Pedestrian Accident situations involving vehicles at low speeds in Japan

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Abstract
In Japan, there were 3,694 traffic deaths in 2017 and the highest proportion of these was pedestrians (1,347, 37%). Safety technologies, such as automated emergency braking systems that detect pedestrians, would be an important role for vehicles travelling on roads. To reduce pedestrian fatalities more, further countermeasures would be necessary to introduce as active safety technologies to vehicle maneuver, such as taking off from standstill or backing. For making a new safety rule regarding such technologies, current accident situations of vehicles at low speed manoeuvres should be investigated. This study aimed to clarify the features of traffic accidents involving fatal pedestrians, focusing on low travel vehicle speeds (10 km/h or less), day and night, road types (intersections with or without traffic lights, near intersections, and straight roads), impact locations of vehicles, and vehicle maneuver.

We used macro vehicle–pedestrian accident data from the Japanese Institute for Traffic Accident Research and Data Analysis (ITARDA) database. Vehicle types were classified into nine categories: gross vehicle weight [GVW] ≥ 7.5 × 103 kg (7.5 t) trucks, GVW < 7.5 × 103 kg (7.5 t) trucks, buses, box vans, minivans, SUVs, sedans, light passenger vehicles and light cargo vans.

The results revealed that the traffic accidents at 10 km/h or less occurred more often at day time than at night time for all vehicle types. The results also showed that the road types, impact locations of vehicles and vehicle maneuver of the higher frequency were different among the vehicles types at 10 km/h or less at day time. The front-left area of vehicles was the higher-frequent impact location for GVW ≥ 7.5 t trucks (28%), buses (38%) and box vans (38%) than other types of vehicles. To start moving was the higher-frequent vehicle maneuver for GVW ≥ 7.5 t trucks (50%), while to turn right was the higher-frequent for GVW < 7.5 t trucks (42%), sedans (44%), box vans (50%), minivans (32%), SUVs (45%), light passenger vehicles (45%) and light cargo vans (32%).

The findings from this study could be useful in developing new technologies to improve pedestrian safety, such as alert devices for vehicle drivers and wireless communication systems between pedestrians and vehicle drivers.
To reduce pedestrian fatalities in all over the world, the results also suggested that new vehicle safety rules at low speed manoeuvres shall be established as in UN regulations for certain vehicle categories including commercial vehicles.

**Paper No.19-0016-O**

**PEER REVIEW**

**THE POTENTIAL OF VEHICLE AND ROAD INFRASTRUCTURE INTERVENTIONS IN FATAL BICYCLIST ACCIDENTS ON SWEDISH ROADS – WHAT CAN IN-DEPTH STUDIES TELL US?**

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**Abstract**

Bicyclist fatalities account for approximately 8% of all road fatalities in the EU. The objective was to describe the characteristics of fatal crashes with bicyclists on Swedish roads and to investigate the potential of different vehicle and infrastructure interventions to prevent them. The study has a holistic approach to provide road authorities and vehicle manufacturers with important recommendations for future priorities.

The Swedish Transport Administration (STA) in-depth database of fatal crashes was used to study killed bicyclists on rural roads (n=76, 2006-2015) and urban roads (n=108, 2009-2016). The database consists of information from the police, medical journals, autopsy, accident analysis performed by the Swedish Transport administration and witness statements etc. The potentials of several vehicle and infrastructure safety interventions were determined retrospectively for each case by analyzing a chain of events leading to the fatality. The future potential of vehicle safety countermeasures was analyzed based on prognoses on implementation rates of several vehicle safety technologies in the Swedish vehicle fleet.

The most common accident scenarios on rural roads were that the bicyclist was struck while cycling along and at the side of the road. On urban roads the majority occurred in crossing. Most accidents involved a passenger car followed by a heavy truck. The majority of the fatal accidents occurred under daylight conditions (73%). Forensic reports suggested that 47% of the non-helmeted bicyclists would have survived with a helmet. It was estimated that a large proportion of the fatal accidents could be addressed by advanced vehicle safety technologies, especially Autonomous Emergency Braking (AEB) and Autonomous Emergency Steering (AES) with bicyclist detection. With regard to interventions in the road infrastructure, separated paths for bicyclists and bicyclist crossings with speed calming measures were found to have the largest safety potentials. In total 89% of the killed bicyclists could potentially be prevented.

The study included all fatally injured bicyclists for the accident years studied. However, the accident years included varied for the fatalities occurring on rural and urban roads. The potential of improving car crash safety for pedestrians and bicyclists (such as protective front-end design) was not included in the analysis. A further limitation of this method is that it may be difficult to take future trends into account. An example could be the steadily increased popularity of e-bikes.

It was found that 89% of the killed bicyclists could potentially be prevented by existing countermeasures. It was estimated that it will take a long time until the advanced and potentially effective vehicle safety technologies will be widely spread to reach the 89% reduction, which shows the importance of speeding up the implementation rate. A fast introduction of effective interventions in the road infrastructure is also necessary, preferably using a plan for prioritization.

**Paper No.19-0277-O**

**Improving the Effectiveness of Active Safety Systems to Significantly Reduce Accidents with Vulnerable Road Users - The Project Prospect (Proactive Safety for Pedestrians and Cyclists)**

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26ESV/Program Book
Abstract
Accidents involving Vulnerable Road Users (VRU) are still a very significant issue for road safety. ‘PROactive Safety for Pedestrians and Cyclists’ is a collaborative research project funded by the European Commission. The objective of PROSPECT was to improve significantly the effectiveness of active VRU safety systems compared to those currently on the market by: (i) expanding the scope of urban scenarios addressed (ii) improving the overall Autonomous Emergency Braking (AEB) and Autonomous Emergency Steering (AES) system performance (iii) proposing extensive validation methodologies for consumer testing, simulation and acceptance studies with tools for testing. Concepts for sensors and control systems were shown in three vehicle demonstrators and a mobile driving simulator and tested with novel VRU dummy specimen. Those systems address the well-known barriers of current AEB systems such as limited sensors field-of-view, fuzzy path prediction, unreliable intent recognition and slow reaction times for the actuation. User acceptance tests with the participation of drivers were also crucial in PROSPECT for the success of all active safety systems. Driving simulator studies were then used in a controlled and repeatable environment for the collection of data regarding the interaction between the driver and the safety function. Finally, project consortium implemented a novel benefit estimation methodology that includes an assessment of the combined effect of active and passive safety measures of PROSPECT-like systems.

Paper No.19-0048-O PEER REVIEW
Forward Collision Warning Based on a Driver Model to Increase Drivers' Acceptance
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Research
Systems that can warn the driver of a possible collision with a VRU have significant safety benefits. However, incorrect warning times can have adverse effects on the driver. If the warning is too late, drivers might not be able to react; if the warning is too early, drivers can become annoyed and might turn off the system. Currently, there are no methods to determine the right timing for a warning to achieve high effectiveness and acceptance by the driver. The aim of this study is to validate a driver model as the basis for selecting appropriate warning times, specifically solving the question: “Can a model describing the behaviour of drivers interacting with VRUs be used to develop well-accepted warnings?”.

Methods
The present study was conducted as part of the European research project ‘PROSPECT’. The goal was to determine drivers’ acceptance towards Forward Collision Warnings (FCWs) based on the comfort boundary (CB) model developed during a previous project. The CB model states that the driver’s braking time, i.e. comfort boundary, when encountering a cyclist in a crossing scenario depends on the moment the cyclist appears before reaching the intersection (time to arrival; TTA). This model was used as the basis for the warning times selected for the present study. Two warnings were selected: one inside
the CB and one outside the CB. The scenario tested was a cyclist crossing scenario with a TTA=4 seconds. The timing of the warning inside the CB was at the time to collision (TTC) 2.6 seconds (asymptotic value of the model at TTA=4secs) and TTC=1.7 seconds for the warning outside the CB (value below the lower 95% value of the model at TTA=4secs). Thirty-one participants took part in the test track study (between subject design where warning time was the independent variable). Participants were informed that they could brake any moment they felt the scenario became critical after the warning was issued. At the end of the study, participants completed an acceptance survey.

Results
Participants reacted faster to the warning outside the CB compared to the warning inside the CB. This confirms that the CB model represents the criticality felt by the driver. Participants also rated more disturbing the warning inside the CB and they had a higher acceptance of the system with the warning outside the CB. The above results confirm the possibility to develop well-accepted warnings based on driver models.

Discussion
Similar to other published studies’ results, drivers prefer warning times that resembles their driving behaviour. It is important to consider that the study tested only one scenario. Also, in this study participants were aware of the appearance of the cyclist and the warning. A further investigation should be conducted to determine the acceptance of distracted drivers.

Conclusion
The results of the present study are an important step to ensure the protection of VRUs. Developing systems that are better accepted by drivers can reduce the risk of drivers turning off these systems. Therefore, this study is of vast importance for researchers interested in ESV’s conference Track A.

**Paper No.19-0340-O**

**Detection of Cyclist and Pedestrians Around Heavy Commercial Vehicles**

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**Abstract**
Large trucks have significant blind spots, and urban settings often bring these vehicles in close proximity to vulnerable road users (VRUs). Over 13% of VRU fatalities in Canada in 2016 involved collisions with heavy commercial vehicles. Transport Canada launched a multi-year field trial, in collaboration with municipal partners, to evaluate the state of VRU detection and warning technologies. The project evaluated cyclist and pedestrian alert systems retrofitted onto different types of heavy-duty commercial vehicles. Prior to the field trial, in depth assessments were conducted on a test track to identify suitable systems for more extensive long term testing. The equipment had to accurately and reliably alert drivers of an imminent risk of collision, based on a time to collision warning, as well as limiting the number of false positive detections. Five different candidate systems were subjected to a series of simulated “urban environment” scenarios performed on a close track. The results of these tests are presented in this paper. The technologies included, ultrasonic, radar, 360 video cameras, smart cameras, and a combination of these systems. The test scenarios were based on the most common real world VRU-truck collisions identified from collisions investigation reports. Six dynamic and four false positive scenarios were created to test the capabilities of sensors designed to alert the driver of VRUs. Data were recorded on the timing of audio and visual alerts, the GPS position of the vehicle/VRU, the velocity and environmental conditions. All the detection systems were installed on a single vehicle, traditional cabin dump truck. Three test dummies were used: a 50th male, a 7 year old child and an adult cyclist. The results suggested that the current VRU detection and warning technology may not be sufficiently mature to fully address the risks. No single system could successfully warn the driver in time to avoid a collision in all of the test scenarios. The smart camera system performed best overall and was selected for more extensive testing on different vehicles in a multi-city field operational test.
**Effect of Subaru EyeSight on Pedestrian-Related Bodily Injury Liability Claim Frequencies**

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**Abstract**  
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The objective of this study was to evaluate whether Eyesight was preventing vehicles from striking pedestrians. Insurance claims under bodily injury (BI) liability coverage without associated first-party (collision) or third-party (property damage liability [PDL]) claims for vehicle damage were used as a surrogate measure of pedestrian crashes. Methods & Data Sources EyeSight is an option on various 2013–17 Subaru series. The presence or absence of EyeSight is discernible from information encoded in the vehicle identification numbers (VINs). The number of BI-only claims per insured vehicle year was compared for Subaru vehicles with and without EyeSight, using regression analysis to account for other factors also known to affect insurance claim frequency. A Poisson distribution was used to model claim frequency. Covariates included calendar year, garaging state, vehicle density, age group, gender, marital status, risk classification, and vehicle model year and series. Twenty percent of the insured-vehicle-year exposure came from vehicles equipped with EyeSight. Prior investigation has shown that injury-only BI claims are consistent with pedestrian or other nonoccupant injuries. Even so, these may include some nonpedestrian crashes, and some pedestrian crashes that were severe enough to also cause vehicle damage may be excluded. This study was based on vehicles with overlapping BI liability, collision, and PDL insurance in U.S. states with traditional tort liability insurance laws. Results When all series were combined, Subaru vehicles with EyeSight showed a statistically significant 35% reduction in BI-only claim frequency. When the Subaru Forester, Legacy, and Outback were separated by generation, results also showed statistically significant reductions of 33% for the first generation and 41% for the second generation. When the vehicle series were modeled individually, claim frequency reductions ranged from 18 to 57%, although only the Legacy (57%) and Outback (34%) results were statistically significant. Discussion & Limitations Claim frequency reductions for the EyeSight generations are similar, but it is promising that the second generation is showing a larger reduction. There are limitations to the data used in this analysis. Covariates describing driver characteristics are generally those of the primary driver of each vehicle and not necessarily the driver involved in the crash claim. Likewise, geographic covariates describe where the owner of the insured vehicle lives and not necessarily where crashes occurred. Nevertheless, these variables are consistently predictive in explainable ways. Conclusions & Relevance to Session Submitted Subaru’s Eyesight system is associated with a lower BI-only claim frequency than the same Subaru vehicles without EyeSight. In 2016, there were nearly 6,000 pedestrian fatalities in the United States, up 9% from 2015, and an 11% increase in bicyclist deaths. Pedestrian detection systems like Subaru EyeSight have the potential to effectively reduce these numbers, and efforts to promote similar systems will help protect vulnerable road users.

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**Handling Of Child Restraint Systems (CRS) with Special Focus on Misuse**

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**Abstract**  
The purpose of the presented study was to analyse the actual situation of children safety in cars with special focus on the misuse topic. In order to completely cover all relevant aspects of misuse both data on the frequency, severity and types of misuse and the underlying knowledge, attitudes and skills of the users were recorded. Thus, a threefold concept of observation and inquiry was constructed. First of all misuse of CRS was observed in public areas such as shopping centres,
Responses of the Scaled Infant Human Body Model in Simulated Frontal Motor Vehicle Crashes

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Abstract
Most motor vehicle crash deaths occur among children traveling as passenger vehicle occupants, and proper restraint use and direction of use can reduce these fatalities. There is little to no literature on systematic evaluation on the responses of children under three-years of age in motor vehicle crashes. The study presents the first ever endeavor at developing 18MO, 24MO, 30MO, and 36MO pediatric finite element models from the 6YO PIPER human body model as the baseline and comparing their responses in rear-facing and forward-facing simulations of the same crash pulse conditions in the FMVSS No. 213 test bench and a vehicle seat. The 6YO PIPER model was scaled down to create anthropometrically accurate models of the 18MO, 24MO, 30MO and 36MO child using the PIPER scaling tool and Snyder anthropometric data. Each model (N=4), along with a convertible car seat and either the 213-test bench or a 2012 Toyota Camry vehicle rear seat was simulated in a full-frontal crash (24G, 120ms pulse). Kinetics and kinematics were extracted and processed as per SAEJ211 metrics. On the 213-test bench, models in forward-facing configuration showed higher head accelerations, but lower pelvis accelerations for 30MO and 36MO models. Chest displacements were between 84-90% higher in the forward-facing models, with the exception of the 30MO model, which was 35% higher. Neck moments were lower in all rear-facing configurations. Upper neck forces were at least six times higher forward-facing. HIC36 in rear-facing models ranged from 300-344, while HIC36 in forward-facing models ranged from 410-494, showing no linear trend as age increased. Forward-facing head excursions grew over two-fold from their rear-facing counterparts, from an average of 240 to an average of 518. Head trajectories generally followed a longer path in forward-facing models. NIJ for all forward-facing models were five to eight times the values for rear-facing. On the vehicle seat, the forward-facing models showed higher head accelerations for 24MO and 36MO models. Chest displacements were 33-49% higher in forward-facing models, except 36MO, where it was 128% higher. Neck forces and moments were consistently lower for rear-facing models as compared to forward-facing. Upper neck forces were 6.5-9.75 times higher in forward-facing models. HIC36 values were lower in rear-facing, ranging from 335-394, as compared to forward-facing which were 455-624. Head excursions for forward-facing were three times that for rear-facing, except the 36MO model, where it was 1.75 times higher. NIJ for all forward-facing models were six to nine times the values of rear-facing. Kinetics and kinematics numbers across the board were within IARV limits. Pediatric models in rear-facing configurations generally had lower injury
numbers than those in frontal configurations. However, there is no consistent trend seen in injury values as age progresses. This is the first study to conduct a systematic evaluation of the response of children under three years old in frontal motor vehicle crashes.

**Paper No.19-0045-O**

**PEER REVIEW**

**Analysis of rider and child pillion passenger kinematics along with injury mechanisms during motorcycle crash**

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Research
Road traffic fatalities among Power Two Wheelers (PTW) users are intolerably high in Thailand. It accounts for 73% of total road fatalities. Children are among these victims. Save the Children Thailand reports that there are 1.3 million child pillion passengers on motorcycles. To support improvement of countermeasures and design of protection equipment, understanding biomechanics of PTW users under impact conditions is necessary. Therefore, the objective is to analyse overall kinematics and injuries sustained by the rider and the child pillion passenger in various accident configurations.

Methods
Thailand motorcycle accident data was statistically analysed in terms of frequency and pattern to identify common accident scenarios and impact parameters. Two numerical approaches were employed to study kinematics and injuries of both rider and child passenger. The multibody model was validated with the motorcycle crash test and used to generate possible accident cases for various impact configurations specified to cover all common accident scenarios. The overall kinematics were analysed. Specific impact configurations which represented typical kinematics were selected for detailed finite element analysis. The finite element simulations of motorcycle-to-car collision with THUMS as a rider and a child passenger were conducted to provide insight understanding on kinematics and injury mechanisms.

Results
Four common accident scenarios identified from accident data revealed two typical impact patterns with two different corresponding global kinematics. Cars were involved most in motorcycle accidents. The first impact pattern was when motorcycle front-wheel impacting car. Both rider and child passenger were translated together towards the impact point. The rider’s trunk impacted handlebar while the head impacted the car. The child passenger mostly impacted to rider’s back. The second impact pattern was when the car impacting lateral side of motorcycle, upper bodies of rider and child were laterally projected towards car front. Windshield, hood and A-pillar were the top three locations on the car mostly visited by the rider’s and child’s heads. Finite element simulation of motorcycle-front impacting car has manifested high risk of rider’s head and thorax injuries but low risk of severe injury in the child. Both had low risk of DAI. However, the simulation of car impacting motorcycle showed that both rider and child passenger were at high risk of head, brain, neck and thorax injuries. High chance of DAI was pronounced. Lower extremities and pelvic injuries were seen.

Discussion
One limitation of this work was a validation of whole body kinematics in motorcycle-to-car collision. However, motorcycle components were separately validated with experiments.

Conclusion
The motorcycle-to-car crash simulations of various test configurations based on identified real-world accident scenarios highlights two different overall global kinematics. These leads to different injury mechanisms. Both impact patterns result in a high risk of skull fracture due to high HIC. However, severe brain and neck injuries are more pronounced for cases of other-vehicle impacting motorcycle. High chance of lower extremities injury is also found in these cases. While rider’s thorax injury due to handlebar impact is only observed for cases of motorcycle impacting other-vehicle. The child pillion passenger exhibits less risk of severe injury for these cases also.

**Paper No.19-0014-O**

**Development and Evaluation of a Thorax Injury Prediction Tool (TIPT) and Possibilities for Incorporation within improved Test and Assessment Procedures – Results from SENIORS**

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Abstract
Test and assessment procedures for passive pedestrian protection of passenger cars are in place for many years within world-wide regulations as well as consumer test programmes. Nevertheless, recent accident investigations show a stagnation of pedestrian fatality numbers on European roads alongside increasing injury severities for older road users. The EU-funded SENIORS (Safety ENhancing Innovations for Older Road userS) project developed and evaluated a thorax injury prediction tool (TIPT) for later incorporation within test and assessment procedures. Accident data indicates an increasing portion of AIS2 and AIS3+ thoracic injuries of older pedestrians and cyclists which are currently not assessed in any test procedure for vulnerable road users. Therefore, SENIORS focused on the development of a test tool predicting the risk of rib fractures of vulnerable road users (VRU). While injury risk functions were reanalyzed, human body model (HBM) simulations against categorized generic vehicle frontends served as input for the definition of test setups and corresponding impact parameters. TIPT component tests against a generic frontend and an actual vehicle were used for the evaluation of the technical feasibility. The TIPT component tests shows the general feasibility of a test procedure for the assessment of thoracic injuries, with good repeatability and reproducibility of kinematics and results. Impact parameters such as the inclination angles of the thorax, angles of the velocity vector and impact speeds well replicate the parameters gained from the HBM simulations. The proposed markup and assessment scheme offers the possibility of a homogeneous evaluation of the protection potential of vehicle frontends while maintaining justifiable testing efforts. During evaluation testing, the proposed requirements were entirely met. The developed prototype of TIPT and launching system offer impact angles and speeds as suggested by HBM simulations. However, since thorax impacts during pedestrian accidents do not occur perpendicularly to the vehicle surface in most cases, the TIPT built-in linear potentiometers do not acquire the true resultant intrusions on the ribcage and thus, TIPT rib deflections do not reflect the actual human injury risk. However; for the impact forward to the bonnet leading edge, the TIPT seems applicable without further modifications. The test and assessment procedures using the TIPT offer for the first time the possibility of replicating the kinematics of a pedestrian thorax with a component test. The developed assessment scheme gives a first indication on how the risk for thoracic injuries could be implemented within the Euro NCAP Box 3 assessment. Future development of the TIPT may focus on implementing a rib cage that can deflect in all axes in a humanlike way.

Paper No.19-0285-O
RESEARCH OF PEDESTRIAN INJURY REDUCTION MECHANISM BETWEEN THE BEGINNING OF THE COLLISION AND FALL OF THE GROUND
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Abstract
Recently, safety standards for pedestrian protection in third party evaluation typified by NCAP have been increased, and safety performance of vehicles is improving. Among them, the safety performance of the bonnet hood has been particularly enhanced in terms of injury index represented by HIC from the viewpoint of head protection. However, according to the accident statistics, pedestrian fatalities have remained high, and the causes of death include not only the vehicle injury but also the ground injury. Therefore, it is necessary that pedestrian protection technology includes not only vehicle but also ground. In order to reduce the number of pedestrian fatalities, this research focused on the control of the pedestrian’s behavior after accidents and studied methods that can reduce head injuries caused by various factors. In many pedestrian accidents, the speed difference between the vehicle and the pedestrian is large. The pedestrian is accelerated to the speed of the vehicle due to force input from the vehicle. Therefore, if pedestrians can be gently accelerated, the action is expected to be effective in reducing various injuries. For this purpose, it is important to restrain the pelvis close to the center of gravity at the beginning of a collision. As for the ground, by controlling behavior so that a pedestrian can fall from their leg to the ground, head injury can be greatly reduced. For this purpose, it is important to reduce local input to the legs and suppress the swinging up of the legs. In this research, the effect of early pedestrian pelvis restraint was verified using a pedestrian dummy (POLAR) and modified vehicle model. Head injury was evaluated by using Convolution of Impulse Response for Brain Injury Criterion (CIBIC). For verification, a sedan type vehicle with a small initial input to the pedestrian’s pelvis was used, and the collision speed was limited to 40 km/h. Then, based on the vehicle
model, which can change the input part and the load characteristics, the relationship between the behavior of the pedestrian and the injury value was studied. In this research, it was confirmed that the angular velocity of the upper body around the center of gravity is reduced by the early input to the pedestrian pelvis, and it is effective for various injury values of the head. It was also confirmed that the swinging up of the leg can be suppressed by controlling the input to the pedestrian leg. Although collision speed and physique are limited in this research, it is necessary to consider the influence of the difference in physique and speed.
Furthermore, it is important to integrate with external sensing technology in order to deploy the pelvis restraint device in front of the vehicle before a collision. In this research, it was confirmed that a pedestrian behavior control device may be effective for reduction of generalized injury by vehicle crush and secondary damage by the ground as one solution for further reduction of the number of pedestrian fatalities.
Evaluation of the Safety Performance and Weight Reduction Using CFRP Modified Automotive Structures in NHTSA’s Frontal Oblique Impact Test

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Abstract
In a project conducted for NHTSA during 2016-2017, finite element analysis simulations were conducted representing NHTSA’s right and left oblique impact configurations being developed for possible use in the agency’s New Car Assessment Program. For the study using this test procedure, simulations were conducted representing an offset moving deformable barrier impacting a stationary 2015 Toyota Camry with a 35 percent overlap and an angle of 15 degrees (from collinear) at a speed of 90 km/h. In the NHTSA project, the model was successfully used to develop structural countermeasures in order to reduce occupant compartment intrusion for the new oblique impact configuration. Higher strength steel materials and modification of component thicknesses allowed the reduction of occupant compartment intrusion by more than 50%. As part of this effort, George Mason University (GMU) calculated mass and relative material expense comparisons to traditional materials. As a result, three optimized models using traditional materials were created. The accomplished reduction of occupant compartment intrusion ranged from 52% to 69% and the associated added mass ranged from 7.3 kg to 17.3 kg. The significant reduction in intrusion was achieved without unintended consequences, i.e., no considerable increases in the vehicle pulse severity for oblique and co-linear crash configurations were observed. Following these results, the American Chemistry Council (ACC) commissioned this subsequent study to determine if the vehicle could be lightweighted and provide a similar reduction of occupant compartment intrusion for NHTSA’s right and left oblique impact configurations using carbon fiber reinforced plastic (CFRP) composite materials. Different thicknesses for relevant components were evaluated and associated reductions in intrusion, associated changes in mass, and associated critical areas with material failure were determined. As a result of using selected components made out of a composite material, a similar reduction in occupant compartment intrusion was achieved in NHTSA’s right and left oblique impact configuration as realized for the best high strength steel model. In using the CFRP composite material, the associated change in mass was a reduction of 7 kg of the baseline vehicle as compared to an increase of 17 kg in the baseline vehicle mass when using more traditional countermeasures—higher component thicknesses and use of high strength steel materials. The developed and incorporated countermeasures using composite materials were also evaluated to determine if they produced unintended consequences in other impact configurations. The developed FE models, which showed reduced occupant compartment intrusion due to components made out of the CFRP composite material in NHTSA’s oblique crash configuration, were also evaluated in NHTSA’s NCAP full overlap and in the Insurance Institute for Highway Safety (IIHS) partial overlap crash configurations. No unintended consequences were observed when the results were analyzed with respect to vehicle pulse and intrusion when compared to the results using the baseline simulation model. In addition to the above technical achievements, in partnership with Honda R&D Americas and LSTC; other efforts are underway.
These include the development and validation of a material constitutive model of the CFRP material for use in modeling and subsequent simulation in automotive crash applications.

**Paper No.19-0188-O**

**Optimization of Front End Structures for IIHS Small Overlap Frontal Crash Test**

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**Abstract**  
The Insurance Institute for Highway Safety (IIHS) introduced a small overlap rigid barrier (SORB) crash test in 2012. In the IIHS SORB tests, the rigid barrier primarily impacts a vehicle's outer edges instead of the main longitudinal structures traditionally designed to absorb frontal impact energy. Due to the test condition, the front wheels are often forced to move rearward and into the footwell, contributing to significant and localized intrusion in the occupant compartment. To investigate the design countermeasures for such a severe test mode, the full vehicle model developed in the final phase of the Future Steel Vehicle (FSV) program by WorldAutoSteel was adopted as a baseline. In this study, innovative countermeasure design concepts for the front end structures, especially bumper beam, shotgun, front rail, A-pillar, hinge pillar, and rocker, were proposed and optimized with the FSV full vehicle model. The optimized designs helped the vehicle slide away from the small overlap rigid barrier and converted more impact energy to vehicle kinetic energy. When used together with ultra high strength steel (UHSS), the intrusion into the occupant compartment was reduced and the overall structural rating was improved from “Marginal” to “Good” in the SORB test. In the meantime, the design concepts reduced intrusion in the IIHS 40% overlap deformable barrier (ODB) test and maintained a similar crash pulse in the US-NCAP full frontal crash test. The potential mass reduction opportunity with the design concepts and UHSS was also evaluated.

**Paper No.19-0232-O**

**Injury Mechanism and Evaluating Methods For Small Overlap and Oblique Frontal Crashes**

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**Abstract**  
According to a National Highway Traffic Safety Administration (NHTSA) study, small overlap and oblique frontal crashes account for 25% of fatal accidents in the United States. This is a large proportion, and comprises the accident mode with the highest fatality rate. The fact that occupants collide with the cabin is a factor in this. The purpose of the present research is to recreate the injuries that occur to occupants in actual accidents involving small overlap and oblique frontal crashes, and to formulate a method for evaluating them. By enhancing vehicle body performance and occupant restraint performance, the goal is to reduce fatalities and injuries. In order to verify the circumstances of injury during small overlap and oblique frontal crashes, crash simulations were performed by numerical computation. A human body model was also placed in the driver’s seat to verify the occupant movement and extent of injury. The oblique mode that the NHTSA is slated to adopt was first verified using numerical simulation, but collision on the occupant’s chest could not be confirmed. For the present research, therefore, verification of the angle and speed parameters was carried out so that occupant movement could be recreated in a way that conformed to actual accident circumstances. The result of simulation was that occupant movement with respect to the vehicle together with vehicle body deformation showed the occurrence of collision with the occupant’s chest when the evaluation vehicle (a passenger car) was impacted by an OMDB with an overlap (LAP) of 25%, at an angle of 30°, and at a speed of 110 km/h. The collision occurred in the same place, with injury to the same areas, and with the same degree of injury as shown under actual accident circumstances in a small overlap and oblique frontal crash. In light of these results, it was confirmed that injuries would be reduced by increasing the body strength of the evaluation vehicle to reduce deformation and by installing air bags on doors where oblique loading affected occupant movement. Numerical simulation of the above modes was performed using a passenger
car that received the highest evaluation from the Insurance Institute for Highway Safety (IIHS). While vehicle body deformation was evaluated at the GOOD level even in oblique mode (in-house data), vehicle body deformation increased and occupant chest collision occurred that resulted in AIS4+ level injuries. This method of evaluation was confirmed to offer possibilities for evaluation of small overlap and oblique frontal crashes that conforms to actual accidents, and for evaluation that may further reduce fatalities and injuries. The effectiveness with respect to these injuries of measures taken through restraint devices and the vehicle body by means of numerical simulation using a human body model was verified. The results confirmed that combining vehicle body and restraint device measures had the effect of reducing injuries.

**Paper No.19-0065-O**

**Factors contributing to serious and fatal injuries in belted rear seat occupants in frontal crashes**

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Research
Earlier research has shown that the rear row is safer for occupants than the front row, but there is evidence that improvements in front seat occupant protection in more recent vehicles have reduced the safety advantage of the rear seat versus the front seat. The objective of this study is to identify factors that contribute to serious and fatal injuries in belted rear seat occupants in frontal crashes.

Methods
A case series review of belted rear seat occupants who were seriously injured or killed in frontal crashes was conducted. Occupants in frontal crashes were eligible for inclusion if they were 6 years old or older and belted in the 2nd or 3rd row of a 2000 or newer model year vehicle within 10 model years of crash year. Injury crashes were identified using the 2005-2015 National Automotive Sampling System Crashworthiness Data System (NASS CDS) and included all eligible occupants with AIS 3 or greater injuries. Fatal crashes were identified using the 2014-2015 Fatality Analysis Reporting System (FARS) then local police jurisdictions were contacted for complete crash records including pictures, autopsy reports, and detailed crash reconstruction reports. Fatal case review focused on two age groups of interest: ages 6 through 12 years and 55 years and older.

Results
Detailed case series review was completed for 119 rear seat occupants: 35 with MAIS 3+ injuries in NASS CDS and 84 fatalities identified in FARS. More than half of injured and killed rear occupants were more severely injured than front seat occupants in the same crash. Serious chest injury, primarily caused by seat belt loading, was present in 22 of the injured occupants and 17 of the 36 fatalities with documented injuries. Nine injured occupants and 18 fatalities sustained serious head injury, primarily from contact with the vehicle interior. Cervical spine injuries were not present in injury cases but were documented in 10 of the fatal cases. For fatal cases, 12 crashes were considered unsurvivable due to complete loss of occupant space. For cases considered survivable, intrusion was not a large contributor to injury or fatality.

Discussion
Rear seat occupants sustained serious and fatal injuries due to belt loading in crashes in which front seat occupants survived, suggesting a discrepancy in restraint performance between the front and rear rows. Restraint strategies that reduce loading to the chest, such as belt force limiters, should be considered but there may be potential tradeoffs with increased head excursion, particularly in the absence of rear seat airbags. Novel restraints such as inflatable belts or rear airbags may provide increased protection but any new restraint designs should consider any unintended consequences to vulnerable occupants. Case reviews were limited by inconsistent documentation of crash damage and injuries in fatal cases. Fatal case review was limited to 2 vulnerable populations: children and older occupants.

Conclusion
Rear seat occupants sustain serious or fatal injuries in frontal crashes in which front seat occupants are well-protected, suggesting there is an opportunity to improve protection in the rear seat to levels comparable to the front.

**Paper No.19-0201-O**

**ASSESSING INJURY RISK OF CAR OCCUPANTS ON REARWARD FACING SEATS IN A FULL**
FRONTAL IMPACT – SLED TESTS IN A GENERIC TEST ENVIRONMENT

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Abstract
With the introduction of fully-automated vehicles, new seating configurations of the passenger compartment has been proposed. Rearward facing front seats are considered to provide so-called living room seating. At least as long as conventional and fully-automated vehicles share the same roads in mixed traffic, crashes may occur. Occupant protection on a rearward facing seat must therefore be on the same level as on a forward facing seat to comply with legal requirements. In order to assess dummy response on a rearward facing seat in a 56 km/h full frontal impact, sled tests were performed, analysed, and discussed. A total of 23 sled tests in three series with a Hybrid III 50th percentile adult male dummy were performed to simulate a vehicle frontal impact against a rigid barrier at impact speeds up to 56 km/h. In the first test series, a serial vehicle seat was used, but it showed already considerable deformation at an impact speed of 40 km/h. Therefore, a generic concept seat was developed. In the second test series, the concept seat was tested and tuned to enable it to perform tests at the target impact speed of 56 km/h. In the third series, tests to investigate repeatability were performed. Dummy loadings at 56 km/h were compared with reference values from legislation and literature. Focus was set on thorax and lumbar spine loadings. For a qualified interpretation of dummy loadings and the performance of the restraint system, the crash was divided into three phases: (1) impact phase until the maximum dummy rearward displacement, (2) dummy rebound before interaction with the seat belt, and (3) dummy in rebound and interaction with the seat belt. The impact phase (1) is characterized by the highest 3 ms chest acceleration, close to 60 g in 56 km/h tests. Notably, this was the loading closest to the injury assessment reference value (IARV). The lumbar spine was mainly loaded in compression with forces rising up to 5.8 kN. Chest deflection of about 8 mm was caused by inertia of the dummy rib cage. The rebound phase before interaction (2) did not show any substantial dummy loading. The rebound interaction phase (3) was influenced by the seat belt system, chest deflection ranged from 5 mm in the test with lap belts to 19 mm in the test with two crossed shoulder belts (crisscross belt). The viscous criterion was below 0.1 m/s in all tests. Overall, the tests showed good repeatability and the ability of the generic concept seat to control dummy kinematics. A limitation of our study is, that only full frontal loading directions were studied, dummy kinematics of oblique impact direction, simulating e.g. +30° impacts to the barrier, were not included. The head rest was not in focus of our investigation and the head was fixed to the head rest without any gap in between.

Paper No.19-0137-O
Role of Traumatic seatbelt fat stranding in automotive crash injury analysis

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Abstract
The seatbelt is a primary and the most important passive safety device protecting occupants in all crash modes. The belt must work in harmony with other passive safety devices such as the frontal airbag, knee bolster and the seat to increase the level of occupant protection in a head-on crash. Failure of any component to restraint the occupant effectively in conjunction with the seatbelt can produce adverse occupant kinematics. Occupant submerging in a frontal crash is an occurrence when the belt moves from the desired stronger skeletal site and loads undesired anatomical location during the forward excursion of the occupant. The focal loading of the abdomen and ribs by the seatbelt produces abdominal and thorax severe injuries. Subcutaneous fat appears typically darker on the radiographic film with an appropriate window. The focal loading from the seatbelt on the body tends to increase the density of the fat along the course of the seatbelt routing. The increase in the density of fat rises its attenuation and makes the fat appear lighter/whiter on the film. The change in the density, due to traumatic seatbelt loading, can be used in conjunction with other medical and physical evidence to demonstrate the occurrence of submerging. This type of analysis is also useful for the medical provider to take appropriate actions when the trauma patient first appears in the emergency department. The purpose of this study is twofold: (1) to demonstrate the submerging detection techniques and methodologies using the NHTSA crash-test instrumentation data; and (2) to present real-world crashes as evidence of occupant submerging using fat-stranding analysis in conjunction with other medical and physical evidence.
Banging heads onboard buses: Rating scheme to improve injury mitigation for bus passengers

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Research
Although bus travel is one of the safest modes of transport, a substantial number of bus passengers in London are still injured in collision and harsh manoeuvre incidents, in particular emergency braking. It is not well understood how these passengers are injured. The objective was to understand better the injury mechanisms and develop counter-measures with a test and assessment procedure to prevent or mitigate these injuries.

Methods
The UK national Stats19 data was used to determine the size of the problem. Bus operator collected data, including CCTV footage, in combination with inspection of current buses, were used to determine injury mechanisms and identify features and areas in buses associated with more injury. A rating system based on visual inspection, to encourage a reduction in the number of features associated with injury, was developed. An analysis of benefits and costs for its implementation was also performed.

Results
The Stats19 analysis showed that three-quarters of all injured casualties occurred in incidents where there was no impact, with this proportion rising for seriously injured casualties. Older females (56+ years) formed one third of serious casualties. The CCTV analysis and bus inspections highlighted issues with poorly positioned handrails, lack of compartmentalisation (restraint), and objects with sharp edges and corners. It also showed that a much higher proportion of passengers seated in the area close the middle doors and wheelchair area were injured compared to other areas of the bus. Contributory factors to this result were that this area contained more injury associated features and that person’s with reduced mobility have greater exposure in this area, i.e. the more vulnerable passengers currently sit in the less safe areas of the bus. The benefits and costs analysis showed a robust case for implementation of the rating system, with a return on investment within the first year.

Discussion
The main limitations are related to the CCTV analysis, namely the difficulty in identifying the passenger injury severity and the relatively small size of the sample used for the analysis.

Conclusion
A novel analysis of CCTV footage has enabled a better understanding of injury mechanisms for bus passengers to be developed. In combination with inspection of current buses this has been used to develop a rating system to improve the safety of buses in London. Increased urbanisation will likely result in an increased demand for mass transit systems and this paper presents ways in which crash protection of buses can be improved, particularly in frontal impacts.

Hearing loss analysis in full scale accident reconstruction

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Abstract
Airbags are, together with the three-point belt, the most effective passive safety equipment of vehicles. However, literature shows that sound pressure levels of up to 170 dB can occur during airbag deployment. A literature review revealed no systematic experimental data on possible hearing loss by airbag deployment, that also takes any other crash accompanied noise into account, such as deformation and impact noise. Also the rising number of airbags per vehicle resulting in a higher number of deployed airbags in an accident was not addressed with respect to hearing loss. Thus, an extensive test matrix of noise measurements during airbag deployments was conducted including onboard measuring during crashes and static measurements. Dynamic and static experiments with single and multiple airbag deployments were conducted. The results of this study show, that in the analyzed crash constellations the acoustic emission of the
collision as well as the car deformation can trigger the stapedius reflex before the airbag deployment. The stapedius reflex protects the inner ear at least partially in case of dangerous sound levels. However, it seems that multiple airbag deployments in a short sequence pose a considerable risk for hearing impairments despite the fully contracted stapedius muscle. Further and in line with Price et al. (2013) it was found that the risk of hearing loss is lower with closed windows. The analysis of patient and accident data showed no link between airbag deployment and hearing loss. This might be caused by low case numbers of reported hearing loss problems up to now. In conclusion the results show that a singular analysis of the sound pressure of airbag deployments without crash accompanied noises is not sufficient as the protective effect of the stapedius reflex is neglected. Still, successive airbag deployments in a short timeframe raise the risk of hearing loss. Further investigation on hearing impairment due to airbag deployment and triggering of the stapedius reflex is needed and the data acquisition of accidents and patients should consider hearing loss aspects.

**Paper No.19-0034-O**

**PEER REVIEW**

**Trends in aggressivity and driver risk for cars, SUVs, and pickups: Vehicle incompatibility from 1988-2016**

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Research

When two vehicles of different sizes collide, the occupants of the smaller vehicle are more likely to be injured than the occupants of the larger vehicle. The larger vehicle is both more protective of its own occupants and more aggressive toward occupants of the other vehicle. However, larger, heavier vehicles tend to be designed in ways that amplify their incompatibility with smaller, lighter vehicles (by having a higher ride-height, for example). A 2012 study by the Insurance Institute for Highway Safety (IIHS) concluded that fatalities caused by design incompatibility have decreased in recent years (Teoh & Nolan, 2012). The current study was conducted to update the 2012 IIHS analysis and to explore trends in vehicle incompatibility over time.

Methods

Analyses examined deaths in crashes involving 1- to 4-year old passenger vehicles from 1988 to 2016 collected from the Fatality Analysis Reporting System (FARS). Trends in driver risk were examined by comparing case vehicle driver death rates per million registered vehicle years across vehicle type and size. Trends in aggressivity were examined by comparing partner vehicle driver death rates across vehicle type and size.

Results

Cars and SUVs have continued their trend toward reduced incompatibility. In 1988-91, SUVs were 151% more likely to kill the driver in a partner car compared to when a car crashed with another car. By 2013-16, this value had dropped to ~4%. Pickups and cars remain incompatible, however. In 2013-16, pickups were still 153% more likely to kill the driver of a partner car compared to when a car crashed with another car. Remaining pickup incompatibility may be largely due to excess curb weight rather than to shape or design features, as pickup-car incompatibility dropped to 20% when the two vehicles were in the same weight class.

Discussion

The trend toward reduced fleet incompatibility has continued in the latest crash data, particularly for cars and SUVs. Although pickup-car incompatibility has also decreased over time, they remain disproportionately aggressive toward other vehicles, possibly due to their greater average curb weight. The current study did not isolate the effect of size from the effect of weight; disentangling the two variables is difficult because they are highly collinear (i.e., large vehicles are also heavy). Nonetheless, reducing the weight of some of the heaviest vehicles and more widespread crash avoidance technology fitment may be a promising means to reduce remaining fleet incompatibility.

Conclusion

The current study produced updated estimates for incompatibility between cars, SUVs, and pickups in the United States. Although vehicles have grown more homogenous in size and design, pickups remain largely incompatible with other vehicles in the fleet. Identifying the source of remaining incompatibility will be important for safety improvements going forward.
Relationship between Frontal Car-to-Car Test Result and Vehicle Crash Compatibility Evaluation in Mobile Progressive Deformable Barrier Test

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Research
From 2020, the world first crash compatibility rating test will be introduced in European Mobile Progressive Deformable Barrier (MPDB) test. However there is hardly any systematic study regarding the improvement effect of this new test on car-to-car (C2C) impact. In this research, the quantitative change of partner protection (PP) performance of large vehicles in C2C impact was studied when these large vehicles will be designed in future based on MPDB test addressing crash compatibility rating.

Methods
First, representative vehicles of European fleet were selected and CAE parameter study was conducted. In concrete, with changing homogeneity (i.e., the degree of uniformity of barrier deformation) / mass / stiffness of large vehicle systematically in step by step approach, the evaluation results of large vehicles in MPDB and occupant injury score of small vehicles in C2C impact were compared. After that, the above mentioned CAE result was validated with that of C2C physical impact tests.

Results
1) CAE parameter study In C2C impact condition, effect on occupant injury of small vehicle brought by the changes of large vehicle were as follows. i) Homogeneity change: Maximum improvement for cabin deformation and deceleration was 9% and 5%, respectively. ii) Mass change: Same as above, 30% and 5%, respectively. iii) Stiffness change: Same as above, 17% and 3%, respectively. On the other hand, PP evaluation result in MPDB test showed that the effect of homogeneity change is 2.8 times effective than mass / stiffness change. This is inconsistent with the results observed in C2C impact condition. 2) Physical impact tests Two large vehicles selected in this research showed following result in MPDB and C2C physical tests. Large vehicle A: (i) PP evaluation in MPDB test was superior than vehicle B, and (ii) Occupant injury value of small vehicle in C2C test was higher than vehicle B. Large vehicle B: (i) PP evaluation was inferior than vehicle A, and (ii) Injury value was lower than vehicle A. Also it was found that PP evaluation of both vehicles was mainly decided by homogeneity evaluation.

Discussion
Both CAE and physical test results indicate that the correlation between the PP evaluation result of currently proposed MPDB test and the occupant injury score of the partner vehicle in C2C impact is relatively small. This may be mainly caused by the proposed homogeneity evaluation method of MPDB test. Above mentioned result was derived under the condition that using a B-hatchback, B-SUV, C-sedan, C-SUV vehicles for European market as subject vehicles and applying evaluation method being proposed as of today. For other conditions, such as different fleet or different evaluation method, further study might be necessary.

Conclusion
Currently proposed PP evaluation method of MPDB test showed some tendency to overestimate the effect of homogeneity change and resulted in quantitatively inconsistent outcome regarding the occupant injury of partner car in C2C impact condition. To maximize the occupant injury mitigation effect in real world accident, there is room for further additional improvement of the present evaluation method. Session to be submitted to: ‘Safety Performance in Frontal and Rear Crashes’

Structural Countermeasure Study on Oblique Offset Frontal Impact

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Abstract
National Highway Traffic Administration (NHTSA) has been investigating an oblique offset frontal impact test. This project evaluates test and simulation results to determine structural changes to reduce occupant compartment intrusion.
Review of test results indicated that mid-size Sedans and Pickup trucks showed higher structural intrusions and higher passenger compartment decelerations. Existing Computer Aided Engineering (CAE) models for a mid-size Sedan and Pickup truck were used to evaluate structural changes and the corresponding cost impact to improve performance in the oblique offset test condition. This paper describes the CAE study carried out to study structural reinforcement countermeasures for both the driver and passenger sides of the vehicle in left- and right-side oblique offset frontal impacts. This paper presents the structural mass changes due to reinforcement countermeasures and the cost impact.

**Paper No.19-0185-O**

3D Stroke Calculation and Application using 6-DOF Sensors

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Abstract

Time history of movement (stroke) is crucial information for crash test analysis. The stroke is often calculated from double integration of linear acceleration data when direct measurement by a potentiometer is impossible. But this method may not be accurate for the cases with large rotations. Newer crash tests like IIHS small overlap and NHTSA oblique involve large rotation, creating 3-dimensional (3D) occupant motions compared to front rigid barrier tests which are primarily 2D events. To help overcome some of the challenges posed by newer crash tests, the authors developed a method to calculate accurate 3D motion with 6-DOF (Degree-of-Freedom) instrumentation including angular rate sensors (ARS). The calculation of accurate 3D position and orientation for a rigid body requires data collection of 6-DOF: 3 linear accelerations and 3 angular velocities. The mathematical calculation to account for rotation of a rigid body was done by using the screw-axis method. The quaternion was calculated using numerical integration via the 4th-order Runge-Kutta method. A dynamic component test was designed and conducted with a linear impactor to validate the 3D stroke calculator. The test set up included a 6-DOF sensor pack mounted on a polyethylene stick with an offset. The stick was mounted on a base, which was pushed by a linear impactor with controlled speed. The sensor experienced 3D motion when the stick was decelerated by the base impacting a honeycomb backstop. This method of 3D rigid body tracking has various crash testing applications. The authors compared occupant head kinematics among three different frontal offset crash modes. A finding of the study was that one test mode resulted in more driver head stroke (relative to vehicle interior) compared to the other two crash test modes. The maximum head stroke, compared to the least, was more by 64% (longitudinal) and 49% (lateral).

**Paper No.19-0249-O**

INFLUENCE OF SEATING POSITION ON OCCUPANT’S INJURY CRITERIA

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Abstract

The number of fatalities in traffic accidents has been reduced continuously. One of the factors for such reduction may be improvement of safety devices. However, though total number of deaths has been reduced, many lives are still lost in traffic accidents. Nearly half of the deaths while driving automobile is in frontal crash. On the other hand, driver seating position is variable and the distance between the occupant and occupant restraint system becomes longer in rearmost position (RM) than mid position (MP) of seat slide, resulting in a delay of occupant restraint onset. Because of the delay of occupant restraint, pelvis restraint is also delayed and pelvis displacement increases. At that time, the motion of pelvis increases the tension of lap belt and it is transferred to the inboard shoulder belt through the thorough tongue. Tension in inboard shoulder belt increases the loading to the lower rib cage and may increase the risk of chest injury. This research examined the influence of seating in RM position to the occupant’s lower thorax injury and the influence on lower thorax injury by controlling pelvis behaviors in RM position. In this study, finite element (FE) simulations of the sled test in flat56km/h were conducted in MP and RM seat positions. Firstly, it was confirmed that the tension of the lap belt caused by pelvis motion transferred to the inboard shoulder belt and it compressed lower rib cage. Especially it seemed to occur in RM. Secondly, simulation was conducted by changing constraint conditions on pelvis translation and lateral axis rotation to confirm the effect on injury criteria in RM. Since the distance between the instrument panel and the occupant became longer in RM, knees were not constrained by instrument panel(IN- PNE), therefore chest deflection increased. It is confirmed that the lap belt tension was increased with the pelvis forward motion caused by reduction of restraint force,
and the tension transferred to the shoulder belt, and consequently the deflection of the lower rib cage was increased. By constraining pelvis translation or rotation, or both of them, the constraint of the pelvis was improved and the chest deflection decreased in each condition. In case of fixing translation and rotation, there was an increase in acceleration of the pelvis and acceleration of T12 also increased through the lumbar spine. Therefore chest deflection was reduced. In terms of effect to the tension of seat-belt, there was not transferring of tension to the shoulder belt from the lap belt. Since the tension of the shoulder belt was declines after 80ms, it was seen that loading to the chest from shoulder belt to the chest declined. It was found that in order to reduce chest deflection in lower right side, it is effective not only reducing the load from inboard shoulder belt but also increasing a degree of constraint on the lumbar spine. Loading to the chest from the inboard shoulder belt was able to be reduced by suppressing pelvis rotation and it was effective to reduce chest deflection further.

