of the proposed system on driving behavior and user acceptance. The experiment was carried out in a driving simulator equipped with prototypes of visual, auditory, and tactile human-machine interfaces (HMIs). The participants performed driving tasks in two different driving scenarios. The subjective ratings of system acceptance were assessed with questionnaires on two dimensions, a usefulness scale, and an affective satisfaction scale. The results indicate that, compared to an existing FCW system, all HMIs reduced driver reaction times and the visual HMI showed positive average scores of both usefulness and satisfaction in the driving scenario with high and medium collision risk. On the other hand, there was no HMI that achieved a good balance between the effect on driving safety and system acceptance in the scenario with lower criticality. These results suggest that the proposed notification system can improve driving safety and be perceived as subjectively acceptable in situations with high and medium collision risk despite the early signal. This makes it a promising approach for circumventing the tradeoff between notification timing and risk perception. To address system effects on driving safety in situations with lower risk, further development iterations and long-term evaluations in a variety of traffic situations may be required.

PAPER NO.23-0226-W

Monitoring system of driver's health condition to prevent traffic collision caused by health condition risks and cognitive decline

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Abstract
Driving risks for elderly drivers are known to be associated with age-related diseases and cognitive decline. Furthermore, daily physical conditions such as drowsiness and fatigue also affect cognitive function and driving behavior. Therefore, in order to prevent traffic accidents involving elderly drivers, it is important to provide personal driver support that takes into consideration the effects of daily physical conditions. In this study, we explored the feasibility of a monitoring system utilizing daily physical condition data that can be assessed by wearable devices on elderly subjects. Focusing on the sleep characteristics that affect the physical condition, we found the relationship between attention function and driving behavior. As a result of the attention function evaluation by the Attention Network Test, irregular sleep time was associated with greater variation in attention function, suggesting that people with irregular sleep time had more unstable attention function. In addition, as a result of the driving behavior evaluation by the Driving Simulator Test, greater variation of the attention function was

associated with the larger steering entropy and maximum acceleration of the car. These results suggest that instability of the attention function may cause the rough driving. Combined with the results of relationship between variability of sleep time and attention function, these results suggest that people with irregular sleep time are more likely to engage in rough steering and pedal operation, which may lead to sudden steering and acceleration that can cause accidents. It is also known that elderly people have problems in falling asleep and maintaining sleep than younger people. In order to eliminate traffic accidents involving elderly drivers, a support system that incorporates information on sleep habits will become more important. In recent years, the use of wearable devices has made it possible to objectively acquire daily activity and sleep data, and it is expected to utilize a wider range of daily activity data. In the future, we are planning to acquire actual vehicle driving data to understand the relationship between physical condition and driving behavior in more detail.

PAPER NO.23-0229-W

The impact on driving performance from graded cognitive load with visuo-spatial and phonological processing of visual and auditory input

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Abstract
The majority of human factors in traffic accidents are the result of cognitive error. Errors of cognition are produced by the relationship of the cognitive load of the traffic environment and vehicle interior environment with the driver's information processing. The cognitive load while driving is made up of the loads from the sense organs of sight and of hearing. The resources used for processing of visuo-spatial information and phonological information are independent, and it has been proposed that each processing resource has its capacity. It has been reported in previous research that when the cognitive load increases, driving becomes unstable. On the other hand, it has been reported in other research that when the cognitive load becomes high, driving becomes stable. Considering that cognitive load has been reported as an influence that both increases and decreases performance, it is conceivable that performance varies with the type and magnitude of the cognitive load from each category of information, and that a moderate degree of load exists under which performance reaches its highest level. For this paper, a driving simulator was used to study the influence on driving performance caused by graded cognitive load from the visuo-spatial process and phonological process of input from the sense of sight and sense of hearing. In testing, drivers drove on a course with a series of gentle curves while responding to n-back tasks that use visual/visuo-spatial process and auditory/phonological process. The result was that in the case of n-back tasks using visual/visuo-spatial processing, driving performance was diminished as the difficulty of the n-back task increased. However, in the case of n-back tasks using auditory/phonological processing, driving performance did not change when the difficulty of the n-back task increased. Also, although the load under which performance reaches its highest level was not determined, it was confirmed that auditory n-back tasks do have loads under which performance tends not to change. This is thought to be because the visual/visuo-spatial process used in driving and other information processes tend not to influence each other, while the same information processes did interfere with each other. The conclusion is that, in order to maintain stable driving performance, it can be considered important that the cognitive load on the driver does not interfere with the processing of visual/visuo-spatial information while driving.