**Paper No.19-0025-O**

**The Analysis and Experimental Development of Aspirated Airbags for Conventional and Autonomous Vehicles**

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**Abstract**

As a part of the Automated Driving Systems (ADS) strategy, the developed aspirated inflation system is applicable for conventional and autonomous motor vehicles where larger airbags are required and the location of vehicle occupants is less precise. It is built to provide for the air entrainment into an airbag from the car passenger compartment. The objective is set to inflate a 50 L airbag within 30 ms with an aspiration ratio, A, no less than 4. Advantageous features of the offered system are a much smaller (less than 1/3) gas generator and stopped airbag deployment on contact with an occupant that eliminates out-of-position occupant injuries. Regarding engineering, the aspirated inflator is a supersonic pulse ejector designed on the basis of Prandtl-Meyer effect realization. The modeling includes numerical flow simulation combined with subsequent engineering design, fabrication, and experimental testing of models. The results are presented for the "cold-gas" inflator testing where the gas generator operation is imitated by a jet generation from a compressed-air tank using a specially designed high-speed valve. Such an approach enables the verification of the numerical procedure and calculation results obtained for "cold" and "hot-gas" cases. The experimentally found "cold-gas" aspiration ratio is in a good agreement with the numerical prediction for A varying within 3.1 - 2.1 depending on a particular design and the operational motive pressure. For the gas generator case, the aspiration ratio values are calculated to be more than 4. Several different designs of the supersonic pulse aspirator are modeled, designed, manufactured, and tested including outer and inner circumferential slit nozzle and multi-nozzle systems. To meet the engineering requirements, multi-stage multivariate studies of measured pressure fields and airbag inflation process are performed.

**Paper No.19-0134-O**

**Front Seatback Strength Improvements Study in Rear Crash Events**

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**Abstract**

National Highway Safety Administration (NHTSA)'s seat back standard FMVSS No. 207 [1] establishes a minimum strength requirement to reduce occurrence of seat back collapse in rear crash events. NHTSA also has a separate standard for head restraints. FMVSS No. 202a, that is intended to mitigate whiplash injuries in rear end crashes. In
general, seat backs in current production vehicles will not significantly deform or collapse when subjected to the FMVSS No. 202a test pulse. Thus, a more severe test impulse would be needed to demonstrate a change in seat back performance in a rear impact. Recently rear crash events had fatal injuries to rear seat occupants that was attributed to the collapse of a front seat back. This study was to study seat back design changes that could reduce seat back motion in high speed rear impact [2]. The Bio-RID II dummy was used for testing and simulation in this study. This paper provides details of seat back strength changes from a baseline 2014 Honda Accord.

Crash Avoidance: Driving Automation Systems Level 0, 1, and 2. Product Evolution; Evaluation; and Real-World Deployment Challenges

Tuesday, June 11, 2019 | 08:30-12:30
Chair: Jost Gail, Germany | Co-Chair: Eric Traube, United States
TRACK C | Room: TBD

Paper No.19-0143-O
Tolerability of Unexpected Autonomous Emergency Braking Maneuvers on Motorcycles - a Methodology for Experimental Investigation

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Abstract
Motorcycle riders are subject to a high risk of suffering severe or fatal injuries. Previous research has identified autonomous emergency braking for motorcycles (MAEB) as one of the most promising technologies to increase safety for riders (e.g., [2]). Compared to drivers of two-track vehicles, emergency braking maneuvers are much more challenging for motorcyclists. As there is no restraint system such as a safety belt, riders need to support their upper body movement and they need to control and stabilize their vehicle. This requires attention, situation awareness and body tension. Before applying maximum deceleration, the rider has to achieve this ‘prepared-for-braking’ state. To generate optimal crash mitigation or even crash avoidance, the velocity should be reduced even before this state is achieved. Therefore, it is necessary to determine applicable preparatory braking profiles. As sudden unexpected braking maneuvers are critical for unprepared riders, there is still a great uncertainty on how high these decelerations can be. The identification of the limits would enable to determine the safety benefit of MAEB, when the full deceleration potential before reaching the ‘prepared-for-braking’ state is used. One of the main challenges in MAEB studies is the rider state. On one hand, to evaluate to what extent autonomous interventions can support riders, participants need to be unprepared to receive unbiased results. On the other hand, due to safety and ethical reasons, it is out of question to determine the limits of controllable decelerations with unprepared riders. For this purpose, the experiments within this project are split up: In a first study with experts, the deceleration limits are identified. The experts are asked to evaluate if different automatically applied braking interventions are controllable for unprepared average riders. By increasing the decelerations until the
experts rate them as intolerable for unprepared riders, maximum tolerable decelerations for different braking profiles in real riding scenarios are defined. In a following participant study, average riders experience a realistic emergency braking scenario (suddenly braking vehicle ahead). The deceleration profiles defined during the expert study are applied. With these experiments, the reaction of the unprepared participants to unexpected autonomous braking maneuvers are analyzed. The result is an evaluation on how partial braking maneuvers can help to reduce the transition time and on the potential decrease of velocity during the transition period. In a third study, more critical scenarios (different secondary tasks) and the influence of warnings prior to the autonomous braking intervention are investigated on a dynamic motorcycle simulator. The studies provide empirically obtained data on maximum deceleration values for different automatic braking interventions that are tolerable for average riders in unexpected emergency braking situations. The results also show the maximum amount of velocity – and thus kinetic energy – that can be reduced during the partial automatic braking phase before the maximum deceleration can be applied. The simulator experiments show the influence of different secondary tasks and the effect of visual-auditory warnings. The described method can be used as a reference for future development and configuration of MAEB.

**Paper No.19-0315-O**

**Assessing the case for requiring AEB on city buses and developing technical requirements and test procedures**

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Martin Dodd
Apollo Vehicle Safety, United Kingdom

Alix Edwards
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**Abstract**

In London, around two-thirds of those killed in collisions involving a bus are pedestrians and most of these are killed crossing the road. The time between the pedestrian first being recognisable as a threat and the moment of impact is usually less than 2 seconds. Human drivers have very limited opportunity to avoid the collision. Automated Emergency Braking (AEB) has been developed to avoid such collisions and is becoming widespread on passenger cars. However, city buses pose a unique additional challenge. Bus operations already generate a significant quantity of non-collision injuries because passengers fall during normal operation. This includes when standing, or seated but unrestrained, passengers fall under braking. Automated brake applications where deceleration exceeds what a human driver would have applied increases this existing injury risk. The research was sponsored by Transport for London (TfL) and aimed to quantify this balance of opportunity versus risk, and generate technical requirements allowing them to encourage or mandate AEB on their London bus fleet. The work involved: Traditional collision data analysis Case by case review of both collision and non-collision incidents recorded by CCTV systems provided by a London bus operator A road trial involving an AEB-equipped bus AEB Performance tests on a closed test track. Up to around 25% of bus-pedestrian fatalities could be prevented. In true positive situations, any additional risk to bus occupants was small. Human drivers rarely failed to brake in collisions with pedestrians, they just braked too late to avoid collision. Earlier intervention would mean that in some cases AEB could achieve avoidance with lower deceleration than the driver actually applied. In others, only a small increase was required. False positives always create additional risks. The extent of the risk was strongly related to the level of deceleration and increased very substantially at 6 m/s² or above in the modelling. The net balance was a likely increase in slightly injured casualties but a substantial decrease in deaths and serious injuries. Technical requirements were developed based on adaptations of the Euro NCAP standards with two false positive tests added to discourage systems that were inadequately tuned. The analysis is strongly dependent on the rate of brake applications in service at different deceleration levels, the number of bus occupant injuries that occur at those levels and the decelerations achieved during an AEB false positive event, which is often of very short duration. Larger scale in-service trials would help to quantify these parameters more robustly. Despite some risks, overall AEB would have strong safety potential on city buses and can be encouraged through TfL’s bus safety standard in co-operation with manufacturers and researchers to mitigate risks as far as possible.

**Paper No.19-0088-O**

**Future potential of Automatic Emergency Braking Systems for heavy trucks**

**Daniel Schmidt**

26ESV/Program Book
Abstract
The European Union requires an Automatic Emergency Braking System (AEBS) for all new heavy trucks (N3) since 2015. In case of an anticipated rear-end collision, the AEBS in accordance with EU regulation 347 – 2012 has to provide an adequate two-fold warning cascade and a subsequent emergency braking. After becoming a mandatory system, a strong increase of market penetration of AEBS has been established. However, first analyses in 2017 on German highways showed only minor impact of AEBS in the field [Petersen, E., “Wirksamkeit von Sicherheitssystemen im Straßenverkehr”, Zukunftskongress Nutzfahrzeuge, Berlin, 08. Nov. 2017]. Identified reasons for the minor impact are, amongst others, overruling of the AEBS by braking / accelerating, a probable system deactivation by the driver, and limited implications of an EU conform AEBS. Concerning the requirements, the EU conform system demands in its current level (effective November 2018), for instance, a deceleration of 20 km/h during an emergency braking on a highway approaching with 80 km/h a standing opponent at the end of a traffic jam – the collision may still occur with up to 60 km/h. Being aware of the limitations of AEBS requirements, BOSCH established top level requirements for a high-performance AEBS assumed to not only mitigate but to prevent most rear-end collisions of trucks. The present study evaluates the benefit of Automatic Emergency Braking Systems exemplarily for German roads. It comprises of a thorough analysis of rear-end collisions involving N3-trucks, followed by stochastic simulations of a truck assumed to be equipped with either of the systems: the current EU-conform AEBS or a generic high-performance Automatic Emergency Braking System. In the first part of the study, the German in-depth accident study (GIDAS) was used to identify a potential field of effect for AEBS. In the second part, a simulation framework specifically designed for the stochastic approach was established. It includes a sensor system, various road conditions from on-spot measured data and a simplified truck driver model accounting for driver reaction times and the specific kind of driver reaction. About 2,300 N3-truck rear-end collisions with casualties per year in Germany can be positively influenced by an AEBS (field of effect for truck AEBS). In the second part of the study, after 2.5 mio stochastic simulations, avoidance potentials of at least 7% for the EU-conform minimum system and up to 84% for the high-performance AEBS were identified (assuming full AEBS penetration in N3 vehicles). These avoidance potentials could scale up to 1,900 collisions with casualties in Germany per year, if each truck would be equipped with the high-performance AEBS. For the remaining accidents the collision velocity would be significantly reduced, too. In summary, this study reveals that an AEBS applied to and accounting for real-world accident situations can increase the effectiveness of an Automatic Emergency Braking System preventing rear-end collisions of trucks.

Intersection AEB implementation strategies for left-turn across path crashes

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Research
Left-turn across path with traffic from opposite direction (LTAP/OD) is the second most frequent car-to-car intersection crash type after straight crossing path (SCP) in Germany and the United States. Studies published in recent years have indicated a high potential for avoidance and injury mitigation in intersection crashes using Intersection Automated Emergency Braking (AEB) for passenger cars. This study investigates two implementation strategies of Intersection AEB addressing LTAP/OD crashes: 1) only the turning car is equipped with an Intersection AEB, and 2) turning and straight heading cars are equipped with an Intersection AEB. For each strategy, accident avoidance, injury mitigation, and change of velocity (delta-V) of remaining accidents were evaluated as a function of market penetration.

Methods
A total of 372 LTAP/OD crashes from the time-series Pre-Crash Matrix (PCM), a subsample of the German In-Depth Accident Study (GIDAS), were re-simulated in the simulation framework PRAEDICO with two implementation strategies.
and increasing market penetration of Intersection AEB. A Kudlich-Slibar rigid body impact model and an injury risk curve derived from GIDAS were used to predict remaining moderate to fatal (MAIS2+F) injured car occupants.

Results
When the turning vehicle only was equipped with an Intersection AEB, 58 percent of the crashes were avoided at a 100 percent market penetration. With both vehicles equipped the rate increased to 77 percent. MAIS2+F injured occupants were reduced by 60 and 76 percent, respectively. With both implementation strategies, the relative percentage of remaining front and right-side impacts decreased slightly, whereas the relative part of left-side impacts increased. The delta-V decreased strongly with market penetration in remaining left-side impacts, but only slightly in remaining front and right-side impacts.

Discussion
When both cars are equipped with Intersection AEB, crash avoidance is almost as high as in SCP crashes while injury reduction does not reach the predicted 90 percent for SCP crashes. The relative shift towards more remaining left-side impacts may require more focus on this crash type in restraint system development. Remaining delta-V does not decrease broadly, hence there is no evidence that future LTAP/OD crashes will be generally of lower severity. This highlights the need for continuous development of in-crash protection. Main limitations include using ideal sensing and coefficient of friction estimation in the pre-crash simulation.

Conclusion
Intersection AEB in LTAP/OD can be nearly as effective as in SCP in case the turning and the straight heading vehicle are equipped. Already at low market penetration rates, difference in crash avoidance and injury rates with Intersection AEB for the turning vehicle only and for both vehicles are clearly present. Thus, it is recommended to consider Intersection AEB not only for the turning, but also for straight heading vehicles in development and testing. The paper contributes to the session submitted with estimates of potential safety benefit of Intersection AEB systems considering different implementation strategies.

**Paper No.19-0076-O**

**PEER REVIEW**

**Characteristics of Rear-End Crashes Involving Passenger Vehicles with Automatic Emergency Braking**

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**Research**
Forward collision warning with automatic emergency braking (AEB) reduces front-to-rear crash rates by 50% (Cicchino, 2017). While the size of this benefit is impressive, vehicles with AEB are still involved in some rear-end crashes. This study identified the types of rear-end crashes in which striking vehicles with AEB are overrepresented to determine if the system is more effective in some situations than others.

**Methods**
Rear-end striking police-reported crash involvements were extracted from 23 U.S. states during 2009-2016 for passenger vehicles with and without forward collision warning and AEB among models where the systems were optional. Logistic regression was used to examine the odds that rear-end crashes with various characteristics involved a striking vehicle with AEB, controlling for driver age and gender, state, year, and vehicle make/model/model year.

**Results**
Striking vehicles were significantly more likely to have AEB in crashes where the striking (OR=1.68, 95% CI 1.32, 2.13) or struck (OR=1.72, 95% CI 1.35, 2.20) vehicle was turning, changing lanes, merging, or passing relative to when it was moving straight, negotiating a curve, slowing, or stopped; when the struck vehicle was not a passenger vehicle or was a special use vehicle relative to a car (OR=1.61, 95% CI 1.01, 2.55); on snowy or icy roads relative to dry roads (OR=1.83, 95% CI 1.16, 2.86); or on roads with speed limits of 70+ mph relative to those with 40-45 mph speed limits (OR=1.49, 95% CI 1.10, 2.03). Overall, 28.1% of crashes where the striking vehicle had AEB had at least one of these characteristics, compared with 18.7% of strikes by vehicles without AEB.
Discussion
The typical rear-end crash occurs when two passenger vehicles are proceeding straight, on dry road, and at lower speed. Because atypical crash circumstances are overrepresented among the rear-end strikes by vehicles with AEB, it appears that the system is doing a better job of preventing the more typical crash scenario. A limitation is that AEB was optional on study vehicles. Differences in rear-end crash characteristics could in part reflect different driving habits by drivers who chose and did not choose to purchase the system, although controlling for driver characteristics accounted for this possibility to some degree.

Conclusion
Consumer information testing programs of AEB use a test configuration that models the typical rear-end crash type. Testing programs promoting good AEB performance in crash circumstances where vehicles with AEB are overrepresented, such as those where the striking vehicle approaches the struck vehicle at an angle or where the struck vehicle is not a passenger vehicle, could further increase AEB effectiveness by informing automakers how their braking systems perform in these additional rear-end collision scenarios.

Paper No.19-0272-O
Typical Pre-crash Scenarios Reconstruction for Two-wheelers and Passenger Vehicles and Its Application in Parameter Optimization of AEB System Based on NAIS Database
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Abstract
The crash between two-wheelers and passenger vehicle causes a higher fatality rate and many casualties for the two-wheelers riders. Both two-wheelers and pedestrians are considered as VRU. Compared to pedestrians, two-wheelers are featured with fast moving speed and uncertain driving route, which poses a challenge to the optimal control for the autonomous emergency braking (AEB) system. This paper firstly screened 216 cases of frontal collision accidents between passenger vehicles and two-wheelers from the database of National Automobile Accident In-depth Investigation System (NAIS) in China, extracted the static and dynamic variables related to the pre-crash scenarios reconstruction in each case. This paper extracted four typical pre-crash scenarios between two-wheelers and passenger vehicles from 216 accident scenarios through clustering analysis and chi-square test, reconstructed and simulated typical pre-crash scenarios by using PreScan software and completed matching, optimization and analysis on the field of view (FoV), braking trigger width (w), time to collision (TTC) of AEB system to obtain the boundary parameter conditions of the AEB system to avoid crash or greatly reduce the collision speed, providing a reference for the development of AEB systems applicable to China's road traffic scenarios. The research method used in this paper is applicable to the reconstruction and simulation analysis of pre-crash scenarios for passenger vehicles and pedestrians as well as the parameter optimization of other ADAS. In addition, the research method used in this paper also provide a technical solution for the design, test and evaluation of the automatic driving function based on typical scenarios.

Paper No.19-0223-O
How close to zero fatalities can Volvo cars get by 2020? An analysis of fatal crashes with modern Volvo passenger cars in Sweden
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Abstract

In 2008 Volvo Cars set out its vision - by 2020 no one should be killed or seriously injured in or by a new Volvo car. Today, 2020 is very close and it is possible to assume most of the safety technologies that will likely be fitted in Volvo cars by then. The objective of the present study was to estimate how close to zero fatalities Volvo Cars can get in Sweden by 2020. The Swedish Transport Administration (STA) carries out in-depth studies of all road fatalities in Sweden. Cases involving at least one modern Volvo car were extracted for the period 2010-2017 (MY 2010 and onwards, excluding the C30, S40 and V50 models) and analyzed retrospectively (n=62). The yearly average number of fatalities in Sweden during 2010-2017 was 2.8 for occupants in Volvo cars and 5.0 for either occupants in other vehicles or VRUs impacted by Volvo cars, respectively. The actual fitment of safety technologies was investigated among the Volvo cars involved in these crashes. The basic assumption was that by 2020 the boundary conditions in each crash would be unchanged, but the Volvo car would be a MY 2020 and therefore would be fitted with the same safety technologies as the V60 MY 2019. An assessment was then made of whether a certain technology could have prevented the crash or substantially reduced the crash severity in 2020.

Cases involving extreme violations such as excessive speeding, were included in the analysis but presented separately. It was also assumed that no major improvements in crashworthiness would be introduced between the analyzed Volvo models and Volvo cars MY 2020. The analysis showed that almost half of the fatalities in and by Volvo cars could have been prevented with the safety technologies fitted on the V60 MY 2019. It was also found that most of the fatalities that could not be prevented with a V60 MY 2019, occurred in crash scenarios where at least one safety technology was relevant, although the current performance was estimated not to be sufficient to prevent the fatality. Only three cases occurred in crash scenarios without any relevant existing safety technology. It should be kept in mind that that these results were based on retrospectively upgrading already relatively safe cars to the following generation. This suggests that reducing fatalities by almost 50% through the introduction of only one new car generation would be a very impressive achievement. It is also important to note that these results were based on the assumption that the road infrastructure, speed limit and crash opponents would be unchanged. Clearly, taking safety improvements in the road infrastructure and other vehicles into account would result in an even higher reduction of fatalities in and by Volvo cars by 2020. In conclusion, regardless of whether Volvo’s vision will be achieved by 2020 or not, it is very important to set road safety targets, develop new solutions and follow up the results, also for a car manufacturer.

Paper No.19-0176-O

Car-to-car accidents at intersections in Europe and identification of Use Cases for the test and assessment of respective active vehicle safety systems

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Abstract
The Intersection 2020 project was initiated to develop a test procedure for Automatic Emergency Braking systems in intersection car-to-car scenarios to be transferred to Euro NCAP. The project aims to address current road traffic accidents on European roads and therefore sets a priority of the identification of the most important car-to-car accidents and Use Cases. Taking into account technological and practical limitations, Test Scenarios are derived from the Use Cases in a later stage of the project. This paper presents parts of a larger study and provides an overview of common car-to-vehicle(at least four wheels) collision types at junctions in Europe and specifies seven Accident Scenarios from which the three scenarios “Straight Crossing Paths (SCP)”, “Left Turn Across Path – Opposite Direction Conflict (LTAP/OD)” and “Left Turn Across Path – Lateral Direction (LTAP/LD)” are most important due to their high relevance regarding severe car-to-car accidents. Technical details about crash parameters such as collision and initial speeds are delivered. The analysis work performed is input for the definition and selection of the Use Cases as well as for the project’s benefit estimation. The numbers of accidents and fatalities in accidents at intersections involving a passenger car were shown per intersection type. In both statistics, it was found that accidents at crossroads and T- or staggered junctions are of highest relevance, followed by roundabouts. Focusing on accidents at intersections between one passenger car and another road user shows that around one-third of all accidents and related fatalities could have been assigned to car-to-PTW accidents and one-fifth of all accidents and fatalities to car-to-car accidents. Regarding car-to-car accidents with at least serious injury outcome 38% out of 34,489 car-to-car accidents happened at intersections. These figures correspond to 18% of the fatalities (4,236 fatalities in total). Considering all intersection types, around half of all related accidents happened in urban environments whereas this number decreased to one-third of all fatalities. Further, the proportion of road fatalities per country occurring at intersections varies widely across the EU. Also, there are proportionately more fatalities in daylight or twilight conditions at junctions. Use Cases are supposed to be derived from Accident Scenarios and by adding detailed information for example about the road layout, right-of-way and the vehicle trajectories prior to the collision. Instead of applying cluster algorithms to the accident data, a pragmatic approach was finally preferred to create them. Note: Use Cases serve as an intermediate step between the Accident Scenarios and the Test Scenarios which describe the actual testing conditions. Finally, 74 Use Cases were identified. This large number indicates the complexity of intersection crashes due to the combination of several parameters.

Paper No.19-0046-O PEER REVIEW
Towards Harmonizing Prospective Effectiveness Assessment for Road Safety: Comparing Tools in Standard Scenario Simulation
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Research
Active safety systems are an increasingly common focus for car manufacturers offering the possibility to avoid accidents or mitigate the consequences – a possible solution to the current stagnation of the number of road fatalities worldwide. The most important question during development of such systems is to what extent the system is capable of reducing road casualties. The objective of prospective effectiveness assessment is to provide a quantified answer to this question. Virtual simulation is the preferred tool for prospective assessment in terms of repeatability, the possibility to investigate
high numbers of configurations even in complex traffic situations and the option to test without having a fully functional physical prototype. There are many approaches possible for using virtual simulations to estimate the effectiveness of an active safety system. Moreover, there are many tools on the market to support virtual simulation. One of the reasons to start the P.E.A.R.S. initiative is to determine how large the impact is of the use of different approaches and tools on the simulation results. The main objective of this paper is to study the state-of-the-art of tools for prospective effectiveness assessment and to gain insight in which items in the approach need standardization.

Methods
A Round-Robin virtual simulation is performed with several P.E.A.R.S. partners all using their own approach with a different tool set. The study aims at assessing the effectiveness of a generic autonomous emergency brake (AEB) system in defined test scenarios. The system is specified by sensor, algorithm and actuator properties. The test scenarios are based on the CATS project and the Euro NCAP 2020 test protocol. Results of the different studies are compared and discussed. The comparison is done using parameters such as collision avoidance, the speed of collision as well as time-dependent position, speed, and deceleration of the vehicle-under-test in the simulations.

Results
Differences in results from the different approaches are found to result from 1) different time delays between the initiation of the emergency braking to the start of the actual deceleration, 2) differences in braking behavior of the different vehicle dynamics models used, and 3) differences in the calculation of time-to-collision (TTC).

Discussion
The study shows that further harmonization is required in the use of the simulation tools, e.g. for calculating the TTC. The study momentarily covers 8 tools for virtual assessment of a cyclist AEB system. The aim is to extend the study to more participants, other test scenarios and safety functions to get a broader picture on the comparability of different simulation tools and approaches.

Conclusion
This paper will describe how various simulation tools are used by different companies/stakeholders for the assessment of a cyclist AEB system in test cases as proposed by the CATS project. This Round-Robin study reveals which items need to be further harmonized for prospective effectiveness assessment of active safety systems by virtual simulation. Further harmonization and standardization will enhance the trustworthiness of results of prospective effectiveness assessment by means of virtual simulations.

Paper No.19-0313-O
An Assessment Approach to Assisted Driving Systems

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Abstract
An increasing number of vehicles on the global market provide Assisted Driving technology, also referred to as SAE Level 2 partial automation, providing the opportunity for increased driver and road safety. It is the next step towards automated vehicles. To ensure its safety benefits consumers need to be aware and informed about the capabilities of these systems. With these systems being at the cutting edge of modern vehicle technology only limited vehicles currently have these systems fitted, although they are slowly being installed into lower priced mass-produced vehicles, and therefore few consumers have experience or know of the capability of these systems. This paper investigates a way of assessing the driver support capabilities and HMI of vehicles with Assisted Driving systems to provide information of how the systems cope in different everyday scenarios which they may encounter. This paper outlines the development process of these assessments through both desk-based literature considerations and on track testing methods. Ten different vehicles where put through the assessment process to prove out the test method and offer information on the abilities of various systems. The vehicles are all produced by different manufactures and range from cheaper less capable to higher end advanced systems with the purpose of showing that within Assisted Driving systems there is vast difference in the performance outcome in both everyday driving and safety critical situations. The assessment of the systems will
allow for a basis which will be expanded on for greater in-depth evaluation into the overall safety of the systems and ultimately the assessment of automated vehicles. The assessment protocol has been developed in agreement with Euro NCAP for the evaluation of ten production vehicles available to buy late 2018, looking into developing the protocol for future testing and grading of new vehicles to be released with Assisted Driving technology.

**Paper No.19-0256-O**

**Hydroplaning avoidance – a holistic system approach**

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**Abstract**

Accidents in severe weather mainly arise due to a drastic loss of friction between the tires and the road surface unexpected by the driver. Beside all kinds of slippery winter conditions hydroplaning situations are even more dangerous not just for manually driven vehicles but also for automated vehicles when cruising at speeds above 80 to 100 km/h. This paper describes the Continental approach for a cascaded holistic safety system in imminent hydroplaning situations independent of the degree of automation. First, to reduce the overall hydroplaning risk a continuous tire tread depth monitoring function is integrated to trigger a timely replacement of worn-out tires. Second, a surround view camera and new tire-sensor-based early hydroplaning risk recognition allows an in-time driver warning or a system-initiated speed adaptation in case of automated vehicles. Especially for Automated Driving (AD) vehicles it is of major importance to avoid hydroplaning before it happens. Third, this information is send to the cloud-based eHorizon service so that also other traffic participants can be informed before entering a hydroplaning risk area. In case hydroplaning cannot be avoided a control system is designed and tested to evaluate an innovative assistance strategy in hydroplaning situations. The test cases demonstrate the suitability of this assistance concept.

**Paper No.19-0078-O**

**Safety evaluation of automated vehicle through actual vehicle tests in cut-in and lateral overlap cut-in situation.**

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**Abstract**

This paper describes the safety assessment results of level 2 automated vehicles in cut-in and overlap cut-in collision situations. The test results were compared with typical rear-end and 50% overlap rear-end collisions. From analysis of NASS CDS data, cut-in rear-end accidents occur at a rate of 25% out of rear-end accidents. The cut-in and 50% overlap cut-in situation were tested for the evaluation of level-2 automated vehicles. Main parameters of the cut-in scenario are speed of vehicles, TTC(Time to collision) and TLC(Time to lane changing). The speed of vehicles for scenario composition was selected from NASS CDS data analysis. The speed of the vehicle target was selected at 20km/h. The speed of the VUT(Vehicle Under Test) consisted of 5 types: 30, 40, 50, 60 and 70 km/h. Cut-in scenarios were designed with TTC 4 seconds and the target vehicle changes the lane to the front of the test vehicle at each TTC. The target vehicle’s TLC was set to 2 seconds at all scenarios. For comparison, rear-end collision and 50%-offset rear-end collision scenarios suggested by EuroNCAP 2018 were also tested. A low platform robot vehicle target was utilized for all test scenarios. The low platform robot vehicle and a balloon dummy were used to imitating the causative vehicle in the accident and reproduce the accident situation. The robot vehicle target and the VUT were communicated with their position, speed, and acceleration data from GPS INS data. The data were recorded for further analysis.
Quantifying Vision Zero: Crash Avoidance in rural and motorway accident scenarios by combination of ACC, AEB and LKA projected to German accident occurrence

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Research

The Vision Zero initiative pursues the goal of eliminating all traffic fatalities and severe injuries. Today’s Advanced Driver Assistance Systems (ADAS) are an important part of the strategy towards Vision Zero. In Germany in 2017 more than 26,000 people were killed or severely injured by traffic accidents on motorways and rural roads with car involvement. Focusing on collision avoidance, a simulative evaluation can be the key to estimate the performance of state of the art ADAS and to identify resulting potentials for system improvements and future systems. This project deals with the Effectiveness Assessment of a combination of ADAS for longitudinal and lateral intervention based on German accident data. Regarded systems are Adaptive Cruise Control (ACC), Autonomous Emergency Braking (AEB) and Lane Keeping Assist (LKA).

Methods

As an approach for the Benefit Estimation of ADAS the method of Prospective Effectiveness Assessment is applied. Using the software tool rateEFFECT it is performed a Closed Loop simulation on accident scenario data of the German In-Depth Accident Study (GIDAS) Pre-Crash-Matrix (PCM). To enable the projection of results to entire Germany, the simulative assessment is amended by detailed single case studies of all treated cases without PCM data.

Results

Three categories among today’s accident occurrence on German rural roads and motorways are reported by this study: green, grey and white spots. Green spots identify accidents that can be avoided by state of the art ADAS ACC, AEB and LKA. Grey spots contain scenarios that require minor system modifications, such as reducing the activation speed or increasing the steering torque. Scenarios of category white cannot be addressed by state of the art ADAS. Thus it is shown which situations demand future systems. The proportions of green, grey and white spots are determined related to the considered data set and projected to the national level of German accident statistics.

Discussion

This elaboration covers three state of the art ADAS and the assessment of these based on German rural road and motorway accident scenarios with at least one severely injured person. The simulative Closed Loop approach gives the possibility to easily change parameters and system settings in order to identify sensitivities that influence the system performance for crash avoidance. The aim is to extend the study by including urban scenarios and considering generic implementations of future driving functions.

Conclusion

This paper will describe a systematic approach to assess the effectiveness of ADAS using GIDAS PCM data in a way to be able to project the results to whole Germany. The Closed Loop simulation run in rateEFFECT covers the systems ACC, AEB and LKA as well as the relevant sensors for environment recognition and actuators for longitudinal and lateral vehicle control. The identification of green spots evaluates the safety benefits of state of the art Level 0-2 functions as a baseline for further system improvements to address grey spots. Figuring out which accident scenarios could be solved by standard ADAS helps to focus the evolution of future driving functions on the white spots in order to aim for the Vision Zero.
Research
Approximately 22% of all crashes in the United States are related to turning left in intersections. Intersection Advanced Driver Assistance Systems (I-ADAS), sometimes referred to as left-turn assist, are a promising countermeasure to prevent or reduce the severity of some of these Left Turn Across Path / Opposite Direction (LTAP/OD) crashes. The objective of this study was to estimate the number of LTAP/OD crashes and injuries that could be prevented in the United States if all vehicles were equipped with an Intersection Advanced Driver Assistance System (I-ADAS).

Methods
This study reconstructed 501 vehicle-to-vehicle LTAP/OD crashes in the United States which were investigated in the NHTSA National Motor Vehicle Crash Causation Survey (NMVCCS). The performance of thirty different I-ADAS system variations was evaluated for each crash. These variations were the combinations of five TTC activation thresholds, three latency times, and two different response types (automated braking and driver warning). In addition, two sightline assumptions were modeled for each crash: one where the turning vehicle was visible long before the intersection, and one where the turning vehicle was only visible within the intersection. For resimulated crashes which were not avoided by I-ADAS, a new crash delta-v was computed for each vehicle. The probability of Abbreviated Injury Scale 2 or higher injury in any body region (MAIS2+) to each front row occupant was computed based on logistic regression modeling of crash injury in the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS).

Results
For LTAP/OD crashes across all I-ADAS variations and both sightline assumptions, 0%-25% of all LTAP/OD crashes could have been avoided using an I-ADAS system which warns the driver. An I-ADAS system that automatically applies emergency braking could avoid 19%-73% of all LTAP/OD crashes. An I-ADAS system that warns the driver in LTAP/OD crashes was able to prevent 1%-28% of front row occupants from receiving MAIS2+ injuries. A system which applies emergency braking could prevent 45%-82% of front row occupants from receiving MAIS2+ injuries.

Discussion
This study considers an idealized I-ADAS algorithm and may not generalize to a specific design. Our model assumes all intersections reside in urban canyons which the sensors cannot see around. With the introduction of vehicle-to-vehicle communication technologies, this assumption may not be important. With I-ADAS, some crashes are modified. These are cases in which the crash occurred with I-ADAS, but the crash conditions changed. In the majority of cases where this occurred, the injury outcome improved. In a very small number of cases, the injury outcome was worse with I-ADAS. The vast majority of these so-called “disbenefit” cases had very low magnitudes of disbenefit. The maximum average increase in injury risk across all I-ADAS configurations was 8.7pp.

Conclusion
This study presents the simulated effectiveness of an idealized intersection active safety system on real crashes which occurred in the United States. This work shows that there is a strong potential to eliminate crashes and injuries in the United States. This work considers the evaluation of a Level-2 vehicle system and is highly suited to the Tuesday Track C session.
Paper No.19-0135-O
Simulation Assessment of Injury Trends for 50th Percentile Males Using Potential Seating Configurations of Future Automated Driving System (ADS) Equipped Vehicles

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Abstract
Occupants in vehicles equipped with automated driving systems (ADS) may sit in various seating positions (e.g. forward facing, rear facing, oblique facing) and at different seatback recline angles. Since forward facing impacts have been studied in detail, the objective of this study was to: A) analyze rear impacts using finite element (FE) human and seat models; B) update the seat model based on lessons learned from part A and then analyze the injury metrics trend for the 50th percentile male occupant: i) at various seatback recline angles, and ii) in different carriage style seating configurations; and C) investigate a potential countermeasure for reducing injury metric values. For analyzing rear impacts, the Total Human Model for Safety (THUMS) FE model along with a FE driver seat model of a Toyota Yaris was used. Simulations were carried out at both low (Delta-V=15 mph) and high (Delta-V=35 mph) speeds to understand the effect of seat hinge stiffness on THUMS kinematics at both speeds. Other design changes such as integrated seat belts and active head restraints were also evaluated. Then injury metrics were analyzed for the 50th percentile male occupant at various seatback recline angles and in different carriage style seating configurations. For this part of the study, Global Human Body Models Consortium (GHBMC) 50th percentile simplified (M50-OS) male FE model was used along with a Honda Accord FE driver seat model. Head Injury Criterion (HIC) and Brain Injury Criterion (BrIC) were used as injury metrics for the head/brain, while max chest deflection was used as the chest injury metric. A potential countermeasure for reducing BrIC was investigated for the seating configuration with the highest BrIC value. From the rear impact study, it was found that having a rigid seat hinge, an integrated seatbelt, and an active head restraint help in reducing the injury metrics. Higher BrIC values were observed at higher seatback recline angles for both frontal and rear impacts. Chest deflection was also higher at higher seatback recline angle for frontal impact but showed an inverse trend for rear impact. For occupants experiencing frontal/oblique-frontal impacts, the BrIC and chest deflection values ranged from 0.75 to 0.81 and from 33 to 45 mm respectively whereas for occupants experiencing rear/oblique-rear impacts, the BrIC and chest deflection values ranged from 0.23 to 0.93 and from 17 to 24 mm respectively. HIC15 values were below 300 for the various recline angles and seating configurations investigated except one instance where the head contacted the knee. The potential countermeasure (redesigned head restraint) investigated was effective in reducing BrIC by a third for the case with the highest BrIC value (0.93).

Paper No.19-0056-O
Posture and Belt Fit in Reclined Passenger Seats

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26ESV/Program Book
Automated road vehicles are likely to result in a larger number of passengers exposed to crashes, because many current drivers may become passengers. Due to the lack of the constraints imposed by the driving task, passengers may assume a wider range of postures. Highly reclined postures, defined here as those greater than 30 degrees from vertical, are expected to become more common among occupants exposed to crashes. Currently minimal data are available on the postures and belt fit experienced by people at high recline angles. Detailed posture and belt fit data are needed to ensure that human surrogates, including crash test dummies and computational human body models, are positioned and used in a quantitatively accurate manner when simulating these scenarios. The goal of this study was to address this gap through a laboratory study of reclined passenger postures.

Methods
A laboratory study of 24 men and women with a wide range of body size and age was conducted. A mockup was constructed using a front seat from a late-model SUV and a three-point belt that was configured so that the upper anchorage followed the seat back as it reclined, simulating a seat-integrated belt. Participants assumed comfortable postures with and without head support at seat back angles (SAE A40) of 23, 33, 43, and 53 degrees. Posture and belt fit were measured by digitizing landmarks using a FARO Arm coordinate measurement machine.

Results
All torso body segment angles increased linearly with seat back angle but at different rates, so that lumbar spine flexion decreased. Sitter-preferred supported head postures were markedly more rearward than unsupported postures, with approximately constant cervical flexion across back angles. Shoulder belt fit was unaffected by back angle due to the seat-integrated configuration, but the lap belt routed further forward and lower, relative to the pelvis, with increasing seat back angle. Regression models are presented for use in posturing human surrogates used to assess crash safety for reclined passengers.

Discussion
This is the first study to present detailed posture and belt fit data for passengers at highly reclined seat back angles. The study is limited by the short duration and static laboratory setting. A single seat that was not specifically designed for highly reclined postures was used.

Conclusion
Postures in highly reclined seats are markedly different from the human-surrogate postures typically used for assessing restraint system performance. Of particular interest are the altered pelvis orientation and lumbar spine flexion, which may affect belt restraint interactions during crashes that necessitate changes in belt system design. These results will be valuable for assessing ATD design, developing accurate posturing methods for ATDs and other human surrogates, and as design guidance for developing safer occupant environments.

**Paper No.19-0062-O**

**The Influence of Reclined Seating Positions on Lumbar Spine Kinematics and Loading in Frontal Impact Scenarios**

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**Abstract**
With the advent of alternative seating positions in Highly Automated Vehicles, vehicle manufacturers must take care to ensure the safety of new seating positions. The use of Human Body Models (HBMs) can aid in the use of analyzing these new concepts, as they closely represent a human being. HBMs are constructed with Finite Element (FE) modelled bones, muscles, and organs; whereas crash test dummies are made of foams, rubbers, and metallic structures. Due to these differences. HBMs show a different response compared to traditional crash test dummies. A sensitivity study on spinal posture using the THUMS v5 was performed using a BMW prototype reclined concept seat. By changing the initial of the posture of the lumbar spine, changes in spinal kinematics as well as varying force responses were observed during a frontal load case. This type of study could not be conducted with a crash test dummy as the spine of standard front crash dummies does not easily allow for postural changes. These variations suggest that initial spinal posture plays a role in the
Paper No.19-0115-O PEER REVIEW

Passenger Muscle Responses in Lane change and Lane change with Braking Manoeuvres using two belt configurations: standard and reversible pre-pretensioner

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Research  
The introduction of integrated safety technologies in new car models call for an improved understanding of the human occupant response in pre-crash situations. The aim of this paper is to study occupant muscle activation in these situations and to provide validation data for Human Body Models (HBMs) capable of controlling muscles in simulations of evasive manoeuvres which can potentially occur prior to a crash.

Methods  
Front-seat male passengers wearing a seat belt in either standard or pre-tensed configuration were exposed to multiple autonomously carried out lane change and lane change with braking manoeuvres while traveling at 73 km/h. This paper focuses on muscle response data (surface electromyography normalized using maximum voluntary contraction data (MVC)) obtained from 38 muscles in the neck, upper extremities, the torso and lower extremities. The muscle response data were compared to results presented in a preceding paper; head and torso kinematics; seat cushion pressures; footwell forces; belt forces and payout; and vehicles dynamics.

Results  
In normal driving conditions prior to any evasive manoeuvre, activity levels were low (<2 %MVC) in all muscles except for the lumbar extensors (3-5.5%). During the lane change maneuver, selective muscles were activated and these activations restricted the sideway motions due to inertial loading. Averaged muscle activity, predominantly in the neck, lumbar extensor and abdominal muscles, increased up to 24% of MVC soon after the vehicle accelerated in lateral direction for all volunteers. Differences in activation time and amplitude between muscles in the right and left side of the body were observed relative to the vehicle’s sideway motion. Small elevation in right acromion up to averagely 22 mm was observed during the first second of the manoeuvres with no noticeable upper Trapezius muscle activation (below 2% MVC).

Discussion  
The manoeuvres were carried out on an airfield; the riding did therefore not include all elements of riding in normal traffic. The quite sitting was however similar to that of occupants riding in the passenger seat in normal traffic. Several manoeuvres were carried out with each volunteer and to reduce the effect of muscle habituation they were randomized.

Conclusion  
The results showed that for specific muscles, lane changes with the pre-pretensioner belt were associated with earlier muscle activation onsets and significantly smaller activation amplitudes than for the standard belt (p<0.05). This was consistent with previously found lower sideway and forward displacements for head and T1 with the pre-pretensioner belt versus the standard belt. The data provided in this paper can be used for validation and further improvement of HBMs with active musculature in both sagittal and lateral loading scenarios intended for simulation of pre-crash situations.

Paper No.19-0103-O PEER REVIEW

Validation of a Simplified Human Body Model in Relaxed and Braced Conditions in Low-Speed Frontal Sled Tests

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Occupant kinematics in low-speed frontal pulses differ significantly in relaxed and braced states due to the effect of active muscle tone. The Global Human Body Models Consortium (GHBMC) average male simplified occupant model (M50-OS) has been validated against dynamic post mortem human subject (PMHS) experiments, yet the lack of active musculature precludes its ability to model human volunteer kinematics. Therefore, the goal of this study was to add active musculature to the GHBMC M50-OS model and validate its performance in low speed frontal crash scenarios.

Methods
Volunteer (n = 5) and PMHS (n =3) data from low-speed frontal sled tests by Beeman et. al., including 2.5g and 5g acceleration pulses, were used to simulate the events in LS-DYNA (R. 9.1, LSTC, Livermore, CA). The baseline M50-OS model was used to simulate PMHS tests. All the muscles are modeled as one-dimensional beam elements and assigned Hill-Type muscle material. Origin and insertion points were based on anatomical texts. The M50-OS with active muscle (M50-OS+M) employs varying levels of initial muscle activation to represent volunteer relaxed and braced condition sled tests. Initial activation levels for muscles were taken from normalized EMG data from Beeman et al. Affine scaling is used to run matched pair simulations of each experimental trial with a scaled version of the GHBMC M50-OS or -OS+M model, for a total of 32 simulations. The activation level for each muscle is calculated using firing rate of motor neurons sigmoid function, which uses output of the proportional–integral–derivative (PID) controllers. The PID controller attempts to preserve the initial posture of the model, which is an assumed behavior of the volunteers. Controller gains were optimized using LS- OPT (V5.2.1, LSTC, Livermore, CA). Percentage contribution of each muscle and the co-contraction ratio of muscles were taken from previous literature.

Results
PMHS simulation results shows good agreement with experimental results. Preliminary results from volunteer simulations have shown a strong dependence of reaction loads and kinematics on muscle activation, with 51.9% and 5.6% decrease in overall head kinematics of M50-OS+M in braced as well as relaxed condition respectively, compared to the baseline M50-OS. Similar reductions in the overall kinematic motion in the anterior (x-direction) were observed in volunteer tests, demonstrating the ability of selected approach to capture the active muscle response.

Discussion
All three conditions showed different head kinematics as observed in the experiments, but there was no significant change in the run time between M50-OS and M50-OS+M. The goal of the M50-OS+M is to provide occupant kinematics from the pre-crash phase and switch over to detailed model for the actual crash phase, as demonstrated in a previous study. The main limitation is that it is limited to lab sled data only in the frontal direction, but future work will focus on alternative loading directions and pulses, such as oblique and lateral directions.

Conclusion
We demonstrate the effect of active muscles in simplified models to predict pre-crash kinematics of relaxed and braced subjects. An active muscle version of the GHBMC simplified occupant model was developed and validated in frontal sled conditions.

Paper No.19-0215-O
Development of a Hybrid Muscle Controller in LS-DYNA for an Active Finite Element Human Body Model Capable of Occupant Kinematics Prediction in Frontal and Lateral Maneuvers

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Abstract
Automotive safety has made a definite shift towards the continually increasing use of active safety systems in standard and highly automated vehicles (HAV) with a crucial need for the development of tools to supplement the assessment of such systems. Finite Element Human Body Models (FE HBMs) emerge as an innovative pre-requisite for this process in a virtual toolchain. Traditional passive HBMs were developed for in-crash simulations and are not suitable for straightforward use in the pre-crash phase because of inappropriate soft tissues response in low gravity scenarios and the absence of active muscle elements with a proper controller. The current contribution addresses some transformation issues from passive to active behavior for HBM and focuses on the development of a physiologically motivated controller for the whole HBM utilizing standard LS-DYNA keywords. The controller operates with the contraction dynamics of *MAT_MUSCLE material (also referenced as *MAT_156) through Hatze’s activation dynamics and is capable of resembling
a valid occupant response during maneuvers. The proposed neural control model is a form of intermittent control and based on the assumption that the central nervous system governs the controlled motion through shifting between particular states of the musculoskeletal system – so-called “equilibrium points”, where equilibrium of all acting external and internal forces is presumed for a resulting desired position. A hybrid formulation of the controller allows for taking closed-loop muscle stimulation (target muscle lengths “λ”) as well as open-loop stimulation (“α”) into account. Previous to the whole body application, the equilibrium point hybrid controller (EPHC) approach was validated separately for some parts of the body only. Posture control capability was investigated by tracking motion speed, maximum muscles activation level and the effect of co-contraction. Subsequently, the full HBM simulations were carried out for lane change and 1g braking scenarios retrieved from the experimental database of the Occupant Model for Integrated Safety (OM4IS) project. A modified Total HUman Model for Safety (THUMS) model was correlated to a matched size volunteer with the comparison of head and torso excursions to appropriate experimental corridors. Each single body region model was validated with in vivo kinematics and dynamics enabling an integration of the single body parts into the entire HBM. Measured maximal deviations for the whole HBM reside within the experimental corridors and correlate well with the volunteer. The proposed approach permits modeling of active and reactive human responses with the help of an existing passive FE HBM after adequate adaptation of the model, muscle elements insertion and controller parameters tuning. Such model paves the way for the evaluation of new HAV interior concepts and the development of advanced vehicle safety systems.

Paper No.19-0257-O

A Step Towards Integrated Safety Simulation through Pre-Crash to In-Crash Data Transfer

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Abstract
Occupant simulation methods in the area of passive safety address usually the investigation and prediction of crash dummy behavior after the time of collision. The development and optimization of active and also pre-triggered passive safety systems [1] require new simulation methodology including improved occupant models [2][3] and data transfer possibility between pre-crash and crash phase of a crash event. Prediction of occupant behavior in the pre-crash phase is one important enabler for such a new occupant simulation methodology dealing with optimization of integrated safety systems. In this work, a semi-automated method is developed for posture and velocity data transfer between pre-crash Active Human Body Model (AHBM) and in-crash Human Body Model (HBM) or dummies. In one use case the application of the developed method is shown.

Paper No.19-0341-O

A FRAME WORK TO CONSIDER THE NEW INJURY SEVERITY SCORE (NISS) AND A FUNCTIONAL CAPACITY INDEX (FCI) IN DETERMINING AIRBAG DEPLOYMENT THRESHOLD

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Objective: The current study aimed to develop a framework to consider the new injury severity score (NISS) and a whole-body functional capacity index (WBFCI) in determining airbag deployment threshold during frontal crashes using a computational human surrogate model and real-world crash data. Methods: Common AIS2+ injuries that front row seated occupants sustained during frontal crashes (|PDOF|<30 degrees) were identified from the NASS-CDS database 2006-2015. Injury mechanisms of the common injuries were assigned based on literature. A finite element mid-size male occupant model (Global Human Body Model Consortium-owned GHBMC Model, v4.5) was instrumented to measure those injury metrics so that the risk of the injuries can be calculated from crash simulation results. The whole body was divided into 21 body regions considering the capability of the human surrogate model. For these body regions, body region specific injury pattern bins, which contain a list of the abbreviated injury score (AIS) codes, were collected from each occupant from the NASS-CDS database. Monte Carlo Sampling was performed to infer AIS levels for each body region of the human body model based on predicted injury risk from a crash simulation. Another Monte Carlo Sampling was conducted to map a body-specific injury pattern to each body region based on the predicted AIS level, which allowed us to calculate WBFCI values for each virtual occupant. Lastly, a series of frontal crash simulations were performed in a simplified sled environment for various velocity changes with and without deploying pyrotechnic restraint systems. Results: 449 AIS2+ unique injuries were observed from frontal crash involved occupants from the NASS-CDS. As the change of velocity increased, the predicted ISS values increased, and WBFCI values decreased for both with and without deployment cases. There were intersection points where the deployed conditions began to show a protective effect compared to the non-deployed conditions. Discussion: The current study proposed a way to consider polytrauma metrics, which are widely used in epidemiology studies, for the evaluation of the performance of the restraint systems. The capability of the proposed method was demonstrated for determining airbag deployment threshold regarding the change of the velocity. As the next step, the proposed method requires to be further evaluated regarding the biofidelity of the human surrogate model, qualities of the injury metrics, and accuracies of the Monte Carlo sampling steps. Conclusion: While the proposed method requires further evaluation for its validity, if successful, this method could be a useful tool to evaluate various integrated occupant protection systems, which is expected to be introduced in the field in the future.

Paper No.19-0052-O
DEVELOPMENT OF A HUMAN FE MODEL FOR ELDERLY FEMALE OCCUPANTS IN SIDE CRASHES

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Abstract
A high fatality rate of the elderly in traffic crashes is an important issue to consider when facing an aging society in the future. Left side impacts have been found to be the most frequent when considering severe crashes involving elderly people that resulted in Abbreviated Injury Scale (AIS) 4+ injuries in the United States. Additionally, the frequency of rib fractures in female occupants is significantly higher than males in those over sixty years in a side impact. Therefore, there is a need to reduce rib fractures in elderly females in side impacts, which should significantly decrease the number of
fatalities in these types of crashes. Currently there are no evaluation tools for elderly female occupants with increased fragility. The objective of this study was to develop a Human Body Model (HBM) of an elderly female with increased fragility to use in simulations which focus on side impacts. The material properties of rib cortical bone were determined using average data from published literatures. A rib bending simulation was conducted to compare force-deflection response with published experimental data. The rib cortex model included thirty-two sections of a rib, in which the thickness of each section was determined by comparing to published precise cross-sectional data. The evaluated rib model was then applied to the full-body HBM of an elderly male which was developed in a past study. Using the full body model geometrically scaled to elderly female, published side impact sled tests at 28 km/h of delta-V with post mortem human subjects were simulated to compare kinematics, rib fracture locations, and thoracic deflection obtained from chest band data. Comparison of the force-deflection response of the rib in bending showed that the simulation result fell within the overall experimental range. In the side impact sled simulations, the predicted trajectories of T1, T12, and the pelvis were found to be similar to those from the experiment. The number of rib fractures, fracture timing, fracture locations and overall thoracic deflection in the simulation exhibited a similar trend to the experimental data. The HBM developed by applying rib material properties and geometrical scaling for an elderly female well represented upper body kinematics, rib fractures and thoracic deflection in a side impact when compared to published PMHS experiments.

Paper No.19-0105-O  PEER REVIEW

Elderly Rib Fracture in Nearside Crash in Real-World Crash Data

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Research
The purpose of this study was to use the detailed medical injury information with analytic morphomics in the University of Michigan International Center for Automotive Medicine (ICAM) database to evaluate rib fracture in elderly patients in real world nearside crashes.

Methods
Inclusion criteria for the nearside crashes was based on the Collision Deformation Classification (CDC) of the impact (either 2-4 o’clock and 8-10 o’clock). In cases with multiple impacts, only the primary impact was considered. Occupants were older than 15 years and an injury was defined by an Abbreviated Injury Scale (AIS) severity of 3+ chest injury with an available thoracic CT scan. Occupants in nearside crashes were seated with and without 3-point belts in the first and second row outboard seating positions and categorized by age in either an under 60 (non-elderly) group or 60 and over (elderly) group. The total number of case occupants fitting these inclusion criteria was 65. Chest injury rates were first examined with occupants involved in nearside crashes with AIS severity of 3+ from the ICAM database. Then, the 3-dimensional location of rib fractures present in CT scans from the ICAM population of car crash occupants was documented using the analytic morphomics system. Univariate analyses were conducted to investigate the association between analytic morphomics measures and rib fracture.

Results
Among 65 occupants in nearside crashes, there were 50 non-elderly occupants, and 15 elderly occupants. Compared to the non-elderly group, rib fractures were more likely to occur in the elderly group even with smaller lateral intrusion. In addition, the location of rib fractures of nearside occupants were mainly on the outboard side and distributed over a wide area. For the elderly group, fractures tended to be located more laterally, rather than posteriorly. Among the various morphomics variables, bone density and fat distribution were significantly different between the two groups in nearside crashes.

Discussion
Although the sample size is limited, the bone density and fat around the torso area were among the most significant morphomics variables from the univariate analysis from the two age groups in nearside crashes. In a prior study, fat
thickness was important to determine injury severity and this fat distribution may affect the severity of thorax injuries caused by the impact. Therefore, the role of fat potentially has a protective effect for the occupant. On the other hand, decreased bone density, which is well known as an age-related factor, increases rib fracture risk in nearside crashes. Therefore, the effect of morphomics variables as well as vehicle and demographic variables would be beneficial to understand the potential important factor for predicting rib fracture for elderly occupants.

Conclusion
This study used detailed injury and crash data in conjunction with medical imaging from the ICAM and morphomics databases to evaluate the effect of elderly in nearside crashes. Results, confirmed with real-world crash cases, morphomics measures are important when predicting rib fracture.

Paper No.19-0068-O
EVALUATION OF THORACIC DEFLECTION CRITERIA IN FRONTAL COLLISION USING THORACIC IMPACTOR SIMULATION WITH HUMAN BODY FE MODEL
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Abstract
When involved in vehicle accidents, the fatality rate of thoracic injury is high, following head injury, and the major causality is a rise of organ injury rates due to an increase in the Number of Fractured Ribs (NFR). Previous studies suggested a high correlation between thoracic deflection and NFR. However, the correlation was evaluated primarily using test data in frontal collisions with restraint systems such as seatbelts or airbags. Thus, it was not evaluated by local loading. The objective of this paper is to evaluate the correlation between the thoracic deflection criteria and NFR under local loading conditions by thoracic impactor loading. In order to evaluate the relationship between thoracic deflection criteria and NFR by localized loading, thoracic impact is more proper than sled impact, in which loading location and direction depend on restraint systems. Impact simulations were conducted on 19 points to cover the whole right side of the thorax. The simulations were conducted with the Global Human Body Model Consortium (GHBMC) 50th percentile male model for LS-DYNA. Deflection of each rib was measured at its anterior tip and Rmax was calculated using the deflections on the 4th rib and the 7th rib to represent Anthropometric Test Dummy (ATD) measurement points. In addition, Average Deflection of All Ribs (ADAR) and Weighted Average Deflection of All Ribs (WADAR) were calculated as proposed criteria. Then the correlation between NFR and each of those criteria was evaluated using the correlation coefficient. The results showed that some specific impact points lower the correlation between NFR and Rmax. Impacts around 1st through 3rd ribs incur rib fractures without deflection on the representative points because the sternum and costal cartilage do not transmit the force and deflection to other ribs. On the other hand, ADAR showed a higher correlation with NFR than Rmax, and WADAR further improved correlation with NFR. The results showed that WADAR needs to be taken into account to improve correlation between NFR and thoracic deflection. It suggests that deflection of all ribs modified by homogeneity of each rib deflection need to be considered in order to properly evaluate rib fractures caused by localized loadings. The thoracic deflection criterion using weighted average deflection of all ribs showed the highest correlation with NFR and it allows evaluating rib fractures even under localized loading conditions.

Paper No.19-0072-O PEER REVIEW
Simulating cerebral edema and delayed fatality after traumatic brain injury using triphasic swelling biomechanics
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Research
Contemporary finite element (FE) models, like that from the Global Human Body Models Consortium (GHBMC), have been useful for developing automobile safety systems to reduce the severity of injuries in motor vehicle crashes (MVCs), including traumatic brain injury (TBI). However, not all damage/injury occurs during the MVC. Cerebral edema or brain swelling is a significant clinical consequence of TBI contributing to its high rate of mortality by increasing intracranial pressure (ICP) and preventing adequate cerebral blood supply. The focus of this study was to model post-traumatic cerebral edema and subsequent ICP-increase to better predict outcome after MVCs.

Methods
Brain tissue swells in a manner consistent with triphasic biomechanics, which models biological tissues as a mixture of a charged deformable porous solid matrix, i.e. a fixed charge density (FCD), a solvent, and monovalent counter-ions, i.e. cerebrospinal fluid. Fluid uptake into the brain is driven by the Gibbs-Donnan osmotic pressure as the FCD is exposed when cells die. Post-TBI edema was simulated in FEBio (febio.org), which includes triphasic material formulations. The GHBMC mesh and nodal deformations from GHBMC-simulated crashes, were imported into FEBio to calculate maximum principal strain (MPS) on a per-element basis. To simulate swelling, each element of the FEBio mesh was assigned an FCD based on the maximum MPS to represent post-traumatic cell death.

The ensuing pathophysiology was simulated in two steps. First, the brain swelled in response to exposure of FCD, causing some adjacent elements to be compressed as fluid was redistributed. Biologically, the compression results in reduced blood flow and subsequent ischemic cell death, which was represented by exposure of FCD, producing additional swelling and raising ICP.

Results
Using example head impact cases of different severities, FEBio was able to simulate post-traumatic swelling and subsequent ischemia damage to predict changes in ICP. The post-traumatic volume of elements ranged from less than 40% (compaction) to greater than 220% (swelling), depending on injury severity. Predicted ICP values for a fatal impact were as high as 40 mmHg.

Discussion
To the best of our knowledge, this is the first study to simulate post-traumatic brain swelling to predict outcome. By incorporating swelling, ischemia, and subsequent cell death, our novel simulation approach may improve fidelity of predicting outcome after MVCs, which in turn may improve safety systems. A strength of our approach is relying on the highly validated GHBMC model to predict brain deformation in the crash scenario, avoiding unnecessary re-validation of a new impact model. The main goal of the current study was to demonstrate feasibility of simulating post-injury swelling using triphasic biomechanics. We successfully predicted clinically relevant increases in ICP that suggest a high likelihood of death when simulating a fatal impact scenario, however, more validation of our methodology is needed.

Conclusion
We have devised a new strategy for predicting outcome after MVCs that simulates cerebral edema and death in the subacute period after injury.
Research
Brain injuries account for a large percentage of fatal head injuries in traffic accidents. Except direct injury to the brain stem, fatal brain injuries experience some physiological changes in brain tissues, subsequent to primary damage caused by head kinematics and/or impacts. Although efforts have been made in past studies to estimate probability of severe/fatal injuries due to brain injury, none of them involved prediction of such physiological changes to the best of the authors’ knowledge. The goal of this study was to evaluate fatality prediction capability of a novel approach to predict increase in intracranial pressure (ICP) due to head kinematics/impacts by combining the predicted pressure with probability of fatality taken from past clinical findings. As the first step, focus was given to qualitative comparison between field or experimental observations and predicted probability of fatality in select cases simulating various severity of brain injuries.

Methods
A total of 18 time histories of head linear and rotational accelerations were used to represent various severity of brain injury. The time histories were obtained from either reconstruction simulation of accidents with fatal, severe and no brain injuries, or the literature describing reconstruction tests of head impacts in non-injurious volunteer sled tests. These time histories were first applied to GHBMC head-brain model to predict nodal displacement time histories of the brain model, which were then fed into FEBio to predict ICP. Weibull survival model was applied to the survival rate as a function of ICP obtained from a clinical paper to estimate a fatality probability function. Probability of fatality estimated for the 18 cases was compared with the injury severity levels to validate the prediction. In addition, probability function of severe disability or fatality was developed using the same procedure to compare prediction of probability of severe or fatal injuries against that predicted using the methodology proposed by a past study using a probability function based on animal testing.

Results
The results of the prediction of probability of fatality for the 18 select cases showed that the predicted average probability clearly increased as the severity of injury increased. In all of the 6 cases simulating fatal accidents, the predicted ICP was found to be more than 23 mmHg of the threshold proposed by the clinical paper. It was also found that the methodology proposed by the past study predicts much higher probability compared to the one used in the current study.

Discussion
The results of this study suggests that probability of fatality can be more reasonably estimated using the proposed methodology than that from the past study. More head impact cases need to be investigated to quantitatively validate the proposed methodology.

Conclusion
Prediction of probability of fatality by means of a combination of the simulations of the brain deformation and the increased ICP was found to provide a more reasonable estimation compared to the risk curve from a past study in the select 18 head impact cases.

Abstract
This study investigates the adequacy of comparing the risk of brain injuries based on the available National Automotive
Sampling System/Crashworthiness Data System (NASS/CDS) field data to the risk predicted by Brain Injury Criterion (BrIC) measured from an Anthropomorphic Test Device (ATD) in NHTSA’s Research Moving Deformable Barrier (RMDB) oblique tests (fleet). Finite Element (FE) analysis was utilized to simulate crashes with a given range of Principal Direction of Force (PDOF) and change in velocity (Delta-V) to illustrate their effect on the field vs. fleet risk comparison. The simulation based results indicate that BrIC is highly dependent on PDOF and Delta-V. The methods applied for estimating brain injury risk from the simulation results demonstrate the importance of accounting for the distributions of both PDOF and Delta-V when comparing brain injury risk estimates from the field data versus those calculated from fleet testing.

KEYWORDS: BrIC, field data analysis, fleet data analysis, head/brain injury
Abstract
Since 2003, the Insurance Institute for Highway Safety (IIHS) has rated side impact crashworthiness based on tests involving a 1,500 kg moving deformable barrier (MDB) with the geometry of pickups and SUVs (LTVs) striking the side occupant compartment of a stationary vehicle with driver and rear passenger SID-IIs dummies. Previous examinations of real-world side crashes revealed that one quarter of 2016 side crash fatalities were in good-rated vehicles, suggesting that more improvements in side crashworthiness may be necessary. Research focused on injured occupants suggests that a higher severity test in a similar configuration may be the most effective at driving continued crashworthiness improvements relevant in real-world crashes. This study investigates how well the IIHS MDB impact and injury patterns replicate those observed in modern striking LTVs in a higher severity laboratory test. Four recently designed good-rated vehicles were impacted by an MDB, a pickup and SUV at 50 km/h and 60 km/h. Two vehicles, the Toyota Camry and Volkswagen Atlas, were chosen because they had very low structural intrusion measures at the B-pillar in the current (or established) IIHS test, with 22 and 32 cm of survival space for the driver, respectively. Two vehicles, the Honda Accord and Infiniti QX50, were chosen because their survival space measures were on the borderline of a good/acceptable rating, with 14 cm and 15 cm of survival space, respectively. Data collection included external and internal measurements along the side structures of the vehicles. All other measures and test setup were conducted according to the current IIHS side test protocol. Observations from the crash tests were compared with real-world higher severity crashes involving good-rated vehicles with configurations like the IIHS test to understand the potential real-world benefit of a new crash test configuration. The MDB produced vehicle kinematics, deformation, and injury patterns that were not representative of striking LTVs. LTVs loaded the struck vehicles with force concentrations at the striking vehicle’s front longitudinal structures while MDBs loaded vehicles more uniformly, both vertically and laterally. Dummy injury patterns were consistent with the deformation patterns; elevated pelvis/femur injury risk was present when struck by the LTVs and elevated head and chest injury risk was present when struck by the MDB. The four good-rated vehicles exhibited a range of performance when struck by the LTVs, suggesting that a different test configuration, speed, or crash partner may highlight those differences in performance among the current good-rated vehicles. Additionally, MDB tests at 60 km/h revealed dimensional limitations of the barrier that must be addressed prior to further higher speed barrier research. The current research suggests that increases in severity – mass or speed – of the current MDB would not necessarily encourage vehicle countermeasures that would confer benefit to occupants in real-world side impacts. To encourage relevant real-world design changes, the MDB must be redesigned to replicate the damage and injury patterns of current LTVs in a field-representative impact condition. This test configuration could potentially address an additional 10% of real-world, injury-causing side crashes.
Real World Accident Analysis of Car-to-Car Intersection Near-Side Impacts: Focus on Pelvis Injury

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**Abstract**

Near-side impacts are one of the severe crash modes of all the impacts. Even though 90% of vehicles have achieved "Good" in IIHS rating, there is hardly any sign of decreasing trend in side impact fatalities for last few years. IIHS is planning to introduce a new test protocol because even the cars with “Good Rating” in IIHS tests can still have AIS3+ injuries. In side impacts, a higher number of severe injuries were found in thorax, head and then followed by pelvic region. Though many researchers addressed the mechanism of thorax and head injuries, there are a few in-detail accident analysis of pelvis injuries. Pelvis injury often leads to significant medical expense and impacts the long-term quality of life. This study is focused to find out (i) the relation between pelvis injury with structural deformation (ii) the frequency and the type of pelvis injuries (iii) the type of target of population to considered (size: small/large, gender: male/female) with the help of accident data and simulation results. C2C intersection accidents were selected from NASS-CDS (CY2004-15, n=913 cases) to identify the influential parameters by logistic regression. From the accident analysis it is found that a) pelvic ring fracture is one of the most frequent injuries, b) 10 o’clock impact caused the highest number of injuries, c) pelvis injury frequency is more in female than male, and d) risk of pelvis injury increases when the maximum intrusion of B-pillar and surrounding door structure exceeds a certain level. Logistic regression indicates that angle of impact, location of impact and initial velocity of the struck car are also important parameters. To gain more benefit in real-world accidents by introducing future side impact protocols, a rational approach is necessary to focus more on evaluating the most frequent pelvic ring fracture by introducing more bio-fidelic dummy (say World-SID) in future protocol tests.

**Occupant Injuries Related to Rollover Crashes and Ejections using Recent Crash Data**

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**Abstract**

The goal of this paper is to determine the recent annual occupant populations and trends related to rollover injuries and fatalities, and to assess the risk factors that may have significantly contributed to occupant injuries and fatalities when rollovers and ejections occur.

Fatality Analysis Reporting System (FARS) 2004-2017 data were used to obtain the recent occupant fatalities related to rollovers and ejections. National Automotive Sampling System (NASS) – Crashworthiness Data System (CDS) 2013-2015 weighted survey data were used extensively to estimate the occupant injury severities and occupant ejection details associated with rollovers. For rollover cases, the injured body regions (e.g., head, neck, shoulder and back, and chest) and injury contact sources (e.g., vehicle roof, side door, or seat back) were investigated in detail. This study paid close
attention to the interaction between the vehicle roof and occupant injuries for the consideration of the requirements from Federal Motor Vehicle Safety Standards (FMVSS) 216a and 226. Finally, occupant injury risk and key risk factors were evaluated using methods of relative risk, including multiple logit model and case-control study. The data analysis using FARS showed a decrease in annual fatalities from approximately 10,500 during 2004-2006 to approximately 7,000 during 2014-2017. Approximately one thirds of all occupant fatalities of light passenger vehicles (Gross Vehicle Weight Rating, GVWR <=10,000 lbs.) are related to rollovers. FARS data also provided the occupant ejection status (complete or partial ejection) and ejection path associated with rollovers. The CDS data indicated that rollovers are strongly associated with the injury sources of vehicle roof, side doors, and seat back/support; rollover crashes also resulted in primarily the injured body regions of head, neck, shoulder/back, and chest. The occupant ejection paths are usually side windows and roof opening. The analytical results also revealed that light trucks/vans, with relatively higher centers of gravity, tend to have relatively higher likelihood of rollover crashes than passenger cars, but passenger cars tend to result in a higher rate of occupant serious injuries (Maximum Abbreviated Injury Scale 3+, or MAIS 3+) than light trucks/vans, if rollovers did occur. Overall this study explored the trends and annual occupant populations related to rollovers and ejections using recent traffic data. Logistic regression model was used, with considerations of multiple risks and confounding factors, to predict the occupant injury relative risks of several key risk factors simultaneously. The analytical results using both FARS and CDS indicated that higher occupant injury risks were especially associated with higher delta-V, unbelted occupant, rollover, ejection, side impact, and older occupant age. This study, utilizing the recent crashes from three main databases of FARS, NASS CDS and NASS General Estimates System (GES), may enrich the understanding of rollover and ejection related occupant injuries.

**Paper No.19-0336-O**

**A framework for improving of heavy truck cab crashworthiness under rollover conditions**

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**Abstract**

In 2012 the US Congress directed the Federal Motor Carrier Safety Administration (FMCSA) to improve commercial motor vehicle safety through the MAP-21 Act. NHTSA reported to the US Congress in 2015 that heavy truck rollover crashworthiness should be improved. To that end NHTSA sent a letter to the president of SAE asking if improvements in test methods could be suggested that would result in improvement of rollover performance. In this study we review the performance of heavy truck cab structures that meet the requirements of J2422 and suggest a framework for improving rollover crashworthiness for heavy trucks.

**Paper No.19-0036-O**

**Status of NHTSA’s Ejection Mitigation Research**

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**Abstract**

The objective of this paper is to present an update on the research conducted by the National Highway Traffic Safety Administration (NHTSA) to assess the performance of roof glazing in production vehicles and certain countermeasure designs in preventing occupant ejections. Federal Motor Vehicle Safety Standard (FMVSS) No. 226 "Ejection mitigation" set requirements for ejection mitigation systems to reduce the likelihood of complete and partial ejections of vehicle occupants through side windows during rollovers or side impact events. In the preamble of the final rule establishing the standard (Jan 2011), the agency stated "NHTSA is interested in learning more about roof ejections and would like to explore this area further..." It also stated that while sun/moon roof ejection could be potentially cost effective to mitigate, the agency was not in a position to extend coverage to roof glazing in the final rule because the agency wanted to research a viable performance test procedure. The assessment of ejection protection offered by sunroofs was made using a guided impactor (18 kg) directed toward roof glazing (pre-broken) from inside the vehicle, based on the procedures developed in the FMVSS No. 226 regulation2, with test speeds of 14, 16, and 20 kilometers per hour. Tests were
conducted on production and countermeasure sunroof designs for the 2016 Ford F-150, production sunroofs for 2012 Toyota Prius, and production sunroofs provided by the Aisin Technical Center of America. For sunroofs with both a fixed and a moving panel (F-150, Aisin), the movable panels presented more challenges to contain the headform than fixed panels. For the moving panels, the sunroof attachment structure separated at the inserts (into the rails). Fixed panels had higher excursions at unsupported transverse edges or edges without any metal encapsulation frames. The F-150 fixed rear panel had front and rear transverse unsupported edges, while the Aisin had longitudinal edges without metal frames. Laminated glazing panes with thicker polyvinyl butyral (PVB) inner layer in and polyethylene terephthalate (PET) film with tempered panes used as countermeasures for the F-150 sunroof reduced glazing stretch (and ram excursions). However, this transferred more forces to the edges and presented a greater challenge for movable panel containment at rail attachments. The fixed polycarbonate panel used in the Prius had low ram excursions but high ram decelerations. Meeting some excursion limit will require designs that have strong attachments to the vehicle roof or rails. Deformation of the glazing and encapsulation frame should be limited when impacted at the center of the panel. Any tear/rip of the plastic layer would add to the excursion of the ram. The number of vehicle designs tested was limited by the availability of laminated glazing used in production or countermeasure designs. This paper details performance of selected production and countermeasure sunroof designs in limiting headform excursions. Some of the fixed sunroof designs had excursions of less than 100 millimeters. The movable sunroof designs tested will require additional countermeasures to perform at this level.

**Paper No.19-0330-O**

**REPEATABILITY OF THE CAROUSEL DYNAMIC STABILITY AND ROLLOVER TEST DEVICE**

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**Abstract**
A novel test device (Carousel) for measuring the dynamic rollover stability of vehicles and initiating a full-scale dynamic rollover test has been installed and evaluated for repeatability and reliability. This work describes the test device function and presents results from preliminary repeatability testing. Both the test device and the test article were evaluated to objectively identify the repeatability between tests using correlation analysis. The results demonstrate that the fixture is capable of producing highly repeatable responses.
Accidents involving cars in automated mode – which accident scenarios will (not) be avoided by level 3 systems?

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Abstract
In the coming years systems will become available that will be able to drive in automated mode for certain periods of time but will only be able to handle selected situations. This is referred to as conditional automation (level 3), whereby the driver no longer has to monitor the vehicle continuously but does have to take control on request when the limits of the automation driving system are reached. What we can say today is that vehicles with different levels of automation will be sharing the roads with manually driven vehicles in the foreseeable future. It is still unclear whether automated vehicles sharing the road with manually driven vehicles will lead to additional road safety risks (mixed traffic). With the presumption that vehicles will still be involved in accidents while they are driving in automated mode, following question arises: how will these accidents look like in the future? The German Insurers Accident Research therefore analyzed the impact of automated driving on motorway accidents. For this study, the UDV used its own accident database (referred to as the UDB) which contains a representative cross-section of all third-party vehicle claim files of the insurers involving personal injury and at least € 15,000 total claim value. The analyzed pool consists of accidents which occurred between 2007 and 2013. In a first step, relevant accident scenarios were determined based on all motorway accidents involving cars in the data pool. In a second step, generic automated driving functions and their characteristics were defined. Thereby, starting with driver assistance and comfort systems (DACS), automation Level 3 and 4 were defined and analyzed. By means of a case-by-case analysis the theoretical benefit potential of these systems was evaluated. Results of the analyses are: It can be expected for the future that cars driving in automated mode will still be involved in accidents. An active Level 3 function as described above could prevent up to 6% more motorway accidents than modern cars equipped with DACS. But negative effects that haven’t been quantified up to know may decrease this potential significantly. With these systems it can anticipated that the frequency of rear-end accidents will decrease. But accidents caused by lane change will remain a big challenge for the automated driving systems. With a Level 4 system which drives in automated mode a total of 21% of all motorway accidents were considered as avoidable. The approach used in the study is based on limited knowledge on automated driving available today. It can be stated that the driver is the most critical part up to Level 4 automated driving. Starting with Level 4 this uncertainty will be nearly eliminated. A significant change in the accident situation can be expected only from systems with a very high level of automation (Level 4+) which exclude the driver from the driving task completely. But even with a Level 4 system, accidents will still happen in the future, e.g. due to mixed traffic.
Based on Naturalistic Driving and Accident Data Analysis

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Abstract
Automated driving systems of SAE Level 3 and beyond allow transferring the driving task and responsibility to the vehicle and its automation systems. A crucial challenge for development and real-world performance is the balance between functionality, availability and safety, as a human driver only needs to be available as a fallback after sufficient lead-time. Consequently, automated driving requires enhanced capabilities of sensors, algorithms and actuators. This paper focuses on improved safety and driving comfort of automated vehicles and upcoming technical requirements compared to driver-only or assisted driving. It uses and adapts the state-of-the-art prospective effectiveness assessment method of ADAS to estimate accident avoidance potentials of automated driving systems. The data sources for this analysis are the Strategic Highway Research Program 2 (SHRP2) and the German In-Depth Accident Database (GIDAS). Exemplary automated driving functionalities for highways are prospectively evaluated and the impact on both traffic safety and driving comfort are presented using crash, near-crash and baseline data. Furthermore, relevant technical requirements for corresponding automated driving systems are derived. For an exemplary use-case, possible impacts on system functionality, availability and safety are presented. Additionally, safety potentials of installing high-performance sensors for automated systems of Level 3 and beyond when driving manually are discussed.

Paper No.19-0024-O
An optimization-based method to identify relevant scenarios for type approval of automated vehicles
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Abstract
The objective of this paper was to propose a novel approach for an intelligent preselection of relevant scenarios for the certification of automated vehicles. During this process mainly two problems occur. Firstly, due to an unlimited number of possible traffic situations, a selection of a manageable number of representative situations to be tested must be applied during certification of automated vehicles. Secondly, nowadays a limited number of standardized test cases are used for the type approval of vehicles. This can lead to so-called gaming of tests, which means that the manufacturer optimizes the system’s performance in the predefined test cases. Hence, the information about the system’s behavior in real driving situations is limited as the problems of the emission test clearly revealed. This paper addresses both stated problems and exemplifies a method for a system specific selection of test cases for the certification of automated vehicles, which are not known to the manufacturer in advance. Based on a system analysis and an objective driving behavior characterization, weak spots of the system under test are identified and connected to complex scenarios to be tested. With the presented approach, an economic and meaningful certification process of automated vehicle is possible.

Paper No.19-0129-O
A Method for Scenario Risk Quantification for Automated Driving Systems
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Abstract
Recent innovations such as automated driving and smart mobility have elevated the safety-criticality of automotive systems due to the impact of these technologies in traffic behavior and safety. New safety validation and assessment methodologies are required to provide the level of assurance that matches the societal impact of these systems. The objective of this paper is to introduce a novel method for assessment and quantification of the risk of a driving scenario taking into account the operational design domain. For our proposed method, we assume that a scenario consists of activities (performed by different actors) and environmental conditions that lead to a potentially hazardous consequence. The risk of a driving scenario is the product of the probability of the exposure of a scenario and the severity of the hazardous consequence of that scenario. We introduce a systematic method for calculating the probability of exposure, where we assume causal relations between the activities that constitute a scenario. By making educated assumptions on the dependencies among the different activities and environmental conditions, we simplify the calculation of the probability of the exposure. For estimating the severity, we employ Monte Carlo simulations. We illustrate the use of our proposed method by applying it to an example of a collision avoidance system in a cut-in scenario. We use naturalistic driving data acquired from field studies on the Dutch highways to determine the risk. The presented example illustrates the potential of our proposed risk estimation method. Using our proposed method, we can compare the safety criticality of various scenarios in a quantitative manner, which can be used as a safety metric for evaluating automated driving systems. This can lead to a stronger justification for design decisions and test coverage for developing automated vehicle functionalities.

Paper No.19-0166-O
Prospective effectiveness safety assessment of automated driving functions – from the method to the results
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Abstract
The development in the areas of sensors and electronics has been bringing the automotive industry increasingly closer to automated driving in recent years. Automated functions that need to be continuously supervised by the driver are already on the market. Highly automated driving functions (HAD) will enter the market in the near future. The German Ethics Commission for automated and connected driving stated in its report that “the licensing of automated functions is not justifiable unless it promises to produce at least a diminution in harm compared with human driving, in other words a positive balance of risks” [1]. This leads to the question, how the traffic safety effect of automated driving functions can be assessed taking into account possible positive and negative aspects? This paper introduces comprehensively a method that is used by BMW for the prospective safety assessment of HAD by means of virtual experiments. This method is besides others part of the evaluation and safety assurance activities for HAD. The method is described from the scenario selection via the simulation up to the validation and verification. In contrast to other simulation approaches in this area, which mainly use accident re-simulation, this approach uses Monte-Carlo techniques, in which the initial starting conditions of the simulated driving scenario as well as the parameters of the involved drivers are randomly selected from distributions. These distributions base on accident data as well as on naturalistic driving data. A core aspect of this approach is the stochastic cognitive driver behavior model to describe the behavior of individually different traffic participants in a scenario. In contrast to accident re-simulation based approaches, this approach allows to analyze time-wise larger driving scenarios, which are of importance for HAD, since these functions act throughout the driving within the operational design domain and not only in critical situations. The method for assessing the safety performance is applied to exemplary HAD. The results cover the positive effects, which are mainly achieved in today known accident scenarios, as well as scenarios, in which potentially new risks compared to manual traffic can occur. One example for this is the minimum risk maneuver, for which the consequences of different implementation is discussed. Like all other methods
(accident analysis, studies in driving simulator or on test track, field operational test) the simulation based approach has advantages and disadvantages.

The main criticism is that the assessment is done virtual, which poses the question on the validity of the simulation. In order to tackle this aspect the validation and verification of the method and tool is a key aspect. Therefore, our current conceptual considerations regarding validation and verification are described in this paper.

**Paper No.19-0192-O**

**Different approaches to the new regulatory challenges for connected and automated vehicles (CAV)**

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**Abstract**

Automated Driving (AD) is foreseen to be one of the major social and technological challenges in the coming years. Many manufacturers are developing new models with cutting-edge functionalities, which are not included in the scope of the current regulatory framework.

Apart from demonstrating their know-how and expertise on AD, their willingness to sell their AD models in the European market is accelerating the rule-making system. However, what is the roadmap for the European regulatory framework? Policy makers and regulatory bodies are pushing their boundaries at all levels (national and international) in order to introduce modifications in existing regulations. These regulations will enable the introduction of these new functionalities into the market. Without decreasing the standards of safety and security, the implementation of a clear and harmonized regulatory framework and approval process is extremely necessary. The last amendments of the UN Regulation nº79 related to steering equipment or the creation of new standards such as the ISO 21448 regarding Safety and Intended Functionality (SOTIF) are examples of recent efforts from the regulatory bodies to achieve this goal. The aim of this paper is to show the state of the art of the regulatory framework regarding automated driving. In order to provide a thorough understanding of the forthcoming amendments and new standards, the different challenges that the European Commission (EC) / United Nations Economic Commission for Europe (UNECE) are facing will be analysed, as well as the different approaches to be considered by the international regulatory bodies. Finally, as a result of this research, the conclusions will be presented as considerations and proposals for all players involved in this change of paradigm: users, manufacturers, approval authorities and technical services.

**Paper No.19-0012-O**

**TOWARDS A QUANTITATIVE “SAFETY” METRIC FOR AUTONOMOUS VEHICLES**

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**Abstract**

Future mobility systems are expected to incorporate a broad range of transport modalities (passenger cars, truck platoons, etc.) at different automation levels (SAE Levels 3/4/5). During operation, automated vehicles will have to independently take safety-critical decisions (e.g., when to brake or change lanes) and estimate the impact of their behaviour on the surrounding traffic, thus balancing individual and group safety. To achieve this, automated vehicles will require a quantitative metric of safety to guide their actions. This article proposes one such metric, suitable for decision-making and autonomous navigation. The metric is meant to provide a quantification of the risk a vehicle incurs during operation by taking into account three main aspects of its operation: the probability of a hazard occurring (e.g., a rear-end collision), the potential impact of the driving conditions on the health of the vehicle's passengers were the hazard to occur, and the capability of the vehicle to avoid the hazard. The article focuses on introducing the conceptual aspects of the metric first and then presents the initial results on estimating and collision probabilities. The other two aspects will be
addressed elsewhere.

**Paper No.19-0023-O**

**Intention of manoeuvre and motion prediction of other road users: a hybrid approach**

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**Abstract**  
Automated driving is gaining more and more interest in the recent years. In order to drive safely, automated vehicles reconstruct the environment using mainly the information coming from the in-car sensors. By using this reconstruction a prediction of the future states of the surrounding vehicles can be computed, which in turn is used to decide which manoeuvre and accompanying path to accomplish. This problem is known as motion prediction. Whilst physics-based models perform well on a short horizon, machine learning has the potential to predict a more accurate motion on a longer horizon, especially if the manoeuvre of the other road user is known in advance (manoeuvre-based prediction). In this paper a hybrid approach is proposed that consists of an intention of manoeuvre predictor, a physics-based motion predictor and a manoeuvre-based motion predictor. The vehicles around the host vehicle are continuously tracked. The intention of manoeuvre predictor, based on Support vector machines (SVM), computes the probability for each surrounding vehicle of changing lane or of staying in lane. In addition, a kinematical model which assumes a constant turn rate and velocity (CTRV) is used to predict the trajectories. Once the intention of manoeuvre is known, the manoeuvre-based motion model, based on machine learning algorithms as Gaussian Processes and SVR, predicts the lane change or lane following trajectories. The models are trained using a collection of cut-ins manoeuvres from 60 hours of naturalistic driving. In the end, the physics-based and the manoeuvre-based motion predictions are merged together by a weighting function. The models were validated with cross-validation and the performance and the integration between sub-modules was tested in a Hardware In the Loop (HIL) environment. The models are capable of detecting the intention of a surrounding vehicle of changing lane with a positive predictive value of 82% 1.2 second before it crosses the lane marker. The combination of SVR and CTRV is capable of predicting well for shorter and longer horizons, keeping the advantages of both methods. The combined model predicts the longitudinal distance and the lateral distance with an error that is 50% lower than the one using the physics-based model, after 4s and an even better performance on shorter horizons in comparison with SVR. The presented approach is capable of predicting the motion of the other road users in a standard situation. In order to handle more sophisticated scenarios, the road information should be used for training. The training set needs to be extended for better results and the models need to be validated on safety-critical scenarios. A hybrid approach for predicting the motion of vehicles from a host vehicle perspective is presented in this work. A combination of machine learning and physics-based models is used to enhance the accuracy of the prediction in shorter and longer horizons. The information coming from the prediction module can be used path planning of (partly) automated vehicles. The results and the integration in the HIL environment show great potential to allow autonomous driving to go to higher levels of automation.

**Paper No.19-0061-O**

**Development and Implementation of safety evaluation scenarios for automated driving vehicles on test bed**

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**Abstract**  
Regulation for the testing and operation of automated driving vehicles on public roadways has been recently developed all
over the world. For example, the licensing standards and the evaluation technology for automated driving vehicles have been proposed in California, Nevada and EU. Like M-city, the test bed has been developed worldwide to evaluate automated driving vehicles and K-city has been developed as the test bed in Korea. The K-city has a variety of facilities such as merge, ramp, tollgate, tunnel, intersection and so on according to five road conditions: motorway, suburban road, urban road, community road and valet parking zone. Therefore, it is necessary to have automated driving evaluation scenarios that would actually be implemented in K-city. For scenario implementation as vehicle tests, automated driving vehicles are needed. The safety evaluation scenarios and criteria for level 3 and level 4 automated driving vehicles were developed in consideration of the actual driving conditions, the real road driving data, and the existed automated driving evaluation methods (ISO, NHTHA, and so on). Then, the safety evaluation scenarios were determined by considering whether the test bed could be realized, repeatable, and safety performance could be well assessed. In order to evaluate automated driving on actual test bed, vehicles as well as evaluation scenarios are needed. For scenario implementation as vehicle tests, automated driving vehicle that is evaluated. The evaluated vehicle is called as a subject vehicle. Besides the subject vehicle, vehicles that can help evaluation are also needed and are referred to as target vehicles. Target vehicles have the ability to driving autonomously in accordance with the scenario, maintaining safety performance with the surrounding vehicles, and recognizing subject vehicle to measure safety criteria. For example, the target vehicles are used to produce a variety of situations, such as cutting in front of the subject vehicle, decelerating in front of the subject vehicle, or driving on the main road when subject vehicle is on the merge road. In the study, a subject vehicle and four target vehicles have been developed and utilized. To verify the developed evaluation scenarios, vehicle tests were conducted using subject vehicle and target vehicles. The subject vehicle has level 3 and level 4 of automated driving that have diverse functions such as lane keeping and lane change. In accordance with the scenarios, all vehicles were self-driving and the subject vehicle was checked whether it meets the evaluation criteria. Through vehicle tests, the developed evaluation scenario was verified to be feasible on the test bed and to evaluate the performance of subject vehicle well. In this paper, the vehicle test result of merge scenario is presented among various motorway scenarios.

**Paper No.19-0101-O**

**Development of an emergency control algorithm for a fail-safe system in automated driving vehicles**

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**Abstract**

This paper proposes the concept of automated driving vehicle failsafe system structure. It contains vehicle hardware and software structure design for automated driving vehicle failsafe system. Moreover, it handles the contents fail detection, fault-tolerant control, and emergency braking strategy in case there is no driver intervention in the fail condition of automated driving vehicle. According to the 2017 'AUTOMATED DRIVE SYSTEM 2.0: a vision for safety' report released by the NHTSA, it states that deployment of the crash avoidance system is essential to switch to a minimum hazardous condition in the event of a problem with the self-driving vehicle, or the system cannot operate safely. First, the method used to build the hardware & software of the vehicle was based on the guideline of ‘AUTOMATED DRIVE SYSTEM 2.0: Section 1 fallback (Minimal Risk condition)’ report released by NHTSA. Second, a method of an algorithm is sliding mode control based fault tolerant control and emergency deceleration control which designed to target SAE International standard J3016 autonomous driving phase 4: automated driving system perform ass aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene. In this paper, to meet the requirements of autonomous driving phase proposed by SAE International standard J3016 phase 4 and NHTSA safety standard, the hardware configuration was created to ensure that the automated driving vehicle could perform the given task without proper driver intervention. In detection part, hardware (Actuator, Sensor, CAN signal, Upper&Lower controller) and module based failsafe diagnosis method and algorithm were proposed to detect fail condition. In decision and control part, when a failure of an automated driving vehicle is diagnosed, and no driver intervention was detected, the automated driving vehicle failsafe phase is a move to the system error. In the phase of the system error (lower controller), proposed methodologies are utilized. Automated driving vehicle experiments have demonstrated the algorithms as mentioned earlier and failsafe structure. First of all, it is true that not many papers and studies have been done on the failsafe system of an automated driving vehicle. NHTSA's safety report of an autonomous
vehicle only contains a "suggestion" that says, "It is a good thing to do this," and has not yet created a rule. However, this paper proposes an automated driving vehicle failsafe system that is not commercialized but has been configured to meet NHTSA's requirements to take into account safety. The proposed failsafe system is applied to the automated driving vehicle, and the vehicle experiment was completed with the proposed algorithm. The proposed system is considered to be very compatible with the subject of the technical session by suggesting the system that meets the NHTSA standards as well as testing control and emergency systems targeted automated driving vehicle phase 4.

**Paper No.19-0027-O**

**PEER REVIEW**

**Proposal of a Test Procedure for Evaluating the Human-Machine-Interface of Vehicles with Automated Driving Systems**

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Research  
With the Federal Automated Vehicles Policy, the U.S. National Highway Traffic Safety Administration (NHTSA) has provided a valuable framework that can be used to guide the development and validation of Automated Driving Systems (ADS). Acknowledging that the Human-Machine-Interface (HMI) – identified as one of the 12 priority safety design elements in this voluntary guidance – will be crucial for the success of ADSs, we developed a two-step iterative test procedure that can be employed to evaluate the agreement of ADS HMIs with NHTSA’s voluntary guidance. The current research describes the underlying considerations and structure as well as methodological details of the test procedure, as well as an exemplary application for the evaluation of a Society of Automotive Engineers (SAE) Level 3 HMI.

Methods  
The proposed test procedure was developed based on combinatorics of SAE levels of driving automation. The resulting set of test cases was narrowed down by theoretical and practical considerations derived from an extensive literature review of published research, standards, processes, (voluntary) guidances, and design principles. Finally, the test procedure was evaluated and refined in a simulator study as well as an on-road study.

Results  
The proposed test procedure includes a) an expert-based checklist assessment and b) empirical evaluation(s) of ADS HMIs using a standardized study design, test cases and performance metrics as well as suggestions for implementing these methods. The empirical evaluation framework can be used in conjunction with the expert-based checklist assessment to further improve its economy and the validity of findings. Together, they can be employed to generate objective, reliable and valid evaluations of HMIs.

Discussion  
By relying on combinatorics of SAE levels of driving automation, the described method can be adapted to test every conceivable ADS, and combinations thereof, making it a valuable tool for both researchers and practitioners alike. The exemplary application for evaluating the HMI of an SAE L3 ADS HMI shows how the test procedure could be employed to evaluate a specific system, and helps to identify areas that require further research. At this stage, the proposed test procedure focuses on the interaction between an ADS equipped vehicle and its human driver / operator / occupant, while HMI considerations for interaction with external actors are part of a separate research project.

Conclusion  
The described test procedure can be employed in a variety of settings to testing ADS HMIs, therefore making it a valuable tool for both researchers and practitioners alike. By providing an overview of relevant research and proposing a methodological framework it should help to stimulate discussion and advance the development of ADS evaluation approaches.

**Paper No.19-0081-O**
Estimating expected levels of mutual interference in automotive RADARs and system impacts

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Abstract
The primary goal of this paper is estimate the power, due to other radar transmitters, expected to be incident on the receiving antenna of a given automotive radar, and secondly, simulate the impact this may have on the performance of an example radar system. The approach uses stochastic geometric methods to weigh the spatial, temporal, and spectral overlap, for realistic scenarios with multiple radars operating in proximity. The results show that a given radar receiving antenna may face more interference power (10 to 50 dB) than what is expected from the reference target used to specify system performance. Under these conditions, a radar system, without interference mitigation strategies, will likely suffer significant degradation in performance.

Paper No.19-0286-O
Development of a safety assurance process for autonomous vehicles in Japan

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Abstract
In order to introduce autonomous driving systems into the market, socially acceptable and technically sound safety assurance methodologies need to be agreed. In Japan, vehicle manufacturers and traffic safety experts have gathered regularly under the auspice of the Ministry of Economy, Trade and Industry, in a coordinated initiative to harmonize the required collaborative research, methodology development and standardization activities. Within this initiative, a comprehensive safety assurance process is to be agreed and made publicly available. The process shall be driven by top safety goals defined by authorities, shall consider the systems’ performance limitations, and must be supported by state-of-the-art methodologies and real-world data. At this point, consensus on the overall safety assurance process for SAE Level 3+ autonomy in motorways as well as on the methodology to develop testing scenarios has been achieved and the results are hereby reported. The process and methodology are directly applicable to support the development of systems towards a safer autonomous driving society.

Paper No.19-0123-O
Development of safety evaluation scenarios for infra-cooperated automated valet parking systems

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Abstract
This paper presents an evaluation procedure for an infrastructure based automated valet parking system. Because parking is one of the difficult and complicated tasks for drivers, park assistance system (PAS) has been already developed and commercialized by several auto-manufacturers. As a further step for PAS, researchers are focusing on automated valet parking system which is a fully automated system of PAS and periodically demonstrated their automated parking system. However, from an institutional point of view, evaluation standard and scenarios for automated parking system are progressing slowly compared to the automated driving. Because of speciality that in valet parking system, driver has to get out of the vehicle, most of the developers can not mass produce the system by legal issues. Thus, the necessity of evaluation procedure for parking system rise. Considering many automated valet parking systems are designed with digital map or infrastructure. Thus, in this paper, automated valet parking system cooperating with infrastructure is focused. To design the evaluation process for automated parking, we divided the parking situation into two sides. 1) Nominal parking process, which is a static obstacle avoiding case related to static factors. 2) Complicated parking process, which is avoiding not only static obstacles but also moving obstacles such as pedestrians. As a valet parking is a very sequential service, to design evaluation items for nominal parking, we considered a procedure of manual parking and divided valet parking process into three different stages. 1) Driving in the parking lot while moving near to the parking space. 2) Parking to the aimed space. 3) Parking out from the space. Finally, the component of nominal parking scenario classified as static factors to test basic parking performance of the target vehicle and addable evaluation scenarios listed up as dynamic factor which can reproduce the complicated and frequent situation that can happen in the parking lot by combining with the nominal scenario. Both the nominal scenario and additional scenarios are organized as an evaluation matrix.
Paper No.19-0295-O

Q10 Euro NCAP 2020 update dummies compared with current Q10 in frontal and side impact sled tests

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Abstract
There is a need of improving the current Q10 (Q10original) due to unstable seatbelt interaction with the shoulder. Several design changes to shoulders and torso have resulted in a prototype Q10 (Q10update). Some design changes were removed which resulted in a second prototype Q10 (Q10light). The aim was to compare kinematics, shoulder belt interaction and dummy responses to the Q10update and Q10light with the current Q10original in frontal impacts. Q10original and Q10update were also compared and evaluated in side impacts. Q10original, Q10update and Q10light were compared in frontal sled tests in a midsize SUV, for two different crash pulses. Three different belt geometries were evaluated. Dummy kinematics and loadings were analysed. The dummies were positioned on booster cushions and restrained by seatbelt with pretensioner and load limiter. Q10original and Q10update were included in eleven side impact sled tests simulating a Euro NCAP 2020 Side AE-MDB impact, using a midsize passenger car. The dummies were positioned on booster cushions and restrained by seatbelt and combinations of thorax side airbag (SAB) and inflatable curtain (IC), in addition to a reference test without SAB and IC. All tests included a retractor with pretensioner and load limiter. Two arm positions were evaluated in one restraint configuration. In the frontal sled tests, the Q10update was less sensitive to initial shoulder belt position far out on the shoulder than the Q10original. The shoulder belt had a tendency to move inboard on the Q10update during the crash, even if the shoulder belt was initially positioned far out on the shoulder, possibly influenced by the soft tissue at upper chest and forward shift of the shoulder joint compared to Q10original. The Q10light had a similar shoulder belt interaction as the Q10original. Both update dummies showed a greater forward excursion of the head and a larger tilt of the upper torso than the Q10original, potentially due to the mass redistribution from pelvis to upper body. The increased excursion is considered an improvement, since the mass redistribution is more biofidelic compared to Q10original. Both update dummies had higher chest deflection, lower chest acceleration and lower neck tension compared to the Q10original. The differences in dummy responses in the side impact sled tests were mainly due to mass redistribution. Especially in tests without SAB, lower chest acceleration, but higher chest deflection was obtained for the Q10update compared to Q10original. Furthermore, the shoulder force was higher for Q10update compared to Q10original for the three restraint combinations, while in the reference test head impact to the vehicle interior occurred. Angled arm position resulted in both reduced shoulder force and reduced chest deflection, compared to aligned arm position. Due to its improved kinematics and sensitivity to changes in seatbelt geometry, the Q10light was preferred of the three tested dummies for frontal impact testing. Q10light was not evaluated for side impact loading. For side impact testing, this study provides no firm recommendation on the Q10update, acknowledging that a biofidelity evaluation needs to be made. Further dummy refinements and lateral validation and
certification tests are encouraged.