PAPER NO.23-0279-W

Non-invasive blood alcohol detection using near infrared spectroscopy and chemometric techniques

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Abstract

An updated research, development, and manufacturing of a novel passive contact-based Near-Infrared Alcohol Sensor (NIR-AS) for non-invasively measuring Blood Alcohol Concentration (BAC) in human subjects and thus, provides potential for application in support of the new US Infrastructure Investment and Jobs Act bill, section 24220, signed into law on 11/15/2021 once it is enforced. Alcohol-impaired driving remains a global problem. According to the most recent published report in 2020, U.S. motor vehicle crashes, alcohol-impaired fatalities represent over 30% of the total fatalities; a 14% increase over 2019 and a 29% increase relative to Vehicle Miles Traveled (VMT). The Infrastructure Investment and Jobs Act bill, section 24220, cites statistics on the societal and human costs of alcohol impaired driving and specified intent to make BAC sensors standard equipment in all new U.S. cars in the future. The NIR-AS design and process for analyzing performance in quantifying BAC builds on the R&D carried out in support of the Driver Alcohol Detection System for Safety (DADSS). The published research from DADSS provides valuable technical guidance and performance targets for BAC sensing in motor vehicles. Blood testing is the established gold standard for measuring driver BAC. Although blood testing is the most accurate reference for comparison against NIR-AS (or any new BAC sensor), it is highly invasive, time consuming, and cost prohibitive. Breathalyzers are well established sensors for estimating BAC, however, they also have performance limitations in practical, real-life conditions. Even so, based on published research, including DADSS, breathalyzers can provide an appropriate surrogate reference under controlled clinical and analysis conditions, for analyzing the performance of any new BAC sensor. The NIR-AS sensor described in this paper targets the passive detection performance requirements specified by DADSS. An alcohol dosing Design of Experiments (DOE) was carried out using a set of Near Infrared Alcohol Sensor (NIR-AS) prototypes with human subjects using a repeat low level alcohol dosing protocol. BAC reference data was also collected using several law enforcement grade and commercial breath analyzers. NIR-AS spectra were processed and analyzed using commercially available and proprietary software. The DOE resultant data was analyzed using commercially available software packages to produce chemometric models. The paper presents model performance statistics including root mean square standard error of calibration (RMSEC), root mean square standard error of prediction (RMSEP), and square of the correlation coefficient, R2, for the NIR-AS calibration. A global model employing multiple sensors was tested across the same DOE and performance statistics are presented. Using NIR-AS, it is shown that BAC can be measured at varying concentrations of alcohol within the human body, including low alcohol dosing levels. Further improvements on the NIR-AS design and function will also be presented. Based on our results, there is significant correlation between BAC breathalyzer and NIR measurements at low dosing levels. The results demonstrate a high correlation between NIR-AS spectra and reference breathalyzers and achieve low RMSEP, RMSEC, and RMSECV. NIR-AS, with continued development, can be a potential tool for assessing driver alcohol impairment in support of ADAS and/or ADS countermeasures.

PAPER NO.23-0291-W

Driver alcohol Detection System for Safety (DADSS) – risk-based approach to alcohol sensing outcomes modeling/Human Subject Testing (HST) /Human Subject Driving (HSD)/Field Operational Testing (FOT)

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Abstract
A large number of fatal crashes every year in the United States is caused by alcohol-impaired drivers The Automotive Coalition for Traffic Safety and the National Highway Traffic Safety Administration entered into a research agreement to explore the feasibility of developing a passive in-vehicle alcohol detection system, known as the Driver Alcohol Detection System for Safety, with the goal of significantly reducing the incidence of drunk driving. This paper presents an analysis of the net benefit that could be achieved by installing such technology in the passenger vehicle fleet, using a risk-based approach to model potential outcomes. This outcomes model will calculate the net benefit of, and the public policy challenges associated with, more widespread use of non-invasive technology. Such an approach can be beneficial in determining the merits of the new technology and could be used to help guide public policy with respect to implementation. Furthermore, the technical data can be used to further refine the Driver Alcohol Detection System for Safety performance specifications.