Paper No.19-0197-O
Biomechanical Validation of a new biofidelic Dummy

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Abstract
In order to improve the preciseness in pedestrian-vehicle accident reconstructions, a new biofidelic dummy had been developed. The objective of this work was to biomechanically validate the biofidelity of this new kind of anthropomorphic testing device. Therefore, nine crash tests have been conducted with the biofidelic dummy and the results were compared with four crash tests earlier performed with the Žilina dummy, an anthropomorphic testing device widely used in accident research due to its low cost and robustness, cadaver tests obtained from published research papers and 21 real-world pedestrian accidents. The trajectories of both anthropomorphic testing devices were computed and compared with those of cadaver tests, highlighting that the biofidelic dummy performs much more human-like than the Žilina dummy. Damages to the vehicle’s front caused by both anthropomorphic testing devices and real pedestrians were compared with each other, as realistic damages are very important for reconstruction purposes. It can be shown that the biofidelic dummy causes damages similar to those a pedestrian would cause in an accident of similar severity, whereas the Žilina dummy causes damages which are far too severe, which may mislead the expert witness to assume an impact velocity which is too slow. The C-ratio, defined as closing speed over collision speed, was computed for both anthropomorphic testing devices, showing that the two deliver similar results. Computing the dynamic, time-dependent C-ratio, however, highlights differences in the kinematics and dynamics of the two anthropomorphic testing devices. The throw distances of both anthropomorphic testing devices were compared with throw distance charts developed in-house by DEKRA based on experiments with the Žilina dummy and well-documented real-world accidents. The results show that the biofidelic dummy’s behaviour is good. Finally, the damages to the biofidelic dummy were analysed and transcribed to injuries of a human being. These “biofidelic dummy injuries” were compared with injuries of real pedestrians, focusing on five injuries, which can be used for reconstruction purposes. In general, the “injuries” of the biofidelic dummy correspond well with those of the pedestrian.

Paper No.19-0233-O
Photogrammetry and Motion Analysis Methodologies for Head Dummy Behavior Observation

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Abstract
While the airbag is essential for occupant protection, it is also an obstacle to visualizing the distance between the dummy head and rigid objects on the car or other occupants. During the restraint system development process, it is important to understand where the dummy head is in order to modify the restraint systems and avoid bottoming out. Photogrammetry and motion analysis combined with 3D software enables the minimum distance between the 3D scanned dummy head and any other 3D surface to be calculated. Using the videos from the high-speed cameras the 3D position of any visible point can be obtained. As the head is a rigid object, it is possible to determine where the entire head is relative to the steering wheel with just the position of any point on the back. With the arrival of 3D high-resolution scanners, HD high-speed cameras and new tracking algorithms, the results obtained from this methodology have increased in precision up to the millimetre scale. This methodology shows the behaviour of a rigid object during a crash or sled test in a 3D environment and can be used as a strong tool in passive safety laboratories. In this particular case, displacement and rotations of the head dummy relative to the car coordinate system determine if the head is too close to the dashboard, “B” pillar, steering wheel, etc.
This methodology requires two high-speed cameras. During a passive safety development process, it is essential to have all high-speed cameras available to monitor critical parts of the car. To reduce the number of cameras required to calculate the behaviour of the head relative to the car, the 6DoF tracking method can be used. This method uses the static position of a group of points in a rigid object to calculate the 3D rotation and displacement of the centre.
coordinate system. There are some difficulties that limit this process, which will be dealt with here. This methodology is not commonly applied in every test, usually because the two cameras and the digital process required increase the cost of the crash or sled test. Reducing the number of cameras needed to only one can reduce the cost of this methodology and its implementation for all related tests. Also, there is the possibility of calculating this methodology by using onboard cameras, which is very helpful when the car deploys the curtain airbag. With the coming of the autonomous car, the Passive Safety Department must have all measurement tools available to understand how dummies behave inside new car morphologies. This tracking methodology could us help to understand how dummies interact with rigid parts of the car in order to modify the restraint systems so as to be adapted to new technologies.

**Paper No.19-0337-O**

**Study on Identification of Characteristics of Thorax of THOR-M50 (Metric)**

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**Abstract**  
The current study aimed to characterize the structural responses of the thorax during compressive loading conditions to aid interpret the behavior of the thorax during more complex loading conditions or validate computational THOR dummy models. A series of quasi-static compression tests were performed for individual ribs and the thorax complex using two types of indenters. For a rib compression test, an indenter with a 10 mm diameter was used to load the end of a rib. This indenter was installed on a linear guide array to minimize the application of shear forces to the dummy. The influence of the thoracic bib was investigated by performing this test with and without the bib. The displacements of the other ribs were measured using a three-dimensional motion tracking system. Another 52 mm by 104 mm indenter was used to apply more belt-like loading to the loading site. From these two series of tests, stiffness was calculated using the applied force at 25.4 mm of compression. In addition, compliances of the four thoracic IR-TRACC sites (rib 3 and 6) were calculated using the applied force at 25.4 mm of compression and deflection of the IR-TRACCs. During the rib compression test without the bib, the 7th rib exhibited the highest stiffness (2.3 N/mm) while the stiffness of other ribs ranged from 0.8 to 1.5 N/mm. During the rib compression test with bib, the 1st rib region demonstrated the highest stiffness (17 N/mm), while the stiffness of other regions ranged from 6.8 to 11.3 N/mm. The bib increased the rib stiffness substantially, and its effect was the highest for the 1st rib region. The compliance results indicated that the IR-TRACC deflection is mainly influenced by the forces applied to the ribs that the IR-TRACC was installed and their adjacent ribs, e.g. rib 2 and 4 for the upper thoracic IR-TRACC, on the same side. The thoracic responses of the THOR-M50 obtained from the current study can be utilized in model validation and interpretation of the response of the thorax during more complicated loading conditions such as crash test.

**Paper No.19-0236-O**

**Updated Chest Injury Criterion for the THOR dummy**

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**Abstract**  
Anthropomorphic crash test dummies are designed to predict the risks of injury in automotive crash conditions. These
dummies must therefore measure parameters that make it possible to calculate a metric related to injury mechanisms. This metric must evaluate the risk of injury whatever the solicitation, in a range covering all the solicitations arising in a crash. More specifically for a frontal impact, the risk of chest injury associated with this criterion must be the same, whatever the contributions of the belt or the airbag load paths. The objective of this paper is to develop such a criterion for the chest. Several thoracic criteria were proposed by Poplin in 2017 for the THOR dummy, based on the measurement of the 4 3D deflections of the thorax. Unfortunately, for the sample studied, these criteria did not predict the risk of rib fractures better than the central deflection measured on an Hybrid III. The in-depth analysis of the sample showed that the sample configurations were too similar and that the deflection range was too small. Additional tests were added to the Poplin sample, which diversified the types of restraint systems and increased the extent of deflections. A new analysis was performed on this sample. A new criterion was proposed. This criterion is a linear combination of the maximum value of the 4 chest resultant deflections and the absolute value of the difference of the upper right and left deflections. A risk curve was then constructed based on this criterion and age. The consistency of the results of the new tests performed with the THOR dummy was assessed against the identical tests performed on the Hybrid III dummy. Similarly, the consistency of the injury assessments between the new tests and those of the initial sample was carefully studied. The results of these analyses confirmed the relevance of the added data. If the statistical methods used have shown the best performance of the new criterion, it has been optimized on the sample used and must be validated on external data. This could be verified on some data from the bibliography and further tests are planned to confirm it. The use of an expanded test sample allowed to successfully develop a new thoracic criterion for the THOR dummy. It better predicts the risk of rib fractures, while being more consistent with crash investigation findings related to the age effect and the balance between the seat belt and the airbag. This paper brings new experimental data and analysis to improve the ability of the THOR to better predict the risk of rib fractures as a function of age.

**Paper No.19-0266-O**

**Application of Multiple Rib Gages to Improve Chest Injury Measurements**

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**Abstract**

**ABSTRACT**  
In 2011 the National Highway Traffic Safety Administration (NHTSA) made changes to the new car assessment program (NCAP) frontal full-width test rating that introduced a chest deflection metric. The dummy seating protocol did not specify routing procedures that consistently control shoulder belt positioning on the dummy. Thus, most NCAP tests were conducted with the D-ring in the full up position, placing the shoulder belt far above the center chest potentiometer, thereby loading the dummy’s chest asymmetrically. The objective of this study is to investigate the use of supplementary chest deformation sensors, such as RibEye and IR-TRACCs for identifying belt fitment procedures which provide accurate chest readings by ensuring that the shoulder belt is routed near the dummy's center chest gage. The present study examines in detail the chest deflections observed in the initial series of sled and full vehicle tests with the Dodge Caliber. In addition, the study examines the chest deflections observed in NHTSA and Transport Canada (TC) full frontal tests with dummies containing supplemental chest deformation sensors. The supplementary data took the form of Hybrid III 5th female dummies outfitted with either RibEye sensors or IR-TRACCs and Hybrid III 50th male dummies outfitted with IR-TRACCs. The results indicate greater disparity between the center chest gage measurements and the supplemental RibEye or IR-TRACC readings when the belt routes higher on the dummy’s neck, associated with the upper anchorage D-ring in the full up position. Effects of the D-ring positioning are lessened as the seat track is moved from full forward to midtrack for the 5th female dummy. Since the belt routes closer to the center gage, both the center gage and maximum RibEye measurements indicate more deflection than at the full-forward position. Other factors also contribute to these higher peak measurements. For both the 50th male and 5th female right front passenger dummies, when the belt was routed closer to the dummy’s design intention at the center gage, the center gage and left side supplemental (RibEye or IR-TRACC) measurements were similar. Additionally, when the belt was placed across the center of the dummy’s chest, the supplemental sensors deflected quite uniformly across the chest. Despite the promising test results of these supplemental chest measurement devices, currently, there is no US federal basis for calibrating or interpreting RibEye or IR-TRACC measurements in Hybrid III dummies, so using these devices to relate to injury risk remains...
problematic. RibEye and IR-TRACC supplemental chest deflection technologies have the potential to better identify belt routings consistent with the design characteristics of the dummy chest and deflection sensor. This knowledge could be used to develop testing and belt placement protocols which support more meaningful and consistent estimates of chest injury risk. This, in turn, would greatly enhance the utility of NCAP programs to drive restraint system changes to further reduce real-world chest injuries.

**Paper No.19-0308-O**

**Improved Thoracic Injury Risk Functions for the THOR-M-50 developed in a new simulation-based Approach**

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**Abstract**

To assess occupant safety in a crash test, criteria associating the measurements made with a crash test dummy to injury risk are necessary. To enable better protection of elderly car occupants the objective of this study was to develop improved thoracic injury criteria for the THOR average male dummy. The development of these criteria is usually based on matched dummy and Post Mortem Human Surrogate (PMHS) tests by relating the obtained PMHS injuries to dummy measurements. This approach is limited, since only a few tests in relevant loading conditions are available and any new test series requires high efforts to be performed due to their complexity and costs. To overcome these limitations and to extend the dataset for the development of THOR dummy chest injury risk functions a simulation-based approach was applied within the EC funded project SENIORS (Safety Enhanced Innovations For older Road Users - www.seniors-project.eu). Within this study frontal impact sled simulations with an FE model representing a THOR average male dummy and matched simulations with a human body model (HBM) representing an elderly car occupant were carried out. The HBM used for this study was the THUMS TUC with modified rib cage, which was developed in SENIORS. The modifications included material and geometry changes aiming to represent an elderly car occupant. The rib fracture risk was predicted with a deterministic approach whereby a rib was considered broken when the strain exceeded an age-dependent threshold. Furthermore, a probabilistic method was applied to predict the probability of sustaining a certain number of fractured ribs by comparing local strain values to the distribution of cortical rib ultimate strain. By relating the output from the HBM simulations to a multi-point dummy injury criterion, injury risk curves were calculated by statistical methods. The wide range of loading conditions resulted in the desired range of injuries and THOR ATD output. The number of fractured ribs predicted by the HBM based on the deterministic prediction method was between 0 and 15. Furthermore, the probabilistic risk for the number of rib fractures equal or greater than two, three or four was calculated for each load case. The THOR rib deflection criterion Rmax was between 18 and 56 mm, while the PC Score was in the range of 2.5 to 7.2. Based on these outputs new risk curves for the predicted deterministic (AIS2+/3+) and probabilistic injury risk were calculated. The new curves show reasonable shapes and significance that provide trust in their application. The new risk curves are compared to risk curves obtained by traditional methods. The results were found similar to previous injury risk functions based on physical tests, which gives a high level of confidence in the chosen approach. The simulation-based approach of matched ATD model vs. HBM simulation was successfully applied. Rmax curves show a slightly better quality than the injury criterion PC Score.

**Paper No.19-0309-O**

**STUDY OF CHEST INJURY RISK PROBABILITY WITHIN THE SENIORS PROJECT FOR 45- AND 65-YEAR OLD CAR OCCUPANTS USING CURRENT AND ADVANCED RESTRAINT SYSTEMS IN SLED TEST WITH THOR DUMMY**

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Abstract
From European accident data the proportion of fatal and severe crashes suffered by over 65 year old road users is increasing. In response to this, the SENIORS project [1] aims to improve the safety of elderly road users by determining appropriate requirements towards passive safety systems. The objective of this paper is to present the results obtained in frontal deceleration sled tests with the THOR (Test Device for Human Occupant Restraint) dummy using different restraint systems to compare the chest deflection for each of them. The frontal sled tests were performed at two speeds 56km/h and 35km/h with the THOR dummy as driver and co-driver following the test procedures defined in the SENIORS project. The different safety systems were used one by one at the low-speed deceleration to understand the effect on the dummy deceleration and chest deflection. The standard restraint systems – frontal airbag and seatbelts – were combined with advanced restraint systems for the driver – Knee airbag (KnAB), Pelvis restraint cushion (PRC) and the Driver Load Limiter Adaptive seatbelt (DLLA) – and for the co-driver position – Pelvis Restraint Cushion (PRC) and the Load Limiter Adaptive seatbelt (LLA). Then, at the higher speed deceleration pulse the basic restraint systems and the chosen combination of advanced safety systems were performed. It is aimed at comparing the chest deflection with the injury risk AIS3+ that is calculated from $R_{max}$ and PCA (Injury criteria) for a 45- and 65-year old person. The results observed showed that all the advanced restraint systems reduce the thorax injury risk for both ages 45 and 65 years old, however not always reducing all the IR-TRACC displacement but reducing the $R_{max}$ and the PCA calculations. It could also be observed that the most effective restraint system to reduce the thorax high injury for people over 65 years old is Load Limiter Adaptive seatbelt. In this study it can be concluded that with the current standard or advanced restraint systems the chest injury risk for elderly people over 65 years old is very high in high deceleration tests but is also important at lower decelerations. Moreover, the differences in position P1 and P3 are compared in this paper.

Paper No.19-0274-O
Comparing restraint system sensitivity between the THOR and the Hybrid III, and potential implications in restraint optimization
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Abstract
Restraint system optimization is affected by the sensitivity of dummies to relative loading between the seatbelt and airbag. Differences in design between the THOR and Hybrid III dummies may affect the mechanisms of interaction with the various restraint system components, and the factors that influence compression measured in the dummy’s chest. Previous studies have compared dummy responses in sled tests representing select specific configurations. The goal of this study was to compare the mechanisms of chest compression in the THOR and Hybrid III, and sensitivity to loading by various restraint system components, in full vehicle crash tests.

The NHTSA full-vehicle crash test database was queried to find cases of matched tests with the THOR and the Hybrid III. Four cases of matched tests were found - one with a sub-compact hatchback, one with a compact sedan, one with a mid-sized sedan, and one with a full-sized pickup. All were 56 km/h frontal-impact, rigid barrier tests, with the dummy seated in the driver position. The vehicles were matched based on make, model, model base year, and restraint system characteristics (e.g., observed belt force limit). Shoulder belt forces, chest deflection time histories, and frame-by-frame videos were examined to restraint system interaction and factors influencing compression measured in the chest. In all four cases the shoulder belt force time histories were similar between the THOR and the Hybrid III. In one case the chest
compression in the Hybrid III appeared to be predominantly dependent on force limiting in the shoulder belt, while the THOR exhibited a greater sensitivity to combined loading by the belt and airbag. In two cases the results were mixed, with both the dummies exhibiting some sensitivity to both belt and airbag loading (though the airbag appeared to contribute to a greater degree with the THOR). The nature of chest compression appeared most similar in a case of an apparent digressive force limiter, with both dummies exhibiting a plateau associated with a transition to airbag loading with a drop belt force limit. These results suggest that the relative sensitivity to belt and airbag loading can vary between the THOR and the Hybrid III, depending on the specific characteristics of the restraint system and vehicle being studied. The THOR is more flexible, tends to experience greater forward excursion into the airbag, rides up higher on the airbag, and is capable of measuring deflection in the upper chest where a majority of the airbag loading occurs in some cases. As a result, in some cases the THOR appears to be more sensitive to loading by the airbag than the Hybrid III. Sensitivity to loading by the various restraint system components will likely affect optimization of the restraint systems, affecting the perceived optimal apportionment of load between the belt and the airbag. These results suggest that the two dummies may lead to different strategies for restraint system optimization in some cases, and that the relation of restraint system interaction between the THOR and Hybrid III may vary in the fleet.

**Paper No.19-0172-O**

Comparison of Thorax Responses between the Belted Elderly Occupant Human Body and THOR-50M FE Models under Typical Frontal Crash Test Conditions

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**Abstract**

In Japan the ratio of traffic accident fatalities of elderly people has been increasing, and the main factor is thorax injury. An elderly human body model (HBM) has been developed to evaluate the vehicle safety systems. At the same time, Test device for Human Occupant Restraint (THOR) ATD that has high bio-fidelity is being used in frontal crash tests including lateral vehicle motion. This paper describes the comparison of the thorax response between an elderly human and THOR 50th percentile male (THOR-50M) under a simulated frontal crash including lateral vehicle motion, and clarifies whether there is the correlation between them, especially, the correlation between the rib fractures of the elderly HBM and the thorax deformation of the THOR-50M. The elderly HBM and THOR-50M model were compared under the condition of a driver seat position in a left-handed midsized sedan vehicle equipped with a three-point seat belt, a driver airbag, a knee airbag, and a side curtain airbag. The frontal crash motions of Full Width Rigid Barrier (FWRB) at 56 km/h, Offset Deformable Barrier (ODB) at 64 km/h, Small Overlap Test (SOT) at 64 km/h and Oblique Moving Deformable Barrier (OMDB)-to-vehicle crash test at 90 km/h were applied. From the results the thorax responses and deformation were investigated respectively. The kinematics of each body component was in same trend between the elderly HBM and THOR-50M model in each test condition. For the elderly HBM and THOR-50M model in all the test conditions, the thorax deformation at the upper right was largest among four measurement locations, and that of the elderly HBM and THOR-50M model showed good correlation. In the elderly HBM, the locations of rib fractures were roughly assorted into three regions on the ribcage. The upper left ribs around the belt path in all test conditions, the right ribs around the belt path in FWRB and OMDB, and the lower left ribs in SOT and OMDB were fractured. The R2 (correlation coefficient) between the number of fractured ribs of the elderly HBM and the overall peak resultant deformation (Rmax) of THOR-50M was high as 0.83 for total rib fractures over all regions, while that wasn’t high as 0.7 or less for those of each region. The structural differences between the elderly human and THOR-50M such as the ribcage, spine and shoulder were considered to affect the differences of the kinematics and thorax deformation between them under frontal loading with lateral and vertical input. The comparison results showed a certain correlation between the rib fractures of the elderly HBM and the thorax deformation of THOR-50M, and several differences of the partial thorax responses due to structural differences between humans and THOR-50M. The results of this study suggested that further study for the methods to evaluate detailed thorax injury using THOR-50M should be needed in order to correlate any other indices and possible thorax injuries in the crash conditions with lateral motion.
**Paper No.19-0243-O**

**Test Methodology for Evaluating the Reclined Seating Environment with Human Surrogates**

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**Abstract**

Automated vehicles introduce the potential for non-traditional seating postures, including various degrees of recline. To date, there have been no human surrogate studies in the literature describing reclined occupant response in frontal or other crashes, which suggests that new biofidelity reference targets are needed to evaluate anthropomorphic test device (ATD) and human body model (HBM) predictions. The goal of this study was to develop and demonstrate a methodology for performing biofidelity reference tests for reclined occupants that incorporate methods for capturing these complex kinematics and kinetics. The test methodology developed here is demonstrated with a frontal impact sled test performed with one post mortem human surrogate (PMHS). A simplified, generic, semi-rigid seat pan and minimal back support (at 50 degrees reclined with the vertical) was used to support the occupants as they underwent a 50 km/h crash pulse while restrained with a three pretensioner force-limited seat-integrated belt restraint. Occupant kinematics, seat deflections, belt spool-in and spool-out, and buck motion were collected with an optoelectronic motion tracking system and lumbar spine and pelvic load timing were collected with additional instrumentation. Boundary conditions are critical for finite element (FE) model validation. The forces beneath the seat pan, toe pan and buckle were measured in 6 degrees of freedom (DOF). Additionally, the forces at the lap belt and shoulder belt were measured. This is the first effort in the field to develop and evaluate a methodology for reclined occupant biofidelity reference testing, which can (and will) be used for: i) additional PMHS testing to generate biofidelity reference targets for assessing the performance of occupant models in reclined postures, and can also be extended to: ii) generate reference data for other reclined configurations and iii) to assess the performance of new and novel restraint system designs.

**Paper No.19-0162-O**

**THOR 50M Suitability for Automated Vehicle Crashworthiness**

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Abstract
The objective of this study is to use finite element (FE) models to understand the differences in response between human body model (HBM) and THOR-50M dummy in reclined seating scenarios that may become more common in automated vehicles. The Total Human Model for Safety (THUMS) v4.01 and Humanetics THOR-50M Anthropomorphic Test Device (ATD) FE model were used in both frontal- and rear-impact scenarios. The seating postures were based on data from a recent volunteer study. Front and rear impacts with seatback angles of 23, 33, and 43 degrees were simulated for a total of six test conditions. A US NCAP midsize sedan pulse was selected for the analysis. A publicly available seat model based on a 2012 Toyota Camry driver seat and a model of a ZF seatbelt system with pre-tensioner and load limiter were used in the study. Both dynamic and kinematic data were analyzed and compared between the THUMS and THOR models, including motion, load measurements and displacements at numerous anatomical positions and sensor measurement locations. In addition, the seat cushion and seatback contact forces were compared. Due to the anthropometry discrepancies between the two models, the sensor measurement locations in THOR 50M do not necessarily coincide with THUMS anatomical locations. In such case, the anatomical location in THUMS was selected. The responses between the two FE models were similar in some parameters and quite different in others. The study could not determine which FE model has better biofidelity because no biofidelity specifications from Post Mortem Human Subject (PMHS) testing are available for such assessment.

Paper No.19-0139-O

THOR ATD response in Oblique and Lateral Far-side Sled Tests

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Research
The research objective was to evaluate the THOR response in oblique and lateral far-side impacts.

Methods
A NHTSA THOR-M ATD was placed on a rigid seat sled buck fabricated to evaluate oblique and lateral far-side impact tests. The buck had a rigid center console, simulated rigid dash, and side structure. The components had limited adjustability to simulate different vehicle interiors or intrusion levels. Center console and dash were covered with honeycomb cardboard (22 psi) and Ethafoam-220 covered the simulated intruded side structure. THOR was positioned per THOR seating procedures (v2015) and restrained using a standard three-point seatbelt with a pretensioner and load limiter. Tests were conducted at 30-degrees (n=2), 45-degrees (n=2) and 90- degrees (n=1) from pure frontal. 45- and 90-degrees tests were conducted at 30 km/h and 30-degree at 36 km/h. One 45-degree test was conducted without a pretensioner. High-speed digital cameras were used. Data: Head accelerations, angular rate, neck loads, thoracic accelerations and forces, thoracic deflections, and pelvis accelerations, ASIS and acetabulum and belt webbing loads.

Results
THOR reacted differently in each angled test. Resultant head accelerations and BrIC ranged from 13–45 g and 0.8-0.6 (highest in 90- degree). There were no head impacts. Neck tension forces were higher in the 90-degree test and as the test angle increased, peak neck tension (483-1655 N) occurred later. Thoracic resultant spine forces were highest in the
90-degree test and ranged from 1644 N-3328 N between all tests. For the 90-degree test thoracic tension forces were highest and compression forces were lowest. Pelvis accelerations and acetabulum resultant forces were highest during the 90-degree test. Femur forces were highest during the 30-degree tests. Lap belt forces ranged from 1196-2071 N. The test without pretensioning produced the lowest lap belt force, 1196 N, and the shoulder belt slid off. As the test angle increased, shoulder belt forces decreased for pretensioned cases, ranging from 1806-3633 N. Chest deflection contours and associated viscous criteria will be included in the full-length paper, if accepted.

Discussion
THOR responded as expected for the oblique far-side tests, and results between two same tests configurations were similar. The THOR’s response between test configurations differed. THOR response for head, thorax, and pelvis were highest during 90-degree test compared to the other angles which may be due to constraints of rigid seat and center console, and low shoulder belt interaction. The 30-degree tests produced highest femur forces and shoulder belt forces due to forward interaction of THOR with dash and shoulder belt. This test series was limited to the number of tests conducted and limited number of test angles.

Conclusion
The THOR ATD performs well for oblique impact tests, and response is repeatable and indicates differentiation between test type set-ups. The THOR ATD may be a good test device for future oblique and far-side testing. The data are relevant to performance of THOR ATD in multiple test configurations, and its reproducibility and repeatability.
**Paper No.19-0289-O**

**EFFECTIVENESS OF SEAT BELT REMINDERS among CHILDREN AND TEENAGERS in real-world crashes**

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**Abstract**

The seat belt is one of the most effective ways to protect occupants in car crashes. Unfortunately, the average seat belt use in Europe (2018) was 83% for drivers and 81% for front seat passengers, where teenagers often have the lowest rate. The study aimed to use real-world car crashes to analyze the seat belt use among 0 to 18 year old children and teenagers as occupants and 18 to 20 year old drivers in Sweden 2011-2018. An additional aim was to analyze the effectiveness of seat belt reminders for both the front and the rear seats for the same age groups. The Swedish Traffic Accident Data Acquisition was used, which is the Swedish national system for road traffic injury data collection. The data included 26,270 car crashes involving 30,447 car occupants in passenger cars. Regarding passengers, 5% were children aged 0 to 18 years and 12% of the drivers were aged 18 to 20 years. Occupants aged 14 to 18 years had a lowest seat belt usage rate (89%), where the rate was even lower when these passengers had a young driver, 86% if the driver was aged 18 to 20 years and 93% if the driver was aged 30 years or above. And male passengers had a higher seat belt usage rate if they had a female driver, 94% if they had a female driver and 87% if they had a male driver. In the rear seat, children and teenagers aged 12 to 18 had a lowest seat belt usage rate and 18 year olds had the lowest (79%). The usage rate was lower when the passengers were sitting in the rear seat and when the driver was young. For children above 8 years, seat belt use was higher in cars with an SBR. This was also the case for adults (over 30 years). There was a clear difference for the rear seat, especially for teenagers 14 to 18 years, among whom 100% used the seat belt in a seat with an SBR. Young drivers had a higher risk to be involved in a road traffic accident compared to other age groups. Unfortunately, teenage passengers to these young drivers also have the lowest seat belt usage rate in the data. And there was indications that male teenage passengers have lower seat belt usage rate if their drivers also were male. One conclusion may be that the seat belt usage for a teenage passenger can depend on the driver. Therefore, it is important to put extra focus on this age group of drivers to increase seat belt use for their passengers. The present study clearly shows the need of actions aimed to increasing the seat belt use for rear seat passengers. The seat belt use in the rear seat is lower compared to the front seat, especially when the driver is young. The SBR has been shown to be effective in the front seat, and should therefore have the same specifications in the rear seat.

**Paper No.19-0218-O**

**A Usability Study of Seatbelt Buckle Accessibility for Elderly Occupants**

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Abstract
Elderly occupants form a sub-group in the population spectrum that is often categorized as “vulnerable” in the automotive industry. By 2050, the segment of the population aged 60+ is expected to approximate 26%, which reinforces the importance of developing more adaptable safety technologies that provide optimal and accessible restraint.
Following previous research where we analyzed the performance of motorized adjustable buckles in increasing the ease of access to recessed belt buckles for children in booster seats, we extended the examination to study their applicability to elderly occupant comfort and safety. Thereby, the objectives were: 1.Perform a series of usability studies to prove that the current industry trend of recessed buckles is causing accessibility issues. 2.Attempt to confirm if motorized adjustable buckles improve latching performance while maintaining the intended geometry, given the previous objective was proven true. A series of studies were conducted with a fixture that simulated the rear right side seat of a mid-sized sedan. The fixture was equipped with a motorized adjustable buckle which replicated two buckle modes – recessed and elevated. Occupants were asked to latch themselves with the buckle in both positions. Observations were made of the number of latch attempts, latching times, occupant preferences, and difficulty levels. The data shows a statistically significant difference for the mean latching attempts and durations between the two buckle modes (recessed and elevated). Objective feedback collected from the occupants shows that a majority of the sample population preferred the elevated mode. However, a strong explanation by the predictor variables (age, sex, weight, standing height, sitting height, arm length, arm to buckle length, and location) of response variables (latch attempts and durations, and buckle preferences) could not be established, unlike our previous study where strong correlations were found. This study’s results indicate that elderly occupants are influenced by categorically different factors than children, as variables like age, weight, height, and sex had a limited influence on the outcome of the study. Observations and analyses conducted during the trials point towards more subjective factors that may have had a greater impact on the outcomes; predominantly general health, which can be arbitrary and indifferent to the predictors that were considered in this study. Furthermore, a singular seating configuration was used in this study. More permutations of seat sizes and buckle mounting types will aid in confirming this study’s hypotheses.

An Examination of the Effectiveness of Seat Belt Assurance Systems: A Naturalistic Driving Study Solution
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Research
Seat belts are one of the most important motor-vehicle safety devices ever developed. The nationwide seat belt use rate has increased from about 70% in 2000 to about 90% in 2017 (Li & Pickrell, 2018). It is expected that further increases in seat belt use for occupants would continue to produce substantial reductions in injuries and fatalities. Passenger-vehicle seat belt assurance technology has been suggested as a promising way to further promote seat belt use. The purpose of this study is to evaluate the potential effectiveness and user acceptance of different prototype seat belt assurance systems (SBAS).

Methods
Two types of prototype SBASs were used in this study, including a transmission interlock system and a speed limiter system. The transmission interlock system prevented a vehicle that had just been started from being shifted into gear if
either the driver or front-seat passenger is unbelted. The speed limiter system limited maximum vehicle speed with an unbelted driver or unbelted front-seat passenger to speeds below 15 mph. Each vehicle was equipped with a data acquisition system (DAS) including two cameras. A naturalistic driving study was conducted with a mixed design of 48 part-time seat belt users. Half of the participants were randomly assigned to the speed limiter group while the other half were assigned to the transmission interlock group. Each participant was given one type of research vehicle for a total of three weeks, including one baseline week (i.e., the SBAS was not activated), and two treatment weeks (i.e., the SBAS was activated). Data on participants’ driving behavior and their interactions with each seat belt assurance system were collected over the three-week period and along with subjective ratings were used in the final analysis.

Results
The results showed significant effectiveness for both SBAS types such that the percentage of unbelted driving time (or trips) significantly decreased during the treatment period as compared to the percentage of unbelted driving time (or trips) during the baseline period. The average treatment period related reduction in unbelted driving time is about 14.4 percent while the reduction in unbelted trips was about 19.8 percent. Comparative differences between the two SBAS systems were observed with different measures (i.e., based on unbelted trips or unbelted driving time). The measure of “percentage of unbelted driving time” may be a better indicator of system effectiveness because it includes total trip duration, factoring overall exposure into the analysis.

Discussion
Generally significant system effectiveness in both SBASs and high levels of user-acceptance were observed. Participants rated their experience with the technology in terms of perceived benefits (including resulting attitudes) and ease of interaction. One limitation of this study is that this study was conducted in Michigan, where the average seat belt use rate is about 90%.

Conclusion
This paper is a good topic for the session titled with “Restraint System Design and Performance Challenges: Addressing the needs of Diverse Populations” as it addresses potential strategies to increase seat belt utilization, particularly among that segment of the population who are less inclined to use seat belts to begin with.

Paper No.19-0057-O
A PARAMETRIC STUDY OF AN ADAPTIVE LOAD-LIMITING RESTRAINT SYSTEM WITH WEIGHT SENSING CONSIDERATIONS
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Abstract
The subject study provides an overview of several rear seat restraint configurations, with a focus on the restraint performance of a real-time adaptive (RTA) retractor system. The simulated RTA system assumes the integration of the TCJ Technology into the retractor. The near real-time response and high torque generation capabilities of the TCJ technology are briefly discussed and physical test data are shown in support. Simulations of both a conventional retractor and a 3kN LL retractor are carried out as well. Both the 3kN LL and the RTA systems are equipped with energy management functionalities. Simulations of the three restraint configurations are conducted in the MADYMO software with five different ATD models and six different crash pulses. The ATD models range from the HIII 6YO to the HIII 95th percentile male. The vehicle crash pulses originate from the NHTSA database for barrier impacts, with five pulses at the 35-mph severity level and one pulse at the 25-mph severity level. The MADYMO Control System modeling capabilities are relied upon to develop and implement the feedback control system for the RTA model. Seatbelt pay-out amounts and seatbelt pay-out rates are monitored during the simulated crash events. The sensor data are fed real-time into the RTA control system and real-time adaptive retractor seatbelt forces are thus generated. The research initially assumes direct occupant weight sensing is absent and later assesses that the RTA system can indeed function without this third input. A recommended load-limiting performance envelope for the RTA system is specified based on the simulation results. Data interpretation highlights the benefits of an RTA-type system for the full spectrum of modeled occupant sizes and weights, with an understanding that the smaller and more vulnerable occupants (elderly) tend to benefit most when restraint systems are more compliant, and yet able to prevent excessive seatbelt pay-outs for heavier occupants, without any significant detriment in injury numbers across the board. The noted improvements in the 25-mph simulation further
bolster the broader benefit aspect, as a greater majority of occupant exposures occur at less than the 35-mph severity.

**Frontal Crash Simulations Using Parametric Human Models Representing a Diverse Population**

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Research
Crash injury data have shown that older, obese, and female occupants have increased risks of death and serious injury in motor-vehicle crashes compared with young, midsize men. The objective of this study was to use parametric finite element human models to examine these injury trends and identify safety concerns for various vulnerable populations in frontal crashes.

Methods
We sampled 100 occupants based on age, sex, stature, and body mass index (BMI) using the Uniform Latin Hypercube method. The target anatomical geometry for each of the 100 models were predicted by the statistical geometry models for the ribcage, pelvis, femur, tibia, and external body surface developed previously. A regional, landmark-based mesh morphing method was used to rapidly morph the GHBMC-M50-OS model into the target geometries. The morphed human models were then positioned in a validated generic vehicle driving compartment model based on a statistical driving posture model. US-NCAP frontal crash simulations were conducted. Body region injury risks were calculated based on the risk curves used in the US-NCAP, except that scaling was used for the neck, chest, and knee-thigh-hip injury risk curves based on the sizes of the bony structures in the corresponding body regions. Age effects were also considered for predicting chest injury risk.

Results
The simulations demonstrated that driver stature and body shape affect occupant interactions with the restraints, and affect occupant kinematics and injury risks in severe frontal crashes. Driver age affects injury risk through the associated lower tolerance. Taller occupants tended to pitch more forward with their heads and necks wrapping around the upper margin of the airbag. The torsos of obese occupants pushed the airbag upward, which was most evident for shorter female models due to proximity of the abdomen to the airbag prior to deployment. U-shape relations between occupant stature/weight and head injury risk were observed. Chest injury risk was strongly affected by age and sex, with older female occupants having the highest risk. A very strong correlation was also observed between BMI and knee-high-hip injury risk, while none of the occupant parameters meaningfully affected neck injury risks.

Discussion
This study is the first to use a large set of human models to investigate the combined effects of age, sex, stature and BMI on injury risks in frontal crashes. The work is further differentiated by the use of a validated driving posture model to accurately position the morphed human models based on body size. All the model-predicted injury trends are broadly consistent with previous field crash data analyses. This study is limited by the use of a single vehicle model and crash condition. The injury risk curves were scaled using simple geometric relationships.

Conclusion
This study demonstrated that parametric human models can effectively predict the injury trends for a diverse population and may now be used to optimize restraint systems for people who are not similar in size and shape to the available ATDs. New restraints that adapt to occupant age, sex, stature, and body shape may improve crash safety for all occupants.
The geometrical relationship between the lap belt and occupants' anterior superior iliac spine

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Abstract
The restraint of the pelvis by the lap belt is a prerequisite for occupant protection in a 3-point seatbelt system. If the lap belt slips over the anterior superior iliac spine (ASIS), the lap belt can penetrate the abdominal area during impact, leading to abdominal injuries. Many studies of this phenomenon (known as submarining) have focused on cases in which the lap belt is initially positioned correctly, but slips off due to the dynamics of impact. However, lap belt riding over the iliac bone can also occur when the lap belt is placed on the abdomen from the beginning, without overlapping the iliac crest. In this research, the relationship of the lap belt to the ASIS of seated occupants was investigated, first by statically measuring the initial lap belt-ASIS overlap in a group of volunteers and then by using FE analysis to assess the dynamic interaction of the lap belt with ASIS during test-sled crash simulations. The lap belt-ASIS overlap of ten volunteers was measured as they sat in a small car’s rear seat (where the lap belt anchor is further back). The lap belt did not overlap with the ASIS for four volunteers: of these, three had a body mass index (BMI) of less than average (that is, <24.1 kg/m²). Further measurements of 20 male volunteers sitting in a rigid seat were conducted to examine the factors which affect the lap belt-ASIS overlap. When volunteers sat in an upright posture, the overlap increased as the height of the ASIS relative to the thigh increased. When they sat in a reclining posture, for low-BMI volunteers the lap belt was located higher on the (flat) abdomen and the overlap of the lap belt with the ASIS tended to decrease. FE analysis was carried out for rear seat occupants whose ASIS was located at the torso-thigh junction.

For the occupant with a protruding abdomen, even though the lap belt did not initially overlap the ASIS, during impact the lap belt was pulled rearward and down; there was sufficient time for the lap belt to interact with the ASIS. However, for the occupant with a flat abdomen, since the abdomen fore-aft diameter and the flesh thickness on the ASIS was small, there was not enough time for the lap belt to interact with the ASIS even though the lap belt was pulled downward, and the lap belt penetrated into the abdomen. Thus, for low-BMI occupants in the rear seat both the initial lap belt-ASIS overlap and the dynamic interaction of the lap belt with the ASIS during vehicle deceleration tend to be insufficient for effective restraint of the pelvis.

Investigation of Restraint Characteristics for Elderly Occupant Chest injury reduction

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Abstract
Objective In recent years, the increase in the number of traffic accident fatalities of elderly in Japan is one of the urgent tasks for future traffic accident countermeasures. Moreover, from the trend of a global aging society, in the future it is expected that the number of traffic fatalities involving the elderly and the importance of correspondence will also
increase. In this research, in order to cope with the reduction of elderly traffic accident fatalities, chest injuries are focused on as one of the factors of elderly occupant fatalities, measures to reduce chest impact of elderly occupants at the time of a frontal collision are examined and then, the direction of the corresponding technology required for realization was considered. Methods In this study, using a human body FE model with different physiques to reproduce the bone characteristics and skeletal shape of both adults and elderly people, frontal collision simulations within different collision speed ranges were performed. Comparison of chest injuries was undertaken of elderly occupants, which can occur in the middle and low speed range, to adults. Examination of optimum occupant restraint characteristics by seat belts enabled chest injuries of elderly occupants to be reduced to the same level of adults.

Then, the effect of reducing elderly occupant’s chest injuries in each physique was confirmed. Results The occupant restraint characteristic by the seat belt calculated was able to confirm the chest injury reduction effect of an elderly occupant in each physique in the front collision in the medium to low speed range. In addition, this restraint characteristic combines the restraint characteristics for reduction of chest injuries of elderly occupants with different physiques, and secondary collision damage reduction. Discussion In this research, focus was on medium and low speed and frontal collision. In order to realize this occupant restraint characteristic, it was necessary to be compatible with occupant protection performance in the collision mode of each regulation. For this purpose, achieving sensing technology to determine the severity of car body deformation at the time of a collision, occupant protection system technology that can change occupant restraint characteristics according to the situation is essential. In order to further reduce the number of deaths, it is necessary to investigate occupant restraint characteristics that can reduce injuries, and look at other measures for reducing chest injuries in the high speed region for each type of collision. Conclusion In this study, we used a human body FE model with different physiques to calculate the occupant restraint characteristics necessary for a reduction of chest injuries of elderly occupants and reduction of secondary collision damage in frontal collisions in the medium and low speed range, and confirm the effect. In order to further reduce elderly occupant injuries, as a type of integrated safety technology with more damage mitigation effects, collision prediction technology by evolution of ADAS’s external detection technology uses identification of an occupant’s physique, posture, and age judgment technology. It is necessary to evolve protection device technology, which can vary occupant restraining force and time according to situation and occupant.

**Paper No.19-0284-O**

**INVESTIGATION ON RESTRAINT APPROACH: REDUCE THORACIC INJURY BY DISTRIBUTING HIGH RESTRAINT FORCES IN OBLIQUE CRASHES**

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**Abstract**

The number of traffic fatalities is decreasing due to improvements of vehicle crash safety performance, which is promoted by crash safety regulations and consumer information assessments such as the New Car Assessment Program (NCAP). On the other hand, according to Japanese accident statistics, the reduction of fatality rates of those involved in oblique impact crashes is less than those in frontal and side impact crashes. This is considered because the risk of secondary impacts with interior structures increases as the seat belt slips, or occupants do not properly interact with the airbag due to lateral occupant motion induced by oblique vehicle movement. If restraint force is increased, thereby reducing the amount of occupant movement, it is possible to increase the injury risk of vulnerable people, such as the elderly. Therefore, applying high restraint force while distributing such loading to mitigate occupant injury should be the focus. The objective of this study is to develop restraint approaches that achieve effective occupant restraint and a reduction of injury risks by restraining body regions that have relatively high stiffness. The stiffness sensitivity of a rib cage was investigated by using the thoracic impactor simulation with the Human Body Model (HBM) and it was found that the stiffness of the shoulder region, which includes upper rib cage and clavicle, has relatively higher stiffness than other thoracic regions. Therefore, it was determined to restrain around the shoulders. Subsequently, the influences of restraint around the shoulders with respect to occupant kinematics and injury reduction were compared with those of conventional restraint systems under oblique impact simulation with the Test device for Human Occupant Restraint.
Anthropometric Test Dummy (THOR ATD). In addition, the influences of each restraint system on the number of fractured ribs caused by thoracic loading were investigated with the HBM under the same loading conditions as the THOR ATD simulation. When the shoulder region was restrained, THOR ATD movement and chest deflection were reduced compared to the conventional restraint systems. The HBM results indicated that shoulder restraint reduces the chest deflection, similar to the THOR ATD, and the number of fractured ribs also reduced. It was found that the load generated by the shoulder restraints was broadly distributed on the whole thorax, compared to loads of the conventional restraint systems. The restraint force was higher than that of conventional restraint systems and it reduced amount of occupant movement however the concentrated force on the thorax decreased. Based on these findings, an investigation of the mechanisms of load distribution is necessary considering the structural differences between the THOR ATD and the HBM. This study described an approach to reduce thoracic injury while distributing loads over the whole thorax and keeping high restraint forces by restraining the shoulders, which have a relatively higher stiffness than other thoracic regions. In order to reduce the number of traffic fatalities, it is desirable to develop restraint systems based on the approach in this study.

Paper No.19-0322-O
New Passenger Restraints with Adaptivity to Occupant Sizes, Seating Positions and Crash Scenarios through Paired ATD-HM Study
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Abstract
This study was undertaken to develop new passenger side Advanced Adaptive Restraint Systems to better protect automobile passenger occupants from serious injuries in frontal and oblique motor vehicle crashes. New concept designs of a passenger airbag and a knee airbag, each with controllable dual-volume and tunable vents, were developed. A new advanced adaptive restraint system, integrated with such developed passenger airbag, knee airbag and an updated seatbelt system consisting of a switchable dual-load limiter retractor with shoulder and lap pretensioners, was optimized to achieve good performance for all the fourteen load cases defined in this study. The fourteen load cases represent various real-world crash scenarios comprising passengers of three body sizes seated at different seating positions (the small-size female at full-forward, mid-track, and full-rearward, the mid-size and large-size males at mid-track and full-rearward) under a “hard” pulses representing the 35mph full frontal and frontal oblique crashes of a sub-compact passenger car. The system performances were evaluated with the two sets of occupant injury assessment tools: 1) the Anthropomorphic Test Devices (ATDs) of the three body sizes (the Hybrid-III 5th%ile female dummy, the THOR 50th%ile mid-size male dummy and the Hybrid-III 95th%ile large-size male dummy) with the injury risk functions used in current regulatory lab tests, and 2) the full body Human Models (HMs) of the three body sizes (the 5th%ile female model F05-O v3.1, the 50th%ile male model M50-O v4.5 and the 95th%ile male model M95-O v1.2) developed by Global Human Body Model Consortium (GHBMC) with the published injury risk functions derived from the Postmortem Human Subject (PMHS) tests. For each load case, four passenger side sled system models were developed, paired with the ATD and the HM of the same size, and for the current production restraints (baseline) as well as the new restraint designs. The injury risks of the occupant body regions and combined injury risks (referred to “Occupant Injury Measures”) were estimated with both ATDs and HMs. The new adaptive restraint system design was developed through individualized optimization for all the fourteen cases in multiple iterative steps. Firstly, the new concept designs were made at the component level, evaluated using two validated ATD sled test models simulating the two load cases (5th%ile female at full-forward position and 50th%ile male in full-rearward position). Secondly, the new advanced adaptive restraint system was optimized with the ATDs in seven successive steps, obtained the optimal restraint design parameters set for each load case. And finally, the optimal adaptive restraint configuration for each case was verified with the HMs sled models. Hundreds of the sled simulations were performed in such processes. The results demonstrated that the new adaptive passenger restraint system design has more versatile adaptivity and improved performances for all the considered load cases than the baseline restraints. The benefits for the occupant injury risks reduction vary case by case, within 12%-79% margin estimated with the ATDs and 8%-66% with the HMs.
Paper No.19-0241-O
New approaches in modeling belt-flesh-pelvis interaction using obese GHBMC models
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Abstract
Obesity is associated with higher fatality risk and altered distribution of occupant injuries in automotive collisions partially because of the increased depth of abdominal soft tissue, which results in limited and/or delayed engagement of the lap belt with the pelvis and increases the risk of pelvis “submarining” under the lap belt exposing occupant’s abdomen to belt loading. Previous modeling studies have shown that pelvis submarining could not be replicated using existing human body models. The goal of this study is to perform model modifications and investigate whether they could lead to model submarining. By detaching the connections between the pelvis and surrounding flesh, submarining like belt kinematics were observed. By remeshing the flesh parts of the model, similar belt kinematics was observed but the pelvic wings were fractured. Finally, large shear deformation on the flesh together with submarining like kinematics were observed in the model with its flesh modelled using the meshless Smooth Particle Galerkin Method (SPG) method. The results of this study showed that SPG method has potential to simulate large deformations in soft tissue which may be necessary to improve the biofidelity of belt/pelvis interaction.

Paper No.19-0140-O
Analysis of the interaction between child occupants and deploying frontal passenger airbag in simulated frontal crashes
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Abstract
Objective: Since the 1990s there has been an emphasis on designing the vehicle airbag system to depower the front passenger airbag to improve the safety of child occupants in the front seat. Recommendations based on first-generation airbag designs varied from switching off PAB to having children less than 13 years of age to be seated in the rear seat. Airbags have evolved over the years and there have been changes to the intensities and deployment characteristics of modern airbags. The aim of the study was to quantify the responses of the 6-year-old ATD installed in child restraint systems seated in the front passenger seating position exposed to a deploying modern front passenger airbag. Methods: Finite element (FE) models of a 2012 Toyota Camry model (National Crash Analysis Center archives), child seat models (developed internally), a tuned modern front passenger airbag (PAB) (Takata Inc., MI), a Q6 anthropomorphic test device (ATD) model (Humanetics Inc., MI), and a tuned 3-point lap-shoulder belt with pretensioner/retractor (developed internally) were used for the simulations. Seating conditions consisted of a convertible seat in forward-facing harness mode (FFC) with and without a top tether, a highback booster (HBB) and a baseline condition without any child restraint system (No-CRS) in normal seating and a misuse condition with seatbelt behind the back. Models were simulated (N = 12) for NCAP frontal test at 35mph.

Results: Head contact was observed with the instrument panel (IP) in all misuse conditions without PAB (HBB and No-CRS condition with seatbelt behind the back, and FFC without top tether). This contact was eliminated for HBB and FCC seats by the deployment of a PAB. PAB and no-PAB conditions for HBB in normal seating resulted in HIC15 values of 390 and 359 respectively, and resultant head acceleration of 72G and 71G respectively. For FCC with top tether, deployment of PAB resulted in 24.4% reduction in HIC15 (754 to 570) and 12.9% reduction in resultant head acceleration (93G to 81G) as compared to no-PAB condition. For FCC, utilization of top tether resulted in 15.6% reduction in head excursion in the no-PAB condition (471mm to 397mm) and 5.2% reduction (324mm to 307mm) in the case with PAB. In the No-CRS
normal usage condition, there was minimal head interaction with the PAB. The PAB and no-PAB conditions showed similar HIC15 (204 and 188 respectively) and resultant head acceleration values (51G for both). In the misuse condition, the Q6 head slid under the deployed PAB and contacted the IP. Conclusions: In all situations, deployment of PAB provided similar or a relative positive effect as compared to no-PAB condition. There was a clear benefit of using a PAB in all the misuse conditions as it eliminated head contact with the IP. Even in cases where there was no contact with IP (no PAB), usage of PAB resulted in reduced head excursion and comparable or lesser values of HIC. Additional simulation conditions and testing are necessary to explore crash pulses, directions and vehicle/airbag models.