PAPER NO.23-0316-W

Characterisation of drowsy driver behaviour and drowsiness baseline data set in a dynamic driving simulator

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Abstract
Drowsiness is one of the mean causes of road accidents, accounting for 1,200 fatalities and 76,000 injuries per year, according to several authors [1]. This transitional state between awake state and the sleep state behaves physiological symptoms such as yawning, loss of neck muscle tone, pupillary constriction, ptosis, decreased attention, psychomotor and cognitive performance [2]. The purpose of the present study is to observe the effects of monotonous driving on long journeys on driver behaviour

in order to develop driver monitoring systems capable of detecting symptoms of drowsiness and thus be able to reduce its negative impact on the road. The experiment is conducted on a dynamic driving simulator, where conditions were configurated according to the aim of having a monotonous environment free from any distraction. Participants drive for 90 minutes and every 5 minutes the experimenter ask about their level of KSS, using the Karolinska Sleepiness Scale, a standardized instrument that measures the participant's subjective level of drowsiness. Moreover, participants are instrumented to collect physiological data (ECG, EEG, EDA, and respiratory rate) and an eye-tracking system monitors other drowsiness behaviours such as blinking or yawning. The test finish when 90 minutes passed, or participants reached an advanced level of drowsiness on the Karolinska Sleepiness Scale (KSS). The study consists of two phases of testing. The first phase, with 10 participants, aims to validate the test method for both sleep induction and the integrated data collection setup. The second loop of testing, planned in January 2023, will involve 20 participants with different age and gender representation and aim to try to define the sleep behaviour patterns in relation to the different levels defined by KSS. In this paper we present the preliminary results of first phase of testing.

PAPER NO.23-0318-W

Exploring driver distraction in adaptation to lower levels of automation: Older adult driver comparisons

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Abstract
This project examined how middle-aged and older drivers adapt to the use of Level 2 (L2) advanced driver assistance system (ADAS) features (i.e., the system controls lateral and longitudinal motion). Data were drawn from two naturalistic driving studies (NDS). In the L2 NDS study, 82 participants were recruited from the Washington, DC metro area and drove L2 vehicles for four weeks. A second NDS was conducted with 14 older adults (Older Driver NDS). In the Older Driver NDS, participants aged 70-79 drove L2 vehicles for six weeks. Speed setting above the speed limit was significantly more common when L2 was active than when it was available-but-inactive in the Older Driver NDS dataset. Older adults had shorter off-road glances than middle-aged drivers in the L2 NDS when L2 was available, regardless of L2 engagement status. Older drivers showed shorter glance durations overall. Older adult drivers had fewer glances away from the forward roadway and were significantly less likely to engage in secondary tasks when L2 was active. Evidence of older adult driver adaptation to L2 systems is seen most predominantly in the speed selection.

PAPER NO.23-0322-W

Exploring driver adaptation to Lower Levels of Automation (L2) using existing naturalistic driving data

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Abstract
This project evaluated driver adaptation in the hours, days, and months after the introduction of level 2 (L2) advanced driver assistance system features (i.e., the system controls lateral and longitudinal motion) into the driving task. Two existing naturalistic driving study databases were analyzed: the L2 Naturalistic Driving Study and the Virginia Connected Corridor Elite Naturalistic Driving Study. To best assess driver adaptation, the analysis identified three phases of exposure time to L2 features: Phase 1 (immediate, under 3 hours), Phase 2 (short term, 3 to 8 hours), and Phase 3 (long term, over 8 hours). The results suggested that driver adaptation was present for high-risk secondary tasks, as significant increases in engagement were observed over the three phases, but only when L2 features were active. Additionally, drivers set their vehicle speed above the speed limit more frequently between Phases 1 and 2, with higher speeds set when L2 features were active as opposed to when they were inactive. While these results may be concerning, research efforts at a larger scale are needed to determine if there is increased crash risk associated with speeding and high-risk secondary task engagement with L2 features active. We also need to better understand the impact of traffic/roadway conditions on speed selection with L2 systems.