**Paper No.19-0331-O**

Paired comparison of ATD responses for the CMVSS 213 bench and Proposed FMVSS 213 Bench

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Abstract
A controlled matched pair comparison of child ATD responses, installed in different models of child restraints was conducted to investigate differences between the current CMVSS 213 bench and the proposed FMVSS 213 bench. The effect of acceleration and deceleration pulses on ATD responses were also examined. The CRABI 12-month-old and the Hybrid III 6-year-old were placed in rear facing and forward-facing child restraints installed on the current CMVSS 213 bench and the proposed FMVSS 213 bench. Repeatability of installation was verified with a 3D Faro measurement system. A total of 114 tests were conducted on the Seattle Safety acceleration sled and on the Messring HydroBrake deceleration sled. Head, chest and pelvis acceleration responses were compared for pairs matched as a function of ATD, seat type, and installation method. Maximum head excursion, maximum knee excursion, and seat excursion at the time of maximum head excursion were estimated using video recordings. Downward displacement of rear facing seats was reduced on the proposed bench when compared to the current CMVSS 213 bench. The Hybrid III 6-year-old head, chest, and pelvis responses on the two benches were similar (difference of ≤ 5g). One forward facing seat exhibited a higher chest response on the proposed bench. Maximum head excursions relative to both the bench and the seat tended to be greater on the proposed bench for all seats regardless of installation method. Paired responses on the acceleration and deceleration sleds were similar. Differences in paired responses were found to be more strongly linked to product design characteristics than to test bench characteristics or sled type. The study contributes to an understanding of the influence of test configuration and is pertinent to the development of child restraint regulations or consumer evaluation programs.

**Paper No.19-0294-O**


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Abstract
In 2015 Euro NCAP updated its test protocols and in 2016 Euro NCAP updated its assessment protocol. The aim of this was to advance the vehicle restraint systems in the second seat row for both small adults and children. This included the introduction of a full width frontal test and modification to the existing offset frontal and side impact tests. The update to the protocols aimed to enhance the vehicle restraint systems towards a more efficient one, including belt load limiters and belt pretensioners. As far as child occupant protection is concerned the objective of Euro NCAP was to seek a combined restraint strategy allowing both the vehicle restraint system and the child restraint system (CRS) to work together. The child restraint systems used for the crash testing are a highback booster for the Q6 and a booster cushion for the Q10. The aim of this study was to investigate the performance of the vehicles tested with regards to the three key areas covered by the protocol: i.e. CRS installation checks, safety provisions in the vehicle and crash performance. The
Test results from 97 vehicles tested by Euro NCAP between January 2016 and December 2018 were analysed. Where possible the reasons for differences between the best and worst performers for each assessment were investigated.

**Paper No.19-0063-O**

**COUPLING DEVICE FOR CHILD RESTRAINT SYSTEM (CRS) FOR INFANTS AFFECTED WITH OSTEOSTENOSIS IMPERFECTA: DESIGN AND NUMERICAL ASSESSMENT**

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**Abstract**

The second death reason in children since 5 until 14 years is related with injuries produced during traffic incidents mainly due to vehicle’s passive safety systems, which are not designed to safeguard their lives. Thus, current traffic norms impose the usage of Child Restraint Systems (CRS). Notwithstanding, CRS for children with different ailments as bone-degenerative ones do not exist. For instance, around half a million persons suffering Osteogenesis Imperfecta (OI) are estimated to exist. At the best knowledge of the authors, currently, there is no CRS specially development for children with OI. This work in progress aims to provide a solution for car mobility of infants with OI based on a CRS designed to dissipate a part of kinetic energy during vehicular impacts. The proposed mechanism consists on a Cartesian mechanism system with linear displacements in axis X, featuring springs and dampers, which is aimed to dissipate kinetic energy in order to reduce the decelerations reaches for the child during a frontal crash. The system is designed in CAD software and is then analyzed numerically, through a 2D dynamical Software simulation. In order to obtain a cheap and adaptable CRS, it was established a methodology based on the research, recovery, and analysis of information. The mechanics has been development to the new European standard R129 (I-SIZE). This appliance can dissipate kinetic energy in critical amounts, which could cause damage to OI minors. Numerical analyses show the appropriateness of the design for the purpose of safeguarding OI bones from fractures during front impacts. Critical deceleration can be present during this kind of impacts. Nevertheless, numerical results validate them obtaining lower decelerations using the proposed system than using ones of the typical CRS. Despite 2D dynamical recreation, manufacture of the prototype and its further test in a sled platform to confirm that the design accomplishes its goal for different age groups according to R129 is required. Further research on optimizing the CRS is required so to improve these features. It is important to remark that even the new European standard R129 (introduced completely) in 2018, as well as traffic regulations around the world (up to the best the knowledge of the authors), do not require the usage of any specialized CRS for infants with OI or for any other bone-degenerative diseases. Thus, this research sets an important precedent for the development of this type of specific systems as well as for corresponding regulations to protect OI child population of high risk in vehicular accidents.
Development of a modular tool for safety assessments of human-machine-interaction for assisted driving functions (SAE Level 2)

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**Abstract**

Per definition, SAE Level 2 (L2) Systems perform both the lateral and longitudinal vehicle motion control with the expectation that the driver completes the Object and Event Detection and Response (OEDR). Since every system performs also parts of the OEDR itself and this amount of OEDR also varies between different L2 systems depending on the intended system design, it cannot be taken for granted that drivers automatically understand their roles and responsibilities in interaction with the system. Especially highly reliable L2 systems performing a greater amount of OEDR while at the same time requiring only little driver input over time can make it difficult for drivers to correctly identify their role and responsibility. Until now, neither application-oriented assessment methods nor design guidelines for OEDR related system design features taking safety of human-machine-interaction into account are available. The objective is therefore to deliver a standardized tool for the assessment of human-machine-interaction-related safety of vehicles with L2 systems currently available on the market. To evaluate the impact of different system design aspects on safety of human-machine-interaction and also to be able to differentiate between system designs, a holistic, standardized and application-oriented assessment procedure is proposed.

The novel tablet-based assessment tool focuses not only on available standards and guidelines but measures also concrete user behaviour and user understanding in interaction with the L2 systems. The aim is to gain further insights which cannot be measured directly by simple checklist instruments. For preparation, based on international standards, literature reviews and expert consultations, a first checklist-based expert-evaluation for currently available vehicles with L2 systems was developed. These assessments are focusing on different sources of user information (e.g. user manual), human-machine-interface design as well as the prevention of unintended use by different driver monitoring techniques. The checklist-tool was developed in cooperation with experts of different EuroNCAP test laboratories and validated in a common expert workshop to gain high level of standardization and agreement. However, to assess safety of human-machine-interaction holistically beyond these rather explicit forms of information design criteria, also implicit forms of driver-vehicle-communication via vehicle dynamics, functional behavior or reliability play an important role and should be taken into account.

Therefore, the main and novel methodological aim is to consider also interaction related processes regarding user’s understanding of roles and responsibilities when applying automated driving functions as well as user’s awareness of automation modes or traffic situations in the modular tablet-based assessment tool.

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**Paper No.19-0006-O**

**BENEFITS OF INTUITIVE AUDITORY CUES FOR BLIND SPOT IN SUPPORTING PERSONALIZATION**

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Abstract
Supporting drivers with auditory cues has been shown beneficial, but is also known to reach a certain level of annoyance. To fully understand the benefits of intuitive auditory cues as an HMI element, further research is needed. This paper investigates the benefits of increasing input to aid in the reduction of hazard risks caused by blind spot using intuitive auditory cues. Intuitive auditory support is a naturalistic sound of an object using volume to indicate the distance of the side object (including blind spot area). The experiment involved twenty participants (2 women, 18 men) between 21 and 24 years of age. The experiment was conducted in a 360-degree view simulator with a car body on a turntable with a six-axis control. Using lane change scenarios, participant-perceived benefits of enhanced awareness of hazards, feelings of increased security, and annoyance caused by intuitive auditory support, were compared to a USNCAP target blind spot warning system (with buzzer), and unsupported as baseline systems. For this, subjective measures (i.e., survey analysis), as well as galvanic skin response data to measure participants' physiological responses, were used. The results indicate that intuitive auditory cues support enhanced hazard awareness, increase the participants feeling of security, and are perceived to be less annoying for rare drivers compared to blind spot warning, while for frequent drivers a blind sport warning seems to better support these variables. Our results indicate that auditory support provides a suitable basis for supporting those who drive only rarely in lane change maneuvers (supporting maneuverability, providing a feeling of security, and decreasing annoyance levels compared to BSW). Research thus far shows that auditory support could irritate drivers. However, our results do not confirm this. Intuitive auditory support appears less annoying than existing BSW technology. Furthermore, ASIS seems to decrease drivers' stress levels compared with no support. We suggest that personalization could improve blind spot warning systems, by integrating auditory cues for drivers who drive rarely and keeping BSW technology for the remaining groups.

Paper No.19-0050-O

Improvement of driver active interventions during Autonomous driving by displaying trajectory pointers – A driving simulator study

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Research
The interaction between driver and autonomous vehicle has been subject of extensive research, and the transition of vehicle control back to the driver is especially important. An autonomous driving system (ADS) alerts the driver to resume control, for instance, when it detects an obstacle on the road and judges it doesn't have the ability to avoid it.
However, it is possible that the ADS misses the detection of an obstacle. In such case, the ADS will not provide any information regarding the obstacle and the driver will need to detect it and take the decision of retaking control on its own. Therefore, the driver has two main tasks: (1) To monitor both the vehicle trajectory and the surrounding environment. (2) To intervene actively if there is some kind of problem in the trajectory. An effective HMI of an ADS should make easy for the driver to accomplish these tasks. In this study, we propose the continuous display of the vehicle’s future position using trajectory pointers. We use the Toyota Dynamic Driving Simulator to verify the effect in the driver’s active interventions and compare it to a notification only active at trajectory changes. Kondo et al. (2018) reported that the display of trajectory pointers makes the trajectory easy to understand and helps avoiding unnecessary driver interventions.

Methods
24 participants were assigned to each the continuous trajectory pointers (CTP) display and the notification of the trajectory changes (NTC) (48 total participants). First a general explanation was given to all participants, specifying the limitations of the ADS and to retake control of the vehicle in case each judged the necessity (e.g. avoiding an obstacle). The participants were allowed to drive not holding the steering wheel. Each participant drove the ADS vehicle until they were familiar with the HMI. After around 20 minutes of driving in a highway, they faced a situation where the system couldn’t detect an obstacle in the trajectory of the vehicle, so they needed to intervene actively to avoid it. We compared the rate of crash avoidance and the decision process behind each intervention for both HMIs.

Results
All participants drove hands-off the steering wheel at the time of the obstacle event. We found that the CTP display improved the rate of crash avoidance, yielding statistically significant difference ($\chi^2=6.38$, $p<0.05$) compared with the NTC. We noticed that the participants using the CTP HMI were statistically significantly (t test, $p<0.05$) faster to get their hands on the steering wheel and to retake manual control. The majority of the participants claimed they relied on the CTP for the decision of retaking manual control.

Discussion
It remains for future research to verify whether the effect continues even when the driver is completely accustomed to the display. We believe more research is needed on methods of evaluation of such long term phenomena.

Conclusion
In this research, we found that the display of CTP improves the driver’s awareness to an impending obstacle during autonomous driving, allowing a faster and more accurate active intervention and thus increasing the crash avoidance rate.

Paper No.19-0092-O
A new methodology to model driver behaviour accounting for the variation in driving manners using naturalistic driving data.

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Abstract
Our aim is to develop Advanced Driving Assistance Systems (ADAS) which are suitable for all customers in all driving conditions. To achieve this goal, a new methodology was developed to characterize driving manner in each scenario by a mathematical model based on Naturalistic Driving Study (NDS) data. To represent the variety of driving manners, a new parameter named “aggressiveness” is introduced. By adjusting “aggressiveness”, the ADAS’ behaviour can be modified, matching natural driving behaviour in a wide range of operating conditions. This methodology is applied to model when drivers start to brake when approaching another vehicle that’s driving in the same lane. This model can be used to detect when a driver is not assessing a threat correctly by comparing his instantaneous driving behaviour with his normal driving behaviour.
**Paper No.19-0148-O**

Distracted Driving Detection using On-Board Sensors

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**Abstract**

The frequency of distracted driving and its impact on safety is rapidly become a serious social issue. Given that distracted drivers pose an increased crash risk not only to themselves, but also to other road users, it is important to investigate ways to address this growing issue. This research project aims to realize a real-time identification and detection system for distracted driving for use in real-world driving scenarios. Therefore, the main goal of this research is development of a real-time model using on-board sensors, to classify whether the driver of the leading vehicle is distracted or not. This research also investigates the typical types of distracted driving behavior that can be detected by host vehicles (depending on the available sensors) and their key characteristics on driving data pattern.

**Paper No.19-0245-O**

The influence of a gaze direction based Attention Request to maintain mode awareness

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**Abstract**

Future vehicles will combine different levels of driving automation characterized by varying responsibilities for users. This development will intensify system complexity which poses the risk of confusing the driver. We hypothesize that the users’ mode awareness suffers especially when changing from Level 3 “Conditional Automation” to Level 2 “Partial Automation”. Therefore, automated systems need to be designed in a way that minimizes confusion with regard to the automation mode. The article describes the influence of a gaze direction based Attention Request (ATR) to avoid mode confusion with the aim of contributing to the reliable operation of different levels of automation in one vehicle. Two similar studies were conducted. One took place in a dynamic driving simulator with 40 participants. Every participant drove for 10 minutes with a partially automated driving (PAD) (SAE level 2) system and conditionally automated driving (CAD) (SAE level 3) system in the order PAD/CAD/PAD. The second study was conducted on a German highway in a Wizard-of-Oz car. All 40 test persons drove in each PAD and CAD phase 8 minutes in the order of PAD/CAD/PAD/CAD/PAD. The CAD-system was in both studies a high performing Hands-Off Level 2 system that required no input of the driver. To promote the same mental model for all participants as it is a requirement to measure the differences in mode awareness, all persons became a detailed description of the Level 2 and 3 systems presented by video and text. Both studies used a between-subject-design to measure the influence of an ATR. The ATR was based on the gaze direction of the driver and initiated by the investigator when the drivers gaze was not in the street AOI for longer than 4 seconds. Mode awareness was operationalized by the visual attention towards driving-relevant areas, a qualitative analysis of a questionnaire and followed by an interview. The ATR was proven to be an effective action to maintain the mode awareness by using a level 2 and 3 system within one car. Specifically, the visual attention did not decrease by an intermitted CAD drive during PAD. Moreover, the visual attention to the road scene increased for the group with an ATR during PAD. This was indicated by the measurement of a significant interaction effect for the development of the visual attention to the road scene for the groups with and without ATR. Thus, the gaze direction based ATR was proven to be an effective measure to maintain mode awareness, if different levels of automation are combined in one vehicle. This result helps to take the next step for realizing such combined multilevel systems with tailored HMI’s for advanced driver assistance systems. Moreover, it has to be considered, that the studies put the emphasis on the first glance of the drivers, during their first contact with partly and conditionally automated systems. Further studies should investigate the long term effect of an ATR.

**Paper No.19-0325-O**

Driver Workload Estimation based on Realistic In-vehicle Sensors

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Abstract
The introduction of automated driving motivates the need for driver state detection, prediction and monitoring. The first introduced systems for automation (SAE level 2 or 3) rely on the ability of the driver to resume the driving task, both manually (steering control) and visually. The automation system monitors the presence of the driver’s hand(s) on the steering wheel and some systems monitor the driver’s visual attention as well. This is necessary to ensure that the driver monitors the automated drive and responds manually and/or visually to HMI cues from the automation system. Considering higher levels of automated driving (SAE level 3 or 4), several challenges and opportunities arise. First, as driver confidence in the performance of automation grows, they will switch attention to secondary tasks increasing their cognitive workload. The driver may be busy doing other tasks and a system which estimates cognitive workload can indicate that a longer take-over period is necessary, or, in the extreme, a human driver take-over may not be safe or even feasible.
Secondly, the driver may be visually, manually or mentally overloaded (or a combination of these) during manual control and the automation system might encourage or intervene automation modes to enhance safety. These two use cases can be improved using accurate real-time prediction of the driver’s mental workload using one or more in-vehicle sensors. In this paper a robust method for estimating driver workload based on real in-vehicle sensors is presented. Sensors in the seatbelt and at the steering wheel rim derive heart rate metrics which are used to estimate cognitive workload. Furthermore, an analysis is conducted to determine if additional metrics derived from vehicle dynamics data have an impact on the calculation accuracy. Comparing individual-based driver classification approaches versus a generalized driver algorithm is also part of this investigation. A driving simulator study with n-back task induced workload is used to validate the driver cognitive workload estimation method accuracy.

The Detection of Drowsiness Using a Driver Monitoring System
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Research
Driver monitoring systems are appearing in more vehicles, and are gaining acceptance as a method to mitigate various types of driver impairment, such as distraction and drowsiness. The opportunities for impaired driving are growing as cars become more automated, drivers become more distracted, and new drugs become available. This paper is concerned with the ability of a driver monitoring system to classify drowsiness in a driver. Its performance is compared with algorithms that use vehicle-based data, such as steering inputs.

Methods
A driving simulator experiment was conducted at the National Advanced Driving Simulator, and used an AISIN’s Driver Monitoring System (DMS). Twenty participants were recruited in the age range 18-66, and balanced across gender. The experiment consisted of a four-hour drive along a 45-mile interstate nighttime loop. Drivers could set the cruise control using steering wheel controls. The drive contained light ambient traffic, a combination of heavy trucks, passenger vehicles, and other light trucks. On average, participants encountered two to three slower moving vehicles and two to three faster-moving vehicles every ten minutes. The spacing and order of this traffic within these ten-minute segments was semi-random, such that participants could not identify specific patterns. A simplified scale for Observational Ratings of Drowsiness (using values 0-4) was administered at regular intervals to serve as ground truth for the algorithm.
Results
Several measures were derived from driver monitoring variables, including face orientation, eye closure, glance times to the right and left, etc. Additionally, measures were derived from steering and lane position, such as steering reversals and standard deviation of lane position. Random forest models were trained on 75% of the data that used vehicle-based measures, driver monitoring measures, and a combination of the two. They were tested on the remaining quarter of the dataset. The accuracy of the vehicle-based and driver monitoring-based models were around 68% and 77% respectively, while that of the combined model was about 87%. The confusion matrix suggested a binary model that split Observational Ratings of Drowsiness of 0 and 1 into one class, and 2-4 into the other class. The area under the ROC curve for the binary model with combined measures was 82%.

Discussion
Even with four hours of driving, there are relatively few cases of extremely drowsy observations. Additional video coding could be done to obtain more granular ground truth data and would provide more samples for the machine learning model. Crucially, if automation is engaged, then the algorithm would lose all vehicle-based signals, increasing the importance of driver monitoring system as the only measure for drowsiness as well as distracted detection.

Conclusion
The use of a driver monitoring system significantly improved the performance of a drowsiness classifier, and drowsiness warnings could have been issued in advance of adverse events such as lane departures. Driver monitoring offers potential beyond simply detecting where the driver is looking, and could estimate type and severity of driver impairment. It is related to the technology of driver monitoring and its application to driver state detection.

Paper No.19-0260-O
Driver Alcohol Detection System For Safety (DADSS) – A Non-Regulatory Approach In The Research And Development Of Vehicle Safety Technology To Reduce Alcohol-Impaired Driving – A Status Update.

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Abstract
Alcohol-impaired driving continues to exact a significant toll among road users both in the United States and around the world. In 2017, in the U.S. alone, alcohol-impaired motor vehicle fatalities totaled almost 11,000 – a number that has seen very little change since 2009. 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 technology 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 prevent alcohol-impaired drivers from driving their vehicles. Exploratory research in Phases I and II established the feasibility of two sensor approaches, breath- and touch-based, for in- vehicle use. In Phase III, the sensors have become increasingly refined, in terms of both hardware and software, as the program strives to meet the very high standards required for unobtrusive and reliable alcohol measurement. Numerous parallel research programs are currently underway including sensor development, development of calibration processes, materials and instrumentation that will verify the technologies are meeting these elevated standards, human subject testing in conditions that replicate those likely to be experienced in the real world, and real-world pilot field operational trials in diverse settings. At the completion of this effort a determination will be made as to whether the DADSS technologies can ultimately be commercialized. This paper will outline the technological approaches and the status of the various DADSS research programs.
**Paper No.19-0262-O**

Driver Alcohol Detection System For Safety (DADSS) – Pilot Field Operational Tests (PFOT) Vehicle Instrumentation & Integration of DADSS Technology.

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Abstract
The Driver Alcohol Detection System for Safety Program – a joint effort between the National Highway Traffic Safety Administration and the Automotive Coalition for Traffic Safety since 2008 - has been developing unique, in-vehicle breath-and touch-based alcohol detection systems to address the problem of alcohol-impaired driving. The sensors under development are intended to be passive, seamless with the driving task, non-intrusive, accurate, fast, reliable, durable, and requiring little or no maintenance. When installed in vehicles, the technology is intended to prevent alcohol-impaired driving when the driver’s blood alcohol concentration is at or above 0.08%.

Sensor technology, now in Phase III of development, is undergoing more extensive testing in real-world driving environments. Research vehicles are being fitted with breath-based alcohol sensors and comprehensive Data Acquisition Systems (touch-based sensors will be integrated once they have completed the requisite test protocols). Pilot Field Operational Trials have recently begun, and data are being collected. In this paper, an overview is provided of the instrumentation and integration of the test vehicles in readiness for field trials. Data is being collected from the DADSS alcohol sensors as well as from breath-alcohol reference sensors. Instrumentation also has been installed to track environmental conditions, vehicle system data, and test participant video. The data are uploaded via 4G and WIFI and stored in the cloud. These data will be critical in determining the effectiveness (accuracy, precision) of the DADSS sensors in real-world driving environments and when compared with breath alcohol reference sensors. They will also be used to evaluate the effects of repeated use and vehicle mileage on sensor function and in diverse environments, analyze driver behavior and user acceptance, analyze and assess the impact of the DADSS sensors using real-world data, improve awareness of in-vehicle alcohol detection systems and assess potential impact of the sensors on alcohol-impaired driving.

The findings will be used to refine the DADSS Performance Specifications and ultimately for modifying the systems designs and enhance product development. The DADSS technology, if proven to be reliable and reproducible under diverse environmental and biological conditions, would represent a significant technological breakthrough in crash avoidance and a significant advance in driver monitoring technologies in vehicles.

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**Paper No.19-0263-O**


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Abstract

The Driver Alcohol Detection System for Safety Program—a joint effort of the National Highway Traffic Safety Administration and the Automotive Coalition for Traffic Safety—has been developing unique, in-vehicle alcohol detection systems to more effectively address the problem of alcohol-impaired driving. These technologies, both breath-and touch-based, are intended to be seamless with the driving task, non-intrusive, accurate, fast, reliable, durable, and require little or no maintenance. Now in Phase III of development, the breath-based technology is ready for real-world road testing in a naturalistic setting in the State of Virginia, U.S.A. The Driven to Protect Powered by DADSS initiative, is a partnership with the Virginia Department of Motor Vehicles Highway Safety Office and the Automotive Coalition for Traffic Safety. As the technical and program management lead, KEA Technologies, Inc. has instrumented and deployed a small fleet of pilot test vehicles to examine the data from breath-based prototype sensors under various environmental, driver/user interaction, and user demographics conditions. The alcohol detection system is known to be accurate, precise, reliable, and maintainable based on laboratory and controlled test results. This pilot program seeks to obtain data from naturalistic, uncontrolled test conditions. The pilot program will determine if: a) the system is generally accepted by drivers, b) there are any technical modifications required to significantly improve the system, and c) the system is ready for wider implementation in fleet, privately-owned, commercial, or other vehicles. Four 2015 Ford Flex “For Hire” commercial livery service vehicles have been instrumented with in-vehicle breath-based alcohol detection sensors including supporting data collection and transmission systems. The Pilot Deployment Project is ongoing with a goal of collecting at least 15,000 data points from the sensors. Lessons learned will be used to refine the performance specifications, sensor technology, and data acquisition systems for future on-road vehicle testing.

Paper No.19-0268-O

Driver Alcohol Detection System for Safety (DADSS) – Human Testing of Two Passive Methods of Detecting Alcohol in Tissue and Breath Compared to Venous Blood

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Abstract

Alcohol-related traffic crashes and deaths remain a major problem in the United States as data indicate that there are approximately 37,000 traffic fatalities yearly, with 30% (~11,000) of them alcohol related. The Automotive Coalition for Traffic Safety (ACTS) and the National Highway Traffic Safety Administration (NHTSA) entered into a Cooperative Research Agreement to explore the feasibility of using passive technologies as an in-vehicle alcohol detection system that is less intrusive than ignition interlocks, but still able to reduce the incidence of drunk driving. Two passive technologies (TruTouch™ and Senseair™) were tested against breath (Alco-Sensor-FST™) and venous blood under a number of environmental scenarios in which individuals engage every day. A total of 92 healthy male and female volunteers (age 22-38) signed an IRB-approved informed consent and participated in experiments in which they consumed 0.9 g/kg of alcohol under a variety of drinking regimens and scenarios that mimicked real-life situations. The volunteers then provided passive breath and tissue (finger touch) samples and had their blood drawn at 5 min intervals for quantification of alcohol via gas chromatography. Lag time of appearance of alcohol, peak concentration, time to peak, and elimination
rate were the primary dependent variables. The overall aim of the experiments was to test whether the alcohol concentrations measured by the two prototype devices correlated with venous blood under the following scenarios: lag time, eating a snack, eating a full meal, exercising, and “last call.” Each scenario was simulated in the experimental laboratory. The lag time experiment revealed that the order of alcohol appearance after drinking was (from first to last): breath, blood, and tissue, although early breath samples were contaminated by mouth alcohol. However, with over 4,000 matched points, the concentration-time curves for both prototypes paralleled that of blood with correlation coefficients of 0.7876 and 0.819 for touch- and breath-based technologies, respectively. Similar profiles were observed in the “last call” experiment with a “surge” of alcohol being observed after an extra drink was consumed during the distribution phase. The exercise scenario revealed similar profiles, and finally, the two eating scenarios indicated that blood alcohol concentrations (BAC) were lower after consuming a meal compared to a snack; the breath and tissue samples paralleled this profile. The data not only support the proof-of-concept that two different passive technologies (breath and tissue) can detect alcohol fast enough to be useful in a motor vehicle environment, but extend the parameters by demonstrating that the measurement of alcohol in the human body is not affected by many of the common scenarios that are known to alter blood alcohol concentrations. The passive devices each tracked the time course of BAC regardless of the situation demonstrating that these two compartments provide a high degree of accuracy while at the same time minimizing the disruption to the driver. These two devices, if proven to be reliable and with reproducible results under additional environmental and biological conditions, represent a significant technological breakthrough in strategies to reduce alcohol-impaired individuals from driving a vehicle and causing injuries and/or deaths.

**Paper No.19-0296-O**

**VEHICLE INTEGRATED NON-DISPERSIVE INFRARED SENSOR SYSTEM FOR PASSIVE BREATH ALCOHOL DETERMINATION**

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**Abstract**

The objective of the present investigation performed within the Driver Alcohol Detection System for Safety (DADSS) program is to demonstrate the effect of further recent improvements of the breath-based nondispersive infrared sensor technology in realistic settings. More specifically, sensor systems installed in vehicles have been tested by: a) exposing them to a controlled, realistic breathing pattern from artificially generated gas pulses mimicking that of an intoxicated driver and b) human subjects entering a test vehicle and performing a simulated drive while under the influence of alcohol. The tests with artificial gas pulses correspond to human directed forced exhalation from positions up 70 cm from the sensor. The tests provide experimental evidence that in-vehicle, driver breath alcohol determination is feasible with a single sensor positioned at the top of the steering column. The human subject study was designed to test both active and passive detection modes. Good correlation to the breath alcohol reference instrument was found in both cases over the full range of alcohol intoxication exceeding 0.08 percent (the legal limit in most U.S. states). Time to detection is a remaining challenge of the passive mode but is manageable by requesting an active breath in the absence of reliable data. The results illustrate the feasibility of using breath-based NDIR based sensors in different operational modes. In the active mode, a simple exhalation directed towards the sensor is enough for a test to be approved and the alcohol content quantified. In the passive mode, the operator does not actively interact with the sensor. In a real-world scenario, sensors set to a passive mode could be used for driver monitoring and to assist the driver to choose a smarter option when alcohol is detected. The overall conclusion from the present investigation is that in-vehicle breath-based alcohol determination is feasible with the current state of the art sensor technology.

**Paper No.19-0181-O**

**DEVELOPMENT OF PORTABLE BREATH-ALCOHOL-DETECTION SYSTEM**

**MASUYOSHI YAMADA**

26ESV/Program Book
Abstract
A portable alcohol detection system based on exhaled breath analysis has been developed. The system consists of a breath sensor, a smartphone to control the sensor and communicate various data, and a data cloud system. The system can be used to monitor a driver’s status from a remote location. The breath sensor consists of four separate sensors. The first is a water vapor sensor that is used to verify if the applied gas is human breath. The others are semiconductor gas sensors to detect ethanol, acetaldehyde, and hydrogen. The detector is connected to a smartphone, and the driver’s alcohol check results are automatically sent to a data cloud system. To prevent abuse of this detector by blowing substitute gas, it can recognize human exhaled breath by detecting small amounts of metabolites as well as saturated water vapor. The ethanol concentration is obtained from the voltages of the three semiconductor gas sensors. Each sensor has a specific sensitivity for ethanol, acetaldehyde, and hydrogen. We apply the differential evolution algorithm to the relationship between each sensor’s output voltage and its calibration curve. Then we calculate the ethanol concentration of the human breath. This multi sensor method is more accurate than a single sensor method that only uses one gas sensor to measure ethanol concentration. We also employ an original humidity sensor that was suitably designed to detect highly humid (saturated) water vapor using a comb-shaped electrode pattern. From our field tests, in which we used more than 30 sets of detectors, we investigated the performance of exhaled breath recognition. When the field test users of our detector did not consume alcohol, their ethanol, acetaldehyde, and hydrogen concentration levels, as a result of natural human metabolism, were 1.8, 1.9, and 0.1 ppm on average, respectively. Based on these data, we set the threshold level on each gas sensor to recognize human breath. As a result, the detector could measure the breath alcohol level within 3 s. It could also successfully distinguish human exhaled breath from ambient air or spray gas. Since the detector is small (Size: 75 mm(W), 55 mm(D), 20 mm(H), Weight: 20 g, approx.) and connected to a smartphone, it can be used at any time and can contribute to the safety of professional drivers by enabling remote and central management of alcohol test data. It is possible to connect this detector to a vehicle engine interlock system by wireless communication so that the system can recognize the driver’s status, even before they enter a vehicle. This will help prevent drunk driving. We believe that our detector is helpful to decrease alcohol-related accidents and enable remote management of alcohol inspection.
Student Safety Technology Design Competition

Wednesday, June 12, 2019 | 14:00-18:00
Chair: Art Carter, United States | Co-Chair: Bernd Lorenz, Germany
TRACK A | Room: TBD
DEVELOPMENTS IN CAR CRASH SAFETY AND COMPARISONS BETWEEN RESULTS FROM EURO NCAP TESTS AND REAL-WORLD CRASHES

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Folksam Research, Sweden
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Abstract
Developments in car crash safety is preferably demonstrated by analyzing results from real-world crashes. Also results from crash tests can be used to show improvements in crash performance. Previous research has shown a positive development regarding safety performance. Studies from the early 2000 have shown that the European New Car Assessment Programme (Euro NCAP) consumer tests seem to predict the outcome in real-world crashes, although they consider only a part of all accident scenarios. In 2009 Euro NCAP added rear-end crash tests to the test protocol and since 2012 Euro NCAP has gradually further revised the rating protocol. It is therefore important to study developments in crash safety, and to evaluate how Euro NCAP test results correlate with real-world performance. This study aimed to show developments in car crash safety in cars launched since the 1980s based on real-world data, and to present how Euro NCAP crash test results predict the outcome in real-world crashes. Two-car crashes reported by the police (n=202 360) and occupant injuries reported by emergency care centers (n=57 863) to the Swedish Traffic Accident Data Acquisition database (STRADA) were analyzed. The cars were categorized in 5-year periods, according to the year of introduction. Developments were studied in terms of risk of any injury, risk of serious injury, risk of fatality, and risk of permanent medical impairment (PMI).

Correlations with Euro NCAP test results were evaluated based on star levels for all categories of injury severity. It was found that vehicle crashworthiness has improved steadily over the years studied. The proportion of serious injuries was found to be reduced, as well as the injury risk for all injury severities studied. In a comparison of car models launched 1980-1984 with those launched 2015-2018 the proportion of AIS 3+ injuries was 67% lower. Furthermore, the risk for serious and fatal injury was 58% (+/-17%) lower, the risk for fatal injury was 88% (+/-57%) lower, and the risk for PMI was 73% (+/-14%) lower. It was also shown that Euro NCAP crash test ratings mirror real world injury outcomes for all injury severities studied. Comparing 5-star with 2-star rated cars, the proportion of AIS 3+ injuries was 34% lower. Furthermore, the risk for serious and fatal injury was 22% (+/-4%) lower, the risk for fatal injury was 40% (+/-16%) lower, and the risk for PMI was 42% (+/-4%) lower. Large improvement in crash safety was found, especially regarding the risk for fatal injuries and injuries leading to PMI. Euro NCAP star ratings were found to well mirror the risk for fatal injuries and injuries leading to PMI. Consumer crash tests play an important role for the development in car safety. It is however important to continuously study how well these consumer tests predict the outcome in real-world...
crashes. Especially considering rating systems that reward the overall safety of a vehicle, such as the Euro NCAP.

**Paper No.19-0290-O**

**GUIDELINE FOR A VEHICLE PURCHASE POLICY AIMING AT A SAFE AND SUSTAINABLE VEHICLE FLEET**

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**Abstract**

Vehicle safety and emissions are addressed in the UN Sustainable development goals 3.6, road traffic safety, and 13, reduced climate impact. In Sweden, a large proportion of new passenger vehicles (62%, 236,546 vehicles) were purchased by legal entities in 2017. Those vehicles are driven for 18 years in average. Therefore, well-reasoned company car policies in terms of safety and emissions are imperative to meet the global goals. The objective was to show how a company car policy that includes requirements regarding safety and CO2 emissions can be a tool to reach global safety and environmental goals. The paper describes the development of a vehicle purchase policy that was introduced by Folksam Insurance Group in 1998. The criteria of the policy have been revised on a yearly basis to meet developments of vehicle safety and environmental technology, as well as environmental goals. The vehicle data consists of new passenger vehicles available on the Swedish market. Data regarding crash tests, safety equipment and CO2 emissions are listed for every vehicle model and version. The safety requirements cover crashworthiness, performance in whiplash tests, and availability of selected safety systems. The environmental criteria are adapted to meet global goals regarding CO2 emissions. The goal is zero carbon emissions from new vehicles in 2030. A general goal is that approximately 15% of the new vehicles on the Swedish market should fulfill the requirements in the policy. It is shown in this study that safety and environmental criteria have changed rapidly during the last two decades. Furthermore, it is shown that safety and emission policies are important tools to guide fleet procurement managers as well as private consumers. A comparison of vehicles for sale and with those that are actually sold shows a higher rate of safety assist system in sold models compared to models for sale. The CO2 emission requirement has been halved during the two decades the policy has been active, indicating that the vehicle fleet has made large progress in reducing their CO2 emissions as the proportion of vehicles fulfilling the requirements has been approximately 15% during the two decades. It is important to guide vehicle fleet buyers of vehicles for private use to choose the safest and most environmentally friendly vehicles since those vehicles will be used for many years. Company car policies are important tools in this process. A vehicle purchase policy will indirectly influence car manufactures to offer vehicles that fulfil the requirements in the policy. An important recommendation is that a vehicle purchase policy should be revised annually to follow rapid changes in available safety technology and emission standards in order to substantially influence the vehicle fleet. A vehicle purchase policy is an important tool to guide vehicle consumers towards the safest and most sustainable vehicles. It is recommended that a vehicle purchase policy should consist of requirements regarding crashworthiness, fitment of important safety systems, CO2 emissions. Preferably, it should be complemented with a vehicle list for tangible and feasible advice to consumers.

**Paper No.19-0287-O**

**The role of vehicle age in road fatalities and the community awareness activities employed to encourage fleet renewal and reduce road trauma**

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**Abstract**

Following a period of steady decline in national road tolls in Australia and New Zealand, recent consecutive increases in annual road fatalities have caused community concern, with policy makers and road safety organisations working to ascertain reasons for this trend reversal. It is well established that newer vehicles generally offer higher levels of safety when compared to older vehicles, due to technology developments and the inclusion of specific safety features, with studies based on real-world data supporting this [1,2].
Statistical studies of real world crashes often report on factors such as driver age, crash type and posted speed limit, however the involvement of vehicle age in fatal crashes is less understood. To build a greater understanding of the age of vehicles involved in crashes occurring in Australia and New Zealand, ANCAP began monitoring the age of light passenger and sports utility vehicles involved in fatal crashes, with the findings used to inform road safety policies and community education and awareness activities. In 2018, ANCAP developed a national community awareness campaign targeting community consideration of vehicle age with the objective of encouraging fleet renewal. This paper sets out the research findings over the analysed five-year period from 2012-2016 and the effectiveness of the subsequent national community awareness campaign.

**Paper No.19-0276-O**

**IMPROVEMENTS TO ASEAN NCAP CRASH TEST RATING SANS A PLATFORM CHANGE**

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**Abstract**

Besides other reasons, car manufacturers often develop new cars with the aim to improve on their ASEAN NCAP crash safety performance rating. Apart from car safety assist, such ratings depend on the degree of adult occupant protection (AOP) and child occupant protection (COP) measured via the seriousness of injuries to dummies. This study shall explain how car manufacturers can improve their crash performance rating without changing the platform structure of a new car. The move shall be more cost effective as platform structure development is expensive; and less time consuming to enable a product to be launched in time (Al-zaher & Elmaraghy, 2014; Al-zaher & Elmaraghy, 2014). Two ASEAN NCAP crash tests have been conducted on 2 car brands on two different occasions, with the more recent result showing improvement from 3-Star to 4-Star rating. This proves that without a platform structure change, a high rating can still be achieved. Such a situation will help manufacturers save cost and reduce time to develop a new car by using the same platform structure but with better safety performance.

**Paper No.19-0196-O**

**Euro NCAP-new frontal impact test with mobile progressive deformable barrier (MPDB)**

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**Abstract**

Volker Sandner ADAC e.V. Germany Michiel van Ratingen, James Ellway Euro NCAP Belgium On behalf of the Euro NCAP Frontal Impact Working Group Paper Number 19-0196 ABSTRACT In 2015 Euro NCAP announced that the current offset deformable barrier frontal impact test procedure would be revised and a frontal impact working group was set-up to develop the new procedure. The aim was to bring together individual research efforts by FIMCAR [1], ADAC and other organisations [2,3] on the development of a ‘moving barrier to vehicle’ frontal impact test and derive common specifications for the new Euro NCAP test and assessment procedure from this. In partnership with the European Enhanced Vehicle safety Committee (EEVC), Euro NCAP examined the extent to which the advanced frontal THOR-M ATD is ready and suitable for use in this new test procedure. The overall results of the accident analyses, the specification of the test setup and the definition of the barrier were reported at the ESV 2017 in Detroit [4]. In the subsequent stage, the group focussed on the assessment criteria for the THOR dummy, the compatibility assessment and the full-scale evaluation of the procedure. Several round robin tests were organised to check the feasibility and repeatability of the method, in particular with regards to the THOR dummy and the barrier scanning. The group has released the final test...
and assessment protocols in 2018 for adoption in 2020, but will continue to monitor relevant developments, in particular related to dummy hardware and certification updates.

**Paper No.19-0278-O**

**Euro NCAP Side Impact Working Group Report**

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**Abstract**
The European New Car Assessment Programme (Euro NCAP) has been evaluating side impact protection since 1997. The original side impact test procedure utilised the EuroSID anthropometric test device (ATD) and Multi 2000 barrier face. In the year 2000, the side impact assessment was expanded to incorporate the perpendicular pole impact test. Both procedures were upgraded in 2003 to use the ES-2 ATD and Advanced 2000 barrier face in the side barrier impact. The most recent update to the side impact test procedures saw the adoption of the WorldSID 50th male ATD and the Advanced European Mobile Deformable Barrier face (AE-MDB) along with the oblique pole impact in 2015. To date, the adult side impact assessments have focussed on struck-side impact protection with the use of a driver dummy only and two child occupants in the rear. A number of European research projects have interrogated accident databases to establish the nature and magnitude of the risks to far-side occupants. In 2015, the Euro NCAP Board of Directors agreed that the level of side impact protection offered to drivers and front seat passengers should be improved and the Euro NCAP Side Impact Working Group (SIWG) was tasked with addressing far-side occupant protection. The group was asked to draft an updated far-side impact procedure that could be incorporated into the existing assessment regime without significantly increasing the test burden. The focus of the new procedure is on passengers seated in the front row and will evaluate excursion and contact injury risk. The new assessment is sled based rather than being a full-scale test, allowing for a wider coverage of real-world scenarios and offering a method for the development of countermeasures in the most effective and efficient way. This paper details the group’s work in the development of a far-side occupant test procedure. The outcome of real-world accident analyses from numerous European databases has been summarised along with a review of existing work already undertaken for far-side occupants. This data allowed for boundary conditions to be established, which were evaluated by the group with the use of physical and CAE testing. The outcome of this research has been used to develop a Euro NCAP assessment procedure for non-struck side front seat occupants.

**Paper No.19-0250-O**

**ANCAP Child Occupant Protection Assessment – Performance of Australasian Child Restraints in Full Scale Crash Tests**

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**Abstract**
From the start of 2018 ANCAP’s testing and assessment protocols are substantially common with those of Euro NCAP. One key area of difference is assessment and rating of Child Occupant Protection (COP). While alignment of protocols is maintained where possible, differences in products and in vehicle installations require a unique assessment. The differences arise from a mandatory product standard regulating Child Restraint Systems (CRS) in the Australasian market (AS/NZS 1754). The requirements of the standard mean that all booster seats sold in Australia are high back boosters, while prohibiting the use of ISOFIX attachments for booster seats. Australian law also mandates use of booster seats by age (up to 7 years). The 2018 protocols see the first opportunity for
assessment of the performance of Australasian booster seats in full scale frontal and side impact crash testing. Typical vehicle accelerations recorded in ANCAP frontal offset tests are above those specified by existing regulatory or consumer CRS testing, and some parties expressed concerns regarding performance of Australasian CRS in comparison with European specification restraints, in particular those CRS recommended by vehicle manufacturers and used in Euro NCAP dynamic COP testing. The paper provides an overview of early results, considerations for vehicle manufacturers and areas for future consideration in relation to child booster seats in the context of consumer ratings.

**Paper No.19-0279-O**

**Consumer Initiatives to Improve Child Safety in Europe**

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**Abstract**

Safe transport of children in cars is the joint responsibility of parents, child restraint suppliers and vehicle manufacturers. Responsible parents and caregivers must ensure that children are properly restrained in a correctly installed child restraint system (CRS) that is appropriate for the size and weight of the child. Child restraint suppliers make certain their products meet local regulations, offer adequate protection and can be fitted easily and correctly in all cars. Finally, it is the vehicle manufacturers’ obligation to guarantee that children are as well protected as adults in the event of crash and that special any provisions needed for children are offered as standard. In practice, this joint responsibility leads to a set of complex interactions and a patchwork of solutions that make it difficult for average consumers to know how their child is carried in the best and most safe way. In Europe, two independent consumer-oriented programmes work cooperatively to help consumers find the best answer for their unique situation. Child restraint testing is carried out by European consumer groups under the umbrella of International Consumer Testing and Research (ICRT) and the Automobile Clubs. The program publishes ratings based on standardised dynamic sled tests and an ease-of-use assessment, amongst other items. The European New Car Assessment (Euro NCAP) rates vehicle performance and equipment availability for new cars on the market. Its Child Occupant Protection assessment includes full-scale crash tests with child test dummies in child restraints and evaluates the availability and functionality of attachments and provisions for safe transport of children. Collectively, these programmes address one of the most pertinent and persistent challenges in child safety: the risk of misuse and incorrect installation of a child restraint system in a vehicle. Child restraint testing is based on body-in-white setup applying standardised pulses. This set up only broadly approximates real life use in actual cars. In-vehicle testing comes closer to actual crash circumstances, but the result only applies to the combination of car model and CRS type. Both approaches are complementary, and both are needed to improve child safety in cars.

**Paper No.19-0270-O**

**Trends in pedestrian protection for vehicles rated by Australasian NCAP**

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**Abstract**

Analysis of scores in pedestrian protection tests conducted by ANCAP between 2001 and 2017 indicates that the average score has improved from 7.5 to 25. This has been achieved by steady improvement in the design of relevant vehicle components. Many of these improvements are unlikely to have significant adverse effects on costs or vehicle appearance, provided that good design for pedestrian protection is taken into account early in the design phases for the vehicle. Based on several real-world crash studies, it is estimated that the improvement of 17.5 points is associated with
Paper No.19-0310-O
Development of a Certification Procedure for Numerical Pedestrian Models

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Abstract
In the Euro NCAP testing of deployable pedestrian protection systems (i.e. active bonnets and airbags), head impact time (HIT), wrap around distance and bonnet deflection due to body loading are assessed by means of simulations with numerical pedestrian models. The aim of this study was to define requirements for numerical pedestrian models and simulation setups to ensure comparable performance of models and simulation results. These requirements were summarized in a certification procedure which focuses on the pedestrian’s kinematics that are important for the Euro NCAP assessment. Twelve different institutions (academia and industry) applied a harmonised pedestrian simulation protocol, which was established within a previous study. Numerical pedestrian models in the stature of the 50th percentile male (all applicable for the assessment of deployable systems until 2017) were impacted with four differently shaped generic vehicle models at three different collision speeds according to the protocol. Trajectories, contact forces and HITs were evaluated. Finally, 18 full data sets including the 12 load cases were available covering different Human Body Models and Humanoid Multibody Models in four different FE codes. Reference values, corridors and tolerances for the certification procedure were derived, based on identified consistent results. Comparable behaviour was observed for the majority of pedestrian models. However, a small number of simulations showed clearly outlying behaviour in terms of HITs, trajectories and contact forces. The consistent models were within a range of +3.5% and -7% throughout all load cases. Corridors for the z- and x- trajectories as a function of time were developed for the head centre of gravity, T12 and the centre of acetabuli for each load case. Furthermore, corridors for the contact forces between pedestrian model and generic vehicle model were established. The developed certification procedure ensures that a specific pedestrian model within a specific environment, solver version and specific simulation settings gives comparable kinematic results relevant for the assessment of deployable systems. Inconsistent pedestrian models, incompatibilities with control settings and user errors can be identified and sorted out. The procedure was implemented in the Euro NCAP Technical Bulletin 24 and has been in force since January 2018.

Paper No.19-0329-O
Assessment of new active safety systems addressing urban intersection scenarios including Vulnerable Road Users

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Abstract
Bicyclists and pedestrians belong to the most endangered groups in urban traffic. The EU-funded collaborative research project PROSPECT (‘PROactive Safety for PEdestrians and CyclisTs’) aims to significantly improve safety of those unprotected traffic participants by expanding the scope of scenarios covered by future active safety systems in passenger cars. Concepts for sensor control systems are built into three prototypes covering emergency interventions such as Autonomous Emergency Braking (AEB) as well as Autonomous Emergency Steering (AES). These systems tackle the well-
known challenges of currently available systems including limited field-of-view by sensors, fuzzy path prediction, unreliable intent reaction times and slow reaction times. These highly innovative functions call for extensive validation methodologies based on already established consumer testing procedures. Since these functions are developed towards the prevention of intersection accidents in urban areas, a key aspect of the advanced testing methodology is the valid approximation of naturalistic trajectories using driving robots. Eventually, several simulator studies complemented a user acceptance and benefit analysis to evaluate the expected overall impact of the PROSPECT systems. The results achieved within the PROSPECT project are highly relevant for upcoming test protocols regarding the most critical situations with Vulnerable Road Users (VRU). With introducing the new methods in Euro NCAP (European New Car Assessment Programme) a significant increase in road safety is expected.

**Paper No.19-0328-O**

**Establishing and Communicating Rules for Automated Driving Vehicles**

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**Abstract**

There has been considerable confusion in the interpretation of the SAE Levels of Automation J3016, in particular when defining whether a vehicle can be classed as automated. This is particularly relevant for insurers where there is a question of liability over who was in control of a vehicle when an accident has occurred. To clarify this a set of Requirements for Automated Vehicles has been developed to give a common benchmark for consumers, manufacturers, insurers and regulators. The approach to developing the rules has been iterative. Initially they were formulated from an insurer paper focussed on the emerging Regulation 79 UNECE steering function rules and the requirements for partial automation. The challenge of driver disengagement and driver as back-up from Level 3 automation highlighted the issue of classifying these vehicles as automated. To address this, Thatcham Research defined vehicles as Automated or Assisted based on whether they can meet ten specific criteria for automation. The criteria are based on road safety experience, anticipated vehicle capability, consideration of other road users and the fundamental requirement that these vehicles will generate less accidents. Experience using ADAS and Assisted Vehicles helped to give practical experience of some of the challenges that needed to be addressed. These ten requirements have now been through insurer, regulator and manufacturer challenge and review in a number of different international territories. The rules have been strongly welcomed by manufacturers and regulators who had not seen any clear guidance when the rules were first issued. They have been used in a number of European countries for insurers to lobby government for safe and insurable vehicles. At the same time the marketing and communication of the rules combined with differentiating Assisted and Automated Driving have been key to disseminating the message to the wider public. Campaigns promoted wider understanding of the differences between the new technologies and the driver’s responsibility in Assisted Vehicles. The Classification of Automated Vehicles will be a key challenge for international regulators over the next five years making the development of the rules and framework essential at this time.
Paper No.19-0058-O
CONTRAST BETWEEN ROAD AND ROADSIDE MATERIAL FOR ROAD EDGE DETECTION IN VEHICLE ROAD DEPARTURE MITIGATION SYSTEM
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Abstract
Vehicle roadway departure crashes results in a large number of fatalities in the U.S. Road departure mitigation (RDM) systems rely on the road edge and road boundary identification. Cameras are widely used in RDMS for identifying road edges. The contrast between road and road boundary objects is one of the key image features used by the camera to detect road edges. This paper analyzes and compares the contrasts between various road surfaces and road edges.

Paper No.19-0059-O
Determine Characteristics Requirement for the Surrogate Road Edge Objects for Road Departure Mitigation Testing
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Abstract
Road departure mitigation system (RDMS), a vehicle active safety feature, uses road edge objects to determine potential road departure. In the U.S., 45%, 16%, and 15% of car-mile (traffic flow * miles) roads have grass, metal guardrail, and concrete divider as road edge, respectively. It is difficult to test RDMS with real roadside objects. Lightweight and crushable surrogate roadside objects that have representative radar, LIDAR and camera characteristics of real objects have been developed for testing. This paper describes the identification of automotive radar, LIDAR, and visual characteristics of metal guardrail, concrete divider, and grass. These characteristics will be referenced for designing and
fabricating the representative surrogate objects for RDMS testing. Colors and types of the roadside objects were identified from 24,735 randomly sampled locations in the US using Google street view images. The radar and LIDAR parameters were measured using 24GHz/77GHz radar and 350-2500nm IR spectrometer. Metal guardrail: The peak 24GHz RCS (Radar Cross Section) of W-beam and I-beam of guardrail are 10dB and 13dB. The peak 77GHz RCS for W and I-beam are 15dB and 20dB. When the radar beam direction is not perpendicular to the metal guardrail surface, the reflectivity decreases significantly. As the illumination/measurement angle increases from 0 to 70o, the IR reflectance of metal guardrail decreases from 1.3 to 0.1, and the variation among samples decreases from 1.5 to 0.05. The age of the metal guardrail does not affect the RCS if steel rust is not present. Concrete divider: Both 24GHz and 77GHz radar reflectivity are -7.3dB. The age of the concrete divider does not affect the radar reflectivity, but the surface smoothness and material affect the reflectivity. As the illumination/measurement angle increases from 0 to 70o, the IR (Infrared) reflectance of concrete divider increases by only 0.1. Grass: The peak 77GHz RCS is -18dB at 10o depression angle. Different kinds of grass (wild vs. maintained, short vs. long, even vs. uneven) have similar RCS value when measured under the same conditions (same radar type, same polarization, and same pitch angle). Same grass field will produce different RCS during different seasons or after rain where the moisture content of grass produces different reflectivity. As the illumination/measurement angle increases from 0 to 70o, the IR reflectance of grass increases from 0.1 to 1 and the variation among samples increases from 0.2 to 1. The most representative grass road-edge is uneven yellow/green mixed short grass followed by even green and short grass. 18 most occurring grass color patterns were selected.

Paper No.19-0167-O
Societal Benefit of Automatic Emergency Braking and Lane Departure Warning Systems in Large Trucks
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Abstract
The objective of this study was to provide scientifically-based estimates of the societal benefits and costs of two large truck advanced driver assistance systems (ADASs): automatic emergency braking (AEB) and lane departure warning (LDW). For each technology, benefit-cost analyses (BCA) were performed for installing the technology on all large trucks (including retrofitting old trucks) and for equipping only single-unit trucks, only combination-unit trucks, and all large trucks. Sensitivity analyses examined three cost estimates, two estimates of system efficacy, and three discount rates. Equipping trucks with LDW systems were found cost-effective under almost all scenarios examined. Results for AEB were mixed. Only the low cost estimate was cost effective for all large trucks regardless of efficacy rate.

Paper No.19-0227-O
Estimation of Potential Safety Benefits for Pedestrian Crash Avoidance/Mitigation Systems in Light Vehicles
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Abstract
This report presents and exercises a methodology to estimate the effectiveness and potential safety benefits of production pedestrian crash avoidance/mitigation systems. The analysis focuses on light vehicles moving forward and striking a pedestrian with the front of the vehicle in the first event of a crash without attempting any avoidance maneuver in two priority scenarios: 1) vehicle going straight and pedestrian crossing the roadway and 2) vehicle going straight and pedestrian in or adjacent to the roadway, stationary or moving with or against traffic. System effectiveness is estimated for crash avoidance and crash severity mitigation. Safety benefits are projected in terms of annual reductions in the number of police-reported vehicle-pedestrian crashes, fatal vehicle-pedestrian crashes, and injured pedestrians at Maximum Abbreviated Injury Scale 2-6 and 3-6 levels. The methodology relies on target baseline crashes obtained from the 2011 and 2012 General Estimates System and Fatality Analysis Reporting System crash databases, system performance data from characterization track tests, and basic kinematic computer simulation of vehicle-pedestrian conflicts.

**Paper No.19-0306-O**

**Dynamic Evaluation of Cloud-Based Active Safety Systems**

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**Abstract**  
The field of driver assistance systems faces new technologies like vehicle-to-x (V2X) communication [1] and cloud services to improve safety on the streets. These upcoming functions carry new possibilities and new challenges as well. Thanks to scaling-up techniques, it is already possible to gather and manage huge amounts of data in the cloud with less time consumption compared to standard systems. This data is suitable to be used for statistics and pattern recognition based functions with time-critical demands. But beside the development of these functions there is always a need for evaluation to assure correct functionality. Therefore, IAV created a concept to dynamically evaluate cloud-based active safety systems like the wrong-way driver detection function developed by IAV, which is conceived to warn oncoming vehicles on motorways. This goal is achieved with cloud and V2X techniques. The wrong-way driver warning is a service running on the cloud, which receives V2X messages from vehicles including their positioning data, heading and other information to reference their traces via map matching [2] algorithms. An underlying database compares the data with continuously calculated thresholds to recognize wrong-way drivers and warn others in the surrounding areas via V2X against them. As changing infrastructures like construction sites have an effect on the false-positive rate of the classification, it needs to be dynamically tested if the function is able to react appropriately. For this reason we propose an approach for an evaluation process based on an integrated self-controlling module. This module notices changes in trajectories which can be caused by changed traffic guidance and adapts the detection parameters. As a result, the following detection should classify the vehicles correctly based on the changed conditions. The discussed process of the introduced wrong-way driver warning shows an example how a specific cloud-based function can be dynamically evaluated without dependence on the functional logic. Especially functions whose results strongly depend on ever-changing input data need solutions to test their behavior in critical situations. This approach delivers also a possible answer how to implement additional methods to create more flexible and long-term reliable cloud-based active safety systems.

**Paper No.19-0317-O**

**AMOK SAFETY LOCK (ASL) DEVELOPMENT AND DEMONSTRATION OF A NEW FUNCTION FOR THE PREVENTION OF INTENTIONAL VEHICLE MISUSE AGAINST PEDESTRIANS**

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Abstract
Most fatalities and serious injuries in traffic result from accidents caused by human error. Today, a series of driver assistance functions exist to help avoid or reduce the severity of such accidents (e.g. Autonomous Emergency Braking), while still allowing the driver to interrupt the function at any time. This overriding behavior – mandated by the Wiener convention [1] – is particularly important in the case of an incorrect function activation on the part of the vehicle’s system. Due to this built-in override functionality, driver assistance functions – which typically support the driver in de-escalating a critical situation – cannot help preventing cases where drivers actively target pedestrians with the vehicle (as in recent vehicle ramming attacks). This makes clear the need for active safety functions able to prevent the driver from (intentionally or unintentionally) causing harm to other traffic elements. The function Amok Safety Lock (ASL) was developed as a prototype function to research the possibility of increasing the safety of pedestrians in the case of vehicle misuse. The function ASL looks at the driver’s driving behavior, the predicted vehicle’s motion and the relative positions and motions of pedestrians in the vicinity of the vehicle to identify an imminent collision. If the driver does not act to de-escalate the situation, the function initiates an emergency braking maneuver without the possibility of overriding. Simultaneously, warning signals (horn, front and turn lights) are emitted to alarm the pedestrians nearby. This behavior was confirmed in both simulations and vehicle tests using IAV’s Vehicle-in-the-Loop approach. Due to its unilateral behavior, changes in the legal framework are necessary before such a function can be deployed.

Paper No.19-0258-O
Approach for Deriving Scenarios for Safety of the Intended Functionality
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Abstract
Safety of the Intended Functionality (SOTIF) is a safety process in the automotive industry that addresses unintended system behaviors in the absence of electronic faults. Electronic system malfunctions are addressed through industry’s functional safety process, ISO 26262. SOTIF on the other hand helps mitigate hazards that may arise when the driving conditions exceed the technology limitations of one or more system components or from certain human factor considerations, such as foreseeable system misuse or mode confusion. The current approach applies a combination of analysis, simulation, test track, and on-road testing to identify unknown and potentially unsafe scenarios. This study supports the analytical part of this approach by developing a structured framework for deriving scenarios necessary for a SOTIF analysis. The scenarios derived through this framework could then be used to inform simulation and testing. This paper provides a brief overview of the SOTIF process, describes the development of a framework for deriving scenarios, and presents preliminary results from applying this framework to a highly automated chauffeur system. The framework described in this paper could evolve over time as additional SOTIF-relevant parameters are identified.

Paper No.19-0221-O
Development of Trailer Identification System for Implementation of Vehicle Safety Communications in Articulated Tractor-Trailers
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Abstract
Develop and demonstrate methods by which a vehicle safety communications system on a heavy vehicle tractor can automatically determine the geometric parameters of the trailer being towed. This information is required to assemble a Basic Safety Message (BSM) that conveys the dynamically changing position of an articulated tractor-trailer combination vehicle to surrounding vehicles. A review of existing object-detection technologies and the means to extract the trailer
parameters from these technologies was conducted. The classes of trailers with highest market penetration were identified and used in the development process of the trailer detection system so as to maximize the applicability to a majority of trailers on the road today. Using the required trailer descriptive parameters defined in the previous study, accuracy requirements were developed. These were derived based on the light vehicle requirements for Vehicle-to-Vehicle (V2V) communication specified in SAE J2945/1. Trailer-identification related data were collected using LiDAR (2D and 3D), radar, camera (monocular, stereo and thermal), and ultrasonic sensors. Subsequent evaluation of the data resulted in the selection of a subset of these technologies for development into a prototype system. The final system technologies included: camera (stereo and monocular), LiDAR (2D and 3D), and ultrasonic. The 3D LiDAR based measurement system developed was able to accurately detect and measure the trailer parameters for box and tanker style trailers which accounts for nearly 90 percent of the trailers in use on roadways in the United States. Also demonstrated were trailer identification solutions based on other technologies. The camera-based solution provided a less robust means than the 3D LiDAR while the ultrasonic and 2D LiDAR was found to be applicable for fixed axle trailers only. The system designs did not require any special trailer markings or input from the driver. In addition, a simpler alternative solution for some fleet applications was developed that utilized markings (AprilTags) placed on the trailer for identification. This research demonstrated that there were methods to determine trailer parameters automatically for use in vehicle safety communications systems on articulated heavy vehicles. The system developed in this study allowed for a sufficiently accurate representation of the position of tractor-trailers during turning maneuvers in the BSM. This is important for effective implementation of safety applications based on vehicle safety communications.

Paper No.19-0302-O

Power Requirements for a Redundant Automated Steering System for Trucks

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Abstract

For automated driven vehicles with a driving automation level above two, the driver is not available immediately as fallback when the automated driving system fails. Therefore, a redundant design for each automated driving system (e.g. the automated steering system) is a central safety requirement. The grade of redundancy, i.e. if it has to be fully fail operational or just a certain level of fail degraded, depends on the definition of the safe state in case of a failure and on the way how to reach it. The safe state itself depends on the driving situation respectively the type of road, where the automated vehicle is driving. The goal of this article is to determine the amount of steering power and energy required in different use cases and road types to reach the safe state. Therefore, a definition of the safe state for automated driving trucks is determined using the ISO 26262 and existing definitions. With the help of German national road construction guidelines for highways, rural roads and urban roads, the safe state and the necessary driving maneuvers to reach it are determined for different defined road types. A 12-t two-axle truck has been equipped with measurement equipment as test vehicle. The determined driving maneuvers to reach the safe state are driven with the test vehicle and the required steering power and steering energy are measured. The results of this investigation are the minimum required steering torque, power and energy for each tested driving maneuver. The minimum redundancy requirements to the automated steering system for a specific use case of automated driving, such as fully automated highway driving, are determined considering all driving maneuvers to reach the safe state in the worst case. Depending on the intended use cases for the automated vehicle, different fallback requirements are determined for the redundant automated steering system. Although the achieved results of this contribution are only representative for the used test vehicle, they are still helpful to get an impression and some real data for the required fallback steering torque, power and energy. It has to be considered that the required steering power and steering energy are highly influenced by the front axle load and thus by the load of the vehicle and by the steering and axle geometry of the vehicle as well. However, based on the findings of this article, the fallback concepts of future redundant active steering systems for highly and fully automated driven trucks can be developed according to the intended use cases. The requirements for the mentioned exemplary use case of fully automated driving on highways with hard shoulders are very low, thus it should be possible to realize the steering redundancy with low effort. However, for other use cases the redundancy requirements are much higher.
ADAS TESTING IN CANADA: COULD PARTIAL AUTOMATION MAKE OUR ROADS SAFER?

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Abstract
As part of an ongoing effort to further improve the safety of its road transportation system, Transport Canada (TC) has been evaluating Advanced Driver Assistance Systems (ADAS) for a number of years now. The main objective of this paper is to determine the potential of ADAS technology in reducing fatalities and injuries on Canadian roadways while using proven international test protocols and certified test equipment. The findings will be used to provide science-based evidence in support of future regulatory, research and policy development. Results from this study clearly demonstrated that Automatic Emergency Braking (AEB) and Pedestrian AEB (P-AEB) technologies can provide significant improvements in terms of collision mitigation which can directly result in reduced road fatalities and injuries. These findings are also in line with those of studies based on real-World data predicting significant reductions in rear-end collisions due to AEB deployment. Nonetheless, this ADAS program also exposed an important number of flaws and performance variability. While the best AEB and P-AEB systems were able to fully avoid collisions with vehicles and pedestrians at speeds up to 60 kilometers per hour (km/h), others were challenged at speeds below 10 km/h. Also, a few P-AEB systems were never able to avoid a collision with a pedestrian despite manufacturers’ claims of pedestrian avoidance capabilities. Scenarios replicating AEB activation in moving traffic showed that most systems unnecessarily came to a full stop rather than match the speed of vehicles they detected on their path, potentially generating higher safety concerns than those they were designed to prevent in high density traffic. Finally, due to variability in test results and overall unpredictable system behaviour, it was not possible to gather enough data to confidently assess the potential safety benefits associated with Lane Support Systems (LSS). AEB, P-AEB and LSS are essential components of automated driving systems which will need to reliably brake and steer at all time to safely avoid other road users. That level of performance is not yet evident from the extensive testing carried out within this project. Substantial progress is therefore needed to reach the level of detection, braking and steering performance that will be required to make commercial automated driving systems a reality.

Informed Trust – An External User Interface for Highly Automated Vehicles

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Abstract
Traffic research so far was focused on accidents and accident prevention. With the introduction of automated or semi-automated cars into the public realm however, the question is, how automated cars must be designed to blend in. The presentation is based on the approach of traffic seen as a cooperative activity, where people are implicitly collaborating in the frame of given traffic rules. The Perception Action Model (PAM, Stephanie Preston 2007) in short suggests that perception and action are inseparable - people perceive actions of others and act immediately. This process is mutual and draws on empathy to predict the activities of the others. “Mind-Reading” (Eric Kandel, 2012) enables to read mood, energy, intention out of the other traffic participants. Today it seems sufficient to perceive the way other drivers move their vehicle to trigger the Mind Reading process and enable predictive behavior. In case of automated vehicles, human perception has to be triggered properly to avoid misinterpretation or just wrong results of the empathic process. Based on this approach the presentation introduces an experimental external user interface for highly or fully automated...
vehicles to address the underlying functionality of traffic. It includes the following features: Indication of highly automated mode according to and exceeding the SAE recommendation, Signaling of cooperative behavior, Communication especially with vulnerable road users.

The system is demonstrated in various everyday driving situations on highways and city roads, such as merging traffic or a stop for pedestrians at a cross walk. Especially the aspects of an intuitive and intercultural understanding are discussed. The presentation aims to demonstrate and discuss how an intuitively designed external user interface can help build informed trust in highly automated vehicles as a major factor of success and even give back to society by sharing its situation awareness. Informed Trust is a major factor of success for Real-World Deployment of Automated Driving Systems. Most of the time our movement through the public realm is simply uneventful, and it is so because humans are cooperating with one another to make it so [1]. Traffic research has so far focused on accidents and accident prevention. With the introduction of automated or semi-automated cars into the public realm, however, the focus changes to understanding the magic of normal traffic and asking the following questions: how do we manage to avoid bumping into each other all the time? What will happen when automated cars are mixed into the magic? Automated cars must be designed to blend into this process; otherwise, known types of accidents will only be replaced by new types of accidents. We have developed a conceptual framework, building on Social Sciences and Neuroscience, to understand the behavior of the involved actors in mobility. Informed Trust is our approach to designing self-driving cars in such a way that allows all actors to achieve agency. The overarching goal is to enable all actors in mobility to produce a successful and harmonious mobility, with fewer accidents than in today’s traffic.
BMW's Safety Guidelines For The Testing And Deployment Of Automated Vehicles

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Abstract

As automobile manufacturers take the leap from Advanced Driving Assistance Systems and implement Automated Driving Systems into their vehicles, certain aspects of vehicle safety become increasingly important. Whereas in today’s level 2 automation, the human driver is involved in the dynamic driving task, in level 3 and above, more technological measures are necessary to ensure safety, therefore requiring a newly designed electronic architecture. Nonetheless, analysis of human factors remain a key element to ensure the safe operation of the vehicle. Though conventional techniques may be employed to solve some of these challenges, others require new tools to be developed. In the absence of an international standard, the foundation for discussions of completeness is missing. With an expert analysis of topics and tools a focus can be brought into discussions and serve as a basis for further development. This analysis may also lead to uncover areas where final answers and methods are missing, but serves also to identify areas where effort must be concentrated. When members of the industry apply these principles to the development of automated driving systems, the number of accidents will be minimized following the testing and deployment of this new technology, therefore maximizing safety and customer acceptance. This submission represents the culmination of multiple sessions within industry, but also with contracting parties and government agencies with the goal of the creation of a comprehensive list of guidelines for the safe development of automated driving systems. BMW has defined 12 different areas that have been focused into guidelines for the development of a vehicle with a safe automated driving system. These areas include topics from functional safety through the human factors aspects of system handovers to the consideration of passive safety. While the 12 guidelines are selected to be a comprehensive list of safety topics, they are general in form and do not contain the details necessary to apply it as a blueprint for the development. As these automated driving systems are not on the roads in appreciable numbers, the data from real world events are missing. Also the projects to develop the methods to generate and analyze data are still underway, which also forces some guidelines to remain broadly formulated. The proposed guidelines concentrate the capabilities and limitations of today’s safety evaluation for vehicles when applied to automation. By following the guidelines, the industry can ensure that this technology meets an acceptable level of safety when it comes to market.

Occupant protection for AD – the paradigm shift in crash safety?

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Abstract
When moving towards unsupervised autonomous driving (AD) and the customer expectations of those vehicles, the approach, tools and methods used today in occupant protection assessment are likely not sufficient. Single sitting postures, limited sizes of occupants and crash test set-ups used today will not cover the situations arising. Fundamental changes in evaluation approach and underlying assumptions are foreseen, similar to a paradigm shift. The objective of this paper is to elaborate on and concretize the research needed, specifically targeting the question: How do we assess the protection of the heterogeneous passenger population in future vehicle crashes enabling occupant protection in unsupervised AD, providing the extended customer benefits of those cars? This paper summarizes relevant state-of-art research in the area and identifies topics for further research focusing on methods and tools for occupant protection assessment. Future unsupervised AD cars, in addition to future manually driven cars, are likely to be exposed to crashes. Hence, the occupants' need to be protected is obvious, as today. The paradigm shift is driven by and relates to the mindset on car usage and occupant requests. It calls for new ways of addressing crashworthiness evaluation, emphasizing the large effort in research and knowledge creation needed, as well as a new setup in procedures and responsibilities of stakeholders involved. It likely requires addressing expanded crash set-ups, taking the whole event into account (including pre-crash maneuvers), in addition to a larger population of occupants, and a larger range of seat positions, seating configurations and sitting postures. A human-centric approach is proposed as the way forward. Being an alternative to a technology-driven approach (e.g. the SAE levels of automation), the human-centric approach sets the human needs and abilities in focus, and designs technology around them. Substantial data on sitting postures and behavior in cars today needs to be collected and analyzed, to enhance the interpretation of existing real world data and to form the knowledge foundation towards the future challenges. Furthermore, user studies of future expectations are desired, especially in the light of changes in mobility trends. Simplified crash test dummy designs will not be sufficient. There is a need of continuous development of today's human body models facilitating the expansion in sitting postures and sizes, enhanced injury predictability and capable of simulating pre-crash kinematics. This includes generation of validation data and biomechanics research on injury mechanisms as well as material data such as adipose tissues. Pediatric occupant tools need special attention, in addition to investigating and cooperating around the protection of children in future cars. In order not to be a stopper for enabling the customer benefits in the development of autonomous drive, the occupant protection challenges need to be addressed. This paper discusses some different aspects of this, however being a paradigm shift, a common discussion and cooperation among stakeholders is needed to cover the whole spectra of aspects.

Paper No.19-0292-O
Euro NCAP’s first step to assess Automated Driving systems  
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Abstract
Technology is evolving quickly and more and more of the driving function is being handed to the vehicle. Given that a significant portion of road accidents are attributable to "driver error", the potential safety benefits of increased automation are clear, if the automation is at least as competent as the driver in complex traffic situations. It is therefore in Euro NCAP’s interests to raise awareness of the technologies that exists and to promote their introduction in such a way that these safety benefits are realised. Based on the Euro NCAP’s existing active safety testing protocols, extended test scenarios were derived that cover the Operational Design Domain of currently available SAE Level 2 systems. These systems are designed for use on motorways where speeds up to 130 km/h are most typical on European roads. With the first round of evaluating Assisted Driving technologies, Euro NCAP is entering a whole new area of safety and safety assessments where public expectations are high yet understanding may be low. Euro NCAP is striving to promote automated driving technologies while at the same time raise awareness of their safety benefits and moreover their limitations.
**Paper No.19-0261-O**

**Assessment, Evaluation, and Approaches to Technical Translations of FMVSS and Test Procedures That May Impact Compliance of Innovative New Vehicle Designs Associated with Automated Driving Systems**

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**Abstract**

The project described in this paper provides research findings in terms of options regarding technical translations of select Federal motor vehicle safety standards (FMVSS) and related Office of Vehicle Safety Compliance (OVSC) test procedures. The research findings are based on potential regulatory barriers identified for self-certification and compliance verification of innovative new vehicle designs that may appear in vehicles equipped with Automated Driving Systems (ADSs). This paper documents the framework used to evaluate the regulatory text and OVSC test procedures with the goal of identifying possible options to remove regulatory barriers for the self-certification and compliance verification of ADS-Dedicated Vehicles (ADS-DVs) that lack manually operated driving controls. It also describes the research activities for 15 crash avoidance standards (100-series) and 15 crashworthiness/occupant protection standards (200-series). This research effort incorporates feedback obtained from stakeholders and subject matter experts (SMEs).

**Paper No.19-0301-O**

**A Framework for Automated Driving System Testable Cases and Scenarios**

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**Abstract**

Automated Driving Systems (ADS) are being developed to perform the primary functions of the dynamic driving task (DDT). These technologies hold great promise to improve safety and mobility for transportation. Test scenarios are critical for assessing the safety assurance of ADS in a range of operational environments and roadway conditions. The development of testing scenarios for ADS is proving to be an important challenge for the development of safety assurance requirements, certification and licensing frameworks, testbed services, standards, and international harmonization. This paper summarizes foundational research undertaken to identify a sample preliminary, objective testing and evaluation approach for ADS. The paper considers technologies of interest that fall within Level 3 through Level 5 of the SAE International levels of driving automation and identifies a cross-section of prototype and conceptual ADS that are then categorized into seven generic ADS features. This research also takes the first steps to partition the ADS performance space by identifying and assessing the primary variables that comprise an ADS test scenario. Those primary variables are described in detail, and include: Tactical and Operational Maneuvers Operational Design Domain (ODD) Object and Event Detection and Responses (OEDR) Failure Mode Behaviors Tactical and operational maneuver capabilities largely focus on the control-related elements of the DDT (i.e., lateral and longitudinal control) that enable an ADS to navigate to reach its destination (e.g., lane centering / following, turning). A working list of these capabilities is presented. The ODD represents the operating conditions under which an ADS is designed to function (e.g., roadway types, weather conditions, etc.). A notional hierarchical ODD taxonomy is presented and described. OEDR capabilities include the elements of the DDT that involve monitoring the driving environment and implementing appropriate responses to relevant objects and events. A working list of OEDR capabilities is presented. Failure mode behaviors include fail-safe (FS) and fail-operational (FO) strategies that will allow an ADS to respond to a variety of failures,
including DDT performance-relevant system failures that require the ADS or a DDT fallback-ready user to achieve a minimal risk condition. The paper also considers the implementation of the proposed evaluation framework using existing test methods, including modeling and simulation (M&S), closed track testing, and open road testing. It further seeks to examine how each of the testing methods can be logically used to minimize the complexity of comprehensive safety assessments of ADS by leveraging each method’s strengths to maximize the knowledge gained from each test. It also includes extensive discussion of challenges associated with testing ADS, including challenges related to the technology itself as well as challenges associated with test execution. This paper is based on research completed by NHTSA and its contractors, and is more fully documented in NHTSA Report DOT HS 812 623, “A Framework for Automated Driving System and Testable Cases and Scenarios”; September 2018.

Paper No.19-0343-O
Certification of Highly Automated Vehicles for Use on public roads

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Abstract

Objective: A number of different methods must be combined for the robust certification of highly automated vehicles (HAVs) for deployment in ODDs encompassing public roads. This paper, which is authored by a braintrust of the world’s leading academics in validation, verification and certification and affiliated with Europe's largest autonomous vehicle developer FiveAI, proposes a core set of processes. Methods: The paper discusses in detail: (1) requirements discovery; (2) behaviour requirements; (3) simulation as a tool for verification; (4) useful tools and methods. Results: We propose a process centred around hyper-scale fuzzed scenario-based testing and the use of coverage driven verification methods in digital twins of the ODD and using generative models representative of each ODD. Testing must cover both full stack testing, which will require photo-realistic and sensor-realistic rendering of scenarios and objects, together with accurate sensor modelling and motion planning stack testing, will require robust beliefs over scenario actor behaviours to test predictive, planning and motion synthesis. Discussion and Conclusions: The paper poses several questions for policy makers: (1) Could a validation, verification and certification system that incentivizes sharing of scenarios while protecting the value intrinsic to their discovery, improve safety across the industry? Could it be used by an approval body such as a national Certification Agency to establish a high standard for national certification? (2) Can the industry agree on a scenario description language that supports coverage-driven verification and is extensible? (3) What should the specification of an appropriate simulation environment be? (4) Could the specification for a test oracle be made available and could this be based on a formal description of ‘good driving’? (5) Is auditable adherence to the IATF16949:2016 quality assurance process sufficient to satisfy ‘Conformity of Production’? Key questions also remain, including: (a) What machine learning methods should be applied to directed random testing in coverage driven verification? (b) Given the high dimensionality of the test space, what coverage measures are meaningful in generative and ODD digital twin verification? (c) Which computer vision methods can we apply to the 3D reconstruction of digital twin worlds from
photogrammetry, LIDAR scans and other modalities that mean accurate, up-to-date digital twins are feasible? (d) What hardware acceleration beyond GPUs can we design and apply to enable faster-than-real-time full stack verification of HAVs? (e) How can we apply formal software checking to the complex integrated systems required for autonomous driving to ensure that each build achieves its goals without bugs or gaps? (f) How do we really apply formal mathematical methods to express the Digital Highway Code (DHC), vehicle dynamics and other road user expectations and behaviours to verify the behavioural safety of HAVs? (g) How can we verify HAV systems that comprise of one or more end-to-end neural networks with the requirements to explain failure modes and take corrective actions to improve their performance using human readability and intermediate outputs of modular processes? (h) How might we extrapolate randomized testing, including near collisions, into a measure of probability of collision generally?

**Paper No.19-0335-O**

**Challenges for Occupant Safety in Highly Automated Vehicles across Various Anthropometries**

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**Abstract**  
The introduction of automated driving systems (ADS) is likely to change the very nature of personal transportation. Without the need to drive, occupants will have more freedom to engage in other activities, which could result in major changes to vehicle interiors, controls, and seating configurations. Reclined posture seating may be an option that manufacturers consider in the relatively near term. The goal of this study is to evaluate how varying occupant anthropometry, distance to the knee bolster, and seatback angle affect occupant response. A finite element model of a vehicle occupant compartment with the state-of-the-art seatback integrated restraint system was used, to evaluate three different simplified Global Human Body Model Consortium (GHBMC) occupant models (small female, midsize and large male) in frontal crashes. A full factorial sensitivity study was performed with four different levels of seatback recline (0, 10, 20, 30 deg) and four different distances to the instrument panel knee bolster resulting in total of 40 simulations. Increasing the seatback recline angle caused the occupants’ pelvis to submarine under the lap belt, which, in turn, resulted in poor pelvis-belt engagement and increased occupant excursion. Larger occupants tended to be able to withstand higher seatback recline angles without submarining than smaller occupants. Additionally, across all occupants, increased recline angle resulted in increased lumbar compression and shear force. The new ADS environment is likely to pose substantial challenges to occupant restraints systems. Increased seatback angle increases the propensity of occupants to submarine, and results in increased lumbar spine load.

**Paper No.19-0039-O**

**Research of Minimize Steering Grasping to Take over Driver from System in Advance Safety System**

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**Abstract**  
Advances being made today in electronic technology are evolving the processes that make vehicles more intelligent, in
addition to realizing safer and more comfortable driving. Lane departure prevention systems are also becoming practical due to millimeter-wave radar and onboard forward observation cameras. The U.S. Department of Transportation has implemented a National Automotive Sampling System Crashworthiness Data System (NASS/CDS) for North America that found 10,743 accidents in 2016 involved departure from the road. There were 12,043 fatalities in these accidents. Lane departure prevention systems are expected to make a major contribution to reducing accidents of this kind. Advances are also being made in the development of systems that will enable autonomous driving, and the system to ensure safe and comfortable vehicle operation is being developed. These systems embody great potential for reducing the number of accidents caused by road departure. However, the validity of the systems is largely dependent on the level of acceptance by drivers. System validity will be determined by when they provide driving assistance, how much relaxation will be permissible on the driver’s side, given that the driver needs to maintain contact with the steering wheel, and the extent of assistance provided by the system. This paper will discuss research on the minimum necessary contact and contact strength with the steering wheel on the part of the driver when the autonomous system is in operation. Using a six-axis driving simulator employing an actual vehicle, the research conducted tests involving 22 test subjects, and studied the relationship between the status of the driver’s contact in terms of steering angle speed and steering angular velocity and vehicle behavior when the system failed. The authors analyzed the influence on avoidance behaviors depending on the state in which the steering is held or not grasped when a person performs avoidance behavior. When the steering torque activates, such as in a curve, the reaction will be faster if drivers touch the hand. In the case of a straight road with no steering torque activating, the result of the difference in reaction time depending on whether they are gazing at the front, regardless of grasping or non-grasping, has been clarified from this research.

Paper No.19-0109-O PEER REVIEW

Multi-agent traffic simulations to estimate the impact of automated technologies on safety.
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Research
Automated vehicles are being promoted under the expectation that they will contribute to achieve safer roads. Comprehensive estimations of the potential impact that these vehicles will have on traffic safety at national level require the support of simulation methodologies. Within the Japan SIP-adus strategic research program, our objective is to develop and verify a multi-agent traffic simulation methodology applicable to estimate the potential safety improvements of automated vehicle technologies.

Methods
We developed a software that merges road infrastructure data with a large number of traffic agents including vehicles, drivers, pedestrians, and the interaction between all of them. The drivers’ behavior simulation model combines advanced algorithms for perception/recognition, decision-making and pedals/steering activation. The pedestrians’ behavior model accounts for vehicle-to-pedestrian time to collision parameters and incorporates gender- and age-dependent measurements from observational studies of real-world pedestrians. Driver errors were induced by modeling inattentive driving, misjudgment of preceding vehicle speeds and distances, and crossing preference rule breakers. The software was applied to simulate traffic including more than 500 agents at a time in a prescribed area of 18 km² in Tsukuba city (Japan). First, a 100% manual driving scenario was set to simulate traffic for a total vehicle travel distance of 80,000 km. The accidents from the simulation were compared with real-world accident data from the prescribed area in years 2012 to 2017. Thereafter, four additional scenarios of gradually increasing levels of automated technology penetration (including AEB, LDW and SAE Level 4 automated functions), were implemented in the simulations to estimate their effect on accidents.
Results
Under 100% manual driving, the system simulated a total of 859 accidents of five types: rear-end, frontal and intersection car-to-car crashes, single car departure, and car-to-pedestrian impacts. These accidents occurred in proportions and locations similar to those from real-world accidents. The number of accidents predicted decreased with increasing level of automation down to 156 cases for the highest automation level simulated (25% of vehicles with AEB+LDW and 75% of level 4 automated driving). All the technologies considered contributed to the absolute decrease of accidents which was dominated by reductions of rear-end and lane departure related crashes.

Discussion
The reliability of the simulation results under 100% manual driving was assessed with real-world accident data. Accident reductions attributable to AEB and LDW in the simulations were comparable to those reported in recent field studies. For the highest levels of automation, no assessment data was available, and hence should be carefully treated. Further, in modeling automated functions, potentially negative aspects such as sensing failure or human overreliance have not been yet incorporated. Future work will also address validation of the human behavior models, incorporation of bicycle agents, and expansion of the current methodology to wider regions.

Conclusion
We successfully developed a multi-agent traffic simulation methodology to estimate the effect of different automated vehicle technologies on safety. The results from simulations of manual driving scenario within a limited area in Japan were verified with real-world accident data. Preliminary estimations of the potential safety improvements that may be achieved by different automated technologies were also obtained.

Paper No.19-0026-O
Development and Application of an Expert Assessment Method for Evaluating the Usability of SAE Level 3 ADS HMIs
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Abstract
With the Federal Automated Vehicles Policy, the U.S. National Highway Traffic Safety Administration (NHTSA) has provided an outline that can be used to guide the development and validation of Automated Driving Systems (ADS). Acknowledging that the Human- Machine-Interface (HMI) – identified as one of the 12 priority safety design elements in this voluntary guidance – will be crucial for the success of ADSs, we developed a two-step iterative test procedure that serves to evaluate the conformity of SAE level 3 ADS HMIs with the requirements outlined in NHTSA’s Automated Vehicles policy. The aim of this assessment is to evaluate whether minimum HMI requirements are met that facilitate a safe and efficient use of AVs. The present contribution describes the development of an expert-based checklist, how it was compiled from existing literature, how its content and application were refined in simulator and real-world studies, and how it can be employed as a complimentary or stand-alone tool to assess the conformity of SAE Level 3 ADS HMIs with NHTSA’s AV policy. It also discusses boundary conditions for the application of the method and the generalization of findings. The described method can be employed in a variety of settings to evaluate SAE Level 3 ADS HMIs, therefore making it a valuable tool for both researchers and practitioners alike.

Paper No.19-0041-O
A Framework for Definition of Logical Scenarios from an Egocentric Perspective for Safety Assurance of Automated Driving
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26ESV/Program Book
In order to introduce automated vehicles on public roads, it is necessary to prove that these vehicles are safe to operate in traffic. One challenge for safety assurance of L3+ vehicles is to prove that all physically possible variations of situations can be handled safely within the operational design domain of the automated vehicle. A promising approach to handling the set of possible situations is to identify a manageable number of logical scenarios, which provide an abstraction for object properties and behavior within the situations. These can then be transferred into concrete scenarios defining all parameters necessary to reproduce the situation on proving grounds or in simulation. This paper proposes a framework for defining safety relevant scenarios based on the potential collision between the ego vehicle and a challenging object, which forces the ego to depart from its planned course of action to avoid a collision. This allows adopting common practices that have been established in accident classification.

Methods
The first criterion for defining a scenario is the area of collision with which the object would collide. For this purpose, a distinction between the front, side and rear of the ego is made. As second criterion, eight different positions around the ego have been defined based on whether the object overlaps with the ego in x- or y-direction. Certain positions can be consolidated for different areas of collision. By including the initial position of the challenging object relative to the ego, it is not necessary to assign vehicles to dedicated lanes. This allows utilizing the approach not only on motorways but also in urban environments. The position of objects is given in road-aligned coordinates. To account for other relevant objects in the scenario, factors that impose higher demands upon the ego vehicle can be added to the logical scenario. These have been grouped as: Action constraints Dynamic occlusions Multiple challenging objects

Results
A total of nine basic logical scenarios are identified for the ego vehicle driving in its lane. The complete description of these scenarios with corresponding figures is presented in the final paper.

Discussion
By applying the above stated systematics, a scenario catalogue for a vehicle travelling on a motorway has been generated. The generated scenarios have already been verified in field data and driving-simulator data. A more comprehensive proof of concept can be carried out by identifying the scenarios in a large-scale database. A next step to expand the framework is the generation of logical scenarios for other driving states of the ego vehicle and other traffic environments.

Conclusion
Defining a limited number of safety relevant scenarios helps to realize a systematic safety evaluation process for automated vehicles. Scenarios are defined based on the point of the potential collision of a challenging object with the ego and its initial position. This approach allows defining scenarios for different environments and different driving states of the ego using the same mechanisms. The approach is applied in the German research project PEGASUS funded by the German Ministry for Economic Affairs and Energy.
Abstract
Developing safe vehicle automation systems is crucial for the commercialization of automated driving. One of the major challenges for the release of fully automated driving is functional safety. Automated driving systems explode in complexity due to an infinite number of occurring scenarios. Thereby, the derivation of safety requirements for complex automated driving functions lacks a categorization to tackle the completeness issue. This work presents a structure for a fault tree-based approach to derive safety requirements from safety goals systematically in compliance with the international standard of functional safety for road vehicles known as ISO 26262. The investigation of the state of the art reveals that a functional safety concept for fully automated valet parking (AVP) has not yet been targeted. The methodology is therefore applied on the example of automated valet parking to elaborate a safety concept which was not yet investigated. Beforehand, the AVP system was split into a manageable amount of relevant functional scenarios to decrease complexity. For each scenario, a Hazard Analysis and Risk Assessment (HARA) was performed. A set of safety goals was elaborated. The approach utilizes a fault tree-based Sense-Plan-Act architecture to achieve a large coverage of possibly derivable safety requirements from safety goals. The sense phase contains the acquisition of sensor data and leads to three uncertainty domains: state, existence, and class uncertainty. The plan segment includes the situation comprehension and action planning. Thereby, the transportation mission can be split into five tasks. The act block represents the execution of the planned trajectory. Longitudinal and lateral vehicle dynamics such as steering, shifting, accelerating, and braking are performed. A violation of a safety goal occurs if at least one of the failure events in the sense-, plan-, and act-phase is present. The methodology is suitable for safety goals which follow the specified Sense-Plan-Act pattern.

Research on skillful drivers’ merging behaviors and statistical analysis of traffic lane flow for an investigation of automatic merging assessment method

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Abstract
AM (Automatic Merging) is a driving support system which helps drivers to merge into a traffic lane. It is required to set its performance assessment method to see whether it meets people’s driving style of each country or region. In this paper, we propose methodologies to set suitable assessment method of AM (target performances and test conditions) which can be applied in each country or region. As for target performances, suitable ones are set by studying Japanese skillful drivers’ merging behaviors on highway and on test track. As for test conditions, a new method is proposed to calculate the possibility that a merging vehicle encounters a difficult situation by analyzing traffic camera and cloud data, which allows us to set reasonable test conditions as “X%ile difficulty” of real environment. These methodologies can be applied not only in Japan but also in other countries or regions.
Funcional Decomposition - a Contribution to Overcome the Parameter Space Explosion during Validation of Highly Automated Driving

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Research
Particular testing by functional decomposition of the automated driving function - as proposed by the authors in previous publications - can potentially contribute to reduce the validation effort for highly automated driving. In this study, the required size of test suites for scenario-based testing and the potential to reduce it by functional decomposition is quantified for the first time.

Methods
The required size of test suites for scenario-based approval of a so-called “Autobahn-Chauffeur” (SAE Level 3) is analyzed for an exemplary set of scenarios. Based on studies of data from failure analysis in other domains, the possible range for the required test coverage is narrowed down and suitable discretization steps as well as ranges for the influence parameters are assumed. Based on those assumptions, the size of the test suites for testing the complete system are quantified. The effects that lead to a reduction of the parameter space for particular testing of the decomposed driving function are analyzed and the potential to reduce the validation effort is estimated by comparing the resulting test suite sizes for both methods.

Results
Three main effects that reduce the parameter space for particular testing are identified: The parameter space for one single decomposition layer is smaller than the parameter space for the complete automated driving function. As the decomposed sub functions are less complex as the complete driving function and therefore require a smaller test coverage. The test of the environment perception layers can be aggregated for sets of similar scenarios. The combination of all effects lead to a reduction of the test suite by a factor between 130 and 20, depending on the required test coverage. This means that the size of the required test suite can be reduced by 99% - 95% by particular testing compared to scenario based testing of the complete system.

Discussion
The size of the test suites is mainly influenced by the discretization steps of the influence parameters and the required test coverage. This on the one hand leads to a “discretization challenge” that cannot be solved within this study; on the other hand, the required test coverage could only be defined by analyzing empirical data, which is not available for highly automated driving yet. Therefore this study has to be based on some assumptions. While the absolute values for the test suite sizes strongly depend on the made assumptions, the relative findings are not affected as the same assumed data were used to compare both methods, particular testing and testing of the complete system. Additionally, this study has been based on a small set of exemplary scenarios. Thus, the findings have to be validated with a practical implementation of the functional decomposition approach.

Conclusion
The functional decomposition approach could potentially reduce the size of the required test suite by a factor between 20 and 130, depending on the required test coverage. That would be a valuable contribution to overcome the parameter space explosion during the validation of highly automated driving.
Paper No.19-0042-O
ESF 2019 - Experimental Safety Vehicle Meets Automated Driving Mode

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Abstract
Since the early beginning of the Enhanced Safety Vehicle Program in 1969, Mercedes-Benz has created over 30 ESF cars, and thus played a key role in the development of modern automotive safety. After more than 30 years, Mercedes-Benz presented in 2009 a new ESF based on the very latest safety features, such as Advanced Driver Assistance Systems, Adaptive Restraint Systems, and Integrated Safety Systems (PRE-SAFE®). Nowadays, the automotive industry is facing one of its most challenging paradigm shifts. In the coming years, connectivity, automated driving, shared services, and electric cars will fundamentally change the usage of cars. After ten years, Mercedes-Benz will show again a research car: the ESF 2019. Mercedes-Benz, as a worldwide leader in automotive safety, will demonstrate its vision and ideas for safety for this new vehicle generation: a vision of safety that goes beyond just the passenger and includes the vehicle’s surroundings. With all its innovations, the Mercedes-Benz Experimental Safety Vehicle 2019 represents a further milestone in automotive safety.

Paper No.19-0141-O
Calculation of the Point Of No Return (PONR) from real-world accidents

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Abstract
Continuing efforts in the field of traffic accident research has led to the development of various active and passive safety systems. They act and influence an incident/accident at different points in time in order to mitigate or avoid a collision. In the event of a collision, the decision to deploy passive safety systems must be made quickly, as the typical activation time is between 10 to 40 ms after the initial contact. However, for future interior/seating concepts and earlier deployment times of restraint systems it is necessary to predict an unavoidable collision much earlier. As the knowledge about this so-called Point Of No Return (PONR) is crucial, this paper introduces an approach to calculate it through using numerical simulation. This paper uses real world accidents out of the GiDAS (German In-Depth Accident Study) project. The database contains more than 33.000 accidents with personal damage. The reconstruction of the several phases (normal driving, critical situation, pre-crash, in-crash, post-crash) is the basis for the estimation. Therefore, an imminent collision is predicted by simulating the vehicle’s possible behavior using a multi body system. If any physically possible vehicle
reaction exists that leads to an avoidance of the collision, the PONR has not yet been reached. If all simulation solutions would lead to a collision, the calculations must go one time step backwards. Through an efficient iterative approximation procedure the PONR can be found in a reasonable number of iterations. The approach focuses on the maxima in longitudinal direction (full acceleration or deceleration), in lateral direction (full steering right or left) and in all four combinations of steering and accelerating/decelerating. The approach can be generally used for all collision types. Here, it is applied to rear-end collisions between two vehicles, highlighting the potential of different avoidance strategies like full deceleration or full steering as a function of time. The distribution of time across all PONRs shows that passive safety measures can be activated prior to the collision in the vast majority of cases. Therefore, occupant protection can be further improved and accidents consequences could be mitigated to a higher degree. The suggested approach can estimate the PONR for real accidents. An adaptation to naturalistic driving data as well as real time estimation is conceivable. This would signify a crucial contribution to the current research on the distinction between accidents and incidents. However, some adaptations would be necessary to enable such calculations. The current simulations are based on idealized acceleration/deceleration and steering behavior, while traffic flow is neglected. Both simplifications lead to an underestimation of the PONR. As the approach is modularized, it can be further developed towards other vehicle behavior maneuvers, specific driver models, or interactions with Advanced Driver Assistance Systems (ADAS). The PONR is an important value for improved vehicle safety. The developed approach allows to estimate the further potential of passive safety systems with regard to earlier activation times. Furthermore, it can be used to evaluate collision avoidance strategies and to parameterize ADAS.

**Paper No.19-0083-O**

**Occupant activities and sitting positions in automated vehicles in China and Sweden**

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Abstract

To save lives in future traffic crashes, we need to understand what people will be doing in fully automated vehicles during various types of trips, and shape the restraint systems to protect for the resulting postures. This paper describes how participants of our study in China wished to sit and what they wanted to do as occupants during different trip scenarios, and how they compare to participants in a previous study in Sweden. Both studies used the “Setting the stage” method to explore these future situations. The “stage” consisted of a space with four chairs, designated as a vehicle. This minimalistic setup has been claimed to stimulate the imagination to a greater extent than more developed designs, because it allowed participants to play a more dynamic role when designing and expressing their expectations of a fully automated vehicle, within the constraints of the trip scenarios posed to them. The fully automated vehicle was described as a car that doesn’t need to be driven at all; upon entering, the occupant only has to dial in a destination. Three trip scenarios were presented to the participants in China. After each presentation, participants were encouraged to discuss among themselves what they imagined they would do during such a trip, and how they would like to be seated. Participants could redesign the “vehicle” interior as they wished by manipulating the position of the chairs as they were speaking. An observer took notes and photos as participants were discussing. For a short trip, to or from school or work, participants in China saw themselves seated in a traditional forward-facing, upright position. For weekend rides or longer trips with family, the traditional seating position and a living-room style position with participants facing each other were most commonly mentioned. Participants also suggested a 45- or 90-degree rotated version of the living room position and being able to sleep in a horizontal position. Activities mentioned include relaxing, watching movies and working. Participants in both China and Sweden expected fully automated vehicles to allow for more varied sitting and more comfortable seats. Reclined seats were frequently mentioned, as were swivel seats. Both groups expected the fully automated vehicle, more than vehicles today, to support activities normally not done when driving. Participants in China also wished to lie down during longer trips. The requests for new sitting positions will require novel restraint systems—for example, new seatbelt concepts (such as belt-in-seat) and new types of airbags—as well as new tools to assess the systems’ safety.