PAPER NO.23-0342-W

Role of system status information in the development of trust and mental models in automated driving systems

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Abstract
Research Question/Objective: In transportation, mental models are essential to mobility and safety because drivers rely on them to understand how to interact properly with their vehicles, the transportation infrastructure, and the environment. Poor performance and errors can occur when a driver acts in accordance with inaccurate mental models. Mismatches between mental models and actual experiences can also lead to reduced trust when, for example, the system with which they interact fails to perform to their expectations. The current study examined differing information types regarding Automated Driving System (ADS) capabilities and limitations on development of mental models and trust while using simulated Level 3 (L3) systems and a “dual model” use case of Level 4 (L4) systems (i.e., the vehicle can be both manually operated and can be controlled by ADS in certain ODDs).

Method and Data Sources: 48 females and males between the ages of 25 and 65 had four exposures to L3 and L4 systems in a driving simulator. Participants used either a basic human machine interface (HMI) that indicated the ADS was active, or they used an enhanced HMI that provided additional information indicating when the system was experiencing limitations (e.g., regarding detection of degraded lane lines). Participants used a simulated Level 3 system for two exposures and a simulated Level 4 system for two exposures. The acquisition and development of mental models and trust were assessed with standardized questionnaires. Results: Regardless of exposure to each system over time, participants' mental models were more accurate for the simulated Level 4 system compared to the simulated Level 3 system and trust was greater for the simulated Level 4 system during the second exposure. Discussion and Limitations: This paper summarizes research an ongoing project, and a final report will be published at a later date. Results of the current work suggests that the acquisition and development of mental models and trust can be differentially impacted by how well the ADS performs and the level of automation. However, because the study relied on simulated Level 3 and Level 4 systems, the results may not represent real world implementations of the technology.

Consumer-Focused Approaches to Promote Vehicle Safety in the Automotive Market

Chair: Andre Seeck, Germany

Co-chair: Michiel van Ratingen, Belgium

PAPER NO.23-0258-W

Euro NCAP Rescue – Tertiary safety assessment

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Abstract
The European New Car Assessment Programme (Euro NCAP) has until recently concentrated on passive and active safety assessments. The organisation realised the need to address post-crash (tertiary) safety to improve the outcomes for those involved in vehicle crashes. In 2018 the Rescue working group was created and is supported by Euro NCAP's members, affiliated members and CTIF (International Association of Fire & Rescue Services). Industry also contributes with representatives from both the European Automobile Manufacturers Association (ACEA) and the European Association of Automotive Suppliers (CLEPA). The first Rescue test and assessment protocol was published in early 2019 and from the start of 2020 the topic of Rescue was included in the overall star rating as part of the adult scoring area. The assessment for Rescue is divided into 3 areas: Rescue – Rescue Sheets for the vehicle. Extrication - Unlocking of automatic door locking, door opening forces & seat belt unbuckling forces. Safety - Advanced eCall and Multi Collision Brake technology. In June 2020 Euro NCAP launched the "Rescue App" available for Android and iOS users with support from CTIF and the car manufacturers. This free app gives access to ISO 17840 compliant rescue sheets for hundreds of vehicle models and is constantly updated. Rescue services require detailed but easily understood information regarding the construction of individual vehicles to extricate trapped occupants as quickly and safely (for occupants and rescuers) as possible. This is becoming more important as vehicles become stronger, use different sources of power, and are equipped with increasing numbers of safety devices and new features such as electric door handles. For this reason, Euro NCAP has planned further updates of requirements and will add new ones to be implemented in 2023 and 2026, including requirements related to vehicle submergence and battery safety.

PAPER NO.23-0289-W

Development of a direct driver status monitoring assessment scheme

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Abstract

Analysis of naturalistic driving behaviour shows that engaging in visually demanding tasks and driving while drowsy results in higher near crash/crash risk. In addition, increasingly busy global traffic environments, the trend of vehicles being marketed on their connectivity and ever growing screens loaded with potentially distracting features, it becomes necessary for technology to encourage safe and attentive driving. Indirect monitoring systems have featured in vehicles for many years, identifying decaying control accuracy and advising the driver to take a break. A new development is direct driver status monitoring, typically using infrared camera technology to directly observe the driver's facial orientation, glance behaviour and eyelid aperture, enabling real time assessment of attentiveness. The aim of this research was to develop a test and assessment protocol grounded in real world data to guide the development and evaluate, in an objective and repeatable format, the performance of systems targeted at addressing the most common attributes of the inattentive driver problem to the benefit of road safety. A test and assessment scheme were developed that was proven to successfully enable the differentiation of pioneer direct driver status monitoring systems for inattention in the form of distraction, fatigue, and unresponsive driver. This has been adopted by Euro NCAP to guide the development of new systems entering the market. providing consumers with independent information supporting them making safer vehicle choices. Parameters for warning and intervention strategies were carefully considered to balance the desire for effectiveness in test scenarios with driver acceptance to achieve real world effectiveness. The testing requirements for driver status monitoring systems were novel in that the test driver is necessarily the test subject triggering the system. Therefore, research testing was conducted to refine the driver glance behaviours, necessary measures, and associated instrumentation to deliver repeatable testing. This initial iteration of the scheme was guided by nascent market technology enabling direct monitoring of the drivers face and eyes, and to a certain extent, seating posture. Future technical innovations will see the monitoring scope increase from that of the driver's face to the cabin of the vehicle, and it is recommended that a future generation of the scheme take full advantage of the opportunities of understanding not only the driver attentiveness, but their seating position and posture, hand position and occupancy etc. as well as the presence and attributes other passengers in the vehicle.

New and Improved Field Data Collection, Analysis, and Benefits Assessment Methods

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Field study of the level 2 super cruise using telematics data

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Abstract

Over-the-air data was captured from thousands of vehicles in natural driving across the United States to evaluate the GM production Level 2 (L2) Super Cruise, Front Pedestrian Braking, and camera-based Adaptive Cruise Control (ACC) features. This research mainly focused on how often, when, and where customers used Super Cruise, and examined safety surrogate measures. Super Cruise allows hands-free driving on compatible GPS-mapped roads, which, at the time, included only limited-access freeways and trunk roads. Super Cruise uses a driver monitoring system that includes a face camera and a series of escalating alerts to prompt the driver to pay close attention to the road ahead and to take steering control when takeover requests are issued. Two Cadillac fleets were used, including 2642 model year 2018/2019 vehicles equipped with Super Cruise, as well as 1196 similar fusion ACC-equipped model year 2017-2019 vehicles. During the 14-month data collection period the Super Cruise fleet accumulated 24M miles and the ACC-only fleet accumulated nearly 14M miles. Telematics data was retrieved each ignition cycle using GM's OnStar system, including Super Cruise state changes, harder braking events, and GPS traces. This research examined contextual influences on Super Cruise use and compared crashes, braking levels, and vehicle speeds across Super Cruise, ACC, and manual driving modes. Super Cruise engagements occurred on 72% of equipped vehicles, totaling 1.7M miles of engaged driving. Engagements accounted for 18% of the driven distance on system compatible roadways, with a median engagement duration of 2.6 minutes. Relative to manual driving, Super Cruise and ACC were generally used when there is less surrounding traffic (i.e., free-flow, nighttime) and the roadway environment is less complex (e.g., rural, non-rain, non-curved roads). Drivers frequently interacted with Super Cruise via steering overrides (e.g., to change lanes), receiving and responding to driver attention prompts, and responding to takeover requests. Approximately 57% of Super Cruise engagements included driver attention reminder(s), with 91% of such reminders resolved without further escalating alerts. Takeover request results indicated 58% were due to Operational Design Domain limits, and 24% were driver-attention related. No Advanced Automatic Crash Notification events were observed on Super Cruise compatible roads for either the Super Cruise or the comparison ACC fleet. Modeling analyses under matched driving conditions indicated that harder braking (exceeding 2.6 m/s2) events were 1.7 times more likely during ACC/manual driving than during Super Cruise driving, and that median and top speeds during Super Cruise engagements did not exceed those of ACC/manual driving during free-flow traffic conditions, which was found to be the dominant use case for Super Cruise. Together with the relatively modest median Super Cruise engagement duration of 2.6 minutes, these findings

suggest drivers use Super Cruise selectively, have generally fewer harder braking events when Super Cruise is engaged, and appear comfortable with the interactive Super Cruise feature. Front Pedestrian Braking automatic braking events occurred approximately once per 590,000 miles, mostly on lower-speed private and residential roads. For the camera-based ACC feature, results indicated usage and the incidence of harder braking levels are similar to fusion-based ACC.

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METI Ministry of Economy, Trade and Industry

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