**Paper No.19-0177-O**

**Integrated Safety: Establishing Links for a Comprehensive Virtual Tool Chain**

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Abstract
As technologies for injury prevention and crash avoidance both contribute to injury reduction in car crashes, tools predicting the combined effect of all safety features are needed. This study aims at establishing a computer simulation methodology including two important elements for assessing this combined effect. The first element describes the states of the involved vehicles or objects at crash initiation regarding positions, orientations and velocities as parameters used for crash evaluation. The second element focuses on the car occupant, enabling computationally efficient prediction of occupant position transfer during pre-crash maneuvers. An extended aim is to demonstrate how data flows between these elements in an example case study. Real-world data from the Volvo Cars traffic accident database (VCTAD) was used as the basis for pre-crash simulations involving two cars, with and without a conceptual autonomous emergency braking (AEB) function. For cases in which the crash was not avoided by the AEB function, the crash configuration was identified. A simplified occupant kinematics model (SOCKIMO) was developed and applied to these remaining crashes, supporting the selection of crash situations to be analyzed in detail. The SAFER human body model (HBM) was used for simulation of the occupant response, providing information on pre-crash kinematics as well as the occupant crash response. As a result, a novel crash configuration definition for estimating the consequences of car crashes based on preceding events was established. The Volvo parametric crash configuration (VPARCC) definition can be used as a link between pre-crash and crash simulation tools as well as for illustrating sets of real-world accident data and how these change based on maneuvers preceding a crash. SOCKIMO results demonstrated occupant kinematics similar to those of volunteers, and the subsequent simulations using the SAFER HBM showed considerable changes in occupant crash response based on pre-crash vehicle kinematics. The VPARCC definition can also be applied to collision objects such as trucks or vulnerable road users. The developed SOCKIMO can be used to filter out cases from large crash data sets to be further analyzed with detailed models such as finite element active HBMs. By applying the more detailed HBM, the effects of avoidance maneuvers on occupant kinematics relevant for injury prediction can be evaluated. This approach would not be possible using simplified occupant models only (due to the lack of details) or by using detailed models only (due to the large simulation effort). The presented methodology for estimating combined safety performance can be used for transferring output from pre-crash simulations to input for crash simulations. The feasibility of combining the individual elements of this methodology was demonstrated in an example case where autonomous emergency braking led to a large change in the crash configuration and was predicted to introduce substantial occupant pre-crash excursion. In this example case, it was shown that the present A-HBM tool is able to cover the complete sequence from pre-crash maneuvers to crash in one single simulation.

Paper No.19-0182-O
Euro NCAP’s first step towards scenario-based assessment by combining Autonomous Emergency Braking and Autonomous Emergency Steering
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Abstract
Following the implementation of Autonomous Emergency Braking in the overall safety rating in 2014, Euro NCAP is making its first step towards a scenario-based approach by allowing a driver initiated steering intervention as an alternative to the driver responding to a Forward Collision Warning (FCW) by braking. With this first step, Euro NCAP is acknowledging that there are multiple responses possible to the same threat and that steering, in some cases, may be a better crash avoidance strategy than braking. Within the Euro NCAP Working Group on AEB/AES, Euro NCAP members, test centers and the automotive industry represented by the ACEA, JAMA, KAMA and CLEPA associations, the first protocols are developed for both AEB Car-to-Car (C2C) and AEB systems, responding to vulnerable road users (VRU). The procedures are an extension to the current AEB C2C and AEB VRU test and assessment protocols, with expected adoption in the rating in 2020. This paper describes both the test and assessment protocols.
Paper No.19-0204-O
INJURY RISK-BASED CRITERIA FOR THE APPLICATION OF ADAPTIVE LOGIC TO ADAS SYSTEMS
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Abstract
Performance improvement of advanced driver assistance systems (ADAS) yields two major benefits: an increasingly fast progress towards autonomous driving and a simultaneous advance in vehicle safety. The high safety level provided by ADAS result primarily from the possibility to avoid possible impacts in correspondence of critical road scenarios. Nevertheless, specific obstacles (e.g., stationary vehicles, buildings) can interpose between the opponent vehicles and the working field of the sensors, weakening their functions; in these particular conditions, the impact can be inevitable (inevitable collision state – ICS). The systems currently available on the market are not capable to properly handle an ICS, because its occurrence is not conceived. In the present work intervention criteria for ADAS are introduced which are based on the vehicle occupants’ injury risk (IR), particularly useful in case of ICS. In a critical road scenario, the ADAS must first avoid the impact with maximum margin (maximum clearance between vehicles) and, in case of ICS, minimize impact severity and IR. Referring to a system capable of intervening on braking and steering, the ADAS must monitor the surrounding and act on the degrees of freedom adapting to the possible evolution of the scenario, following an adaptive logic. The sequence of optimal interventions based on such adaptive logic tends toward the best possible outcome. The context (model-in-the-loop) of the adaptive intervention employing the proposed criteria is first introduced, proposing a solution for testing its actual functioning (software-in-the-loop) with a view to its physical implementation (hardware-in-the-loop). The major criticality of the approach consists in the impact phase reconstruction, because IR is also a function of post-impact parameters (e.g., the velocity change ΔV experienced by the vehicle in the crash). To highlight the potential benefits offered by an adaptive ADAS and to monitor its behavior, a software has been developed based on the software-in-the-loop solution introduced. The best intervention selection is based on a database filled with results of simulations: the outcomes associated to each braking and steering intervention are summarized in the database, for many critical scenarios; the ADAS retrieves information from the database and, through IR-based criteria, selects the most favorable action. Testing the logic functioning in correspondence of three critical road scenarios in which two vehicles are involved, at each instant it is observed that the developed intervention logic aims at creating eccentrical impact configurations, associated to low ΔV; the low values of resulting impact severity demonstrate how the intervention criteria based on IR represent an important tool for the development of increasingly performing ADAS devices.

Paper No.19-0210-O
New Driver Safety Concept for Automated and Manual Driving Mode
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Abstract
After ten years Mercedes-Benz is presenting once again an ESF (Experimentales Sicherheitsfahrzeug / Experimental Safety Vehicle) – the ESF 2019. This research vehicle, based on a series production vehicle, represents a platform of
safety innovations in highly automated vehicles, the driver seat occupant is no longer required to maintain a standard driving posture while the vehicle is operating in automated driving mode. This enables new interior concepts with more flexibility and seating comfort, depending on the specific driving situation and responsibility. During automated driving mode, the driver has the option to choose more flexible seating positions to relax, work or enjoy the entertainment system. The visitors of the ESV exhibition will get a chance to experience this safety concept. The option to choose a more relaxed seating position compels further consideration of occupant safety. The new flexible seating positions are expected to provide the same level of crash worthiness that is known from current standard seating positions for manual driving. For future car concepts, the safety systems need added flexibility to enable new situations beyond the standard driving position.

**Paper No.19-0248-O**

**COLLISION DETECTION USING ADAS SENSOR AND ITS EFFECT ON OCCUPANT INJURY**

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Abstract  
In real world, Collisions which are faster than NCAP speed are occurring and fatality rate is high in such collisions. In order to solve such the high-speed collisions, it is important to increase the energy absorption amount of the occupant restraint devise. In order to increase the amount of energy absorption, it is necessary to detect the collision early and for the occupant to be restrained at an early timing. We focused on the integrated system using the advanced driver assistance systems (ADAS) sensor as a method to achieve the early airbag deployment timing. And we research whether the collision detection timing can become earlier and the occupant injury can be reduced. A collision is predicted using the ADAS sensor, and the threshold of an airbag deployment is lowered just before the collision. Furthermore, by lowering the threshold only at the collision speed where an airbag deployment is required, it will prevent an airbag deployment at slight collisions. Also, the threshold is lowered until the rough road toughness can be secured. So the toughness of rough road traveling is equivalent to the conventional one. For confirming the effect of this sensing system, we conducted simulation using LS-DYNA and the actual vehicle test. The airbag deployment timing was calculated by the simulation results. In order to calculate the effect on the occupant injury, sled test was also conducted. The input data of floor G and the airbag deployment timing is the results of simulation. From these results, it was found that the collision would be detected earlier than the conventional one. And we also confirmed the effect of reducing occupant injury.

**Paper No.19-0321-O**

**Evaluation of the Protective Performance of a Novel Restraint System for Highly Automated Vehicles**

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Abstract
As automated driving further penetrates the market, opportunities continue to arise for new vehicle interior designs, and new seating positions might be allowed. Flexible seating with a wider range of positions will require new restraint systems, independent of the steering wheel or instrument panel. The aim of this study was to evaluate a novel seat-integrated restraint system created for future potential seating position, compared to the current conventional restraint system in forward-facing seat condition. The seat-integrated restraint system was evaluated using a virtual simulation model correlated to physical sled tests. The CAE model included a generic seat, the seat integrated belt system with a 2kN load limiter, and the new Dual Shoulder Airbag system (DSA). The DSA was mounted to the seat back on both sides of the seat. The DSA was also connected below the seat pan to raise the occupant’s pelvis-thigh area during a crash, to avoid submarining in the reclined position. For reference, a standard system (3-point 4kN load limiter belt and driver airbag) was used. Occupant injury assessment reference values (IARV) were evaluated using the AM50_THOR, AF05_Hybrid III, and AM95_Hybrid III models and compared to IARVs from the current and new proposed New Car Assessment program in the U.S (US NCAP). The IARVs compared were HIC15, BrIC, Nij and Chest deflection. The load cases evaluated were full rigid-barrier frontal crash (FRB) and NHTSA Oblique Impact (NOI), with crash pulses representing a mid-size sedan. The occupant protection was evaluated for the standard seating position (23 degrees from vertical) as well as for a reclined position (45 degrees from vertical). The new restraint system resulted in lower IARVs than the reference system in every case except HIC15 and Nij in the NOI condition. A comparison of the standard and reclined positions revealed that every IARV was increased in the latter. No submarining occurred for any of the restraint systems. The new proposed airbag system has the potential to offer equivalent or lower IARVs compared to the reference system in frontal crash mode (forward-facing seat condition).

Effect of automated versus manual emergency braking on rear seat adult and pediatric occupant pre-crash motion

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Research
Pre-crash occupant motion generated by emergency braking has the potential to influence the effectiveness of restraints in the subsequent crash, particularly for rear seated occupants who may be less aware of the impending crash. With automated emergency braking (AEB) expected to be standard in majority of the new vehicle fleet by 2022, it is important to explore differences in pre-crash occupant motion between AEB and the traditional manual emergency braking (MEB). Further, due to anatomical and biomechanical differences, differences between AEB and MEB may vary with age. Therefore, the objective of this study was to quantify differences in rear seated adult and pediatric kinematics and muscle activity during AEB and MEB scenarios.

Methods
Vehicle maneuvers were performed in a recent model year sedan travelling at 50 km/h with cruise control. MEB (deceleration ~1g) was achieved by the driver pressing the brake pedal with maximum effort. AEB (deceleration ~0.8g) was triggered by the vehicle radar detecting a 3D Guided Soft Target. Inertial and GPS Navigation system measured the vehicle dynamics. Eighteen participants (5 adults (age 22.0 ±1.9 years), 7 teens (age 14.9 ±1.2 years), 6 children (age 10.8...
were seated in the rear right passenger seat and experienced each maneuver twice. The subjects’ seat position was instrumented with an eight camera 3D motion capture system tracking participants’ head and trunk. Electromyography (EMG) sensors were placed on muscles most likely involved in bracing. Head and trunk displacements, raw and normalized by seated height, and peak head and trunk velocity were compared across ages and between maneuvers. Mean EMG was calculated to interpret kinematic findings.

Results
On average, displacements were 16.1 cm (head) and 8.6 cm (trunk) in MEB, and 11.7 cm (head) and 6.5 cm (trunk) in AEB. No effect of age was observed (p≥0.35). Head and trunk displacement, and peak velocity were greater in MEB than in AEB in both raw and normalized data (p≤0.006). Peak head and trunk velocity was greater in repetition 1 than 2 (p≤0.01) in MEB but not in AEB. Sternocleidomastoid (SCM) mean EMG was greater in MEB compared to AEB, and muscles activity increased in repetition 2 in MEB.

Discussion
Our findings show that, across all ages, head and trunk excursions were greater in MEB than AEB, despite increased muscle activity in MEB suggesting a failed attempt of bracing the head (i.e. neck muscles contracting too late or with not enough force) or the results of a startle reflex. The increased excursion in MEB compared to AEB may be attributed to acceleration differences between the two scenarios: AEB had a more gradual deceleration (jerk = 0.52 g/s) while MEB was more abrupt (jerk = 4.75 g/s).

Conclusion
These results suggest AEB systems have potential to reduce occupant motion during emergency braking across a diverse age groups, due to the vehicle’s ability to detect obstacles in advance and prescribe a more gradual deceleration profile. Quantifying pre-crash occupant motion in emergency braking may guide future development of AEB systems and occupant protection prior to a crash.

Paper No.19-0229-O
Development of a side impact crash using integrated system
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Abstract
It was judged that it was difficult to prevent passenger injuries caused by vehicle intrusion into a side impact only with conventional airbags. So we considered ways to avoid intrusion. Existing restraint systems are not sufficient to prevent injury caused by vehicle intrusion during side impact. In this thesis, we considered ways to improve passenger injuries by applying new lateral air bag technology using the active system to improve injury caused by vehicle intrusion into existing and new collisions.

Paper No.19-0251-O
Research of bicyclist detection by enhanced pedestrian detection system with ADAS
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Abstract
Recent years have seen growing concern with bicyclists in terms of protection for vulnerable road users (VRU) [1]. One instance of this is the establishing of bicyclists to the Euro NCAP protocols for Automatic Emergency Braking (AEB) assessment. In a real-world environment, however, even if AEB operates, there is still a possibility that the vehicle will not slow down sufficiently because of the timing of that operation, the vehicle environment, or the road surface environment. In this case, impact between the vehicle and the bicyclist may occur. Consequently, there remains a necessity for technology to detect impact with bicyclists. For this paper, the investigation was carried out with a focus on the detection of bicyclist impact in two modes. They are run-out mode and rear-end impact mode, in which detection is assumed to present a challenge because the bicyclist and the vehicle bumper do not come into contact. As a method for detecting impact with a bicyclist in the above modes, a detection system was devised that integrates a conventional pedestrian detection system, deformation sensors mounted around the bumper surface periphery, and ADAS information. This will be referred to as the integrated impact detection system. Bumper surface deformation sensors are used to detect minute deformations of the bumper surface caused by a bicycle. ADAS information is used to control the threshold for impact judgment. The conventional pedestrian detection system is used mainly to detect the impact of a bicyclist near the central portion of the vehicle. We conducted CBU tests and simulations on the integrated impact detection system we invented this time and confirmed and investigated the bicyclist impact detection performance. As a result, it was found that minute inputs to the bumper surface caused by a bicycle can be effectively detected by the deformation sensors. The deformation sensors alone are sensitive to inputs to the bumper surface. However, the reliability of impact detection can be maintained by using ADAS information to control the deformation sensor threshold when operation of the vulnerable road user protection device is required. Incorporating the conventional pedestrian detection system into this system also maintains reliability. It was determined from these results that the combination of the conventional pedestrian detection system, deformation sensors, and ADAS information in an integrated impact detection system presented possibilities for detection of impact with bicyclists in run-out and rear-end impact modes.

Paper No. 19-0179-O
Evaluation of the threshold for dispatching the doctor to the accident site being used in AACN
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Abstract
An advanced automatic collision notification system (AACN) called “D-Call Net” started operation in Japan at the end of 2015. D-Call Net reports both the location of the accident and the probability of serious and fatal injuries calculated based on event data recorder (EDR) information such as the collision direction, delta-V, seatbelt usage, and whether multiple impacts occurred. This information is sent simultaneously to fire departments and emergency responders at hospitals operating air ambulances to shorten the duration before a doctor reaches the injured as much as possible. The probability of serious or fatal injury used by D-Call Net was calculated by Toyota Motor Corporation and Nihon University based on 2.8 million items of crash data in Japan. This probability was developed using only driver side data, and is also applied to the passenger side. The recommended threshold for dispatching a doctor to an accident site is currently set to a 5% probability of serious or fatal injury, which means that the under-triage (UT) rate does not exceed 10%. This research investigated 374 accidents notified via D-Call Net to determine whether the current threshold of 5% is appropriate. This investigation found that the UT rate was 0%, the over-triage (OT) rate was 29%, and that the correct judgment was made in 71% of cases. These results satisfy the targets set when operation of the system started (UT: 10%, OT: 61%). This paper also discusses the appropriate threshold for dispatching doctors via D-Call Net to further reduce the rate of unnecessary emergency dispatches.
The Residual Road Departure Crash Problem after Full Deployment of LDW and LDP Systems

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Research
Road departures are one of the most dangerous crashes in the US, comprising only 10% of all crash occupants but over 30% of all crash fatalities. To reduce this risk, a growing number of vehicles are being introduced in the US with lane departure warning systems (LDW) which can warn the driver of a road departure and lane departure prevention systems (LDP) which can assist the driver in steering back to the roadway. Previous studies have estimated that LDW/LDP systems will prevent one-third of road departure crashes. This study investigates these unavoidable crashes to set research priorities for next generation road departure prevention systems.

Methods
The study is based on over 120 road departures cases Event Data Recorders (EDRs) in the National Automotive Sampling System Crashworthiness Data System (NASS/CDS) from 2011-2015. The EDR data provided direct measurement of velocity, brake application and driver steering inputs before the crash. In addition, each case was supplemented with detailed trajectory information and location of fixed objects extracted from NASS/CDS crash scene diagrams. None of these baseline cases had LDW/LDP. The EDR data for each baseline case was mapped onto the vehicle trajectory, and then simulated to assess the potential for crash avoidance if equipped with LDW/LDP. The LDW/LDP model assumed that a warning was delivered when the lead tire crossed the lane line. Driver response times to the warning ranged from 0.38s and 1.36s. Zero latency time was assumed for an LDP system to activate steering. Then the driver attempted to avoid the roadside object by steering toward the road. The target population was the cases in which a roadside collision was not avoided despite the LDW/LDP system.

Results
The model predicted that between 45-79% of single vehicle road departure crashes may not be prevented by an LDW system depending on the reaction time of the driver. LDP systems were more effective, but still may not prevent 32% of road departure crashes.

Discussion
LDW/LDP systems are a promising countermeasure to avoid road departure crashes but many road departures still may not be avoided. With LDP automatic steering, which has zero latency, no crashes were avoided if the time to collision (TTC) from lane crossing to impact was less than 0.45s. The two most important characteristics of these unavoidable crashes were the reaction time, and the TTC after the warning. Obstacles such as guardrails and traffic barriers, which tend to be very close to the road, were overrepresented among the remaining crashes. Likewise, trees and utility poles in close...
proximity to the lane line were not avoided.

Conclusion
Previous studies of LDW/LDP benefits have relied on post-crash reconstructions which approximate the delta-V and pre-crash velocity profiles. This is the first study to characterize the residual safety problem after LDW/LDP deployment based on characteristics measured directly by an EDR. The study shows that LDW/LDP systems are primarily limited by two factors, driver reaction time, and TTC to the roadside object. This paper is relevant to this session as it discussed estimates of potential safety benefits for LDW/LDP.

**Paper No.19-0130-O**

The effect of P-AEB system parameters on the effectiveness for real world pedestrian accidents

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Abstract
The objective of this ACEA funded study was to determine the effect of different pedestrian autonomous emergency braking (P-AEB) systems on the collision speeds of real world pedestrian accidents originating from three different accident databases. The precrash phases of real world passenger car to pedestrian frontal accidents from the in-depth accident databases were investigated using different pre-crash simulation tools. Collision parameters were compared between the original real-world cases and cases with treatment conditions. For treatment simulations, the car was equipped with a virtual generic P-AEB system, triggered at a time to collision (TTC) ≤ 1 s. The range of the generic sensor was 80 m and the opening angle was varied between 60°, 90° and 120°. For the braking system, two different brake gradients (24.5 m/s³ and 35 m/s³) were modelled with different decelerations of 0.8 g and 1.1 g. Accidents from the Austrian in-depth accident database CEDATU (n=50), the German GIDAS (n=1084) and Swedish V_PAD (n=68) were used for the baseline. The effect of using different data samples was compared to the effect of assuming different generic AEB system parameters. The best performing P-AEB system (120°, innovative brake system) avoided 42% of the CEDATU cases, while the baseline P-AEB system (60°, standard brake system) avoided 18%. The best performing AEB System was able to avoid 79.4% of the V_PAD sample. The baseline P-AEB avoided in V_PAD at least 66.2% compared to GIDAS with 39.5%. The lower the mean collision speed of the sample, the higher was the benefit of the P-AEB system, as a higher percentage of cases can be avoided. The study shows that system parameters and the selection of accidents can greatly affect the outcome in prospective traffic safety analyses. As a significant reduction of collision speeds was seen in all three data sources, the study highlights the need for a combined vehicle safety assessment instead of a separate evaluation of active and passive pedestrian safety measures.

**Paper No.19-0208-O**

Applying Lane Keeping Support Test Track Performance to Real-World Crash Data

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Abstract

Lane Keeping Support (LKS) is an advanced driver assistance system (ADAS) technology intended to prevent a vehicle from drifting out of its travel lane. To assess the potential for LKS to reduce real-world crashes where the driver drifts out of their travel lane, test track performance was compared with the real-world crash data. Five light vehicles equipped with LKS were evaluated on the test track using Lane Keeping Assist (LKA) test methods contained within the Euro NCAP Test Protocol - Lane Support Systems. Specifically, the procedures to evaluate a vehicle’s response to an imminent departure over a solid white line were used; tests to evaluate LKS system response to an unmarked road edge were not performed. These tests identified performance differences between the vehicles, and were somewhat dependent on the lateral velocity used during test conduct. Results from these tests were compared to relevant fatal crashes in the National Motor Vehicle Crash Causation Survey (NMVCCS) survey conducted by the National Highway Traffic Safety Administration from 2005-2007, and the agency’s new Crash Investigation Sampling System (CISS). A review of the fatal 2005 – 2007 NMVCCS and 2017 CISS lane/roadway departure cases was performed to classify the shoulder type present on the side of the roadway from which the subject vehicle first departed from, and to estimate the shoulder width just after the departure, where applicable. The objective of this effort was to estimate whether LKS interventions could have potentially amended the real-world pre-crash path of the subject vehicle in the vicinity of the lane departure, given the system performance observed on the test track. When the test track performance of the vehicles was considered in the context of the road shoulder widths and road/lane/shoulder characteristics present in the 43 fatal NMVCCS and 50 CISS crashes analyzed for this paper, estimating whether LKS could have affected the crash outcome was found to depend on a number of factors. From an input perspective, the lateral velocity of the vehicle as it is directed toward the boundary of the lane, and whether that boundary is comprised of a clearly defined painted line or simply a pavement edge, has the potential to affect whether an LKS intervention can even be expected. Even if the input conditions are such that a vehicle’s LKS activation criteria are satisfied, then the ability of the system to effectively address the pre-crash scenario is relevant, yet can depend on a number of factors. The amount of lateral deviation before or beyond the lane line and/or road edge, and the implications of it being too large, are important considerations. In the case of a right-side departure away from the travel lane, excessive lateral deviation may result in at least part of the vehicle leaving the paved roadway. Similarly, left-side departures with excessive lateral deviation have the potential to increase the risk of a head-on crash.

Paper No.19-0213-O

Evaluation of AEB Effectiveness Using Counterfactual Simulations of SHRP2 Naturalistic Crashes

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Abstract

Motor vehicle crashes remain a significant problem in the US and worldwide. Automatic emergency braking (AEB) is designed to mitigate the most common crash mode: rear-end striking crashes. However, assessing the efficacy of AEB in real-world crash scenarios is challenging given that avoided crashes are rarely documented except during naturalistic driving studies. Unfortunately, a large-scale naturalistic driving study involving AEB-equipped vehicles has yet to be conducted. In the absence of such data, AEB can be evaluated in real-world crash scenarios by retrospectively adding AEB to naturalistic crash data using counterfactual simulations. Previous counterfactual simulations have purported the
potential benefit of AEB; however these studies often make simplified assumptions about vehicle dynamics. To this end, the current study aimed to conduct the most realistic AEB counterfactual simulations to date by using measured host and lead vehicle dynamics data and vehicle-specific AEB deceleration profiles as well as accounting for driver reaction and environmental conditions. The SHRP2 Naturalistic Driving Study was reviewed to identify rear-end striking crashes among teen (16-19 yrs), young adult (20-24 yrs), adult (35-54 yrs), and older (70+ yrs) drivers. Forty rear-end striking crashes that had reliable radar data were identified to serve as a basis for counterfactual simulations. Real-world AEB deceleration profiles were taken from IIHS AEB test data. IIHS AEB tests were matched to SHRP2 vehicles by selecting the most recent IIHS AEB test of the same make and vehicle class. AEB onset for SHRP2 crashes was based on a brake threat number (BTN) algorithm. The BTN was adjusted to match IIHS measured AEB onsets using minimum RMSE. AEB curves were then adjusted to match the speed of the subject vehicle at AEB onset. AEB deceleration curves were also scaled based on road surface conditions. Driver reaction was accounted for by beginning the deceleration curve at the current driver-initiated braking level. Counterfactual simulations were conducted using MATLAB to determine if AEB would have prevented the rear-end striking crash. AEB was found to be very effective, preventing 80% of rear-end striking crashes; greater than previously reported. Half of all crashes that were not prevented by AEB occurred during poor weather conditions. This study provides the most realistic counterfactual evaluation of AEB to date, utilizing real-world crash dynamics, driver reaction, road surface conditions, and measured AEB deceleration pulses. These data suggest that AEB is very effective at preventing rear-end striking crashes.

Paper No.19-0300-O
REAL-WORLD EVALUATION OF DRIVER ASSISTANCE SYSTEMS FOR VULNERABLE ROAD USERS BASED ON INSURANCE CRASH DATA IN SWEDEN
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Abstract
In 2010 Volvo cars introduced advanced driver assistance systems (ADAS) designed to detect vulnerable road users (VRUs) in specific conflict situations. The aim of this study was to evaluate the first generation of the optionally mounted Pedestrian ADAS, which covers car-to-pedestrian collisions, and Cyclist ADAS, which covers car-to-cyclist collisions. Data from collisions in Sweden between passenger cars and pedestrians or cyclists were collected from 2015-2017. Crashes involving Volvo cars with third-party liability insurance at If P&C Insurance/Volvia were included in the dataset, and cars with these ADAS were compared to crashes involving cars without the systems. A total exposure of 490,000 insured vehicle years was used in the evaluation. Overall, the number of collisions for cars with the Pedestrian ADAS system was 21% less than the number for cars without it. When studying straight crossing path crashes only, which accounted for more than half of all car-to-pedestrian collisions in Sweden, these were reduced by 36%. However, the results are not statistically significant due to the low number of crashes. For the ADAS, which covers car-to-cyclist collisions, an overview of data available for retrospective performance evaluation is discussed. One clear restriction in the evaluation of VRU ADAS at this point in time is the relatively low number of cars equipped with the system together with the low rates of car-to-cyclist collisions (= 0.0002 per insured vehicle year) and car-to-pedestrian collisions (= 0.0001 per insured vehicle year). This study is the first real-world evaluation of the initial generation of VRU ADAS targeting traffic situations relevant for these technologies. ADAS for avoiding collisions with pedestrians and cyclists have a high traffic-safety potential; recent and future generations of these systems, cover more conflict situations and are thus expected to provide increasing safety benefits.

Paper No.19-0373-O
DETECTING POTENTIAL VEHICLE CONCERNS USING NATURAL LANGUAGE PROCESSING APPLIED TO AUTOMOTIVE BIG DATA
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Abstract
A large volume of unstructured data exists in the automotive industry and needs to be analyzed to detect potential vehicle concerns. Much of this data is textual in nature since customer complaints are made through call center interactions and warranty repairs. Current approaches to detect potential vehicle concerns in text data include various keyword search methods. In this paper, we apply Natural Language Processing (NLP) and shallow machine learning methods on text data to create classifiers to detect the potential vehicle concern of airbag non-deployment. For this potential vehicle concern, we show the performance of multinomial Naïve Bayes (NB), Support Vector Machine (SVM) and Gradient Boosted Trees (GBT) classifiers against keyword search methods. We present challenges of classification model development related to the nature of automotive data and limited training data. Our findings provide insights on robust text classification approaches that can improve identification of potential vehicle concerns.

Investigating accidents involving highly automated vehicles: Concept of a data trustee and data model for future Homologation
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Abstract
According to statements by the EU Commission, 95% of all traffic accidents involve human error, and in 76% of accidents, humans are solely to blame [1]. A similar picture also emerges in the settlement of damages by Allianz Versicherungs-AG, and in detailed analyses of the accident research by Allianz Center for Technology. At the same time, human drivers set high standards with regard to road traffic safety. Based on market figures over the past few years, in Germany, a passenger car causes material damage only every 250,000 km, and personal injury every 2.3 million km. Since the 1960s, the number of liability claims per passenger car has decreased to a third of the previous figure, and today the claims frequency is at around 60 claims per 1,000 insured units per year [2]. Above the level of high vehicle automation [3] from which the driver is no longer responsible for continuously monitoring the vehicle and the driving task, however, completely new issues will arise in the road traffic accident statistics. In the case of highly automated driving, extremely high requirements must be placed on vehicle safety and on protecting functions in order to not only keep road traffic safety at the current level, but actually improve it significantly. Unfortunately, accidents in the USA with vehicle prototypes in highly automated driving mode show that some accidents cannot be prevented with the current state of technology. Coupled with this is the question as to how cases can be investigated should an accident or criminal misconduct involving a highly automated vehicle occur after the legal authorization of highly automated driving functions and their introduction into the market in the EU. As explained elsewhere [4], the German liability and insurance system is well suited to covering the risks that exist in the operation of highly automated vehicles. However, the selective operation of the vehicle by the driver and by a highly automated driving function raises fundamental questions concerning the investigation of cases in the event of accidents or traffic offenses. Early on, Allianz already supported creating conditions so that accidents involving automated vehicles can be reconstructed in the future in order that victim protection, clarification of liability, and regress and product liability claims can still be ensured in a non-discriminatory manner. This is because, in the course of the motor vehicle insurer investigating a case and settling claims, particular importance is attached principally to the driving mode (highly automated driving/transfer phase/driver in control) in which the vehicle was moving at the time of the accident or the traffic offense. On the one hand, a driving error by the driver could be the cause of damage, on the other hand, errors by sensors, inadequate algorithms, deficient software quality or interoperability of systems cannot be ruled out as the cause of an accident. The driver’s statement that a collision or non-compliance with traffic regulations occurred after handing over control to the vehicle cannot be verified or disproved without a sufficient set of relevant data.
**Paper No.19-0097-O**

Speeding in crashes in the United States of America: A pilot study using event data recorder information from NASS-CDS

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**Abstract**

The prevalence of speeding in crashes is only currently reported for fatal crashes in the United States of America (USA) using police reports, and the prevalence reported (27%) is well below that found in a national study that measured travel speeds (65%). The aim of this study was to explore how event data recorder (EDR) data from the National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) database could be used to estimate the prevalence of speeding in crashes in the USA. EDR files collected as part of the NASS-CDS in 2015 were examined to determine the presence and extent of speeding, provided they met certain criteria. AIS coded injury data was also extracted when available to examine speeding by injury severity. 335 EDR files were identified as meeting the criteria. 188 of these had complete AIS coded injury information. From this sample, it was found 61% were speeding, but this reduced to 44% if NASS-CDS weightings were applied. Speeding by more than 10 mph was found in 26% of crashes (16% weighted). Speeding was found to increase with increasing injury severity: 76% of MAIS 3+ crashes involved speeding, and 52% involved speeding by more than 10 mph. EDR data was found to be a useful source of travel speed data that may be used to examine speeding in the USA. It indicates that speeding is a larger problem in crashes than suggested by the current method that uses police reports. Expanding the sample size by using more years of data and calculating the change in impact speed and associated change in injury severity would allow for more robust estimates of the prevalence of speeding and its contribution to road trauma in the USA.

**Paper No.19-0119-O**

Estimated Benefit of Automated Emergency Braking Systems for Vehicle-Pedestrian Crashes in the U.S.

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**Research**

Pedestrian safety in the U.S. is a growing problem with 5,987 fatalities in 2016, a 9% increase from 2015. One proposed solution to this problem is automated emergency braking (AEB) systems that can detect and brake to avoid pedestrians. The objective of this study is to estimate the benefit to pedestrians if all U.S. cars, light trucks, and vans were equipped with an automated braking system.

**Methods**

To conduct this study three U.S. databases were utilized: 1) the Pedestrian Crash Data Study (PCDS), 2) General Estimates System (GES), and 3) Fatality Analysis Reporting System (FARS). PCDS was a study conducted in the U.S. from 1994-1999 composed of 549 in-depth vehicle-pedestrian crash investigations including crash reconstructions and detailed vehicle damage and pedestrian injuries. GES and FARS are national databases that provide the total number police-reported crashes and fatal outcomes that occurred in the U.S. from 2011-2015. An AEB model was applied to real world vehicle-pedestrian collisions from PCDS. The AEB system was modeled with time to collision (TTC) at braking ranging from 0.5 to 1.5 seconds and computational latency ranging from 0 to 0.3 seconds. Both road surface conditions and pedestrian visibility were accounted for in the model. The impact speeds of a vehicle with and without AEB were compared by using the estimated impact speeds in conjunction
with an injury and fatality model to determine risk of MAIS3+ injury and fatality. PCDS data was used to create an injury and fatality model based on vehicle impact speed and pedestrian age. The AEB system risk was compared with models of early braking drivers (TTC = 2.0s and max deceleration = 0.2g) and late braking drivers (TTC = 0.4s and max deceleration = 0.4g).

**Results**

AEB systems reduced fatality risk when compared to a human drivers for most AEB TTC and latency values. An AEB system with a TTC value of 0.5 seconds was shown to have no benefit over early braking drivers, but did show a benefit with late braking drivers. The most beneficial system (TTC = 1.5s and latency = 0s) decreased fatality risk between 70 and 80% and injury risk (Maximum AIS score 3 and greater) between 65 and 75%.

**Discussion**

This analysis was based on a sample of 329 cases from the 1990s. It does not include children or cases without impact speeds. As travel speeds were not available for the majority of the cases, vehicle travel speeds were estimated based on impact speeds and assumed driver braking patterns which could be a potential source of error.

**Conclusion**

While not all crashes could be avoided, AEB mitigated risk to pedestrians significantly. The longer the TTC of braking and the shorter the latency value, the higher benefits showed by the AEB system. To be more effective than a human driver, AEB systems should have TTC values of 0.75 seconds or greater. This paper is relevant to this session because it describes analytical methods for estimating potential benefits of safety technologies.

**Paper No.19-0043-O**

**The L3Pilot Common Data Format – Enabling Efficient Automated Driving Data Analysis**

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**Abstract**

Analyzing road-test data is important for developing automated vehicles. L3Pilot is a European pilot project on level 3 automation, including 34 partners among manufacturers, suppliers and research institutions. Targeting around 100 cars and 1000 test subjects, the project will generate large amounts of data. We present a data format, allowing efficient data collection, handling and analysis by multiple organizations. A project of the scope of L3Pilot involves various challenges. Data come from a multitude of heterogeneous sources and are processed by a variety of tools. Recorded data span all data types generated in various vehicular sensors/systems and are enriched with external data sources. Videos supplement time-series data as external files. Derived measures and performance indicators – required to answer research questions about effectiveness of automated driving – are processed by analysis partners and included for each test session. As a file format, we chose HDF5, which offers a data model and software libraries for storing and managing data. HDF5 is designed for flexible and efficient I/O and for high volume and complex data. The usage of different computing environments for specific tasks is facilitated by the portability that comes with the format. Portability is also important for exploiting the rising potential within artificial intelligence (e.g. automatic scene detection and video annotation). Based on lessons learned from past field tests, we defined a general frame for the common data format that is aligned with the data processing steps of FESTA “V” evaluation methodology. The definitions include representation of the source signals and a hierarchical structure for including multiple datasets that are gradually supplemented (post-processed or annotated) during the various analysis steps. By using the HDF5 format, analysis partners have the freedom to exploit their familiar tools: MATLAB, Java, Python, R, etc. First comparisons between time-series data in previous projects (e.g. AdaptIVe) and the proposed data format show a reduction in storage size of around 80%, without losses in performance. Much of that is due to efficient internal compression and structuring of data. Considering the amount of objective data involved in automated driving, this leads to a great benefit, in terms of
usability. This paper presents a compact, portable, and extensible format aimed at handling extremely large amounts of field test data collected in automated driving pilots. As a harmonized format between tens of organizations performing tests in the L3Pilot project, the proposed format has the potential to promote data sharing as well as development of common tools and gain popularity for use in other projects. The format is designed to allow efficient storing of data and its iterative processing with analysis and evaluation tools. The format also considers the requirements of AI tools supporting neural network training and use.

**Paper No.19-0145-O**

**A Method to Compare the Safety of Autonomous Vehicles to Human-driven Non-Exempt Motor Vehicles in the United States**

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**Abstract**

The objective of this technical paper is to present a method that characterizes autonomous vehicle (AV) safety performance through the application of risk-based validation that leverages existing crash incidence and severity data, physics based model and simulation, and U.S. Federal Motor Vehicle Safety Standard (FMVSS) benchmark metrics. The output of the proposed risk-based methodology is a framework that organizes the number and type of physical tests and model/simulation runs necessary to provide meaningful evidence of AV safety performance statistically equivalent to human-driven non-exempt motor vehicles.

**Paper No.19-0091-O**

**Passenger car safety beyond ADAS: Defining remaining accident configurations as future priorities**

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**Abstract**

New vehicles are increasingly equipped with a variety of Advanced Driver Assistance Systems (ADASs). As these systems have the potential to prevent accidents, accidents of the future will differ from those of today. Predicting the type and characteristics of these future accidents is therefore essential to current research and development in the occupant restraint and new ADAS fields. In this study, accident avoidance of 15 ADASs was modelled using simple deterministic rules for each, creating both a conservative and an optimistic ruleset to account for current limitations and future possibilities. The rulesets were applied to the US National Automotive Sampling System Crashworthiness Data System data from 1995-2015 and verified through the literature. The residual passenger vehicle to passenger vehicle accidents were analysed, treating all accidents and accidents with at least moderate injuries in modern passenger vehicles (model year 2007 and later) separately. Many accidents were found to be avoided through such systems, and their combined effectiveness ranged from 51% to 97% depending on ruleset. Electronic Stability Control (ESC), Lane Keep Assist (LKA), and Crossing and Rear End Automated Emergency Braking (AEB) were highly effective, individually preventing over 25% of accidents in the optimistic calculation. Importantly, remaining accidents will have a different distribution across accident types compared to today: rear end collisions will reduce, leaving turning and crossing scenarios to dominate future accidents. For passenger vehicle to passenger vehicle accidents with at least moderate injuries in modern vehicles, four accident types alone were found to account for 93% of all remaining accidents in the optimistic estimate: Head On, Turn Across Path, Turn Into Path Opposite Direction and Straight Crossing Paths; the latter three are intersection-related and together represent three quarters of all remaining accidents. The intersection accidents are analysed further for deformation pattern, impact direction, 90% cumulative delta velocity and injured occupant position in order to identify possible new impact conditions to be used when evaluating occupant restraints. The well-established frontal and side impacts will still generate many AIS2+ injuries, while new more oblique impact conditions will also be needed to represent the variety of intersection accidents remaining. The description of future accidents and impact conditions
presented here can serve as a basis for the research and design of future ADASs and occupant restraints. We propose virtual assessment methods with Human Body Models (HBM) based on these impact conditions.

**Paper No.19-0113-O**

**Prospective Effectiveness Assessment of Road Vehicle Automation based on Driver Performance Models**

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Abstract  
One of the major challenges for enabling market introduction of automated driving is to identify risks and benefits of these functions. For this purpose, a new framework for assessing the safety impact of automated driving functions (ADFs) has been investigated. This framework is based on accident- and field operational test- (FOT-) data while using simulations for assessment of ADFs with respect to a certain baseline. According to the German Ethics Commission for Automated and Connected Driving, this baseline has to be human manual driver performance. For modelling of this baseline in simulations, so-called driver performance models are introduced in this publication and incorporated in an overall framework for effectiveness assessment. The main idea of the developed framework is that the types of driving scenarios, respectively physical accident constellations, do not change with automated driving. However, since ADFs are continuously controlling the behavior of the vehicle, it is possible that ADFs will get involved less frequently in accident scenarios playing a major role at human driving, e.g. rear-end accident scenarios. On the other hand, it is likely that other previously irrelevant accident types will rise. Consequently, the frequency of occurrence and the severity of the addressed driving scenarios may change with automated driving although the types of driving scenarios stay the same. To investigate the change of severity in a driving scenario, accident re-simulations are used. The changes in frequency of occurrence of driving scenarios are analyzed by using traffic simulations. In this work, so-called driver performance models are introduced for modelling human baseline in accident re-simulations. Key findings concerning the structure of these driver performance models are presented. The developed method and models are applied on two generic ADFs, a generic “Motorway-Chauffeur” (SAE level 3) and a generic “Urban Robot-Taxi” (SAE level 4). The results indicate that, e.g. a Motorway-Chauffeur at a market penetration of 50 % has a potential for reducing about 31 % of all accidents on German motorways resulting in personal injury. This equals 2 % of all accidents on German roads.

**Paper No.19-0108-O**  
**PEER REVIEW**

**Have we collected enough field data?**

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Research  
The amount of collected field data from naturalistic driving studies is quickly increasing. The data are used for, amongst others, developing automated driving technologies, such as crash avoidance systems, studying driver interaction with such technologies, and gaining insights into the variety of scenarios in real-world traffic. Since the collection of data is time consuming and requires high investments and resources, questions like “do we have enough data?”, “how much more information can we gain when obtaining more data?”, and “how far are we from obtaining completeness?” are highly relevant. In fact, deducing safety claims based on collected data, e.g., through testing scenarios based on collected data, requires knowledge about the degree of completeness of the data used. In this paper, we propose a method for quantifying the completeness of a dataset. This enables us to answer the aforementioned questions.
Methods
In this paper, the (traffic) data are interpreted as an endless sequence of different so-called scenarios that can be grouped into a finite set of scenario classes. For every scenario class there exists a parametrization that encodes all information in the data of each recorded scenario. For each scenario class, we estimate a probability density function (pdf) of the associated parameters. Our proposed method approximates the degree of completeness of a dataset using the estimated pdfs.

Results
To illustrate the proposed method, two different case studies are presented. First, a case study with an artificial dataset, of which the underlying pdfs are known, is carried out to illustrate that the proposed method correctly quantifies the completeness of the estimated pdfs. Next, a case study with real-world data is performed to quantify the degree of completeness of the acquired data for which the true pdfs are unknown.

Discussion
The proposed method quantifies the degree of completeness of an acquired dataset, but determining whether enough field data is collected also requires a well-chosen threshold. This threshold might differ from application to application and choosing the correct threshold is still an ongoing topic of research.

Conclusion
The presented case studies illustrate that the proposed method is able to quantify the degree of completeness of a small set of field data and can be used to deduce whether sufficient data have been collected for the purpose of the field study. Future work will focus on applying the proposed method to larger datasets. The proposed method will be used to evaluate the level of completeness of the data collection on Singaporean roads, aimed at defining relevant test cases for the autonomous vehicles’ road-approval procedure that is being developed in Singapore.
Written Presentations

Protection of Vulnerable Road Users

Chairperson: Yasuhiro Matsui, Japan; Rikard Fredriksson, Sweden

Paper No.19-0030-W

Analysis of Kinematics and Head Injury Mechanisms in Car to Child Cyclist Collision Simulation using Human FE model

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Abstract
According to the traffic accident data in Japan [1], the third largest number of fatalities is due to collision between car and cyclist. Head injuries are the most frequent cause of cyclist fatalities. Head injury risk depends on the stiffness of the head collision location of the vehicles. The collision location of a child’s head is different from that of an adult’s head in a traffic accident. Therefore, there is benefit of examining the injury mechanism of child cyclists for safety equipment. In this study, a total of 400 cases of car-to-cyclist collision were simulated by varying car speed, bicycle speed and initial position of collision using child and adult human Finite Element (FE) models and the head injury mechanisms were analyzed by investigating the kinematics and the kinetics of child and adult cyclists. The THUMS Version 4 Ten Years Old (10YO) model was used for the child cyclist and the THUMS Version 4 American Mail 50%tile (AM50) model for the adult cyclist. The bicycle FE model of a city cycle was established bicycle. The occurrence risk of skull fracture and Diffuse Axonal Injury (DAI) was investigated in 10YO and AM50 cyclists. In 10YO, approximately 90% of the head contact points were distributed on the car body and 10% was distributed on the ground. In AM50, the head contact points on the ground accounted for approximately 30%, 70% were distributed on the car body. It was found that the skull fracture and DAI occurrence were predicted in the 10YO when the head contacted the car hood in the car speed of 30 km/h or more. The impact velocity of the upper body was increased by contacting between the pelvis and the front edge of the car hood. As a result, head impact velocity and rotational velocity became high after the shoulder contacted the hood. In the AM50 whose pelvis rode on the hood, the upper body fell down toward the hood gradually. As a result, the skull fracture occurred when the head contacted the A-pillar in the car speed of 40 km/h or more, which was lower than that in the 10YO. In the case which bicyclists head contacted a ground after car collision, the skull fracture was predicted even in the car speed of 10km/h. The DAI occurrence was not predicted.

Paper No.19-0031-W

Prediction of pedestrian protection performance using machine learning

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Abstract
According to WHO’s report, there are over 270,000 people who are involved in traffic fatal accidents. This figure accounts for 22% of traffic fatalities in the world in 2013. To reduce those pedestrian accidents, many countries apply the pedestrian protection tests for the regulation and the third-party evaluation. For that reason, a method to design the pedestrian protection performance efficiently is required for many cars sold all over the world by automobile manufacturers. In recent years, there are some cases to assist or automate the development using the artificial intelligence acquired by the machine learning. The authors investigated whether it is possible to predict pedestrian head protection performance without using tests or CAE (Computer Aided Engineering) in this research. The authors used the
bonnet hood structures compatible with pedestrian protection and head injury value obtained from CAE for the training data. As for the hood structure, the data obtained by converting 3D geometry into a 2D image was used as the input data. Head injury value was examined by both classification and regression as output information. For the learning model, LeNet-5 of CNN (Convolutional Neural Network) was used, and the layer structure of the model was modified to be suitable for learning of pedestrian protection. Using the learned model and validated it with some unknown hood images, the model predicted the pedestrian NCAP (New Car Assessment Program) score with an error less than 5% compared with CAE results. Also the predicted head injury criteria map agreed with accuracy more than 75%. In addition, LeNet-5 showed shorter computation time and higher accuracy when comparing the other algorithms.

Although the model was able to reasonably predict the head injury value in the center area of hood, the accuracy of the perimeter area tended to be lower. Since the data around the perimeter area used for learning was small amount, it is considered that the accuracy is low. In future study, it is necessary to add such data or to device a method to improve accuracy even with the small amount of data.

**Paper No.19-0055-W**

**Responses of a 6-Year-Old ATD Restrained in a Booster Child Seat on the FMVSS 213 Test Bench, Proposed Upgraded Test Bench and a Vehicle Seat in Simulated Frontal Impacts**

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**Abstract**

The National Highway Traffic Safety Administration (NHTSA) is considering upgrades to the FMVSS No. 213 standard seat assembly and test parameters that better represent current vehicle conditions. A preliminary prototype for the test bench was released with upgraded seat cushion stiffness, geometry, seatbelt assembly, and anchorage locations. The objective of this study was to compare the responses of the Q6 ATD (Humanetics Inc., MI) restrained in booster child seats (CRS) on the current and proposed upgrade of the FMVSS 213 test bench, and a vehicle seat in frontal impacts. Three child seating conditions were evaluated: no-CRS, lowback booster (LBB), and a highback booster (HBB) installed on validated finite element (FE) models of the current FMVSS 213 bench, upgraded bench, and a 2012 Toyota Camry vehicle seat. Simulations (N=9) were carried out using LS-DYNA ver.971 (LSTC, CA) on a 16-node double precision cluster. Kinematics and kinetic data were extracted and processed as per SAEJ211 metrics. Head resultant accelerations (Hr) across conditions were comparable, however, for LBB the current bench over predicted Hr by 26G (72.1G) as compared to the upgraded bench (46.1G). For HBB, there was a difference of 13.5G in Hr between the 213 bench (72.9G) and vehicle seat (56.3G) with upgraded bench showing lower values.

HIC36 values for the no-CRS and HBB conditions were lower by 53.4 and 115.4 respectively for the 213 bench (258.7); HBB (443.2) compared to the upgraded bench (no-CRS (312.1); HBB (558.6)). Similarly, these values were lower for no-CRS and HBB conditions by 74.3 and 163.6 respectively for the vehicle seat (no-CRS (237.8); HBB (395.0)) compared to the upgraded bench. Chest displacements were higher on the 213 bench (16.6mm) compared to the upgraded bench (12.3mm) and vehicle seat (18.3mm). Neck Forces (Fz) were higher for the LBB on the current bench (2637.3N) than on the upgraded bench (1982.3N). All injury and excursion values were within IARV limits for all simulations. However, CRSs installed on the 213 bench have larger rotations (sagittal plane) [LBB (-10.2º); HBB (-12.9º)] as compared to the upgraded bench [LBB (1.5º); HBB (-3.6º)] and the vehicle seat [LBB (4.8º); HBB (-3.6º)]. The child seats on the 213 bench, first compress the foam and then rotate over the edge of the foam [Foam thickness (Ft) = 6 inches (4+2)] due to its inherent overhang from the edge of the base structure causing higher rotations as compared to the upgraded bench (Ft= 4 inches) or the vehicle seat, which are similar in construction. Overall, the responses of the upgraded bench matched the vehicle seat more closely than the current bench and is a step towards emulating a real vehicle seat environment.
**Investigation of Strain-induced Brain Injury Mechanism in Simulated Car Accidents**

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**Abstract**

Further reduction of brain injuries is crucial to diminish traffic fatalities. Past studies suggest that strain of incompressible brain tissue is generated mainly due to head rotation. Accident statistics show a higher rate of pedestrian fatalities resulting from strain-induced brain injuries in accidents with AIS 2+ brain injuries than that of car occupants. One factor for this difference would be larger translation and rotation of an unrestrained pedestrian body than those of a restrained car occupant. This study aimed to clarify the influence of whole body kinematics on the brain strain in pedestrians and occupants. Time histories of the head translational and rotational accelerations were taken from the NHTSA crash test database for full frontal and MDB side impacts. Pedestrian crash simulations were conducted for frontal and side impacts using a human, small-sedan and SUV FE models to obtain head acceleration time histories. These time histories were applied to the skull of the GHBMC head/brain model. The time histories of the maximum principal strain from the GHBMC model were compared between occupants and pedestrians in the same impact direction. The body kinematics and the rotational velocity of the head were also compared to identify factors for the difference in the time history patterns of the maximum principal strain. In addition, these time histories were compared to that of the CIBIC (Convolution of Impulse response for Brain Injury Criterion) criterion developed in a previous study under each of the four conditions. Peaks of brain strain were identified in both head pre-impact and impact phase for pedestrian while that was identified only in head impact phase for occupant, regardless of the impact direction. The flip of the rotational direction of the head in the head pre-impact phase was found only in pedestrian, likely resulting in the peak of brain strain prior to the head impact. This trend applied regardless of the direction of impact. The time history of the CIBIC criterion provided waveform patterns similar to the maximum principal strain time history in all impact conditions. Peaks of brain strain in both head pre-impact and impact phase in pedestrian identified in this study would require reduction of peaks in both phases. A criterion predicting time history of brain strain, such as CIBIC, was found to be an effective tool to address reduction of peaks in multiple phases seen in pedestrian. These findings would lead to novel pedestrian safety technologies that control pedestrian kinematics to reduce the primary peak.

**Heavy truck crashes involving pedestrians in comparison to bicyclists**

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**Abstract**

Although crashes with vulnerable road users account for a small proportion of all heavy truck accidents they cause particularly severe injuries. In Germany, collisions with bicyclists and pedestrians accounted for only 9% and 4%, respectively, of all injury crashes between a truck over 12,000 kg gross vehicle weight and another road user in 2015. However, vulnerable road users represented 26% of fatalities in these kinds of crashes. While collisions between trucks and bicyclists, particularly in right-turn situations, have recently gained attention in Europe, little research has been dedicated to crashes involving pedestrians. This study describes the circumstances and injury outcomes of severe crashes between heavy trucks and pedestrians in comparison to those involving bicyclists. The German Insurers Accident Database (UDB) provided data on accidents involving heavy trucks, defined as goods vehicles over 11,900 kg GVW: 39 crashes with 43 pedestrians, altogether, and 62 crashes with one bicyclist, each. The majority of crashes occurred in built-up areas and during daylight, both for pedestrians and bicyclists. While most accidents involving pedestrians took place on a stretch of road (49%) the majority of accidents involving bicyclists occurred at junctions (77%). Females accounted for 58%, each, of the casualties among both groups of VRU’s. Pedestrians averaged 57.8 years of age (median: 61 yrs.), and were approximately six years older than bicyclists with an average of 51.6 years (median: 52.5 yrs.). The collision situations for pedestrians and for bicyclist differed considerably. The truck was going straight in the large majority of cases where a
pedestrian was struck. Often, the truck was initially stationary and then moved off and collided with the person walking or standing near the vehicle. Crashes between a heavy truck and a bicyclist, on the other hand, were clearly dominated by turning manoeuvres, mostly when the truck made a right-turn at a junction and hit a bicyclist who was travelling alongside on the right of the truck and intending to go straight. 40% of pedestrians were run over, five of them with fatal consequences. Bicyclists were run over in 52% of cases, resulting in nine fatalities. Despite different collision scenarios among pedestrians and bicyclists in crashes with trucks, their injury patterns and severities were very similar. MAIS3+ cases accounted for approximately two thirds among all casualties in both groups. The highest proportion of AIS3+ injuries for pedestrians was found in the thorax region (31%) and for bicyclists in the lower extremities region (40%). The present work confirms previous studies related to accidents between trucks and vulnerable road users that noted the prevalence of older persons among the VRU’s. It adds to the body of research by providing detail data on the different collision scenarios typical of truck accidents with pedestrians and with bicyclists and their injury patterns. Truck driver assistance systems hold a large potential to avoid or mitigate crashes with both VRU groups. While monitoring the right side of the vehicle is necessary to avoid crashes with bicyclists, pedestrian detection needs to focus on the area in front of the truck.

**Paper No.19-0114-W**

**Passive safety improvements in child restraint systems placed in rear seats of vehicles by introducing a new ISOFIX accessory**

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**Abstract**

In a 3-abreast seating configuration whenever there is a child restraint system (CRS) present, and especially if it is an ISOFIX one, occupants of the central position miss the room needed in order to rest their back properly against the backrest making them prone to suffer serious whiplash injuries in frontal or rear crashes or to collide with the adjacent passengers in lateral crashes. This lack of space jeopardizes the safety of all occupants as the restraint systems cannot work properly if the passengers are not correctly seated; more so, it affects further the safety of children making safety belt fastening difficult and uncomfortable and causing their CRS to be removed prematurely from the car to give room for that third occupant. Most of those problems can be tackled by introducing an accessory to be inserted between the vehicle ISOFIX anchorages and the CRS ISOFIX connectors, which allows to move laterally the CRS, while keeping that ISOFIX connection, from the CRS nominal position to an extreme position where the CRS is shifted aside resting against the door panel, or at least coming quite close to it. Due to limited resources, full capacity tests have not been possible running 3-abreast configurations. To assess technical feasibility and performance the device was submitted to the tests specified in the ECE R129 standard, comparing sled tests carried out with the CRS alone (baseline reference case) with those same CRS coupled with the accessory device, moving their nominal position 70 mm towards the door panel to establish potential safety improvements. CRS selection was based on their popularity within the Spanish market, and the tests were performed using both Q6 and Q10 dummies for each combination. The analysis of the results of the dynamic tests carried out showed improvements in the level of side impact protection. For instance, the average HPC15 (Head Performance Criterion), directly related with the expected level of damage in the event of an impact, measured for the Q6 dummy was 232.76, while the average HPC15 with the same seats moved closer towards the door panel was 225.08, a 3.3% improvement in average with improvements for one of the CRS of up to 22.5%. For the Q10 dummy the results were similar with an average HPC15 of 103.75 for the stand-alone CRS and an average HPC15 of 99.23 for the CRS coupled with the accessory device, a 4.4% improvement in this case. In every test performed the resulting values remained below the limits designated in ECE R129 for the injury assessment criteria. The introduction of this new device could lead to important benefits on the safety of families, and children in particular, by providing an effective use of the central seat by any passenger or additional CRS, while retaining the ISOFIX connection for a CRS placed in a lateral seat. Specifically, side protection could be significantly improved preventing undesired yaw rotations, and the optimized space usage will allow extending the CRS usage period avoiding their premature removal due to the lack of space.
**Paper No.19-0205-W**

**New safety standards for motorised mobility devices in Australia**

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Abstract  
A motorised mobility device (MMD) is primarily intended as assistive technology for people with limited mobility. MMDs include powered wheelchairs and mobility scooters. In recent years concerns have been raised about the number of fatal and serious incidents with these devices in Australia. These incidents are not reliably recorded in crash reporting systems but special studies indicated that several hundred Australians are hospitalised each year due to incidents involving MMDs. A review using the safe-systems approach resulted in recommended minimum safety requirements for the design of MMDs intended to be used on footpaths/sidewalks and other public infrastructure. In 2018 Standards Australia published a new Technical Specification settings out these requirements. This paper provides background on the development of these requirements.

**Paper No.19-0217-W**

**Advanced Rear Seat Sensing – Further improving occupant safety, using RF technology.**

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Abstract  
Building on previously developed VitaSense technology, IEE has developed a single sensor, which is integrated behind the headliner of the vehicle, and can serve multiple detection purposes. The new low-power 79 GHz RF sensing unit is used as Occupant Detection Sensor (ODS) while driving, and makes this information available to the vehicle, as input for advanced seat belt reminder (SBR) systems. After the drive, the sensor keeps operating, and can thus detect left-behind occupants, including sleeping new-born children. The standalone sensor is hence capable to address two different functionalities playing a role in the Euro NCAP star rating. Advanced rear seat SBR is incentivised since 2018, and "Child Presence Detection" will become part of the rating scheme in 2022. As "VitaSense+ODS", the sensor addresses two rear seat safety issues: a) seat belt usage in the rear seats tends to be at least 10-15% lower than in the front seats, in some regions of the world even significantly worse; b) in-vehicle heatstroke of unattended infants and children in cars, which in 2018 reached a new record in the US with 51 resulting fatalities. Based on the driving tests performed, and static child detection tests, the 79 GHz RF sensing method has been found to be robust. It is important to note that the system presented serves as a reminder, which does not ensure the prevention of rear occupant injury or heatstroke fatalities per se.

**Paper No.19-0228-W**

**Development of an FE model for FlexPLI with Upper Body Mass for enhanced pedestrian safety assessment**

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Abstract  
The FlexPLI GTR tool has been implemented with an Upper Body Mass (UBM) representing portion of the torso mass, hip joint rotation and the response time lag between leg and the upper body during pedestrian to vehicle accidents. The new FlexPLI GTR UBM tool improves the test method at the end of the bumper test area of vehicle by eliminating unrealistic rotation of the FlexPLI GTR without UBM, bringing it closer to human lower extremity kinematics and loading. The tool is an enhancement to the current dummy technology by improving the pedestrian safety. The key benefit is that the UBM can be added to the existing standard FlexPLI GTR hardware being used in the current test procedures. The FlexPLI GTR UBM finite element (FE) model is developed and validated against a selected test condition. The geometry and
connectivity for the FlexPLI GTR UBM FE model are obtained from the hardware design. Material testing was carried out to obtain the material properties and implementation to the FE model for the rubber element representing the hip joint stiffness during rotation of upper body mass. The initial findings of the FlexPLI GTR UBM FE model reveal that the model showed promising predictability for the simulated load-case.

**Paper No.19-0253-W**

**Objectifying and Predicting Motorcycle Accident Risk through Riding Dynamics**

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**Abstract**
The danger of motorcycle accidents is ubiquitous during the otherwise relaxing and enjoyable activity of riding a motorcycle. The consequences can be severe and the economic burden, both on the individual and the state, is high. Yet, when wanting to prevent such accidents, it can be seen that they are hard to predict, due to the high complexity of individual factors playing a role in each single accident. To tackle this issue and extract generalizable characteristics of driving dynamics, the authors present the findings of “viaMotorrad”, a project to obtain motorcycle dynamics data on selected roads in Austria and determine the risk of an accident at given road sections. This is a collaborative project by the Austrian Road Safety Fund, between the partners Austrian Institute of Technology, TU Wien and KTM. Through the use of supervised machine learning techniques we demonstrate that there are indeed generalizable factors in the driving dynamics at previous accident sites and use these factors to determine further critical road sections. These results are a first step towards an objectification of motorcycle driving risk and semiautomated risk assessment of roads for motorcycle riders. The method offers the possibility of identifying critical road sections through analysis of a small number of test drives.

**Paper No.19-0254-W**

**GVTR: A Generic Vehicle Test Rig representative of the contemporary European vehicle fleet**

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**Abstract**
In the ACEA funded project ProPose a generic vehicle model was developed: (1) It was specifically developed for replicating the leg-loads in pedestrian accidents. (2) It is representative of the contemporary European sedans meeting FlexPLI requirements. (3) It is available in numerical and experimental environment. (4) It is intended for investigating the performance of aPLI, for validating numerical models of advanced legform impactors like aPLI and for the comparison of kinematics and responses of different HBM lower limbs. The structural impact response of vehicle front ends was captured with impactors: A rigid cylinder was equipped with 20 contact force transducers along its axis. The impactor’s motion was prescribed, such that an intrusion of (up to) 120mm was consistently achieved. Tests were conducted at four levels along the vehicle height (spoiler through bonnet leading edge) and at six positions along the lateral axis of the
vehicle. The contact forces of individual force transducers were assigned to the four contact regions (spoiler, bumper, grill and bonnet leading edge). Impactor tests were conducted against nine sedans, eight SUVs and three sportscars. For each vehicle category median force-penetration characteristics were established. The geometry of the CoHerent models was adopted (and cross-checked against the median reference lines established in the study ProPose). In the numerical environment the GVTR was tested in impacts with full human body models, an isolated leg with an upper body mass and a beta-release of aPLI. In the experimental environment the GVTR was tested with aPLI and FlexPLI. Body loads in GVTR-vs-HBM and a selected vehicle-vs-HBM match very well. The same applies when comparing full HBM and isolated leg loads. The study included vehicles provided by German, Czech and French manufacturers. The GVTR’s structure and geometry is very simplistic for the sake of repeatability, robustness, testing costs and avoidance of error sources in the numerical model of GVTR.

**Paper No.19-0334-W**

Are Wisconsin Pedestrian Crashes Representative of National Trends?

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**Abstract**

Introduction: The question: “Are Wisconsin Pedestrian Crashes Representative of National Trends?” was asked in the context of how to estimate the denominator of pedestrians using public traffic-ways. Data from the Federal Highway Administration, the National Highway Traffic Safety Administration, the United States Census Bureau, the Wisconsin Department of Transportation and other organizations was used to try and answer it. Method: Comparisons between national and state level data were made relative to: The number of miles of urban and rural roads in Wisconsin relative to the number of miles nationally, the trends in the frequency of fatal pedestrian crashes, the proportion of these crashes in rural and urban areas and factors that may contribute to them. Demographics at the county level were reviewed to assess which counties may be representative of the state. Results: In all categories of rural roadway classification, Wisconsin is within one standard deviation of the national mean and median. The median number of miles of the total miles of rural roadways nationally is 64,672 miles. In most categories of urban roadway classification, Wisconsin is within one standard deviation of the mean and median for the nation. The median number of miles of the total miles of urban roadways nationally is 17,568 miles. With 23,578 total miles of urban roadways, it is closest to the national average of the total number of miles urban roadways 23,530. NHTSA analysis of 2015 pedestrian crash data reported 26% of pedestrian fatalities occurred from 6 to 8:59 p.m. In Wisconsin data from 2011 to 2013, 23% of fatal pedestrian crashes occurred 6 to 8:59 p.m. NHTSA reported the split between fatal urban and fatal rural crashes as: 76% in urban areas and 24% in rural areas. In Wisconsin, the split was 64% urban and 36% rural. Per NHTSA data, 19% of fatally injured pedestrians were 55-years-old or older. A query for fatal pedestrian crashes in Wisconsin for 2017 found that the average pedestrian age was 54 and 43.6% of fatally injured pedestrians were 55-years-old or older. Discussion: U.S. Department of Transportation data collection programs are amenable to using state government documents, which can be transcribed to compile national level data sets. State level traffic crash data can be disaggregated to the county or municipal levels. Both data sets can be linked to U.S. Census Bureau data for each county, down to the level of the census tract, to characterize the relationship of vulnerable populations such as children and older adults and to features in the environment affecting mobility. Conclusion: What is lacking are actual counts of pedestrians at a weighted sample of locations to base a statistical inference of the denominator of pedestrian using trafficways on. With the appropriate statistical technique and accurate counts, a nationally representative estimate of vulnerable road users is possible. In-depth local studies involving agreements with law enforcement and county road department would be advantageous.
Safety Performance in Frontal and Rear Crashes

Chairperson: Younghan Youn, Korea, Republic of; Stephen (Steve) Summers, United States

Paper No.19-0051-W

Development of Adaptive Supplemental Restraint System (ASRS).

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Abstract
The article relates to methods of mitigating results of improper value of force applied to the occupant’s body at a time of an imminent front vehicle collision and preventing fatalities as well as injuries. The article relates to a new method of accurately weighing vehicle occupants that improves their safety in the event of a collision. The statistics show that the number of victims is indirectly proportional to their weight. It means that to significantly improve safety of the vehicle occupants, it is necessary to put stress on controlling the forces applied to the occupants’ bodies by more accurately measuring their weights. It is noted in [1] that the weight of an occupant measured by an air bag system is not the entire weight of the occupant since some of the occupant's weight will be supported by feet which are resting on the floor or pedals. As result, there is overlapping of weight classes in the Passenger Classification System that creates malfunction of the air bag and decreases the number of properly working weight classes to 3 instead of 5. This is a problem that does not allow to accurately weigh a vehicle occupant in a supplemental restraint system to provide the possibility of an accurate control of the air bag inflation force depending on the real value of the occupant’s weight (mass) and eliminate extra force applied to the occupant’s body at the time of collision. NHTSA, Department of Transportation, published in August 2004 requirements of the final rule of Section §571.208 Standard No. 208; "Occupant crash protection" [2] to improve the security of the air bags for children and light women. An object of the article is to find ways to improve the accuracy of the safety system for differentiating the weight of older children from the weight of the light women passengers and support the documents provided by NHTSA that say the modern safety systems should provide improved protection for occupants of different sizes. The method described in the present article provides the possibility to extend the current Passenger Classification System by accurately measuring occupant's weight and more accurately controlling the force applied to lighter weighing people and youngsters in case of accident. The article provides a method of accurately weighing occupants of different weights by employing an ADaptive MUlti-force Safety (ADMUS) system that improves the Passenger Classification System for minimizing the risk of injury or death from a possible improper extra force applied to them by air bags in case of accident especially for light adults in contemporary and self-driving or autonomous vehicles. The ADMUS system, with its accurate innovative occupant weight measuring KEF method [3, 4], provides higher protection to occupant bodies of different weights by keeping an extra force from them in case of accident. The weighing error of a vehicle occupant weight measuring drastically decreased in applications [5, 6] by employing the occupant weighing innovative KEF method and using this weighing method and technology based on it to eliminate the weighing error.

Paper No.19-0094-W

Driver airbag design to mitigate neck and chest injuries for US-NCAP and optimization methods with a dynamic meta model

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Abstract
The frontal airbag in a vehicle is considered supplemental to the safety belt restraint system and is important in lowering measured injury assessment values for Anthropomorphic Test Devices (ATD) during vehicle crash testing. The probability of neck and chest injuries is an important factor for a vehicle’s performance rating under the United States-New Car Assessment Program (US-NCAP) protocol. A shorter lower tether was incorporated into the driver frontal airbag (DAB) to mitigate chest deformation injury, however higher neck injuries were observed with this change. The purpose of this study is to identify the main factors influencing neck injury assessment values through the use of Design Of Experiments (DOE) techniques and find an optimum airbag design which mitigates neck and chest injury assessment values by using optimization techniques. Four different airbag designs were used in the first stage of the DOE, and one DAB design was chosen for the best performance in US-NCAP. Traditional meta model based optimization of the chosen DAB design
followed. The direct optimization method requires a great deal of computational resource, whereas meta model based optimization methods use comparatively little computational resource once there are sufficient sample data from the DOE. Dynamic meta model based optimization methods were introduced with combined CAE runs to reduce computing resource in this study. CAE runs were periodically sampled to update the meta model and provide improved accuracy. Two different optimization methods with dynamic meta models were demonstrated and compared with traditional meta model based optimization.

**Paper No.19-0133-W**

**Interior and Restraint Systems Modeling for Oblique Offset Frontal Impact**

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**Abstract**

National Highway Transport Safety Administration (NHTSA) has been investigating oblique offset frontal impact test conditions. This research developed a validated occupant interior and restraint systems that could be used to evaluate the kinematics and injury implications for frontal crash test conditions. The objective was to develop validated oblique offset crash simulations using both Test device for Human Occupant Restraint (THOR) dummy model and human body models. The vehicle selected for this Computer Aided Engineering (CAE) study was a 2014 Honda Accord. The vehicle interior was scanned and modeled and restraint characterization tests were conducted. The occupant interior finite element (FE) model was developed and validated against available test data. FE models for THOR dummies were seated in driver and passenger seats and validated against both left and right oblique offset test results. Subsequently, the 50th percentile FE Human body model from Global Human Body Models Consortium (GHBMC) was seated in the vehicle and the kinematics was compared against the THOR dummy model. The outcome of this study was to develop realistic FE models that could be used to investigate how crash test conditions can affect optimal occupant restraint system design. The results predicted from the CAE simulations of the baseline vehicle model demonstrated similar safety performance to the available vehicle test results in terms of vehicle acceleration and intrusion responses in NCAP frontal, IIHS moderate overlap, IIHS small overlap test procedures, and left and right NHTSA oblique frontal tests. The CAE simulation results compared well with test results for THOR dummy model accelerations and injury criteria. A comparison of occupant kinematics, belt loads and injury criteria against the simulations using the GHBMC model also was done. The CAE simulation results using the GHBMC also compared well with test and CAE results of using THOR dummy model.
Evaluation of Autonomous Emergency Braking in Preventing Front-To-Rear Crashes among Three Toyota Models

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Abstract
This study estimated the effectiveness of Toyota Safety Sense (TSS) in helping prevent front-to-rear collisions among three Toyota models (Avalon, Prius, RAV4). TSS, offered as an option in model year 2016 vehicles, includes a pre-collision warning system with automatic emergency braking (AEB), in addition to lane departure alert and automatic high beam. This study addresses the hypothesis that TSS-equipped vehicles will be less likely to experience a front-to-rear crash (as the striking vehicle) compared to those not equipped with TSS. Using Toyota-supplied production data linked to police reported crash data from 5 US states (Florida, Louisiana, Michigan, Pennsylvania, Texas) for crash years 2014-2016, the study compared crash rates (crashes per 10,000 vehicle months) of TSS equipped (n= 23,394) versus non-equipped (n= 294,931) vehicles. TSS equipment present per vehicle was identified based on VIN. This study evaluated the impact on front-to-rear crashes where the Toyota was the striking vehicle. Exposure, using vehicle-months, was computed based on aggregate vehicle sales in the five study states for TSS equipped and non-equipped model year 2014 to 2016 vehicles. The crude rate ratio (CRR) of front-to-rear crash rates where the Toyota was the striking vehicle was calculated as the front-to-rear crash rate for TSS-equipped vehicles divided by the crash rate for non-equipped vehicles. Given that TSS is optional, it is possible that customers who choose to purchase these safety systems also exhibit different driving and risk-taking behaviors compared to those who do not purchase the safety systems. To address a possible selection bias, sensitivity analysis examined the control outcome of front-end damage in a multi-vehicle crash, excluding the types of crashes targeted by AEB (front-to-rear). Of the TSS-equipped vehicles, 2.46 per 10,000 vehicle-months (95%CI: 1.75-3.17 per 10,000 vehicle-months) experienced a front-to-rear crash as the striking vehicle, compared to 4.55 per 10,000 vehicle-months (95%CI: 4.37-4.73 per 10,000 vehicle-months) of the non-equipped vehicles. Therefore, study Toyotas equipped with TSS were 46% less likely to experience a front-to-rear crash as the striking vehicle compared to non-equipped (CRR=0.54; 95%CI:0.40-0.67). The study found that when the outcome was broadened to include all vehicles with front-end damage in multi-vehicle crashes, TSS-equipped vehicles experienced 17% fewer crashes than non-equipped vehicles (CRR=0.83; 95%CI:0.71-0.94). However, no significant difference was observed if front-to-rear crashes were excluded (CRR=1.02; 95%CI:0.86-1.16) suggesting that selection bias did not play a significant role in this study. The TSS option was only available in model year 2016 vehicles, limiting the sample size and follow-up time of TSS-equipped vehicles. Future research that includes additional state data, models and model years, will increase sample sizes and may allow for estimates by model and other crash types. In conclusion, vehicles equipped with TSS, were nearly half as likely to be the striking vehicle in a front-to-rear crash compared to non-equipped vehicles. This study contributes to the growing evidence of the effectiveness of AEB in helping prevent a significant number of front-to-rear crashes.
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Abstract
Advanced safety technologies such as automated emergency braking (AEB) systems are key technologies for helping to reduce traffic accidents. This study quantifies crossing scenario accident types by analyzing traffic accident databases from various countries. It then calculates the delta-V reduction collision velocity obtained by a proposed crossing scenario AEB system, and estimates the benefit of the proposed crossing scenario AEB system.
Biomechanics: Advances in Crash Test Dummies, Instrumentation, and Data Analysis

Chairperson: Kevin Moorhouse, United States; Philippe Vezin, France

Paper No. 19-0064-W

Hertz Contact Model to Estimate Paediatric Head Impact Response Variables

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Abstract
This paper describes a study to develop and validate methodology for simulating human infant head impact using the Hertz contact model. The study had two objectives. The first was to simulate Aprica 2.4 dummy head - rigid plate impact using the Hertz contact model to estimate head response variables. Model estimates were then compared with corresponding test variables. The second objective based on success of the first, was to evaluate the feasibility of using Hertz contact model to simulate human pediatric head – rigid plate impact at contact velocities ranging from 1.7 m/s to 6.26 m/s. During objective 1 of this study, known geometric and material properties of the Aprica dummy head and steel plate were used as the Hertz model parameters. Model estimates of peak acceleration, peak head compression, pulse width, and time to peak displacement were compared with corresponding test data for contact velocity of 2.3 m/s. Percentage differences in response variables were: peak acceleration – 2.5; peak head compression – 1.3; pulse width – 6.1; and time to peak compression - 2.2. During objective 2 of this study, human head impacts were divided into 4 age groups – neonate (under 1-month), 5-months, 9-months and 11-months. Objective 2 was divided into 2 stages – Model building and Model validation. In the Model Building stage, a method was developed to estimate Hertz contact model parameters using human 30 cm drop test data. In the Model Validation stage, the model was used to estimate head response variables for 15 cm, 30 cm and 2 m drops for all four age groups and compared with human test data. Model estimates for peak head acceleration of neonates in 15 cm and 30 cm drop tests differed from average test peak head acceleration by 11%, and 13% respectively. Neonate estimated pulse widths for the same drop heights differed from test average by 0% and 1%. Maximum and minimum differences for 5-, 9-, and 11-month infant model estimates from average test values in 15 cm and 30 cm drops were: 13.47% and 0.44% for peak acceleration and 6.68% and 0.03% for pulse width. Simulation results of 2 m drops of 5-month, 9-month, and 11-month old heads indicated that estimated head Jerk (rate of change of acceleration) was very close to human test results. Since the pediatric heads sustained fractures, it was not possible to compare peak accelerations. The model reproduced, very closely, the static force-deformation curve for 5-month old but provided poor estimates for some neonates. Model reproduced finite element model results for 30 cm drop test for 5-month old head on to concrete and hard foam. The proposed model and methodology provide a simple procedure to estimate pediatric head acceleration, head deformation and pulse width for contact velocities ranging from quasi-static to 6.3 m/s onto rigid and soft surfaces.
A STUDY OF AGE DETECTION SYSTEM FOR APPLICATION TO ELDERLY OCCUPANT PROTECTION

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Abstract
Recently, the number of injuries and fatalities in traffic accidents tend to decline. However, the proportion of elderly citizens involved in traffic accidents is tending to increase in Japan and other developed countries. The elderly is known to be less resistant to impacts than younger people due to the deterioration of physical structures, such as bones and muscles. In order to improve safety performance for elderly vehicle occupants, it is necessary to know the age of the drivers in advance. However, actual age of drivers does not always correspond to the representative age because the level of resistance of the elderly has large differences in individuals. It would be necessary to detect not only the driver’s age, but also the aging level of the individual differences. In addition, in order to take convenience for the drivers into consideration, it would be necessary to use simply. Therefore, this research focused on the age of the blood vessels which can be measured easily. The age of the blood vessels expresses the aging level of physical composition, such as the blood vessels and muscle fibers. It is calculated from the acceleration pulse wave of the blood flow. The characteristic points observed in the acceleration pulse wave are classified according to the age. Usually, the blood vessel age is measured by a contact-type photoelectric sensor. This research developed a noncontact measuring method based on an RGB camera. Evaluate accuracy of the blood vessel age with proposed method, moreover examined applicability of the method to onboard use. In order to verify that the camera device developed in this research, measurements of proposal method were compared with that used the conventional method. The evaluation test was held on in indoor. The test subjects were thirty men aged from 20s to 60s. Proposal method is achieved that accuracy is comparable to that of the conventional method. It should be considered that the proposed method will apply for a variety of adverse conditions when fitted in a vehicle. For example, use at night, use under backlight conditions, intrusion of the driver’s arm operating the steering wheel and movement of the captured area due to vibration. It must be necessary for the method to perform detecting the age of the blood vessels accurately even under these conditions. This paper has discussed about a noncontact method of detecting a driver’s age, focusing on the age of the blood vessels, with the aim of improving safety of the occupant protection system. The experimental testing was verified as the basic concept of a noncontact blood vessel age detection system based on camera images. In order to proceed with research for fitting actual vehicle, it will be necessary to research not only improving system accuracy but also improving its robustness under onboard conditions.
Adapting Safety Evaluation Approaches for Vehicles with Automated Driving Systems

Chairperson: Jim Hand, United Kingdom; Nicole van Nes, Netherlands

**Paper No.19-0175-W**

Estimating Preliminary Occupant Injury Risk Distributions for Highly Automated Vehicles with Respect to Future Seat Configurations and Load Directions

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Abstract

While highly automated vehicles (HAVs) will be able to reduce the number of accidents significantly by removing human error, some accidents may remain unavoidable – particularly during the transition period. HAVs also promise increased freedom in seat positioning for all passengers, including the driver. A growing amount of literature deals with individual issues of occupant safety in these new positions, but there is currently no comprehensive overview on the effects of combinations of possible future seat positions and vehicle load directions. Addressing this, the aim of this research is to develop a method to quickly highlight key combinations of seat position/inclination and crash load direction with respect to occupant safety for any given interior layout and set of restraint systems.

Also, the method should facilitate the evaluation of restraint systems’ active principles. Inspired by common safety engineering methods, the proposed approach defines risk as combination of severity, exposure and controllability. To estimate the severity, each restraint system’s ability to restrain the occupant – referred to as restraining potential – is defined as mathematical function of relevant parameters, e.g. various seat adjustments and as function of the load direction relative to the occupant. These individual restraining potential functions which can be plotted as 2D-graphs, can then be combined into a total restraining potential for any specific combination of parameters (seat, load direction...). The required interpolation points for these functions are estimated theoretically and checked for plausibility based on finite element (FE) simulations with a human body model (HBM) and compared to literature.

Additionally, the space available for occupant displacement (and thus available for dissipation of kinetic energy) is considered and combined with the restraining potential to a measure which is inversely proportional to the severity. The exposure is estimated with a distribution of the main accident types (front/side/rear). While the relevant future distribution is not yet known, estimates from recent literature or current accident data can be used as starting points. With a modular approach, effects of different distributions can easily be analysed by changing this input. Controllability (with respect to the risk definition) is not taken into account in this first implementation, since the approach only considers scenarios where crashes occur and all systems are expected to work faultlessly. Based on the calculated severity and exposure the occupant injury risk is automatically computed for a specific interior and then plotted for all reasonable combinations of seat adjustments. This enables an immediate overview for finding key combinations which should be the focus of in-depth analyses, e.g. detailed FE simulations. The proposed approach should not be seen as a replacement for detailed FEA but as a useful supplement for time and resource efficient preparation of simulation studies concerning the occupant safety of future HAVs. Estimating preliminary occupant injury risks for future HAVs provides an insight to their expected performance which highlights key parameter combinations and can aid the development of relevant regulations and test procedures.
Automated and Integrated Crash Safety

Chairperson: Marcus Wisch, Germany; Jac Wismans, Netherlands

Paper No. 19-0178-W

50 years of Mercedes-Benz Accident Research - ready for the next level

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Abstract

Mercedes-Benz accident research has been working on product safety for 50 years. The idea to own an accident research investigation center was conceived due to the fact that in 1960s the number of accidents were increasing. The focus was on self-investigated accidents and affiliated data. In 1969, the Ministry of the Interior provided the mandate for the legitimacy of such accident investigation. Under this mandate, in certain circumstances, the authorized police officials were entitled to report serious accidents involving current Mercedes-Benz vehicles to the accident research center and provide collected data. One of the first investigated vehicles was a W113, so called Pagode. Required investigation methods were developed immediately. The goal of in-depth investigation was to identify the contributing factors for accidents and injuries and derive possible requirements for research and development. Until 2018, more than 5000 accidents were investigated and reconstructed. Today, some of the major tasks of the accident research are accident-data analyses and the benefit estimation for future safety systems and innovations. Accident investigation and reconstruction has changed significantly during the years. Measuring lanes and traces with a tape measure, like it was done in the past, isn’t possible anymore due to more traffic on the roads. A modern 3D-laser scanner is being used for this purpose today. Not only investigating the accident scene has changed, the vehicles themselves have changed significantly. Today, accident research aims at assessing the impact of modern advanced driver assistance systems along with investigating the crash worthiness. Therefore, interpreting all system functions is a new and important task. Modern accident reconstruction software applications can visualize the accident sequence, which can also help to relate the restraint system deployments. This paper will be discussing the progress of available methods and introduce new approaches for future automated driving applications in road vehicles. 50 years of accident research = 50 years of improvements
Assessment of New and Improved Field Data Collection, Analysis and Benefits Assessment Methods

Chairperson: Augustus (Chip) Chidester, United States; Rob Eenink, Netherlands

Paper No.19-0096-W

Passenger Vehicle-Powered Two Wheeler Pre-Crash Trajectory Reconstruction and Conflict Analysis Results for Real-World Crashes in the EU and US and its Application to Advanced Crash Avoidance Technologies

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Abstract
Research Question / Objective: Advanced Driver Assistance Systems (ADASs) such as Forward Collision Warning have been developed for light passenger vehicles (LPVs) to avoid and mitigate collisions with other road users and objects. These technologies may have contributed to a reduction in LPV traffic fatalities in the EU and US. However the number of powered two wheeler (PTW) fatalities has remained relatively constant in the US. To fully realize the potential safety benefits across all vehicle categories, LPV crash avoidance technologies also need to be effective in avoiding collisions with PTWs. To accomplish this, knowledge of the pre-crash LPV- PTW vehicle trajectories and conflicts is needed to guide the development and testing of effective crash countermeasures for both LPVs and PTWs. Methods and Data Sources: Crash scenario database development tools previously developed to evaluate LPV-LPV crash countermeasure effectiveness have been extended to LPV-PTW crash scenarios. This involved using information for a large sample of LPV-PTW crashes from the EU Motorcycle Accidents In-Depth Study (MAIDS) and US Motorcycle Crash Causation Study (MCCS) databases, which are based on in-depth crash investigations and the Organisation for Economic Co-operation and Development (OECD) Common Methodology. The vehicle pre-crash trajectories were estimated based on the coded data and digitized information from the scaled pre-crash scene diagrams. The pre-crash conflict state was then analyzed based on these trajectories. Results: The estimated pre-crash trajectories using this method indicate that LPV-PTW pre-crash trajectories and conflicts in France, Germany, Italy, and the US have many similarities, but there are some differences as well. These results indicate that conflicts in several types of pre-crash scenarios, such as the LPV turning across the PTW path in the same direction or opposite direction, begin less than 1.5 sec before impact, which may not be sufficient time for some crash countermeasures based on conflict detection and driver warnings to be effective. Discussions and Limitations: The accuracy of the results is based on a number of assumptions, approximations, and limitations in the data and methods used. These include the accuracy and representativeness of the data based on in-depth crash investigations, as well as the domain-of-validity and accuracy of the vehicle directional control models used. Conclusion and relevance to session submitted: Analysis of real world accident data is critical to the development and evaluation of ADAS and automated driving systems. This analysis has shown that LPV-PTW crash countermeasures need to function with shorter pre-crash conflict epochs, or in the pre-conflict phase, in order to be effective in preventing collisions. This information may help to define requirements for LPV-PTW crash countermeasures (e.g., C-ITS V2V and Blind Spot Detection), evaluate their effectiveness, and inform the development of performance confirmation tests (e.g., New Car Assessment Programs).

Paper No.19-0098-W

SIMULATION OF TEST DRIVES BY USING POLICE-RECORDED ACCIDENT DATA AND COMBINING MACROSCOPIC AND MICROSCOPIC ELEMENTS

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Abstract
With the development of autonomous driving functions, the evaluation of their functional safety is becoming increasingly
important. Current vehicles are tested with separate simulations or test drives. In order to validate future autonomous vehicles by means of test drives, a substantial number of test kilometers are necessary. In addition, these test drives must be repeated for every new release of the system, which increases the expenses for validation. For this reason, programs that can simulate test drives have a high significance. Previous programs do not include the indispensable combination of routing simulation and accident simulation needed to represent a simulated test drive. Therefore, an approach to combining a macroscopic simulation (routing simulation) with a microscopic simulation (accident simulation) is used in this paper. When the start location and the destination are given, the macroscopic simulation can compute the test route by means of the OSRM (Open Source Routing Machine) routing application. While driving along the test route, the simulated vehicles pass various locations of real accidents. The relevant data is taken from the accident database compiled by the police of Saxony, Germany. A selection procedure ensures that only relevant accident situations along the test route are later simulated microscopically. Only if the accident situation is similar to the current situation of the simulated vehicle can the accident situation be simulated microscopically. Therefore, various boundary conditions are used to determine whether there are similarities regarding weather, traffic, light conditions and trajectories of the accident vehicles. To study different variations of the selection procedure, three different concepts are developed and evaluated. The first concept is based on a given test route between start location and destination and a realistic calculation of the travel time. The second concept is also based on a given test route but combines this with a time window for the entire route. The third concept combines an unknown test route, which is calculated between relevant accident locations during the simulation, with a realistic calculation of the travel time. After the evaluation of all three concepts, only the third concept is implemented in the simulation. Within the microscopic simulation by means of PC-Crash, a relevant accident situation is simulated twice, once without and once with the tested driver assistance system in action. With the help of a collision detection system, a conclusion about the efficiency of the driver assistance system is made. The result is a program that combines completed test kilometers with avoided accident situations to simulate a test drive. The current program can only be used in Saxony, Germany. For an expansion to all of Europe, comprehensive accident data is necessary. In addition, the selection procedure could be improved by means of georeferenced weather and traffic data. Because of the basic simulation tools, the actual simulation is not designed for quality but rather for quantity. However, high-quality simulation tools can be implemented with little effort. The simulation of test drives is an important challenge, and with the program developed here, an opportunity to solve it is introduced.

Paper No.19-0110-W
HARMONIZED PRE-CRASH SCENARIOS FOR REACHING GLOBAL VISION ZERO
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Abstract
Crash data are essential for the development and introduction of new of active safety systems. At first, the target population of a new system is evaluated to understand the situations in which the system shall become active. The respective crashes are then analyzed and requirements towards the system development are derived. Finally, an effectiveness evaluation validates the potential benefit of the system in real-world crashes. Multiple in-depth databases are available for different regions of the world. They are generally based on different crash collection and data coding methods. Thus, comparable data analysis is hard to achieve. This is however necessary for a systematic worldwide approach towards reaching “Vision Zero”. Crash scenarios describe the scene of the crash including the participants and their respective actions and intentions. They are the basis for developing sensor-based active safety systems. The paper discusses possibilities of analyzing in-depth crash data and deriving harmonized crash scenarios. Different databases and their limitations are considered, and a scenario catalogue is proposed. This catalogue will enable various stakeholders to compare and analyze crash scenarios of different regions and countries. The catalogue serves as a new and efficient tool to enhance the policy making for vehicles and the development of safety technology to drive “Vision Zero” worldwide.
**Paper No.19-0147-W**

An Analysis Of Factors Driving The Increases In Traffic Fatalities In The United States

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Abstract

According to the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA), 37,461 people died in the United States in traffic crashes in 2016, a 5.6% increase in fatalities from 2015. It was the second consecutive year of increasing fatalities following an 8.4% increase from 2014 to 2015. This study applies random-effects generalized linear mixed modeling techniques to examine the association of changes in traffic fatality counts with changes in explanatory factors, by state, between 2005 and 2016.

Three regressions modeled different outcomes: 1) passenger vehicle occupant fatalities, 2) pedestrian fatalities, and 3) motorcycle fatalities. Motor vehicle-related traffic fatalities were collected by year and by state using NHTSA’s Fatality Analysis Reporting System (FARS). A variety of sources provided measures on explanatory factors. The Fatality counts (outcome) and explanatory factors were then combined as panel data by year (2005-2016) and state (51 states including the District of Columbia). The models tested the association between fatalities and more than seventy explanatory factors including economic, exposure, behavioral and vehicle factors. The study found that the increases in passenger vehicle fatality counts were associated with increases in vehicle miles traveled (exposure) and an improving economy. In addition, the increase in the population age 65 and older and an increase in the percent of this population in the workforce also was associated with increasing fatality counts. Several behavioral factors were associated with changes in fatality counts, including non-belt use and increased drunk driving. Conversely, improved vehicle safety design was associated with a decline in occupant fatalities. A rise in motorcycle fatalities was associated with increased exposure (motorcycle registrations and overall vehicle miles traveled) and an improving economy. Among pedestrian and motorcycle fatalities, there is some evidence that driver distraction plays a role. While the quasi-experimental study design does not allow for inferences of causality, the models can be applied to forecast future fatality counts based on expected or observed environmental, behavioral and vehicle factors or to evaluate the potential impact of prospective interventions. Increased exposure, the improving economy, and behavioral factors drove increases in fatality counts between 2005 and 2016. However, improved vehicle safety design substantially countered these effects, mitigating the increases.

**Paper No.19-0255-W**

Automatic identification of critical scenarios in a public dataset of 6000 km of public-road driving

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Abstract
An increasing number of driving tasks in vehicles is being taken over by automation as automated driving technology is developed. An important aspect in this development is the safety assessment of new functions and systems. Scenario-based assessment is a promising tool, but it relies heavily on the availability of realistic scenarios for generating test cases. Traditional methods take analyses from in-depth accident databases as a starting point to describe accident scenarios. In TNO's StreetWise methodology, the list of critical scenarios resulting from accidentology is expanded with scenarios that are identified from normal everyday driving data. In this paper, we describe a machine learning approach of automatic scenario identification in a dataset of public-road driving. The dataset, together with the results, will be made public to serve as a benchmark. TNO will publish a dataset containing 6000 kilometers of driving on the public road, containing information on the ego vehicle CAN; the GPS position; information on the objects around the ego vehicle from radar and camera; and road lanes and lines. Furthermore, we propose a framework for automatic scenario extraction from real-world microscopic driving data, including measures of safety criticality. Scenarios that are similar form a scenario class, currently we distinguish approximately 60 of such classes. Each instance of a scenario is described by a set of parameters that is specific for the scenario class. By analyzing large amounts of driving data, not only scenarios to fit in different classes are identified, but also the parameter values for each scenario instance are determined. This results in the frequency of occurrence of scenarios and the probability density function (PDF) for each of the scenario parameters.

Metrics for safety criticality are defined based on time-to-collision, time-headway, post-encroachment time, etc. For each case, the safety criticality is evaluated based on the proposed metrics. We have automatically identified two scenarios in the data: 1. Gap closing; 2. Cut-in of a vehicle in front of the ego vehicle. From the identified PDFs the nominal scenarios are identified as well as corner cases with parameter values in the tail of the PDF. By changing parameter values within a realistic range around the corner cases, a check is made regarding their criticality. The two scenarios that are identified describe only a small part of the total number of kilometers driven. However, this bottom-up approach to scenario mining described here can be extended to more scenarios in a relatively straightforward way, with the goal of describing the entire dataset with scenarios.

Automatic scenario mining from driving data is an essential step towards safety validation of AD functionalities. TNO publishes a dataset with 6000 kilometers of public-road driving, for which we show that it is possible to identify critical scenarios, in addition to nominal scenarios, even if in these kinds of studies critical situations are rare.

Paper No.19-0269-W
Changes in Crash Protection with Vehicle Model Year
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Abstract
NASS/CDS 1993-2015 was queried for frequency of exposed vehicles with belted driver injuries separated by injury severity and vehicle model year. Vehicle model-years were aggregated by 3 model year groupings – 1985-1994; 1995-2000; 2001-2015. These percentages of the crash exposed populations for the 3 groups were: 27%, 34% and 39%. The total exposed population was 27,347,705. The total and Mean AIS 3+ HARM for each model year grouping was calculated for each crash mode – frontal, near-side, far-side, rear and rollover. Changes in total AIS 3+ HARM distribution and Mean AIS 3+ HARM by crash mode and model year grouping were reported. The largest source of AIS 3+ HARM to belted drivers in the 2001-2015 NASS population remains the frontal crash mode. Near-side and rollover injury rates have dramatically decreased in recent model years. Frontal and far-side crash mode injury rates have decreased slightly and rear has remained relatively constant, but at a low injury rate. The data suggests that for light trucks, the near-side Mean AIS 3+ HARM has increased during the 2001-2015 model years. However, the level remains below that of passenger cars which have experienced dramatic reductions in near-side Mean AIS 3+ HARM during the same period.

Paper No.19-0293-W
Analysis of severe injury in car to car accidents to improve of crash test protocols in KNCAP
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26ESV/Program Book
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Abstract
All over the world, there are many institutional programs used to enhance the safety of vehicles. The NCAP is a program that assesses the safety of vehicles sold by manufacturers in order to provide consumers with information on vehicle safety and to induce them to produce vehicles with enough safety. In Korea, the KNACP has been carried out continuously since 1999. However, the fatal rate from traffic accidents per 100,000 population in 2017 is 8.1, which is above the OECD average. Therefore, it is necessary to improve various systems, but it is also necessary to improve the crash assessment protocols reflecting the actual accident. The purpose of this paper is to improve the crash test protocols of KNACP by analyzing the status of the serious injury in case of an accident in Korea. Accident data were used for the latest three years (2015-2017) in car to car accident of domestic insurers. Raw data shows that 9,399 cases occurred due to accidents involving more than MAIS3 + of occupants' injuries. Of these, 279 cases were analyzed. In the collision type, the full width impact was the largest at 68.5%, and the small overlap and moderate at 28.3%. The low severity with 0 failure depth was 2% and the center impact was 2%. Impact angle was 51.1% for co-linear, 33.3% for left oblique angle and 15.6% for right oblique angle. In case of overlap, moderate overlap was about 47.9% and small overlap was about 17.5%. In the case of full width, rash extent3 + was 80.6%, while moderate overlap and small overlap were 36.8% and 24.3%, respectively. The collision type and impact angle compared to other country.

Paper No.19-0303-W
Naturalistic Study of Level 2 Driving Automation Functions
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Abstract
Currently, there are commercially available vehicles that include features capable of providing Level 2, Partial Driving Automation as defined by SAE International. Research on the use and performance of the systems that these vehicles employ in natural settings is needed to help clarify the systems’ potential benefits. The Naturalistic Study of Level 2 Driving Automation Functions (L2 NDS) project described herein has generated practical data to support the understanding of the use of automated lateral and longitudinal control functionality by evaluating a subset of currently available advanced technologies as drivers experience them during daily use. The objective of the L2 NDS project was to investigate, through a naturalistic driving study, real-world driver interaction with commercially available driving automation systems. Ten vehicles equipped with both lateral and longitudinal automated features were instrumented and loaned to participants for a 4-week period. A total of 120 drivers were recruited over a 14-month data collection period. Each study vehicle was equipped with Virginia Tech Transportation Institute’s NextGen Data Acquisition System, which continuously records video of the both the driver and the roadway, as well as vehicle data and automated lateral and longitudinal control activations. These data were used to analyze driving automation system use and driver performance during the study. Focus area 1 investigated System Performance, including overall use of the features. Participants drove 216,585 miles, with 70,384 miles driven with both lateral and longitudinal control features active. Focus area 2 investigated Driver-System Interaction and involved a review of driver behaviors during driving automation system use, specifically the prevalence of non-driving tasks. Drivers were observed engaging in non-driving tasks, but these were not related to feature use. Focus area 3 investigated Driver Performance, which was measured by drivers’ responses to Request to Intervene (RTI) alerts generated by the driving automation systems. Driver behavior was consistent with active driving/supervision of the automated features; drivers were receptive to RTI alerts. No RTIs were associated with any safety-critical events (i.e., crashes and near-crashes). In total, 5 minor crashes (no injury or visible damage) and 66 near-crashes were observed across the entire data set. No statistical relationship was observed between safety-critical event rates and feature activation level. Focus area 4 investigated Driver Engagement, which includes subjective feedback.
obtained from participants. Participants reported that they were generally comfortable and felt safe using the features, with self-reported trust increasing over the course of the study.

**Paper No.19-0305-W**

**Measuring States’ Alignment to the Model Minimum Uniform Crash Criteria (MMUCC) 5th Edition**

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**Abstract**

In 1998, the National Highway Traffic Safety Administration (NHTSA) and the Governors Highway Safety Association (GHSA) developed the Model Minimum Uniform Crash Criteria (MMUCC), a voluntary guideline to encourage greater crash data uniformity by identifying a minimum set of motor vehicle crash data elements and attributes that States should collect and include in their State crash data system. NHTSA relies on State crash data for the Fatality Analysis Reporting System (FARS). FARS is a nationwide census providing NHTSA, Congress, and the American public yearly data regarding fatal injuries suffered in motor vehicle traffic crashes. States have implemented MMUCC differently, often combining or deleting attributes, which causes problems with data uniformity when attempting to aggregate data across States. The purpose of this paper is to describe methods used to measure States’ alignment to MMUCC 5th Edition, examine the variance of States’ crash data to MMUCC data elements, and describe how NHTSA will use the results of this analysis to inform future editions of MMUCC with the goal of improving the quality of FARS data.